International Symposium
"Fundamentals of Laser Assisted Micro- and Nanotechnologies"
(FLAMN-16)

ABSTRACTS

June 27 - July 01, 2016
St. Petersburg
Pushkin
Russia

In frames of International
Congress Lasers & Photonics 2016

INTERNATIONAL SYMPOSIUM FLAMN-16

(In frames of International Congress «Lasers & Photonics 2016»)

Fundamentals of Laser Assisted Micro– & Nanotechnologies

Dedicated to the 100-th anniversary of the birth of A.M. Bonch-Bruevich

ABSTRACTS

Laser Association	Russian Optical Society	Ministry of Education and Science of the Russian Federation	Leading Scientific School of RF “Fundamentals of LAMN”
Journal “Photonika”	Laser systems for technologies and medicine	Optitask LTD	Lasers and Apparatus group

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INTERNATIONAL SYMPOSIUM

Fundamentals of Laser Assisted Micro– & Nanotechnologies (FLAMN-16)

June 27 – July 1, 2016, St. Petersburg - Russia

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- Section Laser-Assisted Micro-and Nanotechnologies	**LT**
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CONTENTS

SOLIDIFICATION BEHAVIOR AND DENDRITE STRUCTURE REFINEMENT AFTER LDMD IN TI BASED ALLOY REINFORCED BY M- AND NANO-ALUMINA 128
Volyansky I., Missemer F., Shishkovsky I.V., Volchkov S., Shishkovsky I.

PL1-1 Surface nanostructuring of carbon materials by multiple ultra-short pulsed laser irradiation

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It will be demonstrated that carbon surface structures with nanometer scale depth can be produced by low intensity femto (pico) second laser pulse trains in atmospheric air.

In the case of mono, poly and nano crystalline diamond, diamond-like coatings and graphite so-called laser induced nanoablation regime is considered. The proposed key mechanism of this method is multiple-pulsed laser oxidation of sp_2 bonded carbon atoms. The reaction products (CO and CO_2) are volatile and leave the irradiated surface. For diamond materials sp_2 bonded carbon atoms (clusters of atoms) are formed as a result of multi-photon ionization and bonds transformation at defect sites by partial transfer of charge careers energy. Nanoablation occurs at laser fluence well below surface graphitization (for diamond it takes place at surface temperature of about 800^0C) and vaporization. The mean nanoablation rates are very small (as low as 10^{-7}-10^{-2} nm/pulse) and to observe laser produced surface structures multiple pulsed laser treatment is needed. It should be noted that nanoablation is not only ultra-precize processing technique but can be quite fast if laser pulse repetition frequency and, correspondingly, mean power are high (≥10 W and 1 MHz).

The novel method of laser nanoprofiling of 4-5 layered graphene sheets was developed. The samples were obtained by exfoliation from graphite crystals and transferred onto a silicon substrate in air. The proposed laser nanoprocessing mechanism is based on multipulsed heating of an adsorbed water layer between the graphene and substrate, radial spreading of the thin water layer outside the laser heating zone and formation of nanopits with the depth of 1-2 nm by a sequence of about 10^5 laser pulses with intensity below graphene ablation threshold.

PL1-2 Sample preparation by laser ablation for 3D electronic device failure analysis

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In order to analyze failures of 3D devices, scanning or transmission electronic microscopy is usually performed. To get access to the deep layers of a component, a large quantity of matter has to be removed and the surface smoothened using Focused Ion Beam (FIB). Currently, the highest sputtering rates achieved by FIB methods reach hardly 104 $\mu m^3/s$, which corresponds typically to several hours of processing to reach the targeted zone. Thus alternative strategies such as laser ablation [1-2] are investigated to reduce the processing time. Thus, cavity laser ablation has to be optimized in order to limit the size of the heat affected and induced dislocation zones. Moreover, the side wall cavities must be as vertical and smooth as possible to minimize the final FIB polishing time. In the present work, we investigated ns, ps and fs laser micromachining at different wavelengths from UV to IR with emphasis on ps ablation at 343, 515 and 1030 nm. Cavities have been engraved in silicon and in heterogeneous structures. SEM characterization of the cavities revealed an evolution of both the cross sectional shapes and surface topologies as the number of laser shots increases. In optimized processing conditions, almost vertical side walls have been engraved. Clear cross sections of contact micro-bumps and cavity openings, exposing multilayer interfaces, are demonstrated. The silicon removal rates, tuned by the applied energy density, have been measured in each condition. Removal rates were typically hundred times higher than those achieved by ion milling and the best efficiency was obtained at 343 nm. The fluence required to remove the matter at a given rate increases with the wavelength. The results will be discussed in respect of the optical properties of silicon and of the ablation thresholds measured at each wavelength.

This work has been carried out thanks to the support of the A*MIDEX project (n° ANR-11-IDEX-0001-02) funded by the « Investissements d'Avenir » French Government program, managed by the French National Research Agency (ANR).

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PL1-3 Combined effective usage of neodymium YAG 1.44 μm and Helium-Neon lasers in ophthalmological surgery

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Purpose: To investigate microinvasive technique of laser cataract extraction (mLCE) with simultaneous action of 1.44 μm Nd-YAG endodissector and biostimulating low-power 0.63 He-Ne laser radiation activating regeneration processes.

Material and methods: We performed comparison of three techniques of cataract surgery: mLCE (148 cases), basic LCE (176 cases), and microinvasive phacoemulsification (mPE, 204 cases). The experimental evaluation of the eye cell cultures reaction on the intraoperative effects of low-energy He-Ne laser radiation.

Results: When compared mLCE with mPE observed 2 times less corneal edema, transient hypertension and corneal endothelial cell count loss. Reduced energy power, the volume of irrigation, induced astigmatism, corneal thickness, endothelial cell count loss, rehabilitation period shortening compared with a basic operation LCE were less, but not statistically significant. The effect of He-Ne laser on organotypic cultures of human eyes in the experiment manifested with stimulation of reparative processes of the surface epithelium of the cornea, retinal pigment epithelium, limbal stromal cells, and the prolongation of survival time of cell-tissue cultures of the corneal endothelium.

Conclusion. New technology mLCE using two kinds of multipurpose laser radiation, is the world's only fully laser cataract surgery applicable in all nuclear density grades, with unique properties providing greater efficiency and safety of surgical operation. During LCE 1.44 μm Nd-YAG laser energy does not overstep the limits of a capsular bag, ultrasonic power and manual fragmentation are not required as well as applanation and corneal compression. It is one step surgery with spontaneous laser nuclear splitting and delamination together with stimulation of reparative process.

PL1-4 Development of laser-excited nano-gold and graphene for drug delivery and sensing

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We review our experimental and preclinical activities on the exploitation of a light excitation produced by a laser source to "activate" suitable nanotransducers like plasmonic nanoparticles and graphene sheets for applications to drug release and SERS sensing.

For drug release, nano-gold and other light-responsive nanomaterials have been employed for the development of an implantable device for on demand chemical release in the form of a light-activated sponge-like scaffold. The photothermal response of the gold nanoparticles contained inside the sponge triggers a contraction in proximal drug-loaded thermosensitive micelles, thus promoting the expulsion of the drug from the sponge in a very controllable and reproducible way. An advanced version of these devices consists in a dispersion of graphene nanosheets in a biopolymer matrix, which is activated by millisecond-long light pulses for confined and precisely dosed drug release.

Examples of the potential of organized assemblies of gold and silver nanocubes decorated with a graphene film will be described for the direct Surface Enhanced Raman Scattering (SERS) analysis of proteins and biomarkers. In this regard, we introduce a SERS sensor we engineered for the rapid and reproducible quali-quantitative detection of toxic amyloid oligomers associated with neurodegenerative diseases. The platform consists of an extended bidimensional array of gold concave nanocubes (CNCs) supported on a PDMS film. CNCs are closely-packed through face–face and face–corner interactions generating a monolayered arrangement featuring well distributed nanoholes. Here the protein under analysis experiences a homogeneous E.M.-field enhancement, which causes a large number of vibrations to be contemporarily amplified and thus clearly detectable in the SERS spectrum. Moreover, in order to improve the sensitivity of the sensor, we realized silver nancube assemblies covered with graphene oxide films, which indicated promising applications for versatile SERS detection of complex proteins.

PL2-1 Near-field laser heating for surface nano-sampling and processing: multi-parametric modeling and experimental studies

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To satisfy the growing demands of modern science and industry, laser ablation methods are under continuous development. The development of laser ablation methods has significantly expanded the scope of their applications for modern laser-assisted micro and nanotechnologies. In particular, in our studies on near-field laser ablation, the possibility to perform laser ablation and surface processing with a nanometric resolution was demonstrated with laser field enhancement near a tip of an atomic-force microscope.

Laser ablation, in our case, may be regarded as a result of the local near-field heating of a sample surface. Laser ablation efficiency and accuracy are affected by both the sample properties (thermal diffusivity, absorption coefficient, etc.) and the near-field parameters (spatial distribution, wavelength, laser pulse duration, tips nature and dimension, etc.). The modeling of the temperature distribution resulting from the near-field heating of the sample surface may be seen as an appropriate procedure to analyze these complex multi parametric effects and corresponding interrelations. The paper presents the results on the modeling for the near-field heating of metal or semiconductor surfaces (gold, tantalum and silicon wafer) along with those obtained experimentally with nanosecond laser pulses (4 ns, 266 nm, 10 Hz, linear p-polarization) and an atomic-force microscope in air, under normal conditions. The properties of nanometer scale craters are in good correlation with the model predictions. The possible improvements of the near-field ablation with a femtosecond laser will be discussed.

PL2-2 3D fast and reversible Foturan modification by double wave–length action

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Realization of local crystallization and secondary amorphization in the bulk of photostructurable glass (PhG) on a par with the ability to control of these phenomena is the actual problem [1, 2]. The solution to this problem opens up new horizons (possibilities) for laser processing techniques of glass-ceramic materials in fabrication of microsystems and photonic devices [3]. However, the following important questions in existing now techniques of PhG processing still do not disclosed. Firstly, local crystallization in the bulk and on the surface of PhG (Foturan mark) realized in two stages, and it takes too much time due to use of heat treatment in a furnace. Today the alternative of this processing is not proposed. Secondly, direct and reverse phase transformations inside PhG such as fast crystallization and melting of crystalline phase (secondary amorphization) is not realized in the present.

For solution of these problems, we were proposed to implement the combined action of ultra-short pulses with femto- or picosecond durations and laser beam with 10.6-μm wavelength. In the work, the direct phase transformation inside the PhG samples by combined action of two lasers: femtosecond fiber laser and CO_2 laser. Direct writing of modified areas inside the PhG plates was carried out utilizing an Yb-doped fiber laser (λ = 515 nm, τ = 200 fs, f = 500 kHz, Ep = 1.5÷2.3 μJ, υ = 0.01÷4 mm/s). The energy of femtosecond pulses was enough to achieve the intensity about ~10^{12} W/cm^2 in the beam waist with diameter of 4.5±0.5 μm (fig. 1).

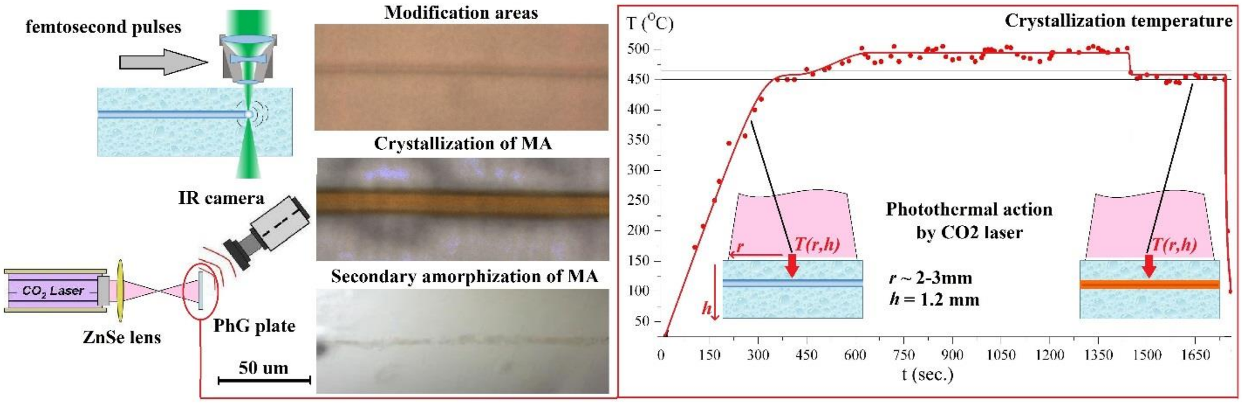

Fig. 1. Scheme of laser writing for MA formation and photothermal action for 3D crystallization and secondary amorphization

Next stage was a crystallization of 3D structures by photothermal action of CO_2 laser irradiation (fig. 1). Crystallization inside PhG on nucleation centers was carried at intensity 75÷95 W/cm^2 and time exposition of 15÷400 sec. Melting (secondary amorphization) of this crystalline phase was occurred at 140÷175 W/cm^2 for 5÷10 sec. Phase transformations were carried at interaction of samples with the wide laser beam (more than 70% by square of plate surface). At this, the crystalline formation of Li_2SiO_3 and $Li_2Si_2O_5$ on modified areas inside PhG was started at the temperature of 490÷520 °C and it was completed by 575÷585 °C. Melting (secondary amorphization) of these crystalline areas was occurred at temperature of 800÷850 °C. After secondary amorphizaton, all optical properties of PhG were returned to its original state. In this way, it is possible to carry out multiple phase transformations.

The work was performed by the RSF agreement № 14-12-00351.

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LMI-1 Large-scale atomistic modeling of short pulse laser induced structural modification of metal surfaces

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Short pulse laser irradiation can trigger a cascade of highly nonequilibrium processes leading to the formation of unique surface structures of interest to various practical applications. In this presentation, we report the results of large-scale atomistic simulations aimed at revealing the processes responsible for the generation of complex nanoscale surface morphology and microstructure. In particular, the mechanisms responsible for the formation of a sub-surface porous region covered by a nanocrystalline surface layer with random crystallographic orientation of nanograins and a high density of stacking faults, twins, and nanoscale twinned structural elements has been revealed in the simulations and related to the experimental observation of surface swelling and incubation effect in multi-pulse laser ablation [1]. The conditions for the generation of surface nanospikes featuring unusual nanostructure consisting of continuous network of pentagonal twinned structural elements arranged into a polyicosahedral structure are discussed based on the results of the atomistic simulations [2]. The processes of growth twinning and emission of dislocations from the liquid-crystal interface during the dynamic relaxation of laser-induced stresses are related to the results of experimental characterization of surface microstructure [3, 4].

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LMI-2 Ab-inito and classical molecular dynamics simulations of nonthermal structural phenomena in laser excited solids

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Intense femtosecond-laser pulses are able to induce ultrafast nonthermal melting of different materials along pathways that are inaccessible under thermodynamic conditions. In order to investigate the nonthermal motion of atoms upon femtosecond laser excitation we performed ab-initio molecular-dynamics simulations on laser-excited potential energy surfaces using our code CHIVES (Code for Highly excited Valence Electron Systems).

We found surprising results. For instance, we were able to show that laser pulses can excite squeezed thermal phonons, which constitute the precursor of nonthermal melting as a function of fluence [1].

Furthermore, by studying irradiated silicon for fluences above the melting threshold, we found that the atoms move successively superdiffusively and fractionally diffusively before becoming diffusive. At relatively low laser fluences we found fractional atomic diffusion, not reported so far in materials, during more than 800 fs [2]. In this talk I will show, that combining the effects mentioned above, control of the nonthermal melting process by two pump pulses is possible. Different signatures of nonthermal melting and the differences to thermal melting will be discussed [3]. In particular, we will show that the energy flow from the excited electron system to the phonon modes is extremely anisotropic in the nonthermal regime.

In order to extend our method for the study of nucleation phenomena, we developed an analytical interatomic potential for laser-excited silicon, which depends on the electronic temperature. Effects like bond softening in the presence of hot electrons are taken into account. With the help of this potential we were able to perform large-scale simulations and study nucleation dynamics during nonthermal melting.

Finally, it will be shown in this talk that the combination of accurate time-resolved optical measurements with ab-initio calculation of atomic displacements from the knowledge of the reflectivity has clear advantages with respect to time-resolved crystallography and allows a detailed visualization and control of two-dimensional atomic motion in solids [4].

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LMI-3 Physical phenomena caused by laser action onto metals

Nail A. Inogamov[1,2], Sergei I. Anisimov[1], Vasily V. Zhakhovsky[2], Yurii V. Petrov[1], Viktor A. Khokhlov[1], Kirill P. Migdal[2], Denis K. Ilnitsky[2], Vadim V. Shepelev[3]

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In the report an action of short (mainly around picoseconds and shorter) laser pulses in the range of absorbed fluences from 0.1 to 1000 mJ/cm^2 is considered. The first two important stages are: the two-temperature (2T) stage and the beginning of the hydrodynamic stage lasting $t_s = d_T / c_s$ in case of a bulk targets or $t_{sf} = d_f / c_s$ in case of a thin film, here $t_s, d_T, c_s, t_{sf}, d_f$ are acoustic time scale, thickness of heat affected zone in a bulk target, speed of sound, acoustic time scale in the case of a thin ($d_f < d_T$) film, and thickness of a film, respectively. New data concerning 2T thermodynamic properties, 2T dielectric permittivity, electron-ion coupling, and 2T electron heat conductance are presented. They have been obtained using density functional theory, quantum molecular dynamics, and semi analytic collision theory. The first two stages are followed by more late hydrodynamic and thermal evolution. During this late evolution the bulk targets may nucleate if absorbed fluence overcomes an ablation threshold. Nucleation is followed by foaming of molten metal and thermo mechanical ablation when a surface layer of a bulk target spalls out from a target. Mechanical evolution is accompanied with the thermal one. Conductive cooling of a surface layer leads finally to its freezing. Combination of foaming dynamics together with recrystallization is a reason for appearance of the nanoscale stochastic surface structures surprising observers. These structures demonstrate many unusual remarkable properties. In the case of a thin film the mechanical and thermal situation is even more interesting. Both cases, one with a large irradiated spot (many microns in diameter) and the second with a tightly focused laser beam (diameter of an order of optical wavelength), are studied. They also are significant for many applications like formation of nanoplasmonics arrays, laser induced forward transfer etc. This work has been done under RFBR grant 16-08-01181 A.

LMI-4 Ultra-short laser induced confined microexplosion: A path to a new landscape of non-equilibrium material phases

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New material phases formed under non-equilibrium conditions at pressures above 10^{12} Pa and temperatures exceeding 10^4 K, the conditions of the warm dense matter (WDM), have become accessible using micro-explosions triggered by ultra-short sub-ps pulse tightly focused in a micro-volume with cross sections comparable to laser wavelength. These are conditions favourable for the breaking and re-arrangement of atoms into unusual material phases. The accompanying isochoric quenching ~10^{14} K/s rates can keep the transformed material 'frozen' in unique atomic arrangements within the pristine structure. The laser affected material remains confined, readily available for the post-explosion investigation, in contrast to the shock wave method where the all pressure-affected material is dispersed after several nanoseconds of its lifetime.

We present a review of recent results on creation of new phases in case of super-dense bcc-Al inside sapphire [1], valence change of Fe-ions in olivine [2], formation of new tetragonal bt8 and st12 phases of Si [3], spatial separation of Ge and O atoms in GeO_2 glass and formation of molecular oxygen inside voids at the microexplosion cites in GeO_2 and SiO_2 [4, 5].

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LMI- 5 Gaining insight into ultrashort laser ablation via studying the particle emission process and the resulting surface morphology

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Ultra short laser radiation in the fsec time domain (8-several 100 fsec) represents nowadays a fascinating and challenging tool for modifying and structuring surfaces. One of the particularly interesting aspects definitely arises from the fact that fsec light pulses exhibit a very wide range of pulse shapes (in the time domain) as well as an intrinsically complicated frequency spectrum. As a consequence, many different physical processes can and will result by changing the laser parameters. In an ideal situation, these parameters can be used to control the outcome of the laser material modification process and drive it to optimized results. However, as it seems it still a long way to go to understand all the different processes and their dependence on laser parameters before a reliable tuning of an optimized surface modification will be possible.

In this overview, we will report on recent attempts to reach this goal by experiments, which have the goal to correlate the particle emission (laser ablation) and the development of surface periodic structures (laser induced periodic surface structures, LIPSS) under various laser parameters (fluence, pulse length, wavelength, number of pulses etc.).

The mass spectrum of emitted particles, their energy distributions, thresholds for ablation and the ion to neutral yield have been studied. This allows to identify different processes, characteristic for fsec laser pulses interacting with surfaces. These experiments have to be performed in UHV. Consequently, the development of LIPSS structures and, in particular, so-called high frequency and low frequency structures (HSFL and LSFL) have been investigated under UHV conditions.

Various possibilities to simulate the development of surface structures will be discussed. Taking into account the wealth of physical processes and the number of atoms involved is challenging task.

LMI-6 Critical assessment of ambient gas effects under ultrashort laser ablation

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The vast majority of scientific and technological applications of ultrashort laser ablation are performed in an ambient environment (air, inert or reactive gases, liquids) which can strongly affect the ablation process. However, this topic still remains poorly understood. In this work, we have performed experimental and theoretical studies of fs-laser-induced gas ionization effects paying a particular attention to relatively low laser intensities, near the gas breakdown threshold, typically used in material processing applications. Transmission measurements for femtosecond laser pulses (800 nm, 120 fs) through the focal region have been carried out in air of various pressures and compared with the vacuum conditions. Spectroscopic study of air plasma emission was performed. Nitrogen molecule lines were detected at laser fluences well below the breakdown threshold determined from the transmission measurements. The plasma absorption effects are found to depend on the pulse repetition rate and are considerably stronger at 1 kHz as compared to 1-10 Hz. This suggests that metastable states of air molecules play an important role in initiation of air breakdown, enhancing the ionization efficiency at high repetition rates. Analysis of the spectroscopic data indicates that the ionization process involves the N2(A3Σu+) state with a decay time in a 10-ms timescale. Experiments on fs-laser-induced damage of metal targets placed in the focal region demonstrate that, in this case, plasma absorption manifests itself at considerably lower fluences than in the absence of the targets due to interference of the incident and reflected beam parts. A model of laser-induced gas ionization has been developed which shows good agreement with the experimental data. Additionally, a developed hydrodynamic model of the laser-induced plasma demonstrates an intriguing picture of the ambient gas motion in the focal region with shock wave formation. The role of ambient gas effects in laser material processing is discussed.

LMI-7 Peculiarities of light scattering by particles with high refractive index

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A review of recent theoretical and experimental results in light scattering by high refractive index (HRI) particles is presented. It is shown, that the process is characterized by sharp, high-Q resonances affecting both the scattered field outside the particle and the one within it. However, the manifestation of the resonances in the former and later cases is quite different. For the scattered field outside the particle each partial mode exhibits an infinite cascade of the Fano resonances. Regarding the field within the particle, in contrast to the common believe that for a HRI particle this field is weak, it is shown that the resonances may give rise to a giant concentration of the electromagnetic field within the particle, exceeding the one in the incident wave in several orders of magnitude. These features of the problem provide physical grounds for numerous applications, especially those related to the design and engineering of high nonlinear heterogeneous nanostructures and cloaking metamaterials.

LMI-8 Time-resolved modeling of ultrafast electron dynamics and energy dissipation in laser-excited solids

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Exciting solids with an ultrashort laser pulse induces a number of processes on a broad range of timescales. Initially, the electrons of the solid absorb the energy from the laser. Later, relaxation and dissipation processes transfer the energy to the lattice and, in bulk materials, away from the surface. For sufficiently high excitations, structural transitions, for instance ablation, are possible. The energy input, determining the possible structural modifications is governed by the optical properties of the material, which may change during irradiation.

In this talk, we present exemplary results of different methods, tracing the material's reaction on different timescales. On ultrashort timescales during excitation with a femtosecond laser pulse, the electrons cannot be described with a temperature. However, kinetic approaches are capable of following the initial excitation and the nonequilibrium electronic energy distribution. We compare the results with those of a temperature-based description. By that we are able to identify distinct consequences of nonequilibrium energy distributions as compared to a near-equilibrium situation.

We analyze the thermalization of the laser-excited carriers, in particular comparing the relaxation of energies and chemical potentials. For the parrticular case that electrons of different bands are excited, as for instance in semiconductors, we show the establishment of a temperature of electrons in different bands as well as the development of the particular electron densities. With help of a density-dependent two temperature model, we further demonstrate the importance of the transient optical parameters.

On picosecond timescales, the energy transfer from the electrons to the lattice takes place. We reveal the mutual influence of electron-electron collisions and electron-phonon collisions and deduce the electron-phonon coupling strength after ultrafast laser irradiation. Lattice heating leads to atomic movement, thus, we show finally results on structural modifications occuring after ultrafast laser-excitation on pico- to nanosecond timescales.

LMI-9 Perspectives of theoretical models of laser photoionization of non-metal crystals: from the Keldysh approximation to time-dependent theory

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Laser-induced photoionization considers electron transitions between valence and conduction bands of non-metal crystals driven by direct action of electric field of laser radiation. In case of high-power ultrafast laser-crystal interactions, it contributes to almost all effects, e. g., nonlinear propagation, laser ablation, laser-induced damage, and structural modifications for waveguide writing. The model of L.V. Keldysh and the Keldysh formula for the photo-ionization rate [1]) was utilized for understanding and simulation of the photo-ionization for arbitrary non-metal solids and arbitrary values of laser parameters for almost five decades starting from the original publication in 1964. In spite of high significance for applications, theoretical studies of fundamental aspects of the photoionization of non-metal crystals experienced very little progress compared to the photoionization theory of atoms and molecules, and have not progressed far beyond the Keldysh approximation. Many important aspects of the photoionization stayed without detailed studies for years, e.g., special features of ionization by circularly polarized light, contribution of quantum interference to the tunneling regime, contribution of dynamic Franz-Keldysh effect to the high-field ionization.

Discovery of generation of high-order harmonics (HHG) by extremely short laser pulses (few optical cycles) [2] and studies of THz generation by ultrafast laser excitation of crystals have pushed theoretical research in this field. Several novel approaches to simulation of the photo-ionization have been proposed over last few years. In this talk, we overview recent progress, qualitative improvements, and challenges in development of the models of ultrafast photoionization for crystals. We consider the Keldysh approach [1] based on the monochromatic approximation for laser radiation as a starting point to measure the progress in this field and to identify the challenges.

Recent developments in the field of time-dependent photoionization theory are overviewed and summarized.

This research is partly supported by a grant from the US Air Force Office of Scientific Research (AFOSR).

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LMI-10 Modeling of laser-assisted nanostructuring processes of the materials

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Laser micro- and nanostructuring of materials is important in many scientific, technological and medical applications. Nanostructures resulting from laser material processing have unique properties and often cannot be produced by other techniques. The development of laser nanostructuring technologies has been stimulated by recent advances in laser engineering, which have made it possible to generate short and ultrashort laser pulses. The femtosecond laser technique, which turned to be an effective instrument in laser applications, is actively updated, and its price reduced. In addition, in recent years the solid diode-pumped lasers are more and more widely used in laser technology. Such lasers produce the pulses of nanosecond duration. The advantages of lasers are the small size, good quality of the beam, and high efficiency.

Research into the process underlying surface micro- and nanostructuring of metals and other materials by short and ultrashort laser pulses has been reviewed. Particular attention is paid to direct laser irradiation involving melting of the material (with or without ablation), followed by ultrarapid surface solidification after the laser pulse. Laser ablation has manifested itself as one of most effective physical methods of nanofabrication. However, the laser methods form rather large-sized nanoparticles with a wide size spectrum. In this connection, in order to reduce the size of nanoparticles their colloids are additionally treated by ultrashort laser pulses.

We review our recently obtained data on a physical model of metal nanoparticles fragmentation in liquids under the action of femtosecond laser pulses and absorption of electromagnetic radio-frequency radiation in aqueous suspensions of semiconductor (silicon) and metal (gold) nanoparticles.

A physical model of gold nanoparticle fragmentation in water under the action of femtosecond laser pulses is presented in this paper. When the colloids of relatively large gold nanoparticles (several tens of nm) are irradiated by femtosecond laser pulses, one can observe their fragmentation into smaller nanoparticles (up to several nm). In the process the particle is heated up to the melting temperature and turns into a drop of liquid. The heating is accompanied by thermionic emission from the drop surface. The emitted electrons take away the negative charge, and the drop of melted metal turns to be positively charged. Thus the model of fragmentation is based on the electrolization of metal nanoparticles heated by a laser pulse, and their division under the development of instability of a charged drop of liquid metal. As a mechanism of electrolization we have considered the emission of hot electrons from the surface of a nanoparticle with further salvation in liquid. The problem of gold particles heating at femtosecond laser pulse absorption has been solved. Time dependence of electron thermionic emission current from the particle surface has been found. The particle fragmentation parameter has been defined. The estimates are given of nanoparticle charge gained under the action of the laser pulse in water.

We examine absorption of electromagnetic radio-frequency (RF) radiation in aqueous suspensions of semiconductor (silicon) and metal (gold) nanoparticles (NPs) and theoretically investigate the heat release in these systems. The absorption of RF radiation is considered in both bulk electrolyte and the region around the NPs. Simulations show a strong dependence of the heating rate on electrical conductivity of the electrolyte rather than on that of NPs properties. The obtained results indicate that NPs can act as sensitizers of the RF induced hyperthermia for biomedical applications.

The heating effect is demonstrated for nanoparticles synthesized by laser ablation in water and mechanical grinding of porous silicon, while laser-ablated nanoparticles demonstrate a remarkably higher heating rate than porous silicon-based ones for the whole range of the used concentrations. Our tests evidence relative safety of Si nanostructures and their efficient dissolution in physiological solutions, suggesting potential clearance of nanoparticles from a living organism without any side effects. Profiting from Si nanoparticle-based heating, we finally demonstrate an efficient treatment of Lewis Lung carcinoma in vivo. The obtained data promise a breakthrough in the development of mild, non-invasive methods for cancer therapy.

The results of theoretical modeling may be used to optimize the laser operation regime destined to produce the nanostructures and nanoparticles of the given size to ensure process control and reproducibility.

LMI-11 Theoretical and experimental investigation of UV short pulse laser periodic nanostructuring of Au at the fluences near and above spallation threshold

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The mechanism of surface restructuring by ultrashort laser pulses involves a lot of fast, non-equilibrium, and interrelated processes while the solid is in a transient state. As a result, the common theoretical analysis of experimental results can not address all of the aspects originating from the mechanism of the nanostructuring. In this work, we present a direct comparison of a simulation and experimental results of UV laser induced surface nanostructuring of gold surface near the ablation threshold with and without confinement due to a water layer at the surface. The experimental results were obtained by using a mask projection setup with a laser wavelength of 248 nm and a pulse length of 1.6 ps [1]. This setup is used to produce an intensity grating on a gold surface with a sinusoidal shape and a period of 270-500 nm. The formation of structures at the surface and in a cross section is analyzed by a Transmission and Scanning Electron Microscope, respectively, Fig. 1b and 2b. Then a hybrid atomistic-continuum model capable of capturing the essential mechanisms responsible for the nanostructuring process [2] was used to model the interaction of the laser pulse with a thick gold target. The experimental and theoretical results are compared then directly on the same temporal and spatial scale for the case of low (near the melting threshold), Fig. 1, and high (above the spallation threshold), Fig. 2, fluences. The good agreement between the modelling results and the experimental data, justifies the proposed approach as a powerful tool revealing the physics behind the nanostructuring process at gold surface and providing a microscopic insight into the dynamics of the structuring processes of metals in general [3].

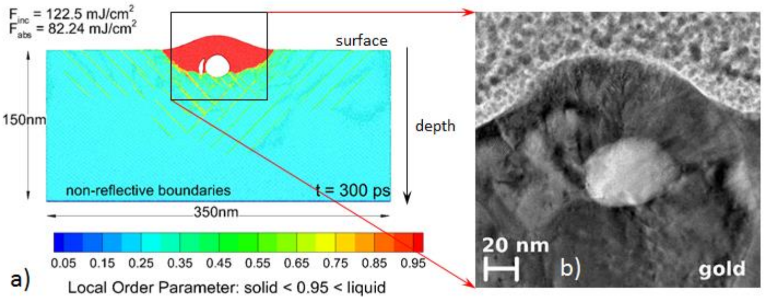

Fig. 1. a) Atomic snapshot at 300ps for the incident fluences of 122.5 mJ/cm^2. The atoms are coloured according the local order parameter with the threshold value of 0.95 indicating atoms with liquid ambient (red) and those with a crystalline surrounding (other than red). b) For the same fluence TEM cross sections was prepared by Focused Ion Beam method (right). The darker areas show the gold, whereas the lighter areas show a protective platinum layer that has filled the empty spaces during the preparation process. The atomic configuration squared in the a) corresponds quite well to the experimentally obtained structure visualized in b).

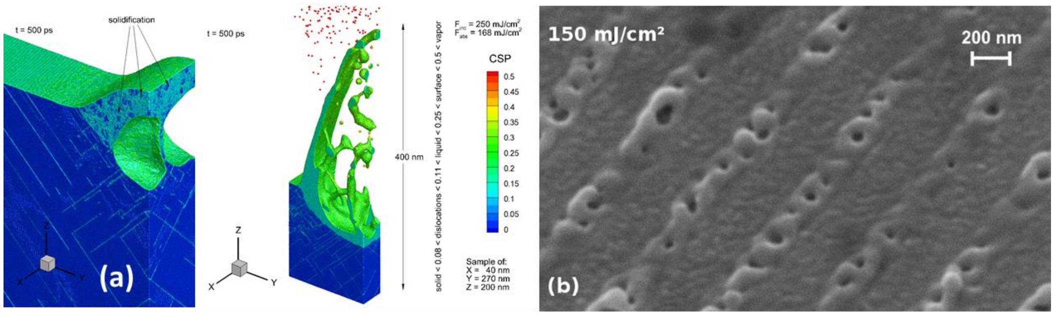

Fig. 2. (a) Atomic snapshot at 500ps for the incident fluences of 130 and 250 mJ/cm^2. The atoms are colored by Central Symmetry Parameter (CSP) to distinguish between solid, dislocations, liquid, surface, and vapor atoms. (b) SEM pictures (tilted by 45° versus the plane normal) showing the periodic nanostructures on a thick gold sample obtained in the experiment at different fluences.

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LMI-12 Photovoltage Formation Across GaAs p-n Junction Under Illumination of Intense Laser Radiation

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Two mechanisms are dominant in photovoltage formation when nonhomogeneous semiconductors are illuminated with intense laser radiation [1]. If the Illumination leads to electron-hole pair generation, an ordinary photovoltage arises across p-n junction due to separation of electrons and holes by internal electric field of the junction. If the photon energy is lower than forbidden energy gap, the intraband free carrier absorption of laser radiation causes rise of thermoelectromotive force of optically excited hot carriers. In this case the polarity of the generated voltage signal is opposite to that of the ordinary photovoltage. In our work we present the results of investigation of the photovoltage formation across GaAs p-n junction under illumination of intense laser radiation with photon energy smaller than the forbidden energy gap.

It is established that the photoresponse induced across GaAs p-n junction under the illumination of Nd:YAG laser radiation of 1.06 μm- wavelength and pulse duration of 15 ns consists of two components $U = U_f + U_{ph}$ .The first term U_f is the fast component having polarity corresponding to that of thermoemf of hot carriers, and the U_{ph} is the slow component of opposite polarity. U_{ph} was indentified to increase with intensity P of the laser radiation according the square law. This fact indicates that U_{ph} is caused by electron-hole pair generation due to two-photon absorption since the photon energy is lower than the forbidden energy gap of GaAs. The measurements of dependence of U_f on P show that Uf linearly depends on the laser intensity. Linear dependence is inherent feature of the thermoemf of hot carriers [1].

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LMI-13 Nonlinear Auger-like optical processes in crystals and nanostructures: multiphoton excitation and utrafast all-optical switching

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New mechanisms of optical excitation of transparent solids are considered. The mechanisms based on elementary processes including simultaneous absorption of one or several photons and energy transfer between electrons are characterized by the extremely high degree of optical nonlinearity. The following effects arising because of these mechanisms were examined:

- multiphoton interband transitions with participation of free charge carriers in *n*-type semiconductors with direct and indirect electron band structure;
- multiphoton avalanche-like pre-breakdown generation of non-equilibrium electron-hole pairs (NEEHP) in wide-gap insulators or intrinsic semiconductors at very high excitation levels;
- multiphoton Auger-like transition and all-optical switching in wide-gap crystals with deep impurities;
- highly efficient multiphoton-avalanche excitation of NEEHP in type I and type II heterostructures with deep quantum wells (QWs);
- photon-avalanche effect and ultrafast low-energy all-optical switching in deep doped QWs;
- "optical trampoline" effect in doped QWs and in crystals with deep impurity levels.

Quantum-mechanical calculations of probabilities of elementary processes involved in above-mentioned phenomena were performed within high-order perturbation theory. The results of these calculations were used by analyzing kinetics of NEEHPs producing and optical switching the media between states with essentially different optical and electrical properties.

It was shown that in all cases under consideration a relatively narrow regions of laser intensities *j* appear where the populations of electron states dramatically change even at small change of *j*. Theoretical results are in a good agreement with experimental data if they are available. A number of impurity and intrinsic crystals and heterostructures, whose electron band structure and geometric parameters allow the above-described nonlinear Auger-like mechanisms of photoexcitation and optical switching, are considered in detail.

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LMI-14 Laser-induced damage thresholds of gold, silver and their alloys in air and water

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Pulsed laser ablation in liquids (PLAL) is an efficient and flexible technique for synthesis of nanoparticles of various materials, in particular of noble metals. In recent years, colloidal metal alloy nanoparticles attract much attention as new multifunctional nanosystems combining functional properties of individual metals. However, in contrast to laser ablation in ambient gases, little is still known about the PLAL mechanisms and the available data are sometimes contradictory and rather poorly understood. In this work, we have systematically investigated the laser-induced single-shot damage thresholds of gold, silver and gold-silver alloys (25 and 50% Ag molar fraction) in air and water. The thresholds were determined by measuring the damaged area induced on the surface by a Nd:YAG laser (1064 nm, 7 ns) as a function of laser fluence. The experimental results are analyzed theoretically by solving the heat flow equation for the samples irradiated in air and in water taking into account vapor formation at the solid-water interface. The damage thresholds of Au-Ag alloys are systematically lower than those for pure metals, both in air and water, by a factor of ~1.4 that is explained by lower thermal conductivities of the alloys. The thresholds measured in air agree well with the calculated melting thresholds for all samples. The damage thresholds in water are found to be considerably, by a factor of ~2, higher than the corresponding thresholds in air. This cannot be explained, in the frames of the used model, neither by the conductive heat transfer to water nor by the vapor pressure effect. In this context, such critical phenomena in the superheated water as critical opalescence and anomalous heat transport due to the piston effect are discussed as possible reasons for the high damage thresholds in water.

LMI-15 Instabilities and ablation phenomena under the laser melting of powder layers

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Laser ablation under the action of laser is a well-known phenomenon. Several mechanisms of particles release in pico – millisecond laser ablation are proposed assuming that most processes are related to decay of the metastable states. Alternative mechanism of laser ablation could be based on initial heterogeneity of irradiated material.

The process of melting of the thick metal powder layers has been investigated under temperature control using a pyrometer and CCD camera. Layer 10x10 mm in square was scanned at a speed of 100 mm / s by spot 70 μm at scan shift 30 μm, which ensured the creation of a thin layer of the melt.

Emission of dispersed particles from the surface of the overheated melt has been established. Particle temperature corresponds to the temperature of the melt surface. Formation of the molten layer leads to a transition of the porous structure into the melt, gas heating in the pores and explosive like destruction the porous structure with the melt particles release. The gas filled in pores, heats up to pores wall temperature through thermal conductivity in a short time to 10^{-8} s. The pressure about 10 MPa, developed by gas, could result in melt surface destruction. Droplet emissions facilitated by melt overheating due to the fall in its viscosity.

At first development of the instability of the contact surface between the liquid - melt and granular matter - powder in a gravity field - Rayleigh - Taylor (RT) instability has been discovered experimentally. Emerged on the surface structures because of the instability have high absorptivity due to multiple reflections of the laser radiation in the pits Numerical simulation of the RT instability suggest that instability develops starting from small scale 0.1 mm passing to the large-scale structure - 1mm. The results of calculation agree with experimental data.

LMI-16 Ablation and high harmonic generation in bulk diamond

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The response of the diamond lattice to an intense linearly polarized laser field is calculated by numerical integration of time-dependent Schrodinger equation [1-3] in one electron approximation. The generation of ultrafast currents in the bulk of the material induced by the intense femtosecond laser pulse is theoretically investigated. Calculations predict transition from nonlinear polarization currents during the laser pulse at low intensities to Zener tunneling into the conduction band at higher intensities. The DC current generated after the end of the pulse at high intensities is considered to be the precursor of optical breakdown on a femtosecond scale. The Fourier transform of the ultrafast current is analyzed in terms of high-harmonic generation (HHG) in bulk diamond3 and the non-linear laser-intensity dependence of individual harmonics (HHG spectrum) is presented. We next focus onto a particular n-th harmonic in the HHG spectrum and calculate the time profile of that harmonic.

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LMI-17 Mechanisms of ultra-short pulsed laser ablation in optical crystals by interferometry and photoelectron spectroscopy experiments

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Knowledge of mechanisms of laser ablation and modification in optical crystals is important for development and optimization of today laser technologies. Processes launched in the transparent materials by intense pico- and femtosecond pulses involve complex and fast photo-electron kinetics. Experimental characterization of those calls for combination of adequate techniques in terms of time resolution, response to the created number of free electrons and ability to monitor their energy inside the conduction band.

Here, we report the results of an extensive research aiming to determine dominating mechanisms of optical energy deposition and relaxation resulting in laser ablation, breakdown and modification in wide-band gap crystals (oxides, including quartz and sapphire, and halides). In situ monitoring of electron concentrations near the damage threshold was performed via fast interferometry, while their energy was measured in variety of photo-electron spectroscopy experiments. In both cases, the surface was exposed to a couple of laser pulses with variable time delay (UV and IR), to treat separately the stage of multiphoton transitions across the band-gap and the following heating of free electrons, keeping in mind possibility of impact ionization. Thresholds of ablation were measured under the same two-pulse irradiation conditions. This way, the most complete and direct set of measurements was performed to characterize electron excitation, relaxation and multiplication ending up at optical breakdown in these materials.

Electron-phonon relaxation was shown to play the clue role in optical crystals where lifetime of electrons is long (sapphire, MgO etc). Multistage intraband absorption and transmission of energy to the lattice results finally in thermal instability. In spite of high energy levels achieved by the electrons (> 20-30 eV) no multiplication effect was observed in such materials. Impact ionization was only revealed in crystals known for binding of free electrons within self-trapped excitons (SiO2, NaCl). We report here the first direct observation of such processes along with simulations and ablation threshold criteria based on the obtained data.

LMI-18 Interaction of femtosecond doughnut-shaped laser pulses with glasses

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Interaction of femtosecond laser pulses with bulk glass (fused silica as an example) has been studied numerically based on Maxwell's equations supplemented by the hydrodynamics-type equations for free electron plasma for the cases of Gaussian linearly-polarized and doughnut-shaped radially-polarized pulses. For Gaussian pulses focused inside glass (800 nm wavelength, 50 – 100 fs duration, numerical aperture <0.3), the maxima of laser intensity, free electron density, and absorbed laser energy density do not considerably change with the beam energy (clamping effect). At pulse energies of 200 nJ – 2 μJ, the free electron density in the laser-excited region remains subcritical while the locally absorbed energy density does not exceed ~4000 J/cm^3. Increasing pulse energy results mainly in increased laser-affected volume.

For doughnut-shaped pulses, the initial high-intensity ring shrinks upon focusing. For relatively low beam energies, the internal and external radii of the light ring are decreasing with almost the same rate. With increasing energy, dynamics of beam focusing can be divided into two stages. First, the internal radius decreases while the maximum electron density is similar to that obtained for the Gaussian pulse. At the second stage, the external beam radius swiftly collapses with abrupt increase of laser intensity, leading to supercritical free electron density generation. The absorbed energy maximum in the beam collapse region can be 10 times higher compared to the Gaussian beam.

Calculated spectra of light transmitted through the sample and scattered to large angles have demonstrated spectral broadening with blue shift. The spectra are considerably different for the two studied pulse shapes that can be used for diagnostics of laser-glass interaction processes.

This research is supported by the Russian Foundation for Basic Research (RFBR project No. 15-51-46007). The work of M.P. Fedoruk is supported by Russian Science Foundation (Project No. 1204 14-21-00110). We thank S.K. Turitsyn for fruitful discussions.

LMI-19 Femtosecond laser-assisted reshaping for hybrid metal/semiconductor nanophotonics

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The recently proposed concept of metal-dielectric (hybrid) nanostructures, nanoantennas and metasurfaces has allowed utilizing the advantages of both plasmonics and all-dielectric nanophotonics: ability to localize and enhance optical field via excitation of strong plasmon resonances (for resonant metallic nanoparticles) and low dissipative losses in the visible range alongside with opportunity for light control via designing of scattering properties (for high index dielectric nanoparticles). The first feature of such hybrid nanostructures is the huge discrepancy between metal and dielectric nanoresonators. The second feature is the necessity of applying of different lithography methods and additional steps to create a metal-dielectric nanostructure with high precision. These requirements are strong liming factors for fabrication of the hybrid nanostructures with certain optical properties.

We demonstrate a novel approach for fabrication of ordered hybrid nanostructures via femtosecond laser melting of asymmetrical (not a core-shell structure) metal-dielectric (Au/Si) nanodimers created by lithographic methods. We have observed that the local laser melting enables selective reshaping of the metal components without affecting the dielectric ones. We have also revealed that the laser reshaping of the gold component in the Au/Si nanodimer allows to modify substantially the structure of the optical modes changing dramatically optical properties of the metal-dielectric nanostructures. The experimental results are supported by molecular dynamics simulations and numerical modeling of optical properties.

The approach of the highly precise femtosecond laser melting at the nanoscale offers unique opportunities for fabrication of nanoantennas and metasurfaces consisting of asymmetrical hybrid nanostructures and manipulation of their optical properties. We believe that the represented results lay the groundwork of the fs-laser application for the large-scale fabrication of hybrid nanostructures and can be applied for effective light manipulation, biomedical and energy applications.

LMI-20 Photoelectron emission from large metal nanoparticles by ultrashort laser pulses

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Ultrafast laser interactions with metal nanoparticles have been successfully employed in multiple applications, e. g., phot-thermal treatment of cancer, development of sources of nanoplasma, and novel methods of nano-lithography. Many of those applications utilize regimes of strong laser-nanoparticle interactions at high intensity that result in melting of nanoparticles followed by total or partial destruction. However, biomedical and chemical applications require avoiding high laser intensities to provide minimum perturbation to environment that is, for example, a biological tissue. In this case, the major effects of interest for the applications are related to emission of electrons from nanoparticles by laser excitation to initiate or support chemical/biological reactions. Those regimes of mild interactions of ultrashort laser pulses with metal nanoparticles have not received significant attention due to the complicated nature of laser-nanoparticle interactions in that case. Electron photoemission by small nanoparticles (clusters containing from few tens to about 100 atoms) has been theoretically treated for a broad range of laser intensity (including the mild interaction regime) based on the models developed for molecules. Emission from large metal nanoparticles containing 10^3-10^4 atoms has not been studied in details.

Here we make an attempt to simulate one of general interaction effects – emission of electrons from metal nanoparticle. For numerical estimations and simulations, we consider femtosecond laser pulses that excite silver nanoparticles of variable radius at wavelength 800 nm. First, we estimate probability of two major emission mechanisms: photoemission due to three-photon absorption; and thermal emission due to heating of electron system by single-photon absorption. The photoemission is simulated for several values of nanoparticle radius using the Keldysh model [1] and the parabolic approximation for electron energy-momentum relation. Total emission yield and peak emission rate are plotted as functions of laser intensity for fixed radius and pulse width and exhibit specific steps associated with generation of several electron pulses. Simulated time dynamics of the photoemission confirms that conclusion and predicts generation of several electron pulses at the leading front of laser pulse. Mechanism of that pulsed emission is discussed and shown to be a quite general. Possible applications of this effect are discussed including optoelecronic devices, catalysis of chemical reactions, controlled stimulation of biological processes.

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LMI-21 Controlled laser-induced optical discharge in transparent dielectric: properties and applications

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Optical discharge at the surface of the transparent dielectric (borosilicate glass) by means of pulsed Yb-fiber laser (pulse energy 1 mJ, pulse duration 200 ns, repetition rate 50 kHz) was induced. For the initial ignition of optical discharge used metal plasma induced by the same laser. Discharge moved according to the motion path of the laser beam, the speed of movement of discharge reached more than 1 mm/s. Also, deposition of glass microspheres at the discharge burning was observed.

The aim of our study is determine the threshold values of the parameters in order to maintain the optical discharge, and study properties of micro- and nano- spheres formed during the combustion of discharge on the surface of glass. We used optical emission spectroscopy to investigations the spectral properties of optical discharge. High-speed camera (AOS X-motion 32,000 frames/s) was used to observation dynamics of formation of optical discharge.

Optical discharge induced pulsed Yb-fiber laser can be used as a continuum source (in the visible spectral range) for fundamental research and applications such as optical metrology, nonlinear spectroscopy. At the same time micro- and nanospheres can be used for medical purposes (as biomarkers), and in microsphere-assisted laser processing method.

LMI-22 Combinatorial pulsed laser evaporation technique for drug delivery and biomimetic implants applications

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We introduce Combinatorial Matrix-Assisted Pulsed Laser Evaporation (C-MAPLE) for the fabrication of organic biopolymer thin films. Structures with compositional gradient are obtained by the simultaneous laser vaporization of two distinct targets. Synchronized MAPLE of levan and oxidized levan cryogenic targets is applied in order to transfer under protection and assemble a two-compound biopolymer film structure. FTIR micro-spectroscopy confirmed the existence of a composition gradient along the length of the sample. In-vitro cell culture assays illustrate characteristic responses of cells to specific surface regions. Cells attached along the gradient are in direct proportion with oxidized levan concentration. Cell signalling response is in correlation with the surface composition gradient and roughness. This basically refers to the existence of an optimum mixture between constituents, and more or less hydrophilic areas. Once identified, the optimum region could be recognized by rapid fluorescence microscopy scanning.

We demonstrate the use of C-MAPLE to the in-situ synthesis of Poly-dl-lactide (PDLLA) and fibronectin (FN). Confocal and FTIR microscopy evidence FN packages embedded in the polymeric matrix. The composition of PDLLA and FN is preserved after C-MAPLE as demonstrated by protein staining and FTIR.

C-MAPLE is applied to synthesize crystalline gradient thin films with variable composition of Sr-substituted hydroxyapatite (Sr-HA) and Zolendronate modified hydroxyapatite (ZOL-HA). The inhibitory action of ZOL on osteoclast viability and activity is more efficient than that of Sr, which plays a greater beneficial role on osteoblast proliferation and viability. C-MAPLE allows to modulate the composition of the thin films and hence the promotion of bone growth and the inhibition of bone resorption.

Our conclusion is that C-MAPLE opens the possibility to combine and immobilize two or more organic materials on a substrate in a well defined manner by laser evaporation under protection.

LMI-23 Opportunity of using pulsed low-intensive terahertz sources for medical practice

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Usage of terahertz radiation in medical and biological research has various aspects, from studying biological effects of this radiation and analyzing characteristics of biomolecules to different medical applications. The advantages of such diagnostics include safety for the personnel, low price and patient's comfort. A significant part of vibrational-rotational spectrum of water and many organic molecules, including bioactive molecules (proteins and nucleic acids), as well as frequencies of intermolecular interactions, lie in the terahertz range.

In this work we created a diagram, where we highlighted the areas of different types of terahertz radiation effects. The data are presented as a plot against power density of THz radiation and against duration of the radiation. It is obvious that the results can be grouped based on the oval-shaped zones.

The experimental study was carried out of optical properties in the terahertz range of whole blood and blood plasma in SHR mice grafted Ehrlich's carcinoma and with chronic inflammation. Additionally physiological saline solution suspension of ascites Ehrlich's carcinoma cells was explored.

Study was performed by time-domain spectroscopy using a system developed in IMTO University. Characteristics of the emitted THz radiation are the following: the frequency range from 0.1 to 1.8 THz, average power of 0.3 μW and pulse duration of 2.7 ps. Most of the power was spread within the 0.1 to 0.6 THz frequency range.

In order to ensure safety in the use of terahertz radiation for medical problems, impact assessment of terahertz radiation was made to investigate functional activity of tumor cells in vitro by flow cytometry method.

LMI-24 Change of microstructure of hair during breast cancer development

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Biotissues and somatic cells are widespread objects for the optical biomedical diagnostics but their significant heterogeneity together with high scattering light significantly complicate obtaining statistically reliable data. That's why new research objects are needed.

In this work the difference of hair microstructure healthy and cancer carrier mice has shown for development of the optical biomedical diagnostics.

The object of the research was wool of mice (line BYRB) with spontaneous cancer tumors of mammary gland. Wool had been cut from all skin surfaces of healthy mice and mice with malignant tumor(s) of same line. Two types of tumors were investigated. Small tumor (nearly 1 cm) was detected by palpation. Large tumor was operated when tumor had been disintegrated.Hair microstructure was investigated by optical microscope Altami invert 3 working in phase contrast mode. The nitrogen and oxygen distribution within hair external layer was researched by electronic microscope JEOL-6000. The size of the external hair layer was measured by “Photocor compact” device.

It is experimentally shown that hair of healthy mice has dense structure. At the time, hair of cancer carrier mice has destroyed external layer. Parts of the external layer are absent. Pathological process development leads to the hair cell size decreasing.

The investigation of nitrogen and oxygen distribution within cell can be also used for biomedical diagnostics. The experiments have shown that concentration of nitrogen in healthy mice is more then in hair of cancer carrier. The mean of oxygen concentration rises for pathology present.

The represented data about wool structure can be used to improve the optical techniques for non-invasive diagnostics of cancer diseases.

This work is partially supported by grant of Ministry of science and education of RF.

PS1-LMI-01 Theoretical modeling of the laser metal nanoparticles fragmentation in water

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Due to the unique optical, physical and chemical properties the metal nanoparticles become more and more popular, and find wide applications in optics, electronics, biomedicine, analytical chemistry and photochemistry. Gold nanoparticles are of special interest because of their chemical stability. There are various methods to produce the nanoparticles. Of special note is the laser ablation [1]. Laser ablation has in liquids is an effective physical method to produce the nanoparticles in the form of colloids. However, the ablation in water and other solutions under the absence of chemically active components results in the formation of rather large-sized nanoparticles with a wide size spectrum. In this connection, to reduce the size of nanoparticles their colloids are additionally treated by ultrashort laser pulses, and this results in in the fragmentation of produced nanoparticles [2]. For example, in [3] was investigated femtosecond fragmentation of the aqueous solution of gold nanoparticles with a diameter of 60 nm. Using in situ microscopy and transmission electron microscopy were identified thresholds of fragmentation: (7.3±1.5) mJ/cm^2 for irradiation at a wavelength of 400 nm and (3.6±0.5) mJ/cm^2 for 532 nm.

A physical model of electrization and fragmentation of gold nanoparticles in water under the action of femtosecond laser pulses is presented. The model is based on the electrization of metal nanoparticles heated by a laser pulse, and their division under the development of instability of a charged liquid metal drop. As a mechanism of electrization we have considered the process of hot electrons’ emission from the surface of a nanoparticle and further solvation in water [4].

The considered physical model of metal nanoparticle fragmentation in water under the action of femtosecond laser pulses is schematically shown in Fig. 1.

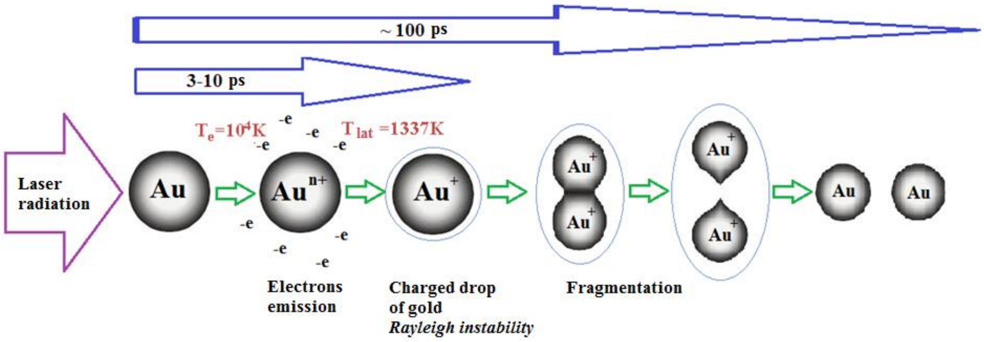

Fig.1 Physical model of gold nanoparticle fragmentation in water under the action of femtosecond laser pulses

A numerical solution has been performed of the problem of gold nanoparticle heating under the absorption of femtosecond laser pulses. A system of equations which describe the propagation of electrons in the dielectric medium taking into account their spatial self-charge was formulated and numerically solved.

The estimates of the potential gained by the nanoparticle due to the electron thermionic emission and their further solvation have been obtained. On the basis of the Rayleigh drop model the criterion of nanoparticle fragmentation has been found, as well as the dependence on the nanoparticle size. It has been shown that at the moment of nanoparticle complete melting the potential gained by the particle due to the electron thermionic emission turns to be significantly higher than the stability threshold of the gold charged drop, and the particle disintegrate. The calculated critical values of laser radiation F_{melt} needed to melt completely the 60 nm nanoparticles for τpul=150 fs and λ=400 nm and 532 nm are in good agreement with the critical values of such nanoparticles' disintegration obtained experimentally and confirmed by numerical calculations in [3]. Thus as soon as the gold nanoparticle goes into a liquid state it turns to be Rayleigh unstable. The discussed mechanism of gold nanoparticle fragmentation does exist in practice.

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PS1- LMI-02 Formation and transport of nanoparticles during pulsed laser ablation of transition metal dichalcogenides

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In this work, the formation of nano- and micro-particles on the surface of MoSe2 target was observed after pulsed laser irradiation of the targets with intensive energy fluence. Morphology, chemical composition and structure of surface layers of the irradiated target were investigated. The particles had various composition and they were enriched with Mo or Se. Deposition of laser-initiated particle-containing plume was carried out in vacuum conditions and in a buffer (He) gas at various distances from the target to substrate. Prepared films were studied using scanning electron microscopy and energy dispersive X-ray spectroscopy. To control the transport of pulsed laser plasma in various conditions, time-of-flight ion signals were detected in places of the target location. For the used condition of PLD, the transfer of nanoparticles from the target to the substrate was assisted with vapor flux transport and the codeposition of vapor flux with the nanoparticles was implemented on the substrate. The formation of the composition and morphology of the deposited MoSex films strongly dependent on the dynamic characteristics of vapor flux. For PLD in vacuum, the bombardment of the growing films with high energy atoms induced sputtering of Se-enriched phase and enhanced nanostructuring of the surface morphology. The He gas has changed the dynamic of the laser plume but it could not prevent the deposition of the vapor flux even at high pressure and large distance from the target. For a medium target–substrate distance, the deposition of the scattered vapor flux caused granulated morphology formation in the film. For a large distance, the condensation of Se vapor occurred and the Mo nanoparticles were captured in the bulk of the film grown due to the deposition of drifted vapor flux.

PS1- LMI-03 Investigation of role of feedback mechanism in processes of multiphoton excitation of semiconductor by ultrashort laser pulses

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Femtosecond laser technologies are based, mostly, on multipulse interaction. It is widely known that in this case feedback can appear, due to the change of optical and thermophysical properties of the material not only during the irradiation, but also from pulse to pulse. It is the most difficult to describe the interaction of ultrashort laser pulses with semiconductors, because during irradiation there is not only a change optical properties, but also there is a change in the mechanism of energy transfer between the plasma of exited carriers and the lattice after the laser pulse, in between the pulses there is irreversible change of absorbance of semiconductor. Such wide time scale of development of these processes (from femtoseconds to seconds) makes simulations significantly difficult and requires a search of original methods of solutions.

In the report we present quantitative-analytical model of femtosecond multipulse laser irradiation of silicon in the regimes of microstructuring of the surface. During a single pulse (of 80 femtoseconds) transient absorbance is determined by electron-electron collisions in electron-hole plasma and is described in the approach of weakly anomalous skin-effect. We discuss the results of simulations of mutual influence of the dynamics of absorbance and the temperature of electron gas.

During irradiation in the regimes of polarization-based microstructuring of the surface, the absorbance is changing from pulse to pulse as well, due to the formation and evolution of surface relief in the irradiated spot, due to the growth of the height of the relief and the coefficient of conversion of incident radiation in surface electromagnetic wave, due to the chemical transformations.

It is proposed it the quantitative-analytical model to take into the account the change of the relief from pulse to pulse and the possibility to accumulate such changes from pulse to pulse by adding an additional, linearly changing from pulse to pulse, component in the absorbance.

Such approach is consistent with appearance of antireflection effect, observed in the experiments, and with linear growth from pulse to pulse of the height of the relief. We discuss the results of simulations of mutual influence of the processes, occurring in macrosystem – the modification of surface relief of silicon from pulse to pulse and the processes, developing in electronic subsystem of semiconductor – spatio-temporal redistribution of concentration of nonequilibrium carriers.

It is shown, that the formation of feedback on absorbed light introduces substantial features in the developing processes, by changing the efficiency of energy distribution at constant energy density of incident radiation.

PS1- LMI-04 Investigation of the mechanism of the combined femtosecond microstructuring of silicon surface

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With the invention of the ultra-short lasers, special attention is paid to research of the microstructures that appear on the surface of the irradiated material. Study of the evolution of the microrelief surface, depends on the density of the laser flow, the number of pulses, pulse repetition rate and relevant in connection with an expanding range of technological applications and solutions for the fundamental problems of different laser-induced processes.

In particular, of special interest are surface periodic structures (SPP), oriented by polarization vector of the incident radiation. Qualitative estimates made in [1] in the framework of the diffusion approximation, showed that taking into account the emission of hot electrons during the action of a femtosecond pulse dramatically changes the spatial distribution of the concentration nonequilibrium electrons in silicon. In the near-surface region is formed optically laminated structure, responsible for excitation conditions of surface polaritons (SP) and waveguided modes (WM). The evolution of microstructures from the center to the periphery is observed under the irradiation by the focused beam. Fig. 1 (a) shows that in the central part of irradiation field, are large-scale structures, parallel to the polarization vector, and on the periphery - the structures perpendicular to the polarization vector. But there is an intermediate region (Figure 1, b), where there are large-scale and small-scale orthogonal structure, forming a two-dimensional lattice. The formation of SPP, that are perpendicular to the polarization vector, associated with the excitation of the SP and formation of the SPP parallel to the polarization vector caused by the excitation of the WM, but the mechanism of the "combined" microstructuring of the silicon surface is still unknown.

This report proposes to discuss the review of the numerical simulation results of the processes that develops in the electronic subsystem of femtoexcitated semiconductor, complemented by measurements of surface plasmon resonance in multilayer objects, simulating transient optical structure of the nonequilibrium media. Methods of modeling of dynamic layered structures by stationary multilayer structures based on the compliance of the excited surface perturbations in both cases.

The results of dynamic and static simulation are compared with the ideas of the polariton structuring mechanism, and with experimental data on the evolution of microstructures on silicon surface irradiated by femtosecond pulses, depending on the density of the laser flow. The paper presents the mechanism of combined femtosecond microstructuring of the silicon surface.

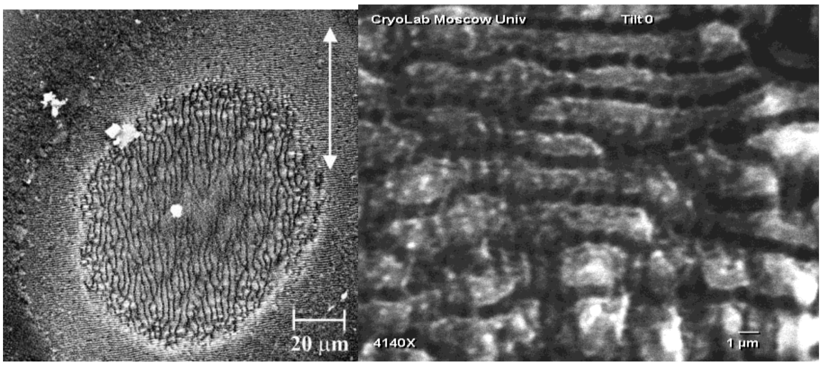

Fig.1. Electronic images of silicon surface irradiated by a series of femtosecond pulses below the ablation threshold [1], at different magnification. Increasing increases from (a) to (b). The arrow indicates the direction of polarization of laser radiation.

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PS1-LMI-05 Laser cooling of nanocrystals doped by Yb^{3+} ions by Gaussian pulse sequence

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Cooling of solid state matter by a laser radiation has the definite advantages over the other types of cooling. Optical coolers are compact, they have no vibrations and they use light for contactless extraction of excess energy. Such coolers can be effectively utilized in the case of the extremely small solid state objects that are used in up-to-date optoelectronics.

In this work a mechanism of laser cooling of nanocrystals doped by Yb^{3+} ions on coherent pulse pumping is considered. Dynamics of the cooling process is described by the matrix density formalism which allows to describe coupling of the ion vibrations with the vibrations of host material by introducing a mechanism of heat loss. In considered case, the loss is attributed to the cooling process. In addition, the establishment of the Boltzmann distribution at Stark shift sublevels of Yb^{3+} ion can be easily explained by the coupling between the vibronic subsystem and phonon reservoir. It is shown that the use of pulse pumping through the dipole-allowed 5*d* level of the Yb^{3+} ion improves the characteristics of the process of laser cooling of solid system in comparison to the corresponding characteristics obtained on pumping at the forbidden transitions between 4*f* levels. In the proposed model, the cooling efficiency can achieve 8 % and is in two times higher than the cooling efficiency in the model with direct pumping. As a result, it becomes possible to implement deep and fast cooling and reach 60 K in a time of some seconds for Yb^{3+}-doped nanocrystals.

PS1- LMI-06 Wavelike cracking in brittle materials by scanned laser beam

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The study of brittle fracture using a thermal field to induce stress in glass plate shows in addition to straight line crack propagation more complex paths: oscillations, branching, fractals.

The production of brittle fracture was studied on glass plate under the action of moving spot of laser radiation and spot temperature maximum more than softening one of glass. Cracks were induced by the local heating of glass plate surface during tightly focused cw CO_2 laser beam scanning along straight line. Especial methods to initiation crack nucleation did not undertaken.

In case of sequential increase of scan speed and constant laser power density there are three main types of observed fractures: well known straight line, wavelike oscillating and branching into the "Y-shaped" modes. For laser power density $q \approx 5$ kW/cm^2 and scanning speed v=10 mm/s the wavelike crack shape is almost sinusoidal having period d~900 μm and value of crack trajectory deviation amplitude in range of ~150 μm. The thickness of glass (t=1.8 mm) was fixed.

Under scanning laser beam (v=35 mm/s) along the surface of silica glass plate (t = 300 μm) we observed the wavelike crack with a period d~500 μm and amplitude ~ 40 μm. It observed under action of linearly polarized irradiation and orientation of a vector, where $\vec{E}$ is the tangential component of electric field strength vector of laser radiation and $\vec{s}$ is the direction of scanning of radiation. The laser power density for the given scanning speed was sufficient to reach the softening temperature of the silica glass surface. We have studied a laser irradiation trace. We observed traces residual regular grating $\vec{g}$) of a relief $\vec{g} \| \overrightarrow{E_\tau}$ with period ~1.3 μm. The glass-air heated interface supports the existence surface phonon polaritons (SPP) at laser radiation wavelength. Their excitation along the vector $\overrightarrow{E_\tau}$ and participation in interference brings to formation of a complex grating of a relief and dielectric constant $\vec{g}$.

Under the crack propagation in condensed media its interaction with moving macrocracks and ensemble of microscopic defects on small scales near the crack tip is important. Additional increase of the latent energy near crack tip from energy of SPP can make a noticeable contribution into fracture dynamics via cracking.

PS1-LMI-07 Mie resonances and terahertz generation in ordered arrays of GaAs nanowires

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We present the experimental results of terahertz (THz) generation in ordered arrays of GaAs NWs with a different fill factor and geometrical parameters, under excitation by ultrashort optical pulses.

The experiments were performed using the time-domain spectroscopy technique, which is able to detect the electric field amplitude and phase of generated the THz radiation. The GaAs nanowire (NW) arrays were fabricated with selective-area epitaxy using the Thomas Swan metal-organic vapour phase epitaxy (MOVPE) system, operating in atmospheric pressure, on p- and n-doped GaAs (111)B substrates.

Dependence of THz generation efficiency according to the geometric parameters of a NW arrays was experimentally shown. From the experimental results, it became clear that the authors of the article [1] wrongly suggested that the efficiency of THz radiation generation will increase with an infallible fill factor gain. It has been demonstrated that the THz generation efficiency is determined by NW’s fill factor, but reaches the maximum at the distances between nanowires («*a*») of the order of the wavelength of the exciting light (λ_{exc}) and extremely decreases when the $a >> \lambda_{exc}$ or $a << \lambda_{exc}$.

Also unusual is the dependence of the THz field on the polarization of the exciting light. THz generation efficiency is higher when the polarization of optical radiation is perpendicular to the axis of the NWs for a certain diameter of the nanocrystal. By dint of the theory of Lorentz-Mie a cross section absorption of light at oblique incidence on the semiconductor nanowire was calculated. The calculated dependence of a light absorption efficiency on the value of k_r is resonant, corresponding to Mie resonance (k - wave vector of the exciting electromagnetic wave, r – radius of NWs). Furthermore, for the quantity k_r = 0.63 (r = 80 nm), the light absorption at an incidence angle 450 is approximately two times greater for the TE polarization than for the TM polarization, when k_r = 0.31 (r = 40 nm) one can see the opposite pattern. This is consistent with the experimental results, since the value of the THz field generated in the process of movement of photoexcited charge carriers in the surface or applied electric field is proportional to the concentration of photoexcited charge carriers and accordingly the value of the THz field is directly related to the efficiency of light absorption [2]. Thus, the experimental results indicate that the efficiency of THz generation process is determined by the excitation of leaky modes for the light incident on the semiconductor nanocrystal and increases due to the resonant excitation Mie modes. Furthermore, it was demonstrated that the efficiency of THz generation in ordered arrays of GaAs nanowires grown on the n-type substrate and with the nanowires diameter of 160 nm, was higher than the efficiency of THz generation for volume p-InAs, which is known as one of the most effective THz emitters of the recent time.

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PS1-LMI-08 SURFACE-ENHANCED INFRARED ABSORPTION (SEIRA) SPECTROSCOPY OF A DYE R6G DEPOSITED IN ARRAYS OF MICROHOLES IN Ag-THIN FILMS

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Surface-enhanced infrared absorption (SEIRA) is a phenomenon in which infrared (IR) absorption of molecules adsorbed on metal nanoparticles and rough surfaces is enhanced by the interaction of IR photon with the metals and the molecules. We used a 30-nm thick silver (Ag) film, deposited onto a 1-mm thick CaF_2 substrate by magnetron sputtering in argon. The microholes were produced using femtosecond laser pulses of the film by moderately weakly (NA $\approx$ 0.25) focused 515-nm, 220-fs TEM_{00}-mode laser pulses of variable energy E = 50-85 nJ. Selective IR absorption at 1268 cm^{-1} enhanced by almost 50 times was demonstrated in a rhodamine 6G monolayer covering a 2D-photonic crystal, represented by a regular array of 4-micron wide holes in a 30-nm thick silver film on a CaF_2 substrate. The reference absorption lines were taken near 2900 cm^{-1}, where the IR radiation is freely channeling through the microholes, indicating the reference substrate coverage by the dye molecules as internal calibration. The limit of background-free detection for the analyte was determined at the level ~10^{-3} monolayer.

PS1-LMI-09 Peculiarities of laser-induced silicon damage in four-wave interference field

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There is the growing interest towards controlled formation of relief micro- and nanostructures including microcone's raster on silicon surface. The formation of microstructures under the action of interference field of four coherent waves (λ=1.06 μm, τ=1.2 ns) at the silicon surface (chemical-mechanical polished (100) Si sheets, thickness 500 μm) was investigated in present work. In select geometry of irradiation the production of an array of local damage sites with the 4 μm step in two perpendicular directions and lateral diameters in the range (1÷2.5) μm in dependence on laser energy density (q) for q higher the melting threshold was observed. For q less than vaporization threshold the microcones production (height ≤ 0.4 μm, diameter at the base about 1.2 μm and tip's radius of curvature near 100 nm) was observed. The suggested mechanism for microcones formation is the material redistribution in the local melt bath in the process of melting and subsequent crystallization. In this process the SiO_2 natural oxide film was not damaged. The existence of oxide film favors to rapid decrement of melt surface oscillations and prevents the melt drops ejection. Under the exceeding the very sharp threshold of vaporization value the oxide film was damaged and the melt was ejected from bath in modes of droplets with diameter up to (1÷1.5) μm. In this case the bath was replaced by the hole of 2.5 μm diameter with dangling SiO_2 film at its border.

The results of a-silicon film (thickness 450 nm) on glass substrate irradiation by four-wave interference field (λ=0.53 μm, τ=1.2 ns) and their discussion also are presented.

The suggested geometry of irradiation can be used for rapid prototyping of micro- and nanostructures on silicon surface.

PS1-LMI-10 Intrinsic optical breakdown of a dielectric by direct bond breaking in the crystal lattice

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The problem of an adequate description of the intrinsic optical breakdown of the widegap (Eg >> ħω) transparent materials under a short laser pulse action arose yet in the beginning of the eighties of the last century [1]. Since then many attempts to develop a model of the phenomenon has been made, but to date there is no adequate description of available experimental data. The traditional analysis of laser damage of the transparent media has been based on two models: the impact avalanche ionization and multiphoton absorption [1,2].

The proposed approach to the intrinsic breakdown description is based on the results of laser damage study for K-8 (BK7) glass and fused silica [3-4]. The most surprising results of this study are independence of the damage threshold on the pulse duration and the band gap of material.

The obtained regularities cannot be explained by traditional models. The independence of the damage threshold on pulse duration and band gap contradicts both multiphoton (tunnel) and avalanche breakdown models.

In these models the important process is disregarded, namely, a profound transformation of the energy structure of the system in strong external electric field. The possibility of the structure transformation (non-thermal instant "metallization" of dielectric) has been noted as early as 1986 in [4], but the concrete mechanism of the process had not been discussed.

We propose an approach based on the assumption that the strength of electric field of the light wave is high enough for direct mechanical disruption of the crystal lattice. This breakdown mechanism for ionic crystals was proposed by Rogowski as early as 1927. The obvious condition of the breakdown in the Rogowski model is the equality of external field strengths F_{th} and internal electrostatic field of the crystal lattice. The evaluation of the external field strength, that is high enough to induce irreversible bond breaking in the NaCl, gives a reasonable value of the breakdown field $F_{th} \approx 10^8$ V/cm ($q_{th} \sim 10^{13}$ W/cm^2). It means that the potential drop $U_{ext} = ea\,F_{ext}$ of the external field F_{ext} at the size of the crystal cell a is about 7 eV, i.e. is close to the published data for the enthalpy of the crystal lattice (lattice energy).

We extend the proposed model for analyzing the laser damage of *covalent* crystals, where the atoms in the lattice are linked via valence electrons. Using the "energy" language, it can be said that in a sufficiently strong field, the localized (valence) electrons acquire an energy amount within a single unit cell, which exceeds the lattice energy E_{bond}. This makes preservation of crystal structure energetically unfavorable. The system goes to the state that largely resembles plasma with a solid density. In this state, the lattice sites displaces, causing the crystal's destruction.

Thus, the destruction begins when the energy E_{crit}, which acquire the valence electrons within the unit cell, becomes equal to lattice energy E_{bond}, i.e., at the pulse field strength above a critical value, $F_{crit} = E_{bond}/ea$, where e - the electron charge, and a – the lattice parameter. Note that E_{bond} values for fused quartz and silica glass are the same (bond is Si=O for both solids). So in the frames of proposed model the values of the optical breakdown threshold for fused quartz and silica glass must be also the same.

For the bond energy $E_{bond} \approx 3{,}8$ V, and cell size $a \approx 5$ Å (quartz, silica glass) we have the calculated value of the breakdown threshold $q_{th} \sim 8 \cdot 10^{12}$ W/cm^2, which is in good agreement with the experimental data [3] and does not depend on the width of the band gap.

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PS1-LMI-11 Influence of electron asymmetry and structure of end groups of cyanine dyes on the component composition and absorption spectra of molecular layers

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We study molecular layers of asymmetric dicarbocyanines (ADCC) of the cationic type, where the anion, ClO^{-4}, and the end group EG1 of the cation are the same for all dyes and the end group EG2 is of different structure. The absorption spectra of dye layers on glass are measured, their dependences on the surface concentration of the molecules are determined, and bands due to the layer components, monomeric stereoisomers and associates, are separated.

The ADCC layers are compared with the layers of symmetric dicarbocyanines (SDCCs), where the end group (EG1=EG2) is the same as EG1 or EG2 in ADCC. For layers of ADCC molecules with the same EG1, the concentration dependences of components are affected by the electron donor ability and spatial structure of the end group EG2. The latter parameters are responsible for the asymmetry of the electron density distribution in the cation, which is in the form of the cation-anion pair, and the intensity of its interaction with the charges on the surface of a substrate. In submonomolecular layers of ADCCs with small electron asymmetry, the concentration of the long-wave monomer (Fm1) relative to the total concentration of the monomers in the layer (ΣFmi) is close to zero. With increasing layer thickness, the relative concentration of Fm1 first increases and then remains constant. For molecules with bulky EG2, the growth of the relative concentration of Fm1 begins at lesser layer thicknesses and is steeper than for ADCCs with less bulky EG2. For SDCCs, the dependences are similar. For ADCCs with large asymmetry and bulky EG2, the relative concentration of Fm1 is maximal for layers of small thicknesses and somewhat decreases with increasing thickness. The above concentration dependences are associated with changes in the difference between the electron charges on EG1,2, which are caused by the interaction of the cation-anion pairs with the substrate charges.

The calculation shows that the interaction of SDCC with the oxygen anion causes charges on both end groups to decrease. The charge decrease is significantly larger for the end group located closer to the oxygen anion, which causes a large asymmetry to occur. In dicarbocyanine layers, the cation forms an angle with respect to the substrate. In layers of ADCCs, the end group with larger electron donor ability is located closer to the surface. In SDCC layers and in layers of ADCCs with low asymmetry, the difference between the charges on the end groups decreases with increasing thickness, whereas the sign of this difference does not change. In ADCCs with large asymmetry, both the value and the sign of the charge difference may vary, whereas variations of the absolute value are lesser than in SDCCs. Thus, in asymmetric molecules with a large difference in the electron donor abilities of end groups it is possible that the interaction with the substrate results in a decrease in the asymmetry of the electron density distribution and leads to its slight dependence on the layer thickness.

PS1-LMI-12 Plasmon-exciton coupling in a hybrid films of the ag nanoparticles and j-aggregates of cyanine dyes

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Plasmon-exciton coupling in hybrid nanostructures has garnered significant attention, due to the tunable and novel optical properties, and potential practical applications in areas such as light harvesting, plasmonic lasers, biosensors, and spectroscopy. These hybrid systems often consist of a core-shell geometry in which the localized surface plasmon resonance of the metallic nanoparticles couples with the exciton resonance exhibited by a J-aggregate dye or a quantum dot shell.

Silver/cyanine hybrid nanostructures are suitable for studying plasmon-exciton interactions because plasmonic nanoparticle morphology and molecule size may be tuned to ensure the overlap of plasmon and exciton resonances.

The hybrid films of the organic dye and the Ag nanoparticles were used as samples. The nanoparticles obtained as the granular film by thermal evaporation in the vacuum chamber Kurt J. Lesker PVD 75 at the high vacuum. The homologous series of pseudoiso-, monocarbo-, and dicarbo cyanine dyes were studied for formation of the J-aggregates in the layers spin-coated from the ethanol solution on the surface. All obtained layers consist of all-trans- and cis-isomers and associated forms such as J-aggregates and dimers. For the homologous series the coupling between the localized surface plasmon resonance of silver nanoparticles and J-aggregate excitons observed only for pseudoisocyanine (PIC). This coupling produced an induced transparency of the PIC samples forming dip in the absorption spectrum.

For J-aggregates of monocarbo- and dicarbo cyanine dyes the coupling is weak, the electromagnetic modes of plasmons and excitons are unperturbed. As a result, the absorption and emission rates, increase. The coupling is considered to be a strong for PIC, when the modes of the plasmons and excitons are perturbed. The strength of the plasmon–exciton coupling measured by the Rabi splitting energy determines the optical properties of the molecules coupled to the plasmonic nanoparticles.

PS1-LMI-13 New opportunities for the multichannel high-power laser facility with ultra-short pulse duration

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Generation of terahertz (THz) electromagnetic radiation with ultra-high field intensity is a fundamental and important challenge on the way of solving laser-matter interaction problems. One of the most prominent methods of THz field generation is so-called "optical rectification" of femtosecond laser pulses having tilted wavefront with sufficient efficiency (more than 0.25% [1]). Conversion takes place in non-linear optical crystals observing phase synchronism. Relative simplicity of this method offers wide opportunities for scaling, that will make it possible to exceed present THz-pulse energies on several orders in the future. Focusing such pulses will provide earlier unachievable field intensities and a new field in physics. Nowadays a new petawatt-class OPCPA (optical parametric chirped-pulse amplification) laser system is being designed in RFNC-VNIIEF [2], that can become a suitable pumping source for record-energy THz-pulse generation to perform target diagnostics in laser fusion experiments.

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PS1-LMI-14 Investigation of laser-induced hydrodynamics and cavitation in liquids resulting of microsecond Yb,Er:glass laser pulses impact

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Eye-safe infrared lasers are widely used in medical applications particularly for cataract extraction [1]. Advanced laser medical technologies stimulate new researches in a field of intense light interactions with water as a main component of soft biological tissues [2].

We report on research of laser-induced hydrodynamic processes arising at impact of dozens kilowatt laser pulses at 1.54 μm into water and saline. The investigation was carried out using three methods like original method of optical probing (OP), acoustic signal detection (ASD) and high-speed video recording (HSV) as well. Developed Yb,Er:glass laser provided 100 mJ energy level pulses of few microseconds width. The radiation was delivered into the liquid volume via low OH quartz optical fiber with core diameter of 400 μm. The 1.54 μm pulse peak intensity in the interaction area exceeded 100 MW/cm^2. The liquid volume in the vicinity of fiber output was scanned by a beam of visible low-intensity CW laser. A photodetector with time resolution of 5 ns was installed opposite to probing beam source. It detected changes of transient optical extinction for the probe beam caused by laser pulse-liquid interaction. Simultaneously a hydrophone with a frequency bandwidth of 1.5 MHz detected an acoustic signal. Time resolution of the used HSV (Photron FASTCAM SA4 RV) is of 2 μs.

As a result of comprehensive researches the correlation between the photodetector signal dynamics, acoustic response and the video information was established. It was found, that the liquid disturbance resulting of impact of high-power 1.54 μm laser pulses is associated both with laser-induced local disturbances of refraction index and cavitation processes. We did not observe any plasma formation in liquids in all the range of used laser parameters. The steam-gas cavity build-up stage occurs at 5-10 μs after the beginning of adiabatic laser exposure with energy of about 100 mJ. The cavity reached the maximum size at 140 μs (on average) relative to laser pulse rising edge. After that, it collapsed to a critical size of 0.5 mm in around 120 μs and detached from the fiber end surface. Then new bubble appeared on a distance comparable with the fiber diameter. One could observe a cloud of shallow bubbles and powerful liquid stream in the vicinity of the fiber output.

The repeated expansion-collapse phases came to the end in about 450 μs after the laser impact. A maximum pressure jump was measured to be as 25 MPa (peak-to-peak value) at the distance of 200 μm from collapse epicenter. This pressure jump value was calculated from the signal of transducer installed at the distance of 9 mm from the sound emission center assuming the inverse distance law of acoustic pressure attenuation in the far field [3-5]. The cavitation bubble diameter in saline reached 2 mm at the stage of maximum expansion.

On the basis of conducted researches it was concluded, that for the particular case of the cataract lens fragmentation procedure [2] the power and energy density is under laser induced volume damage threshold in the water and saline in all the range of the used laser pulses at 1.54 um. Safe laser microsecond monopulses period in batch mode should be not less than 500 μs to avoid a crystalline lens capsule damage by subsequent pulses.

Thus, it is shown that the use of three independent OP, ASD and HSV methods gives a comprehensive objective concept of the liquid's state dynamics resulting of laser radiation impact. The obtained data can be used to optimize laser sources parameters for effective and safe processing of submerged biological objects.

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PS1-LMI-15 Features of influence of recombination processes on accumulative heating of silicon surface during the irradiation by femtosecond laser pulses

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In the technology of femtosecond laser processing of metals, semiconductors and dielectrics multipulse irradiation is widely used. The heat accumulation effects from pulse to pulse play important role in the final result of processing. And if in metals the heat of the solid occurs due to the heat exchange between electron gas and crystal lattice, in semiconductors and dielectrics recombination processes take part in the heating process. Moreover, as previously shown in work [1], during irradiation of silicon by femtosecond laser pulses the contributions of recombination processes: Auger recombination and nonradiative recombination, have opposite orientation. At pulse energy density below the threshold and pulse repetition rate 10-1000 Hz, due to nonradiative recombination additional heating of the lattice occurs, shifted in time relative to the heating by electron gas. Auger recombination decreases concentration of nonequilibrium carriers, without participating directly in the heating of the lattice, which results in the decrease of the maximum temperature of silicon surface.

In the report the results of quantitative evaluations of the influence of recombination processes on accumulative heating of silicon surface during the irradiation by femtosecond laser pulses in the regimes of laser-induced periodic surface structures formation are presented to discussion. In the calculations the quantitative-analytical method is used in which the dynamics of electron processes and the heating of the lattice are modeled using quantitative method, and the cooling of semiconductor between pulses is described on the basis of the analytical solution of the heat equation.

The focus is made on the study of the influence of Auger recombination on the residual temperature of the silicon surface, depending on the coefficient of Auger recombination, pulse repetition rate and laser pulse fluence. Mutual fluence of recombination processes of both types is shown.

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PS1-LMI-16 Femtosecond laser heating: two-dimensional effects

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We consider irradiation of an aluminum film 200 nm thick by a single femtosecond laser pulse. In a one-dimensional (1D) case laser intensity is spatially homogeneous across surface of a film. While in a two-dimensional (2D) case intensity is a sum of a constant and a periodic modulation across surface. Let λ is a period of the modulation. The back (relative to the frontal irradiated side) side of a film is kept at constant in time temperature. The back side temperature equals to 300 K. Thus there is a sink for absorbed laser energy. We consider a range of fluencies approximately twice higher than a melting threshold. Results of a computer simulation of a two-temperature (2T) problem in a 2D geometry are presented. The results describe fast 2T heating, melting, 2T relaxation, and gradual cooling and final freezing. It is shown that the lateral (along a film) electron conductivity at the 2T stage, the 1T stage, and during solidification dumps down modulation of intensity for wavelengths λ shorter than approximately 200 nm. This work has been done under RFBR grant 16-08-01181 A.

PS1-LMI-17 Evaluation of multi-photon dissipative losses in silica glass via nanoscale femtosecond laser ablation

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In our work, an Yb-doped fiber laser radiation with its 515-nm wavelength, 220-fs pulsewidth and 4-W average power at 0.5-MHz repetition rate was focused by a 0.25-NA microobjective. The resulting ablation crater profiles (Figures 1,2) were studied, using a scanning 3D-confocal laser microscope OLS4100 LEXT (Olympus) at 405-nm wavelength with a $100^{\times}$-objective.

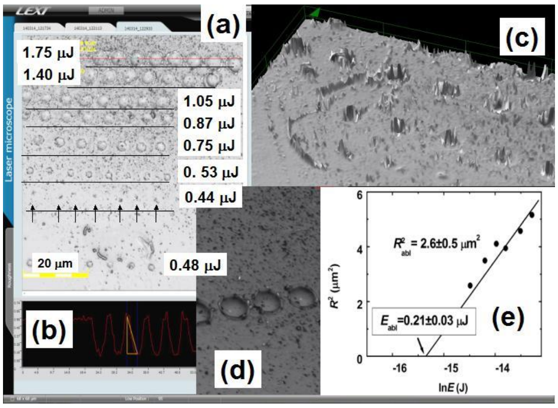

Figure 1. 3D laser confocal scans of single-shot craters on silica surface at variable fs-laser pulse energies (a – top view, c,d – side view), their profiles at the pulse energy E = 1.75 μJ (b). (e) Fluence calibration curve for crater radii, its linear approximation with the slope $R_{abl}^2 \approx 2.6$ μm^2.

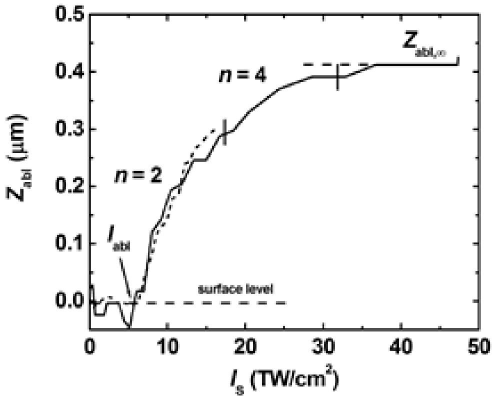

Figure 2. Crater depth dependence on local intensity, Z_{abl}(IS), for peak intensities of I_0 = 30 (dotted curve) and 50 TW/cm^2 (solid curve), with the short vertical lines showing the different n-photon absorption regimes.

The acquired curves Z_{abl}(IS) (Figure 2) were interpreted considering short-scale non-linear transmission in the silica glass, demonstrating two characteristic n-photon absorption regions with n = 2 and 4 above the ablation threshold. The even non-linearity powers represent, saturating two-photon absorption from defect bands in the bandgap and intrinsic four-photon interband (VB –CB) absorption through the 9-eV basic gap in the material. The related non-linear absoprtion coefficients are $\beta_2 \approx 3.7\times10^3$ cm/TW and $\beta_4 \approx 6.8$ cm^5/TW^3. Moreover, the energy density $\beta_2 I_{abl} F_{abl} \approx 3\times10^4$ J/cm^3 (≈2.3 eV/atom) deposited in the silica glass near its ablation threshold $I_{abl} \approx 6$ TW/cm^2 indicates its intense boiling and, apparently, near-critical phase explosion.

PS1-LMI-18 Ultrafast electron dynamics of material surfaces under intense femtosecond laser chirped irradiation

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Emission of erosive plasma has been observed during electric probe and optical emission spectral measurements of plumes produced by single shot femtosecond chirped laser pulse ablation of optical quality surfaces of various materials — copper, titanium, and silicon — at laser fluencies well below the corresponding thermal ablation thresholds, replacing presumably electron emission at lower fluencies. The onset of erosive plasma correlates on the fluence scale with saturation of dependences of self-reflectivity of the pumping femtosecond laser pulses, reflecting the “freezing” of electron dynamics (variation of electron density or temperature) during the pumping pulses, despite the monotonically increasing laser fluencies.

PS1-LMI-19 Comparison of nonlinear Maxwell and Schrödinger approaches to modeling laser beam focusing into bulk glass: Effect of boundary conditions

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Two approaches for modeling of femtosecond laser pulse propagation inside transparent dielectrics are usually used, based on Maxwell’s equations and the nonlinear Schrödinger equation. The latter is easier for numerical solving as it requires considerably smaller computer resources. However, its applicability becomes doubtful for situations with excitation of dense, highly-localized free-electron plasma scattering light to large angles. This contradicts to main assumptions of the Schrödinger model, unidirectionality of propagation of slowly varying envelops.

In this work, these two modeling approaches are compared for irradiation parameters typically used for modification of optical glasses. Simulations are performed for fused silica irradiated at 800 nm. The results show significant difference between Maxwell and Schrödinger solutions even at relatively moderate NA (~0.25) which dramatically increases with further NA increase.

It is known that the spatial Fourier transform of a Gaussian beam entering the sample contains $k_\perp > 2\pi/\lambda$. For Maxwell’s equations, this yields in an imaginary z-component of the wave number, resulting in small-scale perturbations of laser intensity near the focal region. To avoid these effects connected with large $k_\perp$, the boundary conditions with cut-off $k_\perp$ and a smoothing procedure are proposed, which suppress perturbations. The results of the Maxwell-based model with such conditions are close to the Schrödinger-based solution even at NA ~ 0.4.

The questions on what are realistic boundary conditions, which would accurately describe beam focusing, and whether the Schrödinger-based model is valid for modeling tightly focused laser beams call for further studies. Simulations demonstrate that even small variations of spatial pulse shape can cause considerable changes in locally absorbed laser energy and, hence, in material modification.

This research is supported by the Russian Foundation for Basic Research (RFBR project No. 15-01-02432). The work of M.P. Fedoruk is supported by Russian Science Foundation (Project No. 1204 14-21-00110).

PS1-LMI-20 Modeling of propagation of femtosecond laser pulses with

spatio-temporal coupling through glass

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Ultrashort laser pulses are usually described in terms of temporal and spatial dependences of their electric field, assuming that the spatial dependence is separable from time dependence. However, in most situations this assumption is incorrect as generation of ultrashort pulses and their manipulation lead to couplings between spatial and temporal coordinates resulting in various effects such as pulse front tilt (PFT) and spatial chirp. One of the most interesting spatio-temporal coupling effect is, the so-called “lighthouse effect”, the phase front rotation with the beam propagation distance. The interaction of spatio-temporally coupled laser pulses with transparent materials have interesting peculiarities which can be used for microfabrication, such as is violation of axial symmetry of laser energy coupling and the effect of nonreciprocal writing.

In paraxial approach, the PFT and the phase front rotation can be described by the spatio-temporal terms in the boundary condition for the electric field as

$$E = E_0 \exp(-r^2 / w^2 - ikr^2 /(2f) - (t - p_R x - ip_I x)^2 / t_L^2 + i\beta t^2) \,.$$

Here w is the laser beam waist, tL is the pulse duration, and pR, pI, and β are the parameters determining the PFT and its rotation. In this work, we investigate the influence of these parameters on the distribution of absorbed laser energy inside fused silica glass. The model based on nonlinear Maxwell’s equations supplemented by the hydrodynamic equations for free electron plasma is applied. As three-dimensional solution of such problem would require huge computational resources, a simplified two-dimensional model has been proposed which enables a qualitative insight to a number of PFT effects appearing at volumetric laser modification of transparent materials, including violation of axial symmetry of laser energy absorption and the effect of nonreciprocal writing.

The work was jointly supported by RFBR (Russian Foundation for Basic Research, Grant 15-51-46007) and TUBITAK (The Scientific and Technological Research Council of Turkey, Grant 114F502).

PS1-LMI-21 Toward modeling of interaction of dichromatic laser pulses with transparent dielectrics

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Laser microprocessing of materials can be more effective when using spatially and/or temporally shaped laser pulses. Last years, an attention is increasing to dichromatic laser pulses applied simultaneously or with a delay. When the pulses with different wavelength are applied sequentially, widely adopted monochromatic models can be used for studies of material processing. However, for adequate modelling of the action of overlapping laser pulses of different wavelength on dielectric materials, description of photo- and impact ionizations as well as the Kerr effect require considerable revisions.

In this work, the Keldysh theory of photoionization is generalized for the case of the two-wavelength irradiation with the electric field of $E = E_1 \cdot cos(\omega_1 t) + E_2 \cdot cos(\omega_2 t + \varphi)$. Two cases are considered, with integer and non-integer ratios between frequencies ω_1 and ω_2. It has been shown that, for dichromatic pulses, the photoionization rate is usually larger than that for each monochromatic pulse of the same intensity. The ionization rate depends on polarization directions of the electric fields E_1 and E_2. It is smaller for the case of perpendicular polarizations compared to parallel ones. The circular polarization, which can be considered as a particular case of a dichromatic pulse with perpendicular polarizations and equal frequencies, yields in a smaller photoionization rate compared to the linear one that is in line with experimental observations.

The impact ionization in dichromatic cases can be described as the sum of the Joule heating terms from the waves of both frequencies. The description of the Kerr effect is shown to require introduction of terms proportional to $|E_{12}|E_2$ and $|E_{22}|E_1$.

This research is supported by the Russian Foundation for Basic Research (RFBR project No. 15-01-02432).

PS1-LMI-22 Spectral and lasing properties of quantum dots in the near field of silver nanoparticles

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Composite nanostructures based on noble metal nanoparticles and semiconductor quantum dots (QDs) are widely used in various fields of science and technology due to a fortunate combination of the optical properties of their constituent components. Semiconductor quantum dots possess a high luminescence quantum yield and dependence of the spectral properties on the quantum dots size. Metal nanoparticles demonstrates optical properties of a localized surface plasmon resonance, which is a collective oscillation of conduction band electrons, induced by external electromagnetic waves. When a QD is placed in the near field of a plasmonic nanoparticle enhanced light absorption and fluorescence of the QDs may be observed. Of particular interest is the possibility of observation of stimulated emission of QDs in the near field of metal nanoparticles.

In this contribution lasing properties of composite structures based on semiconductor QDs and silver nanoparticles are explored. Silver nanoparticles were prepared by thermal deposition of the metal vapor on the dielectric substrates in a high vacuum. QD solution in toluene was deposited on the surface of silver nanoparticles by evaporation technique. For comparison, similar samples without silver nanoparticles were prepared and investigated as well. To excite the fluorescence of the samples, an optical parametric oscillator pumped by the third harmonic of a Nd-YAG-laser was used.

An increase in the energy density of excitation laser pulses leads to narrowing of the fluorescence spectrum of the composite material containing QDs and silver nanoparticles and to a sublinear increase in the fluorescence intensity. At the same time, in the absence of silver nanoparticles the fluorescence spectrum of QDs is independent of the excitation pulse energy density, and the dependence of the fluorescence intensity on the pulse energy remains linear in the entire range under study. The narrowing of the fluorescence spectrum under intense pumping, which leads to saturation of the resonant transition in QDs, may be related to the inhomogeneous broadening of the exciton band because of the spread of QDs sizes.

PS1-LMI-23 Metal clusters and nanoparticles included in thin dielectric films

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Composite materials consisting of metal nanoparticles included in dielectric matrices find many applications in photonics and electronics. In this study thin dielectric films (quartz and sapphire) with metallic inclusions (silver, gold and copper) were obtained via simultaneous deposition in the vacuum chamber PVD-75 (Kurt J. Lesker) at a residual pressure of 3×10-6 Torr. Metals were thermally evaporated from tungsten boats, while the electron-beam evaporation was employed in the case of dielectric materials. The overall thickness of the obtained structure was 30 nm. After the deposition the heat treatment and irradiation by third harmonic of Nd: YAG laser of the samples were produced.

At these deposition conditions the metallic clusters of several atoms was formed in the dielectric matrix. For the samples with silver the narrow intense absorption bands in the near UV range (200-400 nm) are observed. Gold and copper clusters have the broad absorption band from 200 nm to 700 nm. After thermal annealing the absorption maxima are shifted to longer wavelengths, which is associated with an increase of the cluster size. The laser irradiation led to the formation of larger metal nanoparticles having strongly pronounced plasmon properties with plasmon resonance at 420 nm for silver, 540 nm for gold and 610 nm for copper nanoparticles.

For comparison, thin films of pure sapphire deposited on the sapphire substrate and pure quartz on the quartz substrate were investigated. The quartz film has practically no effect on the spectral characteristics of the quartz substrate while the reflectivity of the thin sapphire film was lower than that of the sapphire substrate. These observations can be explained by the porous structure of the deposited sapphire film.

PS1-LMI-24 Lasing properties of thin films of organic molecules with plasmonic nanoparticles

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Optical properties of metal nanoparticles are determined by the excitation of plasmon oscillation. These oscillations result in the appearance of strong local electromagnetic fields near the nanoparticles surface. Placing of organic molecules in these fields leads, to an increase of absorption, enhancement of the fluorescence intensity and Raman scattering (SERS), etc. Of particular interest is the possibility of observation of stimulated emission of organic dye molecule in thin films with metal nanoparticles.

In this contribution lasing properties of composite structures based on organic dyes and silver nanoparticles are explored. Silver nanoparticles were prepared by thermal deposition of the metal vapor on the dielectric substrates in a high vacuum.

To create organic thin film, coumarin 481 was selected due to the high quantum yield, and spectral closeness of its luminescence to the maximum of the plasmon resonance of silver nanoparticles. Organic thin films on the surface with nanoparticles were prepared by evaporation technique from ethanol solution. For comparison, similar samples without silver nanoparticles were prepared and investigated as well.

To excite the luminescence of the samples, an optical parametric oscillator pumped by the third harmonic of a Nd-YAG-laser was used. When the energy of the laser pulses was changed from 0.4 mJ and 3 mJ, in the samples with Ag nanoparticles a nonlinear increase of the fluorescence intensity was observed. At the maximum pumping energy the fluorescence intensity increased 30 times with respect to the minimum pumping energy, while the spectral width of the fluorescent band was diminished from 54 nm to 9 nm.

Thus, the obtained organic thin films with plasmonic nanoparticles demonstrated stimulated emission in the visible range.

PS1-LMI-25 Amplified hard X-ray emission and hot electron generation at high intensity femtosecond laser-plasma interaction utilizing laser induced nano-structured targets

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The recent results of experimental and numerical investigation of relativistic femtosecond laser-plasma interaction are presented. We show that the efficiency of hard X-ray generation and hot electron acceleration may be significantly increased if sub-wavelength scale structured targets are used. The modified targets were made by the laser ablation (fluence slightly over damage threshold) of solids (metals and dielectrics). Varying the regime of interaction and by additional etching in acid solution the periodic structures with different shapes (cones, bubbles, etc) and size (from ~0.1 to ~20 micrometers) could be formed. This method allows creating large area sample, suitable for high repetition rate laser-plasma experiments.

The hot plasma was formed by the irradiation of samples by the Ti:Sa laser pulses (τ=50 fs, E>10 mJ, 10 Hz, $I_{peak}>10^{18}$ W/cm^2). We found that the femtosecond damage threshold of structured targets is one order of magnitude lower, than for initial flat material. Hence the high contrast laser pulses must be used. It is demonstrated, that the hot electron temperature is significantly increased (from ~150 to almost 500 keV) and fourfold growth of hard X-ray emission is observed, when the sub-wavelength structured target is used, compared to a flat one with the use of high contrast laser radiation (ASE pedestal contrast ration ~10^{10} ten ps prior to main pulse with the use of XPW contrast cleaner). The energy grow effect is much less pronounced if the pulse with moderate contrast (~10^8 ration) is applied. This shows the role of high contrast in preserving the modifications from damaging before the main pulse arrival. The PIC simulation revealed that the observed effect of hot particles generation may be related to the acceleration of electrons in the complex field formed on the edges of the structures. This work was supported by the RFBR grant #15-02-08113-a.

PS1-LMI-26 Femtosecond laser ablation of porous silicon and silicon nanowires in gases and liquids

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One of the most promising methods for producing nanostructures is a laser ablation of the solid surface, characterized by low content of undesired impurities. Femtosecond laser ablation of porous medium is of great interest due to increase in these media as linear-optical effects, such as the enhancement of the Raman scattering efficiency [1]; as non-linear-optical effects, for example the enhancement of the cubic nonlinear susceptibility [2]. The nanoparticles, formed at these conditions can be used for potential applications in biomedical field as contrasting agents in optical coherence tomography [3] due to biocompatibility and biodegradability of silicon nanoparticles.

This paper presents the results of experiments of the nanoparticle formation as a result of femtosecond laser ablation of porous silicon p-type and Silicon nanowires in helium and hexane (C_6H_{14}). During the experiment, the target was irradiated with Cr:forsterite femtosecond laser (1250 nm, 180 fs) pulses at room temperature.

Atomic-force microscopy analyze of samples, formed by ablation of por-Si wafers in helium evidenced about monotonic dependence of nanoparticle size variation on the buffer gas pressure: the nanoparticle size decreased with increasing pressure (Fig.1).

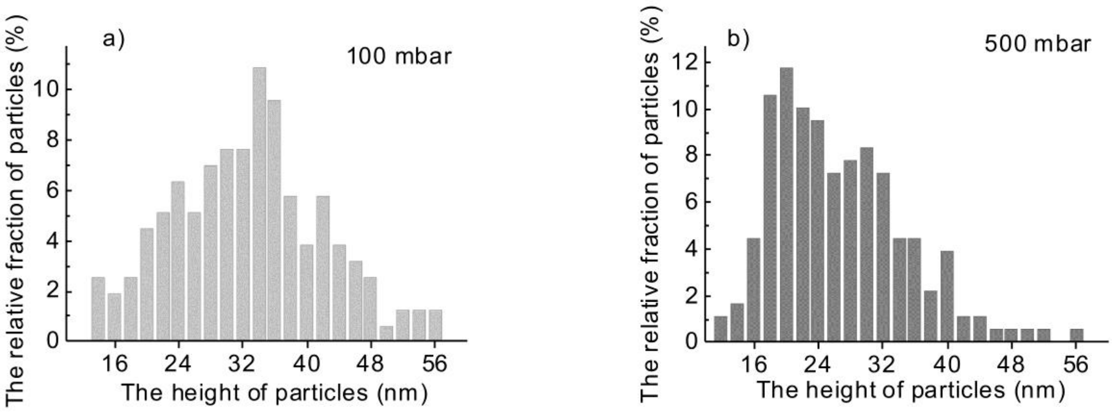

Figure 1 Particle size distribution of silicon nanoparticles, formed by means of the laser ablation of por-Si in helium at different pressure: 100 mbar (a) and 500mbar (b).

Raman scattering measurements indicated the presence of crystalline phase of silicon, which corresponds to a 520 cm^{-1} line.

The carried out experiments indicate possibility to fabricate silicon nanoparticles by means of laser ablation of porous silicon films with higher mass yield in comparison with nanoparticles, formed by laser ablation of crystalline silicon. This fact could be related with lower ablation threshold at the case of porous silicon. In addition, the observed photoluminescence of porous silicon samples in the visible range provides possibilities for potential applications of the formed samples in biomedicine.

This work was financially supported by the Russian Foundation for Basic Research (project 15-32-20227).

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PS1-LMI-27 Dependence of the intense blue light radiation from optically in-excited $6P_{3/2}$ Rb state in extremely thin cell on the atomic density

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The detailed knowledge of the processes of the excited alkali atom interaction with the surface of wide-band transparent dielectrics is important for surface physics as well as for a wide range of applications. The fundamental sensitivity of chip-scale devices such as atomic clocks, chip-scale atomic, magnetometers is limited by the interactions of an excited atom with surface.

We have investigated rubidium atom excited states in extremely thin cell with variable size of about

250–500 nm. The cell consists of two round polished sapphire plates, the plates are connected together with a minute angle and comprised a wedged gap with variable thickness. Atomic vapor density ~10^{13}–10^{15} cm^{-3} is controlled by Rb reservoir temperature. Rubidium atoms were excited from the ground state to $5D_{5/2}$-state by resonant two-step excitation. We use narrow-line continuous wave external cavity diode lasers (ECDL), with wavelengths of 780 nm ($5S_{1/2}\rightarrow5P_{3/2}$ transition) and 776 nm ($5P_{3/2}\rightarrow5D_{5/2}$ transition). Laser beams were directed to cell window at right angle and focused in a spot of 20–50 μm size. A spectrometer with CCD-camera was used for fluorescence light detection.

We have observed an intense 420-nm blue light radiation from $6P_{3/2}$-state, which is not populated directly. The spontaneous decay from $5D_{5/2}$-state is populating while atom is travelling between the walls. But, the atomic time-of-flight is only about 1 ns and much less than spontaneous decay time from $5D_{5/2}$-level, which is about 700 ns. The observed blue-light radiation intensity is inconsistent with common assumption of compete quenching of excited atom by surface.

We have investigated the dependence of 420-nm light on the cell thickness with different atomic densities. With low densities ~10^{13}–10^{14} cm^{-3} the light intensity is proportional to third fourth power of the thickness. At densities above 10^{15} cm^{-3} the power dependence is lower, it possibly be explained by other mechanism of $6P_{3/2}$-state population.

PS1-LMI-28 Analysis of scanning fields for laser induced breakdown measurements

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We present some features of laser complex assigned for measurement of light induced damage thresholds (LIDT) of optical surfaces and materials along with system for automated image processing of acquired scan fields. Setup contains scanning system with F-Theta lens for focusing and high precision positioning of the laser beam relative to the sample. Diode pumped Q-switched Nd:YAG laser provides laser pulses at 1064 or 532 nm with 1 kHz repetition rate. High repetition rate and available option to control each pulse energy give opportunity to study LIDT under single- and multishot irradiation [1].

Program for processing of scan fields images received during LIDT measurement based on Canny edge detector algorithms. It allows to automate image analysis process and plot the diagram of LID probability vs laser pulse energy. At first step, area and necessary parameters of the scan field are specified. Image got blurred and binarized, which clearly distinguish areas corresponding to LID marks from noise. Then border of acquired areas is selected. Length value of these contours allow to determine the presence of each LID mark on scan field and calculate the probability of LID for chosen laser pulse energies. Algorithm configured to recognize and properly process different LID marks artifacts such as merged marks, micro inclusions, scratches and ring-shaped optical breakdown (Fig.1), which can provide double contour for Canny edge detector algorithms and should be properly processed. Program can be easily complemented with additional conditions and restrictions for LID mark recognition if necessary. Presented setup allows measurement of LIDT both for volume of optical materials and optical surfaces.

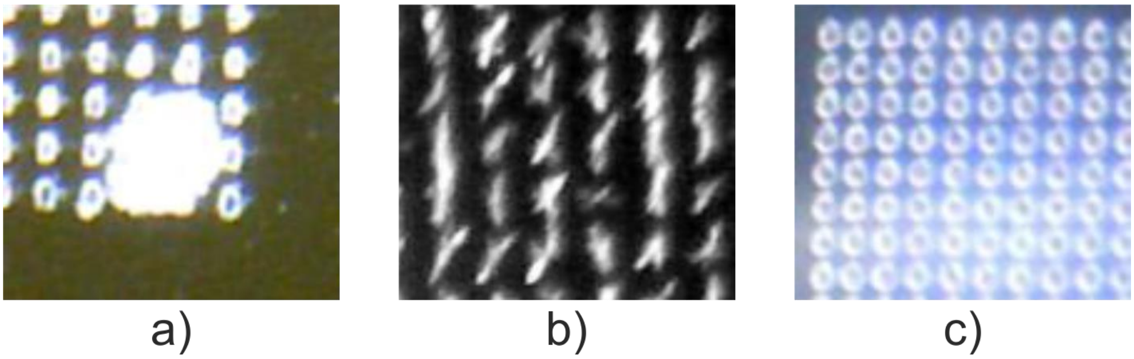

Fig. 1. LID marks artifacts: a – merged marks for optical coating; b – merged marks in volume of optical material; c – ring-like marks

We also report regarding some features of LIDT determination for the high reflective mirrors applied onto absorptive at laser wavelength substrates such as polycrystalline SiC, ZnSe etc. Partial transmission of powerful laser radiation through coating causes local heating of the substrate. For CW laser or pulsed laser with high repetition rate significant moving of laser beam relative to sample induce dynamically changing gradients of temperature and stress distribution, which can influence on LIDT value significantly. Measured LID threshold should depend on speed of laser beam scanning. In our experiments LIDT value measured while scanning vs LIDT value measured for fixed beam position decreased up to three times for reflective coating on polycrystalline SiC substrate. During LIDT measurement substrate material from damaged area can be ejected to the surface. Since material has high absorption at lasing wavelength this may dramatically affect LID threshold for nearby scan field marks especially for repeated exposure. This should be taken into account when geometry and distance between marks is established.

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PS1-LMI-29 Calculation of electron-phonon coupling coefficient in the conditions of strong photoexitation of semiconductors and dielectrics by ultra-short laser pulses

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Absorption of intense ultra-short laser pulses in semiconductors and dielectrics lead to formation of dense electron-hole plasma with concentration up to 10^{21} cm^{-3} [1, 2]. The temperature of this plasma during some time is much higher than the temperature of lattice. Under such conditions the energy flux from electrons to lattice appears. The speed of energy exchange between electrons and lattice is characterized by electron-phonon coupling coefficient G, which depends on free carriers concentration, electron temperature and lattice temperature. Due to the difficulties of experimental determination of coefficient G in such conditions it is advisable to use the theoretical methods of it calculation. Currently there are no such calculations for a number of important semiconductors and dielectrics. So the aim this work is to make theoretical estimations of electron-phonon coupling coefficient for semiconductors and dielectrics and to reveal its temperature and concentration dependences. The calculations were made under the following assumptions: electrons interact with acoustical and polar optical phonons, electrons and phonons have equilibrium distribution functions, characterized by their temperatures, electrons have parabolic dispersion law, dispersion of acoustic phonons is linear (Debye approximation) and optical phonons have constant energy. It is shown that there are significant dependence of coefficient G on electron temperature, at the same time the dependence on lattice temperature is negligible. The concentration dependence of coefficient G is close to linear. The estimation for silicon and silicon dioxide are done. Also the analytical expressions of this dependence, which are suitable to use in modeling of laser-matter interactions, are given.

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PS1-LMI-30 Formation of Si-nanoclasters in SiO_2-matrix by laser oxidation of silicon nanoparticles produced by laser ablation in liquid environment

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Composed material consisting of silicon nanoclasters in silicon dioxide layer (nc-Si/SiO2 composite) has broad application prospects for the creation of new devices of microelectronics and photonics. The unique properties of such material depends on size, structure and concentration of silicon nanoclasters embedded in the dielectric matrix. So the development of simple and cheap technologies that allow to obtain such nanocomposite with controllable parameters is an actual scientific problem.

In this work we proposed and realized a new method of formation of nc-Si/SiO_2 composite consisting of the following main stages: obtaining a colloidal solution of silicon nanoparticles by nanosecond laser ablation, deposition of the nanoparticles on silicon plate to form a thin continuous layer of nanoparticles, laser oxidation of formed nanoparticles layer. To prepare the colloidal solution we used nanosecond ytterbium fiber laser. It is shown that the size of produced nanoparticles depends on energetic pulse parameters and can be decreased after the further fragmentation of colloidal solution. For the laser oxidation of deposited layer of nanoparticles we used the same nanosecond ytterbium fiber laser. Irradiation was carried out in air under normal conditions. Formation of the oxide phase was confirmed by measuring IR spectra. The properties of obtained nanocomposite were investigated by electrophysical and optical methods. The prospects of its using in practice are discussed.

LT-1 New approaches in transparent dielectrics micro- and nanomachining based on oncoming interaction of two color tightly focused femtosecond laser pulses

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We report theoretically predicted and experimentally verified by us new physical concept on laser-based micro and nanomachining inside transparent dielectrics based on oncoming interaction of tightly focused (NA = 0.5) pair of visible (SH) and infrared (IR) femtosecond laser beams with third harmonic on-line diagnosis of the electronic density in the local area of laser pulses interaction. High localization of laser energy (~6 μm^3) i.e. minimal collateral damage is guaranteed by two-pulse excitation regime in which SH pulse generates "seed" electrons and IR pulse involving them in avalanche heating brings to breakdown in microvolume determined by the short wavelength pulse. Since laser-induced modification of wide bandgap dielectric (for instance, fused silica) is defined by the plasma electrons distribution after the laser pulse excitation we were focused in presented research on studying ultra-fast laser microplasma ignition. We have demonstrated an effect of absorbed energy density saturation at the energy density which is associated with the saturation of electron density. Non-monotonic increasing of the third-harmonic signal and corresponding decreasing of IR laser pulse transmittance as a function of the delay between the SH and IR laser pulses tightly focused into the bulk of fused silica was revealed experimentally. Pair action of two color pair of oncoming laser pulses with subthreshold energies in a bulk of fused silica leads to the absorbed energy density enough for residual micromodification formation which in our experimental conditions close to 4.5 kJ/cm^3. In addition, we predicted that the oncoming two-color excitation of wide-bandgap dielectric in comparison with single pulse microplasma ignition regime allows providing a much higher absorbed energy density and overcritical plasma which is the key point for investigating the extreme state of matter. Using the UV laser pulse for seed electrons generation and mid-IR laser pulse for ponderomotive heating is the most prospective way to increase the localization of the incoming energy giving the route to the sub-micrometer spatial resolution with high energy efficiency in forthcoming femtotechlogies and for investigating the extreme state of matter.

LT -2 Improved through-Silicon-via (TSV) fabrication with optimally tailored femtosecond Bessel beams

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We present high-speed, high-quality fabrication of high-aspect-ratio TSVs, using tailored femtosecond (fs) Bessel beams operated at 1.5-μm wavelength. By performing laser ablation in air using the conventional Bessel beams, almost taper-free TSVs with diameters of ~5 μm (measured at the middle part of TSVs) in 50-μm-thick Si substrates can be realized, which corresponds to an aspect-ratio of ~10. Furthermore, to suppress the severe damages induced by the side-lobes of the conventional Bessel beam in TSV fabrication, specially designed binary phase plates (BPPs) are employed for the first time to tailor the conventional fs Bessel beam. We theoretically and experimentally demonstrate that this method can create a fs laser beam with ~7-μm lateral spot size (diameter measured as the FWHM) and ~400-μm focal depth (measured as the FWHM along the optical axis), while reduce the side-lobe ratio (SLR, the ratio of peak intensity of the maximum side lobe to that of the central lobe) to ~0.6%, which is much smaller than a ~16% SLR of the conventional Bessel beam. The developed technique successfully eliminates the side-lobe-induced damage for high quality TSVs fabrication. Our technique can be potentially applicable for 3D assembly in manufacture of 3D Si ICs.

LT -3 Ultra-short laser processing of optical materials: can random inhomogeneities, nanoholesor nanoparticles be seeds of periodic volume nanostructutres ?

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Ultrashort lasers are used for a wide range of micro- and nanomachining applications of different materials. The most promising of them includethe formation of 3D nanostructures inside glasses, surface and volume periodic nanostructrures and ultra-short laser interactions with composites and metamaterials. For further development of these applications, detailed 3D numerical models are required combining both simulation of light propagation effects and the following laser-induced material excitation and modification. Some of these processes occur simultaneously (i. e., propagation and ionization), whereas other are much longer (thermal-mechanical effects) and can be taken into account separately. In this paper, several potential applications of bulk laser-induced plasmas ranging from Bessel beam-induced long laser channel formation to laser-induced volume nanograting formation are analyzed.

It is demonstrated that light propagation dynamics considerably affects femtosecond laser treatment of transparent materials.In particular, volume nanograting formation induced by femtosecond laser irradiation of fused silica with the presence of randomly distributed nanometric defects, such as holes or nanoparticles, is investigated numerically [1-3]. The created nanoplasmasare shown to elongate perpendicular to the laser polarization direction with a period significantly smaller than the incident irradiation wavelength. The characteristics of these nanoplanes are found to depend strongly on the concentration of the initial defects and on the irradiation wavelength in a good agreement with several experimental observations.

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LT -4 Ultrafast energy transfer at the nanoscale

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Heat transfer at the meso/nano-scale is an emerging multidisciplinary topic, at the crossroad of physics, engineering and environmental/life sciences, covering both fundamental [1] and technological issues [2-4]. Research in the field is advancing at a tremendous pace driven by the progress in nanomaterial processing and the availability of novel experimental and theoretical tools. The application fields range from non-destructive testing of materials on the nm/μm scale, thermo-acoustic metrology of sub-surface embedded nano-structures, to probing mechanical properties of sub-cellular structures and bio-materials in vivo. An important technical progress to further develop this field is the capability of optically studying a single nanostructure, thus opening the path to a variety of photonics applications.

The investigation of biosystems or nanostructure in complex chemical environments is not easily rationalized in terms of deterministic analytical or numerical models.. For these reasons a different approach aimed at rationalizing spectroscopic data is here proposed. The present approach allows extracting useful informations from the experimental data without previous knowledge of the detailed physical mechanism underlying the experimental trace [5]. These analysis techniques are generally addressed as Data Mining or Pattern Recognition. They are finding applications in a variaty of fields, including signals analysis, meteorology, genomics, biology and medicine. These computational techniques allow exploring large data arrays by recognizing patterns, appropriatly reducing data dimensionality and classifying the otherwise-overhelming information content.

In this work the thermomechanical dynamics induced by the interaction of short laser pulses with metal nanospheres and their chemical environment is investigated. The extraction of information from time-resolved experiments is accomplished through data mining techniques. Singular value decomposition (SVD) and a Hierarchical Cluster Analysis provide the basis for the analysis of both a single and ensemble of nano-objects. Paradigmatic examples are shown where ultrafast optoacoustic traces allow to discriminate the dimensions and predict the influence of the environment on nanoparticles bonded to surface-adhering chemical complexes, without previous knowledge of the investigated system. These techniques bear great potential as screening platform, to evidence casual or systematic errors and reveal patterns hidden in the data.

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LT -5 Multigram nanoparticle synthesis by high-power, high-repetition-rate ultrafast laser ablation in liquids

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Pulsed laser ablation in liquids is an innovative method which is used to obtain colloidal solutions of nanoparticles that show unique properties and are not achievable by conventional synthesis methods. However, this method lacks of key parameters and scaling factors as well as a correlation between these factors and the occurring operating costs.

During the laser driven synthesis cavitation bubbles filled with nanoparticles are formed. [1] These cavitation bubbles along with already dispersed nanoparticles in the solution are the two major factors that limit the energy that can be coupled into the target material by shielding subsequent laser pulses. While the latter shielding effect can be avoided by suitable fluid handling [2] avoiding the former is more difficult due to the lifetime (~100µs) and the size (~100µm) of cavitation bubbles which depend on the laser energy and pulse duration.

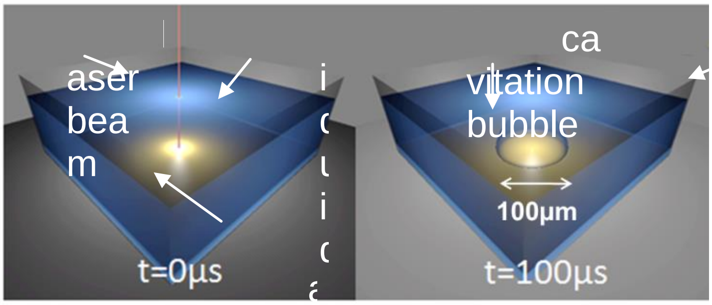

Figure 1: Illustration of the life time and size of a cavitation bubble induced during Pulsed Laser Ablation in Liquid.

In this work we present strategies to scale up the process by enhancing the productivity of the synthesis. One approach utilizes a high-repetition rate laser system consisting of a 500W ps-laser source and a laser scanner that reaches a scanning speed of up to 500m/s. This unique system enables spatial bypassing the cavitation bubble and thereby applying most of the laser energy to the target. The cavitation bubbles are laterally separated by varying the scanning speed in order to obtain the best scanning parameters. [3]

A further approach includes a multi-beam scanner that is capable of splitting up the laser beam into up to 144 separate beams. [4] Thus, higher energies can be applied to the target without forming too large cavitation bubbles.

These strategies are discussed and productivities of up to 5 gram per hour are demonstrated in a continuous process. [3]

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LT -6 Soft laser methods for biofabrication: 2D and 3D structures of nanomaterials for new top technologies

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Soft laser technologies in 2D and 3D environments compensate the need of substitution at small dimensions. By processing at micro- and nano-scale, lasers emerged as versatile tools for fabricating innovative devices for tissue engineering or biomimetic delivery systems for local release.

Recent results in organic/inorganic composite nanostructured layers synthesized by PLD, MAPLE and LDW are reviewed. The optimum deposition regime was reached based upon the results of investigations by SEM, TEM, SAED, XTEM, AFM, XRD, XPS or FTIR methods. Biocompatibility, bioactivity and biodegradation were assessed by dedicated in-vitro tests.

The coating of metallic implants with composite alendronate-HA or Sr-HA layers by MAPLE and PLD, respectively, was demonstrated to enhance human osteoblasts proliferation and differentiation, while inhibiting osteoclasts growth, with benefic effects for the treatment of bone diseases. Magnesium or strontium substituted OCP deposited by MAPLE on Ti substrates efficiently boost osteoblast activity and differentiation.

We showed that the composite PMMA-bioglass films deposited by MAPLE efficiently protects metal implants against the action of human fluids.

The antifungal efficiency of the nano-sized HA and Ag:HA layers obtained by PLD was tested against the Candida albicans and Aspergillus niger strains. The Ti substrates modified with TiO2 nanotubes covered with Ag:HA thin films demonstrated the highest antifungal activity.

The MAPLE obtained nanocomposites Ag:HA-organosolv lignin proved noncytotoxic, supporting the normal development and promoting the proliferation of the adhered human mesenchymal cells. The lignin addition potentiated the anti-microbial activity of HA doped with silver ions against either bacterial or fungal biofilms.

Mesotetraphenylporphyrin clean and liquid-free micropatterns on Si substrates were fabricated by LDW. The propulsor metal film thickness was found to be a key parameter, which determines the laser fluence range allowing the clean transfer, predominant mechanism of the blister formation and laser-induced heating of the transferred material.

We conclude that the thin films prepared by PLD, MAPLE and LDW techniques were identical in chemical composition, structure, morphology, and most likely functionality resembling the base material, as proved by physical-chemical characterization and in-vitro assays. One may say that light really regenerate life, even when in laser beams.

LT -7 Laser-induced graphitization of diamond for demanding applications in nuclear physics

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Laser induced graphitization of diamond is a well known process. In this work, we have studied and optimized the diamond graphitization process by UV excimer laser for a specific application: the realization of full carbon detectors for nuclear applications in the field of dark matter.

CVD diamond-based detectors present interesting properties with respect to silicon-based devices, but many process steps are required to obtain an ohmic contact on a diamond surface. Laser-induced graphitization represents an interesting alternative for the realization of low-cost single step ohmic contacts.

In order to reach the final goal, the graphitization process has been studied, on thermal and detector CVD diamond slabs at different values of laser fluences and number of laser pulses, by micro-Raman spectroscopy and Atomic Force Microscopy. Moreover, a detailed nano-indentation study has been carried out to determine the mechanical properties of the graphitic structures (spots and strips) Fig. 1. The ohmic nature of the graphitic contacts and their resistivity have been evaluated using the transmission line model (TLM) method. An electrical resistivity value of the order of 10^{-5} Ohm·m has been determined. Furthermore, morphological, mechanical and electrical properties have been correlated to Raman results showing the sp3-to-sp2 graphitization process. Whit these results, a sensor prototype has been built by the graphitization of a detector grade polycrystalline diamond, with twenty graphitic strips on one surface and a graphitic pad on the other one, and it has been tested with 120 GeV pion during a Testbeam at CERN. As a result, good charge collection properties of the graphitic electrodes have been obtained together with a charge collection efficiency (CCE) of 42% as expected for the diamond.

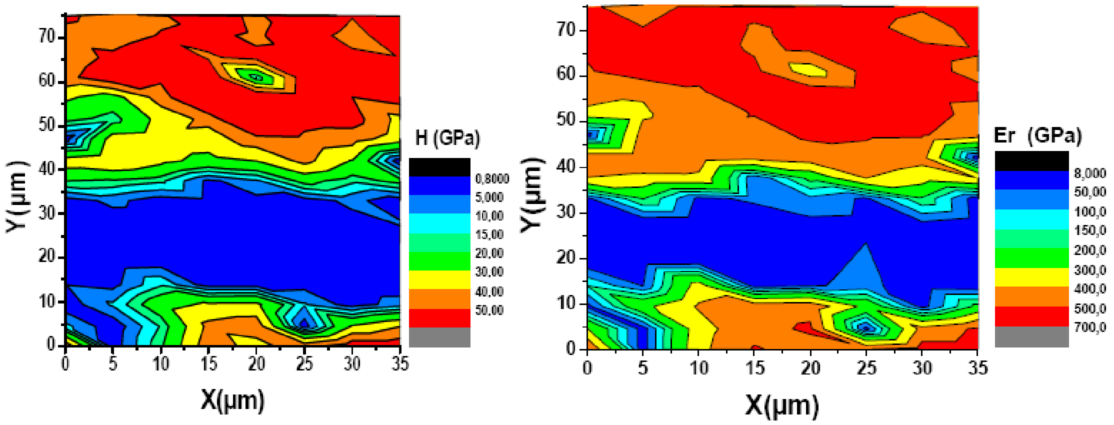

Fig. 1: Hardness (H) and reduced- elastic modulus (Er) maps on a laser-induced graphitic strips obtained at a laser fluence of 7 J/cm^2 with two laser scans.

LT -8 Femtosecond laser pulses for plasmonic, all-dielectric and hybrid nanoantennae fabrication and reconfiguration

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The resonant metallic nanoparticles are proven to be efficient systems for the electromagnetic field control at nanoscale, owing to the ability to localize and enhance the optical field via excitation of strong plasmon resonances. In turn, high index dielectric nanoparticles with low dissipative losses in the visible range, possessing magnetic and electric Mie-type resonances, offer great opportunity for light control via designing of scattering properties [1]. Recently, the combination of these two paradigms in the form of metal-dielectric (hybrid) nanostructures (nanoantennas and metasurfaces) has allowed utilizing the advantages of both plasmonics and all-dielectric nanophotonics.

We present our recent results on femtosecond laser-assisted fabrication and reconfiguration of above mentioned types of nanoantennae. In particular, we developed novel methods for plasmonic [2], all-dielectric [3], and hybrid [4] nanoantennae fabrication. Also, we proposed a novel concept for ultrafast reconfiguration of scattering properties of an individual all-dielectric nanoantenna by means of generation of electron-hole plasma [5].

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LT -9 Recent progress on interference femtosecond laser processing

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Plasmonic devices such as metamaterial have distinctive electro-magnetic characters. They consist of nano- or micron-sized metal unit structures in lattice. They have been fabricated by lithography and ion beam figuring techniques. On the other hand, we have investigated the fabrication of them by interfering femtosecond laser technique. In the past experiments, a variety of meta-atoms such as nanowhisker [1,2], nanobump [1,3], MHA (Metallic-Hole Array) [4], nanodrop [1,3,5] and designed pattern [5–7] have been fabricated. In this presentation, plasmonic devices such as MHA etc. fabricated by our technique will be shown. In addition, interference pattern of 6 beams were applied to our technique, and resultant structures fabricated on metallic thin films will be also shown.

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LT -10 Fs-laser writing of photonic elements via ion migration processes in glass

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We have recently shown the production of high performance optical waveguides via local modification of the glass composition using high-repetition rate femtosecond laser writing [1, 3]. The material used is a phosphate glass with Al2O3, La2O3 and K2O modifiers in which laser irradiation induces the cross migration of La and K ions, the local refractive index being determined by the final local concentration of La2O3. The later parameter, as well as the overall dimensions of the guiding region can be controlled very precisely through the processing parameters [3, 6].

The samples consisted of home-made and commercial phosphates glasses with different doping levels of Er^{3+} and Yb^{3+}, and contents of La_2O_3 and K_2O of the order of 10 mol.% [2,3]. Waveguides were produced using a fibre-based fs-laser amplifier (Amplitude Sistemes, 500 kHz rep. rate, 1030 nm, ~400 fs pulse duration), with a beam diameter of 4.3 mm ($1/e^2$), focused 100 μm underneath the surface with a 0.68 NA aspheric lens. Before being focused in the sample, the laser beam was slit shaped. Typical sample scan speeds were in the order of 60 μm/s. Plasma emission images in writing conditions were also recorded in order to acquire information about the energy distribution in the irradiated region during the process [4]. After polishing, the passive and active performance (including laser action) of the waveguides was measured. The structures were also characterized by different techniques ((DIC) microscopy (DIC), X-ray micro-analysis…).

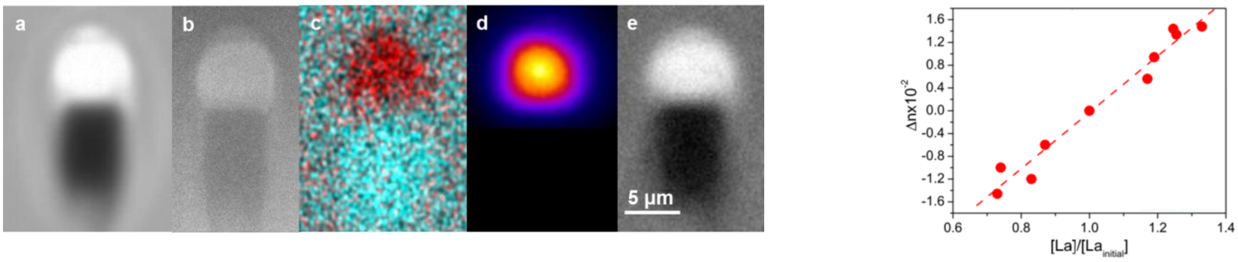

Fig. 1(Left) (a) DIC microscopy, (b) SEM, (c) EDX, (d) Guided mode at 1620 nm and (e) Refractive index profilometry images of a waveguide written via laser induced ion-migration. (Right) Local refractive index contrast vs. local La-enrichment. Figures adapted from Ref.[3]

In this work we will summarize part of our previous results regarding the degree of control that can be exerted using this mechanism to produce passive waveguides with refractive index contrast values beyond 10^{-2} as well as optical amplifiers and lasers. We will describe and analyze different factors conditioning the performance of the laser written structures like the writing parameters, beam wavefront, material composition or writing beam polarization.

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LT -11 Industrial laser-based equipment for materials processing

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At the present time, many new laser processes have been enabled by novel lasers with higher power, higher repetition rate, shorter wavelength, and shorter pulse width. For example, ultrafast laser sources with pulse duration of around a few or below one picosecond enable a new area of precision machining.

On the other hand in the past few years, new laser-based materials processing technologies are growing rapidly. In particular, additive manufacturing of metal parts has drawn an enormous surge of industrial interest. Recently, electronic components are increasingly miniaturized and they are required laser systems capable of precise micromachining.

In order to apply modern laser-based technologies, development of new laser workstations is required. Recently, we have developed a number of laser systems with improved performance. In this paper we present various material processing results achieved using our new laser workstations.

LT -12 Laser assisted 3D printing biofabrication of functional graded structures from polymer covered nanocomposites

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As a method for conservation of nanoparticles with perspective properties, the selective laser sintering/melting (SLS/M) is a promising technique for modelling, fabricating of the functional graded structures (FGS) with nano additives and the functional devices. But a direct SLS/M fabrication of the nano powders by multilayered techniques is a difficult technological task. Laser sintering and melting are well known to be a thermally activated processes, accompanied by coagulation of the nanoparticles into the micro-sized conglomerates. The acute problem is an aggregation prevention, which significantly levels the potential advantages of the materials use in the nano or submicron state. One of the methods for this problem solution is the isolation of nanoparticles into the inert matrices, where they do not undergo aggregation, “aging” and can be controllably released with the retention of chemical and phase composition.

Stabilization of the nanoparticles in a polymeric matrix and additionally reinforced porous structure makes it possible to arrange a desired distribution of the nanoparticles in the polymer and thus to protect them from oxidation and corrosion and even to design of the FGS. The results suggest that nanoparticles mechanically reinforced the polymer matrix and the elastic modulus and the maximum stress significantly increased. Finally, the correlations “the prehistory of obtaining (i.e. “background”) - the chemical composition of the nanoparticle’s volume and surface condition - phase /structural composition - morphology - perspective properties” will determine the nanoparticle’s behavior int5o future applications.

Earlier we demonstrated how a laser-assisted technique of the 3D synthesis was used to prepare a porous core shell polycarbonate (PC) structures containing encapsulated nickel and/or copper nanoparticles distributed heterogeneously over the sintered polymer and dangerous for cancer tissue. A principal feasibility for fabrication of functionally graded 3D items with iron oxide particle structural ordering was demonstrated us and corresponding laser optimal regimes were determined. The SLS-fabricated 3D samples of biocompatible iron oxide core/PEEK shell magnetic nanocomposites have potential medical opportunity for tissue engineering scaffolds and cell targeting systems.

Functionally graded 3D parts with alternating ferromagnetic Ni–PC and non-magnetic Cu–PC layers exhibited hysteresis phenomena also that may turn out useful for use in MEMS–NEMS applications where the time response must depend on the relaxation rate. The synthesized nanocomposites with high porosity and large specific surface may also find their application in catalysis, lab-on-chips, drug delivery systems, and 3D crystalline structures for hydrogen storage devices.

LT -13 Ink microprinting through laser-induced forward transfer

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Laser-induced forward transfer (LIFT) appears as an interesting alternative to conventional printing techniques in microfabrication applications. LIFT was originally developed for printing inorganic materials from thin solid films, but it was later proved that the same approach was feasible for printing liquids as well. In this way, the range of printable materials was substantially broadened; complex materials such as nanoparticle inks, polymers, and even biological materials as DNA, proteins or living cells can be printed through LIFT at room conditions.

Its principle of operation is based on the localized absorption of a focused laser pulse in a thin film of the ink containing the material to be printed (donor film). This results in the generation of a cavitation bubble which expansion displaces a fraction of the liquid around it, leading to the formation of a jet which propagates away the donor film and towards the acceptor substrate, placed at a short distance. The contact of the jet with this acceptor substrate results in the deposition of a sessile droplet. Thus, each laser pulse leads to a single droplet. The generation of micropatterns is achieved through the overlap of successive droplets.

In this work we review our main achievements on the LIFT of inks, paying special attention to the analysis of the liquid transfer dynamics and to the most recent developments towards the optimization of the performance of the technique.

LT-14 Timescales and spatial resolution in femtosecond laser nanofabrication

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Basic femtosecond-laser ablation mechanisms involved into nanoscale fabrication of advanced surface structures for nanophotonics and plasmonics are overviewed on the basis of long-term diverse studies of electronic, lattice and phase-transition processes on surfaces of condensed matter.

Electron dynamics investigated by time-resolved optical reflection microscopy, pump-self-reflection and electric probe measurements of charge emission, revealed ultrafast surface charging via electron emission and subsequent plasma yield, resulting in ultrafine abnormal and near-diffraction normal surface ripples, as promising textures for wetting, boiling and friction control. Subsequent electron-phonon relaxation was shown to be dominated by electron emission and hot-carrier transport mechanisms.

Onset of spallative fs-laser ablation was observed on sub-nanosecond time scale, occurring via homogeneous sub-surface boiling and elemental chemical segregation in the thermally-strained molten surface layer long after its acoustic relaxation and accompanied by sub-threshold nanoscale boiling processes, prospective for nanofabrication. High-fluence picosecond supercritical phase explosion yields in advanced plasmonic nano- and microscale antenna for optical and IR-range sensing applications.

This work was supported by the Government of the Russian Federation (Grant 074-U01) through ITMO Visiting Professorship Program (for S.I. Kudryashov), the Presidium of Russian Academy of sciences, and the Russian Foundation for basic research (project nos. 15-52-04037 Bel_mol-a, 16-52-540002_Viet-a, 16-32-00880_mol-a).

LT -15 Laser-ablative synthesis of functional nanomaterials for cancer theranostics

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The presentation will overview our on-going activities on laser ablative synthesis of some biocompatible colloidal nanomaterials (Au, Si etc) and their testing in biomedical tasks. Our approach is based on ultra-short (fs) laser ablation from a solid target [1] or already formed water-suspended colloids [2] to achieve an efficient control of size characteristics of “bare” ligand-free nanomaterials, or fabricate nanomaterials coated by functional biopolymers (dextran, PEG) to minimize immune response of biological systems. Our experiments in vitro demonstrate an excellent cell uptake of both bare and functional nanomaterials, while the composition of protein corona covering nanoparticles complexes in biological environment promises a good transport of nanomaterials in vivo [3]. We also found that a systemic administration of such nanomaterials in small animal model is not accompanied by any toxicity effects, while Si nanoparticles are rapidly sequestered by the liver and spleen, then further biodegraded and directly eliminated with the urine. Laser-synthesized nanomaterials are now actively tested in cancer diagnostics and therapy (theranostics) tasks. In particular, our experiments showed that laser-synthesized nanomaterials can provide a much better efficiency compared to chemically synthesized counterparts in a newly introduced method of mild cancer therapy using Si nanoparticles as sensitizers of radiofrequency radiation-based hyperthermia [4]. Finally, we showed that bare metal nanoparticles synthesized by laser ablation can provide an order of magnitude better response in glucose oxidation tasks, which promises their use as elecrocatalysts in bioimplantable therapeutic devices [5].

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LT -16 Optical properties of photonic films and metasurfaces fabricated by direct laser writing

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We fabricate both direct and inverted dielectric photonic structures as two-dimensional periodic arrays of scatterers with the square C_{4v}, orthogonal C_{2v} and hexagonal C_{6v} lattice symmetry. The structures were fabricated using direct laser writing technique. The samples with the square and orthogonal lattice symmetry were fabricated with the square or rectangular shape. The direct photonic structures are composed of dielectric particles with an ellipsoid-like shape with a typical size of 100 - 300 nm in the surface plane. With "inverted photonic structure" we term a structured thin dielectric film with an array of holes.

A quantized nature of optical Laue diffraction observed experimentally from two-dimensional photonic structures is demonstrated. Surprisingly strong optical diffraction from limited number of particles provides an excellent approach to determine not only the symmetry but also exact number of particles and a shape of samples. For the theoretical analysis of diffraction patterns from low-contrast periodic structures (that include the photonic structures fabricated by the direct laser writing technique), we use the Born approximation when the interaction between the scatterers is neglected. It was found that the diffraction patterns at different high symmetry directions are independent. As a result a set of anisotropic samples demonstrates unchangeable diffraction patterns in one direction and transformation from Laue diffraction typical for photonic crystals to a non-diffraction regime characteristic for metasurface in other direction. When the number of scatterers increases, the quantized diffraction reflexes start to overlap merging into continuous patterns similar to the well-known transformation of isolated energy levels to continuous bands in crystalline structures.

This work was supported by the Russian Science Foundation (No. 15-12-00040).

LT - 17 Volume Holographic Elements for High-Power Laser Applications

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This presentation summarizes the results of volume holographic elements development for high power laser applications that were performed by research teams at CREOL, University of Central Florida and OptiGrate Corp. Holographic optical elements are recorded in photo-thermo-refractive (PTR) glass where permanent change of refractive index is provided by nano-crystalline phase precipitation resulted from exposure to near UV radiation followed by aging at elevated temperatures. The main types of elements are described: reflecting and transmitting volume Bragg gratings (VBGs), longitudinal and transverse chirped Bragg gratings (CBGs), tunable and achromatic holographic phase masks (HPMs), and distributed Bragg reflector (DBR) and distributed feedback (DFB) monolithic solid state lasers. No optical bleaching of holograms in PTR glass was detected for any type of CW or pulsed laser radiation. The main effects caused by high power CW radiation are shift of Bragg wavelength and induced lensing caused by thermal expansion of PTR glass resulted from absorption of laser radiation. The methods of heat management enabling operations at multikilowatt CW regimes are described. Bulk laser damage by pulsed laser radiation is caused by self-focusingand absorbing micro-inclusions that are byproducts of PTR glass fabrication. Nonlinear refractive index for PTR glass is the same as for fused silica enabling operations for ultrashort pulse lasers. Exposure of PTR holographic optical elements to extremely high power femtosecond pulses results in self-phase modulation and supercontinuum generation. Examples of the use of PTR holographic optical elements in high power laser systems are presented. Limitations of the use of PTR holographic optical elements in high power pulsed laser systems are given.

LT -18 Laser-induced nanocluster structures and thin films with controlled morphology for manifestations of new topological physical effects in quantum range

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Our study of the problems is based on (1) the laser-induced nanostructures fabrication in time domains from cw to femtosecond due to different mechanisms of laser interaction with matter and (2) physical properties of nanocluster systems are very sensitive to the form, size and distance between their composing elements and number of their layers. The last fact is very well known for any solid state object in general, but to change these parameters we need extremely high pressure ($\geq 10^6$ atm) and low temperature range ($\leq$ 30 K). In contrast, nanocluster structures can be easily modified in necessary direction and by controlled way in femto- nanophotonics experiments.

The laser synthesis technique to produce the nanoparticles/nanoclusters of different composition in semiconductor samples (PbTe), metal-carbon complexes and bimetallic (Au-Ag) films is presented by two laser ablation methods consequently: direct laser modification of thin films and laser evaporation of substance from target in liquid to produce the colloidal system and subsequent deposition of particles from colloid on solid substrate. The optical and electro-physical properties of the induced structures have been controlled in our experiments by various induced topology.

We demonstrated the new experimental opportunities are opening up in nanoclusters system to produce the correlated states in analogy with quantum states; the jump electroconductivity; the topological superconductivity tendency; the variation of optical characteristics for thin films. Possible principal interpretations and modelling for observed effects are given.

In progress, we should carried out the more detailed study of the correlation between the nanostructure topology/size/shape and functional dynamic properties (including a quantum domain) and also, to control the optical characteristics of the units. Such approach is very principal to construct the elements and devices of photonics and optoelectronics in hybrid circuits on new physical principles.

LT -19 Laser-assisted fabrication of plasmonic nanostructures and their application

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A simple and high-performance laser-assisted technique for plasmonic nanostructures fabrication, which includes the ablation of noble metal film (Au, Ag, Au/Pd or Cu) with focused nano- or femtosecond laser pulses followed by processing with accelerated ion beams or plasmon-polariton waves. Plasmonic elements including nanoscale cupolas, voids, jets, rings, holes, crowns and periodic structures can be fabricated on both metallic and dielectric surfaces. The geometry of these nanostructures was shown to be well tuned over a wide range varying both excitation conditions (focal spot diameter, pulse duration and energy) and metal film characteristics (thickness, chemical composition). Underlying physical mechanisms responsible for the formation on different functional plasmonic nanostructures are revealed and discussed. All the structures possess pronounced and well-tuned geometry- and size-dependent plasmonic response in visible spectral range, which can be utilized to enhance the photoluminescence or surface-enhanced Raman scattering signals from organic dye molecules and rare-earth complexes.

LT -20 In-situ characterization of the synthesis of silver nanoparticles obtained by laser ablation in ethanol

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The pulsed photoacoustic (PA) and pulsed transmittance techniques were used to study the synthesis by laser ablation of silver nanoparticles in ethanol. The samples were produced by using a pulsed Nd:YAG laser with 1064 nm of wavelength, 7 ns of pulse duration and pulse energy that varied from 10 to 100 mJ. The obtained nanoparticles were spherical with an average size close to 10 nm and showed the typical plasmon absorption peak around 400 nm. The results show that PA technique allowed to determine in-situ the ablation efficiency, understood as the amount of ablated silver mass per laser pulse. The ablation efficiency showed a significant reduction during the first hundreds of laser pulses and then was kept almost constant. Besides, PA technique allowed to know the evolution of the collapse time of the cavitation bubble with the number of laser pulses. Coinciding with the evolution of the ablation efficiency, the collapse time of the cavitation bubble falls rapidly during the first hundreds of laser pulses. Our results show that for the same number of laser pulses, the ablation efficiency increases with the increment of the repetition rate of the laser pulses, in the range from 1 Hz to 10 Hz. This fact contradicts to what was stated in previous references, which established that for this frequency range there was no dependence of the ablation efficiency on the repetition rate of the laser pulses.

LT -21 Micro-structuring of Rb thin metal films on the surface of porous glass by Bessel beam technique

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We report the experimental realization of non-diffracting Bessel beam technique for micro-structuring of few tens nanometre thickness rubidium metallic films on the surface of dielectric material. The technique of optical micro-structuring of metal films is based on processes of metal atoms adsorption on the surface of dielectric substrate and simultaneous controllable photo-stimulated desorption of atoms by non-uniform laser beam illumination.

Experiments were performed on a porous glass sample (SiO_2 -7 nm mean pore diameters) inserted in the 8 cm length cylindrical pyrex cell, previously evacuated, filled with rubidium and sealed off. The cell was kept at room temperature 20°C, corresponding to atomic density of $\sim 10^{10}$ cm^{-3}. Porous glass plate loaded with Rb atoms was preilluminated by UV light from Hg lamp with 100 W power during one hour, which causes an additional formation of nanoparticles and clusters. This provides more favorable conditions for microstructuring of Rb film on the surface of porous glass by nonuniform green 532 nm laser beam.

A Bessel beam at 532 nm wavelength was used as a nonuniform beam. The porous glass plate located near the output window of the cell was illuminated by a Bessel beam with ~1 W/cm^2 intensity during 30 min. This provides the non-uniform spatial distribution of the illumination intensity over the glass surface and the optical control of Rb atoms deposition on the porous glass substrate thanks to the redistribution and growth of metal nano- structures induced by light. Experiments showed that the Bessel beam pattern was well reproduced by the Rb deposits thus creating the annular micro-structured pattern on the porous silica surface.

The suggested technique opens new ways for the laser structuring of metal films with micro- and sub-micrometric scale resolution promising for numerous applications in all-optical and photonic devices.

LT-22 Physical vapor deposition of metal microstructures under the laser control

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Lasers are used in production of surface micro and nanostructures mainly to remove some unwanted parts of already deposited thin films. In this contribution we discuss a somewhat different approach based on the possibility to prevent deposition of the film material at the predetermined places via laser illumination. Our approach is based on the process of photodesorption of single atoms from the surface of transparent substrate.

In the routine physical vapor deposition atoms arrive at the surface, adsorb on it, diffuse over it, meet each other, and finally form a nucleus of the future metallic phase. Subsequent deposition of atoms leads to the growth of the island or continuous film depending on the temperature of the substrate and the rate of deposition. When atoms arrive at the laser illuminated surface their residence time is diminished due to the enhanced probability of desorption. Hence the surface number density of adsorbed atoms is reduced and the probability of the nucleus creation is lowed. Balancing the deposition rate with the intensity of laser illumination it is possible to keep the illuminated parts of the surface free from the deposits.

To demonstrate the feasibility of the proposed technique we employed the Bessel beam illumination. This kind of illumination is advantageous because its non-diffracting character softens demands for accurate alignment of the substrate with focal plane of the optics. Thus the ring pattern of sodium metal film on sapphire substrate was obtained in the course of 30 min long laser controlled deposition. The obtained metal deposits form the sharp-cut circles with the pitch of 10 □m, coincident with the dark rings of the Bessel beam.

LT-23 Recent achievements in nanodomain engineering in single crystals of lithium niobate and lithium tantalate family

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Formation of the self-assembled submicro- and nano-scale domain structures by spatially nonuniform pulse laser heating has been investigated in single crystals of congruent lithium niobate (CLN) and lithium tantalate (CLT).

The polar surfaces of CLN and CLT wafers have been irradiated by IR laser (10.6 □m). The domain structure formation was in situ recorded by optical microscopy and high-speed camera. The static domain structures were visualized with high spatial resolution by piezoresponse force microscopy, scanning electron microscopy and confocal Raman microscopy.

The formation of quasi-regular submicron domain structures: maze-type in CLN and isolated circular-shaped in CLT was achieved by multiple pulse laser irradiation. The chains of nanodomains appeared along the domain wall position of the ("wall's trail") was revealed in CLN during multiple laser irradiation of the surface covered by ITO layer. The application of the effect allowed to explain the formation of self-assembled domain structures.

Three types of the self-organized domain structures were obtained in CLT: (1) the self-similar domain structure formed in crystal regions heated below Curie temperature, (2) the maze-type domain structure, and (3) irregular-shaped isolated domains formed in the regions heated above Curie temperature. The results of calculation of the time dependent spatial distribution of the temperature and pyroelectric field have been used for explanation of the peculiarities of domain structure formation.

For the first time the self-assembled structures of nanodomain rays with width down to 20 nm were achieved. The stable regular domain structures with the periods down to 2 microns and depth above 8 microns have been produced in CLT by laser ablation of the moved sample with periodical metal applications.

The equipment of the Ural Center for Shared Use "Modern nanotechnology" UrFU was used. The research was made possible by Russian Scientific Foundation (Grant 14-12-00826).

LT-24 Femtosecond laser writing with sub-100 ps bursts

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Femtosecond laser direct writing is a disruptive technology in the field of micromachining, which is attractive for a variety of applications ranging from integrated optics and microfluidics to printable flat optics. Micromachining with femtosecond pulse trains that exploit material dependent relaxation processes have been proposed for creating sub-micrometer features [1], drilling long channels, writing waveguides with a circular cross-section [2]. The pulse shaping technique exploits development of avalanche ionization on sub-picosecond time scale [1], and the burst mode method is based on control of a heat deposition when pulse separation in a burst is of about 10 – 1000 ns [2]. Here we propose and demonstrate the method of efficient micromachining with burst of laser pulses separated by 10 – 100 ps, which allows exploiting absorption of femtosecond pulses by self-trapped excitons (STE) in fused silica.

The femtosecond modification is initiated by high order multiphoton absorption, and an intensity threshold should be exceeded to launch this process, which in turn initiates the linear absorption by the electron-hole plasma and the STE. The later processes have no low limits on the energy or intensity. In our experimental setup we used Fabry-Perot cavity to split the 180 fs pulse into a burst of such pulses. Pulse separation in the burst was equaled to 10 -100 ps defined by the cavity length. The first pulse had the highest energy, and the energies of the subsequent pulses exponentially decrease with the decay time of 20 ps. Thus effective burst duration is nearly 10 times greater than duration of a burst, produced by the third order chirp [1], and we did not stretch pulses in the burst. Such temporal form of the burst allows reducing the energy of the first pulse in the burst to the inscription threshold energy. Nevertheless, we obtained strong modification due to the linear absorption of the subsequent pulses by the STE. It was found, that in contrary to a single pulse with the same energy, absorption of the burst is strong enough to produce a birefringent micro-structure in fused silica. It consists of two elongated birefringent spots with parallel slow axes separated by area without birefringence (Fig.1).

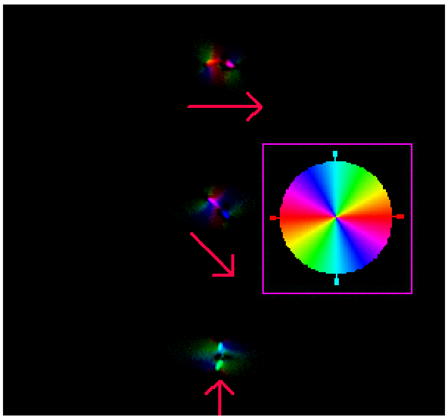

Fig.1. Microscopic pictures of birefringent spots, produced by the burst of femtosecond pulses. Colors code direction of slow axis in accordance with the legend. Red arrows show direction of laser beam polarization. Burst energy is equaled to 110 nJ. Lens NA=0.65.

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2. Rezaei, S., Li, J. & Herman, P. R. Burst train generator of high energy femtosecond laser pulses for driving heat accumulation effect during micromachining. Opt. Lett. 40, 2064–7 (2015).

3. Richter, S. et al. The role of self-trapped excitons and defects in the formation of nanogratings in fused silica. Opt. Lett. 37, 482–484 (2012).

LT-25 Application of thermochemical laser-induced periodical surface structures as mask for metal underlayer etching

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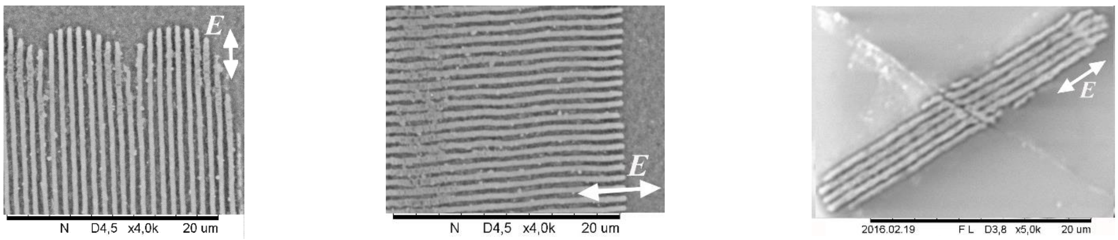
Thermochemical laser-induced periodic surface structures (TLIPSS) became a research subject relatively recently. They are characterized considerably higher order in comparison to ablative LIPSS. Typical height of oxide ridges of TLIPSS is in range of 50-150 nm. Typical range of periods is 700-900 nm. In the current work, we investigated possibility to transfer a topology of TLIPSS into metal underlayer, on which they have been formed. Our technological approaches are based on known data about selective liquid and dry etching of metals through mask formed in their oxides.

For TLIPPS formation we used x-y scanning writing system with femtosecond laser PHAROS 6W having a central wavelength of 1026 nm and 230 fs pulse duration. The repetition rate was 200 kHz. The focal spot size was in range 6-12 μm, the radiation power was near 16 mW for 400 nm Ti film and 9 mW for 300 nm Cr film, and the scanning speed was varied from 1 to 5 μm/s. Metal films were coated on glass substrates by magnetron DC sputtering.



a b c

Fig. 1. a and b - gratings etched in Ti film through TLIPSS mask by RIE ICP process, c - gratings etched in Cr film through TLIPSS mask by selective liquid etchant. E – polarization direction.

Experiments on selective etching of Ti films in inductively coupled plasma (ICP) of chlorine-containing gas were conducted in ICP RIE system Plasmalab 100Plus. The Cr films with TLIPSS were developed in the selective etchant consisting of 6 parts of 25% solution of K3Fe(CN)6 and 1 part of 25 % solution of NaOH. Images on Fig.1 obtained by SEM proves prospectivity of application of liquid and reactive ion etching for transfer of TLIPSS gratings into metal films with thickness of several hundred nanometers.

In the research, we used equipment of multiple-access center "High-resolution spectroscopy of gases and condensed matters" at IA&E SBRAS. This work was supported by Russian Foundation for Basic Research (grant 16-32-60096).

PS1-LT-01 Pore collapse dynamics during laser melting of metal surfaces

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Empty pore collapse dynamics during laser melting of metal surfaces is studied. A self-consistent model of pore radius variation in the melt is constructed. Pore size variation with the distance from the melting front is determined.

Laser pulse irradiation of the coating surface containing defects, i.e., empty pores, results in material heating and melting. During the melting front motion, empty isolated pores are formed, whose sizes are controlled by initial defect sizes. Fluid motion in the formed melt will be characterized by two spatial scales. First, the local motion on the pore size scale which results in molten material flow into pores and their collapse. Second, it is clear that material flow into pores should be accompanied by melt motion from the irradiated surface to the collapse region and the formation of corresponding averaged macroscopic motion.

The averaged motion is defined by the pressure difference on the free surface and at a given melt depth. The velocity of melt flow into a separately considered pore depends on the relation between the capillary and the near-pore pressures. Thus, the dynamics of the melt flow into pores and its translational averaged motion from the surface to the collapse region appear self-consistently related by the pressure at a given depth. The local fluid motion near the pore under surface tension forces and external pressure control the collapse dynamics; the spherical cavity boundary motion in the moving liquid element is described by Rayleigh equation.

The analysis of the empty pore collapse dynamics during laser annealing of the metal surface containing defects in the form of empty pores shows that the crucial role is played by the pressure in the molten material. On the one hand, it defines the velocity of melt homogeneous motion from the surface to the collapse region; on the other hand, the velocity of the melt flow into empty pores.

PS1-LT-02 Interaction of the electromagnetic radiation with optical surfaces and thin-film coverings

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R&DI “Polyus” named by M.F.Stelmakh, Moscow, Russia. azarovav@hotbox.ru

Interaction of electromagnetic radiation with an optical surface and study the impact of the quality of surface and thin film layers on the characteristics of modern optical instruments and devices of quantum electronics is of great scientific and practical interest. The quality of the modern high sensitive optical measuring devices, such as interferometers for seismic measurements and earthquakes predictions, optical corvette in atmosphere pollution analyzing equipment, huge amount of laser devices and first of all laser gyros mostly depends on the surfaces quality in the cavity both for mirror or prism cavity.

It’s formulated the requirements to precision optical surfaces and laser mirrors used in the most high-tech fields of optics and quantum electronics, namely, in the optical interferometry and laser gyroscopes in this paper. The characteristics and statistical parameters of precision optical surfaces are discussed. We compare the results of measurements obtained by different metrological methods, namely by atomic force microscopy (AFM), optical and X-ray scattering (TIS, ARS, XRS) and by optical profilometry (WLI) by using the power spectral density function (PSD-function). Power spectral density function gives complete statistical information on the distribution of the heights of roughness in the spatial frequency. The general criterion of surface quality in this case is the value of the effective roughness σ_{eff} in a predetermined spatial frequency band.

It’s analyzed the relationship between the surface profile of the multilayer coating and the surface of the mirror substrate. It is shown that the value of surface integral scattering S (λ) is proportional to the square of its roughness σ. If the surface is a multilayer mirror coating, the full correlation between the layers of interlayer σ change will be minimal and the observed light scattering value is close to that determined by the roughness of the substrate surface. Not perfect layering process and environmental conditions at the same time insufficient purity target materials when applied layers can prevent complete interlayer correlation. When the partial correlation between the layers, S (λ) will vary with each additional layer and the scattering will depend not only on the quality of the substrate surface, but also on the number of layers. This leads to an increase in scattering loss in turn. The paper also discusses the results of the analysis of the characteristics of surfaces and thin films of homogeneous and gradient by utilizing the methods of laser and spectroscopic ellipsometry. The investigations of synthesis of thin film multilayer interference coatings, laser mirrors and optimization of their production has allowed to reduce by several times the loss absorption resonators.

As a result of the analysis in the following conclusions:

- The method of optical profilometry (WLI) is the most effective method for the metrological control of roughness of precision optical surfaces of substrates laser mirrors.
- Mirrors, obtained by ion-beam sputtering on the super- smooth surface substrates have minimal losses and minimum value of the backward scattering in the resonator mode.

PS1-LT-03 Ferroelectric microstructure formation by femtosecond laser annealing

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Quazi-amorphous $Pb(Zr,Ti)O_3$ (PZT) precursor film which was deposited by RF magnetron sputtering on a platinized silicon substrate was annealed by femtosecond laser pulses at the wavelength falling into transparency band of PZT. Power was absorbed by platinum sublayer. We show that crystal growth started at the PZT surface instead of PZT/Pt interface. This can occur due to thermal stress-induced modification of the activation energy. Annealing was performed using femtosecond titanium-sapphire laser with pulse duration of 100 fs, wavelength of 800 nm, and repetition rate of 100 MHz. The beam was focused on the sample by confocal microscope. Different types of microstructures are shown: local circle structures, local ring structures and planar waveguides. In-situ crystallization kinetics was studied by method of second harmonic generation (SHG). Ex-situ SHG images allowed to distinguish ferroelectric phase and thus to find optimal conditions of processes (power density, annealing time for local structures and scan speed for waveguides). The presence of several types of crystallization was shown, including ultra-fast (explosive) crystallization occurring immediately after the start of exposure, and slow (self-sustaining) crystallization, occurring after termination of exposure. The advantage of the second-harmonic generation microscopy for the study of annealed microstructures was shown.

PS1-LT-04 Acceleration of structuring and optical properties of thin silver granular films upon exposure to ethanol and acetic acid

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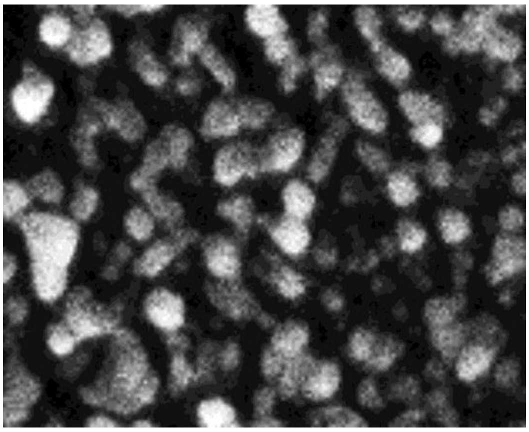
The stability of silver island films is still poorly understood. It is known that the structure of the films produced by physical vapor deposition in a high vacuum is unstable, and starts to change immediately after the deposition of metal on a substrate [1, 2]. At the room temperature, the rate of such changes is small, but upon heating the process is accelerated, and films move into long-living metastable states with lower surface energy of islets and more uniform distribution of their size and shape than in initial unstable films [1, 2]. Such changes in the structure of films are clearly manifested in their optical properties, in particular in positions and shapes of plasmon resonances in the spectra of extinction [1, 2].

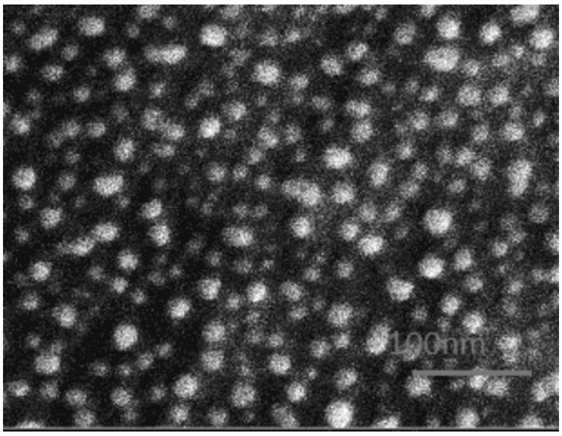
In this paper we report the peculiar phenomenon: a change of the size and shape of silver nanoparticles, which form a granular film on a sapphire substrate, when they are dipped into ethanol (C_2H_5OH) and acetic acid (CH_3COOH). While the influence of these two liquids is similar, water (H_2O) leaves granular silver films virtually unchanged. The changes in the structure of the films were found via observing changes in the optical spectra of extinction, and confirmed by scanning electron microscopy.

We also discuss possible mechanisms of the observed influence of the fluids on the structure of granular silver films, and the similarities between this influence and the processes occurring during thermal annealing.

The films were produced in a 10^{-7} torr vacuum provided by a Kurt J Lesker Company vacuum chamber with an oil-free pumping. We used the method of deposition of a thermally vaporized silver to the surface of the sapphire substrate. The deposition rate as well as the equivalent thickness were controlled by a quartz microbalance The structure of the film with a thickness of 3 nm is shown on the image taken by a Merlin (Zeiss) scanning electron microscope immediately after deposition (Figure 1,a). The average size of islets in the plane of the substrate is about 40 nm, and the degree of coating is greater than 50%. Taking into account the equivalent thickness of the coating, it can be concluded that the islands are strongly flattened and, therefore, have an excess surface energy.



a)



b)

Fig. 1. An electron microscopic image of the silver film immediately after its preparation (a) and after soaking in ethanol for 1 hour at room temperature (b) with the same magnification. The rated equivalent film thickness is 3 nm.

The shape of metal nanoparticles varies due to diffusion of atoms on the surfaces of the island (self-diffusion) and the substrate [1, 2]. The speed of this process depends on the heating temperature. The characteristic time, required for changes in the structure of the silver film to occur due to immersion in acetic acid and ethanol, is equal to one hour. This value is close to the characteristic time for which similar changes in the structure of the film occur due to thermal annealing at a temperature of 70 ^{O}C. Thus, the influence of these fluids can be explained by the acceleration of self diffusion of surface atoms of silver, although the mechanism of the influence is different. While the increase of the temperature during annealing accelerates the diffusion through constant potential barriers, the change in the chemical environment at a constant temperature seems to reduce potential barriers.

The adsorption of molecules of ethanol and acetic acid on the surface of silver has not been studied. One can, however, believe that it is in many ways similar to the adsorption of water molecules. Indeed, the valence orbitals of oxygen in the hydroxyl group of ethanol and the carboxyl group of acetic acid are the same as in the water molecule. At the room temperature, all three liquids have almost the same viscosity (1 cP) and the energy of the hydrogen bonds between molecules (0.2 eV).

What distinguishes water from the other two liquids is the size of its molecules. It appears that this is the factor that causes the peculiarity of liquids influence on the granular silver films, as the formation of hydrogen bonds between large molecules of ethanol and acetic acid, attached to the surface of metal by oxygen atoms, is difficult.

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PS1-LT-05 Physical mechanism of surface modification of transparent dielectric by laser ablation of graphite in confinement regime

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The technique for laser-assisted modification of fused silica and borosilicate glass surface is suggested. The method is based on the heating of glass by graphite plate irradiated by laser being in direct contact with the glass surface from the backside. Transparency of fused silica and strong absorption of graphite for an incident laser radiation provide the diversity of applicable lasers wavelength and pulse duration. In our case, the ytterbium pulsed fiber laser was used. After exposing of graphite surface with calculated power density, the boundary conditions of plasma creation were found. This process consists of two stages: firstly, graphite is heated to metastable liquid ; at the second stage graphite plasma formation appeared. Plasma creation boundary conditions were also clarified by opto-acoustic investigations and optical emission spectrum of plasma plume in the air and under fused silica/borosilicate glass sample. This investigation might be helpful to any technique that include laser modification of transparent materials with high efficiency, process speed and application area.

PS1-LT-06 Double pulse ytterbium fiber laser ablation of solids

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A simple way of implementing double nanosecond pulse generation in ytterbium fiber laser is suggested. The regime is provided by controlling an acousto-optic modulator with a specially developed radio-frequency generator. Different generation modes have been achieved: the pulse duration in the couple ranges from 70 ns to 500 ns, the delay between the pulses may vary between 400 ns to 1000 ns.

We investigated influence of some modes of double pulses generation on laser ablation of solids (titanium, steel, ceramics), and more specifically, influence of temporal shape of double-pulse regime on the ablation crater geometry and the emission intensity of plasma plume.

The results have shown that using double pulses results in a crater twice as deep as when using a mono pulse of the same intensity. The double pulses mode allows controlling the crater form and getting craters with a diameter smaller than that of the laser beam in the focal plane. The research has also shown that emission intensity of plasma plume increases when decreasing the second pulse duration and is twice as high compared to mono pulse mode.

Thus, double pulses laser mode appears to be highly promising for application in laser micromachining, laser cleaning, drilling, libs etc. It is to be noted that the implementation pattern suggested does not lead to any decrease of the average laser source power and results in increasing the peak power.

PS1-LT-07 Femtosecond laser peening of titanium and aluminum alloys

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Shock waves (SW), produced by single-shot femtosecond (fs) laser ablation of titanium and aluminum alloys, were studied in the investigation. To evaluate initial fluence-dependent ablative pressures P_{abl}, driving in the air the acquired shock waves the numerical code, based on the point explosion model was used. Non-contact broadband ultrasonic transducer MiniWAT-2 (effective bandwidth (with a pre-amplifier) 30 MHz, sensitivity – 10 V/bar) was used to characterize SW, arising in the air and in the solid target, and to acquire initial data for calculation [1].

In an experiment at laser fluence ~ 10 J/cm^2 the calculated values of SW initial pressures was ~10^3 GPa. Obtained samples were characterized by means of X-ray diffraction, energy-dispersive analysis, and microhardness measurements. X-ray characterization of the laser-affected surface layers revealed permanent broadening and upshift by $\Delta\theta$ of all detected diffraction peaks, as compared to the unablated (initial) material. This effect corresponds to depth-dependent residual compressing stresses with a peak value up to 1 GPa. No microhardness change was detected for titanium alloy, but aluminum alloy it increased by a factor of 1.4: from 0.94 to 1.36 GPa. Energy-dispersive analysis revealed that chemical composition was essentially constant not only for titanium but also for aluminum alloy.

Suggested approach can be used for surface peening of different alloys. In addition, fs-laser peening has an obvious advantage over ns-laser peening, because it does not require a confinement medium and ablated surface is damaged in a less degree.

1. APPLIED PHYSICS LETTERS 108, 084106 (2016)

PS1-LT-08 Laser induced structural and compositional changes of ZnO nanoparticles: photoluminescence and Raman studies

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Many practically important properties of zinc oxide, such as luminescence, magnitude and type of conductivity, are strongly dependent on the concentration and nature of the intrinsic and extrinsic defects. The optical properties of zinc oxide, in particular, photoluminescence (PL) and Raman scattering are directly linked to the features of the crystal structure and a presence of the structural defects and doping elements in Zn oxide structures. In this work the effect of doping and structural defects on the luminescent properties of ZnO nanoparticles synthesized by laser ablation technique in liquid was investigated. For formation of doped ZnO nanostructures experiments were performed using aqueous NH4NO3 solution or a mixture of NH_4NO_3 and colloidal silver solutions. The morphology, structure and optical characteristics of the synthesized NPs depending on the experimental conditions were analyzed. It has been shown that laser ablation of zinc target in NH_4NO_3 solution results in the formation of nanoparticles of wurtzite-type structure as is proved by SAED, Raman and FTIR spectroscopy. In addition to the host phonons of ZnO the modes at 270, 515, 565, 680, and 856 cm^{-1} were observed in the Raman spectra of the doped samples that can be attributed to the local vibrational modes of N introduced to the ZnO lattice. Two major peaks, a near-band edge emission at 380 nm and luminescence related to the oxygen-vacancy defects at 600 nm, were observed in the PL spectra of the undoped samples at room temperature. The PL features of the doped ZnO samples, related to the appearance of the band at 468 nm, are most likely due to the defects in ZnO. It was revealed that laser treatment of the ZnO nanostructures by the second and third harmonics of the Nd:YAG laser improves the conditions of the introduction of N acceptors into the ZnO lattice.

PS1-LT-09 Investigations of luminescent properties of Si/SiO_2 structures with Si^+-implanted SiO_2 films

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The use of nanocomposite materials based on silicon is a perspective direction of development modern micro and nanoelectronics. Special interest is shown to structures of dielectric film of silicon dioxide, with silicon nanoclusters formed in its bulk. Such structures can be used, for example, as a basis for the creation of memory chips and integrated optoelectronic elements. Despite the large number of publications related to investigations of such structures, the overall concept of understanding the correlation between various properties of Si/SiO_2 with silicon's nanoinclusions and their technological modes of production is not developed.

The aim of this work was to investigate the structural properties of thin films of silicon dioxide with particles of silicon formed by ion implantation. Structural investigations were made by cathodoluminescence. The essence of this method consists of analysis the luminescence spectrum in the visible and infrared bands, which occurs when the flow of electrons irradiated films. It was assumed that thermal annealing will reduce the intensity of the luminescence of defects related to oxygen deficiency.

As a result of thermal annealing was significant decrease in the intensity of luminescence in the spectral range corresponding to the intrinsic defects of silicon dioxide, which may be associated with the restoration of stoichiometry of the oxide. It should be noted that annealing the experimental structures, doped with a dose of 10^{13} cm^{-2}, also decreases the luminescence caused by the presence of silicon nanoclusters. However, increasing the dose of implantation up to 10^{14} cm^{-2} leads to a stabilization of luminescence nanoclusters during annealing. Thus, certain modes of annealing can positively influence on the luminescence of samples with a higher concentration of silicon nanoclusters.

PS1-LT-10 Laser ablation of silicon target under a layer of liquid: nanosecond and femtosecond pulses

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It is well known that the properties of nanoscale objects are substantially different from those of bulk materials. Therefore, such objects are a relevant topic of research and their number of applications is constantly growing. In particular, nanoparticles (NPs) of silicon, due to peculiarities of the band gap at the nanometer size and harmless to the environment, are used to absorb and to convert radiation. Coatings from Si NPs can be used as a protective filter against radiation in the ultraviolet range, and as converters of the incident radiation to increase the efficiency of solar cells, the catalysts for oxygen release, etc.

The main problem in the use of these techniques is to obtain NPs with a predetermined size. There are a large number of ways, starting from mechanical grinding and chemical methods and finishing with laser "printing" of NPs. All of them have different strengths and weaknesses (poor dispersion, chemical pollution, the high cost of equipment and low productivity).

The goal of the present study is the creation of silicon NPs by laser ablation using nanosecond and femtosecond pulses, investigation of their properties and comparison of efficiencies of these two techniques.

Two laser systems were used in the experiment. The first one based on fiber laser (λ = 1,064 µm, $\tau \approx$ 100 ns, $q \approx 2\cdot10^{10}$ W/cm^2); and the second is femtosecond laser system consisting of a Ti: sapphire laser oscillator TiF-100-F4 and regenerative amplifier RAP1500 (λ = 785 nm, $\tau \approx$ 200 fs, $q \approx 7\cdot10^{12}$ W/cm^2).

NPs was made by pulsed laser ablation of silicon plate under liquid layer. The resulting colloidal solution was dried at room temperature on a silicon substrate preliminary cleaned in the ultrasonic bath.

Analysis of the samples was made by means of the scanning electron microscopy (SEM) and the obtained images were studied for evaluation of formed NPs shapes and sizes distribution.

Results of the investigation:

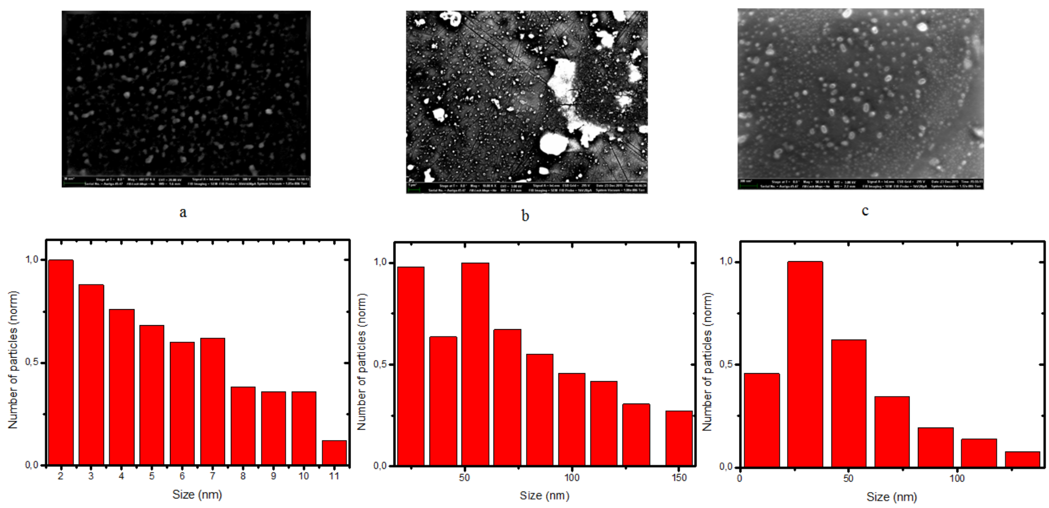

Fig. 1. SEM images (top) and sizes distribution (down) of silicon NPs obtained by pulsed laser ablation with (a) nanosecond pulses under water layer, (b) femtosecond pulses under water layer, (c) femtosecond pulses under acetone layer.

1) After nanosecond exposure, nanoparticles have a uniform size (2-10 nm) and relatively uniform distribution.

2) Femtosecond exposure resulted in the formation of nanoparticles which size is between 20-160 nm. When using acetone as the liquid dispersion of nanoparticles in size also remains sufficiently wide (5-120 nm), and their average size decreased.

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PS1-LT-11 Generation of nanodimensional objects by femtosecond laser ablation of silicon target in ambient air

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A great difference between fundamental properties of nanoparticles (NPs) and properties of macroscopic objects causes a strong scientific and practical interest to their generation, research and creation of NPs-based composites. There are many physical, chemical, physicochemical and biological methods of NPs synthesis. Among them pulsed laser ablation (PLA) is a promising method to produce NPs of various materials which allows obtaining structures with desired characteristics by changing environment's properties or parameters of laser radiation. The main problem of PLA method is a difficult process of establishing the relationship between particle's sizes and processing parameters.

Silicon nanoparticles have electronic and optical properties that are different from properties of the bulk material due to the effect of quantum confinement. At the same time, photophysical properties of nanosilicon are determined by phase composition (crystalline or amorphous). For this reason, laser-induced fabrication of silicon nanoparticles is a promising technique enabling to obtain nanostructures with desired sizes, shapes and phase composition.

The objective of the work is a generation of silicon nanoparticles by femtosecond laser ablation and studies of their properties.

Silicon NPs were made by femtosecond laser ablation of a silicon target in the ambient air. The laser-induced backward transfer (LIBT) technique was used. Laser pulses were focused on a monocrystalline silicon wafer (100) with a natural oxide layer by a short-focal lens (NA=0.17). Generated silicon nanoparticles were collected on a borosilicate glass substrate placed above the irradiated silicon sample (acceptor plate). For laser fabrication of silicon nanostructures a commercial femtosecond laser system consisting of a Ti:sapphire oscillator TiF-100-F4 and a regenerative amplifier RAP1500 (Avesta Project Ltd.), with the central wavelength of 800nm, half-maximum pulse width ~200 fs, maximal pulse energy of 1 mJ (TEM_{00}-mode), coming at the 10-Hz repetition rate was used. Obtained nanostructures were studied by dark field optical microscopy, scanning electron microscopy (SEM) and Raman scattering spectroscopy.

All used intensities led to the generation of silicon nanoparticles and their transfer to the glass acceptor substrate. Obtained structures can be divided into two groups: first, branched structures with a size of the minimal element about 10 nm; second, larger particles with a smooth surface and typical size about 50-200 nm (fig. 1).

In addition, an influence of environment on resulting phase composition of silicon nanoparticles was investigated. It was achieved by theoretical approximate evaluation of NPs cooling rate. The calculation results are in good agreement with experiment.

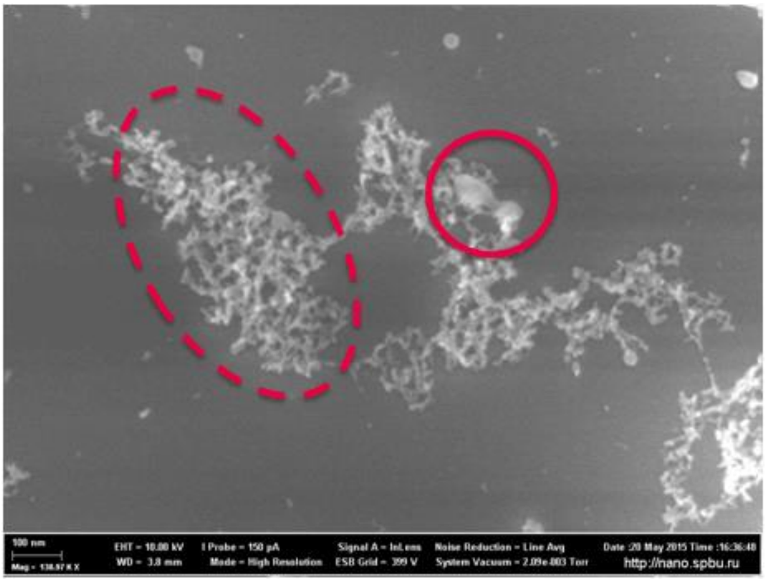

Fig. 1. SEM picture of nanostructures deposited on glass substrate by femtosecond laser pulses (intensity ≈ 11 J/cm^2). The branched structure is highlighted by the dashed line, the particle with a smooth surface is highlighted by a solid line.

PS1-LT-12 Laser-induced submicron periodical structures on titanium films

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Local laser thermochemical modification of thin metal films is a powerful technique for recording a microstructures, for instance, for purposes of diffractive optics [1]. Also a laser-induced periodical surface structures (LIPSS) formation is a well-known effect of laser thermochemical action on solid-state materials. Recording of these structures is performed including (but not limited) by femtosecond laser pulses nowadays [2].

Nanosecond pulsed radiation of fiber Yb-laser was used in presented work for recording on 20 nm thick titanium films, while secondary denim-like periodical microstructures appeared transversely. Results of research the geometrical parameters dependences of structures are reported. Using optical and scanning probe microscopy a period of microstructures was found to be equal to 0.8 μm approximately. Results obtained in our work could be useful in the laser thermochemical technology of recording the diffractive optics, where the discussed microstructures could be either the reason of defectiveness or the basics of the recording method.

This work was supported by RFBR’s grant for oriented fundamental research 14-29-07227.

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PS1-LT-13 Laser multipulse metal films oxidation with transparent oxides formation

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Local laser oxidation of thin metal films plays an important role in recording planar structures such as diffractive optics, thin-films topology, microelectronics, etc. A search for new methods and mediums for recording with enhanced productivity, resolution and quality becomes a challenge for researchers recently. Laser modification of thin titanium and tin films were researched theoretically and experimentally in purpose of developing a one-step thermochemical recording in presented work. While the laser-induced transparent dioxide layer is thick enough to change the optical properties of the film, recorded structure does not have to be revealed chemically (however it is strictly necessary for structures recorded, for instance, on chromium films). An analytical attempt for modeling the multipulse laser oxidation of thin metal films was developed considering strong increase of transmittance during laser action. An estimation and visualization of main dependences (oxide layer thickness, absorbance, and temperature dynamics) on machining parameters were performed. Fiber Yb-laser was used for conducting the supporting experiments, during which thermal imaging camera FLIR Titanium 520M was used for observing the time-resolved temperature dynamics; microscope-spectrofotometer MSFU-K was used for measuring the optical properties of modified areas at films. Presented results are highly important for developing the one-step high-resolution laser thermochemical recording technique.

This work was supported by RFBR’s grant for oriented fundamental research 14-29-07227.

PS1-LT-14 Technical methods for observation the dynamics of laser ablation of ceramics

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Rapid laser-induced processes in solid-state materials are difficult to observe directly so frequent videography is used commonly. Acceleration of a laborious process of gained images and video data manual processing requires the applying the digital processing methods which are widely used in different fields of science and technology currently. Solving the issues of recognition, detection and measurement of the object on one or more images is essential for many applications, including the observation of laser-related processes. However, since there is no universal method for developing an object description model, writing special software is required in many particular practical goals.

Observation and facilitation the description of the rapid processes related to laser ablation of ceramics using computer image rapid analysis is the aim of presented work. AOS X-Motion high-speed camera and Flir Titanium 520m thermal imaging camera were used for observing the ablation processes in aluminosilicate ceramics under Yb-laser action. Program intended to detect and calculate properties of dynamically changing objects on high-speed videos was developed in presented work. LabView National Instruments visual programming platform with IMAQ Vision library including image processing and analysis components were used for implementing the software. Presented work examines the basic aspects of the receiving, storage, processing and analysis of the concrete images of the explored object on videos of rapid laser-induced processes.

PS1-LT-15 Conjugated short-pulse generation in longitudinal channels formed within an active crystal by segmented end pumping

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Conjugation of multiple emitters is a universal approach for increasing energy and power of laser systems. We study this technique aiming to bust output characteristics of the end-pumped Q-switched Nd:YAG lasers with several (2 to 7) longitudinal pumped segments. As a result, the record values of energy and pulsed power were achieved for such type of compact devices (20mJ in 3ns pulses) [1]. That allowed us to build a family of miniature lasers for high-tech applications.

In the experiments with a couple of pumped channels, we see that conditions for conjugated generation can only be achieved when the distance between them is small enough. Synchronized emitting of two short pulses is observed in this case. To simulate the phenomenon, we use a model based on the diffraction “redistribution” of radiation between two confined channels under conditions of short pulse generation at a given spatial profile of amplification in the active crystal. When one of the channels in such system starts lasing, the second pulse, of the same duration, is triggered too after a fixed time delay. Depending on distance between the channels, the time delay between them varies in the range from few hundreds of nanoseconds to several hundreds of picoseconds. In the last case, the pumped channels generate the pulses nearly simultaneously. This simple theoretical approach demonstrates fairly good agreement with the experimental data, which can be even improved by taking the rate equations into consideration.

The proposed approach allows simulation and building the laser systems for variety of application including ignition of fuels, remote sensing and laser treatment of materials where small package, high peak power and well controlled beam quality are the main priorities.

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PS1-LT-16 Laser colouring of metal and polycarbonate surfaces - as a method of protection against falsification

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At the present day, a protection of products against falsification is a serious problem for manufacturers and consumers. In some cases, existing security methods, such as holographic stickers, trademarks, printed on a package by special IR and UV pigments etc. do not guarantee a reliable protection against counterfeiting. Therefore, it is necessary to improve existing methods of protection, as well as to create new ones.

To solve this problem we proposed a method of laser surface structuring. This technology allows creating of structures on the metal; therefore, its colour becomes a function of the viewing angle.

Surface periodic structures can be found after nanosecond laser irradiation of stainless steel and nickel film. The reason for the formation of these structures can be associated with changes in optical properties of a sample surface, which occurs during the melting of the material under laser exposure, and with the generation of a surface electromagnetic wave. This work shows the possibility of the formation of periodic structures on the surface of stainless steel and nickel films of the order of 1 μm, which corresponds to the laser wavelength used in the experiment. Diffraction of light on these structures causes a surface colour shift with a change of viewing angle (Fig. 1).

Figure 1. Photography of the picture formed on the Ni film by laser exposure

Another reliable method of counterfeit protection is a change of optical properties of the surface laser-induced oxidation of the material. In the case of exposure of the thin polycarbonate film coated with a thin layer of titanium by laser pulses with nanosecond duration a controlled local heating of the surface takes place. Titanium reacts with the environment (in particular with oxygen), and we can find a formation of titanium oxides on the surface of the polycarbonate film. A result is a film painted in different colours (Fig. 2) due to the interference of light in the formed oxide.

Figure 2. An example of the colour image obtained by laser oxidation on a surface of polycarbonate film coated with a thin layer of titanium.

PS1-LT-17 Wetting and evaporation processes on functional silicon surfaces after direct femtosecond laser surface processing and thermal training

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The key factors in controlling the diverse interfacial phenomena, including wettability and heat transfer, are morphology and physico-chemical properties of a surface. Surface engineering is a critical technology that is of great importance to different industry sectors including power generation and electronics. Over the past decade direct femtosecond laser surface processing emerged as a versatile technology to produce a variety of surface nano/microstructures and to impart unique physico-chemical properties to the surface. Recently carried out experimental studies of laser-processed surfaces have shown significant enhancement of pool-boiling heat transfer [1], extraordinary shifts in the Leidenfrost temperature [2], superhydrophilic and superhydrophobic surfaces with reversible wettability controlled by external stimuli [3,4], enhanced light absorption by thin film solar cells [5] and others [6]. However, the data concerning investigation of evaporation processes on femtosecond laser-processed silicon surfaces are almost entirely lacking. In addition, the effect of thermal training of laser-processed silicon surfaces has been observed for the first time.

In this study the effects of micro/nanostructuring, surface chemistry and thermal training of silicon surfaces on wettability, evaporation and the Leidenfrost temperature are experimentally investigated. The multifunctional surfaces with two alternative patterns, namely with an array of parallel microgrooves covered by flake-like nanostructures and with a net of spaced mesostructured zones (craters) were originally fabricated via direct femtosecond laser surface processing. Generally, the laser-processed silicon surfaces exhibit superhydrophilicity, enhancement of the heat transfer as the droplet evaporation time decreased by 100-600% in the temperature range of 25-150°C and an increase in the Leidenfrost temperature of about 30°C relative to the polished silicon surface. However, after its heating above 300°C the surface turns from superhydrophilic to the permanent superhydrophobic state (150°) that naturally results in increased droplet evaporation time and in a reduction of the Leidenfrost temperature of about 20-30°C.

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PS2-01 Organic nanoparticles synthesis with pulsed laser ablation of nonlinear molecular crystals

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Organic nanomaterials could provide solutions to challenges in optics, photonics and technology at large, because of their unique properties and perspective applications. There are several methods of organic nanoparticle fabrication. Chemical synthesis is a key approach to nanoparticle synthesis, but this method has the main disadvantage of its toxicity and the need to control the chemical reaction which most of the time is not feasible. Pulsed laser ablation in liquid is a physical method of nanoparticles synthesis. It is the instantaneous evaporation of target and the condensation of its steam with the formation of nanoparticles. Since in this case there is no need for chemical reactions, this method is more widely used, as the obtained nanoparticles are not contaminated during the process, the sizes of the nanoparticles can be controlled, and the process is potentially clean and economical.

This paper discusses in detail about pulsed laser ablation of a molecular co-crystal DAST (trans-4′-(dimethylamino)-N-methyl-4-(stilbazolium tosylate)) in different liquids, namely dodecane, monomer solution isodecyl acrylate and highly viscous liquid - polyphenylene oxide. Nd:YAG laser was used as a source of radiation with a pulse repetition frequency of 3.8 kHz, pulse energy is 5.5 mJ, a pulse duration of 10 ns, wavelength 355 nm, and power density of 170 kW/cm2. Irradiation was carried out for two hours – until there was a visible coloration of the liquid.

The products of laser ablation were analyzed using UV and visible spectroscopy, optical and scanning electron microscopy. It was found experimentally, that DAST nanoparticles could be synthesized in monomer solution.

Acknowledgements, The reported study was funded by RFBR according to the research project No. 16-32-00448.

PS2-02 UV alteration of photoluminescent properties by creation of CdS and Au nanoparticles in polymeric matrices

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UV irradiation of materials consisting of a polymer matrix that possesses precursors of different kinds can result in creation of nanoparticles within the irradiated domains. Such photoinduced nanocomposites are promising for photonics applications due to the strong alteration of their optical properties compared to initial nonirradiated materials. We report our results on the synthesis and investigation of plasmonic, excitonic and exciton-plasmonic photo-induced nanocomposites. Plasmonic nanocomposites contain metal nanoparticles of noble metals with a pronounced plasmon resonance. Excitonic nanocomposites possess semiconductor nanoclusters (quantum dots). We consider the CdS –Au pair because the luminescent band of CdS nanoparticles enters the plasmon resonance band of gold nanoparticles. The obtaining of such particles within the same composite materials is promising for the creation of media with exciton-plasmon resonance. We demonstrate that it is possible to choose appropriate precursor species to obtain the initially transparent

polymethylmethacrylate films containing both types of these molecules either separately or together. Proper irradiation of these materials by a light emitting diode operating at the wavelength of 365nm provides material alteration demonstrating light induced optical absorption and photoluminescence properties typical for the corresponding nanoparticles. Thus, an exciton-plasmonic photoinduced nanocomposite is obtained. It is important that here we use the precursors that are different from those usually employed. Our studies also show that the process of the material modification is complicated and cannot be reduced either to pure photochemical or to pure photothermal effects. Due to the relatively low efficiency of luminescence, we plan to improve the materials involved and irradiation regimes. Besides, the spatial distribution of the plasmonic and excitonic nanoparticles should be correlated with each other for best result. For instance, for spaser-like structures one should have the plasmonic particles closely surrounded by the excitonic ones.
The authors thank Russian Scientific Foundation (Grant No. 14-19-01702) for financial support.

PS2-03 Colloidal particle lens array assisted high density surface nanostructuring using fundamental frequency and second harmonic of a Ti:sapphire femtosecond laser

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We consider laser nanostructuring of the material surface by means of a colloidal particle lens array. Here, the monolayer of dielectric microspheres placed on the surface acts as an array of near-field lenses that focus the laser radiation into the multitude of distinct spots, allowing the formation of many structures in a single stage. By combining the fundamental frequency (FF) and the second harmonic (SH), one benefits both from the power of the former and from the focusing ability of the latter. This combination provides an efficient nanostructuring with sphere diameter close to the wavelength of the SH. The possibility to create arrays of nanostructures with surface density above half a billion per square centimeter with femtosecond Ti:sapphire laser operating at 800 nm was demonstrated by employing 450 nm spheres. The layer of polystyrene spheres deposited on a dielectric substrate focuses the radiation of the SH and does not focus the radiation of the FF. The SH provides the seed structure formation, while the FF radiation provides an energetic effect. We experimentally show that converting several percent of the energy of the FF pulse into the SH offers an opportunity to obtain structures on the surface by means of the spheres with diameter close to the wavelength of the second harmonic. It is not possible to obtain such structures by means of only the FF radiation. At the same time, the formation of structures by means of only the SH requires a significantly higher energy density than the energy density of the SH within the bichromatic pulse. Thus, the use of two-color pulses permits a significant increase in the structure recording density compared to the opportunity provided by the initial FF beam.

The authors thank Russian Foundation for Basic Researches (Grant No. 16-02-00792 A) for financial support.

PS2-04 Controlled growth of oxide films on titanium surface heated by femtosecond laser pulses.

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Oxidation of solid metals, especially titanium, by nanosecond laser pulses is widely studied regarding diverse potential applications [1, 2]. Laser exposure produces a metal oxide film, which significantly changes optical [3] and physical [4] characteristics of the metal surface. Oxide layer is reported to protect surface of titanium implants from hydrogen embrittlement [5]. The similar effect takes place during microstructuring of Ti surfaces by ultrashort laser pulses. Therefore, the research of titanium oxidation by laser pulses of femtosecond duration is important. Such action will allow a strong localization of the oxide layer including its thickness. One can manage the thickness and the composition of forming layer by varying the fluence and the number of pulses.

Chemical EDX analysis at variable electron energies was performed for titanium samples obtained for different fluences and number of focused 800-nm, 200-fs Ti:Sa pulses. The distribution profiles of elements were measured for different treatment regimes. The oxygen content rapidly rises with the increase of a number of pulses. For the low number of pulses, oxygen content doubles from the initial level in the region of treatment. The high number of pulses results in the formation of the crater, but in the regions below an ablation threshold, oxygen content sharply increases. The fact testifies to film growth in the region. At the same time for a high number of pulses, it is possible to find a connection between the oxygen content and the fluence distribution.

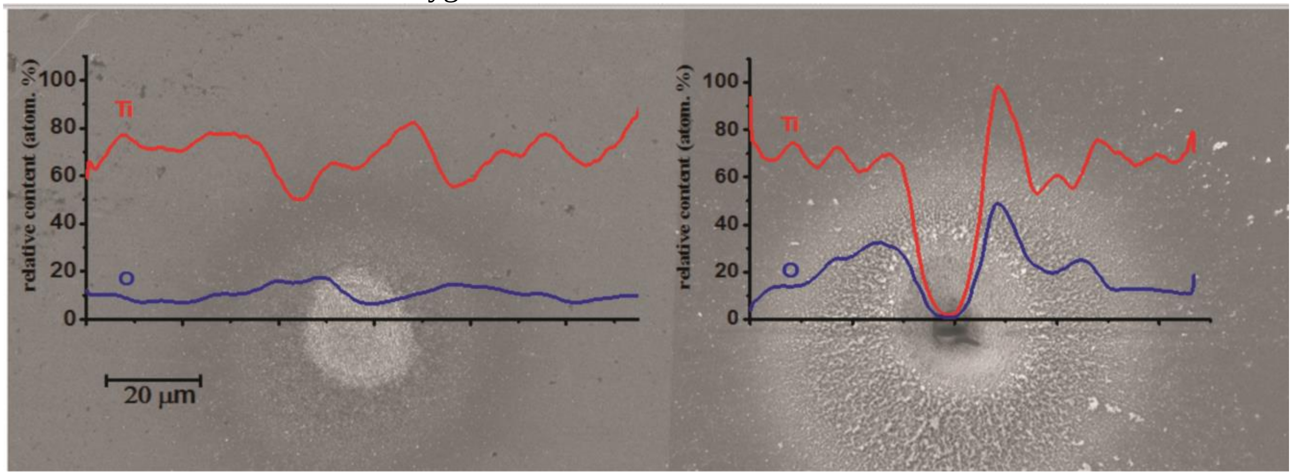

Fig. 1. Oxygen and titanium distribution profiles at 5 keV accelerating voltage for different number of pulses N: 100 (left) and 3000 (right). (F0 ≈ 1.7 J/cm2 in the air)

The thickness of oxide layers depending on laser fluences and the number of pulses were determined and compared to results, based on calculation of dynamic thermal fields and oxidation kinetics.

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PS2-05 Pulsed laser ablation of titanium in liquid media: Influence of pulse repetition rate on nanoparticles synthesis

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Laser ablation of a solid target material in a liquid is a quick, easy and green method for nanoparticles synthesis. Most importantly, it provides with the opportunity to synthesize NPs in a surfactant free environment and thus obtain NPs with impurity free surfaces.

NPs of the titanium dioxide are important nanomaterial for a large number of applications in environmental engineering usually for the photocatalytic degradation of water pollutants, paints industry, electrically conductive fillers, biomedicine and fabrication of organic solar cells.

In this work we report the synthesis of titanium dioxide nanoparticles by pulsed laser ablation of a bulk titanium metal target in deionized water. Fiber Yb-laser radiation source with a wavelength 1,06 μm, 1 mJ pulse energy and tunable parameters of repetition rate, laser power and scanning speed was used for the ablation.

Morphological observations by means of electron microscopy, demonstrating the spherical shape of the synthesized NPs, was utilized to investigate the variation of particle size distribution with the laser pulse repetition rate. The results indicate that the increasing of laser ablation's pulse rate promotes reduction of NPs minimal size and narrowing of nanoparticles size distribution. Average grain diameter ranges from 37 nm at 1.6 kHz to 17 nm at 100 kHz. But its also reduce the mass yield of NPs due to defocusing of laser beam on cavitation bubbles.

Raman spectroscopy shown that the anatase/rutile crystalline phase ratio of synthesized NPs vary with pulse repetition rate as well. Anatse fraction decreases with rising of laser pulse rate.

It is also worth noting that increasing of laser power density leads to synthesis instability and NPs aggregation.

PS2-06 Laser-induced plasma investigations during femtosecond laser micromachining process of the materials immersed in water

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In this report we present results on the application of the laser-induced breakdown spectroscopy (LIBS) in monitoring of the micromachining of different materials immersed in water with femtosecond high repetition rate pulses. By applying a thin (<1 mm) water layer on the top of the machined samples and focusing powerful (energy >50 □J) femtosecond pulses through a low NA objective, self-focusing and nonlinear absorption phenomena transform the beam to a filament which enables more efficient ablation compared to the conventional focusing in air. It results in superior micromachining quality and throughput due to additional spatial shaping of femtosecond pulses, cooling and cleaning properties of the covering fluid [1]. This method was successfully applied for fabrication of complex objects from transparent, semiconductor and metallic samples. The experiments were carried out using the Yb:KGW laser system with pulse duration 300 fs and power up to 20 W at 1026 nm wavelength, galvanometric scanner and f- theta lens (f = 100 mm). The emission from ablated materials was collected through f- theta lens, scanner and taken away at dielectric mirror used for direction of the laser radiation. One of the investigated samples was soda-lime glass. The strongest emission line (Na I at 589 nm) in the spectrum of analyzed soda-lime glass was monitored in dependence on the number of scans for different scanning speeds. Figure 1 (a) shows that LIBS signals decay faster and have no secondary increase of intensity using the scanning algorithm when spacing between the processed grooves was 600 μm. Figure (b) represents spectra that were taken using the algorithm when spacing between the grooves was 200 μm. Narrower spacing between the processed grooves does not provide sufficient irrigation of processed zone, so intensity increases after several numbers of scans and decays at a slower rate than using wider spacing between the grooves. This effect is more conspicuous at higher scanning speeds. LIBS signal was estimated during the laser processing using various scanning algorithms, pulse repetition rates, pulse energies and its relation to the processing speed was established.

PS2-07 Spectral interrogation system of fiber bragg gratings using a tunable narrowband source

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The fiber optic sensors based on the fiber Bragg gratings (FBGs) are dynamically developing in the last few years. They are widely used in various types of measurements such as strain, vibration, acoustic wave, acceleration, pressure, temperature, humidity and various physical magnitudes. The FBG sensors are applied in the industries of petro-chemistry and oil production, medicine, construction, energetics, engineering, and others. These sensors present some advantages – compactness, low weight, insensitivity to electromagnetic fields, possibility of putting a large number of sensor components into a single optical fiber and a complete protection against explosion and fire. Structural variations of the fiber optic sensors offer great opportunities for the development of the instruments operating under extreme environmental conditions. The fiber optic sensor systems usually comprise two units – the sensoric one and other one for the signal processing. The main disadvantages of the signal processing units are its bulkiness and heavy weight. It also usually requires accurate calibration and strict operation temperature conditions. Hereby we are presenting the research results directed on a new method creation as concerns the FBG sensor parameters checking. The method is based on the features of the 1550 nm vertical cavity surface emitting laser (VCSEL).

PS2-08 Automated femtosecond laser workstation for high-speed fabrication of reticles and microchannels

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Ultrashort high intensity laser pulses can provide micro machining of glass and other brittle materials with high reproducibility, minimal heat affected zone (HAZ) and thus minor edge chipping, microcracks, etc. Despite these advantages, the use of workstations based on femtosecond lasers in industry is still limited, due to both their high cost and the following technological factors:

- 1. for high precision micro machining of workpieces in area of more than 100×100 mm^2 with high productivity (scanning speed higher than 1 m / s) the use of combination of mechanical components and high-speed galvanometric scanners is required, and respectively, the development of special control algorithms is needed;

- 2. the topography of surface being machined is usually substantially larger than the depth of focus (~5 μm), which requires the automated focusing of the laser radiation and dynamic estimation of maximum area to be machined without refocusing;

- 3. the high-quality production of large series of workpieces requires the development of embedded automated inspection system;

- 4. to achieve high quality at productivity the development and implementation of methods for determining of optimal regimes of laser micromachining is required;

Taking into account these factors, we developed the workstation for high-speed femtosecond laser micromachining. The basis of this complex is laser micromachining system (Yb:KGW, λ=1026 nm, 535 nm or 332 nm), laser beam is focused to 5 μm spot in 6×6 mm^2 area by means of short range distance sensor (50 nm resolution) and moved by galvanometric scanners and motorized x-y-z positioning stage in 200×200 mm^2 field. The methods were proposed for precise positioning and correction of dynamic errors of the system. To perform automated inspection the optical profilometer based on confocal chromatic sensors was developed. The technique was proposed based on design of experiments and developed inspection methods to optimize the technological parameters.

PS2-09 Creation of field emission cathodes by micro-sized laser cutting

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One of the promising areas of modern electronics is the creation of a vacuum nonincandescent electron sources for devices with nanosecond time availability, resistance to temperature and radiation. The creation of such devices is possible to be based on the use of field-emission cathodes instead of traditional cathode operating on the principle of thermionic emission.

The development of field-emission cathodes is carried out by many scientific centers of the world, including Russia. The main direction of development is the selection of the material, and an appropriate method of its processing to produce periodic microstructure which provides the most dense and strong flow of electrons in the device without or with negligible heating of the cathode.

Glass-phase materials, such as glass-carbon, ceramics etc., are a wide class of substances applied in electronic industry. These materials often need special technologies for their processing. Unlike traditional methods of micromachining, focused ultrafast laser pulses of sufficiently high fluence makes it possible not only to avoid the majority of side effects, including temperature, but also to create a qualitatively new laser technology for "hard materials".

The report describes the method for producing the spike-shaped structure surface of the glassy carbon with a high ratio of the height to the radius of top tip curvature by means of laser technology. Structures of this type have prospects of application in vacuum microwave electronics of terahertz range.

PS2-10 Accurate measurement of spectral properties of Bragg structures using a tunable laser

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The properties of the spectral filter of Edmund Optics are available in the range 400-700 nm were accurately measured. The filter has geometric dimensions 60×12 mm. The filter has 60 separate zones, each with a narrow function bandwidth of about 10 nm, therefore the geometric width of the zone with function bandwidth is 1 mm. The NT242 tunable laser was used for measurement. The NT242 tunable laser allows you to change wavelengths with a step of 1 nm. This allows you to measure the bandwidth function of the filter with very high accuracy. It is shown that the bandwidth function of the filter is far from the ideal form which shows the manufacturer. The deviation of the real bandwidth functions from the manufacturer can be 15%. It is shown that the filter cannot be used when it is not perpendicular to the light propagation. So with the angle of propagation over 10 degree change in the bandwidth is especially strong, because in this case, shifts of the bandwidth function in the spectral band.

PS2-11 Comparison of low and high pulse energy regimes of femtosecond waveguide writing in Nd:phosphate glass

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In the investigation we compared experimentally and numerically both regimes of femtosecond waveguide writing: low and high pulse energy mode, - with ultrashort pulses oscillator and laser with amplifier accordingly. We developed two corresponding geometries of waveguides, providing fine mode matching with conventional active fibers for the purposes of laser amplifier development in Nd:phosphate glass. We have separated the fields of application for both regimes of writing. To broaden the scope of high pulse energy one, we have developed novel 2-lens turning focusing system for inscription of depressed cladding waveguides. The system allows to control self-focusing effect and adjust the geometry of induced waveguides in the broad range of parameters, preventing dramatic optical breakdown. The prospects of industrial application of 2-lens turning focusing system were discussed on the base of experimental results. Based on the obtained results there was made a comparison of both geometries. It was shown that with the help of the developed 2-lens system writing at high pulse energy could show mode field diameter. It was showed that high pulse energy inscription process provides relatively low induced refractive index (-2·10-3) in large area (190 μm^2) of treated material, while low pulse energy process provides relatively high induced refractive index (-6·10-3) in small area (90 μm^2). Due to anisotropy of high energy written waveguide, it supports propagation only of horizontal polarization, while the low energy written one supports propagation of both polarizations with near circular mode field. Slight ellipticity of the main mode in the first structure results in relatively low power coupling with conventional single mode fibers (<80%), while design of the second structure provides power coupling better than 92%.

This work was partially supported by Foundation for Assistance to Small Innovative Enterprises in Science and Technology (4806ГУ1/2014 №0008340, 23.12.2014).

PS2-12 Comparison of core- and cladding-written waveguide`s parameters inscribed with femtosecond laser pulses

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Direct writing with femtosecond laser has become an advanced, maskless and widespread technology for waveguides inscription inside optical materials. Glasses and crystals could be divisible into three groups based on sign of permanently induced refractive index, where it: 1) increases under femtosecond emission, 2) decreases, and 3) “transitional” materials like fused silica, where refractive index could increases or decreases under different experimental conditions. In 3rd group of materials could be written both core- and cladding-written waveguides with comparable numerical aperture, but significantly different mode and scattering losses. In the investigation we compared advantages and disadvantages of both types of femtosecond written waveguides and separated their fields of application. Actuality of the work arises from wide use of “transitional” materials in photonics and necessity to resolve experimental trade-offs. In the paper we compared typical mode fields, radiation, scattering and back-scattering losses, which it`s proposed, for what is believed to be the first time. The comparison was made based on analytical methods and numerical modelling of inscribed waveguides with perturbations and periodic modulation of parameters that usually observed in experiments. We examined perturbations of induced refractive index and geometry of waveguide`s cladding to estimate its influence over total losses. It was shown, that distinct from widespread core-written method, inscription of cladding shows higher coupling efficiency (by 15-20%), lower scattering losses (by >14 dB) and prove oneself significantly more stable to perturbations of experimental conditions (by an order of magnitude) due to efficient averaging over number of tracks, forming the cladding. Results, obtained in the investigation open a new avenue in design and formation of optical waveguides with low scattering losses.

This work was partially supported by Foundation for Assistance to Small Innovative Enterprises in Science and Technology (4806ГУ1/2014 №0008340, 23.12.2014).

PS2-13 Nonmonotonic dependence of femtosecond writing parameters in 3D-waveguide formation process within significantly broad depths range

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Direct femtosecond laser inscription has become advanced and widespread maskless technology for waveguides writing inside active laser glasses and crystals. One of the advantages of the technology consists in combination of both: high efficiency of integral optics and perfect thermal and spectral characteristics of bulk optical elements. Until recently, the technology was applied only for writing of quasi-planar waveguides in depths range narrower than 100 um. Consequently, such waveguide elements were used only in integral laser schemes. In this paper we proposed, for what is believed to be the first time, femtosecond inscription of waveguides within significantly broad depth range (more than 550 um). Proposed result broadens field of application of femtosecond writing technology into 3D-waveguides formation and hybrid integral-bulk laser schemes that create an opportunity to develop novel optical elements.

Laser induced tracks with controlled refractive index were written with aspherical lens (NA=0.6) at all the depths within range between 550 um and 1100 um under the surface of the sample. Continuous writing process at significantly different depths was based on dynamic adjustment of femtosecond pulses energy to compensate negative effect of spherical aberration. In the investigation we thoroughly examined dependences of writing energy range and geometry of induced refractive index tracks on writing depth in record wide range. Experiments were carried out in Nd:phosphate glass and compared with numerical simulation. It was shown, that dependence on depth of working range is nonlinear, nonmonotonic (with pronounced minimum) and significantly differs for positive and negative shift from optimal depth of the lens.

Novelty of the results consists in advanced technique of 3D-waveguides writing that significantly broadens working depths range and opens a new avenue in integrated photonic devices, creating an opportunity to develop novel laser elements architectures.

PS2-14 Optical monitoring and control of the laser technological processes

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Now the elaboration of monitoring and control systems integrated with laser technological systems for control of technological processes in real time are in progress. Precision control of the main physical parameters of these processes – maximum surface temperature, temperature distribution in the processing area, size of the melt and control their evolution are necessary.

The system was developed for monitoring of temperature distribution in laser irradiation zone based on registration using a high speed digital CCD – camera and maximum temperature

measurements in laser spot by pyrometer. Using a calibrated pyrometer and camera allows to fully control the process of melting. Also the principles of measuring the surface temperature in the focal spot of the laser radiation while scanning the surface using galvanoscanner with F-teta lens have been designed.

Developed multi-wavelength pyrometers allow by measuring the brightness parameters of surface with high spatial (50 μm) and time (50 ms) resolution at 3-4 wavelengths to calculate the thermodynamic temperature using software in real-time.

For precise control of dimensions and quality of the 3D – object in the process of selective laser melting the new method and apparatus have been elaborated. After sintering of each layer of the 3D object, when applying the next layer of powder, the image of the sintered layer is registered by scanner with a resolution of up to several microns. The image is compared with the program-specified section and the exposure parameters (laser power, speed and the laser spot scanning software) are adjusted before sintering the following layer.

The results of the application of the developed methods and apparatus are presented.

PS2-15 Selective laser sintering in ceramic turbine components production

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Ceramics are considered as the most promising materials for long- term mechanical loading at high temperatures. They, however, have a number of disadvantages: low stability against cracks and insufficient bending strength. The other problem is the difficulty to manufacture components of complex geometry.

A solution to the above problems is development of a new type of ceramic material and application of the laser selective sintering. New nanostructured ceramic powders based on SiC-Si- Al2O3 system were created by procedure of their manufacturing process includes mechano-activating ball milling using planetary mills, vacuum calcination, disintegration, and mesh classification.. The fraction with the average particle size 10 μ was used in selective laser sintering which was done using a modified SLM machine. It was found by SEM and X-ray tomography that the calcination mechanism in this material is the formation of bridges between agglomerates comprises 30-50 nm layers. The ceramic material is compact enough for the requirements of a construction material. As a result of research a micro turbomachines elements have been produced by selective laser sintering and tested: ceramic parts for high-temperature non-cooled tunneling turbine engine (Ti = 1623 K = 1350° C), ceramic combustion chamber with uncooled flue pipes and cleaner burning of fuel in the counter-offset swirling jets for multimodular gas turbine engines. The ceramic micro gas turbine with power 2 kW, rotor speed of 230.000 1/min was produced. For sintering ceramic parts for up to 1.5 MW turbomachine a advanced selective laser sintering system based on some patents is designed and now is manufactured. Several sources of concentrated energy flows are used in the sintering technology implemented on the machine. Optical system should be used for sintering turbomachine parts quality control. Investigations of optical characteristics of the powder layers have been elaborated for optimization of sintering process.

PS2-16 Collective generation in laser diode array of single mode emitters

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High power diode lasers are widely used in today technologies due to high efficiency, compactness and extremely long lifetime, meanwhile, achieving of single mode emitting in such systems remains to be a challenge. We report phase locking in an array of twenty five gain-guided laser diodes placed in an external cavity formed by the waveguide grating mirror (WGM) [1]. This mirror introduces an inter-diode coupling resulting in emitting of single collective mode (supermode) due to high angular reflection selectivity for incident radiation. WGM angular alignment allows to select any of the supermodes permitted in the system.

In experiments, we use an array of twenty five gain-guided diode lasers with a pitch of p=8 μm and the diode width of 4 μm. The most effective collective generation was obtained in a kind of single mode output, called out-of-phase mode. Spatial distribution of that is featured by two main lobes separated by an angle $\alpha = \lambda / p$ with respect to the axis of diode emitters in the array. One of the radiation peaks is returned by WGM back to the resonator with efficiency close to 100% while the second one contributes to the laser output, as far as WGM is transparent for it. WGM is also featured by high spectral selectivity, which provides narrow band generation centered at 930,8 nm with the spectral width of ~0.1 nm. The CW output at the level of nearly one Watt was achieved in this case. Quality of the output beam was close to the diffraction limit with M2 parameter of 1.2 both, in parallel and orthogonal directions with respect to p/n junction plane. This value for p-n junction plane appears to be very close to the theoretical limit for one lobe radiation which can be achieved in the laser array emitting in the out-of-phase laser mode. The experimental data presented are compared to the results of collective mode simulations.

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PS2-17 Comparison of TLIPPS formation on surfaces of different metals

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Laser-induced periodic surface structures (LIPSS) are formed on surfaces of metals, dielectrics and semiconductors with period close to the laser wavelength and orientation perpendicular to the direction of the electric field. The formation of thermochemical laser-induced periodic surface structures (TLIPSS) featured by high-ordering in contrast to the ablative structures has been recently demonstrated. The topology of surface relief is also different in comparison with that for ablative TLIPSS. It consists of oxide periodic structures with height in the range of 50-150 nm, which are orientated parallel to the direction of the electric field.

In this work the experimental results on comparison of TLIPPS formation on surfaces of different metals (Ni, Cr, Ti, NiCr) are presented. These metals and alloy were chosen because of different values of oxygen diffusion coefficients and other physical parameters. In the experiments, femtosecond laser PHAROS 6W with central wavelength of 1026 nm and pulse duration of about 230 fs was used. The laser repetition rate was 200 kHz. The focal spot size was varied in the range 4 - 20 µm, the radiation power range was 1.5 - 25 mW, and the scanning speed range was 1 - 5 µm/s. Thin metal films were deposited by a magnetron sputtering technique onto a glass substrate.

It was found that the power range for TLIPPS formation is relatively narrow amounting to about 10% for Ti and Cr. The period of presented structures equals to 920±35 nm for Ti and 876±17 nm for Cr. As we found, the TLIPSS are not formed on Ni surface. Possible reason is much less oxygen diffusion coefficient of Ni in comparison with Cr and Ti.

In the research we used equipment of multiple-access center “High-resolution spectroscopy of gases and condensed matters” at IA&E SBRAS. This work is supported by Russian Foundation for Basic Research (grant 16-32-60096).

PS2-18 Preparation of hybrid WSe_2-containing nanocatalysts of hydrogen evolution using pulsed laser deposition

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Pulsed laser deposition (PLD) was used to obtain some hybrid (WSe_2/WO_3 and WSe_2/carbon) nanostructured films. At present, hybrid nanostructured materials have been shown to be promising nonprecious metal electrocatalysts for the hydrogen evolution reaction (HER). For preparation of WSe_2/WO_3 film, the PLD from WSe_2 target in a mixture of Ar and oxygen gases was used for pre-deposition of W-Se-O layers. The variation of gas pressure and its composition allowed to form amorphous layer with nano-granulated morphology. Thermal post-treatment caused the formation of flower-like morphology and the films consisted of ultra-thin sheets. Dimensions of the sheets did not exceed 200 nm, and the thicknesses of the sheets were several nanometers. Micro-Raman studies have shown that the nanosheets of pure WSe_2 and WO_3 phases were grown. The nanosheets were oriented perpendicularly to the surface of the graphite microcrystals (substrate material). Largely exposed catalytically active sites on the edges of sheets and good conductivity of ultra-thin sheets make the hybrid WSe_2/WO_3 films exhibit superior catalytic performance. For preparation of WSe2/carbon films, the pulsed laser co-deposition from WSe_2 and carbon (graphite, glazy carbon) targets was realized in varied conditions. The influence of PLD conditions (e.g., laser fluence, buffer gas pressure, and substrate temperature) on the C, W, and Se atoms bonding and phase separation was studied. To initiate the separated growth of WSe_2 and carbon-based phases, the layer-by-layer deposition of WSe_x and graphite-like films with appropriate thickness at elevated temperatures was proposed. The nanostructured films that composed of the WSe_2 nanoparticles dispersed in graphite-like matrix layer were prepared. Nano-sized WSe_2 inclusions having high surface density of catalytically active sites were combined with the conductive and loose carbon phase that resulted in an enhanced rate of HER in $0.5H_2SO_4$ acid solution.

PS2-19 Thresholds for two-photon recording of fluorescent centers in chromone-doped polymer films

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Organic molecules of chromons embedded in polymer films are promising media for optical data recording based on multiphoton absorption [1,2]. These compounds can be irreversibly converted from non-fluorescent form A to stable fluorescent photoproduct C. An absorption spectrum of photoproduct shows additional excitation band in the visible range above 400 nm, which was not observed in state A. Thus, an optical excitation in the spectral range between 400 and 500 nm leads to stable fluorescence photoproduct C. Some advantages of two-photon recording of the fluorescent voxels in chromons doped films were demonstrated in [2].

This work focuses on study of multiphoton absorption in different chromons class compounds. We measured pulse energy densities required for two-photon recording of luminescent marks by laser pulses in wide range of the pulse durations from 80fs to few nanoseconds at writing wavelengths λw = 530-640 nm. It was noticed that for the pulses as short as 80 fs the measured energy density threshold increases in times in compare with picosecond range at the same wavelength (532 nm). For used sample of KSR15 compound the measured threshold value exceeded 500 mJ/cm^2 . in compare with 220 mJ/cm^2 for 200 ps pulses even at lower intensities. For the femtosecond pulses the peak intensity was rather high (of 5 GW/cm^2). The extreme increasing recording fluxes for the short femtosecond pulses indicates that the mechanism proceeds via a sequential two-step excitation in which the leading edge of the laser pulse prepares molecules in the S1 state and the trailing edge of the same pulse re-excites those molecules to a higher-lying excited state. Comparison to similar experiments on photochromic diarylethene molecules gives an evidence for existence of barriers in the potential energy surface of the first excited state [3]. The time required for overoming of those barriers is of a few picoseconds. Actually the lifetime of S1 dictate the optimal duration of the recording pulse.

One can conclude that threshold optical fluxes required for recording of fluorescent marks within chromone-doped polymer films and optical destruction of the materials in wide temporal and spectral range are compared. The most promising compounds and writing pulses parameters ranges were selected for the subsequent investigations.

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PS2-20 Subjoule diode-pumped slab erbium glass laser with cavity dumping

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Lasers of eye-safe wavelength range (1.4–1.8 μm) are successfully used in range-finding, data transmission lines, technologies and medicine. In a large number of technological and medical applications laser pulses with energies of tens and hundreds of millijoules are required. In some cases optical fiber delivery of the high energy pulses to processing objects is extremely desirable.

We present the results of experimental study of fiber coupled powerful diode pumped Yb,Er:glass slab laser operating in Q-switch or cavity dumping mode in the meaning of active losses modulation. The mode was provided by shutter based on frustrated total internal reflection (FTIR-shutter). An active element Yb,Er:glass 1.7×12×42 mm made of heat-strengthened phosphate glass was pumped through sides 12×42 mm using two 8-bars laser diode assemblies (QD-Q5608BSS, Quantel Laser) operating in QCW mode. A pumping peak power was up to 1.2 kW in pump pulses with duration up to 4 ms and duty cycle 0.08. The laser cavity was formed by three high reflective mirrors. The outcoupling was carried out through the facet of the developed FTIR-shutter. Polarization-insensitive FTIR-shutters are the most suitable for Q-switching with low-gain laser active elements especially for the case when thermally induced depolarization in the active element is significant. The shutter was controlled by two-cascade driver and worked in the stretching-collapse mode. Optical to optical efficiency in the cavity dumping mode was nearly 1.5 times higher in compare with usual Q-switch mode. It reached 2.4 % for single microsecond structured monopulses lasing with pulse energy over 100 mJ. In the mode of regular pulse trains generation by several FTIR-shutter switching on one pump pulse (burst mode) it was possible to obtain trains with a total energy up to 0.5 J with higher efficiency.

The pulse spacing in the train is chosen on the basis of the application task in the range of 0.1–1 ms. The output radiation was compressed along fast axis by the prismatic telescope for the coupling into low OH optical fiber with a core diameter of 400 μm. The coupling efficiency was of 86 % at average output power up to 7.5 W.

The report also presents the results of the developed laser utilizing in some applications like cataract lens fragmentation, microdrilling of skin, mucosa and bone tissue for the purpose of their regeneration or for a drug delivery.

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PS2-21 Control on output characteristics of laser radiation by change a gain profile in laser medium

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To provide high productivity in a range of technological operations a high average power together with the maximum peak power are often required simultaneously. A promising approach to get such a regime is a use of a microchip or short cavity miniature diode pumped solid state laser (DPSSL) with a subsequent multipass multistage amplification of laser radiation. The whole laser system becomes rather complex and expensive. Neither DPSSL with a side pumping nor fiber lasers can provide mJ pulses with duration less than 30 ns and repetition rate about 10 kHz without additional time compression schemes and amplifier stages.

A simple method is considered here for the control output spatial and temporal characteristics of a Q-switched solid state laser using a hybrid end-side (or, in more exact words, «axial-side») laser diode pumping.

As a basic component we used a standard technological side pumped laser module CEO RB30-2C2 (9x20 W CW laser diode arrays), with 0.65 at.% Nd:YAG laser rod Ø3x60 mm. The laser head together with an active Q-switch was placed inside a plane-concave resonator of 155 mm length. A focused pump radiation from an additional fiber coupled 50W CW laser diode module MU55-808-02 (SvetWheel) was paraxially injected into the laser rod through a dichroic high-reflective cavity mirror. The focused pump beam waist was of 360 mm that was even less than calculated TEM00 mode diameter unlike schematic proposed in [1]. By this means a small volume with extra gain was formed in a paraxial zone of the active rod. The buildup of lasing in Q-switch mode starts namely within this area, providing generation of the pulse with duration much shorter that it would be under side pumping only. Further, the pulse radiation expands from the paraxial zone to the whole cross section of laser medium suppressing an independent lasing at higher order modes of its peripheral zones.

The emission spectrum of the auxiliary laser diode module was controlled by the temperature change. It caused changing an effective absorption coefficient of the pump radiation in the laser medium. Together with an axial moving of the focusing area inside laser rod, this gave a possibility to change the parameters of the laser resonator within its diagram of stability caused by the corresponding changing the optical power of the combined thermally induced lens in the laser rod. To define an optimal resonator configuration the numerical simulation of space and energy characteristics of laser radiation in a wide range of hybrid pumping power was carried out. It was shown that the laser generation power increases significantly together with a maintenance of close to single-mode beam quality by means of resonator conversion into an unstable region. Thus, laser MOPA configuration was realized using a single laser rod. With this approach, we were able choose an optimal regime of lasing by the criteria of high average power combined with good beam quality and the shortest nanosecond pulse length.

In summary, we obtained in compact single rod Nd:YAG laser near-TEM00 laser pulses with energy up to 3 mJ, pulse duration of 20 ns at repetition rate of 8 kHz owing to use the combined hybrid axial-side pumping. This laser device is planned to be used as a master oscillator of laser system for getting an EUV radiation [2].

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PS2-22 The strength solder joint is increased as a result optimization and harmonization parameters laser soldering

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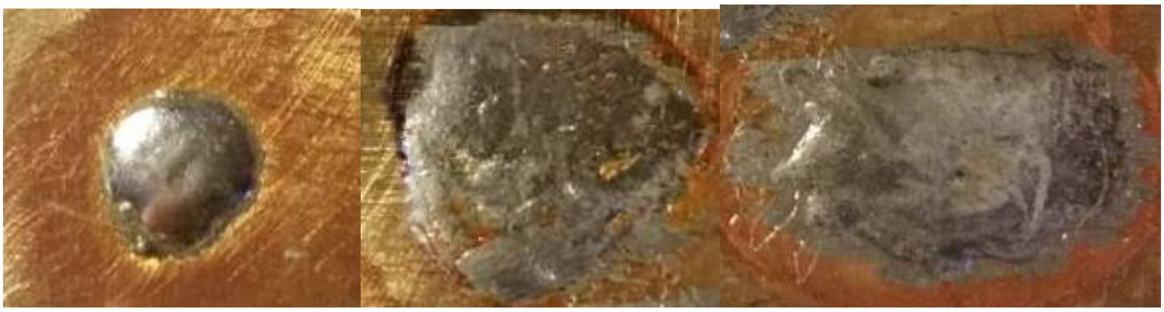
Increasing strength and reliability of solder joints (SJ) is an urgent task in the production of electronic equipment at the present time. Laser source provides a perfect result, which is forming of the adhesion-type compounds when mass transfer processes in the interphase boundaries are limited.

Most important objectives are being to research factors affecting on the formation high-quality and high the strength SJ, improvement technology and experimental modes laser soldering.

We will need to study several tasks: to harmonize parameter of the spectral absorption laser radiation by solder; to determinate the range necessary power density; short-time wetting is required selection solder pastes with high fluxing activity; to use dosage's mode of the solder paste (SP), which there are solder fillets, but there isn't "skeletal soldering" in printed-circuit board. The criterion for optimization all the parameters it will be get maximum strength rupture test formed of the SJ.

The first stage experimental investigation has been test three kinds of the SP. We have done the experiment (picture 1) for defining spreadability's factor [1] of the SP on the surface copper plate. Optimal result have been attain on the SP № 3. It's on the basis phosphoric acid.

In the second stage have been try dosing selected paste. We have picked up a diameter dispensering needle, and pressure compressed air, through which has dosed the SP. The speed of moving boards on a laser complex has chosen as 10 mm/s, which has corresponded to time the laser soldering approximately 0.3-0.5 s for planar leads at the diameter laser spot size about 2.5 mm and printed-circuit board has been width 0.625 mm.



Picture1. Defining spreadability's factor.

Measurement tensile the strength SJ has performed on a tensile testing machine. It has registered the maximum strength in the range of 15-17N one solder connection that in 3 times exceeds the results manual soldering by soldering iron.

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PS2-23 Optimization of nonlinear crystal position inside laser resonator at intracavity second harmonic generation with account of multilayer dielectric coatings dispersion

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As well known second harmonic generation (SHG) efficiency critically depends on value of so called common phase [1, 2]. At single-pass SHG when there are no SH wave at nonlinear crystal entrance common phase automatically keeps its optimal value $\pi/2$ at which SHG efficiency reach maxima. In situations when input SH wave is present (SHG in multi-crystal systems or double-pass SHG) common phase differs from optimal value which causes new effects appearance. For example maxima of SHG efficiency may shift out of phase match condition. However it is easy to show that these new side maxima provide lower SHG efficiency than efficiency at optimal common phase [2]. That is why it is so important to provide optimal relation for phases of laser wave and its SH wave at each crystal entrance.

At intracavity double-pass SHG after the first pass of nonlinear crystal radiation meet anti-reflective coatings, high-reflective coating and air gap. Each coating produces its own common phase shift which should be accounted to balance common phase at the second pass of nonlinear crystal.

Dispersion of air in normal conditions provides common phase shift π/2 at ≈130mm of air layer thickness [3, 4]. So a way dispersion of air gap may be used for compensation of common phase shift associated with optical coatings. Such compensation will take place at optimal distance between nonlinear crystal and rear mirror.

In this paper we estimate incomes of different multilayer coatings in total common phase shift. We classified different dielectric double-wave (e.g. 1064nm+532nm) high reflective mirrors based on value of its common phase shift. Experimentally we found optimal distances for few double-wave mirrors from popular optical catalogues.

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PS2-24 Change of biocompability due to laser modification and oxidation of titanium surface

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In modern medicine the titanium is widely used as good material for orthopedic and dental implants due to its nature properties: biostability, biocompatibility, mechanical performance and long-term durability [1, 2]. One of the most important aspect of titanium implants is surface micro- and nanorelief. Different types of relief like nanopores and nanoprotrusions, periodic grooved patterns, microroughness and also smooth surface can be effective [3]. Different methods allow to change the surface relief such as grit blasting [4], chemical etching, electrochemical [5] and laser treatment [3]. The last one provides convenient surface topography with a minimal of contaminations.

The aim of present work is investigation of nanosecond laser modification of Ti (Grade 2) surface in air and formed oxide structures influence to biocompatibility increasing. We used our previous results [6] to define a behavior of nanosecond laser titanium oxidation by fiber laser and to identify phase composition of this oxide structures theoretically [7]. We selected an optimal regimes of laser interaction to produce different roughness on titanium. Investigation of surface microstructure before and after laser treatment was hold to analyze the relief changes by means of atomic-force microscopy and surface profilometry. Laser treatment of titanium results in the change of wettability, friction and durability measured with utilizing sessile drop method and tribometry.

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PS2-25 Fabrication of multilevel diffractive structures on hybrid photopolymers by laser writing system with circular scanning

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The applications of hybrid organic-nonorganic photopolymers are being actively researched in the application to fabrication of microstructured components of purposes. The optical microstructures fabricated on the photopolymers have much better chemical inertness and thermomechanical stability than the structures formed in standard positive photoresists based on novolac resins. The usage of hybrid photopolymers (HP) allows manufacturing phase micro-optical elements without transfer of surface profile from photoresist to optical substrate, which is usually made by expensive reactive ion etching. However, HP such as OrmoComp® (one of the UV-photocurable Ormocer® polymers manufactured by Micro Resist Technology GmbH) are mainly used for replication of micro-optical elements. It is also known the OrmoComp® due to high-contrast characteristic curve can be used for direct laser writing of deep binary microstructures intended for micro-electromechanical systems. Our task was to investigate a possibility of direct laser writing of multilevel diffractive structures.

In our experiments the manufacturing of multilevel diffractive structures was consisted of several stages: (I) photopolymer spin coating after diluting in Ormothin® ma-T 1050 solvent; (II) pre-exposure from the substrate side; (III) pre-baking; (IV) laser writing ; (V) post-baking; (VI) development in Ormodev® developer; (VII) drying and curing in oven at 150 ° C for one hour. The HP film on glass substrates were exposed by circular laser writing system CLWS-300IAE which has diode laser with 405 nm wavelength and 15 mW power. The laser beam is focused to 0.8 μm diameter spot. Specialty of the writing system with circular scanning is extremely large range of scanning speed.

The characteristic curves for direct laser writing at different pre-exposure doses, laser beam scanning speed and HP film thickness have been defined. Multilevel diffractive structures operating in first diffraction order have been fabricated.

In the research, we used equipment of multiple-access center “High-resolution spectroscopy of gases and condensed matters” at IA&E SBRAS.

PS2-26 In-situ measurement of probe beam diffraction pattern for finding optimal processing parameters at TLIPSS formation

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Thermochemical laser-induced periodic surface structures (TLIPSS) are characterized considerably higher order in comparison to ablative LIPSS. Typical height of oxide ridges of TLIPSS is in range of 50-150 nm. Typical range of periods is 700-950 nm. It was found that the power range for formation of these structures is relatively narrow. High order disappears if power changes by 10%. It is evidently that in-situ optical testing of the grating formation is very important even at experimental research. In the current work, we investigated possibility to measure diffraction pattern of reflected probe beam for in-situ testing of fabricated gratings.

For TLIPPS formation we used x-y scanning writing system with femtosecond laser PHAROS 6W having a central wavelength of 1026 nm and 230 fs pulse duration. The repetition rate was 200 kHz. The focal spot size was around 10 μm. Scanning speed was below 10 μm/s. Metal films were coated on optically polished glass substrates.

For TLIPPS testing we used 532 nm DPSS laser. This wavelength compatible with main optical channel of system. The beam of testing laser was combined with writing beam. The testing optical channel adjusted so that beam size on processed area was near 5 μm. The typical angle of 1st diffraction order of the probe beam reflected from TLIPSS is in range of 350-500. Ground glass screen was used for visualization of the diffraction pattern. Digital camera detected the diffraction pattern on the screen. The resulting images was observed and processed by computer. Correspondence of the spot position and diffraction angle was calibrated by measurement of test binary linear grating. This system allows one to provide feedback during TLIPPS formation.

In the research, we used equipment of multiple-access center “High-resolution spectroscopy of gases and condensed matters” at IA&E SBRAS. This work was supported by Russian Foundation for Basic Research (grant 16-32-60096).

PS2-27 Correction of refractive index profile by femtosecond laser in proton-exchanged $LiNbO_3$ Y-branching power divider

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There was proposed the technique of direct femtosecond laser writing of structures with decreased refractive index in proton-exchanged lithium niobate. In the paper we investigate influence of these structures on operation of the Y-branching power dividers for design of the multi-function integrated optics chips (MIOC) for the purposes of advanced applications. The parasitic spectral selectivity is established to be serious drawback of MIOC, which utilize the channel proton-exchanged $LiNbO_3$ waveguides with the standard Y-branching geometry. It has been attributed to the technological uncertainty of photolithography and proton exchange processes, providing excess of refractive index increment within Y-branching area. The resulting Y-branching power dividers were observed to undergo asynchronous, oscillatory power exchange between the output branches at monotonous temperature variation. Note, that even a small temperature-dependent variation of splitting ratio may present dramatic problem for some particular applications, e.g. for high-precision fiber optic gyroscopes. For suppression of this parasitic effects, the branching topology was modified by direct femtosecond laser writing of an extra structure within the Y-branching power divider in order to decrease the influence of technological uncertainty on mode coupling within initial stage of channel branching. Such a modification of Y-branching geometry gives only the partial suppression of the spectral selectivity, allowing, by the way, to reach the appropriate levels of temperature-dependent variations and insertion losses with MIOC fabricated by annealed proton exchange in $LiNbO_3$. The optimal parameters of this extra structure have been experimentally found for MIOCs operating at wavelengths near 1550 nm. Thus, the modified MIOC with a long extra fs-written structure (35-50 μm) is determined to be suitable for some practical application.

PS2-28 Concentration quenching for laser dyes in variety of solid matrices and liquid solutions

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Organic dyes laser are widely used in science and technology. Impregnation of dyes into polymers demonstrates many technical advantages, especially in the case when the dye impregnated material is embraced inside cavities of nanoporous glasses (NPG-P composite), building this way rigid, true solid state active element. Peculiarities of luminescence in such compositions are the subject of the work.

Luminescence of 12 laser dyes was studied in a variety of liquid solution (ethanol, MMA) and solid matrixes such as PMMA and NPG-P composite. Concentration dependences were measured for pyrromethenes, phenalemines, xanthenes and other types of dyes to define the quenching limits of luminescence. The luminescence spectra and intensity was measured by Perkin-Elmer 650-40 fluorimeter using the front excitation geometry, in the same conditions for all the materials. The excitation wavelength always corresponded to the absorption maximum of the particular dye.

It was found that luminescence quenching in pyrromethene and phenalemine dyes in PMMA and liquid solution occurs at $2{,}5\div5\times10^{-3}$ mol/l which is significantly (from 10 to 100 times) higher than quenching concentrations for other types of dyes. Quenching of pyrromethene dyes in tne composite NPG-P is even more shifted towards higher concentrations, compared to the initial monomer composition, due to incomplete penetration into NPG-P. The quenching threshold of $1\div2\times10^{-2}$ mol/l was measured for investigated dyes. Contrary to pyrromethene, phenalemine dyes in NPG-P composite revealed quenching shifts towards lower concentrations in the initial monomer compositions due to their extremely high penetration into the porous matrix, demonstrating the quenching threshold at $1\div5\times10^{-5}$ mol/l for the reference set of dyes. The observed difference in dye doping for NPG-P matrix was also confirmed by absorption spectroscopy of the manufactured active elements.

These results obtained allow optimization of concentrations in solid state day lasers aiming at the maximum of conversion efficiency and life time.

PS2-29 Laser direct imaging platform – from UV photolithography to q-switched laser microstructuring

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The demand for micro-structured devices in different fields of science and technology is constantly growing. The most commonly used manufacturing method is based on photolithography process that involves precisely made masks aligned with the substrate, and a source of near-UV light. That approach is well established and suited for a mass production. However any design changes incur mask redesign which is time consuming and costly process. For research, development and low volume applications, direct laser imaging of patterns on a photo resist with a continuous laser source and direct laser structuring with q-switched laser pulses that micro ablate material offer many advantages due to their design implementation flexibility and fast turnaround time. Here we present a comparison between the two approaches. Direct laser imaging experiments were performed on a commercial PL LDI device manufactured by LPKF. High aspect ratio structures, vertical photo resist walls, and multilayer structures were demonstrated.

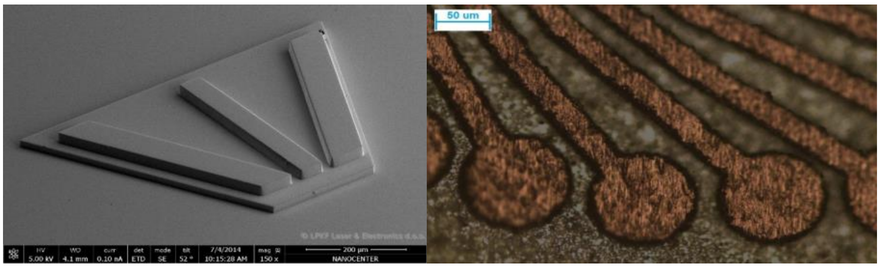

Figure 2: A comparison of approaches: SEM image shows a two-layer photolithographic structure (left) and microscopic image shows a precisely structured copper layer (right).

For direct laser structuring experiments we used PL LDI opto-mechanical platform and modified it for use with a q-switched frequency doubled Nd:YVO4 laser operating at 70kHz repetition rate. In both cases precise laser beam steering with acousto-optic deflectors (AOD), tight focusing through a microscope objective, and compensation of sample movement was used to realize structure features sizes down to a micrometer. AOD beam steering and q-switched pulses were synchronized to allow for an individually and independently assigned position of each q-switched laser pulse. Microablation was successfully demonstrated on various materials including bulk and thinly layered copper, silicon, thin metal layers, thin transparent oxide layers and bulk sapphire crystal. We have demonstrated precise structures in the target materials with little effect on either the substrate or the remaining material.

PS2-30 The modeling of diode end-pumping of erbium active media

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In the 3um spectral range the lasers based on Er-ions activated crystals are widely used. The diode pumped lasers based on erbium crystals can provide high generation energy in free running mode as well as in Q-switch mode [1]. Taking into account the low gain ratios of erbium active media, the increase of diode pumping efficiency seems to be important in case of realization of high-power laser systems. This paper presents the results of a modeling of diode end-pumping system of erbium active media.

The model for diode end-pumping allows investigating of radiation absorption processes in the active media, taking into account the spatial characteristics of pumping radiation and the saturation of pumping absorption ratio. The developed model based on a system of nonlinear partial differential equations describes the distribution of diode pumping pulse in active media. The model allows exploring of the population of laser levels 4I11/2 and 4I13/2 also the intensity of diode pumping, which depend on the radial and longitudinal coordinates and time. This model has been complemented by equations, taking into account the population of the three upper levels of the active media for considering the up-conversion processes. The concentration of the activator was varied in the range 0.5-1 at%. To determine the optimum pumping parameters the stored energy in the active rod and pumping radiation absorption efficiency were evaluated. As a result, the greatest absorption efficiency can be achieved with 1-2ms pumping pulses and activator concentration of 0.8-1 at% at small pumping power. Maximum of stored energy was achieved with 4ms pumping pulses and activator concentration of the 0.8-1 at% at maximal pumping power. At pumping pulse duration of 1ms the stored energy weakly depends on the concentration at average pumping power up to 30W.

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PS2-31 The investigations of thermo-optical distortions in erbium crystals under diode end-pumping

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When creating the compact diode pumped solid-state lasers of average output power up to 20W, as well as micro-chip lasers that generate the sub-nanosecond pulses, usually a diode end-pumping of active media is used. The significant spatial gradients of heat dissipation in the active rod are a characteristic feature of these lasers. In this paper we present the results of numerical simulation of thermo-optical inhomogeneities and thermo-induced stresses in Er: YLF active rod under diode end-pumping.

The modeling of thermo-physical processes in active rod was performed using the heat equation, taking into account the spatial non-uniform heat dissipation [1]. The investigations of the influence of space and energy parameters of pumping and the parameters of the active rod on the temperature profile and mechanical stresses was carried out using an approximation of radial symmetry and stationary pumping. For different pumping spatial profiles, pumping power and activator concentration the temperature profiles in active rod and stress tensor components were obtained. As a result, the range of concentrations of 0.2-1at.% activator that allows minimizing the absorbed power gradients while maintaining a high absorption efficiency of pumping radiation was defined. An increase of the activator concentration and decrease of the diameter of the pumping beam lead to increasing of stress gradients and reducing of their localization area. The dependences of the absorbed average power, optical power of thermal lens and maximal longitudinal stress on activator concentration were obtained. An increasing of concentration over 1at% does not lead to a significant growth of pumping efficiency. For different diameters of pumping beams the range of activator concentrations that provides minimum values thermo-optical distortions and stresses while maximizing the efficiency of pumping absorption was defined: for pumping beam diameter 0.5mm – 0.5-0.7 at.% for 0.8 and 1mm – 0.5-1 ат.%.

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PS2-32 One-step deep nanosecond-laser surface hyperdoping of silicon in liquid ambient

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Single-shot IR nanosecond laser processing of commercial silicon wafers was performed in ambient air and under a 2-mm thick carbon disulfide liquid layer. The surface spots modified in the liquid ambient, as well as reference spots of the initial silicon and the silicon ablated under the same conditions in air, were characterized in terms of its surface topography, chemical composition, band-structure modification and crystallinity by means of SEM and EDX microscopy, as well as of FT-IR and Raman spectroscopy. These studies indicate that single-step deep (up to 2-3% on the surface) hyperdoping of the crystalline silicon in its sub-micron surface layer, preserving its crystallinity and high (10^3-10^4 cm^{-1}) spectally-flat absorption coefficient, can be obtained in this novel approach.

PS2-33 Mo/Si multilayer coating controllable XUV reflectivity change by processing with fs laser pulses

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In this paper we discuss the possibility of controllable change of Mo/Si multilayer coatings reflectivity by modification of Mo/Si structure by fs laser pulses. Mo/Si multilayer coatings are widely used as reflective coatings of XUV optics, particularly - mirrors and photomasks in EUV

(13.5 nm) lithography.

For experiments coating samples deposited on fused silica substrate were used consisting of 40 Mo/Si bilayers with reflectivity of 0.69 at the central wave length of 13.1 nm. Multilayer coating was irradiated by laser pulses with 200 fs duration and repetition rate up to 100 kHz. Scanning of laser beam on the multilayer coating surface was performed by galvoscanner which provided irradiation of coating both in the mode of strong overlapping of laser pulses and isolated laser spots. For characterization of the processed coating EUV spectral reflectometry, Nomarski optical microscopy, white light interferometry and atomic force microscopy were used.

The damage threshold for multilayer coating was defined. When the laser dose on the coating was below the damage threshold the modification of the coating took place which resulted in formation of the coating surface depression in nm-range assisted by reflectivity spectrum change. Depending on laser radiation dose reflectivity at the central wave length (CWL) decreased in a controllable way down to 0.2. It was suggested that laser treatment of the coating can create either a shift of the reflectivity spectrum CWL due to a change of the multilayer coating period with corresponding decrease of reflectivity at CWL, and/or a change of the reflectivity itself due to Mo and Si layers intermixing and molybdenum silicide formation.

PS2-34 Organic noncentrosymmetric co-crystals based on aminopyridine derivatives

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The paper presents synthesis and co-crystallization of five co-crystals of five different aminopyridine derivatives with 4-nitrophenol resulted in five new adducts. Molecular hyperpolarizability calculations show possibility of using these compounds as nonlinear optical materials. Good quality single crystals were grown by slow evaporation technique using isopropanol as a solvent. Optical transparency in the region of 190–1100 nm was found to be suitable for second harmonic generation of Nd:YAG laser. X-ray analysis confirms non-centrosymmetricity of obtained compounds; studied compounds crystallize in the P21 and Pna21 space groups. Thermogravimetric and differential thermal analysis show good quality and thermal stability of these crystals with melting points at 99–170 ºC. Hydrophilicity of the obtained crystals were studied by gravimetric technique and show zero level of hydrophilicity. The comparative studies on the nonlinear optical (NLO) properties shows that these compounds has good second order NLO response for laser radiation at 1064 nm. The nonlinear optical coefficients of the compounds was found to be more than 10 pm/V. Laser induced damage thresholds of named crystals were carried out using laser radiation of Nd:YAG laser operating at 1064 nm, obtained results show good laser-induced single and multiple shot damage thresholds values. Obtained results show potential applicability of these crystals for NLO applications.

PS2-36 Optical module of power laser technological system

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Remote metal cutting technology is indispensable in cases of flowing gas and oil wells fire. The application of common tools for metal cutting is difficult and unsafe near the accident site, so it is necessary to use a laser cutting. An important aspect in this technology is to deliver radiation to the target. The aim of this paper is to show the creation of zoom optical system, which is capable of focusing intense laser radiation to a very small light spot at the necessary distance. The lens is designed to focus high-power laser radiation with a wavelength of 1.071 μm at a distances range from 29.5 m to 75.2 m. Power laser technological system can consist of several identical lenses, which centers are located in the corners of regular polygon. An optical module provides both beams reduction and their focus. Fiber laser with the power of 8 kW is used in this optical module as a radiation source. Laser radiation is transferred to the lens through 90 meter long optical cable with a core fiber having 150 μm diameter.

Dimensional and power calculation of the system was conducted so as modeling of the spatial and energy distribution of the spot at the target for 3, 4 and 5 optical modules.

Laser technological system has to operate in difficult conditions. Any change in the optical elements position results in a deterioration of the spot quality and device error. In Lambda Research TracePro software spatial and energy evaluation of the spot at the target with the extreme positions of the optical elements was conducted. In the presence of optical elements decentering energy center of the beam shifted relative to the sight line by 0.044′, 0.0040′ и 0.036′ with a t-parameter equals 0.1, 0.5 и 1 respectively.

The values of center deviations do not exceed 10% of the total spot size. Beam quality has changed insignificantly and provides necessary radiation power density at the target.

PS2-36 Local crystallization inside lithium silicate glass by CO_2 laser action

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In modern laser technologies take place active development of micro- and nanostructured optically transparent materials. An important issue in this direction is to study the local phase transitions on the surface and in the bulk of multicomponent lithium-silicate glasses. Their production represents a very time-consuming and complicated process. Wide application for getting glass-ceramic materials take the method, which is based on the image recording with laser light in glasses, having in its composition photosensitizers, and its further manifestation during heat treatment.

Aim of this work is to obtain and research the local crystallization in the bulk of lithium-silicate glass that does not contain in its composition photosensitizers, using the combined influence of ultrashort pulses and photothermal action by CO_2 laser.

In this work the method of laser-induced crystallization in lithium silicate glass was presented. At first the microstructures preimage inside the sample was wrote with using of ultrashort pulses. The next step the photothermal action by a CO_2 laser (τ = 190 ms, f = 5 kHz) was occurred. Observation of appearance change and RGB chromaticity indicators of modification regions in the recording process allowed to determine the rate of crystal growth. The temperature range at which began crystallization, was determined by IR camera. After recording microstructures preimage and crystallization of modification areas, glass samples were chemically etched in aqueous solution of hydrofluoric acid (HF). It allowed to evaluate the dissolution rate of the crystalline phase and to determine the velocity ratio of crystalline and amorphous phases etching. As a result of the experiment the preimages of structures with a diameter d = μm were recorded. After exposure of CO_2 laser radiation were observed two crystallization zones: central d = 16 μm and external d = 33 μm. Crystallization occurred spontaneously, observed a sharp and rapid growth of the crystalline phase. It was also revealed that the range of temperatures at which crystallization occurs is extremely narrow in the bulk.

The work was performed by the RSF agreement № 14-12-00351.

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PS2-37 The formation of micro - and nanostructures on molybdenum films by laser ablation

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Currently selective ablation laser metal films are widely used in areas such as production of semiconductor, photovoltaic devices, diffraction gratings, and other high-tech applications. One of the trends in this area of research is to increase the degree of integration of structural elements. The typical resolution of such structures, as a rule, does not exceed the size of the focal spot, which creates an obstacle to the creation of structures with submicron resolution. To overcome this barrier is possible due to the search and application of materials with contrasting characteristics to selectively use a maximum normal radiation intensity distribution in the focal spot. In this respect it may be promising molybdenum thin films that are used in photovoltaic and semiconductor devices.

In this paper we consider physical and technological basis for the formation of micro- and nanostructures in thin films of molybdenum, supported on an insulating base, by laser ablation. In molybdenum films with thicknesses of 17-45 nm deposited on a dielectric base, a circular grating with dimensions of 0.2-0.3 mkm were obtained, which is approximately 3-4 times less than the diameter of the focal spot of laser (d = 0,8 mkm). It has been found that films evaporation occurs at considerably lower values of the laser power density than suggested by the data. In order to explain the discrepancy between the practical and the theoretical data presented model description thermo-oxidative degradation of the films. To test the model description of the results of the optical properties of film studies, their chemical and elemental composition. ablation zone size reduction phenomenon is explained with the use of numerical modeling of the process.

PS2-38 The method of the experimental research of dusting regimes of refractory metal coating deposition using laser ablation

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There are methods of nondestructive check of thin metallic coating deposition: the X-Ray method and the method of the laser reflectometry [1,2]. However, the use of these methods requires expensive and complicated apparatus and qualified service. There is also a method of optical displacement interferometry [3]. However, this method is a method of destructive check of thin metallic coating deposition.

This report presents a nondestructive and low price method of research of the growth speed and the coating structure of dusted refractory metals in dependence on the power density radiation and the distance between the target and the substrate. This method was based on the coating deposition upon glasses. The results of the research of the influence of gas pressure on the ablation speed (growth of the coating thickness) are within 10^{-3} – 1 Torr. The optimum distance between the target and the substrate was determined. The threshold and the optimum of the power density laser radiation were also determined. The comparison of coatings on glasses and Steel 3 was carried out.

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PS2-39 Laser processing of metal surfaces for increasing corrosion resistance

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Corrosion causes huge losses, it is devastating effect we see in all that surrounds us, due to corrosion fail cars, machinery, various equipment [1]. A large number of accidents indicates that the requirements of existing normative documents, as well as test methods have become insufficient to ensure the required corrosion resistance and operational reliability. Protection against corrosion and its prevention – is quite time-consuming and costly measures. At a present time, the urgent development of additional requirements to the steels and methods of their testing to improve the corrosion resistance and service life [2]. Study of physic-chemical processes and mechanical properties occurring on the surface of metals under laser irradiation to protect the metal from corrosion are actual scientific and practical task.

The object of study in this work was metal stamps “steel 20” (Russian name), which exposed to corrosion. For treatment of surface of this metal we used CW fiber laser with a wavelength of 1.06 μm and a power up to 18.5 W. Experimental samples were irradiated during time up to 35 seconds at room temperature of 23 °C and a air relative humidity of 55 %. After laser processing samples were placed for 20 seconds into a chemical solution, which is a mixture of copper sulphate and hydrochloric acid.

A new method of laser processing of metal surfaces improving their mechanical properties was proposed. The study results allow one to choose optimal parameters of laser treatment of “steel 20”. Coatings having best protective properties have been created by use irradiation with laser output power density in the range of 93.5 W/cm^2 to 95.3 W/cm^2. Analysis on the change of physic-chemical composition on the metal surface as a result of laser treatment has been carried out. Also mechanical properties of “steel 20” have been investigated.

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PS2-40 Random phase plates formation by LIAMP

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Glass microstructuring is a very promising method for different applications upon making any micro-totalanalytic systems as well as microoptical elements (MOEs). Laser technologies are advanced in the field of such elements fabrication due to its high accuracy, speed and efficiency during micromaching process. MOEs in the form of microlens arrays, random phase plates and diffractive optical elements such as phase grating are active use in laser technologies with the aim to change and enhance the quality of laser beam intensity distribution as well as for laser beams multiplexing, that used in schemes of laser interference writing [1].

Along with traditional technologies of MOEs fabrication, such as photolithography, hot embossing process, direct laser beam writing, the combined technologies based on strong absorption of laser radiation with different solution or metals contacting with the back side of the glass plate obtain an extensive use for glass surface microstructuring [2, 3].

Thus, a new laser technology for glass surface microstructuring has been developed by our team and called laser-induced action of microplasma (LIAMP). We could form different MOEs, such as random phase plates with elements of a square shape (0.2–0.7 μm), diffraction phase gratings with period 30 – 100 μm and microlens arrays with microlens diameter 150 – 500 μm.

The aim of this work is the investigation of the main processing parameters for fused silica by LIAMP technology and the correlation of these parameters with the depth, the shape and the size of microstructures.

According to received knowledge about depth of formed microstructures, we could form the random phase plate of fused silica and tested it in the laser scheme for laser beam homogenizing.

The work was performed by the RSF agreement № 14-12-00351.

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PS2-41 Non-monotonous variation of Ag and Au nanoparticles yield during femtosecond/picosecond laser ablation in water

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The ablative synthesis of Ag and Au nanoparticles' colloidal solutions was carried out using an Yb^{3+}-doped fiber laser (the central wavelength λ = 1030 nm, FWHM pulsewidth τ = 300 fs, repetition rate f = 500 kHz, average energy up to 10 μJ in the TEM_{00} mode). The laser beam was focused via silica glass lens (focal length of 100 mm) to a spot with radius $\sigma_{1/e} \approx 15$ μm (Ag) and 10 μm (Au), with peak laser fluence on the surface reaching F0 ≈ 2,1 J/cm^2 and $F_0 \approx 3{,}18$ J/cm^2 for Ag and Au, respectively, and raster-scanned across 2×2 mm^2 regions of optically-polished Ag or Au samples (Savings Bank of Russian Federation, 99.99% purity) covered by thin (~ 2 mm) layer of deionized water at the constant scanning velocity of 6 mm/s via galvanoscanner "Ateko" with pulsewidth values from 0.3 to 9.9 ps, varied by a built-in pulse compressor. After the processing of each region for 50 times, the obtained colloidal solutions were removed for their characterization by means of white-light transmission spectroscopy and scanning electron microscopy (SEM). The ablation of silver and gold with laser shots of different pulsewidth resulted in a non-monotonous nanoparticles' yield, illustrated by the absorption spectra of colloids. The increase of pulsewidth lead to the local decrease of colloids' absorbance, defined by nanoparticles' yield efficiency, with maximum and minimum values corresponding to τ_{max} = 0.3 ps and $\tau_{min} \approx 4.1$ ps in Ag colloid and τmax = 0.6 ps and $\tau_{min} \approx 2$ ps in Au colloid.

PS2-42 Heat transfer and dendrite growth kinetics in titanium alloys during selective laser melting

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Selective laser melting (SLM) of titanium alloys with strengthening inclusions (i.e. metal matrix composites) is under consideration for aerospace applications, which requires consistent control of microstructure and resulting mechanical properties. Final microstructure is determined by its thermal history and also controls the mechanical properties, especially the grain size (dendrite arm spacing for columnar dendrite) and morphology.

This study describes a self-consistent multiscale model to simulate the dendritic structure during solidification of a titanium alloy in the molten pool of the SLM process. The model includes on macro level the heat transfer equation by the FE method to estimate the temperature distribution in the melt pool for some deposited layers. The temperature field is used in a micro region near solid-liquid boundary, where solute micro segregation and dendrite growth are calculated by special technique. The effect of the SLM process parameters (laser power, scanning velocity, layer thickness and substrate size) on the solidification microstructure was investigated.

PS2-43 Gradient core–shell HTS/polymer covered composites with ultrafine particles fabricated by 3D printing

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In this study, we report the laser synthesis and characterization of the core–shell high-temperature superconductors (HTS) covered with polycarbonate shells of ultra-fine particles and layerwise selective laser sintering of the 3D samples. The optimal regimes of such synthesis are being discussed. Optical and scan electron microscopy with EDX, X-ray diffraction studies show that both core–shell systems have a complex structure with interesting electro-physical properties. Expanding computer aid design of the HTS core distribution in polymer matrix opens door to manipulate of electromagnetic field distribution within such 3D complex core-shell samples.

PS2-44 Anisotropy of structural and electrical properties of amorphous silicon films treated by femtosecond laser radiation

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Femtosecond laser pulses with high emission intensity and low photon energy provide a possibility to achieve uniform nanostructuring and modification over the entire volume of siliceous films [1], and also lead to the anisotropy of their structural, electrical and optical properties. In addition, femtosecond laser processing can produce surface periodic structures [2]. Thus femtosecond laser radiation can be used to process amorphous hydrogenated silicon films (a-Si:H) for potential applications in photovoltaics.

In this paper, a-Si:H films irradiated by femtosecond laser pulses (1250 nm, 100 fs) were investigated. Due to continuous movement of the laser beam in one direction and discrete movement in the perpendicular direction, so-called scan lines were formed (Figure 1,a).

Scanning electron microscopy also revealed the presence of the one-dimensional grating-like structure with a period of about 0.36±0.03 μm on the treated surface (Figure 1,b). This surface periodic structure is perpendicular to polarization of the incident beam. This result is in agreement with the data of [3].

Electrical measurements have shown that the conductivity of a-Si:H film after irradiation with femtosecond laser pulses increased up to 3 orders of magnitude (Table 1) due to dehydrogenation and nanocrystallization of the film [4].

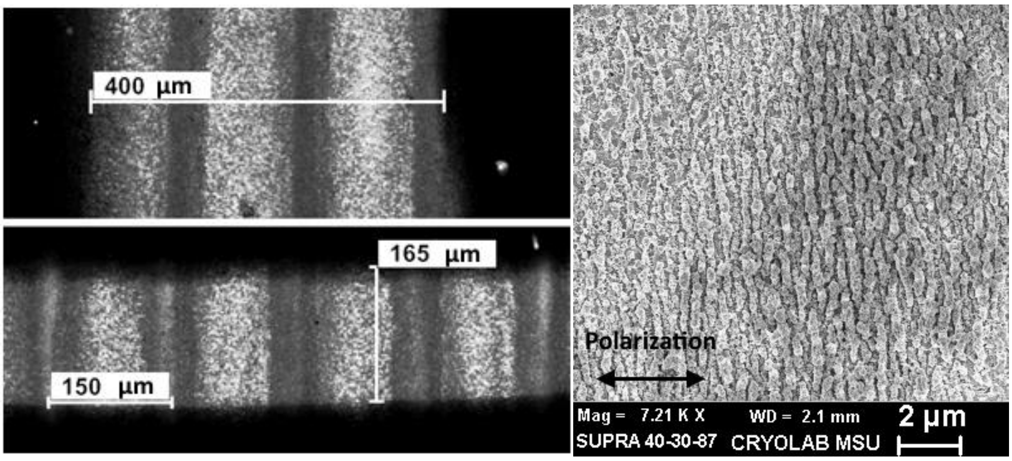

Figure 1. The images of processed a-Si:H film surface, obtained by optical microscopy (a), and scanning electron microscopy (b).

Table 1. Conductivity of a-Si:H film before and after femtosecond laser irradiation.

Sample	Specific conductivity σ $(\Omega\cdot cm)^{-1}$
Processed area, the contacts are parallel to scan lines and surface periodic structures	$1{,}58\cdot10^{-6}$
Processed area, the contacts are perpendicular to scan lines and surface periodic structures	$4{,}48\cdot10^{-6}$
Amorphous silicon	$6{,}73\cdot10^{-9}$

The conductivity along the scan lines and periodic structures is almost threefold greater than in the perpendicular direction. A possible explanation of this effect may be given by non-uniform crystallization of amorphous silicon, and the electric field anisotropic depolarization inside the surface periodic structure.

This work was financially supported by the Russian Foundation for Basic Research (project 16-32-80066.

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PS2-45 Birefringent optical fibers axial positioning technique for fiber Bragg gratings writing scheme

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In these work two methods of birefringent optical fibers axial positioning for fiber Bragg gratings writing scheme were tested. The writing efficiency results of Bragg gratings of type I in birefringent optical fiber with an elliptical stress cladding at two extreme positions of the ellipse were presented. A comparison of the two methods used for the determination of the axis of anisotropic optical fibers was carried out.

Fiber Bragg gratings (FBGs) are currently one of the most important elements in a variety of fiber optics devices and measurement systems of various physical quantities.

FBGs have several advantages compared with other reflective elements (for example, interference mirrors and bulk diffraction gratings) – wide variety of spectral and dispersion characteristics, all-fiber design, ease of fabrication, low loss, and others.

The main feature of anisotropic single-mode fibers is the ability to maintain the polarization state of the radiation introduced into the optical fiber. The anisotropic single-mode optical fiber with an elliptical stress cladding, used in this research, has in its cross-section a circular core and elliptical stress cladding, which are located inside the structural cladding of quartz glass. Optical fibers having such structure have enhanced properties to preserve the polarization of light, which is provided by the radial anisotropy of the stresses due to the elliptical shape of stress cladding.

The experimental results obtained during the FBG inscription in birefringent optical fiber with an elliptical stress cladding showed that the writing efficiency and the resulting characteristics of the FBGs depends on the position of the elliptical stress cladding during the FBG writing.

To control the position of the elliptical stress cladding in the FBG writing scheme two axial positioning methods of birefringent optical fibers were tested. First method is based on the visualization of the ellipse, using white light entering off-axis into the optical fiber, while observing the fiber end under an optical microscope. Another is based on the definition of the fiber axis during observation of the interference pattern of dispersion while illuminating the lateral surface of the optical fiber with coherent radiation source such as He-Ne laser.

In this work the writing efficiency results of FBG of type I in birefringent optical fiber with an elliptical stress cladding at two extreme positions of the ellipse were presented. Also, a comparison of the two methods used for the determination of the axis of anisotropic optical fibers was carried out.

PS2-46 Application of LIBS-analysis in checking of electronic devices

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The development of microelectronic devices requires permanent testing of change of their properties, analysis of defective goods and compliance check. One of the most important and, simultaneously, easily checked property is an elemental composition. Any deviations from the required composition lead to bad work of the device. Especially it is fair for an accidental depositions and contaminations.

The techniques and results of investigation of some types of electronic devices are described in the report. Some approaches of combined examination, comparison and search for the reason of defects are considered.

The applied method is laser induced breakdown spectroscopy (LIBS). The experimental set-up is based on Q-switched Nd:YAG laser (λ=1.06 μm). Pulse repetition rate is 25 Hz. Power density in a monopulse mode reaches 10^{10}-10^{12} W/cm^2. Focus spot size is about 10 μm. Limit of element detection is 10^{-10} g; relative limit of detection is 0.001 %. Registration of spectra is implemented by diffraction spectrograph and CCD camera.

PS2-47 Microstructuring surface of oxidized silicon monocrystals via single pulse Irradiation of frequency modulated nanosecond fiber laser

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We report results of investigation structural features of the silicon wafers (substrates) with a thermally grown silicon dioxide on the surface (of SiO_2/Si) after irradiation by pulse fiber laser of ILI-1-20 type.

Studies were carried out on silicon КЭФ-4,5 wafers oriented in the crystallographic plane (111) with 40 nm and 150 nm thick silicon dioxide (SiO_2) and КДБ-10 wafers oriented in the plane (100) with 500 nm thick dioxide.

Microstructuring of SiO_2/Si system was produced by laser complex based on ytterbium fiber pulse laser ИЛИ-1-20 with following main characteristics: nominal output power of the laser was 20 W, the laser wavelength was λ = 1062 nm, maximum pulse energy was 1,0 mJ. Irradiation was carried out by a focused beam spot with a diameter of 25 microns and a pulse repetition rate of 99 kHz with 120 nc pulse duration. The samples with 150 nm and 40 nm thick SiO_2 were irradiated at a power density of $1{,}2\cdot10^2$ W/cm^2, and the samples with 500 nm thick SiO_2 were irradiated at a power density of $2{,}0\cdot10^2$ W/cm^2. Only one scan line was used at the maximum speed of the beam (8750 mm/s) eliminating the appearance of "long-range" effects between adjacent irradiated areas.

As a result of the research methodology was developed and modes of laser irradiation of SiO_2/Si system, providing while maintaining the integrity of the SiO_2 film on the surface to obtain all experimental silicon wafers similar symmetrical microstructures were selected. Such structures are obtained for the first time and have the form of chamomile flower on the micrographs. There is circular area in the center, around it - radially directed oval figures ("petals") in varying amounts at equal distances from each other, not connected to a central region and spaced from it at equal distances. Irradiated regions have a different number of "petals". Irradiating the plate oriented in the (111) plane the number of "petals" averaged 7, although sometimes observed, and 6, and even more rarely - 9, while irradiating plates oriented in the (100) plane resulted in an average of 10 "petals". The morphology of the substrate surface is completely preserved after etching the SiO_2 film in hydrofluoric acid solution. As it follows from the experiment SiO_2 film must have a thickness above 40 nm for the formation of a microstructure with clearly outlines formed. AFM topographic images of the irradiated regions are typical for all experimental plates: narrowed upward columns of 130 nm in height, arranged around a central column, 260 nm in height. Holes of different depths (maximum depth - 130 nm) are located among the central column and the other ones. These columns (or the contours of the bases of the columns) define the topological pattern of "petals" on the micrographs. It is shown that the columns are composed of the crystallized silicon melt coated with thin ("extended") film of SiO_2, the thickness of which decreases towards the top of the column. It is suggested that localization centers of micromelting are those areas of the surface, where the reconstruction processes of the silicon surface before and during the process of thermal oxidation were carried out. In these surface areas silicon atoms have lower bond energy between each other in comparison with the volume of the single crystal.

Morphology microstructuring of SiO_2/Si system in the exposed surface area is primarily related to the laser irradiation energy distribution in the spot area. Other factors include: the crystallographic orientation of the plate, the initial (before thermal oxidation) treatment of the wafer surface, elastic stresses SiO_2/Si system, dependence of viscosity SiO_2 films from the silicon melt temperature and the temperature on the rest of the substrate.

It is also shown that with increasing temperature SiO_2 film destruction begins above the melt in the central region of the spot. Fracture occurs before reaching the melting point of SiO_2. As a result all silicon melt is "extruded" through the center area of exposed regions from below the SiO_2 film. A deep pit is formed there. The rest of the irradiated area, which maintain the integrity of the film, fully retains the initial topology of the "petals" and the SiO_2 film covers the deepenings left by the silicon melt.

We mark the stability of the results obtained in all the experimental substrates. This confirms the important property of laser radiation - selectivity, which should be more widely used in the semiconductor micro- and nanoelectronics technology.

PS2-48 The composition and structure of the ablation products of monocrystalline silicon formed by the action of pulse-frequency fiber laser radiation

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The results of the research of composition and structure of monocrystalline silicon ablation and ablation products formed by the action of pulse-frequency radiation ytterbium nanosecond fiber laser are shown in this paper. Polished silicon wafers mark КДБ-20 oriented in the crystallographic plane (111), and КЭФ-4,5 plate oriented in the (100) plane were used as experimental samples.

Irradiation of single-crystal silicon wafers was produced by a laser system based on a pulsed fiber laser ИЛИ-1-20, having the following main characteristics: nominal power output - 20 watts, the laser wavelength $\lambda = 1062$ nm, the maximum pulse energy - 1.0 mJ. The pulse repetition frequency was 99 kHz, pulse duration of 120 ns. Irradiation was carried out by a focused beam (spot diameter on the substrate 50 microns). Power density of irradiation was selected so that the silicon ablation process was carried bypassing silicon melting step and was $1{,}02 \cdot 10^6$ W/cm^2.

Scanning was performed using the two-axis scanner based on VM2500+ drives with control via a PC with installed "SinMarkTM" software complex. Managing scan speed and the amount of overlap of the scan lines was carried out in the program mode. Scan speed (v) varied from 10 mm/s to 4000 mm/s.

Control of the experimental samples was carried out on the optical microscope Axio Imager A1m by Carl Zeiss, staffed by a high resolution digital camera. These structures were also studied by atomic force microscopy using probe microscope Nanoedicator by NT-MDT company.

It is necessary to note the specifics of obtaining experimental samples. The first feature on which has already been mentioned - is the high power density of the laser and scan modes, that provide silicon ablation, bypassing the silicon melting process. The second feature is manufacturing samples in modes where intensive silicon ablation takes place, accompanied by a strong ionization of all substances on the exposed silicon surface. In this case appears torch (glowing of air gases ions and silicon) resulting in large amounts of SiO_2 molecules. Torch is observed in a relatively wide range of laser beam scanning speeds and the density of scanning lines overlaps. In modes where there is maximum height and the maximum brightness of the torch, there is a rapid build-up of silicon dioxide layer (the first group of samples). Irradiated regions formed in the presence of torch, but with the scanning speeds below and above those speeds at which the maximum of torch occurs are related to the second group of experimental samples. Finally, the third group of samples was formed at higher scanning speeds, when radiation dose was reduced, and the torch was visually completely absent.

In the study of the first group of experimental samples revealed the following structural features are revealed. The upper layer consists of silicon dioxide clusters, has a loose structure and can be easily removed mechanically. It is completely etched in an aqueous solution of hydrofluoric acid. Its thickness may more than 470 microns. Under the silicon dioxide layer there is a 40-50 microns thick layer of silicon particles of nanometer sizes. These particles settle on the relief layer of the silicon substrate completely filling it. Fractured layer almost does not apply within the scope of the original single crystal, but it fills the volume of the ledges in the relief layer.

Experimental samples from the second group also have upper layer of silicon dioxide clusters with loose structure, so that after the irradiation there are visible pits on the exposed surface.

Irradiating the third group of the experimental samples (starting at a scanning speed of 2000 mm/s), the presence of flame is not visually fixed, the formation of silicon dioxide layer stops, and a layer of the silicon nanoparticles is formed on the surface. The thickness of this layer increases with increasing irradiation time.

It is shown that by varying the scanning parameters (the overlap density, frequency) we can achieve changing the dose of radiation over the surface in a wide range. Thereby allowing the preparation of various products of ablation: SiO_2, silicon nanoparticles, and possibly other products of silicone ions interaction with materials in the environment in which ablation occurs.

PS2-49 Kinetic of fast phase transformations inside Foturan glass by CO_2 laser action

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Study of phenomena that appear at laser action on photostructurable glass (PhG) is of great interest in manufacturing techniques of microsystems and analytic devices for photonics [1]. There are the processes that allow implementing and monitor of local phase transformations inside PhG occupy a special role. Currently the process of nucleation and growing of crystalline phase is carried out only at long stage (4-8 h.) of heat treatment in a furnace. Reduce the duration of crystallization is possible at using of photothermal action by CO_2 laser. Fast 3D crystallization was carried at combined action of two lasers: picosecond Nd:YAG laser or femtosecond fiber laser and CO_2 laser. Ultra-short pulses that focused of objective (10^x, NA 0.25) were used for formed of modified areas (MA) inside PhG as crystallization centers in the future. Phase transformations inside PhG plates were carried by action of wide CO_2 laser beam with intensity of 75÷95 W/cm^2 and time exposition about 15÷400 sec. Duration of crystallization was determined by temperature region at excerpt and it was varied from 490 to 580 ˚C. At this temperature on MA were formed crystals of Li_2SiO_3 and $Li_2Si_2O_5$. Temperature of more than 580 ˚C became the cause of the sharp decrease in the rate of crystallization (fig. 1).

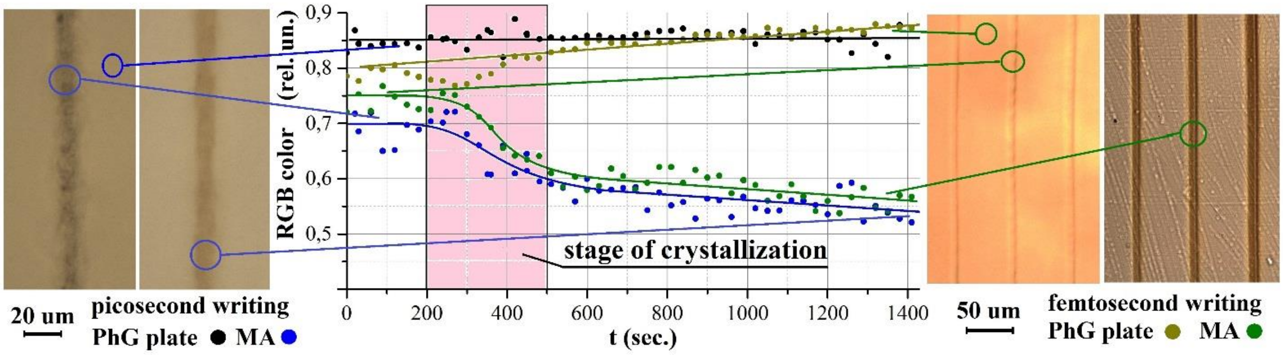

Fig. 1. Optical images of different MA and graphics of RGB color for these MA

The size of microcracks around of MA was increased in the temperature region of 250÷450 ºC. These microcracks completely were overgrown at temperature of 465÷510 ºC. Crystallization on MA was accompanied by changes of its optical properties. Thus, the color changes of MA inside sample and PhG plate were possible to determine the stage of phase transformation. For this, the coordinate system of RGB color relative to white was used (fig. 1). Crystallization was started practically immediately upon reaching 490 ÷ 510°C. This process was accompanied by darkening of MA that it was expressed in the change of color. As can be seen from the curves in the graph of relative RGB color the duration of crystallization stage was about 375 sec. The velocity of phase transformation at further photothermal action gradually was decreased.

The work was performed by the RSF agreement № 14-12-00351.

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PS2-50 Metal surface laser micro structuring technology

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The work is devoted to metal surface microstructuring. The previous researches showed that by changing the surface texture one could control various properties of an object such as mechanical, adhesive, hydrophobic, and optical ones. In our work, significant changes of the surface texture, mainly characterized by roughness parameters, were achieved as a result of the laser treatment.

We used a fiber-optic laser with scanning beam pointing system. By changing working parameters of the laser system, such as power, scanning speed, frequency and duration of impulses, fill density, number of the location passes, we could regulate lateral, longitudinal and altitudinal parameters of the object. Local exposure, small diameter of the laser spot, and simplicity of the regulating of the laser system allows for an easy regulated metal ablation process. Computer graphics software were used to model expected structure of the object surface.

The work process resulted in development of a three-stage surface treatment technology. The first stage – “ablation” by laser is associated with material removal in the form of steam or melt, material redistribution caused by pressure from vaporizing, surface tension of molten material and steam particle settling in the processing area. The second stage - “cleaning” is characterized with decontamination after the first stage and destruction of porous sintered structure of the combustion products. The third stage - “polishing” is characterized by repeated melting of the surface layers and metal mass redistribution because of the surface tension.

Furthermore, we suggest to form nanostructure on the surface of a mill roll. Using the cold rolling technology for production of sheet-like material is promising for making nanostructured surface products at larger scale. This is expected to make a positive impact to productivity and cost efficiency.

PS2-51 Nano-structure and surface activation of recycled $12CaO \cdot 7Al_2O_3$ ceramics by femtosecond laser irradiation in solvents

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$12CaO \cdot 7Al_2O_3$ is highly interesting functional material for its variety of possible applications. The crystal structure of $12CaO \cdot 7Al_2O_3$ can be described as anti-zeolite, and it forms positively charged cage-like structures, partially occupied by anions. The cages are formed by calcium, aluminum and 32 of the 33 oxygen atoms. The cubic unit cell contains 12 of these cages. Two of them are occupied by oxygen atoms or anions. Incorporation into the lattice of multiplicity of foreign anions and electron has been reported. We had explored the surface functionality of this ceramic to store hydrogen safely and desorb in an efficiently way. In this work, we used femtosecond laser irradiation in solvents to increases specific surface area of $12CaO \cdot 7Al_2O_3$ ceramics and to improve the amount of hydrogen adsorbed at its surface. We found that when femtosecond laser irradiation is done in solvents with hydroxyl groups a smaller particle size is obtained and that the particle size become smaller as the polarity of the solvent increases. We confirmed the presence of carbonyl surface function $12CaO \cdot 7Al_2O_3$ sat the surface of $12CaO \cdot 7Al_2O_3$ ceramics after femtosecond laser irradiation by infrared spectroscopy. This is attributed to the direct chemical bonds breaking of the solvent via multiphoton ionization through tunneling followed by Coulomb explosion and then produce ions that are adhered to the surface of $12CaO \cdot 7Al_2O_3$ ceramics. The relation between specific surface area as well as surface functional groups after femtosecond laser irradiation and the amount of hydrogen adsorbed of $12CaO \cdot 7Al_2O_3$ is proposed.

PS2-53 Laser activation of alkali vapor mini-cells for atomic clock

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We present a fabricated Cs, Rb vapor cells for mini-atomic clock. The cells is made of silicon and borosilicate glass method of anodic bonding and has two chambers. One of chamber - technological, for storage of the tablet containing alkaline metal. The tablet from the pressed powder Ti and powder of alkaline metal bichromate was used. The second probe chamber server for spectroscopy of the double radio-optical resonance or optical CPC resonance. Both chambers connected narrow channels for the possibility from the chamber to chamber of the vapor alkaline diffusion. Anodic bonding of a cell was made in the atmosphere of nitrogen at a temperature below than temperature of activation of reaction an restoration of Rb from bichromate. Reaction of restoration of Rb is activated at a temperature of 370-380 ºC. For heating of a tablet with alkaline metal bichromate the laser diode with wavelength 980 nm. Radiation was brought to a tablet by means of optical fiber with a diameter of 0.2 mm. at the power of radiation from 5 W to 10 W. Exit of pure alkaline metal depending on the power of radiation and time of heating was observed.

The activated cells were tested by an absorption spectroscopy method. contrast of lines of absorption on transitions of thin structure of Cs, Rb to 28% in the range of temperatures of cells 70-110 ºC was received. The re-testing of cells which are carried out in one year showed their high reliability.

PS2-53 Solidification behavior and dendrite structure refinement after LDMD in Ti based alloy reinforced by μ- and nano- alumina

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The laser direct metal deposition (LDMD) technology with co-axial powder injection was used to fabricate a complex titanium aluminide structure of Ti based alloy reinforced by Al_2O_3 ceramic of micron and nano size particles. The aim of the study was to demonstrate the possibility of producing TixAly intermetallic phases in remelting powder mixtures with strain-hardening ceramic inclusions in the course of the single-step DMD process. Besides, relationships between the main laser cladding parameters and the intermetallic phase structures of the built-up objects were studied. In our research we applied optical microscopy, X-ray analysis, microhardness measurement and SEM with EDX analysis of the laser-fabricated intermetallics.

PS2-54 FIBER CORE OVERLAPPING IN FEMTOSECOND FIBER BRAGG GRATINGS INSCRIPTION

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Bulk modification of transparent materials with femtosecond (fs) laser is a rapidly developing area allowing fabrication of fiber Bragg gratings (FBG) with advanced characteristics. Ability to modify non-photosensitive materials and to inscribe gratings through the plastic coating of silica fibers significantly expands their properties and makes them attractive for applications in high-power lasers and sensing systems in harsh environments — high temperature, radioactive irradiation and hydrogen concentration. To date, two direct inscription techniques have been reported — point-by-point and core-scanning ones. In comparison with phase mask inscription the above-mentioned techniques allow one to inscribe FBGs with required geometry without the use of additional optical components and post-processing procedures.

In this work, the benefits and drawbacks of point-by-point and core-scanning inscription techniques are discussed. Temperature and strain sensitivity as well as polarization properties are compared. The results of creation of phase-shifted and apodized FBGs created with core-scanning technique are reported for the first time.

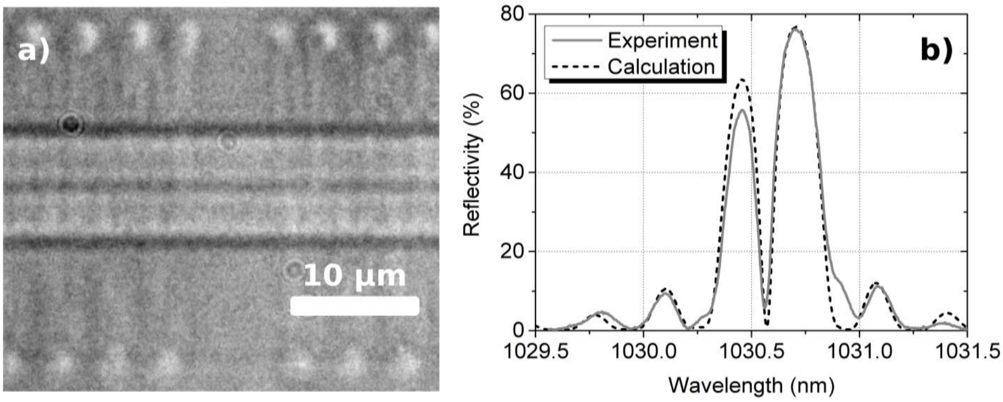

Fig. 1. π-shifted FBG inscribed with a continues core-scanning technique: a) microscope image of the shift, b)reflection spectrum.

This work is supported by Russian Foundation for Basic Research (grant 16-32-00777) and grant of the President of the Russian Federation (MK-6657.2016.2).

PS2-55 3D structure modification inside porous glass by femtosecond laser pulses

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Photonic integrated microsystems as well as micro-totalanalytic systems are rapid growth and improved currently. Their basic advantages are compactness, multifunctionality and performance. Thus, searching for new multifunctional materials, which are suite to create such microsystems, have attracted much attention previous years. On the other hand, development and improvement of methods for local micromachining of such materials becomes an urgent problem. One of such materials is nanoporous glass (PG), which offers unique properties, such as high transmittance, absorbance of molecules from different fluid or air.

Laser-induced variation of local PG density up to complete closure of pores makes it possible to vary broadly adsorption properties inside the PG, thus providing the control of diffusion processes in such branched PG channel and pore network [1]. Local decompaction up to the formation of hollow micro-channels with some pre-defined configuration and channel diameter is also widely demanded. As a result of such local densification and decompaction laser-micromachining processes, PG emerges as a novel optical platform for fabrication of integrated micro- and nano-devices for photonic, plasmonic, microfluidic and micro-pneumatic applications [2, 3].

We used PG samples with average pore diameter was 5 nm and the total porosity $\sigma = 26$ %. Their chemical composition was (mass fraction, %): $94.73SiO_2$–$4.97B_2O_3$–$0.30Na_2O$ [4]. Laser micromachining inside the PG samples was carried out utilizing an Yb-doped fiber laser with the 515-nm wavelength, the pulse duration (FWHM) of 200 fs, and repetition rate of 500 kHz. The samples linearly translated at different scan velocities in the range of 0.01 - 4 mm/s. A objective with NA=0.25 of the microscope focused the fs-laser pulses. The energy ($E_p = 1.5 – 2.3$ μJ) of femtosecond laser pulses was enough to achieve the intensity $8.0 \cdot 10^{13} – 1.2 \cdot 10^{14}$ W/cm^2 in the beam waist.

The work was performed by the RSF agreement № 14-12-00351.

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PS2-56 The femtosecond laser generation of regular arrays of nanostructures (nanospikes and nanoparticles based on them) on thin films of advanced nanoplasmonic materials

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Femtosecond laser fabrication of arrays of different plasmonic nanostructures on thin films. As a result of this research is planned for the first time to make a systematization of experimental data on the study of the mechanisms of formation of nanostructures - the totality of the energy density, the number of pulses of absorbed surface, their duration. It is proposed to use thin films of various materials - fragile (chrome), oxidation (aluminum and titanium), plastic (copper), perspective (silicon), in order to obtain nanospikes, nanojets, cascades nanospikes-multiple nanoparticles

PS2-57 The technology of forming a component for a micromechanical system

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One of the main topics in the subject of optical micromanipulation is the use of vortex light beams for the realization of optical drive for micromechanical systems. It is necessary to form the micro-object special form to transfer the torque of a light beam in a micromechanical system (microturbine). The shape of the object must ensure the maximum efficiency of transmission of torque in a vortex light beam. This can be achieved an exact reproduction of the surface shape of the microturbine during the manufacturing process. Recently three-dimensional micro - and nanostructures are used in various area of science: photonics, optoelectronics, medicine and other area. The manufacturing technology of such structures are developed, though they are made of various materials of arbitrary shape or have a complex architecture. For the manufacture of three-dimensional objects using the two-photon polymerization, multibeam holography, anisotropic etching, and replication – 3D-nanoimprinting.

Technology two-photon polymerizationis the most convenient and accurate method. However, this technology has a distinct disadvantage: considerable time spent in the production of three-dimensional structures, and as a result, produced a small amount of micro-turbines. Photolithography has been used for the manufacture of such a component for microelectromechanical structures (MEMS) for a long time. Demand for compact power sources for portable electronics has increased significantly at the end of the last century. For them, manufactured millimeter size turbine by a photolithography method. Such devices are known as microelectromechanical systems (MEMS).

MEMS technology allows to obtain a micromechanical and optical components are much smaller than traditional technologies. Using photolithography it is possible to make microturbines the right size for an optical drive. Moreover, the earliest work on the rotation of the micro-turbines fabricated by a photolithography method.

In this paper presents a method of manufacturing microturbines on the basis of the ultraviolet beam exposure of thick-film photoresist. This method compares favorably to two-photon polymerization technologies he rate of formation of micro-turbines and precision.

PS2-58 Laser-induced formation of nanoparticles from the ultra-thin metal films in the air

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Recently, the studies of metal nanoparticles have been getting a lot of attention, due to their wide implications. The fields that they are used in are IT, ecology, energy industry, optics, chemistry, biology, medicine, and others. In more detail, in the medical field, they are used to determine the level of certain antibodies in the organism [1] and to study the properties of proteins [2]. In optics and photonics, nanoparticles are used in Surface-Enhanced Raman Scattering [3], enhancing fluorescence [4] and determining the refractive index change of various materials [5]. Another very popular topic nowadays is photovoltaics, where nanoparticles are used to increase the absorption of light in the solar cells [6].

Laser-induced formation of nanoparticles is of great interest due to its chemical purity, which is a very important requirement in a number of applications, simplicity and a wide range of resulting nanoparticles' shapes and sizes.

In our study, thin films of silver were used for laser-induced formation of nanoparticles on the BK7 glass in the air. The thickness of the films was 62 nm, 82 nm, and 175 nm respectively. We used ArF excimer laser (wavelength λ = 193 nm, pulse duration τ = 17 ns, frequency f = 20 Hz, pulse energy Ep is up to 250 mJ). Two regimes of formation were realized by changing the processing parameters (the intensity, the number of pulses per spot): above the melting threshold and above the ablation threshold of material. For reducing the thermomechanical stresses, the films were additionally heated to 100–400 K in a number of experiments.

Silver nanoparticles with a size, ranging from 15 to 200 nm, were formed. Obtained nanoparticles were characterized by means of optical, scanning electron and atomic force microscopy and the transmittance spectra were measured as well. A formation mechanism was studied to demonstrate a possibility of nanoparticles size control.

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PS2-59 Laser-assisted deposition of the bimetal thin films with predifined optical and electrical properties

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In this work, we investigated the influence of morphology (particle diameter, the distance between the deposited particles, the number of layers etc.) on the optical and electrical properties of the deposited bimetal thin films.

Thin nanostructured noble-metallic films demonstrate nonlinear optical effects in visible spectral range because of their plasmonic properties. In addition, optical characteristics of these thin films strongly depend on the period of the formed surface structures. If the distance between the deposited particles is close to their sizes, the optical and electrical properties of the randomly deposited structures may considerably differ from these of the periodical ones. Thus, sintering of the bimetallic gold and silver complexes results in pronounced changes in the properties. In this case, both morphology and shape of the deposited particles influence the final optical and properties. In addition, a control over electrical properties of the deposited structures is of a great importance. In this kind of systems, electron spreading differs from the one in solid films. Electrons locating in the conduction band both near and above the Fermi level give rise to the continuous spectrum because of the movement along the deposited layer. When the height of the layer reaches several tens of nanometers, a competition between ballistic and diffusive conductivities take place.

The optical and electrical properties of the deposited bimetallic films are shown to change as a function of composition and geometry. The morphological properties of deposited nano-clusters were investigated using atomic force microscopy (AFM) and scanning electron microscopy (SEM).

We have presented experimental and modeling investigations of the optical and electrical properties of nanostructured bimetal thin films.

PS2-60 FTIR srectroscopy of organic co-crystals of 4-nitrophenol with aminopyridine derivatives for NLO applications

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One of the classes of nonlinear optical (NLO) materials are organic crystals and co-crystals with large NLO coefficients. The formation of such adducts can be studied by IR spectroscopy. The main idea of this work is to find intermolecular bonds in co-crystals by FTIR spectroscopy. The investigation of IR spectrums co-crystals based on the 4-Nitrophenol with aminopyridine derivatives and their components was carried out by FTIR spectrometer at the range of 450 – 4500 cm^{-1} The co-crystals based on 4-nitrophenol with aminopyridine derivatives: 2-aminopyridine, 4-aminopyridine, 2-methyl-6-aminopyridine and 2,6-diaminopyridine were chosen as the samples. Two methods of sample preparation were used: a tablet with potassium bromide (KBr) and coating of sample on the fluorit (CaF_2) with usage of vaseline. KBr absorbs from 3700 cm^{-1} and has “fail” at 3400-3600 cm^{-1} due to influence of water molecules, thus to identify fluctuations of other molecules is impossible. For obtaining spectrums of other molecules at this range, it was used the second method of sample preparation. The bonds between molecules in co-crystals were detected by single regions of spectrums. Comparative analysis spectrums of co-crystals and mixture of single components showed their differences. Few fluctuations in spectrums corresponding fluctuations of aminogroup were found, which point the bond between crystals in the co-crystals.

PS2-61 Research influence of introduction ZnO and SiO_2 nanoparticles in polymeric matrix on thermal degradation of nanocomposites and holograms based on it

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Currently optical polymer composites, providing modulation of the refractive index in the holographic recording process, are intensively developing class of materials. These composites are technologically advanced, have a high photosensitivity, a wide range of refractive indices and low cost. Thus, the photopolymer composites have become perspective materials for fabrication of holographic diffractive elements [1].

Photopolymer composites typically consist of a homogeneous mixture consisting of various photosensitive monomers and photoinitiator of polymerization. In recent years, to improve the performance of holographic nanocomposites in the monomer mixture began to introduce various nanoparticles. Used in this work transparent nanocomposite materials with low lightscattering consisting of commercially available nanoparticles of ZnO or SiO_2 and acrylate monomers, have been developed at the Department of engineering Photonics for holographic recording [2].

Holographic recording is carried out by photoinduced modulation of the refractive index resulting from periodic changes in composition and density during light curing of monomers, and concurrent mutual diffusion of the component when recording the interference pattern [1].

Thus, were developed transparent nanocomposite materials consisting nanoparticles of ZnO or SiO_2 and monomers suitable for holographic recording. Also, the work was carried out research influence of ZnO and SiO_2 nanoparticles in polymer composites on thermal degradation of the nanocomposite and holograms recorded on this nanocomposite by the methods of thermogravimetric analysis. Was established the time dependence of the diffraction efficiency on the composition and heating. Also studied were the kinetics of polymerization and the features of the formation of periodic structures in holographic recording in polymer composite. Depending on the composition of the polymer matrix and nature of nanoparticles observed significant changes of the induction period, polymerization rate and degree of conversion.

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PS2-62 Recording of interference patterns on thin metal films by laser irradiation

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Micromachining with employing multi beam interference of several laser beams have a numerous application. This approach is capable of producing the subwavelength resolution in the area of irradiation. The resolution of interference pattern can be settled by changing the incidence angle of the beams, wavelength, polarization and so on. Such micro- and nanostructures are in a great demand in diffractive optic, microelectronics and photonics.

Different approaches were supposed and demonstrated for realization of multi beam interference. The usage of microoptical elements (MOEs) as a beam splitter for short and ultrashort pulses is more preferred [1]. Production of which deserves separate consideration. Thus, photolithography, hot embossing and reactive etching are most popular among traditional approaches of MOEs fabrication [2]. Besides, there are a lot of methods and technologies were realized in laser technologies. The combined technologies based on strong absorption of laser radiation with different solution or metals contacting with the back side of the glass plate obtain an extensive use for MOEs formation on glass surface [3].

Thus, a new laser technology for glass surface microstructuring has been developed by our team and called laser-induced action of microplasma (LIAMP). We could form different MOEs, such as random phase plates with elements of a square shape (0.2–1.7 μm), diffraction phase gratings with period 30 – 100 μm and microlens arrays with microlens diameter 150 – 500 μm [4].

The aim of this work is the application of MOEs, formed by LIAMP, as a beam splitter in multi beam interference scheme for metals films processing.

The laser beam was split into two or six beams by using the diffractive phase grating. The confocal imaging system was used to produce interference pattern on the metal film. As a result, microprocessing with a period varying from 1 to 3 μm were produced.

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PS2-63 Technology of glass micromachining by laser-induced plasma

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group from the department of Laser Technology has developed a technology that allows to modify the surface of optically transparent materials [1-3]. The operating principle of the technology is the following: laser light is focused in the contact plane of the glass with graphite plate, and during specific processing conditions the plasma jet can be arisen, which processes the bottom surface of the glass. The fiber laser with a wavelength 1064 nm is used as a laser radiation source. Simple application of complex image is ensured by the use of galvanometer scanners that provide the resolution in the X and Y-axis ~ 2.5 μm.

Particular attention should be paid to the possibility of the optical materials microstructuring. Thus one of the application of this technology - is the creation of a broad class of micro-optical elements, which are used in laser, medical technology and photonics. The ability to create contrast images allows to use the technology for the marking of transparent products. For example, printed bar code or QR code can be recognized by the mobile applications. Besides, it is possible to control the degree of image stability to mechanical stresses. So, the image can be easily removed or long-life, depends on real need. Simple images can be formed within seconds, that allowed to apply the technology at production site.

The main advantages of the technology - non-waste, environmentally friendly due to the absence of chemicals or dyes, mobility, ability to integrate, and more economical use of consumable materials.

The work was performed by the RSF agreement № 14-12-00351.

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PS2-64 Features of the nanosecond duration laser pulses thermostrengthening

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One of the most popular uses of lasers in the metal is laser thermostrengthening. This technology is used to change the functional and physico-mechanical properties of steels and alloys through structural changes. Thanks to the aforementioned technology a significant increase of products wear resistance achieved.

The aim of this work is to identify the differences between the results of thermostrengthening conducted by the laser operating in the mode of nanosecond pulses, from the results of a cw laser. It is also important to obtain a description of acting on the material during nanosecond processing effects and physical-chemical transformations occurring in the material being processed.

The comparison of the results obtained on two lasers: continuous ytterbium fiber laser IRE-Polus and a fiber pulsed laser Minimarker is presented in the work.

PS2-65 Design of single mode all-solid photonic bandgap fiber for nonlinear scattering suppression

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Power scaling of the fiber lasers enhance nonlinear processes during the light propagation in the fiber. The fundamental solution to fiber nonlinearities is to increase mode areas in fibers while maintaining single-mode operation. This gives rise to a high-quality output beam that enables tight focusing onto distant targets. However, increasing the physical dimensions of waveguide areas in fibers results in multiple modes being supported. One solution is to design fibers that suppress higher-order modes. We discuss the design of large mode area fiber which can support the propagation of single fundamental bandgap mode in a wide spectral range. A special arrangement of high refractive index cores in transverse cross-section of the fiber allows to design narrow band stops in transmission spectrum. The band-stops arise due to excitation of index-guiding modes in the high-refractive index cores. The band-stops depends on the radius of high-refractive index cores. The transmission of the fiber can be tailored to suppress stimulated Raman scattering and Brillouin scattering. Suppression of the nonlinear scattering allows to maintain spectral shape of laser output radiation.

PS2-66 Laser methods for production of the glass-like material based on silica sol-gel with impregnated nanoparticles

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Glassy nanocomposite materials due to their unique properties, depending on the initial composition, methods of production and processing with increasing frequency are used in photonics and microsystem technology as new functional materials with controlled optical properties. Silicate sol-gel used as a base of the future material are of the great interest in the manufacture of such composites. However, sol-gel technologies that are currently in use are quite difficult and based on the time-consuming heat treatment in a furnace. The possibility of local and rapid processing of the sol-gel impregnated with a variety of nanoparticles (NPs) is the actual problem. Probably, one way to solve the problem is the use of laser radiation at the stage of initial sol-gel impregnation, drying and sintering of the final composite.

The goal of the research is a feasibility study of laser radiation use for development of thin glassy structures, based on silica sol-gel with impregnated NPs.

Silicate gel obtained on the basis of homogeneous solution transition into a sol and then into a sol-gel may serve as a matrix for NPs embedding. Whereas after heat treatment, it allows the formation of a final product with different properties. Laser method provides a fast heat treatment process, and the use of laser sources with pulse duration ~ 10^{-8}-10^{-6} s gives a high localization of an impact on the sample. To obtain glassy structures it is necessary to realize two steps during the laser processing: heating to the temperature of water evaporation (drying) and the final process of glass formation at a higher temperature (firing and sintering).

In this study, laser processing of composite based on silica sol-gel was realized with nanosecond pulses (1.07 μm, 100-200 ns, 20-70 kHz, 10-15 W). In this case, the material poorly absorbs the radiation; therefore, a silicon wafer was used as a heater for sol-gel layer pressed by fused silica plate. During scanning defocused beam was absorbed by the silicon plate, heating it and allowing heat treatment of the material. As another method of heating of the composites based on sol-gel CO2 laser was used, which photons energy corresponds to an energy of Si-O bonds vibrational levels. It provides a high absorption of radiation by silica gel and its intense heating. Drying at such laser processing was performed at temperatures of 250 – 300°C for 2-4 minutes, and sintering – at 1000–1250°C for several seconds. The temperature was measured by a thermal camera FLIR Titanium 520M. NPs used for impregnation were obtained by the method of pulsed laser ablation of titanium and silicon plates in a volume of the silica gel.

PS2-67 Evaluation of territories with oil deposits using Raman spectroscopy

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Nowadays the question of replenishment of hydrocarbon resource base and finding new and additional sources of energy raw materials becomes more relevant for the oil industry in many countries. Prospecting and exploration of hydrocarbon fields is very difficult and expensive problem. Therefore the development of operative and inexpensive methods for detecting oil and gas fields is the issue of the day. Using vegetative biological objects as local integral indicators is suggested to solve this problem.

Laboratory and field studies were carried out, resulting in more than 100 plants were studied. Territories with oil deposits were selected as study areas.

The main method for monitoring was Raman spectroscopy method, containing radiation source, fiber system of collection and supply of emission, SR-303i spectrophotometer with integrated digital camera ANDOR DV-420A-OE (1024x256).

Accuracy of the method did not exceed 4%. Processing of Raman spectra was carried out in the Mathematica'8 software environment. Statistical variation of optical parameters of plants, selected from the same area did not exceed 15%. In parallel was carried control of light conditions, humidity and soil acidity.

Spectral features of plants growing in territories with oil deposits were obtained. The main changes in Raman spectra of plants were detected at 605 cm^{-1}, 840 cm^{-1}, 2120 cm^{-1} wavenumbers, for oscillations of bromine, aromatic carbons and methane in plant leaves respectively. Based on results, obtained in process of studying, were introduced optical criteria for assessment territories with oil deposits.

PS2-68 Resolution of laser thermochemical recording on metal films: spatial distribution of oxide layers in submicron level

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Laser thermochemical recording on thin metal films is one of the basic processes in diffractive optics producing. The main challenge in this topic nowadays is the recording resolution increasing which is needed for expansion the bandwidth of diffractive optics operation to deep ultraviolet region. A research of spatial resolution of thermal and thermochemical images recorded with submicron laser beam is the problem to be solved necessarily.

So theoretical investigation of resolution of laser thermochemical recording at thin metal films on glass substrate by sharply focused laser beam becomes the main topic of presented paper. The results of modeling the oxide layer thickness and film temperature during the laser action are discussed. Peculiarities of laser heating the thin titanium films (such as quasistationary heating regime and preliminary heat conduction to the glass substrate) that we've shown previously [1] were used to perform the modeling. The main dependences of resolution parameters of recording from laser beam radius and other processing parameters are shown. Gained results are essential for designing and developing the technology of high-resolved recording the subwavelength diffractive optical elements.

This work was supported by RFBR's grant for oriented fundamental research 14-29-07227.

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PS2-69 Glass spheres produced by a liquid-assisted laser ablation of aluminosilicate ceramic: characteristics and process details

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The method of water-assisted laser ablation characterized by the presence of the auxiliary liquid (usually distilled water) in the working area is used widely in precise machining of nonmetallic materials nowadays due to the possibility of significantly enhance the processing efficiency [1-5]. It seems that processes related to this impact were studied insufficiently, and unexpected concomitant effects could occur. As we showed earlier [6] thin glassy spheres appearing over the hole right after the laser drilling of aluminosilicate ceramics. This work presents the results of studying the peculiarities of their appearance.

Laser radiation by fiber Yb-laser (wavelength 1070 nm) was used to conduct the experiments. Aluminosilicate ceramic plates (7 mm-thick, approximate composition: 80% SiO_x, 20% AlO_y, less than 1% FeO_z, etc.) soaked with liquids in the working area were used as the samples.

Temperature and geometrical kinetics of spheres formation was determined by using the AOS X-Motion camera for high-speed videography and FLIR Titanium 520m camera for thermography. The paper presents the characteristic depending on the height, width and volume of spheres formed from the current time with the pulsed and cw laser radiation, assisted with different liquids. The mechanism has been offered, comprising blowing molten layer of glass ceramics the most infusible components (SiO_x, AlO_y) by water vapors from pores.

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PS2-70 Laser glass drilling in liquid combined with metalizing

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Laser ablation of materials is a topic of particular interest among the researchers nowadays, since this technique is widely used in the technological material processing. Improving the quality and efficiency of different materials processing by means of laser ablation in liquid or wet laser ablation have been shown by the researchers lately [1]. Problem of laser processing the transparent materials may also be resolved by treatment in a liquid. For instance, cutting of such systems as sapphire – water solution of the alkali metals salts by radiation of holmium laser [2] and silica glass – the copper sulfate water solution by radiation of Nd:YVO4-laser [3] have been shown earlier. Drilling of soda-lime glass with a fiber Yb-laser in the copper sulfate water solution has been shown by us recently as well [4].

In presented paper the further improvement of the laser drilling of soda-lime glass assisted with copper sulfate solutions is reported. Exposure was performed with pulses of 200 ns duration with repetition rate of 20 kHz. Irradiation of the 1 mm-thick sample for 5 s by the laser beam (wavelength 1070 nm, power density of about 10 GW/m^2) led to formation in the glass the quasiconical profile through-holes with the diameters about 100 μm. The impact of the laser radiation on soda-lime glass was investigated using the high-speed camera AOS X-Motion and optical microscope Carl Zeiss Axio Imager A1m. It is noted that laser drilling in the water solution of $CuSO_4$ causes the sedimentation of highly reflective layer (copper, supposedly). It was shown that this process occurs stronger with an aldehyde-based solution of $CuSO_4$, which is originally supposed to be used exactly for sedimentation process [5]. This way we managed to perform the observation of both laser liquid-assisted ablation and metalizing of glass. Presented materials could be useful for improving modern laser surface treatment and metalizing techniques.

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PS2-71 Method of decoration of jewels by nanosecond laser pulses

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This work describes a method of coloration of precious metals (silver and gold) based on local laser oxidation of covered by titanium film. Reflectance spectra of obtained samples and color coordinates are shown. Wear-resistance tests were also performed.

According to previous works [1,2] it is possible to obtain the oxide films with defined color characteristics on the surfaces of some metals, such as titanium and stainless steel by the technology of local laser oxidation. The growth of oxide film can be realized due to nanosecond laser pulsed heating of metal surface. Thickness of layer depends on laser processing parameters. It was demonstrated previously [3] that interference in thin oxide layer and the intrinsic color of the massive oxide define the surface color. However, precious metals, such as silver and gold can't be oxidized in air. Therefore, the new method of coloration was proposed. The titanium film was deposited with PVD method on the polished silver plate and then it was treated by laser pulses.

Obtained samples were examined with microscope spectrophotometer MSFU-K. Reflectance spectra were measured and coordinates of CIE Lab color space were calculated. Wear-resistance was tested by series of experiments including mechanical, chemical and thermal impact. The sample was rubbed with a felt wheel rotating with a frequency of 6600 rpm for 5 minutes. No visual changes in color and structure were observed. However, the image was completely destructed in 23 seconds of polishing with the Dialux bleu paste. The sample was resistant to immersion in a 5% solution of citric acid and processing in an ultrasonic cleaner. The heating up to 600 ˚C didn't damage the surface but the soldering (temperatures > 1000 ˚C) caused the change of color. Scratching the surface by metal needle destructed it due to the low hardness of metals. Overall, the tests showed a sufficient level of wear-resistance of color coating for jewelry industry.

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PS2-72 Femtosecond laser drilling of layered targets monitored by plasma X-rays

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Nowadays plasma-assisted ablation of materials by ultrashort laser pulses is very attentive field of fundamental research and can be considered as a promising tool in a number of applications. There's often the need for laser drilling of inhomogeneous target that represent a layered structure in such way as to produce a hole within one layer without affecting the other. These tasks are typical in the field of precise micromachining of multi-chip modules or inmicrosurgery when perforation should be done in bone tissue with no affection on the nearby blood vessels and nerve fibers. Naturally, there is an urgent need of on-line monitoring of laser perforation.

We have shown that drilling of multi-layered structures placed in the air by tightly focused femtosecond laser radiation with high fluence (up to 1000 J/cm^2) can be monitored online using plasma-induced X-ray emission and second harmonic of incident laser pulse. Technique based on

X-rays registration appeared to be more flexible than the method based ondetection of second harmonic since its accuracy depends crucially on target type.

We demonstrated that the X-ray signal clearly indicates the transition from one layer to another during the microdrilling of targets consisting of 2-4 layers of titanium foil when fs-laser beam is focused beneath the target surface at a depth comparable to the layer thickness.

The diagnostics of microchannel production in chicken eggshell was firstly performed. It was found that the presence of albumen beneath a shell accounts for longtime generation of X-ray pulses.

This work was supported by the RFBR grant # 14-02-00814 A.

PS2-73 Laboratory setup for fiber bragg gratings inscription based on talbot interferometer

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There are three basic fiber Bragg grating (FBG) inscription methods which are widely presented in modern literature: phase mask method [1,2], point-by-point [3,4] and interferometric ones [5,6]. The interferometric FBG writing method, shown on Fig. 1, has several advantages:

- the absence of direct contact of phase mask with optical fiber allows to write FBGs during the optical fiber drawing process;
- reduced radiation-absorbed dose on the phase mask, compared to phase mask method;
- an obtained diffraction structure period adjustment by mirror rotation significantly simplifies the inscription process of refractive index gratings with required Bragg wavelengths.

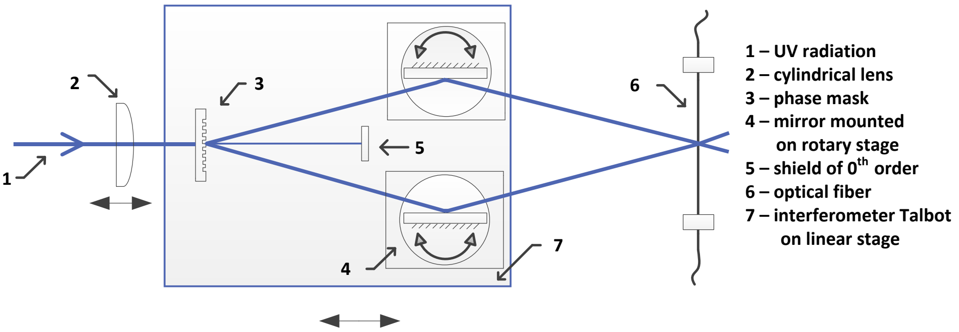

Fig. 1. FBG writing scheme based on Talbot interferometer

The excimer laser system MOPA CL-7550 (Optosystems Ltd. Russia) with a KrF gas mixture was used as the radiation source in the experimental setup. MOPA CL-7550 is a Master Oscillator – Power Amplifier laser system, which provides high temporal (> 10 mm) and spatial (> 5 mm) coherence, operating at 248 nm with a pulse repetition rate and nominal energy up to 50 Hz and 250 mJ respectively.

To provide tuning and stable operation during a long runtime of the experimental setup, the following systems have been assembled with it:

- spectral width control system, based on Fabri-Perot interferometer;
- laser beam energy distribution control system based on beam profile analyzer Ophir Optronics SP 620;
- monitoring system of laser pulse energy density on the optical fiber;
- optical fiber to the laser radiation relative position control system.

The KrF excimer laser system beam polarization influence on FBG inscription efficiency research was carried out. Developed laboratory setup provides stable FBG inducing at single- and multipulse inscription modes.

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PS2-74 The microstructural and spectroscopical investigations of nanoclusters and periodic microstructures induced on the surface of crystal and amorphous silica by resonant CO_2 laser irradiation

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The creation of nanoclasters and micrometer sized periodical structures at the surface of silica (crystal quartz and fused quartz) by action of pulsed CO_2 laser radiation (pulse energy of 1 J, pulse time of 70 ns) have been investigated. The samples was irradiated by CO2 laser in two regimes – single-mode (fluency of 40 J/cm^2) and multi-mode (fluency of 48 J/cm^2) and with two laser frequency - 975 and 1076 cm^{-1} .

The images of laser spots by means of the high resolution optical microscop and atomic force microscop have been made. The infrared (IR) reflection spectra and luminescence spectra of irradiated surface also have been recorded. It has been observed that by laser action on the surface of samples two kind of structures have appeared – periodical micron-sized structures with the period length close to wave length of CO_2 laser irradiation and nanoclusters with size close to 50-100 nanometers. It has been observed that the relief depth of the periodic structures depends on laser pulses number. The maximal highness of nanoclusters at the resonant frequency of laser (1076 cm^{-1}) has been observed. We believe that these nanoclusters consist mainly of silicon atoms that confirm the luminescence spectra of irradiated sample.

The IR reflection spectra for irradiated samples show the enhancement of reflectance in the region of laser frequency with the band width of 20 cm^{-1} for crystal quartz. More high enhancements have been found at the frequency of 1076 cm^{-1}. It has established that the reflectance enhancement has an accumulating character, namely, dependence of this ones on the number of laser pulses incident upon the samples take place.

We can conclude that the microstructure and nanoclusters formation connects with the resonant interaction of CO_2 laser radiation with silicates [1].

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PS2-75 Formation of silicon nanocomposite by laser-induced oxidation of porous silicon doped by rare-earth elements

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Oxidized porous silicon has a great prospects as a material of silicon photonics [1] due to its specific optical and electro-physical properties. Laser-induced oxidation of nanoporous silicon allow to realize no-lithography method of creation areas with silicon nanoclusters embedded in silicon dioxide matrix, which can be used as waveguides and provide a basis for different photonic devices.

The aim of this work was to optimize processing mode of laser oxidation in air of nanoporous silicon doped by rare-earth elements for creation of silicon nanocomposite with high photoluminescence yield at transparency window of fiber optics based on quartz.

To form the layers of silicon nanocomposite comprising erbium and ytterbium silicate we used ytterbium pulsed fiber laser at wavelength 1.07 μm. Irradiation was carried out in air under normal conditions. Creation of the phase of silicon dioxide was confirmed by IR-spectra measurements. It is shown that with increase of absorbed radiation dose the intensity of absorption peaks corresponding to silicon dioxide increases. It was found that areas of oxidized porous silicon, which contains erbium and ytterbium silicate, have intense photoluminescence at room temperature at wavelength corresponding to transitions of rare-earth elements (${}^4I_{13/12} \rightarrow {}^4I_{15/12}$ and ${}^4F_{5/2} \rightarrow {}^4F_{3/2}$).

The study of generation-recombination processes and injected charge transfer process allows to estimate the basic parameters of deep traps in system Si-nanocluster – silicon dioxide.

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W1-2 Opto-thermal and opto-acoustical converters for laser surgery

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Laser radiation is widely used for processing of different materials, including biotissue. Recently, diode lasers emitting in NIR wavelengths range 0.81-0.98 μm are used in medicine. The radiation of these diode lasers is extremely low absorbed by biotissues. For most operations, the efficiency of laser treatment is higher, then higher the light absorption coefficient of biotissue. In this case, the conversion efficiency of lasers radiation into thermal or acoustical energy in biotissue is very low. As a result, the efficiency of biotissue destruction is low, and collateral damage (coagulation, denaturation and necrosis) dimensions are significant. To improve the conversion efficiency of laser radiation into thermal and acoustical energy, a special convertersare placed on distal end of optical fiber through which the laser radiation is delivered to the biotissue. These convertersare called fiber-optic thermal converter (FOTC) or fiber opto–acoustical converter (FOAC), sometimes - blackened tip, and sometimes - hot tip.

The report presents the results of theoretical and experimental investigationthe various typesofconverters (FOTC, FOAC).

The technological features of converters creation are discussed. Converters are classified on film and volumetric by the structure. Converters are divided according to the type of absorbing centers also, including carbon, and oxides of titanium or others. Converters can be created as a result of single- or multistage process, with or without involve of laser radiation. Absorbing centers can be placed on the surface of fiber end or integrated inside of fiber end as a meta-material. The temperature and volume expansion of the converterscan be changed during laser surgery and control by feedback system (adaptive processing).

The paper discusses the results of *in vitro* studies and *in vivo* applications of fiber-optic thermal converters (FOTC) and fiber opto–acoustical converters(FOAC) for adaptive processing (coagulation, excision, cleaning) of tissue in dermatology and dentistry.

W1-3 Laser modification of cartilage structure and shape in otolaryngology and orthopedics

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As lasers used for tissue ablation and coagulation in surgery for a long time, their application for controllable tissue modification is relatively new and opens new avenues in medicine. In 1992 we identified laser-induced stress relaxation in the biological tissues. This led to the development of a family of novel laser applications for the non-ablative correction of nasal septum shape, making cartilage implants, restoration the joints and intervertebral discs. This paper will present state of art and some new results in cartilage reshaping and regeneration under thermo-mechanical effect of laser radiation. We will characterize the physical processes and mechanisms involved in the laser-induced modification of tissue nanostructure and stress relaxation. In particular, the following mechanisms of laser-induced tissue regeneration will be considered: 1) Dynamic mechanical oscillations activate ell differentiation, de-differentiation, proliferation, and new matrix production, 2) Temperature gradient enhances mass transfer in cartilaginous matrix, in particular, transport of morphogenetic molecules to stem cells and chondrocytes, 3) Micro-pores in cartilage matrix promote water permeability and provide feeding and breathing of biological cells. Theoretical model allowing optimization laser settings for formation of nanopore system in the cartilage will be presented. The efficacy and safety of laser treatment can be ensured using optical methods for monitoring laser modification of the tissues. We will show that magnetite nanoparticles are useful for early diagnostics of osteoarthritis and optimization of laser technology. Clinical examples and prospects will be discussed.

W1-4 Adjuvant and intraoperative photodynamic therapy in the surgical treatment of malignant tumors

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Long-term results of treatment and quality of life of cancer patients, treated with combined therapy, are often limited to the development of local recurrence. Photodynamic therapy along with radiation and chemotherapy, in many specialized clinics in Russia becomes equal and effective component of a combined treatment of malignant neoplasms.

Purpose - to improve long-term results of treatment of certain nosologic forms of malignant tumors by using neoadjuvant and intraoperative PDT.

Material and Methods. Neoadjuvant PDT was performed in 42 patients with primary melanoma of the skin. The control group was comparable for all clinical parameters, made up of 42 patients who underwent radical surgery only.

Intraoperative photodynamic therapy was performed in 15 patients with pleural mesothelioma and 39 patients operated on for gastric cancer stage II-III.

Results. The postoperative period in comparison groups uneventful. Long-term results were followed up to 60 months. Statistical analysis was performed using the Kaplan-Meier method. The findings suggest that a substantial increase in the performance and reliability of relapse-free and overall survival in patients, treated with neoadjuvant PDT and intraoperative PDT. For example, disease-free survival in the study group with melanoma was 92.7% (in the control-31.7%, $P = 0.002$). Overall survival - 83.1% (control - 56.1%, $P = 0.001$). Five-year disease-free survival in gastric cancer was 78%, versus 38% in the control group. When mesothelioma - of 15 patients from 9 persons have been recorded of local recurrence. At an average follow-up of 20 months the median survival was 19 months. (7-31 months.)

Conclusions. PDT is an effective method of malignant tumors treatment, significantly improves the results of surgical treatment.

W1-5 Features of pain management for lasers application in dentistry

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Incision of tissue with a scalpel or other surgical instrument leads to activation of pain, mechanical and thermo receptors damaging factor converting energy into the sensor information that sensory chain reaches the central nervous system and produces pain in the patient's mind, as well as psychological and somatic motor reaction. Waiting for surgery is accompanied by deterioration of psychosomatic condition, which leads to an exacerbation of pain response and reduced effectiveness of pain relief.

This is most clearly seen with patients who will be treated be a dentist, due to the unique features of the organization of sensory tissues of the maxillofacial region. This explains the need for the most effective analgesics, which is usually achieved by means of additional injections of local anesthetics combined with vasoconstrictors. However, this can affect the patient's general condition and the regeneration of tissue in the recovery area.

Analysis of the results of studies of psychosomatic condition of the patients that were conducted before the operation on its main stage, as well as in the postoperative period, demonstrated that the reduction or elimination of activation of mechano-receptors, through the use of thermo-optical surgery, significantly reduced the amount of sensory information and how consequence, reduced demand for local anesthesia in 5-6 times. Application of new methods of combined anesthesia: conscious sedation patient ksenon- oxygen mixture, e- analgesia in various combinations with minimal doses of painkillers deposits, resulted in significantly better health of patients during surgery, the lack of post-operative pain, less swelling of collateral tissue compared to patients who were operated with "standard Protocol".

This demonstrates the feasibility of further development and introduction into clinical practice of innovative medical technologies that enhance the efficiency and quality of diagnostic and treatment process on the basis of a rational combination of laser technology with effective and safe anesthetic methods and means.

W1-6 Mid-Ir tunable laser system: an alternative to the free-electron laser for medical applications on a tabletop

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We demonstrate efficient tissue ablation using a novel all-solid-state table-top mid-IR laser tunable within the water absorption peak (3,000 to 3,500 nm) as a valuable alternative of mid-IR Free Electron Lasers (FEL). Studies of the ablation process in different types of tissues and at different wavelengths across this biologically important spectral region have been carried out.

Since the discovery of lasers, they have been viewed as promising instruments for producing specific material states by selective manipulations that could not be realized by conventional incoherent addition of thermal or electronic energy to the material. Although the selective laser chemistry is still a dream, the selective control of material processing done by optimization of laser wavelength, pulse duration, pulse energy per unit area and laser average power is frequently used to move some contemporary technology beyond of its limits. The utilization of the unique mid-infrared (IR) laser radiation in hard and soft tissue and in materials research has produced and identified a wealth of high-impact applications and potential technology breakthroughs in these areas. Until now, mid-IR free-electron lasers are major laser sources which have been successfully used to demonstrate a number of new emerging technologies e.g. surgery with minimal collateral damage- brain surgery, optic nerve sheath fenestration, drug and gene transfer and laser induced syntheses of new materials. Free-electron lasers are multimillion-dollar facilities with unique pulse characteristics and they are not accessible to the general public. Many of the above applications require optical pulses shorter than the characteristic thermalization time of the material, and pulse energies sufficiently high enough for material ablation. In addition, the average power of the laser has to be large enough to enable “high-throughput” and acceptable product yields.

A portable and cost-efficient alternative to the FEL providing high energy/average power tunable mid-IR radiation can be obtained based on all-solid state laser technology. Using a optical parametric conversion in combination with novel near-IR laser pump source near 1 μm and new non-linear materials we have obtained high-power (>3 W) tunable laser radiation across the peak of the water absorption ~ 3 μm with an unprecedented energy level (>6 mJ) at a repetition rate of 500-1000 Hz. This laser system promises new capabilities for optimization of surgical treatments because the incision parameters (i.e. ablation profile, collateral cell damage etc.) depend on the structural properties and water content of the tissue. Thus the laser can be used to develop a minimally invasive surgery in a tissue-specific manner.

W1-7 System for Image Guided Laser Surgery

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An all-optical system for imaged-guided laser surgery is presented. Optical coherence tomography (OCT) provides a powerful imaging tool for detection of a variety of tissue structures. Although OCT has become a standard of care in ophthalmology and cardiology, challenges exist to apply this imaging modality to surgical applications in highly scattering tissues. An OCT-guided laser surgical system that can rapidly cut and coagulate tissues is described. Experimental studies demonstrating application of the OCT-guided laser surgical system to perform specialized surgical procedures are described. The prospects and challenges for OCT-guided laser surgery are identified and discussed.

W1-8 Volumetric multi-spectral optoacoustic tomography for high performance structural, functional and molecular imaging

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Optoacoustic (or photoacoustic) imaging is an emerging hybrid modality that can deliver excellent endogenous and exogenous optical absorption contrasts from living tissues. Optoacoustic signals are not affected by light scattering, which further shatters the longstanding depth barrier of optical microscopy by maintaining excellent spatio-temporal resolution representative of ultrasound imaging. Our state-of-the-art implementations of multi-spectral optoacoustic tomography (MSOT) are based on multi-wavelength excitation of tissues to visualize specific molecules within opaque tissues. As a result, the MSOT technology can noninvasively deliver structural (i.e., vascular anatomy, solid tumors, organs), functional (i.e., total hemoglobin concentration, hemoglobin oxygen saturation, blood flow, pH, and metabolic rate of oxygen consumption), and molecular information from living tissues. For highly sensitive molecular optoacoustic imaging, a valuable tool for personalized medicine, exogenous contrast agents (e.g., organic dyes, metallic and nonmetallic nanoparticles, reporter genes, or fluorescence proteins) with biomarkers are commonly utilized. The talk will further introduce the new realm of 5-dimensional (5D) optoacoustic imaging, which enables simultaneous acquisition of information across all the 3 spatial dimensions, the time and the spectral (optical wavelength) dimension. Applications are explored in the areas of in-vivo cell tracking, imaging of agent kinetics and biodistribution, targeted molecular imaging studies, as well as functional imaging of the brain and heart. Clinical translation roadmap will be finally discussed.

W1-9 Laser ablation and electrochemical etching as methods to form silicon nanoparticles for optical coherence tomography

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Currently silicon nanostructures have high potential not only for novel micro- and nanoelectronic devices development, but for biomedical applications as well. At certain fabrication parameters silicon nanoparticles demonstrate high biocompatibility and biodegradability degrees [1, 2].

In this work, ensembles of silicon nanoparticles (2 – 200 nm) fabricated through pulse laser ablation in water, and porous silicon nanocrystals (2 – 50 nm) fabricated through electrochemical etching were studied as potential contrasting agents for optical coherence tomography (OCT). To our knowledge, the detailed research in this field has not been carried out yet.

The silicon nanoparticle ensembles demonstrate effective light scattering for the both fabrication methods. The revealed scattering coefficient of water suspensions formed via laser ablation method was evaluated as about 0.1 mm^{-1} in the visible and near-infrared range at the nanoparticle concentration of 10^{13} cm^{-3}, while in biotissue much higher concentrations and scattering coefficients can be achieved [3]. The diffuse reflectance value of porous silicon layers reaches up to 50% in the 1000 – 1100 nm range.

Additionally, the potential of silicon nanocrystals for contrasting structural elements in OCT diagnostics was studied. The 0.3% agar gel was used as a model object mimicking biotissue. The laser-ablated nanoparticles or the mechanically grinded porous silicon were topically applied on the phantom surface yielding contrasting of maximum 14 dB and 30 dB, respectively, for the considered nanoparticle classes.

Thus, studied silicon nanoparticle ensembles are shown to be promising as contrasting agents in OCT imaging of turbid media including biotissues.

This work was financially supported by the Russian Foundation for Basic Research (project 15-32-20227).

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W1-10 Coherent effects of multiple scattering of light in biomedical applications

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Coherent effects related to the multiple scattering of light have been attracting a great attention during the last decade. This is due to both the diversity of beautiful physical effects observed under multiple scattering conditions (i.e. enhancement of coherent back-scattering, angular and temporal correlations of the scattered radiation, localization of waves, etc.), and due to the extensive use of optical diagnostic techniques in many practical industrial applications. Coherence is one of the principal parameter of laser light characterizing the degree to which the oscillating electromagnetic wave maintains a near-constant phase relationship. The spectacular manifestation of this is observed through the interference effects, such as coherent back-scattering (CBS) and angular and/or temporal fluctuations of scattered light. The radiative transfer in randomly inhomogeneous highly scattering media is successfully described by the Bethe-Salpeter equation, whereas numerical modeling of coherent effects requires particular approaches. Based on the collation of Monte Carlo simulation and the Bethe-Salpeter equation, represented as the series of ladder diagrams, we generalize the computational technique in framework of a common approach of CBS and temporal autocorrelation functions calculation, as well as for Optical Coherence Tomography (OCT). The results of simulation agree rather well with theoretical predictions of generalized Milne solution, as well as with the known experimental and numerical results. This is likely lead for example to development of practical system for the non-invasive monitoring of skin blood microcirculation in different compartments of skin micro-vascular network. Current presentation reviews the experimental approach of the in vivo measurements of skin blood microcirculation, and non-invasive optical diagnostics of skinwith few other techniques that the author deals with the last few years.

W1-11 New methods in ophthalmology

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The laser methods for (1) increasing of uveoscleral outflow path for normalization of intraocular pressure in glaucomatous eyes; (2) non-ablative correction of cornea shape and eye refraction; (3) ablation of secondary cataract are presented.

(1) Atomic Force Microscopy measurements with nanoindentation have demonstrated laser-induced formation of nanopores in sclera providing increase in the hydraulic permeability more than 10 times. At the same time, the collagen structure of the sclera was not destroyed, and tissue mechanical properties were not decreased.

(2) For correction of the eye refraction the ring-shaped laser beam with various ring diameters allows obtaining controllable alterations of the eye refraction with axial symmetry without any pathological changes in central part of cornea. Theoretical model is developed to estimate laser settings for desirable changes in the eye refraction.

(3) Optical transmission and ablation mechanisms in the secondary cataract films under the impact of 1.06-mcm laser radiation are studied. The obtained measurement data on the transparency variation in the process of laser action and calculations of temperature allowed to determine dominant mechanism of laser ablation, as well as the develop recommendations, providing the prevention or reduction of possible side effects.

For these three new methods, variation of laser power, pulse duration and frequency allowed establishing optimal laser setting, which result in (1) substantial increase of liquid transport through eye tissue; (2) controlled nonablative correction of the eye refraction at myopia and hyperopia; (3) controlled ablation of cataract films with different physical properties. Optical methods are useful to provide efficacy and safety of the laser technologies in ophthalmology.

W1-12 Assessing systemic sclerosis using optical coherence elastography

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Systemic sclerosis (SSc) is a connective tissue disease that results in excessive accumulation of collagen in the skin and internal organs. Current methods for SSc assessment can be biased by inter-observer variability and is unable of detecting the disease in its early stages. Optical coherence elastography (OCE) is a novel, rapidly emerging technique, which can assess mechanical contrast in tissues with micrometer spatial resolution. In this work, the OCE technique is applied to assess the mechanical properties of skin in both control and bleomycin induced SSc-like disease non-invasively. Elastic wave propagation and Young's modulus are recorded. Obtained results indicate that OCE is able to differentiate healthy and fibrotic skin using mechanical contrast. It is a promising and potentially useful new technology for quantifying skin involvement in SSc completely non-invasively.

W1-13 Tissue optical clearing as a novel modality to control laser-tissue interaction

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Advances of tissue optical clearing (TOC) in application to optical imaging, spectroscopy and laser treatment of tissues and organs are presented. One of the TOC technologies is based on controlling of tissue optical properties by using immersion technique via application of exogenous optical clearing agents (OCAs). Impact of OCA and water transport in a tissue, caused by an action of a hyperosmotic OCA and leading to tissue reversible shrinkage and dehydration on temporal tissue optical properties, is discussed. The specific features of TOC for fibrous and loose connective, epithelial and muscle tissues are investigated using different linear and nonlinear laser probing and treatment modalities working in the visible, NIR and terahertz ranges. *In vitro, ex vivo,* and *in vivo* studies of a variety of human and animal tissues, including skin, fat, eye sclera, muscle, cerebral membrane, digestive tract tissue, cartilage, tendon, bone, blood vessels, and blood are presented. The technologies of delivery of OCAs are also under discussion, including hidden free diffusion, enforced tissue permeability, including laser heating and shock wave generation. Impact of different OCAs on tissue structure, free/bound water balance and microcirculation are analyzed.

Experimental results on diffusivity of glucose and other biocompatible OCAs in normal and modified by cancer and diabetes tissues will be discussed.

PS1-W1-01 Oxygen dynamic's control in biological tissues by singlet oxygen-sensitized delayed fluorescence

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There is important a problem of oxygen concentration control in living tissue during photodynamic therapy. One of the most promising methods of the oxygen quantity evaluation in irradiated tissue is a using of delayed fluorescence (DF) conditioned by annihilation of singlet oxygen and triplet-exited sensitizer molecules [1, 2]. In present work, the dependence between the tissue oxygen quantity and sensitizer DF intensity is discussed. The observations have been occurring with healthy and tumor BYRB-line mouse tissues. The erythrosine as a sensitizer was used. As shown [1] the erythrosine DF is largely caused by singlet-triplet annihilation in biological tissues. After registration of the erythrosine DF decay kinetic in tumor tissue under excitation of several laser pulses with period more than of 0.2 seconds it was found that from pulse to pulse DF intensity decreases. This DF quenching increases with growth of excitation pulses energy and decreasing of its repetition period. The DF intensity reduction is reversible and it is no new bands in the luminescence spectra. We assume that similar effect is associated with a reducing of the number of free oxygen molecules as reactive oxygen species (ROS). ROS are capable to chemical bond many intracellular structures with oxidizing [3, 4]. The study of DF intensity and excitation pulses period dependence shows that full recovery of initial oxygen concentration near the sensitizer molecules will take a few seconds. Similar effect wasn't observed in healthy mouse tissues. It rises to the development of new tumor diagnostic techniques and to control tissue oxygen concentration during a therapy.

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PS1-W1-02 Subnanosecond 1 Joule laser for medicine and technology

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To reach a Joule level of output energy in nanosecond pulses a master oscillator- amplifier (MOPA) laser schematic is usually applied. This laser design architecture needs very accurate optimization of beam intensity distribution. Regular Gaussian beam profile is characterized by high peak intensity in the center of beam with low energy extraction efficiency from amplifiers. The attempts to increase Gaussian beam size usually lead to appearance of diffraction rings in beam distribution due to even very slight cutting of beam by amplifier aperture. This may lead to small-scale self-focusing in the amplifier stages especially at Joule levels of energy in nano- and sub-nanoseconds pulses [1-2]. To avoid self-focusing super Gaussian beam distribution could be used especially when application of traditional spatial filtering [2] is unreasonable for example in compact and low cost laser systems [4].

In this paper we discuss simple MOPA laser schematics producing beam and pulse shaping allowing to reach up to 1J output energy with 0.7 ns pulses. As master oscillator we used single-spatial and single-temporal mode diode-pumped Nd:Cr:YAG microchip sub-nanosecond laser. Sub-milijoule output energy of microchip laser was found to be quite enough to reach 1J output energy after amplifier with 2 regular lamp-pumped laser heads. In such schematics we do not need expensive components for beam shaping [3] and active Q-modulation [4]. The microchip laser was pumped by less than 10mJ energy of pulses from pig-tailed laser diode. Special optical system with self-made spatial filter helped us to reach optimal beam distribution in power amplifier and to provide high energy extraction and high threshold of small-scale self-focusing. So application of high optical quality and temporal structure of radiation feature of microchip laser provided us possibility to reach up to 1J energy stable sub-nanosecond pulses generation. More than 70% of second harmonic conversion efficiency of this laser output at KTP crystal was obtained.

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PS1-W1-03 The experimental and theoretical investigation of diffusion of compound in blood flow

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In the work the created experimental setup and results of the mathematical modeling of these processes are represented for investigations of diffussion of the injected compound in blood flow.

The experimental setup was created for investigation of photosensitizer diffusion in blood flow and its fluorescence dynamics. The principal scheme of the device includes network of silicon tubes and peristaltic pump which does not contact with liquid directly. Thus, the chemical cleanness is achieved. Tubes diameter is from 2 to 8 mm for vessel blood modeling. Pump power corresponds to rate of blood flow and is 30 l/h with regulation possibility. Pressure sensors are also connected on tube system for registration of pressure changing within its. Each sensor has connected on computer and can registers pressure dynamics. Its scheme let to use tubes for modeling different blood flow path.

It is shown at the mathematical modeling of the system that the curves of fluorescence intensivity have non-monotonic nature [1]. There is a sharp curves decline in the first few seconds. It is especially pronounced for 590 and 580 nm (near the "transparency window" of biological tissues). However, difference between curves for different viscosity is a little. Cells concentration has the most influence to the curves. At 560 nm fluorescence increase is weakly expressed. The greatest fluorescence increasing is observed at 590 nm.

This work was partially supported by president fellowship № SP-273.2015.4.

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PS1-W1-04 Complementary usage of pixel classification algorithm and angiography postprocessing in optical coherence tomography

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In this work we developed new tissue classification approach which allowed us to distinguish between normal and pathological tissue in mice ear with injected CT-26 murine colon carcinoma cells. Proposed classification algorithm uses as initial features only values of OCT signal in the same A-scan in N pixels above and below pixel to be classified. This neighborhood of a target pixel holds information of both local signal average value and attenuation. Method consists of two steps. At first step we used big number of recorded tomograms and decomposed all possible combinations of OCT signal value sequences in 2N neighboring pixels sets in one A-scan, using Principle Component Analysis decomposition. At second step of the method we used small number of tomograms labeled by an expert by comparison OCT and histology images taken at the same day. Thus we used semi-supervised machine learning scheme which allows us utilize information from a number of tomograms much higher than expert was able to label manually. For each labeled pixel we construct 2N A-scan-neighbor feature vector, decompose it into principle components calculated at first step and used these decomposition coefficients directly for classification. As a classification algorithm we choose Random Forest Tree classifier. Classification results were verified by comparison with fluorescence image of genetically-encoded tumor.

Classification results allow us to gain more information from OCT data. Combining vessels structure obtained with OCT-based microangiography and classification result we are able to observe not only information about microvasculature structure, but also see which vessels pass through alleged tumor and which through normal tissue surrounding tumor. This information might be an important predictor of the effectiveness of photodynamic therapy.

PS1-W1-05 Skin cancer texture analysis of OCT images based on Haralick, fractal dimension and Markov random field features

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Optical coherence tomography (OCT) is an effective tool for determination of pathological topology that reflects structural and textural metamorphoses of tissue. In this paper, we propose a report about our examining of the validity of OCT in identifying changes using a skin cancer texture analysis compiled from Haralick texture features, fractal dimension and Markov random field method from different tissues. Described features have been used to detect specific spatial characteristics, which can differentiate healthy tissue from diverse skin cancers in cross-section OCT images (B- and/or C-scans). Speckle reduction is an essential pre-processing part for OCT image analyze. In this work, we used an interval type-II fuzzy anisotropic diffusion algorithm for speckle noise reduction in OCT images. The Haralick texture features as contrast, correlation, energy, and homogeneity have been calculated in various directions. A box-counting method is performed to evaluate fractal dimension of skin probes. Additionally, Markov random field have been used for the quality enhancing of the diagnosis method. Our results demonstrate that these texture features may present helpful information to discriminate tumor from healthy tissue. The experimental data set contains 100 OCT-images with normal skin and tumors as Basal Cell Carcinoma (BCC), Malignant Melanoma (MM) and Nevus. All images were acquired from our own-made Swept Source OCT. We obtained sensitivity about 96% and specificity about 99% for a task of discrimination between MM and Nevus. Further research is warranted to determine how this approach may be used to develop algorithms for counting 3D features and to create, for example, a neural network with unsupervised learning for processing 2D images.

PS1-W1-06 Skin neoplasms surgery by 980 nm diode laser with temperature control

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Diode lasers are widely used in modern dermatology for removing of nosological neoplasms of human skin. The result and efficiency of laser treatment of neoplasms depend on value of temperature reached by laser action in treatment area. In some cases, when diode laser are used, fiber-optic thermal converters (FOTC) are applied to reach the temperature required for neoplasms cutting. Converters contain the materials that absorb of laser radiation and are placed on the distal end of optical fiber. Temperature in the area of interaction between FOTC and biotissue depends on type and properties of converters, laser radiation power, type, size and localization of neoplasms, sequence of surgeon manipulations, etc.

In present report, method of distant temperature control of converter placed on distal end of 400 μm quartz fiber is described. Converter absorbs laser radiation and converter is heated. At converter heating, thermal radiation occurs. Thermal radiation go back through optical fiber of delivery system and falls on IR photodetector. After photodetector calibration, the dynamic of temperature in area of interaction of fiber-optic thermal converter with soft biotissue (neoplasms) in the range of 350-2500^{o}C can be registered.

During in vivo experiments, we removed nevus, papilloma and keratoma. For that nosological neoplasms removing, we used diode laser radiation with blackened tip. Blackened tip was formed during the neoplasms treatment, as a result of irradiation of the skin by laser radiation in contact mode and deposition of carbonized products of skin destruction on the end of quartz tip. Diode laser operate in pulsed mode with pulse duration 400 μs, repetition rate 2 kHz and wavelength 980 nm. Average power of laser radiation was 12-15 W.

Report shows the comparison the real-time pictures from operation zone, real-time dynamic of output laser power, and dynamic of temperature signal, obtained during neoplasms removal by diode laser radiation. Removing of nosological neoplasms was carried out with different surgery methods: cutting, scanning, and traction. To characterize of the efficiency of laser action we analyzed ratio of laser action duration to total treatment duration. Correlation between surgery method, laser power and dynamics of thermal signal are presented and discussed.

PS1-W1-07 3D photomechanical modeling of tooth enamel ablation by Er-laser radiation included peculiarities of laser beam spatial distribution and dynamic of enamel absorption coefficient

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Mid–infrared erbium lasers with wavelength of 2.78÷2.94 μm are successfully used for hard tooth tissues treatment (ablation) in modern dentistry. Modeling of hard tooth tissue ablation is important task for determination of features of tissue destruction and removal, describing experimental results, and prediction of a result of interaction. To date, there are many models of hard tooth tissue ablation, but none of them describes all processes completely. In particular, the influence of tissue structure, peculiarities of spatial energy distribution (flat, gauss, spikes, etc.) on ablation process and changing of optical properties of hard tooth tissue during ablation are not described.

Report describes the 3D cellular model of human tooth enamel, which takes into account enamel structure peculiarities, absorbing centers distribution in enamel at modeling of interaction between mid-infrared erbium lasers radiation and tooth enamel. 3D–model of human tooth enamel takes into account presence of free water in the enamel pores or cracks, and structure changing during ablation, that models presence of modified layer on the crater walls and bottom. As a result of structural change of enamel surface, absorption coefficient changes during ablation. In this report, we present extended 3D cellular model of human tooth enamel ablation by erbium laser radiation, which includes dynamics of absorption coefficient and spatial distribution of laser energy. In addition, we consider laser radiation shielding by enamel debris.

In experimental part of present study, we used single-mode YAG: Er laser radiation with wavelength of 2.94 μm, beam propagation ratio M2=1.5, pulse duration of 105 μs, and energy density of 8-260 J/cm^2. Microcraters were formed in enamel by single pulse of erbium laser. Enamel samples were cut along microcraters axis, microcraters shape was investigated with optical microscope, and photographed.

The model allows calculating laser microcraters shape and removal efficiency of enamel for different laser energy density and spatial energy distribution in laser beam. Satisfactory agreement was obtained between calculation results and experimental data.

PS1-W1-08 Dynamics of thermal signal amplitude during soft tissues fractional treatment by 980 nm diode laser radiation

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It is known, that degradation or lack of adequate attached keratinized gingiva amount at periodontal decease, aesthetic procedures, and dental implantation significantly reduces the quality of therapy. Using of fractional laser technology for improvement of attached gingiva amount could be one of possible solution to this problem. The ability to create microchannels (coagulative or ablative nature) in the tissue by laser radiation stimulating its regeneration is the basis of fractional technology. Some works presents the periodontal pocket depth reduction after fractional treatment (coagulative columns) of gingiva by diode laser radiation. The results of fractional treatment depends on depth of coagulative or ablative column. Obvious, coagulative columns depth depends on temperature in area of laser-tissue interaction and is limited by soft tissue ablation.

In this report, in vitro study of heat signal accompanying processing of porcine oral mucosa by 980 nm radiation of diode laser with an average power of 13.5±0.5 W, in contact mode, for 2000 ms is described. It was found, that the temperature reaches of 370-380°C in the impact area in 12±5 ms during processing of oral mucosa. Further laser treatment leads to coagulative column formation, but the temperature on the oral mucosa surface dramatically increases after 1300±400 ms and crater is formed. Thus, the duration of 980 nm laser action on oral mucosa should not exceed of 1300±400 ms to avoid the destruction of the biotissue surface.

In a series of in vitro histological studies the duration of laser action does not exceed of 100 ms. We investigated the porcine keratinized attached gingiva and oral mucosa on buccal side of porcine mandible. This report shows that diameter (D) of coagulative columns in oral mucosa increases from 150 μm to 300 μm, and length (L) of coagulative columns increases from 900 μm to 1250 μm, when pulse duration changes from 50 to 100 ms at pulse number (Np) of 1. D increases from 250 μm to 450 μm, and L increases from 1050 μm to 1400 μm, at Np of 2. D increases from 250 μm to 500 μm, and L increases from 1450 μm to 2550 μm, at Np of 5. The diameter of coagulative columns is higher and length is less in attached gingiva in comparison with oral mucosa.

PS1-W1-09 Modelling of thermal and deformation fields in the process of laser surgery using fiber–optic thermal converters

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One of the most promising areas of the laser surgery of the soft tissues is a contact laser surgery using fiber–optic thermal converters (thermo–optical surgery). Most often fiber–optic thermal converter (FOTC) is created as a result of placing on the distal end of the optical fiber absorbing laser radiation structures. These structures transforming laser radiation into thermal energy and the energy of heat radiation. At contact of converter with the biological tissue the laser energy, thermal energy and the energy of heat radiation stimulate the destruction (coagulation, ablation, etc.) of biological tissue. In several papers, FOTC is called "blackened tip" or a "hot tip". The great advantage of FOTC is the ability to work together with the popular, simple and high efficient diode lasers with a wavelength of 800–1000 nm. Diode laser radiation with power of 1 W heats up FOTC to +1000°C.

In present study, the structural, optical and thermal properties of FOTC with carbon absorbers was investigated. The film and spherical types of converters was discussed also. The authors proposed a structural, optical and thermal FOTC model and model describing the mechanical deformation inside and outside of the converter. Calculating was performing with "TracePro" and "Multiphysics" software. The local and averaged absorption indexes of various types of FOTC with carbon absorbers were defined. Model of contact heating soft tissues was discussed. Temperature of FOTC heating by laser radiation in air or in contact with the soft biological tissue was calculated and discussed. Influence of the volumetric water content in biological tissues on the dynamics of laser heating of the converter was determined also. Mechanical stress arising within FOTC with carbon absorbers due to laser heating was calculated. The results of the simulation of the deformation field in the aqueous environment surrounding the converter was presented. Theoretical and experimental data was compared.

PS1-W1-10 Blood microcirculation in rats pancreas with alloxan diabetes studied by laser speckle contrast imaging

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The study of blood microcirculation is one of the most urgent problems of the medicine. This is caused by the fact that many diseases, such as cardio-vascular diseases, atherosclerosis, diabetes, chronic venous insufficiency cause functional and morphological changes of microcirculation of blood flow. Hemodynamic changes in diabetes contribute to the emergence of hypoxemia in various organs, leading to retinopathy, neuropathy, nephropathy, coronary heart disease, and peripheral arterial disease. We present the results of experimental study of changes of microcirculation of blood flow of pancreas in rats with diabetes by using Laser Speckle Contrast Imaging (LSCI). Laser speckle contrast techniques are based on the spatial and temporal statistics of the speckle pattern, calculating of contrast of time-averaged dynamic speckles in dependence on the exposure time at the registration of the speckle-modulated images. Character of morphologic changes and modifications microcirculation blood flow under the influence of an immersion solution (70% aqueous solution of Omnipaque, n = 1.407) was also investigated. In our research, we used 20 albino outbred laboratory rats weighing 350±50 g. We used animal model of alloxan induced diabetes. Results show that blood velocity increased in pancreas of diabetic rats group relative to the control group. Topical application of 70% aqueous solution of Omnipaque showed change of blood velocity in the blood vessels of diabetic group of rats, and the blood flow in the control group did not change. The results obtained at the study of blood microcirculation disorders of pancreas show that diabetes development in animals causes changes in the microcirculatory system.

PS1-W1-11 Optical method for quantification of glycerol diffusion in native and diabetic myocardium

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The goal of the study was to quantify by optical method glycerol diffusion in ex vivo myocardium tissue of healthy and diabetic rats to understand its relation to structural changes in the tissue due to diabetic conditions.

In the study *diabetes mellitus* was induced by injection of a single dose of alloxan (Acros Organic, Belgium) mixed with saline to experimental animals as 10 mg of alloxan per 100 g rat body mass.

Six months white rats with body mass of 500 g were used in the study. The investigation was performed on twenty muscle samples (ten samples were taken from healthy rats and ten samples from diabetic rats) obtained ex vivo by autopsy.

Each sample was fixed in the cuvette filled up with aqueous 70%-glycerol solution (n=1.428) using the plastic plate with a square aperture of 7×7 mm^2 in the centre. The collimated transmittance kinetics of muscle samples was measured in the spectral range of 500-900 nm using USB4000-Vis-NIR spectrometer (Ocean Optics, USA) concurrently with administration of the glycerol solution. The measurements were performed at room temperature ~20°C. The thickness of the samples was measured before and after optical measurements.

The increase of collimated transmittance and its further saturation was observed for all myocardium samples, both non-diabetic and diabetic ones, during the immersion in 70%-glycerol solution. Data of collimated transmittance kinetics were used for determination of glycerol diffusion coefficient in diabetic and non-diabetic myocardium tissue ex vivo. Slower diffusion was observed for diabetic myocardium, it can be connected with structural changes of myocardium tissue due to the diabetic conditions.

Results obtained in the study can be used for evaluation of structural changes and tissue permeability in diabetic conditions, subsequent development of biomarkers for assessing of tissue glycation and for prediction of laser beam attenuation in myocardium for diabetic patients at heart disease laser treatment.

PS1-W1-12 Optical analysis of combined biopolymers based on bacterial cellulose

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Application of biogenic and synthetic plastic materials in surgical treatment provides fast and full recovery of centers of destruction and bone defects. Important property of biological polymers with bacterial cellulose is the lack of toxicity and carcinogenicity. Furthermore, these preparations have anti-inflammatory action. However, in production of these biopolymers combination of bio-components is important, that allows receiving fundamentally different characteristics and solving new problems. Evaluation of such combined biopolymers can be carried out by optical analysis.

In this work were studied biopolymers based on bacterial cellulose, including in composition different combinations of hydroxyapatite and collagen. In addition, part of the samples was freeze-dried.

Spectral characteristics of transplants based on BC were studied using experimental stand, including high-resolution digital spectrometer Shamrock sr-303i with built-in cooling chamber DV420A-OE, fiber-optic probe for Raman spectroscopy RPB785, combined with the laser module LuxxMaster LML-785.0RB-04 (with an adjustable power up to 500 mW, wavelength 785 nm). The emission power 500 mW of the laser used within the exposure time to 50 seconds does not cause destructive changes of samples. The polynomial approximation of registered spectra method was used to emphasize the Raman spectrum in the background of autofluorescence.

Raman spectra of combined biopolymers based on bacterial cellulose were obtained. Were introduced optical criteria that allow identifying the best combination of component composition of biopolymers. Results of studies are confirmed by scanning electron microscopy.

PS1-W1-13 Spectral analysis of hydroxyapatites depending on method of their preparation

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Nowadays more and more are widely used biomaterials based on hydroxyapatite in surgical dentistry for bone restoration. According to its physical and chemical properties and physiological reactions in organism finely divided crystalline synthetic hydroxyapatite can be compared with inorganic component of bone tissue. However, the physicochemical properties and biological activity of these materials can vary substantially depending on method of their preparation, and consequently, there are ways to increase their efficiency. Control of physicochemical properties of hydroxyapatite was carried out by Raman spectroscopy.

In this work were studied 30 samples of hydroxyapatite obtained from different types of donor bone tissue: birds, animals, humans and acid concentration and duration of exposure.

As the main research method of hydroxyapatites was used Raman spectroscopy method, implemented by high-resolution digital spectrometer Shamrock sr-303i with built-in cooling chamber DV420A-OE which provides 0,15 nm spectral resolution, with laser module LuxxMaster LML-785.0RB-04 (power up to 500 mW, wavelength 785 nm).

Processing of Raman spectra was carried out in Mathematical 8 software environment.

Results of carried studies:

Were experimentally established features of hydroxyapatites, obtained from different types of donor bone tissue, based on analysis of amplitude of $(PO_4)^{3-}$ line, integral line intensity $(PO_4)^{3-}$, integral line intensity $(CO_3)^{2-}$.

Study results were compared with scanning electron microscopy.

PS1-W1-14 Electromechanical behavior of cartilage at/over/result in laser-induced stress

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Electromechanical behavior of cartilage tissue under the repetitively pulsed laser irradiation is studied to determine the temporal dependence of internal stress laser-induced in this tissue. Experiments were carried out in originally designed testing system, with a piezoelectric pressure transducer and a specially designed electrode system. Data collection was carried out using a computer data acquisition system and software LABVIEW National Instruments. Cartilage tissue irradiated by Er-fiber laser (IRE-Polus Group, Russia) with a wavelength of 1.56 microns up to a temperature of about 45°C, which corresponds to the medical therapeutic regimes. The piezoelectric sensor is disposed perpendicularly to the direction of heat and detects changes of pressure of the sample on its surface. Temporal dependencies of electrical characteristics of the tissue were measured simultaneously with laser-induce stress and relaxation. During the experiment on the DC, the falling time dependence of the resistance has been detected. This dependence has an activation character: the first drop resistance is weak; with each subsequent they sharply increased. The observed temperature dependence of the electrical activation is subject to the law of the growth of carrier mobility regarding the temperature. Behavior of deformation curve is described by the model of thermal viscoelasticity with thermal expansion of the internal fluid source of stress. The temperature dependences of the resistance and mechanical stresses will allow identify changes in the structure of the cartilaginous matrix and will provide the basis for elaboration of laser control systems in medical operations.

PS1-W1-15 Modeling of the thermal response of human skin

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In this work, we present a novel method for simulation of thermal response of human skin to laser irradiation. The approach is based on Monte Carlo modeling with additional heat transfer equation considering blood flow. Laser irradiation of biological tissue is used in particular medical treatment applications e.g. Photodynamic Threapy (PDT). In the developed model calculation is performed in two steps:

1. Modeling of the distribution of absorbed light energy in biological tissue;

2. Calculation of the amount of released heat by solving the heat-transfer equation using finite elements methodology.

For the first task the Monte Carlo method is used, the second problem is solved by the finite element method using heat transfer equation. We utilize Penne's equation of bioheat as the mathematical model for calculations of the thermal field. The final algorithm is implemented using Compute Unified Device Architecture (CUDA) framework designed for massive parallel computations on multiple NVidia Tesla K80 Graphics Processing Units (GPU). We present results of temperature distributions inside skin tissue as well as evaluation of radiation dozes for PDT application. Moreover, result of comparative analysis between our algorithm and a method developed by several other groups is presented.

PS1-W1-16 Raman spectroscopy for assessment of decellularization of heart implants

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Each year, heart diseases kill about 17 million people, representing approximately 29% of all deaths [1]. One way of decreasing mortality of population from cardiovascular diseases is replacement of worn-out heart valves with «new biomatrixes». An important stage of getting a heart bioimplants is the process of decellularization that allows preventing complications, associated with transplantation of native materials, such as calcification, remains of tissue immunogenicity, inflammatory degradation, mechanical damage and lack of biomatrix remodeling [2]. That is why the actual problem is to control the process of decellularization.

Objects of research were heart valves, processed using the decellularization technology from Heinrich-Heine University (Germany) [3], and control samples.

Testing method of implant decellularization, as well as its optical control, was previously carried out on skin biomatrixes [4]. It was established that with varying degrees of biomatrix processing the main spectral differences occur at 1062 cm^{-1}, 1645 cm^{-1}, 1260 cm^{-1}, 850 cm^{-1}, 863 cm^{-1}

wavenumbers, corresponding to important for the quality of implant components. Based on results of carried studies the assessment of composition of component of surfaces of biomatrixes was obtained; selection of optimal bio-carriers and control of efficiency of methods for their treatment were made.

To control the decellularization process of heart valves was used Raman spectroscopy method, implemented by high-resolution digital spectrometer Shamrock sr-303i with built-in cooling chamber DV420A-OE which provides 0,15 nm spectral resolution (about 1 cm^{-1}), with laser module LuxxMaster LML-785.0RB-04 (power up to 500 mW, wavelength 785 nm).

As result of the work done it was established that in process of decellularization of heart valves peaks are disappearing at 988 cm^{-1}, 1450 cm^{-1} and 1340 cm^{-1} wavenumbers, corresponding to oscillations of lipids and DNA. Was carried out separation of the spectra obtained in spectral lines using deconvolution of Gauss-Lorenz functions in MagicPlotPro software environment. The average value of determination coefficient of resulting Raman spectrum for 300-2199 cm-1 area was R2=0.98, average standard deviation of analysis σ = 8,81.

Optical criteria for assessing decellularization of heart implants were introduced, based on which was established that using Raman spectroscopy method makes possible to control the quality of heart implants.

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PS1-W1-17 Numerical modeling of biological tissue autofluorescence using the Monte Carlo method

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Optical biopsy based on optical research methods of biological tissues is actively developing field of medicine diagnostics. One of these methods is the method of autofluorescence diagnostics (AFD).

AFD is based on the fluorescence of fluorophores, which are naturally contain in tissues - endogenous fluorophores. The AFD method consists in registration and comparison of autofluorescence signals from healthy and pathology tissues.

A diagnostic conclusion is based on differences in signal intensities and in their spectral composition.

Autofluorescence diagnosis is widely used for detection of atherosclerotic lesions of the aorta and arteries, and for estimation of the damage degree of these lesions. This report presents the results of numerical modeling of biological tissue autofluorescence using the Monte Carlo method.

Three states of the aorta are considered – normal, fibroplasia and atherosclerotic. Based on the information about the optical, morphological and physico-chemical properties of biological tissue models of these types of aorta are built.

A special feature of the simulation of biological tissue autofluorescence is the formation of two separate program blocks. The first block of the program describes the propagation of the excitation light to the moment of interaction with biological tissue, second block - propagation of autofluorescence radiation. Autofluorescence modeling is required to take into account the fact of changing the radiation wavelength after the interaction with tissue, to consider all the features of fluorescence radiation interaction with biological tissue in the same way as for the exciting radiation.

As a result of simulation autofluorescence spectra of the aorta in a normal state, with fibroplasia and with atheromatous plaque were obtained. Evaluation and comparison of simulation results and experimental results allow to do a conclusion about the appropriateness of the proposed model of aorta autofluorescence in the normal state and in the pathological state.

PS1-W1-18 Cytotoxicity and apoptotic effects of polymer coated copper oxide nanoparticles synthesized via laser sintering in mesenchymal stem cells

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Copper oxide inclusions were incorporated in polymer matrix (polycarbonate, PEEK etc) via selective laser melting (SLM) process. The aim of this study was to observe the cytotoxicity and apoptotic effects of copper oxide nanoparticles on culture of multipotent mesenchymal stem cells (MMSC). The polymer coated CuO nanoparticles (<50 nm) were investigated by X-ray diffraction analysis and scanning electron microscopy techniques. The viable cells were counted using light microscopy. It was determined that CuO nanoparticles have strong toxic effect against a background high biocompatible polymer matrix. We also discuss the implications of our findings regarding the effects of the intrinsic toxic properties of CuO nanoparticles, and concluded that the apparent toxicities of metal oxide NPs can largely be understood as a matter of particle toxicity.

PS1-W1-19 Development of illuminator for autofluorescence diagnosis in endoscopy

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Promising for the early diagnosis of malignant diseases of the respiratory organs and the gastrointestinal tract (GIT) is now considered a fluorescence method. This is due to its high sensitivity, making it possible to determine negligible concentrations of biologically active compounds. Feature fluorescence nature associated with the dependence of its parameters from the microenvironment of luminescence centers, the steric and electronic structure of molecules, the degree of aggregation makes it possible to study living tissues and organs, as for some of the fluorescence characteristics it is possible to monitor the changes in the functional state of these objects in particular to diagnose pathological conditions of the organism.

The aim is to develop a fluorescent light source (illuminator FLU) for videoendoscopy complex and determining on the basis of scientific research and prototyping capability for creating fluorescence

video endoscope.

The solution of the problem based on the method of the study of biological objects in vivo.

Developed fluorescence illuminator allows to diagnose the patient's gastrointestinal tract without prior proper training to the patient survey and without additional costs for chemical dyes and other medical supplies.

Scientific novelty lies in the safe diagnosis of the presence of cancer and other diseases in the digestive tract in situ (in place). Fundamentally the new scheme and the lighting device unit. The use of fluorescence phenomena in endoscopy.

During the implementation of the R&D the following tasks and questions have been performed and resolved:

- confirmed the possibility of creating a fluorescent light for video endoscopy;
- developed all components and block diagrams;
- purchased materials and supplies needed to complete the work of the lighting unit;
- purchased performed calculations of optical systems, laser systems, the design parameters.

There are many features and means of development and modernization of the developed lighting unit. After technical and medical tests we can accurately to understand which way we develop and aspire to become leaders in the production of auto-fluorescence video endoscopy in the world market.

W2-1 Laser 3D scanning in replication and digital reconstruction of artworks

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Three-dimensional digitization (also called 3-D imaging or 3-D scanning) is assuming an important place among documentation and analytical techniques of any objects. At the moment there is a growing interest in the use of this technology in preservation of Cultural Heritage (CH). There are several goals for the 3D digitization and modeling of natural and CH objects, such as for accurate detailed documentation, physical replicas, virtual tourism, and research or education. Capturing the 3-D data requires a technique that is highly accurate; portable due to limited budgets; fast due to the usually short allowed time on the site so as not to disturb works on visitors; and flexible and scalable due to the wide variety and size of sites and heritage objects. It is also important that the techniques captures dense 3-D data on the necessary surface elements to guarantee a realistic experience close up or to monitor surface condition over time. Furthermore, the fine geometric details are needed because even with rich texture maps, models without these details will exhibit too smooth and flat-looking surfaces or polygonized silhouettes that can be easily detected by human eye.

Basic principles of 3-D laser scanning and its applications for creation of replicas and digital reconstruction of objects of CH will be presented in the paper. Several important case studies connected with the use of this technology for replication and reconstruction of sculptural monuments in St.Petersburg will be overviewed.

W2-2 Laser scanners for remote diagnostic and virtual fruition of cultural heritage

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Within the recently started regional project COBRA (Conservation of cultural heritage by means of radiation based and enabling technologies) addressed to the transfer of innovative technologies and methodologies from research to CH end users and SME involved in the conservation, ENEA is promoting the use of its laser scanners. Different prototypes have been developed at ENEA in the Diagnostic and Metrology Laboratory, with software capabilities suitable to optimize their application in highly demanding fields such as the cultural heritage (CH) preservation and fruition.

Three different instruments for high resolution remote applications with imaging capabilities for optical or spectroscopic characterization of the investigated CH surfaces are available:

- Three-chromatic imaging topologic radar (RGB-ITR), detecting the amplitude modulated backscattered laser radiation at three different visible wavelengths, supplying both a native colour images perfectly overlapped with the respective 3D model and structural information as well;
- Hyperspectral LIF-scanning, collecting at each investigated point the entire fluorescence spectra relevant to the utilized UV laser excitation, and the respective reflectance spectra after switching off the laser.
- Combined Raman / LIBS instrument for subsurface chemical analyses in a non destructive or microdestructive operation.

Their combined use not only gives prognostic structural information indicative of potential structure damages, but it also produces multi-layered images with enhanced information content, which is valuable in CH characterization of surface materials including initial constituents and restoration products. In fact the developed diagnostic methodologies with appropriate data treatments reveal material composition, enhanced colour vision and document areas of early deterioration or previous restoration interventions, thus supporting both conservation and fruition.

Significant examples of images analysis, collected in a fully non destructive, non invasive and remote way on different kinds of coloured CH surfaces, will be reported and discussed, stressing the analytical procedures and tools developed to answer to specific characterization problems.

W2-4 Raman, FTIR, LIBS, THz, how the laser spectroscopies lead for cultural heritage characterization

Michel Menu

Centre de Recherche et de restauration des musées de France C2RMF

If the X-ray radiation was the first instrumentation used for artwork inspection, the possibility offer by the laser becomes more important in the field of cultural heritage. The apparition of the Raman demonstrated in many case the capability to offer in situ or in laboratories to characterize pigments, glass etc… This technique is today widely implemented in the laboratories working in Cultural Heritage. Inside a FTIR spectrometer a laser is normally used to align and calibrate the spectrometer while for IR source various kinds of lamps (like Globar) are used. This technique is the first used for the characterization of binding media in painting, well mastered. For years, several examples of use of LIBS (laser induced breakdown spectroscopy) technique have described and published in the field. Its ability to analyze, with a minimal loss, different kinds of materials in laboratory or in situ as material characterization, recognition of fakes and indirect dating is described, reporting general considerations and case studies on metal alloys, mural paintings, decorated ceramics, glasses, stones and gems has been highly appreciated. More recently, the apparition of THz technology using fs laser offers the possibility to look inside the material. Some works demonstrated recently the possibility for this technique to discover underdrawings.

For this talk we will present recent case studies on different artworks where the different techniques have been used and how the laser has taken a prominent place in the laboratories dedicated to cultural heritage.

W2-5 Microanalysis of organic pigments in ancient textiles by surface-enhanced raman scattering on agar-gel matrices

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We present a new method based on surface-enhanced Raman scattering (SERS) for the non-destructive/minimally invasive identification of organic colorants in objects whose value or function precludes sampling, such as historic and archeological textiles, paintings, drawing etc.

This new methodology was developed for the selective extraction and identification of anthraquinones and indigoids in the typical concentration used in textiles by means of an eco-compatible, homogeneous, nanostructured agar matrix. The extraction system was modulated according to the chemical properties of the target analyte by choosing appropriate reagents for the extraction and optimizing the extraction time.

The system has been found to be extremely stable, easy to use and to produce, easy to store and, at the same time, able to be analyzed even after long time intervals, maintaining unaltered its enhancement properties, without the detriment of the extracted compound.

Highly structured SERS band intensities have obtained from the extracted dyes adopting laser light excitations at 514.5 and 785 nm of a microRaman setup.

The use of different chemical environments and excitation wavelengths further improves the capability of the method to identify the presence of different dyes in complex mixtures due to the stabilization of different chemical forms of the analytes and possible resonance Raman effects.

This analytical method has been found to be extremely safe for the analyzed substrates, thus being a promising procedure for the selective analysis and detection of molecules at low concentration in the field of artworks conservation.

W2-6 The use of Lead based pigment in cultural heritage, detection and conservation issues

V. Detalle[1], D. Martos-Levif[1], D. Brissaud[1], B. Trichereau[1], D. Giovannacci[1], E. Bourguignon[1], D. Syvilay[1], F. Surma[2], V. Motto-Ros[3], Frédéric Pelascini[4]

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The lead based pigments are one of the most common components of mural painting in the historical monuments or cultural heritage building. Indeed, they are known since antiquity and even prehistory concerning litharge.

Control of lead exposure at work is regulated by extremely precise and restrictive standards. Recently, concerns regarding lead exposure of workers on historic buildings construction sites have forced some building sites to shut down completely and, in any case, have modified work habits, compelling teams to plan ahead to create a safe environment prior to the beginning of any work.

Today, it is not uncommon to require a lead diagnostic to obtain house insurance. Even if no official standard codifies the manner in which this diagnostic should be carry out, and in particular, how lead concentration should be measured, a number of recommendations exist which mainly use X-ray fluorescence spectroscopy (XRF) as the analytical technique to obtain this information.

Libs is an analytical solution for a long time used for various cultural heritage applications [1]. Recently, this spectroscopy has been used for identifying different lead roof sheets origin based on the identification of trace elements [2].

The question of transposing the information obtained by XRF to measurements obtained by Laser-induced breakdown spectroscopy (LIBS) can therefore legitimately arise. After presenting an analytical study and measurements carried-out on model samples, differences between these two techniques and the possibility to carry out LIBS measurements will be discussed.

1 D. Anglos, V.Detalle, libs , 3rd. ed., (International Publishing House, Laser City, 2014).

2 “Trace element quantification of lead based roof sheets of historical monuments by Laser Induced Breakdown”, D. Syvilay, A. Texier, A. Arles, B. Gratuze, N. Wilkie-Chancellier, L. Martinez, S. Serfaty, V. Detalle, spectrochimica Acta Part B: Atomic Spectroscopy, Volumes 103–104, 1 January–1 February 2015, Pages 34-42

W2-8 Laser removal of biological growth from surface of stone monuments

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At the moment many historical monuments including outdoor stone sculptures are extremely degraded due to the extensive biological growth (lichens, fungi and other organic formations), which cause patinas of black, yellow and green colors. This resulted not only in deterioration of aesthetic beauty of stone, but through weathering and the metabolic activity of the lichen and fungi colonies, stone surfaces lose cohesion and fine details. For this reason, removal of the biological growth is a very actual task, especially taking into account that present conventional divestment methods, based on the use of chemical, mechanical and abrasive techniques, usually damage the stone.

Laser cleaning, in comparison with conventional mechanical and chemical cleaning is a precise and versatile non-contact method. It has lower environmental and health-related side effects and prevents damage to underlying substrates by through self-controlling mechanisms. The cleaning of artworks by laser irradiation is a contemporary technique with many practical advantages (precision, rapidity, localised action, etc.). The greatest part of studies dedicated to laser cleaning are focused on equipment development and cleaning procedures, including research on particles and surfaces. The main problem in the case of the biological degradation of artworks is a complete elimination of biodeteriogens and the treatment efficiency (removal of all active organisms).

In the paper we will present results of intensive experimental works on divestment of biological growth on the surface of marble and sandstone by means of laser treatment, which have been carried out by authors for last 10 years.

W2-9 Laser cleaning of cacti: Solving a thorny problem of Mexican food industry

L.V. Ponce, T. Flores

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International Centre for Theoretical Physics, Trieste, Italy

The succulent leaves of some cacti varieties are a traditional food product in many countries of the world. These leaves are covered with thorns which are necessary to remove before consuming the product. The peeling process is made by knife and provokes strong losses, a decrease in product life, and sanitary risks.

The method of removal of thorns by laser ablation solves these problems. This new technique works thanks to the use of laser pulses that are absorbed in a selective way, specifically in the thorns. This work describes the mechanism of thorns ablation, the technical challenges and the original solutions developed for commercial technology. The use of techniques as Laser Induced Breakdown Spectroscopy and Photoacoustic Induced by Laser Ablation for online monitoring of thorns removal process is presented.

W2-10 Laser-induced brakdown spectroscopy applied to material characterization in archaeology and heritage conservation

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In this work we present applications of LIBS to the determination of the elementary composition of unique pieces of archaeological, anthropologicaland patrimonial value.

We identified the composition of objects and pigments belonging to different South American pre-Columbian cultures as bracelets, masks, metal plates, etc.; with the aim to determine provenance and the manufacturing process. LIBS was applied also to the characterization of objects found in the reconstruction of clandestine detention centers,created during the last Argentinian dictatorship (1976-1983). By LIBS we have detected and measured trace elements, as strontium and magnesium, in teeth and bones of Homo-Sapiens, to obtain information for classification and alimentary habits of individuals and populations. Also in order to implement the appropriate conservation treatment, we applied LIBS in subaquatic archaeology to identify the composition of objects rescued from the sea.

W2-11 Underwater LIBS for investigation of the submerged cultural heritage

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After decades of development in laboratories and land operations, chemical analysis of submerged objects is starting to become a reality. While the analysis of water at variable depth has been demonstrated in the past using florescence spectroscopy and Raman spectroscopy, determination of the atomic composition of submerged objects is much a more complex task. Technology based on laser-induced breakdown spectroscopy (LIBS) has been recently developed for such sub-sea operations. This paper will discuss the operating parameters of a marine LIBS analyzer. Metals, alloys, rocks, marble, concrete, can be analyzed at a depth of up to 50 m. The system has been tested in several coastal surveys in Mediterranean waters.

W2-12 Laser-induced breakdown spectroscopy applied to the detection of aerosol particles

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Laser-Induced Breakdown Spectroscopy is a laser technique dedicated to the analysis of materials. LIBS consists in focusing a powerful laser pulse on solids, liquids, gas or aerosols whose elemental composition is to be determined. The strong heating of the sample at the focusing spot leads to the ignition of a hot and luminous transient ionized gas called plasma. Plasma light contains the signature of all the chemical elements the interrogated material is made of. This signature is read by sending the emitted light through a spectrometer equipped with a detector. The LIBS signal presents itself as an optical emission spectroscopy spectrum displaying lines corresponding to the detected elements. In such application, elemental composition determination is made possible using the laser-induced plasma as a tool to vaporize matter. The technique has been applied to the detection of aerosol particles.

Aerosols may be defined as an ensemble of solid and / or liquid particles suspended in a gas with sizes ranging from a few nanometers to a few micrometers. Their release in the course of industrial processes may represent a threat for workers and the environment. Current elemental analysis techniques require time consuming procedures involving several steps. Skilled personnel are sent to the sites where samples are to be picked up. Back to the laboratory, these are prepared prior to the analysis itself. The above considerations emphasize the need to develop an instrument allowing in-situ and real-time elemental identification and mass concentration determination of airborne particles. A LIBS-based system may be the appropriate tool to deal with such delicate issue. It is intended to be operated on-site, in automatic mode, without manual intervention except for maintenance. LIBS has been used in the field for workplace surveillance, process control and heavy metal monitoring, thus illustrating its potentialities for on-site real-time monitoring.

W2-13 Recent microprobe developments based on Last Laser induced breakdown spectroscopy for physicochemical microanalysis and space resolved micro mapping

Jean Luc Lacour, Alexandre Semerok, Gilles Moutiers

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Last Laser induced breakdown spectroscopy (LIBS) is an analytical methodology for chemical composition analysis of material that presents a set of particularly attractive features because of its fully optic aspect: Simultaneous multi-element analysis, applicable to any type of material (solid, liquid, gas, aerosol) real timely, remotely. Because of its qualities, LIBS is also interesting for micro analysis and micro mapping material surface, including obviously metals but also non-conductive materials such as concrete, clay or soil. Indeed. The analysis of diffusion phenomena in a material to another, for example during welding, the diffusion or retention phenomena of chemical compounds in a matrix at very low rate, or the determination of homogeneity effects of the composition in allows, or in ceramics, require micrometric scale observations, and needs to attempt micrometric lateral resolutions analysis. We developed a micro LIBS probe involving a microscope coupled with a LIBS instrument, which allows chemical composition and chemical distribution mapping with lateral spatial resolution up to 1 μm. Various examples will be exposed of applications and performances.

W2-14 Modeling and diagnostics of laser induced plasma for needs of spectrochemical analysis

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Two topics will be addressed: (i) chemical modeling of laser induced plasma that provides insight into the possibility of simultaneous elemental and molecular analysis by LIBS and (ii) calibration-free LIBS based on Monte Carlo spectral optimization. Both topics heavily rely on plasma modeling and are closely connected to experiment.

A collisional-dominated model of laser induced plasma includes the coupled Navier-Stokes, state, radiative transfer, and material transport equations and incorporates plasma chemistry through the equilibrium approach based on the use of atomic and molecular partition functions. Several chemical systems are modeled including ablation of Si, C, and $CaCl_2$ in N_2 and Ar atmospheres.The model is used to study evolution of number densities of atomic and molecular species in an expanding plasma plume and elucidate mechanisms of molecular formation. Computer simulations will be shown for the mentioned chemical systems that span the time interval of tens microseconds. The simulations will be compared to experimental observations obtained by optical imaging, spectroscopy, and tomography.

Next, a calibration-free Monte Carlo LIBS (MC LIBS) will be presented where concentrations are found by fitting model-generated and experimental spectra. A simplified model of a static uniform and isothermal plasma in local thermodynamic equilibrium is employed. Millions configurations of plasma parameters and their corresponding spectra are simultaneously generated using a graphic processing unit (GPU) that allows for the reduction of computational time down to several minutes for a sample/spectrum. The method is tested on the analysis of industrial oxides containing various concentrations of CaO, Fe_2O_3, MgO, and TiO_2. The agreement within several percent between found and certified concentrations is achieved.

W2-15 Laser production of ITER relevant tungsten particles for associated toxicologic studies

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Expected power and duration of the future fusion device, such as ITER, require the plasma-facing components to withstand considerable plasma fluxes, in particular the divertor target plates. Tungsten has been chosen for its good mechanical properties and low plasma sputtering yield; however, experiments have shown that combination of several phenomena such as melting of the plasma-exposed edge, material fatigue, neutrals and ion implantation, plasma-wall interaction can trigger the formation in the plasma chamber of tungsten dust of variable size from tens of nanometers to tens of micrometers. Tritium retention and recycling in plasma-facing materials is a major concern and applies to such formed particles. It has consequences on potential safety hazards. More precisely, as observed in dusty plasma laboratory, sub-micron dust particles of high specific surface area (SSA) will be formed in the plasma edge due to tungsten sputtering and material accretion. This type of particles with low geometric diameter (~100 nm) can be released in the environment during loss of vacuum accidents because the existing high efficiency filters are not so capable to collect particles in this size range. Due to their exposure to tritium in the vacuum chamber, their release could lead to radioactive contamination; understanding their interaction with tritium is hence of prime importance, before we can investigate their behavior in biological media and potential toxicity.

Existing tokamak-produced dust being very scarce, extensive study of such nanoparticles with high specific surface area (SSA) and sub-micron size requires a specific and efficient (grams of dust are needed) production technique, in order to obtain relevant particles. In this presentation, we will present our production and collection setup based on pulsed laser ablation on bulk ITER-grade tungsten, and the main parameters impacting on the collected dust morphology. We observed that optimum gas pressure is required to control the laser-induced plasma properties and then to favor the production of tungsten nanoparticles with high SSA. The laser pulse duration is also a key parameter to limit the generation of tungsten liquid droplets during the ablation process. The nanoparticles structure and size distribution are then characterized via Scanning Electron Microscopy (SEM) and X-ray diffraction, with SSA and size dispersion determined. Lastly, various types of tungsten dust are loaded with tritium by gas overpressure at high temperature, and their respective retention capability and long term evolution addressed. After tritiation implantation, a rapid release of tritium is observed which ends after 2 to 5 days. Then, the tritium inventory is measured and tritium contents greater than 10GBq/g is observed, which is more than 2 orders of magnitude greater than for massive samples. By comparison with other type of dust as one provided by a supplier, it is observed that tritium inventory increases with the dust SSA and with the dust properties, which stresses the importance of studying different type of powder. Almost all the tritium remaining in the sample is recovered at 500°C. However, 1% of the initial tritium inventory remains in the sample at 1000°C corresponding to at least 0.1G Bq/g.

In addition to this tritium behavior study, biology experiments are led in order to characterize potential toxicity of these nanoparticles being inhaled. In vitro tests are performed with a human cellular model (MucilAir®). Tritiated and hydrogenated nanoparticles are deposited onto the apical side of the cells. In this presentation, the consequences of such contamination will be presented. The Internalization and translocation of nanoparticles will be addressed as well as their cytotoxicity and genotoxicity.

PS1-W2-01 LIBS technique for identification mexican amber

T. Flores-Reyes, G. Vazquez Bautista, L. Ponce-Cabrera,

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The technique of Laser Induced Breakdown Spectroscopy (LIBS) shows strong growth in recent years due to its advantages for the in-situ qualitative analysis. In this paper, the LIBS technique is used for the study of the inorganic composition of Mexican amber samples. This is achieved using an experimental setup that includes a burst-mode laser and a spectrometer with a controllable time delay. Amber is a fossil resin plant of great importance as one of the most popular gemstones and also because provide information on ancient flora. Several elements present in Mexican amber as Na, K, Sr, Ca and Mn were determined.

PS1-W2-02 Compact LIBS device with laser source emitting in bust-mode regime. Development and applications

L.V. Ponce, T. Flores, G. Bilmes, F. Alvira, L. Moreira, A. Ponce

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International Centre for Theoretical Physics, Trieste, Italy

This study presents the development of a portable Laser Induced Breakdown Spectroscopy (LIBS) prototype. The system includes a compact Q-switched Nd:YAG laser which produces pulses in burst-mode regime. A brief survey of applications is showed, including the determination of tobacco leaves origin, the bacteria strains identification and the antique metal jug compositional analysis.

PS1-W2-03 Ultrafast laser cleaning of objects of heritage

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Laser cleaning provides art and heritage conservators with an alternative means to restore objects when traditional chemical and mechanical methods are not viable. However, long (> nanosecond) laser pulses can cause unwanted damage from photothermal processes and provide limited control over ablation depth. Ultrashort (< picosecond) pulse lasers are emerging as a more appropriate tool for cleaning historic artefacts because of their unique ability to avoid heat- and shock-wave generation, thus minimising collateral damage of the underlayers, and to remove material with near-nanometer precision.

Here we demonstrate the effectiveness of ultrashort pulses by cleaning 19th century military gold braid that was untreatable by conventional means, and without any detrimental effects on the gold foil or the underlying silk thread structure [1]. The results are compared with nanosecond-pulse laser treatment that damages the surface structure. By introducing in situ feedback control of the laser ablation via laser-induced breakdown spectroscopy (LIBS) monitoring of the ablated plume, we are able to halt the cleaning process just as the contaminant layer is completely removed. This technique allows ultrafast laser ablation to extend the armoury of conservation treatments, enabling restoration of a range of complex and fragile heritage objects previously untreatable by conventional means.

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PS1-W2-04 Laser cleaning for restoration of archeologically corroded iron

Denis Prokuratov, Vadim Parfenov

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Technology of laser cleaning came in Cultural Heritage preservation more than 40 years ago. It was in first used by John Asmus who proposed to apply it for cleaning of marble monuments in Italy.

Different laser cleaning techniques in artworks conservation were thoroughly investigated along the last 2 decades. The most significant results were achieved for stones where the real effectiveness and advantages of the ablation by Nd:YAG laser systems with respect to conventional techniques were widely demonstrated. The extensive use of the laser cleaning technique on valuable stone sculptures and historical façades reported in the literature documents a growing dissemination of the approach in many countries. Conversely, a few successful studies were reported on metal cleaning, whereas unacceptable side effects were evidenced in other cases, so that metal conservation by laser is far from a widespread acceptance. Surface micro melting and discoloration were the main undesired effects, which did not allow satisfactory cleaning results. The former represents the main problem for properly called metal surface while blackening is a typical side effect produced on mineralized layers often encountered in ancient bronze and iron.

In this paper we report the experimental results concerned with laser cleaning of archeologically corroded iron. Characterization of surfaces, treated by laser irradiation, has been carried out by means of Scanning Electron Microscopy, FTIR and Raman spectroscopy.

PS1-W2-05 Laser cleaning of particularly strong contaminants at SUE «St. Petersburg Metropoliten» facilities

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SUE "St. Petersburg Metropoliten" performs a transportation of a huge amount of people every day, so undemountable constructions on subway stations and their facing materials are constantly in a risk of damaging by contamination which could be either intentional or unintentional (including natural erosion for locating in an aggressive ambience). However laser cleaning is well-known technique for restoring marble [1-2], granite [3-4] and other surfaces.

Experimental results of cleaning the most common for SUE "St. Petersburg Metropoliten" facilities facing materials (polished and grinded granite, marble, plastering, limestone, etc.) from main contaminants are presented. Pulsed 20 W fiber Yb-laser was used for conducting the experiments. The applicability of using laser methods of cleaning in facilities with specific atmosphere conditions (such as subway stations) is discussed. The effectiveness and marketing analysis considering subway peculiarities, efforts, material costs, and ecology damage was performed comparing to other applicable cleaning methods (mechanical and chemical mostly). Perspectives of presented work include a modernization of existing mobile laser cleaning systems specially for working in dust-filled and humid technological on- and underground facilities. Main demands for this system will include speed, mobility of placement and displacement, air cooling, powering from conventional 220 V, 50 – 60 kHz power sources, simplicity and safety of using, which makes the application of fiber lasers more attractive.

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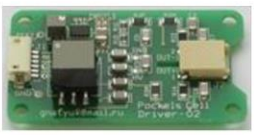

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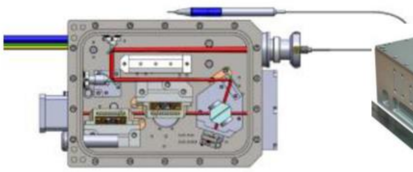

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