International Conference
“Fundamentals of Laser Assisted Micro– and Nanotechnologies”
(FLAMN-07)

Workshop
“Laser Cleaning and Artworks Conservation”
(LCAC)

ABSTRACTS

St. Petersburg State University of Information Technologies, Mechanics and Optics (ITMO)

June 25-28, 2007

St. Petersburg

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)***	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
18-02-2009	Conference Proceedings	25 June 2007 - 28 June 2007

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER**
Fundamentals of Laser Assisted Micro & Nanotechnologies	FA8655-07-1-5070
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Conference Committee	**5d. TASK NUMBER**
	5e. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
St.Petersburg State University of Information Technologies, Mechanics and Optics Kronverksky pr., 49 St Petersburg 197101 Russia	N/A
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
EOARD Unit 4515 BOX 14 APO AE 09421	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)** CSP 07-5070

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited. (approval given by local Public Affairs Office)

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Final Proceedings for Fundamentals of Laser Assisted Micro & Nanotechnologies, 25 June 2007 - 28 June 2007
Physical fundamentals of laser based microtechnologies, modelling and quantitative analysis. Precision laser microshaping: cutting, drilling etc. Local laser modification of different materials composition and properties. Laser surface microstructuring. Laser melting, welding and soldering of microcomponents including plastics. Pulsed laser deposition including LIFT. Laser based methods of photonics components fabrication. Laser cleaning of the surface. Artworks conservation by laser. Laser nanoengineering. Laser processing of microelectronics components. Laser technology for MEMS, biosensors, biocompatible materials, medical tools and fluidic devices. Mechanisms of laser heating, structural and phase transitions in condensed matter. Nonlinear optical effects in matter under intensive laser irradiation. Physical mechanisms of laser damage of optical materials and elements. Laser induced surface phenomena. Laser-matter interaction in the near-field optics. Mechanisms and regularities of laser ablation. Instabilities and self organization processes under laser conditioning. Interaction of ultra short laser pulses with a matter. Laser interaction with bio-tissues. Plasma ignition in gases, liquids and solids

15. SUBJECT TERMS

EOARD, Lasers, Nanotechnology

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18, NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			A. GAVRIELIDES
UNCLAS	UNCLAS	UNCLAS	UL	146	**19b. TELEPHONE NUMBER** *(Include area code)* +44 (0)1895 616205

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

We wish to thank the following for their contribution to the success of the conference:

European Office of Aerospace Research and Development, Air Force Office of Scientific Research, United States Air Force Research Laboratory http://www.london.af.mil ;

Russian Foundation for Basic Research

INTERNATIONAL CONFERENCE

Fundamentals of Laser Assisted Micro– & Nanotechnologies (FLAMN-07)

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Laser Cleaning and Artworks Conservation (LCAC)

June 25-28, 2007

To the memory of A.M. Bonch-Bruevich and M.N. Libenson –
founders of Russian and International conferences
on non-resonant laser-matter interaction

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The official language of the conference is English.

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FLAMN-07

Fundamentals of the resistance of the optical transparent materials to high power laser pulse radiation

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Some of the main fundamental results to laser matter interaction have been received along the investigation of the laser bulk damage.

The report is based on firstly published results on: (Results had been received by author and coworkers in Soviet Lithuanian Republic including, till 1990years):

1. the space scaling of laser-matter interaction,
2. the role Stimulated Brillouen Scattering,
3. direct measurements of the accumulating processes (the temporal and the space statistics have been eliminated!! firstly) in transparent optical materials (as crown glasses K8 and others‘);

(N-on-1 process –i.e. studies of the action of the series of laser pulses onto the same microvolume):

1.Space scaling

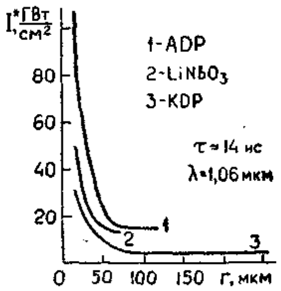

Fig.1. Dependence of the damage threshold for crystals ADP, KDP and $LiNbO_3$ from the beam radius in the focus of lens; τ = 14 ns, λ = 1,06μm
Published on 1969.

2. SBS as moving mirror, reflecting laser radiation

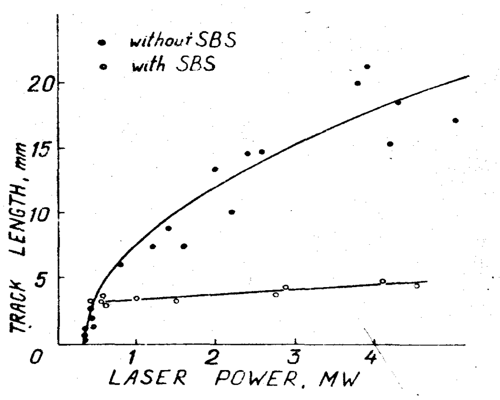

Fig. 7. Track length as a function of the laser beam power.
Published on 1977.

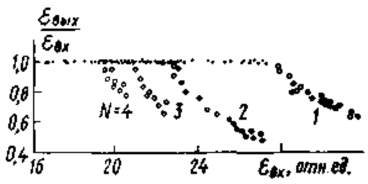

Рис. 1. Зависимость $E_{вых}/E_{вх}$ от энергии импульса излучения Евх для каждого импульса в серии из N импульсов, облучающих стекло К8, для разных N; неразрушающие импульсы обозначены темными точками, последний в серии, разрушающий импульс — светлыми точками
Published on1988

N-on-1 Evidence of color centers generation & quenching

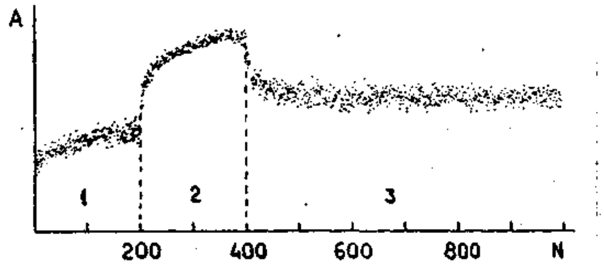

Fig. 4. - The sample acoustic response dependence on the number of pulses passed The same region irradiated by three series of pulses : 1,3-regions energy E_1-= 600; 2-region E_2 = 700 a.u
Published on1988

The role of the other nonlinear optical processes - multi-photon absorption, self-focusing, etc., are discussed, and theoretical model is proposed.

The results are the “classics” for study on laser matter interaction now.

2D and 3D photofabrication by femtosecond laser pulses

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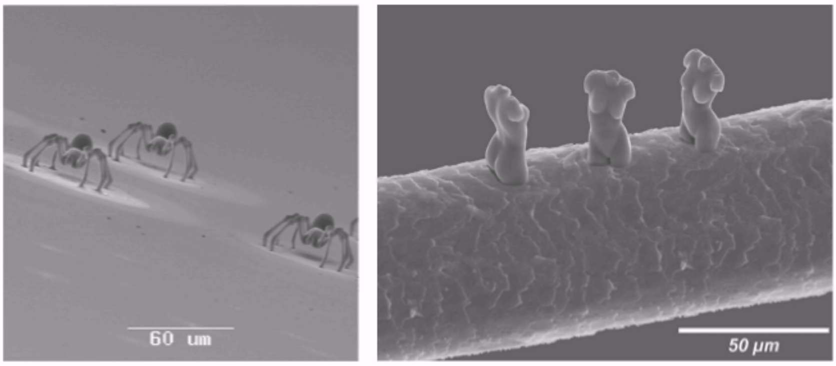
One of the rapidly advancing femtosecond laser technologies is micro- and nanostructuring by two-photon polymerization (2PP) technique [1-5]. In our work, we apply near-infrared Ti:sapphire femtosecond laser pulses (at 800/780 nm) for 3D material processing. When tightly focused into the volume of a photosensitive material (or photoresist), they initiate 2PP process by, for example, transferring liquid into the solid state. This allows the fabrication of any computer-generated 3D structure by direct laser "recording" into the volume of photosensitive material. Because of the threshold behavior and nonlinear nature of the 2PP process, a resolution beyond the diffraction limit can be realized by controlling the laser pulse energy and number of applied pulses. Figure 1 shows two scanning electron microscope images of 3D microstructures fabricated by 2PP technique. One can see the strength of this technology and envision many potential applications. In this contribution, I will report on recent advances of this technology and future short- and long-term prospects. A comparative analysis of the structuring properties of various photosensitive materials will be presented. Many different applications will be discussed.



A scanning electron microscope (SEM) image of a microspider-array and Venus micro-models fabricated by 2PP technique.

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High-power lasers in the Russian Federal Nuclear Center – All Russian Research Institute of Experimental Physics (RFNC – VNIIEF)

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Developments of laser facilities on different purpose, the starting of which was in the middle sixties, are being successfully made at Laser Physics Research Institute (LPRI). Investigations of physical fundamentals of the lasers operation, nonlinear optics and properties of high-temperature dense plasma that is formed under the action of intensive laser emission on matter are realized at these facilities.

The most high-power in Europe 12-channel facility “Iskra-5” with the laser energy of 30 kJ on the wavelength 1,315 μm under the pulse duration 0,3 ns is produced for laser nuclear fusion investigations. A spherical hohlraum construction allowing to receive record symmetry of the X-ray field on the surface of a spherical microtarget (heterogeneity level is < 3%,) and to fulfill unique investigations of compression of the shell with DT- fuel in symmetrical conditions is designed to study DT-mixture compression and heating.

To enhance the investigation abilities on this direction the works on creating of a 128-channel neodymium laser facility “Iskra-6” with emission energy 600 kilojoules, the pulse duration 3 ns, the wavelength 0,35 μm are being conducted now at LPRI. As a first stage “Luch” facility, which is the “Iskra-6” module prototype, has been built. It is a 4-channel four-line phosphate glass laser. The total laser energy in single channel is 3,3 kJ on the wavelength 1,054 μm and the pulse duration is 3-4 ns.

The facility “Luch” start opens new prospects for realization of experimental researches in interaction of high-intensive laser emission with matter in fundamental and applied fields of high densities energy physics. RFNC-VNIIEF in cooperation with the Institute of Applied Physics started a proposal on petawatt laser complex creation on the basis of the “Luch” facility channel and the works are being executed. Research on the properties of matter under the influence of huge radiation intensity 1021 – 1022 W/cm2 is planned to be fulfilled at this facility.

High-explosive photo-dissociation iodine lasers with the energy of several hundred kilojoules have been developed at LPRI. This laser type is a record-holder among pulse lasers on radiation energy. Besides record high energy photo-dissociation iodine laser is remarkable for high homogeneity of radiation (Δv <10-3 cm-1) and relatively low optical non-uniformity of the active medium ($\Delta n \approx 2 \cdot 10\text{-}6 - 2 \cdot 10\text{-}7 cm^{-1}$). A review of results obtained on photo-dissociation iodine lasers during last years is reported. The radiation energy in free-running lasing regime was up to 60 kJ at angle of divergence $2 \cdot 10^{-4}$ rad. In the monopulse mode the beam focusing into the spot of the diameter about the laser wavelength has been experimentally realized and the intensity of 1018 W/cm2 at the duration 0.7 ns has been obtained.

Electric-discharge pulsed-periodic chemical lasers based on non-chain reaction of fluorine and hydrogen (deuterium), which can be used as radiation sources in systems having very different purposes, are being developed at VNIIEF. The laser pulse recurrence rate of the developed facilities varies from 10 to 1000 Hz at the single pulse energy changing from tens of milli-joules to hundred joules. For all that the laser divergence of diffraction quality has been achieved.

Research on high-power iodine-oxygen continuous chemical lasers creation takes an important place among the developments of LPRI. A record-effective unique singlet-oxygen generator with a swirling flow has been built. An experimental test bench of average power ~50 kW with supersonic flow of working medium in the resonator has been developed on its basis.

LIBS Development and Applications for Nuclear Material Analysis

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Laser Induced Breakdown Spectroscopy (LIBS) development and applications to analyse different nuclear materials (solids, liquids, micro particles in gas, melted salt, MOX fuel pellets, impurity contents in thermonuclear reactor walls) are presented. The specific features of LIBS applications in nuclear industry and their performances (detection limits, isotope resolution, elemental cartography, and microanalysis) are discussed. The presentation is based on the investigation results that have been obtained in CEA Saclay (France) for the past ten years. The ways for further LIBS improvements (environmental conditions, laser wavelength, signal normalisation, ultra short pulses, and double pulse plasma reheating) are also discussed.

Effect of electric field on subnanosecond-pulsed laser ablative drilling

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It is found that electric field, applied between supplementary electrode and conductive sample irradiated in air, can lead to dramatic (up to 2 orders of magnitude) enhancement of drilling rates for subnanosecond (~100ps) laser pulses. The effect is attributed to field extraction of charged nanoparticles from the beam path. These particles are produced as a result of metal ablation into ambient gas. Residing for seconds in atmosphere of drilled deep craters, they were shown to cause an optical gas breakdown, when the spot is subsequently exposed to laser radiation. The plasma ignited by pulses of subnanosecond duration essentially screens the crater bottom from the incident beam. Thus, the principal effect of applied electric field is elimination of this low-threshold air breakdown via removal of charged nanoparticles from the laser beam path.

The influence of electric field on productivity of laser drilling and morphology of created channels under atmospheric air conditions was investigated with respect to field polarity and amplitude, kind of ablated material, channel depth, duration and repetition rate of pulses delivered by Nd:YAG and Ti:Al_2O_3 lasers. The comparison between atmospheric and vacuum irradiation conditions was also made. The size distribution of charged ablated nanoparticles will be presented.

Laser Forward Transfer Techniques for Microelectronics Fabrication

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The use of laser-based direct-write techniques might revolutionize the way microelectronic components such as interconnects, passives, IC's, antennas, sensors and power sources are designed and fabricated. The Naval Research Laboratory has developed a laser-induced forward transfer microfabrication process for direct-writing the materials required for the fabrication and assembly of the above components. The laser direct-write (LDW) system used for these applications is capable of operating in subtractive, additive, and transfer mode. In subtractive mode, the system operates as a laser micromachining workstation, while in additive mode, the system utilizes the laser forward transfer process for the deposition of metals, oxides, polymers and composites under ambient conditions onto virtually any type of surface. Furthermore, in transfer mode, the system is capable of transferring a single device, such as semiconductor bare die, inside a trench or recess in a substrate, thus performing the same function of the pick-and-place machines used in circuit board manufacture. The use of this technique is ideally suited for the rapid prototyping of microelectronic components and systems while allowing the overall circuit design and layout to be easily modified or adapted to any specific application or form factor. This presentation will discuss several examples of the types of mesoscopic electronic devices fabricated using the above-mentioned LDW processes.

This work was sponsored by the Office of Naval Research.

High precision ultrafast optical diagnostics of pico- femtosecond laser microplasma

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The review of the recent results of pico- femtosecond laser plasma studies performed in A.M. Prokhorov General Physics Institute with the advanced experimental techniques are presented.

The subject of investigations is the *micro-sized* plasma produced in gases and in transparent solids with high intensity (up to 10^{17} W/cm^2), tightly focused (to a few microns in diameter) femtosecond and picosecond laser pulses. The experimental techniques are: i) a precise pump-probe micro-interferometry, ii) an ultrafast time-space-resolved laser pulse profilometry, and iii) a high-speed micro-spectroscopy. Two latter techniques employ ultrafast streak-cameras providing a pico- subpicosecond time resolution. The main attention in the experiments is paid to *the initial* stage of microplasma formation and evolution characterized by strong laser-plasma coupling resulting in efficient ionization of the media, distortion of laser beams, and nonlinear spectral conversion of laser radiation to continuum and laser harmonics.

With the interferometric technique the dynamics of gaseous plasma is studied in a wide density range - from a minimal detectable electron concentration (10^{19} cm^{-3}) to the almost *total* (down to nuclei) ionization of ions occurred under femtosecond and picosecond excitation. The obtained time-dependences of plasma density are analyzed.

The ultrafast streak-camera-based techniques allow: i) comprehensive investigation of temporal evolution of microplasma emission and the dynamics of spectral lines formation in UV-visible range, ii) observation of laser harmonics generated in plasma; and iii) study the ultrafast time-space transformation of laser beams passed through the plasma.

The work is performed under Russian Academy of Sciences Programs: "Femtosecond optics and new optical materials", "Optical spectroscopy and frequency standards", and Russian Foundation for Basic Research project #06-02-17014.

Time resolved studies of femtosecond laser induced breakdown: review of recent experiments on transparent dielectrics

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Femtosecond lasers have early been recognised as "perfect tools" to achieve ablation and machining of practically any material with high resolution and surface quality, leading to an increasing number of applications.

The aim of the work presented here is to investigate the fundamental mechanisms occurring during the interaction of picosecond and subpicosecond laser pulses with condensed matter at intensity below and above ablation threshold. The samples under study are wide band gap dielectrics, which are widely used, including in optics (Al_2O_3, SiO_2, KDP…), where material damaging is of concern.

The first key point is to understand the mechanism of energy absorption from the laser. There has been a long debate concerning the respective role of laser induced ionisation from the valence band to the conduction band and multiplication of free carriers by electron avalanche.

We have used a time resolved interferometry technique which allows measuring the modification of the dielectric constant and thus the density of excited carriers during optical breakdown [1]. The comparison between different laser pulse duration proves that electronic excitation occurs mainly by multiphoton absorption.

Moreover we observe that the laser absorption by photo-excited carriers in the conduction band is the dominant mechanism of energy transfer to the solid, and that the density of carriers at threshold decreases when the pulse duration increases. Thus the decisive criteria to determine whether breakdown will occur or not is not the excitation density as claimed by many authors, but rather the amount of absorbed energy.

Finally we have measured the geometry of single shot ablation craters for different pulse duration and intensity. Two different ablation regimes with a boundary at about 1ps are observed: deterministic threshold and deep craters for short pulses, shallow craters and fuzzy threshold for long pulses.

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Nanospallation under action of femtosecond laser pulse

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The report is devoted to the description of physical phenomena connected with the action of ultra-short laser (USL) pulses $\tau_L \sim 0.1\,\text{ps}$ upon a gold target. Absorption of pulse creates thin layer of hot electrons strongly overheated ($T_e >> T_i$) above the ion temperature T_i. During pulse τ_L thickness d_{heat} of the layer is very small $d_{heat} \sim \delta$, where $\delta \sim 10$ nm is the thickness of skin layer. Subsequent evolution includes (i) propagation of electron heat wave which enlarges the thickness of heated layer in comparison with δ, (ii) cooling of electrons due to energy transfer to cold ions, (iii) onset of hydrodynamic motion that initially resembles the expansion wave with positive pressure $p \geq 0$, (iv) intermediate hydrodynamic stage when negative pressure appears and grows in its absolute value, and (v) long separation process which begins with nucleation of the first voids and continues up to the total separation of spallation layer. Thickness of the layer is ~ 10 nm (we call it nanospallation). Theoretical model involves two-temperature hydrodynamics with EOS for gold and electron heat conductivity and electron-ion energy exchange rate taken from literature. The decay of metastable strongly stretched matter is described by molecular dynamics (MD) simulation with extremely large number of atoms. Large number of atoms allows simulating creation of foams with representative ensemble of interacting bubbles. Fresnel approach with optical constants for liquid gold was used to calculate theoretically Newton rings and positions of interferometric fringes observed in experiments. Experimental setup includes femtosecond chromium-forsterite laser 1240 nm operating in the pump-probe regime. Measured ablation threshold for gold is 1.35 J/cm^2 (per 1 cm^2 of target surface) at incident pump light at inclination 45^0, p-polarization. Calorimeter measurements give value 30% for absorbed fluence F_{abs}. Therefore the threshold at F_{abs} is 0.4 J/cm^2.

Atomic-level computer modeling of laser-induced plasticity and structural transformations in metal targets

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Web page: http://www.faculty.virginia.edu/CompMat/

Short-pulse laser irradiation of a metal target can induce a cascade of non-equilibrium processes occurring at different time and length scales, including relaxation of excited electronic states and electron-phonon coupling, generation of strong thermoelastic stresses, shock waves, plastic deformation and dynamic fracture (spallation), melting, explosive boiling and massive material removal from the target (ablation). Atomic-level computer modeling can provide detailed information on the complex processes induced by the fast laser energy deposition and can assist in the advancement of laser-driven applications.

Recent progress in the development of computational methods for simulation of laser interaction with metal targets, as well as the results obtained for laser melting, plastic deformation and generation of crystal defects, photomechanical spallation and ablation are reviewed in this presentation. In particular, a hybrid computational model combining classical molecular dynamics method for simulation of fast laser-induced phase transformations with a continuum description of the laser excitation and subsequent relaxation of the conduction band electrons is discussed. The effect of the thermal excitation of the lower band electrons on the temperature dependence of the thermophysical material properties (electron-phonon coupling, electronic heat capacity and conductivity) is analyzed for several representative noble and transition metals. Practical implications of the revealed temperature dependences of the thermophysical material properties for interpretation of experimental data are discussed. The mechanisms and kinetics of laser-induced melting, as well as the mechanisms of generation of crystal defects are discussed based on the results of computer simulations.

Time-resolved description of free-electron generation in laser-excited dielectrics

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When transparent solids are irradiated with high-intensity lasers, an electron-hole plasma may be generated, which consists of free electrons in the conduction band of the solid and holes in the valence band. If the electron density reaches values close to critical plasma density (at which the plasma frequency of the free electron gas equals the laser frequency), the dielectric becomes highly absorbing. The large energy transfer to the solid leads to dielectric breakdown and further to phase transitions and ablation.

Different models aiming to describe the temporal evolution of the free-electron density under laser irradiation are compared in this presentation. A simple rate equation is commonly used to estimate the transient free-electron density for applications like micromachining or further calculations. However, it was shown that this model fails on ultrashort timescales. On the other hand detailed kinetic approaches are rather involved and demand large numerical effort.

Here I present an intermediate description, namely the multiple rate equation (MRE), which unifies key points of detailed kinetic approaches and simple rate equations to a widely applicable description, valid on a broad range of timescales. It follows the nonstationary energy distribution of electrons on ultrashort timescales as well as the transition to the asymptotic avalanche regime for longer irradiations. The role of photoionization and impact ionization is clarified in dependence on laser pulse duration and intensity.

As an application of the MRE, I show that the characteristic of density increase strongly depends on the temporal shape of the exciting laser pulse. Resulting effects of different pulseshapes on laser ablation are discussed and compared with experimental results.

Experimental and theoretical analyses of nanoparticle generation via femtosecond laser ablation

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The mechanisms of nanoparticle formation via femtosecond laser ablation of different materials are investigated experimentally and theoretically. The experimental analyses involve measurements of the ablated mass, plasma diagnostics, and analysis of the nanoparticle size-distribution. For theoretical analysis, a two-temperature model is applied to describe the laser-material interaction. The expansion dynamics is described by a combined MD-DSMC model that allows us to predict the cluster ejection from the target and the aggregation within the plume. In agreement with the experimental results, monomers dominate the plume composition for laser fluences close to the ablation threshold whereas efficient nanoparticle formation occurs at slightly larger fluences.

Hot plasma control and diagnostics during femtosecond Cr:forsterite laser micromachining in ambient air

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Femtosecond laser micromachining has become increasingly important in recent years for many fields. The lasers used in femtosecond laser machining commonly have pulse energies ranging from 10 μJ to 1 mJ and under tightly focusing regime the typical values of intensities are in the range of 10^{12}–10^{16} W/cm^2.

We present femtosecond laser micromachining of different materials from two perspectives: (1) the diagnostics of a hot plasma temperature produced in a cavity during the process of micromachining and 2) hot plasma control during femtosecond laser micromachining in ambient air.

The experiments were performed with femtosecond Cr: forsterite laser system (λ=1.24μm, output pulse duration of 110fs and pulse energy of 0.5mJ). It has been shown in our experiments that under interaction of femtosecond laser radiation with intensity of 10^{15}-10^{16} W/cm^2 a hot plasma with electron temperature of 10-20 keV is switched inside laser produced cone-like cavity at different initial conditions: from the residual pressure of 10^{-2} Torr and up to gas pressure of 760 Torr.

We observed that X-rays yield enhanced after irradiation of a target by sequence (several tens) laser shots and hot electron temperature is 1.5-2 times greater compare with the case of flat surface. We believe that the laser radiation is optically guided inside the channel (cavity) with typical length of 50-100μm and focused at the tip of the produced cone. Due to this reason the laser beam intensity increases up to several times inside the cavity. In our experiments we used Al, Mo, Ti metal foil with the typical thickness of 20-200μm.

We investigated the peculiarities of hot plasma switched in the cavity and average ablation rate as a function of focal position respect to the surface plane.

We present our results directed to the suppression influence of atmospheric gases on delivering of superintense femtosecond laser radiation to the solid target at atmospheric conditions. The suppression of atmospheric gas influence in laser plasma upon exposure of a surface by double-pulse radiation technique is shown to be caused due to reduced gas density in the laser-matter interaction region. In our scheme the first pulse (nanosecond UV pulse from XeCl excimer laser) serves as a vacuum pump and the second one (tightly focused femtosecond pulse) delayed up to several microsecond respect to the first laser pulse delivers main energy to switch a hot plasma on the target surface. Plasma defocusing, self-phase modulation and shielding effects are minimized due to the lower gas density inside the expansion volume near the surface of the target and thus less plasma forms along the femtosecond tightly focused beam path. The intensity of preceding UV pulse and main femtosecond pulse were about of 10^9 W/cm^2 and more than 10^{15} W/cm^2 correspondingly. We observed maximum X-ray yield increasing up to 4 times under double pulses exposure compare with the single femtosecond pulse case.

Ultra-short laser pulse induced charged particle desorption rate enhancement near the damage threshold of dielectric surfaces

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The kinetics of charged particle emission upon femtosecond laser pulse interaction with single fluoride crystals is studied by experiments using time-of-flight mass spectrometry. At intensities below the damage threshold, following the initial electron excitation and emission, singly and multiply charged positive ions are released from the surface in a substantial amount. Their ion velocities are high, with a narrow distribution, indicative of a localized microscopic electrostatic expulsion. The intrinsic mechanisms of ion desorption exhibit higher complexity with increasing intensity. Positive ions with bimodal velocity distribution are detected at intensities near the damage threshold. Under these conditions, negative ions are also detected. The dynamics of negative and positive-ion yields indicate essential differences in their desorption mechanisms. We suggest a concomitant action of a localized electrostatic repulsion, macroscopic Coulomb explosion and also a thermal 'explosive' mechanism.

The excitation process and surface charging effect are greatly enhanced by pre-existing or laser-induced transient defects. The nature and lifetime of these defects are studied by laser induced fluorescence experiments. We analyze the role of defects on surface decomposition, studying the dependence on the number of pulses for both the particle yield and damage threshold intensity. Thus, the incubation effect is coupled to a reduction of the multi-shot damage threshold with increasing intensity. We advance a possible explanation of a sudden increase and 'saturation' of the ion yield with increased number of pulses, by indicating that defects with lifetime of about 1ms can provide, in our irradiation conditions, a pulse-by-pulse increase in the free electron density up to a possible surface breakdown.

FLAMN-07

Peculiarities and consequences of charge-carrier transport in the different types of materials under ultrashort pulsed laser irradiation

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The dynamics of electronic excitation, heating and charge-carrier transport in different materials (metals, semiconductors, and dielectrics) under near-infrared femtosecond laser irradiation has been studied on the basis of a drift-diffusion approach. It is demonstrated that charging of dielectric surfaces results in a sub-picosecond electrostatic rupture of superficial layers (Coulomb explosion), while this effect is strongly inhibited for metals and semiconductors as a consequence of superior carrier transport properties. The Coulomb explosion (CE) threshold is studied as a function of pulse duration for a number of dielectric materials ($A1_2O_3$, a-SiO_2, ULE). Various related aspects concerning the possibility of CE are discussed. This includes the temporal and spatial dynamics of charge-carrier and electric field generation in non-metallic targets and evolution of the reflection and absorption characteristics. The theoretical conclusions are supported by the experimental data. A special attention is paid to studies of interconnection between the electron photoemission yield and surface charging dynamics. It has been shown that, in dielectrics, the photoemission yield saturates with increasing laser flue nee as a result of self-regulation of the free-electron population.

The lattice heating dynamics in the metallic targets is found to be strongly dependent on the photoemission yield that, in its turn, results in noticeable increase of the melting threshold with decreasing pulse duration. However, photoemission can be suppressed by the generated electric field whose amplitude is a function of pulse duration and laser fluence. In order to clarify these aspects, the experimental studies on pulsed laser irradiation of gold samples have been undertaken, aimed to determine the fluence dependence of the photoemission yield and the dependence of the melting threshold on pulse duration. The results of joint analysis of the experimental and numerical data will be discussed.

Theory of interaction of intense laser radiation with atoms, nuclei and femto-second laser plasma at surface. Atomic dynamics with non-rectangular laser pulses

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Consistent QED theory is developed for studying interaction of atoms with an intense laser field. Method bases on a description of atom in the field by the k- photon emission and absorption lines [1, 2]. The lines are described by their QED moments of different orders, which are calculated within Gell-Mann & Low adiabatic formalism. The analogous S-matrix approach is developed for consistent description of the laser-nucleus interaction. We have studied the cases of single-, multi-mode, coherent, stochastic laser pulse shape. An account for stochastic fluctuations in a field effect is of a great importance. Results of the calculation for the multi-photon resonance and ionization profile in H, Na, Cs atoms are presented.

Using super short light pulses changes principally a character of interaction of a laser radiation with substance and may result in forming the femto-second laser plasma.(FLP). Special attention is devoted to the modelling the surface of which there is a great number of bonds with H and OH groups. In a case of D-and OD group's one can wait for realization of the cluster explosion process and reaction D+D$\rightarrow\alpha$+n (3,8MeV). One can wait for appearance of the powerful flow of neutrons under intensity of laser pulse ~ 10^{16} W/cm^2. It is possible an excitation of the low lying isomers (level energy less 20 keV) by means of the channels: photo excitation by own X-ray plasma radiation, the electron impact excitation, electron conversion etc [2]. We discuss an effect of the excitation for isomer nuclear level in laser plasma.

Atomic dynamics with non-rectangular laser pulses is studied and the results of numerical calculation of population kinetics of the resonant levels for atoms in the non-rectangular pulse field on the basis of the modified Bloch equations are presented. The equations describe an interaction between two-level atoms ensemble and resonant radiation with an account of the atomic dipole-dipole interaction. A new idea of this work is discovery of strengthen possibility of manifestation for the internal optical bi-stability effect special features in the temporary dynamics of populations for the atomic resonant levels under adiabatic slow changing the acting field intensity [2]. A discovery and observation and adequate explanation of the optical bi-stability effect is discussed.

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Spectral dependence of conical emission in gases

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Using of ultrashort pulses is mainstream of advanced laser micromashining, the potential advantages of which are: the minimum melted layer, high accuracy and productivity, which seems to be limited only by the incident energy. Not all expectation come unfortunately true, especially those related to high energy ablation. The craters and channels produced in air by femtosecond pulses are typically much wider than expected and featured by complex morphology. It was recognized that inhomogeneity of focused beams producing these craters is caused by strong non-linear scattering of intense radiation in ambient gases, which is contributed by several ultrafast mechanisms effecting the refraction index of the gas media in the propagation domain of ultrashort pulse. These mechanisms are: the non-linear Kerr effect, ionization (field or multiphoton) and possibly the resonance multiphoton transitions in gases. The whole phenomenon is often called conical emission, as the beams are scattered into wide cones having complex ring-like intensity profiles. The scattered spectra are significantly broadened due to self-phase modulation.

Parameters of conical emission were experimentally investigated at focusing of femtosecond and short picosecond pulses in several gases in a wide range of parameters of incident radiation. We measured scattered and absorbed energy, divergence angles, profiles and spectra of scattered beams in the vicinity of the beam waist. The clue parameters mentioned were defined and compared for several wavelengths of laser radiation aiming at elimination of conical emission in a possibly wider range of incident energy. In the experiments, we used the fundamental output and second harmonics of Ti:Sa and Yb:YAG laser (800 nm, 1030 nm, 400 nm and 515 nm). Surprisingly enough, a big difference in scattered energy was observed within this spectral range, and the shorter wavelengths were found to be most beneficial in terms of elimination of conical emission. 515 nm radiation was found to be especially good allowing insignificant scattering of short picosecond pulses in the energy density range up to 300 J/cm^2. Reasons for such strong spectral dependence of non-linear scattering in gases are discussed.

Self-guiding propagation of vortex pulsed beam in ionized dielectrics

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High-power tubular beams have a large potential for variety of applications in such fields as electron accelerators, high harmonic generation, high-efficiency x-ray lasers, laser-driven and high-field nonlinear optics, etc. In this study, the propagation dynamics of high-power femtosecond tubular pulsed beam with singular phase in dielectrics like fused silica under photoionization (PI) conditions is studied. For this aim the system of modified nonlinear (3+1)D Schrödinger equation (NSE) for an electric field envelope as well as kinetic equation for free electron density was numerically solved. The competition of Kerr-self-focusing and plasma defocusing is taken into account. Radiative and/or non-radiative electron recombination processes are considered. The influence of normal and anomalous group velocity dispersion on quasisoliton regime of propagation is considered.

In order to solve the obtained equation set, we introduced a mesh uniform in t domain and non-uniform in r, z domains. The initial task was approximated by difference equations realized via iterative alternating direction method involving intermediate layer in z variable. Obtained algebraic equation set was solved using sweep technique combined with iterations, while the electron density equation was integrated by Runge-Kutta method. In addition, we used the variation approach to NSE investigation and compared the results obtained.

It was revealed multifoci behavior of a vortex pulsed beam with topological charge m = 1, 2, 3 at a near-critical input power. Moreover, the interaction of above-mentioned beam with nonlinear dielectric medium is shown to stipulate higher plasma densities in comparison with gaussian pulsed beams. At this the amount of generated free electrons increases with increasing the beam topological charge. The conditions of self guiding propagation regime of vortex pulsed beams with high topological charge have been established.

Laser-matter interaction and related spectroscopies

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Nanoparticles and thin films of various materials such as metals, semi and superconductors, nitrides, oxides and carbides have been extensively studied in the last years because their unique physical and chemical properties.The growing interest in producing thin films and nanoparticles of these compounds is due to the fact that many of them show novel properties. New electronic materials, including super- and semiconductors, implants for quantum well and quantum dot devices, and photovoltaic devices for solar cells have been produced.

The formation of molecular clusters through laser matter ablation and deposition (PLAD) is an important feature for the production of systems of finite size such as nanostructure materials with tailored properties [1]. The emission spectroscopy, induced by PLAD, has become an excellent tool for the investigation of the costituents of these materials. This technique is well known to produce material removal which usually forms luminous plasma above the solid surface hit by laser. Many aspects of the interaction process and plasma characteristics are strongly influenced by experimental parameters such as laser beam properties, laser pulse duration, surrounding atmosphere and property of the material itself. In the past, the influence of the pulse duration was studied. Ultra short pulses can induce processes which can be treated by different approaches such as the two temperature model, the Coulomb explosion and non-thermal heating. The knowledge of the type, concentration and distribution of laser produced species in biological systems is also of great interest for understanding the processes of biological mutation.

This paper concerns on nanosecond and femtosecond PLAD and laser spectroscopy of inorganic and aromatic organic compounds. The plume diagnostics of the ablated species, allows to characterize the plasma dynamics, i.e. the temporal and spatial evolution of the plume. Optical emission spectroscopy has been applied to characterize the transient species produced in the femtosecond (fs) and nanosecond (ns) regimes.

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Surface-Assisted Laser Desorption Ionization of Organic Compounds from Silicon

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The generation of ions from silicon substrates in Surface-Assisted Laser Desorption Ionization (SALDI) has been studied using silicon substrates prepared and etched by a variety of different methods. Mass spectra of a wide range of analytes with varying basicity and molecular weights were obtained using laser wavelengths from UV to IR. Ionization efficiencies were measures as a function of laser fluence and number of laser shots. It is demonstrated that both the chemical properties of the substrate surface and the presence of a highly disordered structure with a high concentration of “dangling bonds” or deep gap states are required for efficient ion generation. In particular, amorphous silicon is shown to be an excellent SALDI substrate with ionization efficiencies in excess of one percent, while hydrogen-passivated amorphous silicon is SALDI-inactive. Based on the results, a novel model for SALDI ion generation is proposed with the following reaction steps: 1) the adsorption of neutral analyte molecules on the SALDI surface with formation of a hydrogen bond to surface Si-OH groups; 2) the laser electronic excitation of the substrate to form free electron/hole pairs. Their relaxation dynamics leads to trapped positive charges in near-surface deep gap states, resulting in an increase in the acidity of the Si-OH groups and proton transfer to the analyte molecules; and 3) the thermally activated dissociation of the analyte ions from the surface over a “loose” transition state.

Ultrafast interferometric microscopy of femtosecond laser plasma: acquisition and processing of microplasma phase images

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The interferometric technique for precise ultrafast optical diagnostics of laser-induced plasma is described. This technique was applied for experimental studies of formation and evolution of laser microplasma produced in gases. The numerical technique of interferogram processing and reconstruction of instant spatial distribution of refractive index and free electron density in laser-induced plasma was developed. The spatiotemporal distribution of the refractive index and the free electron density were studied with a spatial resolution of ~ 1.5 µm and a temporal resolution of ~ 100 fs. It was shown, that sensitivity of the developed technique is about λ/30. Such sensitivity corresponds to plasma free-electron densities ~ $5 \cdot 10^{18}$ cm^{-3} for plasma objects sizes about 20 µm in diameter.

This work is supported by RFBR project # 06-02-17014 and RAS Program "Femtosecond optics and new optical materials".

Mechanisms of cluster emission from femtosecond-laser-irradiated silicon

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Time-resolved pump-probe measurements of the dynamics of fs-laser ablation of crystalline silicon under ultrahigh vacuum conditions have been performed using time-of-flight mass spectrometry in order to reveal mechanisms of particle emission from the irradiated surface. Strong emission of charged Si_n^+ clusters (n = 2-11) has been observed at low laser fluences, near the ablation threshold. With two consecutive laser pulses applied, the relative cluster yield is maximized at around 400-700 fs delay between the pulses and can reach up to 50% of the total amount of emitted particles. The particles exhibit non-thermal velocity distributions that remind a feature of the Coulomb explosion mechanism of the emission. The cluster emission essentially depends on the number of laser pulses applied with the strongest emission occurring after 30-40 pulses. The observations imply an accumulation of structural changes on the Si surface important for the emission process.

Theoretical modeling based on a drift-diffusion approach has been performed to describe laser-induced excitation, charging and heating of the irradiated Si target under the experimental conditions. Calculations show that silicon surface charging is not nearly enough to cause bond breaking and thus we have to rule out the Coulomb explosion mechanism. Instead, we suggest a new emission mechanism connected with a structural phase transition on the Si surface. The transition is induced by the first (pump) pulse resulting in rebuilding of surface dimer bonds at temperatures well below the melting point. In addition, the pump-probe delays of several hundreds fs correspond to the timescale of surface structural instability due to a perturbation of the interatomic bonds and surface charging. The second (probe) pulse, applied to the modified unstable surface, acts as a trigger resulting in efficient emission of clusters. The mechanism responsible for the non-thermal velocity distributions of the emitted clusters will be also discussed.

The role of plasmon-polaritons and waveguide modes in surface modification of semiconductors by ultrashort laser pulses

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Ultrashort laser pulse induced modification of silicon semiconductors attracts a lot of attention due to both potential for technology development and unique physical conditions of the laser action. One of the most interesting features of ultrashot laser pulse action on semiconductors, in particular silicon, is related to formation of regular microstructures at the surface. Physical mechanisms of this phenomenon are still not fully understood.

Recent results obtained at M.V.Lomonosov Moscow State University in experimental modification of silicon surface by femtosecond laser pulses (Cr^{4+}:forsterite laser; 1.25 μm; 80 fs; 250 μJ per pulse) allowed us to attribute the observed ripple structures to excitation of either surface plasmon-polaritons at the silicon-air interface or TE waveguide mode.

Simple estimations, based on Drude's model, indicate the possibility of achieving negative value of dielectric permeability of silicon under ultrashort pulse action. The effect of "metallization" of silicon results from intensive photo-excitation and growth of non-equilibrium carrier concentration in silicon under the condition of separation between photo-excitation and thermal processes.

We proposed a theoretical model to describe excitation of surface plasmon-polaritons and TE waveguide mode at the interface of two initially transparent dielectric media under laser irradiation, which induces a change in dielectric permeability of one of the media. The proposed model explains the experimentally observed regularities of silicon microstructuring by ultrashort laser pulse.

The work was supported by RFFI grant 06-02-16960 and the Russian Federation President grant for a Leading scientific school 5967.8.2006.

Three-Dimensional Nanomodification with Ultrafast Pulse Laser

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A progress in high power ultrashort pulse lasers has opened new frontiers in physics and technology of light-matter interactions. Various structures can be produced at the focal point inside a transparent material by using pulsed laser operating at the non-resonant wavelength with pulse widths of the order of femtoseconds: colored line due to the formation of color center, refractive index spot due to densification and defect formation, micro-void due to re-melting and shock wave, micro-crack due to destructive breakdown etc. We have succeeded in the three-dimensional structural-phase transformation from diamond to amorphous structures which have high electrically conductive property by the femtosecond laser pulses irradiation. This spatially periodic conductive structure indicates meta-material properties in terahertz region. We have also demonstrated the three-dimensional nanostructuring such as a nanograting and a nanovoid inside a glass material by the single femtosecond laser beam irradiation. The self-organized sub-wavelength periodic nanostructures are created by via a pattern of interference between the incident light field and the electric field of the bulk electron plasma wave. Recently we propose an alternative mechanism of self-organized nanograting formation based on interference of bulk plasma waves excited via two plasmon parametric decay. The mechanism predicts more realistic values for the electron energy, which is of the order of a material's band gap, and for the electron density, which is of a quarter of critical plasma density. More recently, we have observed photoconversion from copper flakes to nanowire via ultrafast pulse laser irradiation. This phenomenon has provided the first observation of a distinct surface plasmon resonance. Nanowires of 50 nm diameter are also fragmented from their initial appearance by interference between the light field and the surface plasmon-polariton waves in the early period of laser radiation.

Possibility of control of propagation regime in medium with cubic nonlinearity for chirped femtosecond pulse under the temporal dispersion of nonlinear response

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In this report an investigation of axial symmetric laser beam in Kerr medium was made taking into account temporal dispersion of nonlinear response. As it is well known, this propagation is described by so-called generalized nonlinear Schrödinger equation in 3D case. The essential feature of this equation is a term which contains a time derivation from nonlinear response. As a result, a group velocity of wave packet depends on laser pulse intensity. On the other hand, there is self-focusing due to local Kerr nonlinearity and, as it is well known, for the picoseconds pulses an unlimited growth of intensity of axial symmetric beam takes place. Both factors results in new quality of laser beam propagation. The main feature of it is a possibility to control of self-action for chirped laser pulse. Under such conditions we can easy to change regime of self-focusing to opposite one. In this case a temporal dispersion of nonlinear response can be the main nonlinear response of medium along definite interval of laser light propagation.

Results under consideration base on computer simulation, which was made with using of conservative difference schemes. They allow doing the simulation with high accuracy. We use multi-processors computer with parallel algorithm of calculations. To get conservation laws, early original transform of generalized nonlinear Schrödinger equation to the form without temporal derivation from nonlinear response was proposed. To explain computer simulation results some analytical consideration is made.

Nanoscale Domain Engineering in Lithium Niobate Crystals by Pulse Laser Illumination

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The formation of tailored nanoscale domain structures (nano-domain engineering) is of the great importance for application of nanotechnology for developing the multifunctional crystals. We will demonstrate a new approach to nanoscale domain patterning through pulsed laser irradiation of the single crystalline lithium niobate (LN) important for nonlinear optical application.

The stable nanoscale domain structure has been formed without any application of external voltage by pulsed irradiation of congruent single-domain LN wafers using various lasers. Domain visualization using optical and different modes of scanning probe microscopy allows to reveal three types of nanoscale domain patterns: isolated “dots” along the boundary of the irradiated area, quasi-periodical “lines” and self-similar “fractals” inside the irradiated area. It has been proposed and confirmed by computer simulation that “line” and “fractal” patterns appear through “domain rays” growth along three Y directions. The growth of straight rays along Y directions always starts from individual nano-domains. Reflection of given ray happens when the tip approaches to another ray. Further spreading occurs due to ray “branching”. It has been shown by us earlier that formation of the rays as a result of merging of isolated nano-domains in oriented arrays is typical for switching in strongly nonequilibrium conditions.

The observed results have been discussed under supposition that the cooling after pulse laser illumination creates the pyroelectric field, acting as a driving force in the switching process. It must be pointed out that the proposed method of polarization reversal can be used for production of periodic nano-scale domain structures thus opening the new page in photonic applications of periodically poled LN.

The research was made possible in part by Grant 03-51-6562 of INTAS; by Grant 06-02-08149 of RFBR; by Grant RNP 2.1.1.8272 of Program "Development of Scientific Potential of High Education” of FAE; by Grant of Federal Special Program of FASI.

The analytical solution of the kinetic equation for the crystallization process with superfast cooling velocities under laser material processing

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Kinetic model for cooling processes after laser material action was creating. The function of crystalline nuclei dimention distribution is found by exact analytical solution of classical kinetic equation for the case of superfast cooling velocity reached at laser treatment using the operator technique. The result for distribution function allows us to calculate the finel crystalline nuclei dimention distribution if we know initial one.

The everage number of particles in the crystalline nuclei and the relative volume change of crystalline phase were found as a function of thermodynamic paramaters of materials and cooling regime.

The critical value of cooling velocity for amorphous phase production was calculated.

PS1_01 Femtosecond laser patterning of micro dimension heterostructures using laser induced forward transfer (LIFT) ♣

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Laser induced forward transfer (LIFT) process using femtosecond pulsed laser to pattern micro dimension heterostructures on a solid substrate is investigated. The technique is attractive because of low material consumption, dry and a precise pattern. A femtosecond pulsed laser (Clark-MXR laser, wavelength: 750nm, pulse width: 150fs), and a MAX341 3-Axis NanoMax, Closed-loop piezo & Stepper Motors are used for patterning. Ribbons with different composition deposited on transparent substrate are back side irradiated and the corresponding dot is transferred on an acceptor substrate. The aim of this study was to demonstrate that controlled size heterostructures containing stoichimetric layers can be reproducible grown just by successive single step laser irradiation.

♣ Letters “PS” before the titles marks the poster presentation

PS1_02 Structural and optical properties of silicon surfaces irradiated by femtosecond laser pulses

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Permanent interest in the laser ablation processes under irradiation by the femtosecond laser pulses caused by the high energy concentration at times shorter than thermal diffusion ones. Upon these conditions the damaged zone has the minimal size and the best quality in comparison with cases when irradiation by the picosecond or longer pulses takes place.

In our work we study the silicon wafers irradiated by the femtosecond laser pulses. The Cr^{4+}:forsterite laser (1.25 μm, 80 fs, 250 μJ per pulse) was employed as a femtosecond pulse source.

The atomic-force microscopy analysis of the irradiated silicon wafers revealed two types of surface structures: the ripples with a period about the laser wavelength and the nanoparticles with a lateral size 70 – 200 nm and a height 2 – 30 nm. Formation and direct observation of such nanoparticles have been achieved in our work for the first time. At the same time ripple formation is a well-known phenomenon of interference between the incident and scattered electromagnetic waves.

To monitor the ripple formation process we used the third-harmonic generation technique. As a pump source we used the same Cr^{4+}:forsterite laser with the laser pulse energy fluence below the ablation threshold. The third-harmonic polarization-sensitive measurements showed that the ripple relief plays a dominant role in distribution of the local electromagnetic fields on the irradiated surfaces.

Study of optical response from the nanostructures was carried out by the Raman spectroscopy and photoluminescence methods. We registered red Raman shift and asymmetric broadening of the line 520.5 cm^{-1} and visible photoluminescence. These phenomena confirm existence of the nanoparticles with a size of several nanometers.

Thus, we showed possibility to essentially modify the structural and optical properties of the silicon surfaces by their treatment by the femtosecond laser pulses.

PS1_03 Maskless super-resolution femtosecond laser lithography

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Conventional lithography is a leading high-throughput patterning method for mass production, but this technology is too expensive for most small-scale manufacturing applications. Development of maskless lithography techniques can provide a potential solution for the photomask cost issue. Furthermore, it could open a market for small-scale industry.

Diffraction is the limiting factor in conventional photolithography. Structure sizes are restricted to a value in the order of the radiation wavelength. Using maskless lithography in combination with femtosecond laser radiation (800nm), however, enables structure sizes far below the diffraction limit. This super resolution is the consequence of the well defined threshold for femtosecond laser photoresist exposure and the nonlinearity of the laser-photoresist interaction.

The principle of this technology is described further. A substrate with etchable surface is covered by a commercially available photoresist. Femtosecond laser pulses trigger a nonlinear response in the photoresist and can provide very precise exposure (slightly above the photorecording threshold) generating required structures and patterns. With femtosecond laser pulses (at the nJ level) one can control irradiation dosage with very high precision, which is impossible with radiation sources used in conventional photolithography. The photoresist can be removed chemically after exposure or directly by nonlinear femtosecond laser ablation, i.e. “during exposure”. After the photoresist is patterned, all further production steps known in common lithography can be used for the pattern transfer.

Using a positive (or negative) photoresist as a coating material enables high-quality microstructuring of metals, semiconductors, and dielectrics by two-photon illumination of photoresist followed by subsequent development and pattern transfer. The critical dimension (*CD*), which can be realized with nonlinear illumination technique using femtosecond laser pulses (at 800 nm wavelength), can be lower than 100 nm.

PS1_04 Supercontinuum generation and micromodifications in porous glass doped with $EuFOD_3$ induced by femtosecond Cr:forsterite laser

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It is well known, that propagation of femtosecond laser pulses with power exceeding the critical power of the self-focusing in transparent dielectrics can cause spectrum broadening and filamentation of laser radiation. The effects depend on beam focusing regime, cubic nonlinearity and band gap of the material.

The purpose of the study is to examine the nonlinear properties of porous glass doped with $EuFOD_3$ molecules. These molecules fill the porous volume and change of the sample properties. We have observed the supercontinuum generation increasing with laser shot number and forming of residual filament-like micromodifications.

In our experiments radiation of femtosecond Cr:forsterite laser (τ~110fs, λ=1.24μm, E~400μJ) was focused with F=3cm lens into the center of the volume of 1.5mm sample. Radiation at the output of the sample was collected with F=6cm lens and forwarded on fiber spectrometer. Porous Vycor glass samples (pore diameter 4nm) were doped with $EuFOD_3$ molecules in ethanol solution with concentration $c=6*10^{19}cm^{-3}$.

In the pure porous glass we did not observe continuum generation at described experimental conditions. But in doped glass sample we registered continuum generation. This continuum generation wasn't arise at once with irradiation starts but progressively increase during spot irradiation and stabilizes to approximately several tens laser shots.

In the doped porous glass we observed uniform contrasting channels passing through whole sample. The diameter of these channels was of 10μm. Into the pure porous glass interaction region was sufficiently less contrasting and didn't have such clear filament-like shape.

We believe that the increasing of supercontinuum generation in doped sample and making of filament-like modifications are due to the laser pulse propagation in laser produced channel. In the presentation we discuss probable reasons for making of filament-like modifications in doped porous samples. The increasing of nonlinear refraction and decreasing of threshold of irreversible modification forming in $EuFOD_3$ doped glass we consider are most evident ones.

PS1_05 Fundamental studies of femtosecond laser induced breakdown in KDP and DKDP crystals

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The wide gap di electric material KDP (KH_2PO_4) and its deuterated analog DKDP are widely used in optics for instance as frequency converters for pulsed lasers. However laser-induced damage in these materials remains a limiting factor in the development of high power laser systems.

We study the mechanisms leading to optical breakdown in KDP and DKDP materials irradiated with femtosecond laser pulse.

At first, we have investigated the mechanism of free carrier excitation and relaxation using the technique of time-resolved interferometry [P.Martin, S.Guizard, et al. Phys. Rev. B 55 (9), 5799, 1997]. With this method we measure the modification of the dielectric constant, which is proportional in our case to the density of excited carriers. For a pump pulse at 800nm, (Ti-Sa, 1.55 eV photon) we observe the following:

- When measured immediately after the pump pulse (200fs), the excitation density varies non-linearly with the pump intensity, indicating direct multiphoton excitation from the valance band to the conduction band.

- Then the density of carriers decreases rapidly, with a rate of the order of 800fs. This is an indication of the formation of self-trapped excitons.

- The same measurement at long time delay (25ps) shows a linear intensity dependence, indicating the presence of electrons excited from defect states in the band gap, having a long lifetime.

Then, we have also measured the luminescence emitted by the sample at temperatures between 10 and 300K. We observe a broad spectrum centred at 5.8 eV, attributed to the recombination of self trapped excitons [I. N. Ogorodnikov et al, Radiation Measurements, 38, 2004].

Finally, the craters obtained with femtosecond breakdown have been observed with an electron microscope, showing damaged shapes which are specific of these materials.

The consequence of all these fundamental observation on optical breakdown mechanism will be discussed in detail in the presentation.

PS1_06 Dynamics of bulk modification inside glass by femtosecond laser

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When a femtosecond laser pulse is focused inside a glass, the structural change occurs around the laser focal region due to nonlinear light-matter interaction. This phenomenon is widely used for fabrication of various micro-optical devices such as 3-D waveguides, 3-D optical memory, micro lens and so on.

For development of the fabrication technique using bulk modification by focused femtosecond laser, it is important to elucidate the dynamics of the structural change and thermal energy released by laser irradiation, because the shock generation and accumulation of the thermal energy are important factors for determining the created structure.

To elucidate the mechanism of the structural change inside a glass by femtosecond laser, we observed the dynamics of the density distribution change and thermal energy dissipation process by a Transient Lens (TrL) method.

In the ps-ns time range, the pressure wave generation and propagation process was clearly observed. We found that the pressure wave propagation produces the decaying oscillation in the TrL signal and that the intensity and width of the pressure wave can be determined easily from the oscillating TrL signal.

In the nano-micro second time range, the re-solidification process and diffusion process of thermal energy are observed. We found that the time-scale of the thermal energy diffusion from the laser irradiated region is 1-10 microsecond. This result indicates that the thermal energy accumulation effect becomes apparent at the repetition rate of laser irradiation above 100kHz.

Base on the observation of the density distribution change and thermal diffusion process, we will discuss the mechanism of the In addition, as an application of the observed pressure wave, we tried the laser machining by the interference of the pressure wave inside a glass by irradiation of two laser pulses at the same time.

PS1_07 Ultrashort electron beam deflection due to gradient field of femtosecond pulse duration

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The ponderomotive force of an intense femtosecond laser pulse can be the basis of a promising method enabling to prepare and characterize an ultrashort electron pulse ($\tau \sim 100$ fs) [1]. The ultrashort electron beam is rather attractive from a practical point of view [2].

In our geometry we implement an evanescent wave created by femtosecond light. The intense evanescent wave can be formed due to the total internal reflection of femtosecond laser beam from a dielectric-vacuum boundary. For such purpose a quartz prizm is used.

We are developing two approaches in order to reach our aim. In the first case we have investigated a femtosecond laser source of nanolocalized directed photoelectrons [3]. The electrons from this e^--source spatially isolated from the prizm can then be reflected by intense evanescent wave prepared on the surface of the prizm.

In the second approach a metal photocathode is created immediately on the prizm. The photocathodes have a special nanostructural shape and are fabricated from gold or tungsten. The obtained results will be presented at the Meeting.

In the investigations the photoelectons (and corresponding deflection of their trajectories) are monitored with a position-sensitive detector combining microchannel plates and a phosphor screen. Femtosecond laser pulses are produced by commercial femtosecond laser system including an oscillator and an amplifier.

The experiments have been done using the financial support from the Russian Foundation for Basic Research (Grant № 05-02-16900).

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PS1_08 Numerical analysis of thin metal film heating by ultra-short laser pulses using a hyperbolic two-temperature model

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For simulation of metal heating by ultra-short laser pulses the two-temperature diffusion model of Anisimov [1] is commonly used. But for pico and especially femtosecond pulses it is interesting to investigate the influence of thermal inertia [2] on the dynamics of the heating process. In this paper for numerical analysis of thin metal film heating by ultra-short laser pulses we use the phenomenological dual-hyperbolic two-temperature model [3,4]:

$$C_e(T_e,T_l)\frac{\partial T_e}{\partial t}+\frac{\partial q_e}{\partial z}=-\Gamma(T_e,T_l)+\alpha(1-R)If(t)e^{-\alpha z},\quad \tau_e\frac{\partial q_e}{\partial t}+q_e=-k_e(T_e,T_l)\frac{\partial T_e}{\partial z},$$

$$C_l(T_e,T_l)\frac{\partial T_l}{\partial t}+\frac{\partial q_l}{\partial z}=\Gamma(T_e,T_l),\quad \tau_l\frac{\partial q_l}{\partial t}+q_l=-k_l(T_e,T_l)\frac{\partial T_l}{\partial z}.$$

Here T_e and T_l are temperatures of electrons and lattice, respectively, C_e and C_l are the heat capacities per unit volumes, k_e and k_l are thermal conductivities. In this two-stage heating model, electrons are first heated by absorbing the laser pulse (last term in the 1st Eq.). The term $\Gamma(T_e,T_l)$ is responsible for the electron-lattice coupling. The strength of the heat flow from the hot electrons to the phonons is often proportional to the temperature difference (T_e-T_l) [5]. For metals the values of the relaxation times τ_e and τ_l are on the order of 10 fs and 10 ps, respectively [2-4]. Assuming that $\tau_e=\tau_l=0$, the heat-flux equations are reduced to the Fourier's law and the hyperbolic 2T model is reduced to the standard parabolic 2T model [1].

For numerical analysis the system of differential equations was approximated by the finite-difference system, and boundary conditions – by the finite-volume method. The numerical simulations were used for description of the thermal wave generation in the electronic and lattice subsystems for a few most commonly used metals, such as Au, Cu, Ni etc. During the lengthening of the laser pulse duration the analyzed dual-hyperbolic model continuously transforms, firstly, to the hyperbolic 2T model, then to the parabolic 2T model and consequently to 1T parabolic heating model. Differences in the thermal wave propagation and the changes in spatial-temporal temperature distributions using above the mentioned models will be discussed in detail.

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PS1_09 Structuring of the surface layer of transparent dielectrics due to the Coulomb fields, generated by intense laser pulses

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Intensive short pulses of laser radiation can ionize the dielectric medium, forming an array of randomly distributed ions. Coulomb interaction of ions causes their displacement and mechanical stresses inside the medium. When Coulomb forces are too weak for causing the direct ion emission, the mechanical strains, induced by them, can be sufficiently strong to stimulate the stretched modification (the "structuring") of the near-surface layer of solid.

When the ionization does not lead to the damage of the solid, the characteristic time of electrons removal from the medium through its surface does not play an essential role in the process analysis. During the surface layer ionization, the state of a solid lattice traces the changes of the coulomb forces arising due to the ionization process. Even at small ionization degrees of the medium the thick ionized layer can be formed, and the coulomb forces will be sufficiently strong at its periphery. Really, at a surface of the layer with ionization degree p and thickness L the electric field strength will be $E = 4\pi epnL$. Fast electrons (~10 KeV) created by the multi-photon ionization of lattice sites, easily pass the distances ~ 1 mcm inside the solid, and the micron-size layer with $p \sim 10^{-6} – 10^{-5}$ can be formed. For the typical values - $L \sim 1$ mcm, $n \sim 10^{22}$ cm^{-3}, $p \sim 10^{-5}$ - the coulomb field strength on the solid surface can reach the value of about 10^6-10^7 V/cm, that is comparable with the strengths of intramolecular fields.

The structuring of the medium due to redistribution of deformations in the near-surface layer of solid is substantially defined by ions concentration and its distribution inside the layer. For instance a charge, regularly distributed in the layer, causes only its homogeneous expansion that does not lead to medium structuring. However, even if the **average** distribution of ions in a layer is homogeneous, actually the charge is distributed in it non-uniformly due to its discreteness and fluctuations of the positions of separate ions. These fluctuations can originate the structures formed inside the solid by the local lattice strains.

Coulomb fields' action on the separate ions causes their displacement and creates non-local deformations around them. The transverse size of such deformed area depends on the local value of coulomb forces and is different at the various depths across the layer.

In frameworks of the continual theory of elasticity the average density of deformation energy and its fluctuations has been calculated for the layer with non-uniform random distribution of ions displacement. It was assumed that ions density decreases exponentially from the surface to the bulk of the layer.

It has been shown, that three types of structuring are possible. The first type can be realized when coulomb forces acting on the individual ion are small in comparison with intramolecular ones. Then the local non-interacting lattice defects having the sizes about the size of a lattice cell can be created. The second type of structuring arises when the coulomb forces are greater than intramolecular ones. In this case ions can be displaced appreciably, so that the deformed areas of a lattice arise at the scales that noticeably exceed a cell size, but remain less than the average distances between neighbor ions. In this process relatively large (but not overlapped) strained areas can be formed inside the solid. And, at last, the third type of structuring arises when displacement of ions is so large, that the "strained" areas in the solid are strongly overlapped. In this case almost homogeneous expansion of a lattice takes place. Since the coulomb fields inside ionized layer can be non-uniform, all three types of structuring can arise in solid simultaneously.

This work was supported by the Russian Foundation for Basic Research (grant 05-02-17534) and the Program of Support for Scientific Schools (grant 7952.2006.2).

PS1_10 Laser micro- and nanopatterning of surfaces of dye doped PMMA samples

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Laser patterning of surfaces of dye doped PMMA samples was experimentally investigated. We used nanosecond pulses of the second harmonic of a Nd:YAG laser and the PMMA samples absorbing laser radiation. The single-pulse formation of convex micro- and nanostructures was studied.

Convex surface microstructures with height from 0.05 to 2 µm and diameter from 10 to 200 µm as well as convex roll-like structures were obtained by laser beam focusing. Dependences of the height and diameter of the convex structures on laser fluence were investigated. It was found that the patterning threshold for the PMMA samples corresponds to the laser swelling threshold. The sample with an absorption coefficient of 50 cm^{-1} had a threshold of 4 J/cm^2. We measured and analyzed the surface shape of structures and laser induced change of the volume of the material. It was shown that both the laser swelling and laser bumping were significant for the patterning. High quality convex structures in optimal regime of laser patterning were obtained by exceeding threshold fluence from 5 to 20 percent. Using this knowledge, a microlens array and 2D pictures from convex elements were created.

The method of near-field amplification and localization of laser radiation by dielectric microparticles with a submicron diameter was used for subwavelength laser patterning. Water suspension of microparticles was deposited on the sample surface of the polymer with roughness of about 3 nm by spin coating technique. After evaporation of solvent the microparticles were distributed and held on surface uniformly or in groups. The microparticles were removed from the surface by laser pulses whereupon the convex nanostructures were formed at the places of microparticle location. Single convex nanostructures and groups of nanostructures on the surface of the PMMA sample with a diameter of about 200 nm and height from 10 to 100 nm were created by this method for the first time.

PS1_11 In-situ crystallization of amorphous films, deposited from laser erosion plasma

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The mechanism of formation and crystallization of amorphous films of metal – oxygen, deposited by laser sputtering of metal targets as in vacuum, and in an oxygen atmosphere was investigated.

The diagram, generalising results of structural researches of films, deposited by pulse laser evaporation of various metal targets (Au, Fe, Co, Cr, Hf, Zr, Ti at the substrate temperature TS = 293 K) in an oxygen atmosphere, is given. The following areas are allocated. (I) - crystalline metal. Sub region (I)' - particular case of formation of oriented and epitaxy structures. (II) - polycrystalline structures with amorphous component between grains of metal. (III) – amorphous conglomerate structures, where the noncrystalline clusters of metal are separated by amorphous interlayer enriched with oxygen. (IV) - amorphous films, whose composition is close to stoichiometric oxide.

Using electron diffraction and transmission electron microscopy in-situ technique, the phase transition from amorphous to crystal state, coursed with the local electron beam heating of the film, have been studied. As a rule, the amorphous phase is transformed into crystalline one according to one of the following types: polymorph, preferential and eutectic crystallization.

It is shown, that the crystallization of amorphizated Au-O films occurs with the participation of intermediate liquid phase under the scheme: Au-O (amorphous) → Au (liquid) + O_2 (gas) → Au (crystal) + O_2 (gas). Depending on a way of thermal influence the transformation can carry both "normal" character and explosive one.

The numerical valuation of volume changes, and also data of a curvature of a crystal lattice are received at phase transition from amorphous into a crystal state. The phenomenon of autoepitaxy from amorphous phase is considered. Typical orientation relation at conjunction of crystals of the various morphological forms is determined.

PS1_12 Laser photoionization method and technologies for cleaning the semiconductor materials and preparing the films of pure composition at atomic level

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Laser photo-ionization and photo-dissociation of molecules method is supposed to be very much perspective method for cleaning the semiconductor materials from molecular admixtures. Laser cleaning of mono-silan represents a great interest for technology of obtaining a poor Si in the semiconductor industry. The paper is devoted to the search and computer modeling the optimal schemes of laser photo ionization technologies for control and cleaning the semiconducting substances. Here at first we construct the optimal scheme of the laser photoionization technology for preparing the films of pure composition on example of creation of the 3-D hetero structural super lattices (layers of $Ga_{(1-x)}Al_{(x)}As$ with width 10Å and GaAs of 60Å). The scheme of preparing the films of the especially pure composition is based on using the multi-stepped laser photoionization scheme. It includes at first step an excitation of atoms by laser field and their transition into Rydberg states and then ionization by electric field [2]. A creation of the films of pure composition (our problem is creation of the 3-D layers of $Ga_{(1-x)}Al_{(x)}As$ with width 10Å and GaAs of 60Å) is directly connected with using the photo ion pensils of Ga, Al, As. Similar pensils can be created by means of the selective photoionization method with ionization by electric field. Then electromagnetic focusing and deflecting systems will provide a creation the 3-D supper lattices. Besides, we present a new multi-level optimized model for definition of the optimal form of laser pulse to reach the maximal effectiveness of laser action in process of photoionization atoms and (dissociation) molecules. Model is based on differential equation of the Focker-Plank type for density of molecules with the vibration energy x [2]. As example, let us consider the conditions and parameters for optimal excitation for molecules of HCl, PH_3, CF_3Br, SiH_4.

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PS1_13 Reverse crystallization of glass-ceramic ST-50-1 under laser action

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Laser modification of glass-ceramic materials is perspective technology to fabrication of optical and mechanic microdevices. Optimal conditions of laser action allow to change a phase state, and this process can repeated scores of times.

Attendant structure rebuilding every times causes radical properties changing.

Some investigations for fabrication of modify structure areas in glass-ceramic materials under CO_2 laser irradiation are allready situated in recent years. But CO_2 laser using has some limits to creating modify areas, and the technology of reverse laser modification is not reaseched enough.

This wok is dedicate to fabrication of reverse crystallization areas in glass-ceramic ST-50-1 using irradiation of different type of lasers: CO_2 and YAG:Nd. That help to find optimal condition of laser treatment. The laser return from amorphous conposition to initial polycristalline phase state of ST-50-1 should be useful for some applications.

PS1_14 Crystallization phenomenon in different glass-ceramic and glass materials under CO_2 laser action

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It is generally known that every commercial glass has its own crystallization ability; it means that a certain temperature interval exists and glasses can crystallize in this interval. We have to know the crystallization ability and crystallization speed to choose the proper regime for glass melting, manufacturing of different articles and for thermal processing in glass-ceramics manufacture. Crystallization character depends on relation between crystallization centers formation rate, crystal growing rate from this centers and viscosity. The larger the interval between peak rates of crystal growth and formation of crystallization centers, and lower the rates themselves, the lower the tendency of glass to crystallization.

Crystallization of glass materials depends on several factors: chemical composition and viscosity of glass, basic material, mutual solubility of every component, duration of exposure on proper temperatures, existence of crystallization catalysts and conditions of thermal processing of glass. To get crystallization conditions one have to provide slow passing through the temperature interval 1000-1200°C.

Earlier the possibility of glass-ceramic crystallization under that CO_2 laser action was experimentally shown. But even now it is not clear enough how crystallization centers can form and grow in such a small period of time (several seconds) and what role do impurity materials play (i.e. Au, Ag etc.). It is known that their atoms play role of crystallization centers in conventional regimes of glass-ceramic crystallization. In this work an attempt is made to crystallize glasses under CO_2 laser action, which doesn’t have an above mentioned impurity materials (i.e. BK7).

Successful completion of this work – crystallization of BK7 glass, will give us an opportunity to make exact conclusions about crystallization mechanisms in glasses under CO_2 laser action, and to prove or to disprove a theory, according to which crystallization process of glasses can occur not only on impurity atoms, but also on inhomogenities in material (in example density fluctuations of matter or oxygen vacancies).

PS1_15 High rate ablative formation of ultra-deep channels by self-adaptive Nd:YAG laser with dynamically adjustable passive Q-switch

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Efficiency of laser ablation strongly depends on parameters of surface plasma introducing shielding of incident radiation. Increasing depth of drilled channels results in growth of plasma density and shielding of the bottom, which is caused by limited expansion of plasma. This is one of the main problems of laser ablative drilling of deep holes. Significant reduction of such shielding was earlier achieved using femtosecond laser pulses [1] and combined laser shots including picosecond and nanosecond trains of pulses [2]. However, formation of ultra-deep channels with aspect ratio higher than 100 and the depth exceeding 2 mm calls for increased laser energy, usually achievable under laser generation of nanosecond giant pulses. At the same time, it is necessary to control such powerful Q-switched generation to minimize the plasma shielding effect.

It was recently demonstrated in our experiments [3] that use of special LiF:F_2^- crystal with variable initial transmittance allows smooth and wide range variation of power and temporal characteristics of the output radiation (the laser pulse energy, pulsewidth and repetition rates) of a high power self-adaptive Nd:YAG laser with dynamic phase-conjugate loop. Due to phase-conjugate self-compensation of intracavity aberrations, such laser generates high power repetitive pulses (10–100 kHz) with the beam divergence close to the diffraction limit. Focusing of laser radiation into a spot with the diameter of about 60 μm and energy density higher than 1 kJ/cm^2 allowed increasing of drilling depth up to 10 mm at 100-μm hole diameter.

In the present study of ultra-deep laser drilling, we estimated parameters of irradiated area and gas environment to the moment of the subsequent irradiation at investigation [4] of plasma spread and conduction cooling of material between the repetitive laser pulses. We have drawn a conclusion on formation of a long-lived area of hot rarefied gas here, which reduces the shielding effect of the surface plasma under exposure to subsequent laser pulses having an optimum repetition rate.

During the hole drilling process, we moved the LiF:F_2^- crystal smoothly in the direction perpendicular to the intracavity laser beam. The speed of movement was optimized for different materials. That provided decrease of the crystal initial transmittance and increase of the laser pulse energy, peak power and repetition period in the Q-switched pulse train and, this way, allowed compensation of reduction of the laser pulse energy density and intensity at the bottom of the hole under deepening. This method allows to increase drilling rates, to reach the maximum drilling depth and to make the channel walls more cylindrical. It also let us to control pressure of the ablated vapor to achieve better removal of material from the channel getting an optimal regime of the deep hole drilling. Using of such technique allowed drilling of holes deeper than 10 mm at the average drilling rate exceeding 1 μm per laser pulse, which is close to the initial drilling rates in steel, aluminum, hard and Ni-based alloys, and ceramics Al_2O_3, AlN, SiC. We achieved the record depth of 27 mm at drilling in Al_2O_3 ceramics keeping the channel diameter within 250 μm.

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PS1_16 METAL FILMS MODIFICATION BY SPATIALLY MODULATED LASER RADIATION

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Results of research of metal films modified by spatially modulated laser radiation, by a method atomic-force and near-field optical microscopy are submitted. Two types of modified metal films were investigated: a copper film on the quartz substrate, deposited by laser electrodispersion method and a gold film on the quartz substrate, manufactured by magnetron sputtering method. Laser beam of second harmonic radiation (λ = 532 nm) of Q-switched Nd:YAG laser (pulse duration ~10 ns) was splitted into two beams of equal intensity. Two beams were then brought together on the sample surface. The angle between two crossing beams was about 12°. Diameter of pumped area at sample surface was about 1 mm. Average energy density of pumped area is changed in the range from 10 to 70 mJ/cm^2 per pulse.

Laser modified copper and gold films were investigated by tunnel scanning near-field optical microscope (SNOM) and atomic-force microscope (AFM). The SNOM experiments were carried out using collection mode of tunneling SNOM combined with Kretshman geometry of light source and sample arrangement.

The analysis of the received images of Cu films has allowed to establish, that the topography of the modified film looks like a lattice with the period equal to the period of interference picture. There, where intensity of radiation was higher, due to heating of film larger metal particles with the sizes about 200-300 nanometers were formed therefore the level of a surface became higher approximately at 10 nm. Optical images have more complex character, than the topographical image. Probably it is caused by excitation in the formed particles plasmons and an interference of these plasmons.

It is necessary to note, that character of copper and gold films modification appeared to be different. This is likely because of different films thickness and modes of their manufacturing. Specified heat conductivity and temperatures of copper and gold fusion have also to be taken into account.

PS1_17 Laser based processing of porous glass for micro optical devices

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The results of research of high siliceous porous glass (PGs) processing under action of pulse - laser radiation are submitted. Plates of PGs are received by HCl leaching of phase-separated glasses of R_2O-B_2O_3-SiO_2 (R = Na, Na+K) with additives of PbO, Al_2O_3, NaF. Communications between PG's flow properties (viscosity) and structure (pore sizes) on sintering modes at laser nanosecond pulses heating (depending on a structure of an initial alkali borosilicate glass and its leaching conditions) are revealed for getting refractive index change in modified areas with typical size up to units of microns. Distinctions between modes of sintering of the PG samples with different structural and thermophysical characteristics under action of continuous and pulse laser radiation are revealed.

PS1_18 Optical properties of the chalcogenide films for interference coatings in IR spectral range

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Interference coating for infrared spectral region required the transparent optical films with different refraction indexes and minimal an absorption factor. It is well known, that chalcogenide materials based on sulphide and selenide are the perspective film's forming materials for manufacturing of the interference coating. Among the known materials, the minimal absorption factors have arsenic chalcogenide films. It allows using them for manufacturing of the high quality optics in wide optical region, including optics for CO_2 powerful lasers.

Despite of good operational characteristics and the small optical losses, many of known chalcogenide materials have not received a wide distribution. One of the reasons of that is the absence of the data of their film's optical constants (OC) of these substances, which strongly depend on a way and conditions of manufacturing and are different from OC of initial monocrystals. In this paper the optical constants of the chalcogenide films various composition were described. Investigated films were manufacturing on fused quartz substrates by vacuum deposition. Initial substances As_2Se_3, $AsSe_4$, AsS_4 and $AsS_{16.2}Se_{16.2}$ were evaporated from molybdenum hull in vacuum $3{\cdot}10^{-5}$ torr. Refractive index and extinction coefficient dispersion in 0.5-2.5 μm spectral range were determined by method is based on analysis of the interference transmission spectra.

PS1_19 Drilling of ceramic objects by means of laser radiation with adjustable impulse shape

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Laser drilling is widely used in microelectronics. “Lazery & apparatura TM”, Ltd. (Zelenograd) has developed and is currently producing modern laser equipment that allows discrete management of peak-time parameters of ML4-2 laser radiation impulses. This type of equipment has been used in the research of dependency of perforation quality on the impulse shape and the peak-time parameters of laser radiation.

Rectangular ceramic samples of two types - XC-22 ceramics and Polikor (Fig. 14) - were used. Both samples were 30x24x0.5 mm in size.

The research has been conducted assuming the following parameters:

Impulse length τ = 1.5 ms. An impulse represents a comb consisting of five peaks. The length of one peak equals 300 mcs.

Three series of drilling have been made depending on the shape of impulse: rectangular, ascending, and descending. Optimization of modes has been made.

PS1_20 Fast crystallization of glasses at laser local heating

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In the work is offered the mechanism of crystallization in the thermodynamically nonequilibrium conditions, which explaining anomalous fast crystallization of glasses at laser local heating.

In offered work with use of a model "a liquid- the crystal was deformed by vacancies" is conducted the analysis thermodynamically unstable on concentration of vacancies of oxygen of a condition of glass which arises at laser local heating. It is shown, that in this case process of crystallization occurs to much high speeds, than it is in an equilibrium condition.

The mode of laser effect at which there is a fast crystallization is found.

PS1_21 Optical diagnostics in laser assisted Rapid Manufacturing

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Absence of on-line control in laser assisted Rapid Manufacturing is one of the main obstacles on the way of its industrial implementation. Application of optical diagnostics for the process of: (a) Direct Laser Manufacturing (DLM) with co-axial powder injection and (b) Selective Laser Melting (SLM) are presented in the paper. Velocity and size distribution of in-flight particles are measured by a CCD-camera based diagnostic tool, and temperature in the laser action zone is measured by pyrometers and infra-red camera.

Optical methods are used also for particle size distribution and particle shape control in powder blends applied in both technologies.

DLM with coaxial powder injection (TRUMPF installations: DMD with 5 kW CO2 laser and LASM A with 2 kW Nd:YAG laser) was applied for fabrication of 3D objects from metallic powder. The complexity of the process and the actual requirements for the properties of the manufactured object, impose application of on-line monitoring and process control. Application of temperature control has certain advantages in comparison to the rest ones.

When using multi-component powder blends, for example, metal matrix composite with ceramic reinforcement, one needs to control temperature of the melt to avoid thermal decomposition of certain compounds and to assure melting of the base metal, to avoid useless overheating and to prevent formation of residual porosity.

The method of non-contact temperature measurements by a pyrometer is rather promising for on-line monitoring and control in DLM. However the proper application of pyrometry requires the solution of a number of methodological difficulties. The innovation of the present approach is the application of specially developed “notch” filters together with an originally developed multi-wavelength pyrometer. As a result, melting–solidification dynamics, i.e. the instant when melting starts, the melt life-time and the solidification stage can be analysed using reliable data on true temperature.

Additional problem in optical monitoring of DLM with coaxial powder injection is the particle-in-flight monitoring. It is necessary to control the particles jet geometry and its position relatively to the laser beam and the substrate, stability of the particles flux, their velocity and temperature, the latter one being the most difficult. The optical monitoring is used to optimise the conditions of particle injection in particular when powders with different particle size, geometry and density are injected simultaneously.

Optical diagnostics in Selective Laser Melting (PHENIX PM 100 machine) is used to visualize the laser beam / powder bed interaction and to measure the brightness temperature in the zone of powder melting. Infra red FLIR camera as well as pyrometers are applied.

PS1_22 3D Transient Model for CO_2 Laser Hardening

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Laser surface hardening of carbon steels is a manufacturing technology which meets the needs of modern industry thanks to its direct applicability on the production line. The possibility to obtain fully martensitic hardened layers on 3D complex and localized surfaces is a great advantage on traditional heat treatments such as induction or flame hardening. The large number of technological parameters involved in this process (beam power density, beam scanning speed, beam focal position, degree of pass overlapping, thickness of eventual coating…) makes optimization very difficult, especially when a great number of geometrically different components has to be treated. Modern computational methods allow to build highly customized simulating tools thanks to which the role of parameter variation, on the resulting hardness and depth of the treated layer, can be foreseen. This article deals with a 3D numerical model of the laser hardening process in which an advanced mesh generator is implemented in order to simulate any complex spatial surface. The final metallurgical structure is calculated taking into consideration any possible intermediate phase such as sorbite, bainite and residual austenite. A further effort has been made in order to take into consideration the presence of a graphite coating layer used to increment beam absorption (this is often used in CO_2 laser treatments) and to understand the role of pass overlapping on the final martensitic structure. An experimental campaign has been set up on industrial mechanical components in order to validate the simulated results.

PS1_23 Microoptical elements for semiconductor laser–to–fiber coupling are based on porous glass

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The intensive development fiber optical lines for computing, passing and keeping of information are required the development of optical elements for semiconductor laser–to–fiber and fiber–to–fiber coupling.

The cylindrical lenses are presented as promising for semiconductor laser–to–fiber coupling [1]. The pieces of fiber or glass rod of small diameter are used for coupling.

The significant values of effective coupling for semiconductor laser–to–fiber has been calculated to geometrical–optical approach for optical circuit from two cross cylindrical lenses xan not be reached at practice because of the significant values horizontal and longitudinal aberration of these lenses.

The densification of the plane sample porous glass irradiated by a CO_2–laser were used for manufacturing of microoptical elements with value of numerical aperture (NA) 0.3 and resolution near 200 l/mm [2, 3].

The principal restriction on the manufacturing of the zone inform of cylindrical lens by the densification of the plane sample porous glass irradiate by CO_2–laser are not existed.

The manufacturing such zones are realized on plane sample with structure as structure samples analogous as in the technology of microelements manufacturing was worked [2].

The thickness of the plane samples was 1.6–2.0 mm. It has been used of plane samples porous glass prepared through the leaching in 3M HCl at 100^0C [4] of two phase alkali borosilicate glasses. These samples were placed in weak solution of alkali 0.5M KOH additionally.

The surface plane of porous glass was irradiated by formed beam CO_2–laser (in the TEM_{00} mode, maximum 25W). The collective lens was made of ZnSe with focal distance 12.4 cm was used. The movement of focused laser beam was realized by scanning with range of frequency 0.2–0.9 s^{-1}.

The cylindrical lenses were made with diameter 0.6–1.5 mm and length 4–5 mm on both sides of the plane samples. The focal distance these lenses were located near 1.0–2.0 mm and were coincided satisfactorily with expected values.

The experimental definition of effective coupling optical circuit of two planes cross cylindrical lenses were realized on model of plant described in [5].

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PS1_24 Laser deposition of SmCo thin film

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Thin film of permanent magnetic material is very important for different electronic applications [1,2].

In this preliminary work results of SmCo thin film deposited on polycarbonate substrate and on steel substrate will be reported. X-Ray diffraction date and Magnetic Scanning SQUID (MSS) analyses have been performed with the aim to study the functional magnetic properties of the deposited thin film. Moreover the magnetic properties of the thin film will be correlated to the laser depositions parameters with the aim to improve the film quality.

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PS1_25 Fabrication of Nd:$Gd_3Ga_5O_{12}$ planar waveguide laser by pulsed laser deposition

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Pulsed laser radiation is used as well for the deposition of the laser active thin films of Nd:$Gd_3Ga_5O_{12}$ (Nd:GGG) as for micro structuring to define wave guiding structures for fabrication of a waveguide laser.

Laser active films with thickness up to 5 µm of Nd:GGG on $Y_3Al_5O_{12}$ (YAG) and sapphire single crystalline substrate are fabricated by pulsed laser deposition (PLD) using a KrF eximer laser (λ = 248 nm, τ = 25 ns).

By variation of PLD-parameters such as temperature and pressure of processing gas amorphous and single crystalline thin films are produced. X-ray diffraction using Θ-2Θ scans in Bragg geometry with Cu kα radiation (λ = 0,15406 nm) is used to determine the structural properties of the deposited films.

By coupling the radiation of a diode laser (λ = 808 nm) into the polished edge of the films the optical properties of the films are determined. The emission spectrum of an amorphous film is broadened inhomogeneously and the spectrum of a crystalline film is similar to that of the bulk Nd:GGG crystal used as a target material for the deposition.

A planar wave guiding structure is generated between two parallel grooves micromachined using laser radiation from a femtosecond CPA-Laser-System with λ = 800 nm and pulsed duration of 100 fs. The structural properties of the films and the extinction losses of the structured waveguide are determined.

For the first time a structured planar waveguide laser of an amorphous Nd:GGG thin film on YAG single crystalline substrate is achieved.

PS1_26 Laser technological system for Precision 3d material treatment and inspection

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We have developed laser technological system LSP-2000 designed for cutting, welding and surface micro profiling with ablation process of samples with arbitrary surface topology. This system is equipped by two Nd-YAG lasers. First laser has the following parameters: the pulses repetition frequency is 300 Hz, average power output is 500 Wt, and laser wavelength is 1.064 μm. Its purpose is laser cutting and laser welding of any metals with thicknesses of less then 6 mm. The second laser is intended for surface precision micro profiling (for articles with the dimensions of some meters, the formed topology is to be differed from the calculated one no more than some tens of microns along the article surface), i.e. for the removal of metal film under the calculated topology. To ensure the high quality of surface treatment it needs the metal evaporation without its transmission in liquid phase (ablation process), that in its turn imposes the presence of high values of power density ($\geq 10^8$ Wt/ sm^2). The requirement of laser system output and the necessity of metal layer evaporation in some micrometers under the specific spot dimension equal to ~ 0.5 mm determine the demand to the energy of single pulse and frequency of their sequence. Thus, the second laser has pulses repetition frequency of 300 Hz, high pulses power ($> 10^7$ Wt), laser wavelength is 0.532 μm, average power output is 10 Wt. Its purpose is ablation of thin metal films on dielectric surfaces. The 5-coordinates (X-Y-Z-φ-θ) robotics for the laser head positioning and CNC control interface are provided for 3D inspection and machining of samples with arbitrary topology. The system spatial working range is about $3 \times 3 \times 0.6$ m^3. Inside this range all types of operations can be performed with continuous contour displacement accuracy about ± 20 μm (start-stop regime is < ± 10 μm) for any point of trajectory. The LSP-2000 was designed as the precision universal laser inspection and processing system with unique combination of the certain parameters /technical characteristics. The system has been successfully tested and put in operation at the Academy of Space Technologies (China) for the production of large sized antennas with given orientation diagram.

PS1_27 Dynamics of CO_2-laser ablation of poly(methyl metacrylate): a combined experimental and theoretical study

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We present comprehensive experimental and theoretical studies of polymethyl methacrylate (PMMA) ablation by single pulses of a CO_2-laser in a wide range effluences. Different aspects and stages of ablation have been investigated: laser heating and vaporization of PMMA surface, mechanisms of ablation, dynamics of the laser-induced plume, nanoparticle formation in the plume and/or ejection from the irradiated surface. A particular attention is paid to the influence of the background temperature on the ablation dynamics and the particle size distribution.

Ablation was carried out in a quartz cell through which nitrogen under the atmospheric pressure was pumped. The ablation products were analyzed with the use of a gas chromatograph and an automatic diffusion battery. The irradiated surface and a substrate with the deposited ablation products were examined by transmission electron microscopy. The size distribution function of the nanoparticles formed during ablation was found to change its form from a single peak to a bimodal shape with increasing laser fluence. A separate set of the experiments was performed for the varied target temperature (from the temperature of liquid nitrogen to 150 C).

Transformation of distribution function is analyzed with the help of thermal modeling which gives a basis for insight into the mechanisms of ablation. It has been shown that, in contrast to metal vaporization, polymer ablation continues for a long time after laser pulse termination. Phase explosion aspects are analyzed. Hydrodynamics of ablation plume expansion into nitrogen under the experimental conditions has been studied on the basis of the Navier-Stokes equations, taking into account the diffusion of the ablation products into an ambient atmosphere. It has been revealed that the plume does not represent an ordinary sonic or supersonic jet but forms a complicated structure with side spreading and numerous vortices that favors nanoparticle formation in the gas phase.

PS1_28 Laser Desorption of Polycyclic Aromatic Hydrocarbons Adsorbed on Soot Particles

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Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds that consist of fused aromatic rings which are primarily formed by incomplete combustion. Their potential carcinogenic effects have motivated various studies. However, an extensive analysis of the PAHs adsorbed on soot particles – i.e. unburned hydrocarbon residues - is still challenging. We are developing an experimental set-up dedicated to this study.

The technique is based on three main steps:

1. samples are placed in a UHV chamber (residual pressure: 10^{-9} Torr) and irradiated by the focused beam of a 7 ns Nd:YAG laser (λ=532 nm) or by an IR optical parametric oscillator (OPO) tuned to ~3.3 µm to ensure resonant desorption via the C-H stretching mode [1].

2. the neutral desorption products are multi-photon ionized by UV (λ=266 nm) laser pulses.

3. the ions are mass-analyzed in a 1-m long reflectron time-of-flight mass spectrometer

In order to provide a better understanding of the complex processes involved in this method, we have successively investigated the laser desorption of pure PAH samples, "synthetic soot" samples (obtained by adsorbing PAHs on activated charcoal surfaces) and combustion soot collected from various diffusion flames.

An exhaustive optimization study has been performed on various parameters of the experiment. At the desorption stage, the availability of both IR and visible sources allowed us to undertake a comparative investigation of the desorption products and give new insights on the desorption mechanism. At the ionization stage, the use of different beam geometries provided fragment-free mass spectra and drastically improved the sensitivity limit of the method (<1fmol/laser shot). An intricate relationship between the desorption and ionization processes has been evidenced [2].

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PS1_29 Universality of Feigenbaum and Sharkovsky order for highly nonequilibrium nonlinear systems

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The spatiotemporal dissipative microstructures formed in highly nonequlibrium nonlinear systems are considered with the examples from laser-induced microrelief of condensed matter surface. The cases of linear polarized and normal incidence laser radiation of various pulse durations and wavelengths are considered. The examples of multiple stepped spatial periods reductions under the changes of control parameter are analyzed for semiconductors, dielectric and metal surfaces. It is shown that such systems usually are characterized by reverse period doubling behavior under the changes of the control parameter the known mathematical model of which is bifurcation cascade of Feigenbaum (Feigenbaum universality). The equation for the total intensity of electromagnetic field under the excitation of surface electromagnetic excitations in frameworks of universal polaritonic model was obtained and analyzed with finding of control parameter and has a type of second order polynomial analogous to one usually considered in one dimensional unimodal (logistical) mapping.

The experimental examples are considered and analyzed with the step-like basic period doubling and tripling. It is shown that such nonlinear nonequilibrium system behavior scenario may not be ended by bifurcation cascade of Feigenbaum but followed by more complex cascade of Sharkovsky order bifurcations.

PS1_30 Laser-induced tip-shaped bump formation on surfaces of highly refractory metals

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The phenomenon of tip-shaped bump formation on *W, Ta* and *Mo* surface when irradiated with neodymium laser pulse at pulse energy less than the threshold one for melt removal by vapor pressure has been discovered and explained. The model experiments have been carried out in vacuum, nitrogen, air, helium and oxygen gas environment with formed melt pool diameter d=100÷1000 μm. The tremendous influence of gas environment on the resulted surface relief after laser irradiation was found. The most height of the tip-shaped bumps was obtained after melt crystallization in oxidizing medium. Thus in air medium the metal bumps with thin oxide layer and height $h \le 0.2d$ on *W, Ta* and *Mo* were obtained. The height of conical shape tip produced as a result of melting pool crystallization rises with laser pulse energy till the energy is not higher the threshold value for melt removal from the pool by vapor pressure.

Tips with relatively small top surface curvature radius r have been obtained. For instance, at d=1000 μm and tip height above the initial Ta plain surface level h=200 μm (tip cone apex angle $80 \div 90^0$) the value of r is about 5 μm.

Sharp tips and bumps obtained by this method are suitable for some technical applications, for gas-discharge device, local type sensors, field emission electronics and so on.

In experiments with other metals (Al, Ni, steel) tip-shaped metal bumps were not found and reasons of this are discussed.

The theoretical model of tip formation in the process of finite melting pool crystallization has been developed. The model is based on consideration of surface tension forces action, changed by the presence of oxidation products, and density changes of material during melting and crystallization.

PS1_31 Destruction of metals at solid state induced by laser

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Thermal and hydrodynamic processes in layer of metals on exposure to pulsed heating by laser radiation ensemble of pores, gas filling of which occur due to the desorption of gas layers, covering the porous wall are considered. The temperature and stress fields dynamics inside the samples were investigated. Previously [1,2] was demonstrated that the destruction of solids can result at solid state when the porous gas pressure exceed the damage threshold of material or at melted, liquid, state. For materials with melt temperature $T_{melt} > 2000$ K the pore structure explosion is quite possible at solid state.

Simulation of material destruction from solid state was conducted for the sample from tungsten, refractory metal. The computer model of heterogeneous solids has been constructed and the simulations of heating and destruction of near surface volume of metal under the pulsed laser action has been accomplished. The calculations were performed using the LS-DYNA program on supercomputer “SCIF”. A solid sample was affected by rectangular form laser pulse of 10^8 W/cm^2 power density during 10^{-8} s time. Numerical simulations were carried out and plastic strain and effective stresses dynamic 3D distributions were studied in the presence of 0,5- 0,05 µm radius pore located in the vicinity of 0,1µm from the sample surface. The LS-DYNA material model MAT_ELASTIC_PLASTIC_THERMAL was used. It allows to set yield stress, thermal expansion coefficient, Young and hardening modulus dependent on sample temperature.

At early stage of process a strong compression stresses act on pore. Plastic strain simultaneously with a pore gas heating cause the fast growth of gas pressure. As the thermal peak is located on the sample surface, the fast decay of compression at the surface layer results in a deformation of pore and destruction of thin layer with a condensed particles release.

The results of modeling allows to put forward mechanism of the initial destruction of metals at solid state under high-energy pulsed action. Pulsed heating of pores surface structure causes to formation of compressive stresses field. By going to plastic flow of metal together with gas desorption from wall of pore and gas heating cause the fast rise of gas pressure. A drastic drop of stresses on the surface as a result of heating stimulate explosive-like destruction of surface layer by gas pressure. The time scale of realization of this mechanism is equal to ~ 10^{-8} s at intensity of absorbed radiation equal ~ 10^8W/cm^2.

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PS1_32 Transrotational microstructure of Re films prepared by pulsed-laser deposition

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Laser evaporation of thin films carries some special features, in particular, using the metal targets it is possible to obtain amorphous areas which either remain stable or can crystallise in the process of deposition, upon aging and heat treatment). Moreover the structure of the films can differ from the films produced by other methods. We use transmission electron microscopy (TEM), including bend contour method and high resolution imaging to reveal the peculiarities of the microstructure on the scale *micro – meso - nano* in *Re* films obtained by vacuum pulsed-laser deposition.

Non-uniform temporal and spatial structure of the laser-generated plasma results in heterogeneous film structure with different zones. The central zone contains the largest grains with lateral dimension 0.1-1 µm (film thickness for one pulse was about 10-20 nm). It is the zone in which TEM images demonstrate numerous diffraction patterns formed by extinction bend contours. TEM analyses of this diffraction contrast revealed the novel **“transrotational” structure** [1]: crystals are formed with strong regular internal lattice bending (up to 120 degrees per µm) round axis or axes lying in the film plane [1].

Such kind of unusual structure (remarkable at the scales from *micro* to *nano)* has been discovered for different thin film materials and usually formed as a result of crystal growth in amorphous films or layers. Therefore we suppose that the formation of these central film areas may not follow the usual island mechanism for metal film growth of deposits but instead amorphous phases were presented initially or at the intermediate stages and later on were crystallized by nucleation and crystal growth processes.

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This work was partially supported by INTAS (00-100), RFBR (04-02-96072)

PS1_33 The angular spectra of ATI photoelectrons at the interaction of molecule of hydrogen with intense two color laser field

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In this paper we study angular above-threshold ionization (ATI) photoelectron spectra at the ionization of molecule of hydrogen, interacting with intense (I ~ 10^{15} W/cm^2) two color laser field. Choice of such field is explained by more effective ionization probability, than for monochromatic field. Possibility of coherent control providing by change of relation of harmonic intensities and phase between harmonics is a reason in favour of such choice also. It is used quantum-mechanical (modified S-matrix approach [1]) and classic kinematic models for define of the intensity of non resonant tunnel ionization of molecule of hydrogen in an intense two color laser fields. The initial ground state of molecule of hydrogen was described by single-centre LCAO-molecular orbital with bonding σ_g symmetry, and final product state was described by molecular ion wave function. We study of angular spectra of photoelectron in two color laser field when change such parameters, as corner β between axis of the molecule H_2 and direction of the linear laser polarization; as the internuclear distance R and corner θ between of the photoelectron flight direction and vector of the polarization of the electromagnetic field. It is obtained, that maximum of ionization intensity rate for monochromatic laser field corresponds to the value of internuclear distance in molecule of hydrogen R~ 2 a.u. The results of the calculations have shown that angular photoelectron ATI spectra of the molecule of hydrogen have sidelobes in electron low energy range at monochromatic and two color laser fields in difference from N_2 [2].

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PS1_34 Laser Assisted Direct Manufacturing

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Direct Laser Manufacturing (DLM) with coaxial powder injection (TRUMPF installation) was applied for fabrication of 3D objects from metallic and ceramic powder. One of the advantages of DLM is the possibility to build functionally graded objects in one-step manufacturing cycle by application of a 2-channel powder feeder. Several models with different types of material gradients (smooth, sharp, periodic) and multi-layered structures were manufactured from SS, stellite (Cobalt alloy), Cu and W alloys.

Technology of Selective Laser Melting (SLM) was applied for manufacturing of net shaped objects from different powders (PHENIX PM-100 machine): Inox 904L, Ni625, Cu/Sn, W. Performance and limitations of SLM technology are analysed. Multimaterial component objects were fabricated in a two-step manufacturing cycle.

PS1_35 Using of middle IR lasers for guided termocleavage of glass

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Method of guided termocleavage of glass, was developed in 80-th [1] and found wide expansion in precession breaking of glass for displays, that is proved with appropriate equipment and a wide variety of publications [1-3]. There are few advantages of this method: high speed of cutting; high accuracy in processing; low power intensity of process; high purity of process, cause of wastelessness of cutting process; zero width of cut.

Feature of this method is that cutting of glass is executed due to making of separating split under the voltage of straining, caused of the heating of material with laser radiation and next freezing of zone of heat using refrigerating medium [1-3].

This method was developing by two trends.

The first is surface microcrack, done by radiation of CO_2-laser (10,6 micron). Radiation of this laser absorbs in oxide glasses for 50-100 micron deep. That's why created microcrack has size no more, than ~ 5-100 micron, but speed of developing of this microcrack is too high – up to 2000 millimeter/sec. For the transparent separation of glass items additional operation is used – mechanical fracture.

The second trend is volumetrical (transparent) microcrack, created by radiation of Nd–laser (1,06 micron). Oxide glasses are known to have low absorption in the area of Nd-laser radiation. But this absorption with the high power of laser (P >> 100 Вт) is enough for creating termovoltages, that result in the creating of transparent microcrack, that separates items. Feature of this method is an opportunity of transparent separating of glasses highly 30 micrometers thick, but with low speed of processing – up to 100 millimeter/sec. Highly purity glasses absorb radiation of Nd-laser less than 1%, but they don't defy termocleavage.

The main using of the technology is size processing of glass for displays, when transparent separation of glasses 0,6-0,8 millimeters thick is needed with accuracy 5-20 micron with speed 500 millimeter/sec. But the using of lasers, that were described above don't help to solve this problem. That's why the search of new laser radiation sources is actual for temocleavage of glasses with given parameters.

Preview analyze showed, that the most optimal laser sources are lasers with the spectrum in the field of translucency of glasses (2-7 micron) with the power of radiation no less than 20 Watt, as shown in Fig.1.

There are few laser radiations in this field: solid-state oscillator εr (2,94 micron), impulse-periodical oscillator on steam of Sr (1; 3; 6,4 micron) and uninterrupted gas oscillator CO (5,1-6,2 micron), that effectively get into glass for ~ 500 micron deep.

Solid-state impulse-periodical laser εr has low power (less than 10 Watt), and, that's why, doesn't fit for this technology. Laser on steam of Sr is unique source of radiation and generates simultaneously few wave-length 1; 3 и 6,4 micron. A big part of power is concentrated in the field of 6,4 micron and has power up to 20 Watt. The results of termocleavage are gotten on it and they prove, that necessity of using laser source in a field of 5-6 micron for this technology.

Another optimal source is uninterrupted gas CO (5,1-6,2 micron) laser. Authors of this investigation used the construction of CO-laser based on the following source – ИЛГН-711, upgraded it to the half-sealed variant with the power up to 100 Watt.[4]

For investigating of the modes of termocleavage a plant was created, the scheme of it shown in Fig.2., the basic elements of this plant are Nd, CO_2-, and Sr, CO-lasers, two-coordinated engines on air bracket and service systems

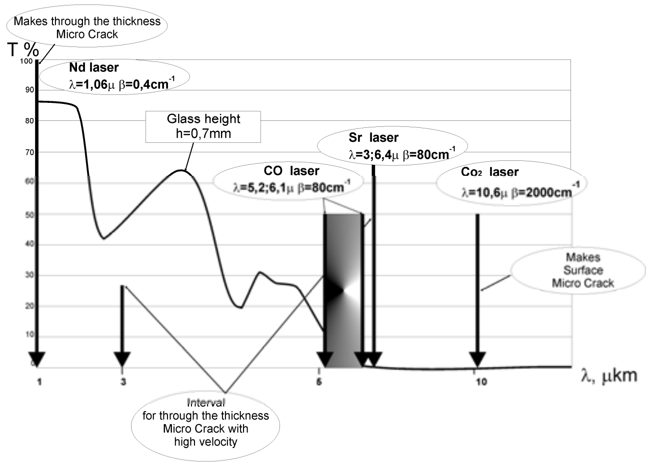

Fig.1 Spectrums of absorption of oxide glasses and radiation of IR-lasers for termocleavage

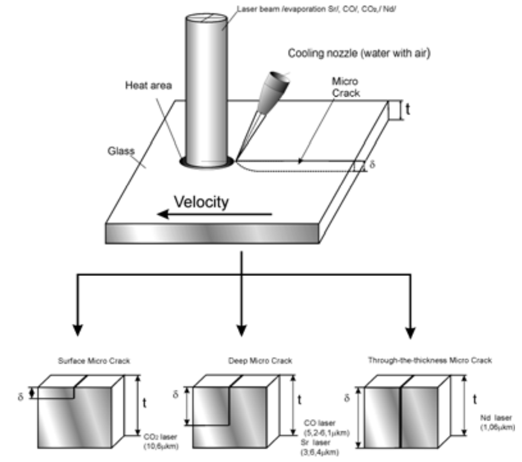

Fig.2 Scheme of guided termocleavage with using of Nd/CO_2/Sr/CO lasers

The experiments of getting maximum speed of transparent termocleavage of glass millimeter thick were done with using radiation of these lasers with the same power. CO-laser allowed to get speed in 2-3 times more than, using the radiation of CO_2-laser.

Comparing the influence of the oscillator type on a technology process was made with following parameters: the quality of surface of chip of glass after cutting (durability, micro heterogeneity) and the maximum speed of termocleavage. Experiments were made on a plant with using Nd, CO_2-, Sr and CO-lasers and showed that, the highest quality of glass chips are done when using Sr and CO-lasers. Using the graphical comparison of mechanical experiments showed that the highest mechanical durability has items of the glass, made of radiation of CO and Sr lasers. It proves, that the radiation of CO and Sr lasers is the major instrument for laser guided termocleavage when making flat displays.

Experiments of guided laser termocleavage with CO and Sr lasers showed:

When the glass t ~ 0,7-1 millimeter thick transparent termocleavage is get with the high speed of processing;

Created chips of glass have the minimum quantity of micro heterogeneity and higher durability, than examples of glasses, got by using CO_2-laser.

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Laser-induced static and dynamic changes in local ordering in the phase change material $Ge_2 Sb_2 Te_5$: snapshots with a 150 ps shutter

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Phase-change alloys constitute the basis for a widening collection of storage technologies both optical and electrical. These uses of phase-change alloys are characterized by reversible switching between amorphous and crystalline phases either by laser irradiation or by an electric current; the resulting changes in material properties can be used for non-volitile data storage. Switching typically occurs on nanosecond or less time scales. Considering the conflicting requirements for high-speed switching, yet long term data storage integrity, a deeper understanding of the switching processes in these materials is essential for insightful application development. We have used synchrotron-based time-resolved x-ray absorption fine structure spectroscopy (XAFS), a technique equally suitable for amorphous and crystalline phases to elaborate details in structural changes in the phase-change process; the results presented here are for phase-change alloys that lie along the $GeTe\text{-}Sb_2Te_3$ pseudobinary tie-line with particular emphasis on the technologically important composition $Ge_2 Sb_2 Te_5$.

We present a summary of our XAFS results on local ordering for both static switched samples as well as data from a new breed of sub-nanosecond time scale dynamic measurements performed using optical pump/x-ray probe techniques. Such dynamic measurements will be key in understanding the details and optimization of the switching process as we will show localized irradiation by laser-light can lead to high-temperature, high-pressure conditions difficult, if not impossible to reproduce in static experiments. In addition to reviewing recent results on pressure-induced structural disorder and high-energy XPS observations of electronic structure, we present the initial results of sub-nanosecond laser excitation of the laser-reamorphized state of $Ge_2 Sb_2 Te_5$. The technique is general and can be applied to a wide variety of nanoscale structures. Preliminary results taken at the Advanced Photon Source as well as recent experiments taken at SPring-8 will be discussed.

Nanostructured metal oxide thin films for optical gas sensing applications

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We report new results on making highly transparent, conductive thin oxide films for nanostructured photonic gas sensors. We grew ZnO, TiO_2, and WO_3 thin films by Pulsed Laser Deposition (PLD) with two laser sources: an UV excimer KrF* (248 nm, 7.4 ns), and a frequency tripled Nd:YAG (355 nm, 10 ns), respectively. The coatings, which were a few tens of nm up to a few microns in thickness, were deposited in (0.1 – 40) Pa oxygen on fused silica substrates kept at a constant temperature within the range (RT – 500) ^oC.

All depositions were highly (up to 90%) transparent. The resulting structures were characterized by XRD, SEM, XPS, and AFM.

We proved by m-line prism coupling method (with accuracy on refractive index variation Δn better than 10^{-4}) that under optimum processing conditions, the obtained nanostructures were able to detect hydrocarbons traces down to 100 ppm [1]. The optical detection process was based on a refractive index variation of the sensitive thin film when exposed to the gas. The refractive index variation was accurately measured by the angular shift of the m-line.

We studied the boost in gas sensitivity of the oxide film sensors after doping or covering with noble metal nanostructures (Pt, Au) [2]. Coverage with nanoclusters enhanced sensitivity 2-3 times over simple structures, while doping led to a sensitivity increase of up to 45%.

We were able to design nanostructures with pre-defined optical characteristics by selecting the nanocluster sizes and shapes showing optimum sensitivity to gas detection.

We found that prolonged contact with the gas mixture under investigation did not alter the sensor’s composition or morphology.

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Laser–induced modification of glass–ceramics materials structure: physical aspects

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There are many experimental facts already accumulated about fast laser structure modification of bulk glass, porous glass, glass–ceramics, glass films etc. In some sense these different phenomena have one common point: all of them have an extremely high speed under laser heating which properly is not more than the other type of heating source comparatively with traditional heat treatment of glass [1].

Two most important peculiarities of laser heating are marked:

1) nonequilibrium (non–stationarity) of laser heating due to high speed of energy loading regarding the inertness of the glass material structure (where a diffusion and a viscosity play an important role in a structure modification).

2) nonhomogenity due to a locality of laser irradiance, which leads to appearance of a high–rate thermal gradients and additional forces – thermogradient force and “fonon wind”, and additional mechanisms like vacancies drift play a sufficient role.

Correspondingly two main mechanisms of structure modification are considered:

1) the theory “Liquid as Vacancies Deformed Crystall (L–VDC) [2] and

2) thermogradient model of laser–induced crystallization (TGM).

Mechanism of laser densification of porous glass laser amorphization of glass–ceramic and laser crystallization of bulk glass and glass–films are considered from the general point of view.

The work was supported by Grant of Leading Scientific school of Russian Federation (NSH.5967.2006.8), RFBR Grant (04–02–16611), State Contract RNP 2.1.1.784 and INTAS Project No 04-78-7124.

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Direct Laser Synthesis of Micro-Scaled Ceramic Components from Liquid Precursors

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In this paper a new method to produce micro-scaled residual stress free and high temperature resistant ceramic components will be presented. The laser induced pyrolysis of preceramic polymers enables a combination of both, rapid manufacturing and micro system engineering. Compared to other rapid prototyping techniques free form direct laser synthesis allows to build up components without restrictions even in a micro-scaled range to meet the requirements of new developments in micro system engineering.

Due to the use of molecular compounded liquid preceramic polymers as precursor materials for pyrolysis, the processed ceramics are nanostructured within the material used to improve the component properties extensively. The processed ceramic components exhibit surfaces with high accuracy and minimized shrinkage even at high temperatures compared to pyrolysis by furnace.

The use of pulsed Nd:YAG-Lasers allows a defined energy input, required to pyrolyse the precursor and enables a minimisation of the active volume to build up the components step by step.

A special optical set-up with beam delivery via mirrors and lenses was used to split up the beam and recombine it in the focus point, thus the energy level for pyrolysis is achieved only within the recombination point, whereby the active volume can be minimised significantly compared to single beam set-up.

Several studies investigate the influence of the laser parameters, e.g. pulse mode, pulse length, pulse energy, frequency on the ceramic built-up concerning the realisation of micro-scaled structures with high aspect ratio.

In order to obtain the atomic structure and composition, the created components were analysed by high-resolution SEM / TEM microscopy, thus the different reaction processes can be described.

Laser interaction with titanium oxide gels and organic-inorganic hybrid materials

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UV irradiation of the titanium oxide gel results in creation of Ti^{3+} centers with much higher efficiency than in colloidal solutions of TiO_2 nanoparticles (sols). These centers absorb in the near UV, visible, and near IR ranges of optical spectrum. Wet gels are semi-liquid bodies which are not feasible for photonics applications. In contrast, the organic-inorganic hybrid materials demonstrated by our group have the same optical properties as the gels but they are initially optically transparent solids that can be polished in order to achieve optical quality of the faces.

We report on possible applications of these hybrids in photonics. These applications owe to the opportunity of providing significant laser–induced changes of optical properties of the materials.

When irradiating titanium dioxide gels by millijoule femtosecond pulses from a Ti:Sapphire laser, we observed that long-lived trapped electrons are generated in titanium oxide gels in the convergent part of a loosely focused beam. The appearance of trapped electrons is accompanied by the generation of white supercontinuum. Considering the relevant physical mechanisms of trapped electron accumulation, we show that two-photon interband transitions with participation of photons at the fundamental frequency and from the blue part of the supercontinuum explain the experimental findings.

These experiments show that the titanium oxide gels and the hybrids are the materials that possess a large amount of traps for electrons (up to $10^{21}cm^{-3}$). We develop a theoretical model for electronic processes in such materials irradiated by femtosecond pulses. Such materials demonstrate incubation with respect to breakdown at multipulse irradiation. We experimentally show that hybrid materials are promising for micromashining applications.

This work was done in close cooperation between groups from IAP RAS (Dr. A. Alexandrov, Dr. A. Malyshev), Paris- 13 (Dr. A. Kanaev), Inst. Pierre and Marie Curie (Prof. C. Sanchez), N. Novgorod State University (Prof. L. Smirnova), Hanover Laser Zentrum (Prof. B. Chichkov). Part of this work constitutes Ph. D. Thesis of Dr. A. I. Kuznetsov.

Growth of metal-oxide semiconductor nanocomposite thin films by a synchronized laser system

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Titanium dioxide (TiO_2) thin films have received significant attention during the recent years due to their photocatalytic and optoelectronic properties. Nevertheless, due to its relatively large band gap TiO_2 absorbs only a small fraction of te solar radiation (the UV component). Significant research has been focused on the development of a new generation of TiO_2 photocatalysts to overcome this shortcoming, through the identification of possible solutions for extending the absorption range in the visible light spectrum. Such attempts include doping of TiO_2 host material with non-metal or metal ions, as well as partial coating with metals. We report the synthesis of nanocomposite thin films formed by gold (Au) nanoparticles embedded in a TiO_2 matrix by pulsed laser deposition (PLD) using a synchronized two laser system.[1,2] The continuous band-gap narrowing and increasing additional surface plasma resonance (SPR) absorption in the visible region with the augment of Au incorporation ensure for the creation of Au-TiO_2 nanocomposite systems with tunable optical properties for a new generation of photocatalysts and solar energy converters.

Organic and nanoparticle thin films deposited by maple for sensor applications

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We report on the potentiality of the MAPLE technique for the deposition of thin films of colloidal nanoparticles and organic materials to be used for gas sensors based on electrical and optical transduction mechanisms. The MAPLE technique seems very promising, since it permits a good thickness control even on rough substrates, generally used to enhance the active surface for gas adsorption.

TiO_2 and SnO_2 (with a capping layer of trioctylphosphine) colloidal nanoparticles were diluted in suitable solvents (0.2% concentration), frozen in liquid nitrogen and irradiated with ArF or KrF excimer lasers. The nanoparticle thin films were deposited on silica, interdigitated alumina and <100> Si substrates and submitted to morphological (SEM-FEG), structural (XRD and FTIR), optical (UV-Vis transmission and photoluminescence) and electrical (sensing tests) characterizations.

A uniform distribution of TiO_2 nanoparticles, with an average size of ~10 nm, was obtained on flat and rough substrates. The TiO_2 nanoparticles preserved the anatase crystalline structure, as evidenced by the XRD spectra. FTIR analysis showed that the SnO_2 nanoparticles maintained the capping layer after the laser-assisted transfer process. This protective layer was removed after annealing at 400 ^{0}C, the usual operating temperature of the sensor. Electrical tests performed in controlled atmosphere in presence of ethanol and acetone vapors evidenced a high value of the sensor response even at very low concentrations (20-200 ppm in dry air) of both vapors.

As regards the preparation of organic based thin films, Methoxy Ge Triphenylcorrole (Ge-TPC-OCH_3) was synthetised and deposited by MAPLE for optical sensors based on the luminescence properties of this material. A liquid nitrogen cooled target of Ge-TPC-OCH_3 diluted in THF (0.01 wt% concentration) was irradiated with a KrF excimer laser. A very interesting result for this new material was that the film preserved the absorption and luminescence properties of the macrocycle present in the starting solution.

Laser assisted micro sheet forming

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The fast growing market for micro technical products requires parts with increasing complexity. Sheet metal forming enables low cost mass production with short cycle times, but is limited by the maximum degree of deformation and the cutting edge quality.

The technology of warm forming partially eliminates these deficiencies. The forming operation takes place at elevated temperatures before structural transformation initiates. It combines characteristical advantages of traditional cold and hot forming processes. Lasers as heat sources provide a high, selective and controllable energy input. Transparent tool parts made of sapphire or diamond permits the guidance of the laser radiation through the tool onto the surface of the workpiece.

The general difficulty of a uniform temperature distribution during the heating process can be reached by using an Axicon which generates an annulus on the sheet metal surface. The temperature of the workpiece, measured by a pyrometer, is tuned by a PI-Controller.

The present focus of interest is the automation of the process to reduce cycle times as well as the forming and stamping of complex parts and the use of hard or brittle materials. Therefore a tool incorporating a multistage operation die is used for the manufacturing of up to three parts at the same time. The tool is integrated into a conventional hydraulical press. This enables the further use of existing equipment with an additional laser system.

As demonstrators a gearwheel and an embossing structure are chosen both made of the magnesium alloy AZ31. The material behaves brittle at room temperature, but through the creation of additional gliding planes it is becoming more ductile above temperatures of 225°C. Beside lower process forces the surface quality of both demonstrators can be improved in comparison to cold forming.

New photorefractive silver-plasmons glass for photonics components fabrication

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A new photo-thermo-refractive (PTR) silver glass has been developed. The UV laser radiation (325 nm) and following thermal treatment (500-600^{o}C) resulted in growth of nanosize silver colloidal particles (plasmons) in bulk of glass host. Such photo-thermo-induced colloid-forming process resulted in change of absorption spectra and refractive index in UV radiation-exposed area. The absorption coefficient in band absorption of silver plasmons at 450 nm achieved more 100 cm^{-1}. The refractive index change was positive and achieved 0.01. Properties of the new PTR silver glass were compared with known PTR fluoride glass based on photo-thermo-induced crystallization process. In case of PTR fluoride glass, the NaF microcrystalline phase segregated in glass host. For example, the refractive index change in PTR fluoride glass was negative and achieved 0.0005. Possibilities of some applications of the new PTR silver-plasmons glass for photonics applications have been discussed. The positive refractive index change in the PTR silver glass can be used for planar waveguides fabrications by UV-laser radiation in volume or on the surface of glass samples. The big dynamic range of refractive index of the PTR silver glass can be used for high efficiency volume Bragg gratings recording and GRIN optical elements fabrication operating at near IR spectral range.

Deposition of films and layers for sensors with PLD and LIFT method

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Thin films were deposited by KrF laser ablation (PLD) of $CrSi_2$ and β-$FeSi_2$ targets with the aim to fabricate silicide films and layers with narrow band gap for sensor applications. $CrSi_2$-based films display both semiconductor and metal properties, depending on the deposition parameters. Thus, the film d ≅ 40 nm thick, deposited on Si at 740K, presents the band gap $E_g \cong 0.18$eV, a thermo e.m.f. coefficient $\alpha \cong 1.0$-1.4mV/K for 300≤T≤340K and the coefficient of tensosensitivity $(R-R_0)/R_0 \varepsilon \cong 5$ (R_0 is the resistance of the as-deposited film; R is the one of the film with relative deformation ε). The film with the same thickness, but deposited on SiO_2 at 740 K, has metal temperature dependence in the range 200≤T≤294K and a semiconductor one for 77≤T≤125K. Its α coefficient changes from 0.005 to 0.0075mV/K for 300≤T≤340K. The 750 nm thick film deposited on SiO_2 at 740 K displays the semiconductor behaviour with $E_g \cong 0.013$eV and $\alpha \cong 0.01$-0.015 mV/K for 293≤T≤340K. The β-$FeSi_2$-based films deposited on SiO_2 at 295≤T≤740K show only semiconductor behaviour. The thicker the film, the higher the E_g: d ≅ 150nm, $E_g \cong 0.032$ eV; d ≅ 70 nm, $E_g \cong 0.027$ eV; d ≅ 60nm, $E_g \cong 0.023$ eV. α is about 0.01mV/K at 293≤T≤340K for the 150 nm thick and is about 0.008mV/K for 60 nm thick film and $(R-R_0)/R_0\varepsilon$ coefficient changes from 4 to 2. Films with only semiconductor phase have higher α and $(R-R_0)/R_0\varepsilon$.

Thin films were deposited by Q-switched Nd:YAG laser (LIFT) of $CrSi_2$ and β-$FeSi_2$ targets. α coefficient for the deposited film from β-$FeSi_2$ is about 0.0022 mV/K with $E_g \cong 0.05$ eV. While decreasing laser power the band gap is being decreased up to 0.005 eV and $\alpha \cong$ 0.002 mV/K for these kinds' films. α coefficient for the deposited film from $CrSi_2$ is about 0.036 mV/K with $E_g \cong 0.09$ eV. While increasing laser power the deposited film $CrSi_2$ had metal temperature dependence owing Cr atom evaporation from the target.

These two methods of film and layer deposition can be proposed for thermo-tensosensors.

Control of steel microstructure by laser-light hybrid technique

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Laser-light hybrid combination allows to create a special form of temperature cycle, which contain several steps of high speed heating and cooling in superficial material layer. The mathematical modeling and real experiments were used for investigation of the influence of temperature cycle of hybrid laser-light action on such microstructure parameters, as size and distribution of nano-scale carbide inclusions in low-carbon and high-alloyd steels. The mathematical model was based on solution of heat transfer problem of solid solution decay with consideration of kinetics of carbide formation and carbon diffusion. For experimental investigation the set-up, consist of pulse-periodic Nd:YAG laser and high power arc lamp with focusing system has been developed. The experiments, which have been fulfilled, prove the increases of plasticity of steel in the zone of hybrid laser-light action.

Workshop
"Laser Cleaning and Artworks Conservation" (LCAC)

The contribution of physics to the conservation of Cultural Heritage

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Following the technological and methodological developments of the last years, the laser cleaning techniques are gradually entering the common conservation practice of stone and metal artefacts. The present main challenge is represented by polychrome surfaces. Recently, very promising demonstrations based on Nd:YAG laser ablation were reported, which could disclose a significantly wider application domain. The consolidation and extension of the present successful results pass through further experimental researches dedicated to the solution of specific conservation problems, as well as through the statement of rigorous multidisciplinary approaches to prevent any improper utilisation. The physical contribution to such a further development is still of crucial importance. Phenomenological investigations, diagnostics, and modelling of the laser-material interaction, for a correct selection of the laser sources and the definition of the irradiation protocols in a variety of specific case studies, represent the most effective way to promote the dissemination of the laser approach. Here, the general criteria for optimising cleaning processes for different classes of artefacts and practical conservation problems will be discussed in some details.

Laser techniques in Cultural Heritage preservation

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The state of the art of laser technologies in conservation of Cultural Heritage is continuously growing around the world. Laser and opto-electronic techniques came in restoration in more than thirty years ago. This approach was first proposed by American physicist J.F.Asmus, who could demonstrate in the church of St.Catherine in Venice, the possibility to remove black crusts from stone artifacts with laser [1]. The validation of advanced laser cleaning techniques has been extensive and diffused in many European countries, USA, Canada and Australia, especially for stone and metals. Laser-based diagnostics have also specialised their tasks toward material analysis, defects detection and multidimensional documentation. Laser and optical methods successfully monitor deterioration effects.

As a result of all above mentioned the appreciation for laser techniques in CH preservation is growing in all the conservation institutions involved at national level, disseminating a positive evaluation about the benefits provided by laser techniques in conservation. At this moment some laser systems already became products for the activity of professional restorers and their increasing sales demonstrates a growing utilization through all Europe and some other countries.

In the paper an overview of laser techniques in CH preservation will be presented.

References:

1. J.F.Asmus, L.Lazzarini, "Laser for cleaning of statuary: initial results and potentialities", Apta of 1st Int.Symp. on the Deterioration of Building Sones, La Rochelle, Paris, (1972).

Physical mechanisms and laser equipment for distant laser cleaning of metallic surfaces

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Laser restoration of works of art is based on the different methods of laser cleaning. Laser cleaning is effective for removal of soiling particles and films from solid surface. The specific peculiarities of the method such as its locality, precision, simplicity, ecological purity, absence of additional operations define its numerous potential applications in the different fields, and essentially for restoration of works of art.

Different physical mechanisms of laser cleaning by restoration of metallics surfaces (at works of art and ancients) are examined: blasting, thermomecanical and evaporative mechanisms. The blasting mechanisms are based on the surplus pressure occurrence at the interface of the substance and contamination, causing the explosive ejection of the contaminating layer from the substance surface. Thermomechanical removal of the contaminating layers and particles is caused by their thermal expansion and formation of the local thermal strain. The evaporative mechanism is realized by sufficient value of acting laser intensity. The peculiarities of the physical mechanisms of laser cleaning are considered depending on physical properties of substrate's and contaminating layer's or particles' materials.

Special laser equipment for distant cleaning of metallic surfaces are designed and examined. The results of laser cleaning of metallic sculptures will be demonstrated.

Laser Cleaning of Marble Sculptures of the Summer Garden: First Experience

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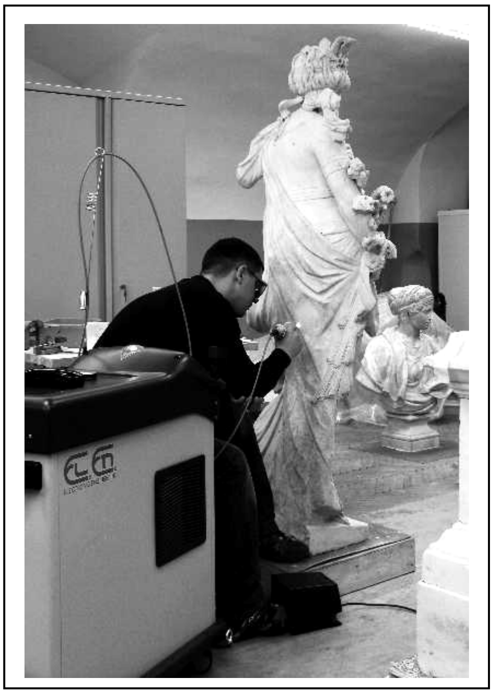
The Summer Garden in St. Petersburg, a out-doar part of the State Russian museum, owns a one of the best collections of Western European marble sculpture of XVII-XIX centuries in the world, which consists of more than 90 statues. Most of these statues are highly deteriorated due to atmospheric pollutants, fungi, lichens and other biological growth. For removal of patinations from the surface of white marble a Nd:YAG free-running laser (model Smart Clean II, El.En., Italy) has been successfully used.

In the paper the preliminary results of laser cleaning of some marble statues of the Summer Garden will be presented.



Sculpture Cerera in the process of laser cleaning

Ultimate color holography for museum applications

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The report presents the latest achievements in display Denisyuk color holography which can be used for museum applications. Two main problems which restrained development of color holography are solved. It concerns of color holographic material and possibilities of record of holograms inside of museums. Development of new “ultimate” material allows to record bright color holograms and the samples of such holograms are demonstrated. Based on new generation of lasers the mobile color holographic system is designed specially for use inside of museums. Full color 3D images of museum objects can be demonstrated in museums, exhibitions, saved in archives or used for the other applications.

Pulsed / CW Laser Applications to Soft- and Bio-materials

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In my presentation, I would like to present the following topics using pulsed- or CW-lasers for soft- and bio- materials, so far as time permits.

1. Laser-Induced Transfer of an Enzyme to Fabricate a Bio-sensor:

Laser-induced forward transfer (LIFT) of the enzyme luciferase was explored as a potential technique to be used in the fabrication of a microchip ATP (adenosine-tri-phosphate) sensor. Poly(dimethylsiloxane) (PDMS) was selected as the substrate for deposition of the luciferase. LIFT of luciferase onto a PDMS substrate using a 355 nm laser was successfully carried out, whilst the bioactivity of the enzyme was maintained. Yellow luminescence ascribed to luciferase was observed from a transferred spot on the PDMS chip from the enzymatic reaction between luciferin and ATP. A microchip ATP sensor was also fabricated by attaching a small photodiode to the PDMS chip. The potential for fabricating biosensors using a combination of the LIFT technique with a PDMS substrate was shown to be very good.

2. Gene Transfer to Tibial Muscle of by a Laser-induced Shock Wave:

We will demonstrate another technique of laser gene transfer in an indirect irradiation mode. Our technique utilizes laser-induced shock wave [1]. Expression plasmid DNA for a firefly luminescence enzyme, luciferase, was injected into tibial muscle and mousse, and then laser-induced shock wave was applied. A week later, the muscle was removed and the muscle protein was extracted with detergent-containing buffer. The luciferase activity in it was measured by a luminometer. The efficiency of gene transfer was comparable to that of erectroporation method.

3. Laser-induced Phase Transition of Polymer Systems:

We examined effects of photon pressure, generated by a focused CW laser beam, on the higher-order structure of several polymeric materials [2]. For this purpose, we recently developed an apparatus of confocal Raman micro-spectroscopy combined with laser trapping technique. Laser induced phase separation/transition of thermo-responsive polymers, and Laser induced formation of micro-particles of proteins will be presented.

1. Y. Tsuboi et al.: J. Phys. Chem. B 2003, 107, 7547.
2. Y. Tsuboi et al.: J. Phys. Chem. B 2005, 109, 7033-7039.

Nanobased materials and micro systems applications in life science and sensortechnology

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Metal and polymer nanobased materials are today used in several direct manufacturing processes e.g. to get “easy-clean” surfaces, to improve biocompatibility of medical implants, to realize multifunctional micro fluidic systems and also for high integrated sensor systems for 3D acceleration and multifunctional sensor systems for chemical processes. RMPD® (Rapid Micro Product Development) technologies use UV curing materials for parallel batch production via parallel laser beams (RMPD-writing system) or uv light (RMPD-mask). After years UV curing materials were used in direct manufacturing for RP, but not for series products, today thanks to nanotechnologies series products made can have scalable properties e.g. mechanical, optical, electrical, surface tension. Applications in consumer electronics and life science are described, particular in point of care diagnostic systems. By the combination of uv curing and advanced chip size packaging technologies the direct integration of stacked dies on smallest space is now possible. Results are presented from European funded projects too like www.inos-ist.org and www.healthyaims.org , an outlook is given about possible impact from research in polytronics and future acitivities about direct optic integration in the EC project Rapid-in-Top.

Laser assisted modification of tissue nanostructure and mechanical stress distribution

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In 1992, we identified laser-induced stress relaxation in cartilage. This led to the development of a new laser application in otolaryngology for the non-ablative reshaping of cartilage. Similar approach allows correcting the eye refraction under non-ablative laser treatment of cornea and sclera. Also we found that non-destructive laser irradiation may activate regeneration processes in cartilaginous tissue. This paper will present state of art and some new results in cartilage and cornea reshaping and regeneration of diseased cartilage. We will characterize the physical, chemical and biological processes and mechanisms involved in the laser-induced modification of tissue nanostructure and stress relaxation. Various mechanisms of laser-induced stress relaxation in cartilaginous tissues will be discussed: “bound-to free” phase transitions of tissue water, local mineralization, reorganization of the chondron structure due to local denaturation and melting of the domain boundaries, nanopores formation, and “cell” formation.

Model for XeCl laser induced photoaggregation in water solutions of eye lens proteins

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Previously we have investigated the kinetics of XeCl-excimer laser induced aggregation in water solutions of eye lens protein by measuring scattering of a trial He-Ne laser beam. It was shown that detectable scattering of the trial beam starts only after some time of UV irradiation of a sample. Further increase in the UV exposure level ($D > D^*$) results in a strong increase in scattering. We have shown [L.V. Soustov, E.V. Chelnokov, N.M. Bityurin, V.V. Nemov, Yu.V. Sergeev, M.A. Ostrovsky, Doklady Biochemistry and Biophysics. v. 388. pp. 683-688, 2003, L.V. Soustov, E.V. Chelnokov, N.M. Bityurin, et al., Proc. SPIE, v. 5149, p. 85-95, 2003.] that needed exposure (D^*) depends on laser fluence and pulse repetition rate. Later on we observed the new phenomenon of postaggregation occurring even at exposures less than D^*. When stopping irradiation of the sample at exposure $D < D^*$ after some time we can measure detectable scattering of the trial beam.

In the present communication we report on a theoretical model, which can explain the main features of the experimental findings.

The main assumption is that the absorption of UV photon by the protein can result in the formation of a photoactivated, e. g. partly unfolded, state of this protein. The life time of this state is finite and can be about seconds at room temperature. Two photoactivated proteins meeting each other can produce a dimer molecule. This dimer is not fairly structured protein molecule and can aggregate when meeting either a photoactivated monomer or already aggregated species.

This model provides the experimentally observed dependences of D^* on laser fluence and pulse repetition rate as well as exposure dependence of the postaggregation level.

The understanding of the mechanisms of UV induced eye protein aggregation helps to create a method for finding and fast selection of possible anti-cataract additions.

Biomimetic glass coatings for advanced metallic implants obtained by pulsed laser deposition

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New bioactive materials have been recently developed and successfully applied to artificial bone engineering. Coatings of hydroxyapatite, glass ceramics and glasses were synthesized to this purpose directly onto metallic alloys surface. Among the wide range of currently available biomaterials, active glasses appear to be very promising because of their performances in promoting rapid new bone growth. We selected for our studies glasses in the system SiO_2-Na_2O-CaO-P_2O_5 with good mechanical stability and adhesion to the substrate but also showing a promising in vitro behavior in SBF.

We report the successful preparation of bioglass nanostructured coatings with different composition by pulsed laser deposition (PLD) on chemically etched Ti substrates heated at 400 °C. An UV KrF* (λ=248 nm, τ ~ 25ns) excimer laser was used for the multi-pulse ablation of targets at 10 Hz repetition rate. The depositions were performed in 13 Pa O_2.

All obtained structures were investigated by XRD, MNR, RPE, SEM, and EDS. The investigations confirmed that BG coatings had a predominant amorphous structure. The thin films were homogeneous with good adhesion to the Ti substrate.

Next, we used fluorescence microscopy to test the behavior of human primary osteoblasts grown on the obtained nanostructures, at time intervals of 1, 7, and 14 days after cultivation. We studied the morphology, proliferation and spread of the cells on pulsed laser deposited coatings. Cell functionality was tested by the flow cytometrical analysis of alkaline phosphatase activity.

Our investigations proved that the films are not cytotoxic, as showed by the MTS test results and by the excellent cell adherence and growth over a span of 14 days in culture. Human osteoblasts showed high potential for proliferation and good viability when cultured on the bioglass coatings.

Laser modification optical and mechanical properties of human tooth enamel

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Modern dentistry has huge opportunities allowing to make are human teeth healthy and beautiful. In XX-XXI centuries the physics essentially has expanded methods and means of influence on are tissues of oral cavity. Not last role in it the laser engineering has played. However, despite of progress, some questions connected to influence of laser radiation on a tooth tissues till now remain open.

In the present work we investigated influences of radiation pulse CO_2 and Er:YAG of lasers on optical and mechanical properties of enamel of a human tooth.

We have established, that radiation of CO_2 laser (wavelength 10.6mcm, pulse duration about 500 mcs, pulse repetition rate 75HZ, energy density up to 26 J/cm^2, the duration of influence about 1.5s) bleaches enamel of a human tooth. Thus factor of reflection of seen light by enamel after laser influence the above, than more average power of laser radiation (in a range 0.1-1.0W). The pulp overheating of a human tooth in vitro, caused by influence CO_2 of laser radiation is measured. Is established, that the given influence is safe at processing sites of enamel, locate from pulp on distance more than 3.5mm and having the area about 2mm^2.

We have carried out experimental researches of a threshold of laser destruction of enamel by submillisecond pulses Er:YAG of the laser. In work are established and the effects accompanying influence of radiation with wavelength 2.94mcm, having a place are described in the field of energy density 1-10 J/cm^2. Effect of simultaneous hardening and bleaching of enamel in area environmental a crater, created by radiation YAG:Er of the laser for the first time is described. In work the behaviour of microhardness and factor of reflection of enamel of a human tooth in seen area is investigated depending on energy density and number of laser pulses influencing the same area of enamel.

Laser micro sintering of SiO_2 with an NIR-Laser

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Many materials have already been investigated for laser micro sintering. Nearly all technical metals can be processed with this rapid prototyping technology. A new field of investigation is the sintering of ceramics.

For industrial and also for medical, especially dental, application silicon dioxide is a multiply applicable material. One of its interesting features is, that the properties of the resulting material can varied between ceramic on the one and vitreous on the other side, depending on extent of crystalline or amorphous character of the nano structure. A special problem with laser micro sintering of ceramics is the poor absorption of Nd:YAG laser radiation by most of the material. Besides that, laser micro sintering of ceramics, in contrary to the process with metals, is not merely a series of aggregational transitions.

A solution for the micro part generation of SiO_2 is reported. A representative selection of laser sintering results from this material is presented. Material specific behaviour during laser micro sintering is discussed.

Diffuse Optical Tomography for Biomedical Applications

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Diffuse Optical Tomography (DOT) is a powerful tool which allows non-invasive investigation of the internal structure of biological objects where light propagates in a diffuse manner.

Recently a highly sensitive CCD-based Fluorescent Molecular Tomography imager was designed capable of performing tomographic imaging of small laboratory animals in the visible. The scanner operates on noncontact imaging technology using constant intensity illumination technique and reconstruction algorithms based on modified diffusion equation solutions. The use of low-intensity lasers as sources with different wavelength allows the application of this scanner for tomographyc imaging of different fluorescent proteins. Scanner can operate in either reflection or transmission mode. Depending on the targeted area or organ, setup can be modified to perform measurements on plain or over a full 360^0. Using noncontact method extremely large data sets can readily be obtained providing the increasing of tomogram spatial resolution.

The reconstruction of images from large data sets is an extremely challenging problem due to the high computational complexity of numerical approaches to the inverse problem in DOT. To address this challenge the novel image reconstruction algorithm is proposed that combines the features of computationally efficient algorithms which can decrease the computational coast of reconstructed images. Novel methods of blurred image restoration and postprocessing applied demonstrate the significant improving of the tomogram quality.

The methodology presented could find great applicability in small-animal imaging research, both in basic biology studies such as gene expression and in studies of disease development, treatment, and drug evaluation.

This work was supported in part by EU Integrated Project ‘‘Molecular Imaging’’ LSHG-CT-2003-503259 and its 6th Community Frame and program of Marie Curie Incoming International Fellowships MIF1-CT-2005-008330 Real time 3D Imaging.

PS2_01 Molecular dynamics study of the mechanisms of Matrix-Assisted Pulsed Laser Evaporation (MAPLE) of polymer molecules *

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There are a number of recent and emerging techniques that utilize the ability of laser ablation of a volatile matrix to entrain, eject and, if needed, deposit large macromolecules to a substrate with minimum chemical modification. In particular, the Matrix-Assisted Pulsed Laser Evaporation (MAPLE) technique shows a potential to produce ultra-thin organic and bioorganic films for optoelectronic, biomedical, and chemical sensor applications. The lack of understanding of the fundamental underlying processes involved in laser ablation, however, hampers further optimization of the experimental parameters in MAPLE. In this presentation we report the results of a comprehensive computational investigation of laser-induced molecular ejection from frozen solutions of polymer molecules in a volatile matrix. Coarse-grained molecular dynamics (MD) simulations are performed for polymer concentrations up to 6 wt.% and laser fluences covering the range from the regime where molecular ejection is limited to matrix evaporation from the surface up to more than twice the threshold fluence for the onset of the collective molecular ejection or ablation. The results are related to experimental observations obtained in MAPLE thin film deposition and address unresolved research questions that are of direct relevance to MAPLE performance [1, 2, 3].

Contrary to the original picture of the ejection and transport of individual polymer molecules in MAPLE, the simulations indicate that polymer molecules are only ejected in the ablation regime and are always incorporated into polymer-matrix clusters/droplets generated in the process of the explosive disintegration of the overheated matrix. The entanglement of the polymer molecules facilitates the formation of intricate elongated viscous droplets that can be related to the complex morphologies observed in polymer films deposited by MAPLE.

In a series of targeted MD simulations [4] we show that an internal release of the matrix vapor in large droplets ejected in MAPLE is capable of pushing the polymer molecules to the outskirts of the droplets, forming transient “molecular balloons” expanding under the action of the internal vapor pressure. Active evaporation of matrix molecules from the surface of the droplet contributes to the formation of a polymer-rich surface layer, hampering the escape of the remaining matrix molecules. The results of the simulations explain unexpected “deflated balloon” structures observed in films fabricated by pulsed laser ablation of frozen polymer solutions in a volatile solvent.

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* Letters “PS” before the titles marks the poster presentation

PS2_02 Vertically Aligned Carbon Nanotube Patterning Using Femtosecond Laser

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Carbon nanotubes (CNTs) have generated much interest, particularly with regard to potential future applications based on their field emission, electronic transport properties, high mechanical strength, and chemical properties. These features make them particularly applicable for use as field emission devices, nanoscale transistors, nano-bio sensor, and tips for scanning microscopy. In this study CNTs are grown on Si substrate using Fe catalyst and plasma enhanced chemical vapor deposition (PECVD) which can make vertically aligned multiwall carbon nanotubes. Carbon nanotubes grown in this experiment have diameters ranging from 60 to 80 nanometers and lengths of about 2.7 micrometers. Patterning of carbon nanotube on selected site is usually performed by photo or e-beam lithography. But these methods need subsequent Si fabrication process such as lift of process or etching. We showed that selective CNTs pattering on Si substrate is possible using femtosecond laser instead of using conventional lithography process. High shock wave generated by femtosecond laser effectively removes the carbon nanotubes without damage of Si substrate. This process has many advantages because the process is performed without chemicals and easily applicable to large area patterning.

The CNTs grown by PECVD have a catalyst cap at the end of nanotube due to the tip-growth mode mechanism. For the application of electron emission and bio sensor, catalyst cap is usually removed by chemical method which makes surface damage of CNTs wall. Precise control of femtosecond laser power and focal position could solve this problem. Selective carbon nanotube cutting using femtosecond laser doesn't cause phase change of CNTs, which is shown in focused ion beam irradiation of CNTs. This presentation will show the fundamental results of vertically aligned CNTs array patterning and cutting by femtosecond laser.

PS2_03 Analysis of SNOM tip aperture by far-field intensity distribution

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SNOM fiber probe is made by laser pulling and also coated with aluminium. Far-field intensity distribution of metal-coated SNOM tips is used for evaluation of aperture parameters. CCD camera, which registries far-field intensity of light, is controlled by a home-made program based on the isophotometric method for increasing of range of sensitivity. Thus, we can receive simultaneously weak and strong signals without saturation. A program for interpretation of the registered information is also developed. So, we can determine the shape and the size of SNOM tip apertures by solution of the inverse task.

PS2_04 Application of laser sputtering of a solid target for the fabrication of semiconductor nanoheterostructures

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The unique method of formation of semiconductor nanoheterostructures on the basis of GaAs was presented. This method combines metal-organic vapor phase epitaxy and laser sputtering of a solid target in the same reactor. Principal restrictions of MOVPE application are connected with the absence of some material fluid sources available, and also with relatively high metal-organic compound or hydride decomposition temperature. Pulsed laser deposition also has several drawbacks. The presence of high-energy ions in laser plasma results in undesirable defects generation in the growing layer. With the increase of a deposition rate the risk of flux macroparticle occurrence in sputtering material appears that leads to impair of a surface morphology. It was shown, that pulsed laser deposition in hydrogen flux allows decreasing ion energy. Depending on a hydrogen pressure and sputtered material it is available to controllably change a growth rate. At the pressure of 50 mm of mercury the growth rate is about 0.3 A/s. The method allows growing either modulation doped or delta-doped semiconductor layers in a wide range of possible doping levels. Moreover this method allows obtaining crystal perfect low-temperature GaAs layers by sputtering of GaAs target in hydrogen flux. One of the important achievements of this method is obtaining the single-phase GaMnAs solid solution layers that reveal ferromagnetic properties at room temperature, and growing a low temperature GaAs layers. These structures recently found increasing number of applications in optoelectronic and spintronic.

This work was supported by RFBR (project 05-02-16624), Russian Ministry of education and science (projects RNP.2.1.1.2741, RNP2.2.2.2.4737) and OFS RAS "Spin dependent effects in solid state and spintronics".

PS2_05 Tip-enhanced secondary emission of semiconductor quantum dots

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One of the most important methods of nanostructure investigation is the near-field optical spectroscopy. It allows studying nanoobjects with ultrahigh spatial resolution as far as some nanometers. In combination with modern spectral devices the method enables to obtain secondary emission spectra with high spectral resolution for single nanoobjects. The analysis of experimental data, specifically Raman spectra, allows us to determine local chemical composition and mechanical stresses in nanostructures. From this point of view the most interesting spectral devices are those based on the effect of local electromagnetic field enhancement near metallic tip apex. Their spatial resolution is determined by the apex radius of curvature. Scanning the nanoobject in lateral plane, one can find spatial map of chemical composition and mechanical stresses.

To interpret spectroscopic data as well as to define optimal experimental conditions of the method it is necessary to develop an appropriate theoretic description of tip-enhanced secondary emission of single nanoobject. To do this electric field near the apex of the conical tip has been calculated. It has been assumed that the field is induced by the plane electromagnetic wave polarized along the tip axis. Moreover, it has been supposed that the presence of nanoobject and substrate do not influence the magnitude and spatial distribution of the electric field. According to calculation, in immediate proximity to the cone apex the electric field strength far exceeds that of the plane electromagnetic wave. Obtained results have been used for calculation of secondary emission spectra of semiconductor quantum dot. This nanoobject is of interest with both fundamental and applied point of view. Calculations have been carried out in framework of the reduced density matrix approach under condition that electric field frequency is close to resonance with the fundamental transition of quantum dot. Spectra of secondary emission depending on tip size and distance between quantum dot and tip apex have been analyzed. It has been demonstrated that the presence of metallic tip results in significant enhancement of secondary emission intensity.

PS2_06 Photoinduced formation of nanosized gold particles in different solid polymeric matrices

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UV irradiation of polymeric films containing $HAuCl_4$ followed by annealing at 60-80^{0}C provides formation of gold nanoparticles directly within the bulk of material.

The overall picture can be understood as follows. UV irradiation causes $HAuCl_4$ dissociation and thus provides a polymeric matrix with atomic gold. The presence of oversaturated solid solution of atomic gold in the polymeric matrix leads to Au nanoparticles formation during annealing. This process can be considered as a phase transition of the first order.

Kinetics of nanoparticle formation was traced by extinction spectra of nanocomposite film changes *vs* annealing time. Also, polymeric film samples were studied by X-ray small-angle scattering (XSAS) technique.

In our experiment polymethylmethacrylate (PMMA) was used as a polymeric matrix because of high optical transparency of the films based on it. Besides, the polymeric matrix based on PMMA exhibits satisfactory physical-mechanical properties and a wide dissolution range which makes it possible to create such film materials for optical application.

With the purpose of analysing the influence of matrix constitution on forming particle distribution, both nanocomposites based on pure PMMA and copolymer methylmethacrylate (MMA) with ethylhexylacrylate (EHA) were synthesized. It is known that the incorporation of units with bulky substituents into the polymer chain and an increase in the length of the side chain in methacrylates result in an increase of free volume content in a copolymer. Considering different polymeric matrix allows us to estimate the effect of matrix structure on gold particle distribution.

We show that kinetics of nanoparticle formation can be satisfactorily described within the frame of Fokker-Plank equation approach with assumption of diffusion-controlled particle size growth. Both homogeneous and heterogeneous models of nucleation are studied. The possible role of aggregation of nanoparticles in matrix with large free volume is also considered.

PS2_07 Near-Field Optical Response of Metal Nanoparticle Structures located within a Dielectric Layer

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The near-field response of optically excited nanoparticle structure buried within thin dielectric layer is theoretically and numerically studied. The model employed is based on the Green's function formalism and the dipole approximation for field scattering by nanoparticles. Nanostructure is modeled as a finite-size periodic array of dipole-like gold nanoparticles, the size of the structure is assumed to be much smaller than the wavelength of the external electromagnetic wave. The layer with particles is located on a dielectric substrate which is irradiated by an external monochromatic optical wave under the condition of total internal reflection.

It has been found that in ordinary conditions (far away from particle plasmon resonance) field distribution and the magnitude of the field intensity in the system strongly depend on the polarization of the exciting external wave and the inter-particle distances in the nanostructure. In order to investigate plasmon resonant response of the structure we calculated an average magnitude of dipole moment of the particles as a function of light wavelength for different parameters characterizing the layer environment and the structure. It has been found, that with increasing the dielectric constant of layer, the resonance shifts to the red. Moreover the magnitude of the resonant dipole moment is also increased with increasing the layer dielectric constant. The spectrum of the average dipole moment magnitude for different inter-particle distances in the structures has been studied. It was found that the position of the resonance wavelength can be modified over a relatively large spectral range by changing the inter-particle distances in the structure. But the direction of the resonance shifts is strongly depended on the polarization of the incident wave. We also analyzed the distribution of the electric field in the plane above the layer with nanoparticle structure under resonance condition and for different polarizations.

PS2_08 Radiation-induced transfer phenomena in nanoscale systems

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Transfer phenomena in the field of resonance radiation are of interest for many branches of nanotechnology. The paper deals with a theoretical study of transfer processes and phase transitions in nanoscale systems under the influence of radiation. Resonance laser radiation can excite gas molecules and respectively change the character of the interaction between gas molecules and a surface of the condensed phase. The possibility to affect surface processes allows changing a momentum transferred by gas molecules to the condensed phase. This can lead to initiation of a mutual movement of gaseous and condensed phases. It is shown that above-mentioned factors can lead to the radiation-induced drift of gas molecules in capillary-porous bodies with nanoscale pores and new components of the phoretic force acting on the aerosol nanoparticles. The influence of resonance radiation on surface processes can affect the attachment of vapor and impurity molecules to the nanoparticles (clusters) that in turn can change the nucleation rate, the growth rate of particles and their composition. The radiation-induced absorption of hydrogen by metallic nanoparticles (which can be used for hydrogen storage) is also considered.

Acknowledgements. This work was supported in part by GACR projects 101/05/2214, 101/05/2524 and 104/07/1093.

PS2_09 Selective modification of size and shape distributions of nanoparticles in island metal films using photoatom emission and photoinduced surface self-diffusion

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Optical properties of island metal films differ considerably from optical properties of bulk metals and single atoms. Absorption spectra of metal nanoparticles show resonance lines caused by collective oscillations of conduction electrons. Contrary to plasmon excitation in the bulk material, plasmon excitations in metal nanoparticles can be stimulated by light. Such excitations are accompanied by local field enhancement in vicinity of metal nanoparticles. Spectral positions of surface plasmon resonance lines vary with size and shape of nanoparticles. These features of optical properties of plasmon resonances attract interest to their fundamental investigations and promise a manifold of different applications.

We studied sodium island films created by thermal vapor deposition on transparent dielectric substrates. Particles in such films have broad size and shape distributions that cause inhomogeneous broadening of absorption lines. On the other hand, to study relaxation dynamics of surface plasmon excitations, the homogeneous line width should be measured. To reach this goal, we employed the method of persistent spectral hole burning. Contrary to the studies performed earlier, our method was based on the laser-induced nonthermal evaporation mechanism known as photoatom emission, rather than on conventional heating of sodium islands by laser light.

In this contribution we present homogeneous line widths obtained for sodium particles supported on glass, quartz and sapphire substrates. Homogeneous line widths measured in the experiments were employed to evaluate the dephasing times of localized plasmon excitations in sodium nanoparticles supported on different substrates.

The detailed analysis of the spectral holes burnt in the plasmon absorption lines led us to a conclusion that the photoatom emission is always accompanied by another nonthermal photoinduced process, namely, photodiffusion of own atoms on a metal surface. In spectral regions where the photoatom emission ceases to operate, photodiffusion is the only mechanism responsible for nonthermal modification of ensembles of metal nanoparticles.

PS2_10 Light action on electron tunneling between nanoparticles in Na island metal film

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Recently, photoelectronic phenomena in systems, representing metal nanoparticles interacting with each other, attract great interest. This interest is explained by their prospective application in quantum electronics devices of new generation. On the other hand, island metal films are traditional objects, on which photoelectronic phenomena in systems of nanoparticles are studied. In this work we choose to investigate mechanisms of optical radiation action on the island film conductivity.

The experiments were carried out with the Na island film supported on sapphire surface in a vacuum cell. The film was disposed between two electrodes separated by 4 mm. Above the film there was the third electrode for registration of the photoemission current. To avoid the «short circuit» effect, photoeffects were investigated in the films with large electrical resistance of 1 to 7 GΩ.

The largest effect of optical radiation on the film conductivity was found to be caused by photons with the energy above the threshold of photoeffect in Na. However, below the threshold, in the spectral interval from 540 nm to 680 nm, appreciable action of illumination on the film conductivity remains.

The experimental results obtained in this research are described nicely by the model of electron hopping between metal islands. Our theoretical model accounts for the non-uniform distribution of charges due to electron transport between islands. The spatial and temporary distributions of charges in the film was found by solution of the diffusion equation. We account also for the fact that photons with the energy below the threshold of photoeffect can cause interband transitions of electrons in metal. The probability of tunneling of the exited electrons in neighboring islands is higher than that of unexcited electrons. This explains the observed reduction of the film resistance under illumination by light that does not lead to the extrinsic photoeffect.

PS2_11 The Features of kinetics of clusters formation under intensive evaporation of small solid particles by short laser pulses

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The clusters formation processes under silicon vapor expansion from a spherical source (the model of laser evaporation of a small particle) into a vacuum and an inert gas of a low pressure are considered. To describe the vapor expansion and clusters formation processes the direct simulation Monte Carlo (DSMC) method is used [1]. The model of clusters formation includes description of processes of clusters growth and decay, as well as heat exchange processes accompanying the specified processes. The cluster is characterized by number of atoms, collision cross-section, binding energy, translation and internal energies. The Larsen-Borgnakke model is used to describe the heat exchange at collisions [2].

The influence of vapor condensation on gasdynamic parameters of the flow has been investigated. The main peculiarities of clusters growth under considering conditions have been researched. The detailed data on time evolution of mixture (silicon atoms and clusters) parameters have been obtained. The obtained results are of interest for applications in which the processes of laser interaction with aerosols play the important role.

This work was supported by the INTAS grant (№ 03-51-5208).

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PS2_12 Modeling of metal nanoclusters formation, growth and deposition on a surface under pulsed laser ablation in vacuum

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Processes of metal nanoclusters formation under pulsed laser ablation (PLA) of a flat target in vacuum and deposition of ablation products on a flat surface have been studied. The general model of PLA includes three parts: a model which describes absorption of laser radiation and evaporation of the target (a heat model of the target) [1], a model for description of vapor dynamics and processes of clusters formation [2] and a heat model of the substrate. A heat model based on nonstationary one-dimensional heat conduction equation with volume heat source has been used to describe laser radiation absorption and heating of the target. Analogous heat model has been used to describe heating of the substrate. The method of direct statistical modeling has been used to describe vapor expansion and formation of clusters.

The process of transfer of ablation products (atoms and clusters) from the target to the substrate under conditions typical for production of thin films (nanosecond pulses, moderate radiation intensities) has been considered on the example of laser ablation of niobium. Performed numerical investigations allow to establish general correlations between parameters of laser radiation, thermophysical parameters of target material, parameters of vapor flow (including parameters of clusters) and lows of vapor deposition on the substrate.

This work was supported by the INTAS grant (N 03-51-5208)

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PS2_13 Polaritonic model for the regular nanostructuring of transparent dielectrics and semiconductors by femtosecond laser radiation

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The proposed by us universal polaritonic model is known to explain the results of the laser-induced damage of the material surfaces with different electronic properties (metals, semiconductors, dielectrics) for a wide range of spectrum and radiation pulse durations and followed by regular structures formation. Recently this model was verified for metals and femtosecond range laser radiation pulse durations. But the related experimental results causing wide band gap dielectrics and semiconductors were unexplained till now.

Experimental results about the interaction of linear polarized femtosecond pulses of laser radiation with wide-band dielectrics (calcium fluoride, zinc selenide, quartz glass) and silicon were analyzed. It is shown that at laser power density of the order 10^{12} W/cm^2 (τ~100 fs) the nonequilibrium hot-electron plasma having concentration $n \geq 10^{21}$ cm^{-3} is produced and the nonthermal phase transition occurs. In this situation at the boundary nonequilibrium hot-electron plasma - dielectric the conditions for surface plasmon-polaritons excitation by the incident radiation arises. Mutual surface plasmon-polaritons interference and one with the incident laser radiation cause the standing interference fringes of nonequilibrium electron density formation. When the dielectric volume breakdown occurs the near symmetric channel surface plasmon-polaritons interference is the cause of the volume nanostructures formation.

As a next step of the periodic nanostructures formation the different ways of the time-dependent evolution of modulated electron density into the remnant periodic nanostructures of material are considered.

So the possible periods of the surface nanostructures for normal incident linear polarized femtosecond pulses of laser radiation are: $d_1 = \lambda/\eta$, $d_2 = \lambda/2\eta$, $d_3 = \lambda/2n\eta$, which well agree with experimental results. Here the η is the real part of the refractive index for surface polaritons for the boundary dielectric – hot electron plasma in excited dielectric, $\eta \geq 1$, n is the refractive index of dielectric, λ is the wavelength of incident radiation.

The near surface spatial inhomogeneities of the order of produced resonant nanostructures to transform an incident radiation into surface plasmons-polaritons are considered. Among them there are instantaneous one and remnant.

The mechanism for the nanostructures formation on the transparent semiconductor surface is the same.

PS2_14 The nanoclusters formation at the surface of silicates induced by CO_2 laser radiation

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The photochemical transformations caused by continuous CO_2 laser radiation (10^5-10^6 W/cm^2) and pulsed CO_2 laser radiation (pulse energy of 3-4 J, a pulse duration of 200 ns, effective laser spot diameter of 1 mm) at the surface of silicates (nepheline - $Na[AlSiO_4]$, rodonite - $CaMn_4[Si_5O_{15}]$, zircon - $ZrSiO_4$ etc.) have been investigated.

The action of laser radiation on these silicates leads to the creation of silicon and metallic nanoclusters at the irradiated surface. The appearance of such nanoclusters has been confirmed both by means of photoluminescence method analysis and the X-ray emission microprobe analysis of irradiated surface. It has been found that the laser irradiation of the surface of zircon ($ZrSiO_4$) results in the formation of defect metallic clusters, in which the zirconium atoms have different electronic states

It has been found also that the laser irradiation of the surface of zircon ($ZrSiO_4$) lead to the creation of long lived zirconium defect metallic nanoclusters $[Zr\bullet\square\bullet Zr]^{n+}$ at the surface of zircon in which the zirconium atoms have different electronic states.

We establish that all observed phenomena are connected with the selective breaking of the strong covalent Si-O bonds induced by resonant laser radiation and photoreduced processes in oxide matters.

PS2_15 Topological Model of Multiple Photon and Thermal Excitation of Carriers of Charge in Low Dimensional Nanostructures

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The question of multiple photon and thermal excitation in low-dimensional nanostructures with deep holes, induced by x-radiation was considered. There are strong grounds for believing that observed thermally stimulated effective luminescence from x-irradiated porous Si (D.W. Cooke et all [1]) connected with generation by x-radiation of Dirac points in nanostructures.

We considered the processes of thermal excitation of carriers of charge in low dimensional nanostructures with deep holes [1] produced by x-radiation within the phenomenological models "Berry Curvature on the Fermi Surface: Anomalous Hall Effect as a Topological Fermi-Liquid Property" of F. D.M. Haldane [2] and ""Luttinger-Liquid" Behavior of the Normal Metallic State of the 2D Habbard Model" of P.W. Anderson [3]. The unique effect in ID and 2D models, specifically 2D repulsive Hubbard models, this is the presence of an *unrenormalizable Fermi -surface phase shift* [3]. Such phase shift signals that the addition of a particle changes the Hilbert space for the entire system of particles - it requires a net motion of field amplitude through the distant boundary of the system, or a net change of wavelengths. The effects of such phase shifts were explored thoroughly in connection with the "x-ray edge problem"[4,5] and are summarized in the "infrared catastrophe theorem" [6]. We can considered of the deep holes as the generators of Berry phases and Dirac points, throughout that possible effective thermal excitation carriers of charge.

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PS2_16 Silicon nanostructure formation under ablation of target by quasicontinuous laser pulse

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The ablation of targets in buffer gas atmosphere by a laser radiation of small intensity ($< 10^5$Вт/см^2) results in a self-assembly of nanoparticles into low-dimension fractal structures.

The self-assembly effectiveness dependence on silicon-silica target composition and buffer gas pressure exhibit clear correlation with percolation in plasma of a laser plume. The structures with fractal dimension $d_f > 2$ most effectively are formed near to a threshold 3D percolation $p_c \approx 0.3$, where p_c is ratio of a atom concentration of silicon to total concentration of all atoms in a laser plume. Near to threshold of 2D percolation ($p_c \approx 0.5$) there are observed fractal structures with $d_f < 2$ assembled on a plane. The basic structural element of obtained objects are the 1D structures – chains containing some tens of nanoparticles with characteristic size ≈ 80 nm. The scanning electron-microcopy study of fractal nanostructures are presented and X-ray analysis is carried out. There is studied dependence of fractal dimension on buffer gas pressure. The mechanisms of nanostructure formation are discussed on the basis of the models: diffusion-limited aggregation of nanoparticles polarized in a field of a laser radiation; diffusion and accumulation of microclusters on a laser plume periphery; stabilization of linear structures in result of generation of electromagnetic traps in a field of a laser radiation.

PS2_17 Pico- and Femtosecond Spectroscopic Detection of Free Charge Carriers in A_1B_7 nanocrystals

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The results of the first experimental observation of free photo carriers generation and trapping in nanocrystals of holographic light sensitive layers by use of high speed optical detection methods are introduced. Experiments were fulfilled at pico- and femtosecond laser spectrometers of IMAPh, described in [1,2]. Radiation of the second and third harmonics of Nd-Glass laser (t_{pulse}~3-5 ps, (λ = 530 and 353 nm) and Ti:Sp laser (t_{pulse}~150-200 fs, λ = 390 nm) were used for samples excitation. The investigation was concerned with thin (5-7 mkm) gelatin layers containing AgBr(J) nanocrystals measuring 25…50 nm in diameter and iodide concentration 0.5… 4% [3].

Three short-living bands of light-induced absorption were detected in regions about 850-900, 600-700 and 500-560 nm with rising times 0,3…15 ps and life-times 3…150 ps. Additional doping of examples with electron acceptors - Ir^{3+} and Pb^{2+} ions as far as analysis of experimental data using known zone structure of AgBr crystals has given an opportunity to connect these bands with light absorption by free electrons, free holes and trapped holes accordingly. So the energy of free electrons absorption band (1,45 eV) corresponded to the energy of the lowest indirect intervallic transitions for electrons being at the bottom of conduction band and free holes absorption band (1,8…2.1 eV) was determined by direct intra-valence-band transitions up to ceiling of it from the nearest branch of the same band.

Under excitation of optically sensitized nanocrystals in absorption band of used dye (λ_{max} = 560 nm) a very fast bleaching of it was detected surrounded by decrease of the bleaching during 10 ps to the permanent level about 0.3 from maximum value of the bleaching. Simultaneously the same delay time was observed for free electron generation. This result permits us to value the velocity of energy transfer from dye molecules to the crystal lattice as 10^{11} s^{-1}. In pair with marked above permanent level of the dye bleaching it is a serious argument for energy transfer mechanism from dye molecules to the crystal lattice by free electron injection. Similar experiments made using the same nanocrystals without dye sensitization but optically sensitized due preliminary deep photolysis. They have shown, that under femtosecond excitation in absorption band of photolytic Ag (λ_{max} = 450 nm) full restoration of absorption in this band during much more short time (1-2 ps) was reached and just in this time rising of absorption bands connected with free electrons and holes was observed. To our opinion it is a real proof for realization in such experiments of immediate energy transfer mechanism from absorbing photolytic Ag particles to lattice resulting in electron-hole pair's generation in it without free electron injection.

This way it was shown the opportunity for realization in AgBr(J) nanocrystals of both widely discussed mechanisms of free carriers generation under light absorption by optical sensitizers.

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PS2_18 Microtools for biomedical purposes based on laser technology

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New biomedical optical microtools based on micropipettes are suggested. These microtools let transport laser radiation through biological solution, situated inside micropipette. Light transmission coefficients and intensity distribution at output of different version of such microtools are measured. Estimation of optical and hydraulic characteristics of requested microtools for biomedical purposes is evaluated.

PS2_19 Effects of Pollutants in Free-Space Optical Communications: Case Study, Mexico City

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Free Space Communications (FSO) has experienced an important growth in recent years. This trend is due to the fact that FSO is an attractive solution to the last-mile problem for several reasons [1, 3]:

- They provide a point-to-point high-speed optical link that can be rapidly deployed with little or no licitation for spectrum use.
- FSO are also feasible to be used in situations when a temporarily link is required, e.g. emergency services, and special events.
- The lack of underground cable installation reduces the costs considerably.

These reasons make FSO technology quite appealing for developing countries where budget restrictions prevent traditional fiber links from being deployed extensively. The performance of this technology, however, can be seriously impaired by atmospheric conditions. In the literature several examples can be found where the attenuation due to scattering and absorption caused by fog and rain are analyzed [1-3]. Few examples, however, are found where the same effects caused by pollution are studied.

The effects of pollution on FSO are of particular interest in big urban areas like Mexico City where the presence of pollutants overcome the presence of fog. A particular challenge is due to the fact that pollutants are not chemically homogeneous, and therefore may have a different absorbtion coefficient than fog. PM10 and PM2.5 suspended particles, for example, are a classification where industrial as well as organic pollutants are englobed. The ubiquity and persistence of these particular suspended particles (they can travel hundreds of miles and be suspended for weeks) are the limiting factor in visibility and therefore we believe that their effects in FSO are considerable.

In this work, the authors present a first approach to model the effects of PM10 and PM2.5 suspended particles in Mexico City's metropolitan area. Wavelength dependence analysis of the suspended particles is presented.

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PS2_20 New possibilities for measurements of pulse shape or beam profile of laser radiation

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As it is well known, for many practical application in technology based on laser radiation application it is necessary to use laser radiation with definite beam profile and pulse shape. Measurements of these characteristics of laser radiation in physical experiments are sufficient difficult problems. As it is know, for this aim an autocorrelation function is used or spatial Fourier transform is used. In the present report we propose new method for reconstruction of these characteristics by use integral measurements of laser energy in several time intervals or in several “holes” on chosen direction across a beam profile.

The methods, which are developed by us, firstly we used for solution of problems of terahertz time-domain spectroscopy. The main question for this problem is a temporal analysis of the medium response spectrum. Now there are some algorithms, which are used in physical experiment. According to [1], they have some bad features, which lead to absurd results sometimes. Hence, the creation of new algorithm for instantaneous spectrum treatment under the action of terahertz laser pulse is actual problem at present time as well. Early we developed two possible ways [2,3] to create an algorithm for the analysis of instantaneous spectral intensities of medium under the femtosecond pulse action. It should be stressed that in the first algorithm [2] we used the Gabor-Fourier windows transform and investigated it. Application of this method to physical experiments shows its practice application. But this algorithm gives possibility to obtain only dynamics of one spectral line for one series of measurements. The second algorithm, proposed by us [3], allows to obtain information about many spectral lines simultaneously from one series of measurements as well. We discuss briefly the application of proposed methods to problem of time-domain spectroscopy with the aim of illustration of validity of our methods.

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PS2_21 Precision laser system based on complementary scanning principle for dielectric materials microprocessing

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To optimize technological modes of laser processing some materials, it is necessary to ensure high-speed displacement of the focused laser beam with a great power density. A required speed of ~1 m/s can be attained owing to scanning systems based on galvanometer deflectors. A high power density is obtained by means of objectives with a minimal focal length and a maximal aperture. In so doing, the writing field of such scanning systems is restricted to a size of less than 1 dm^2 for the lasers with λ=1-10 micron. Many laser microprocessing tasks require a field that must be larger by one order of magnitude, at the least. For the solution of such problems, systems on the basis of complementary scanners can be applied.

We developed several devices with use of complementary scanning principle for microprocessing of flat or curvilinear big format surfaces with submicron resolution. The developed systems contain the “fast” scanning unit consisting of precision galvanometer scanners and F-Theta lens that, in its turn, can be displaced by “slow” drives over the entire writing field. Special control algorithms, software and hardware allow to provide a high speed (m/s) and accuracy of micromachining, at high power density. That is necessary for a technological regime of the explosive (ablative) micromachining minimizing of a burning or a flashing edges effects.

In this paper, we study problems of creation complementary scanner devices, namely, correct image partitioning into small writing zones, “joining” of writing elements occurred in adjacent zones and correcting geometric distortions of the optical system. It is also described some experimental results of microprocessing of the dielectric samples, obtained by means of created complementary scanners system, structure and main technical features of this system.

PS2_22 High-peak-power diode-pumped picosecond laser with high repetition rate

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High-peak-power picosecond light pulses of millijoule-level energy are applicable in micro- and nano-technology, laser spectroscopy, time-resolved measurements, laser radar and laser medicine. Flash-lamp-pumped lasers applications are limited due to low repetition rates and cumbersome design. Diode-pumped lasers provide much better efficiency, stability and compactness. However, systems consisting of cw diode-pumped oscillator, pulse peaker and regenerative amplifier are rather complex and expensive.

We develop approach based on combining generation and regenerative amplification in one optical scheme consisting of paired adjacent resonators on one common laser crystal end-pumped with quasi-cw diode array operating at repetition rate up to 1 kHz [1]. In order to minimize time interval which is necessary for light impulse evolution, we use electrooptical generation control based on active mode-locking and negative feed-back by means electrooptical modulators and passive mode-locking by means of SESAM. Electrooptical switching and cavity dumping are used for resonators optical commutation and light impulse output.

There are three main thermal factors that most critically influence on generation process and cause radiation loss and operation instabilities: thermal lens in active laser crystal (1), deregulation of modulators due to their heating by radiation (2) and pump wavelength shift due to nonstationary diode-array emitters heating (3).

Laser crystal heating by pump radiation leads to appearance of highly aberrative thermal lens in laser cavity that reduce operation efficiency. Approaches to optimization of pump geometry and cavity design will be discussed.

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PS2_23 B-diketonate of europium ($EuFOD_3$) confined in microporous glass: UV laser induced luminescence kinetics and quantum yield

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B-diketonates of europium due to their bright and long-lived luminescence are widely used in chemical and biological applications as luminescent labels and in technology (OLED, UV dosimeters and antireflective coating fabrication). $EuFOD_3$ (FOD=6,6,7,7,8,8,8-heptafluoro-2,2-dimethyl-3,5-octanedionato) is one of such compound. It was found recently that $EuFOD_3$ could be impregnated into porous Vycor glass. Rare-earth doped glasses are advanced materials for photonics devices. Luminescence properties of such glasses determine the area of their usage in technology. Luminescent properties of $EuFOD_3$ are studied in liquid solutions and described in works of Villata [1]. But in transparent porous materials luminescence properties of β-diketonates can be changed due to pore affection.

In the paper we have studied the affection of pores environment on luminescence kinetics of $EuFOD_3$ impregnated in porous Vycor glass.

$EuFOD_3$ molecule absorb energy in UV region due to ligand absorption then transfer it to the Eu ion and then emit from $^5D_0$ level λ~610nm (Fig.1). For luminescence excitation we use XeCl laser radiation λ=308nm. Luminescence signal were registered with FD-24K photodiode placed perpendicular to the laser radiation direction. Photodiode signal from porous glass impregnated with $EuFOD_3$ with concentration $2{,}4\cdot10^{18}$cm^{-3} and its approximation one can see in Fig.2. In obtained approximation 20μs is the response time of the photodiode and t_l =40±0,3 μs is the characteristic time of $EuFOD_3$ luminescence in the porous glass. Quantum yield evaluated from the photodiode signal is $k=4\cdot10^{-4}$.

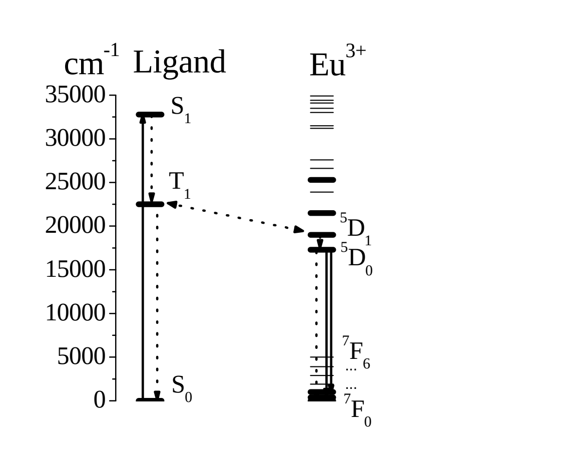

Fig. 1

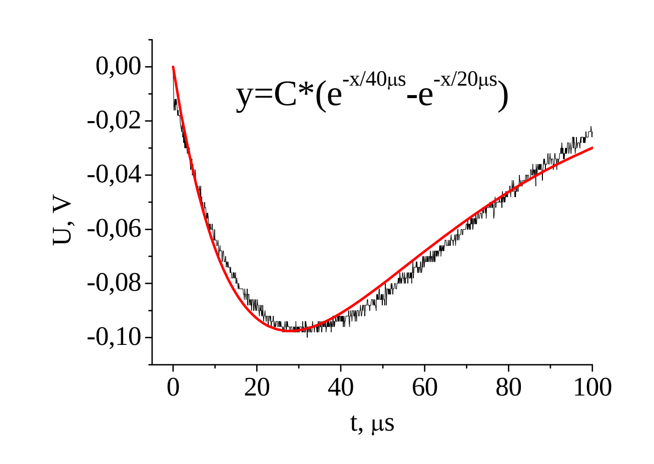

Fig. 2

Obtained characteristic time of $EuFOD_3$ luminescence is sufficiently less than in solutions

150-890 μs or dry powder 620 μs. Decrease of the luminescence time usually caused by increase of the nonradiative relaxation of the $^5D_0$ level. This relaxation can be caused by energy transfer to OH group vibrations or temperature dependent energy transfer to charge transfer from ligand to metal or triplet levels. In our experiments laser radiation causes only 10^{o}C heating of the porous glass sample, and could not lead to sufficient temperature quenching. Thus we suppose that decrease of the luminescence time of $EuFOD_3$ molecules is caused by increasing of OH group number near the molecule into the porous glass.

Decrease of characteristic time of $EuFOD_3$ luminescence and associated decrease of quantum yield limit possible application of porous Vycor glass doped with $EuFOD_3$ for photonics devices. Improvement of impregnation technology in order to exclude the OH group influence is the purpose of our next study.

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PS2_24 CdTe surface layer photoluminescence under nanopulsed laser irradiation

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The wafers of CdTe single crystals were irradiated by 80-ns ruby laser pulses with energy density W in the range of 0.04…0.4 J/cm^2. The each part of surface were irradiated by three pulses with the same W. Photoluminescence (PL) excited by the laser modifying the surface layer has been studied. CdTe photoluminescence and reflected from samples radiation of a ruby laser were simultaneously detected by coaxial photoelectric cell and photomultiplier respectively, the output signals of which were recorded by double-beam oscillograph.

Under laser irradiation with energy density less than the threshold of surface melting W_m, CdTe emits luminescence radiation, intensity of which increases with W rise, i.e. with exciting radiation flux rise. Under $W > W_m$, PL pulse shortens with increase of irradiation energy, trailing edge decreases. The maximum of PL peak is shifted relative to radiation intensity maximum to the pulse beginning. This temporal shift increases with W rises.

Dependences of maximum PL intensity I_m on irradiation energy density and also on the number of pulses have been obtained in the range of W in question. Under the first irradiation dependence $I_m(W)$ has two maximums at energy density 0.1 and 0.21 J/cm^2. It is likely, the decrease I_m after the first maximum is connected with the achievement of some critical temperature at CdTe surface, at which suppression of PL takes place. This minimum is observed close to irradiation energy density, at which maximum I_m is observed at maximum flux density of absorbed energy.

Under the second irradiation with the same W the decrease of the first maximum and the disappearance of the second one are observed. The value of I_m decreases essentially with W increase in connection with departure stoichiometry of CdTe due to phase transitions and defect formation resulting in PL depression. At third pulse of laser irradiation with $W \approx 0.4$ J/cm^2 the value of I_m decreases by order in comparison with reached one at the first pulse irradiation.

PS2_25 Laser photoionization method and technologies for cleaning the semiconductor materials and preparing the films of pure composition at atomic level

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Laser photo-ionization and photo-dissociation of molecules method is supposed to be very much perspective method for cleaning the semiconductor materials from molecular admixtures. Laser cleaning of mono-silan represents a great interest for technology of obtaining a poor Si in the semiconductor industry. The paper is devoted to the search and computer modeling the optimal schemes of laser photo ionization technologies for control and cleaning the semiconducting substances. Here at first we construct the optimal scheme of the laser photoionization technology for preparing the films of pure composition on example of creation of the 3-D hetero structural super lattices (layers of $Ga_{(1-x)}Al_{(x)}As$ with width 10Å and GaAs of 60Å). The scheme of preparing the films of the especially pure composition is based on using the multi-stepped laser photoionization scheme. It includes at first step an excitation of atoms by laser field and their transition into Rydberg states and then ionization by electric field [2]. A creation of the films of pure composition (our problem is creation of the 3-D layers of $Ga_{(1-x)}Al_{(x)}As$ with width 10Å and GaAs of 60Å) is directly connected with using the photo ion pensils of Ga, Al, As. Similar pensils can be created by means of the selective photoionization method with ionization by electric field. Then electromagnetic focusing and deflecting systems will provide a creation the 3-D supper lattices. Besides, we present a new multi-level optimized model for definition of the optimal form of laser pulse to reach the maximal effectiveness of laser action in process of photoionization atoms and (dissociation) molecules. Model is based on differential equation of the Focker-Plank type for density of molecules with the vibration energy x [2]. As example, let us consider the conditions and parameters for optimal excitation for molecules of HCl, PH_3, CF_3Br, SiH_4.

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PS2_26 Light diffraction on modulations of solid surface relief and low threshold IR multi-photon laser-molecular dissociation on surface. Laser microscopy

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It well known that the light diffraction on relief of surface can make a significant influence on dynamics of laser induced reactions, which are taken a place near relief with spatial modulated profile [1,2]. We present new optimal scheme for isotopic selective low threshold IR multi-photon dissociation of molecules near surface with periodic relief. There are considered possible improvements of so called “Stells” technology. It is carried out modelling optimal scheme for isotopic selective low threshold IR multi-photon dissociation of molecules near surface with periodic relief. The physical system is molecular gas (SF6, UF6), that is resonantly excited by the CO_2 laser radiation near surface of the periodic Cu lattice. A definition of local electromagnetic fields and their increasing near surface, contribution of the surface relief parameters (form, depth etc) are quantitatively taken into account within non-linear theory of diffraction of limited 2D and 3D light beams on surface with arbitrary discrete Fourier spectrum of relief [1]. New multi-level model for optimization of excitation of molecular gas is considered and definition of optimal form for laser pulse to reach the maximal effectiveness of laser action in photodissociation process is carried out [2]. Numerical testing of optimized model for molecules of SF_6, UF_6 is carried out. The obtained results are used for proposition of a new laser isotope separation scheme with application to problem of the S, U isotopes separation. At last the modified letokhov’s scheme of photoelectron (photoion) laser microscope is presented.

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PS2_27 Numeric modeling system of scattering process of coherent waves for remote control system of real time

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Tasks of remote control in real time of state and vibrations for finish processed surfaces are very actually in different areas of science and techniques today.

Developing of new methods and system based on principles of remote control and adaptive optics demands to solve the next problems:

– Synthesis of space structure of probe beam
– Pointing and stabilization of beam on object;
– Registration of scattering signal from surface, especially the space-phase component of it
– Processing of space information for detecting, classification and evaluation of signal and parameters of it
– Synthesis of feedback channel for changing of space structure of probe beam

Task of optical waves propagation with defined amplitude-phase space structure to near and forth of Freunel zone is more important. It demands efficient numerical models of the distribution off partially coherent waves dispersed along random space scatterer. Theory of diffraction is in the basis of the wave concepts of the coherent radiation distribution. The present paper offers the architecture of numeric modeling system of waves propagation with flexible geometry. The scalar models of Kirchhgoffs and Freunel-Fraungofer approximations are used here.

It is significant the scalar model of Kirchhgoffs is undoubtedly more accurate for all wave areas in comparison with the Kirchhgoffs and Freunel-Fraungofer approximations valid only in the middle and far wave zones. At the same time, efficiency of the algorithms (time complexity) of the given models differs significantly in behalf of the Kirchhgoffs and Freunel-Fraungofer approximations.

PS2_28 Densimeter of fine particles for sensor of nanometric displacements

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Throughout all this paper we are going to analyze one application of the optical beam deflection method (OBDM), the procedure for its development, as well as its ideal implementation to reach measurements of displacements that could be the most accurate and of the smaller scale possible, this condition is essential for the magnitude of the results to evaluate. We also give an application of the OBDM such as a fine particle densimeter [1].

This present work will analyze the laser beam deflection technique [2], the procedure to apply, as well as its ideal implementation in order to obtain measures of displacements that can sense to the most exact and the smaller possible scale, obtaining results from microns, micrometers and even, until nanometers. Our objectives that are consider in this investigation are two: the first one is to built a device based on this technique, make accurate measures on a very low scale, which could be reliable and in the order of scale of microns.

The second objective that we are searching is to obtain an alternative method for verify the values of density that some substances have and are hard to get.

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PS2_29 Microlenses on the ends of optical fibers for optimization of optical interconnections

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The principle of feedback by optical parameters during laser manufacture of microoptical elements on the end of optical fibers is described. Experimental dependences are received, by means of that functional monitoring under parameters of produced microoptical element can be realized in real-time mode. Presented functional monitoring allows raising of manufacture accuracy and microoptical elements repeatability. Use of numerical aperture as the parameter for real-time control of produced microoptical elements is most effective. Presented technology can be used for various types of optical fibers. Optimization of optical interconnections was examined by the example of effectiveness increase during radiation transmission from LED to fiber.

PS2_30 The development of laser sintering process monitoring

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To control the process parameter settings and to visually inspect the process quality, a monitoring system for the sintering process (MSSP) was designed. The monitoring of the sintering process is based on measurements of the maximum surface temperature and the temperature distribution at the sintering zone by the spectral ratio method.

MSSP consists of a visual observation system (VOS), a special ICCD–camera and a two-wavelength pyrometer (TWP). VOS, ICCD, TWP and the overall optical scheme of MSSP compose an optical-mechanical unit which is arranged in a box and integrated with the SLS-machine optical system.

For discerning defects of the powder layer, positioning laser scanner head, controlling production quality, the visual observation system (VOS) continually monitor a 30x30-mm zone on the surface of the powder being delivered and its representation on the display. VOS rejects efficiently laser radiation and surface thermal emittance through a system of filters and dichroic mirrors.

The surface illumination is carried out using the light-emitted diode (LED) ringlight system. Intensity of the scattered radiation of LED may be set practically equal or higher than the intensities of the laser scattered radiation and the surface thermal emittance.

The image of the sintering zone is projected onto the photocathode plane of a gated microchannel plate (MCP) with a five times magnification. Wavelength bands of $\lambda = 0.55$ µm and $\lambda = 0.7$ µm are spatially separated when radiation passes through a prism and thus two images are obtained. MCP with a gate duration of 2-1000 µs is switched on at a predetermined time point relatively to the laser pulse. The resulting images of the digital video camera are scanned and temperature distribution in the sintering zone with spatial resolution ~ 2µm is displayed.

The advantage of the developed optical monitoring system is that, being non-invasive and remote, it provides visual and temperature field monitoring in the irradiated zone, thus allowing a deeper insight into the sintering process characteristics and realize optimal regime of sintering.

PS2_31 Experimental and theoretical investigations on the dynamics of laser ablation plasma plumes

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The formation and dynamics of laser produced plasma have been experimentally and theoretically investigated. Copper and aluminum targets have been irradiated in vacuum (10^{-7} Torr) by the 2nd harmonic (532 nm) of a ns Nd:YAG laser, with fluences in the range 5-200 J/cm^2. The evolution of the space charge structures created has been studied by means of optical (ICCD camera, 2 ns gate) and electrical (Langmuir) probes. The visible emitting regions of plasma exhibit two structures with different life-times and expansion velocities. The transient ionic signal simultaneously recorded by the Langmuir probe presents an oscillatory structure for the fast component.

A hydrodynamic model in a non-differentiable space-time [1] has been developed to account for the experimental observations. The model successfully reproduces the two patterns of the plasma plume expansion. The self-structuring of the interface as a double layer and its oscillations can also be described by means of a negative differential resistance.

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PS2_32 Laser damage of fused silica induced by subsurface micro fractures in nanosecond regime

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We present numerical simulations of micro fractures irradiation by ultraviolet laser pulses. The laser energy deposition is initiated by quantum surface states within the fractured material, leading to the creation of plasma. Such excited systems are able to provide strong electric field enhancement, depending on the fracture shape and on its orientation with respect to the laser direction of propagation. Hence, subsurface micro fractures are shown to be possible initiators of laser damage for nanosecond pulse durations, the fluence ranging from 1 up to a few dozens J/cm².

PS2_33 Dynamics of shock waves generated in liquids by high-energy KrF laser

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The paper is devoted to the research and development of novel experimental technique - laser-driven shock tube (LST) for studying of hydrodynamic instabilities development at the interface of two immiscible liquids, which is affected by a shock wave. 100-J, 100-ns KrF laser facility GARPUN has been used to irradiate some opaque liquids. A homogenizing focusing system combined multi-element prism raster and a lens to provide non-uniformity less then few percents across a square 7*7-mm spot, laser intensities being varied in the range of q = 0.1 – 1 GW/cm^2. Surface plasma blow off produced a shock-wave propagated into the liquid. Pressure measurements were performed with PVDF pressure gauges of 490-μm thickness. The gauge assemble was set inside the liquid at various depths from the surface irradiated by the laser. In dibutyl-phthalate (DBF), which strongly absorbs laser light, amplitudes of the gauge signals and time delays relative incident laser pulse were measured in dependence on peak laser intensity and DBF thickness. Shock-wave velocity in DBF was close to sound velocity of 1.41 km/s. In the range of q = 0.04 – 1.0 GW/cm^2 where rapid evaporation of the liquid and plasma formation introduce mainly into the pressure $P(q)$ dependence could be approximated by the power law $P \sim q^n$, where n = 0.40-0.43. For lower q a pressure jump is associated with liquid heating. By using the relation for the pressure gauge voltage U on the particle velocity u_2 in the SW and Hugoniot adiabat of the PVDF expressing pressure P_2 through particle velocity and sound velocity c_2: $P_2 = \rho_2 (c_2 + S u_2) u_2$ where c_2 = 2.58 km/s and coefficient S = 1.59, we obtained for a typical value of the gauge response U = 5.5 V the pressure amplitude P_2 = 0.32 GPa. The corresponding pressure generated by laser radiation in the DBF is P_1 = 0.2 GPa. It is something less because of acoustic impedance mismatch between the DBF and PVDF that leads to a partial reflection of the SW by their interface.

Relatively weak pressure damping with increasing thickness of the DBF layer allows performing experiments with acceleration of contact surfaces between immiscible liquids by the SW passage with the aim of investigation Rayleigh-Taylor and Richtmyer-Meshkov instabilities development. Test bench experiments were performed to produce standing acoustic waves as initial perturbations at the interface between two immiscible liquids by a pair of microphones. A reflection pattern of expanded He-Ne laser beam was used to measure a wave number and amplitude of these initial perturbations to be affected by compression wave propagation.

PS2_34 Diffractive model of scattering by a rough surface of radiation. Dependence of a spatial frequency spectrum on size of a roughness

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The scattering of waves on a real surface is of interest for various areas of modern physics. And such practical problems as definition of intensity of a scattered field, computer modelling of a visibility of illuminated objects, measurement of object roughnesses parameters – for opticians are constants.

Used mathematical model of a scattering [1-3], being synthesis of the theory of diffraction and mathematical statistics, and also application of the theory of indignations [4] do not give the adequate description of radiation, scattered as a speckle-structure. In spite of the fact that the speckle-structure grows out scatterings on random phase nonuniformities of object (a roughness, fluctuations of a refraction factor) in numerous works are investigated only its statistical properties which have been not connected to parameters of phase nonuniformities.

In work [5] the diffractive model in which spatial distribution, scattered a rough surface of radiation, is similar to distribution of radiation at diffraction of a wave on an aperture, under the form and the size conterminous with illuminated area is offered. Intensity of a scattered field represents the sum intensities a component of a field, in which intensity of the first components is defined by a root-mean-square roughness on *the base length*, equal *D/n* (*n* – number of the diffractive order of diffraction on the size of the illuminated area, supervision corresponding to a direction), the second components – at length *2D/n*, the third – at length *3D/n* and so on. It is caused by that in a direction of supervision waves are distributed, after diffraction on structures of base lengths, multiple *D/n*, and with numbers of diffractive orders, multiple *n*. In the offered model are not used approach big and small, in comparison with a wavelength, roughnesses. There are numerous experimental acknowledgements for various lengths of waves and types of objects (solid and gaseous).

In the submitted work, within the frame of diffractive model, dependence of a frequency spectrum of motionless spatial fluctuations of intensity (speckle-structure) on geometry of supervision and root-mean-square size of a roughness is received. It is experimentally shown, that the spatial frequency spectrum represents the sum a component of a field, scattered on base lengths, multiple *D/n*.

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PS2_35 Laser-Induced Plume Expansion from a Silicon Wafer in a Wide Range of Ambient Gas Pressure

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Micromachining of metal and semiconductor surfaces by nanoseconds laser pulses including cutting and drilling is usually carried out in atmospheric conditions. In this case the surrounding gas (typically, air, inert gas or a gas mixture) can influence various parameters of the process which are important for improvement of corresponding technologies. In particular, it influences the cluster growth in the ablation plume and also a distribution of ablated material deposited in a vicinity of the laser spot. However, in the majority of theoretical and numerical studies the laser ablation into vacuum or into surrounding gas at pressure which is much lower than atmospheric one is considered. The understanding of the ambient gas influence on the plume expansion at atmospheric pressure is still limited.

In this work, the plume expansion into surrounding gas is considered in details at a wide range of ambient gas pressure. Plume is generated by the nanosecond laser pulse irradiating a silicon wafer. Absorption of laser radiation and the temperature field in the wafer is described by means of a two-dimensional thermal model. Flow of silicon vapor and its mixture with the ambient gas are calculated by the DSMC method. Collisions between molecules are described by HS and VHS models. Energy exchange between translational and internal degrees of freedom of gas molecules is described by the Larsen-Borgnakke model. Ablation rate is found from the Hertz-Knudsen equation. In the kinetic model, the formation, growth and evaporation of silicon clusters are taken into account on the base of the model proposed by Bykov and Lukianov (2006).

The purpose of the work is to study the influence of surrounding gas pressure and its chemical composition on the mixture process in the ablation plume, rate of cluster growth and deposition of the ablated material back to the irradiated surface. Calculations are carried out for the laser wavelength 355 nm, pulse duration (FWHM) 23 ns, spot diameter (FWHM) 26 μm and the intensity of laser radiation up to $2{\cdot}10^{11}$ W/m^2 in atmosphere of argon and air. Computational results include flow fields of various component of the mixture including clusters, their non-stationary temperature fields and distributions of deposited material in the range of ambient gas pressure from 0 to 1 bar.

This work was support by the EU Marie Curie programme, project MTKD -CT-2004-509825.

PS2_36 A study of thermally stimulated reversible rearrangement of the structure and optical parameters of molecular layers and solutions. IR image visualization based on the stereoisomerization of molecular systems

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Reversible change in the optical parameters (optical density, absorption spectra, fluorescence quantum yield, and fluorescence decay rate) with temperature was studied experimentally for solutions and molecular layers of polymethine dyes (PD) in the homologous series of 10 non-substituted dicarbocyanines differing in the electron-donating abilities of end groups. Solutions in ethanol and multilayer coatings on crown glass, obtained by «spin coating» or by evaporation at temperature close to the boiling point of a solvent, served as objects of study. Layers with an optical density (D) of up to 0.03 (~ 30 conventional monolayers), containing two types of monomeric stereoisomers, dimers, and J aggregates, were formed by the first procedure and layers with $D \approx 0.5$ containing monomers as major component, by the second procedure.

The temperature study in the range $(-60 \div +60)^0$C showed that the change in the temperature of PD solutions results in the reversible broadening of the absorption spectrum, with its maximum decreasing and shifting to a high-frequency region. The value and character of the above changes depend on the structure of end groups. The established changes in the optical parameters of the solution are due to reversible change in the relative equilibrium concentrations of four different stereoisomeric forms of PC monomolecules, which include a stable molecule (SM) of all-trans isomer and instable stereoisomers (a long-wavelength gamma-cis isomer and short-wavelength beta-cis- and gamma-beta-dicis isomers. The isomer composition of the solution was determined from the comparison of the differential Einstein coefficient spectra for the absorptive and emissive transitions between the ground and the first excited singlet states (S_0 and S_1, respectively) and from the theoretical calculation of the free energies of the S_0 and S_1 states for isomers with different structures. The conclusion about the isomer composition of the solution was confirmed by the results obtained in studying by laser photolysis method of the photoisomerization of PC solutions at different temperatures and different delays between the start of the excitation and probing.

The gradient of temperature changes in optical density of the solutions depends on the spectral and temperature range and on the dye structure. This is caused by overlapping of the SM spectra with the spectra of instable isomers and shows that the energies of isomerization activation of different forms and the mechanisms of formation of monocis- and dicis isomers are different. For the SM maximum in the range $(-40 \div +60)^0$C the $\Delta D(T)$ function is nearly linear dependence, whereas in the region of a long-wavelength isomer absorption for $T > +40^0$C it undergoes slight saturation. The degree of change in the fluorescence intensity is also determined by the temperature range and by the structure of a PC molecule. In the range $(-20 \div +40)^0$C the fluorescence yield vs. temperature curve is a nearly linear dependence, with the saturation observed in regions with $T > 40^0$C and $T < -20^0$C. The typical relaxation times of nonequilibrium stereoisomers for symmetric PC molecules in solutions at room temperature lie within (0.02÷2) ms and those of asymmetric PC, within (1÷300) ms.

The study of the fluorescence decay time and fluorescence quantum yield of the PC solutions showed that the temperature changes of the above parameters are determined by competition of two quenching mechanisms: photoisomerization and internal conversion. The photoisomerization is the main quenching process at T> 270K.

We studied how the temperature affects the absorption spectra and relative concentration of the molecular components in layers on glass substrates. We showed that the heating of the sample to a temperature of 47^0C leads to both irreversible and reversible changes in the relative concentration of layer components, with the character of the layer rearrangement depending on the structure of a molecule and on the deposition procedure. In the temperature range studied here, the reversible changes were considerably larger than irreversible changes. In layers formed by "spin coating" the heating caused both the reversible rearrangement of associated forms into monomeric forms and the mutual rearrangements of monomeric stereoisomers. In layers obtained by evaporation, which contained mainly two monomeric forms, the reversible rearrangement of beta-cis-isomer into all-trans isomer was predominant. In the studied temperature range $(22÷47)^0$C the increase in the absorption density in the SM maximum varies linearly with the increase in the layer temperature. The relative change in the SM maximum of the layer absorption spectrum at temperature changed by 1^0 is close to the corresponding value in a solution. The relaxation rates of reversible rearrangements of the layer structure depend on its composition, deposition procedure, and the structure of a molecule. For spin-coated layer containing botn monomeric and associated forms the relaxation rates are considerably lower than the changes in the substrate temperature. The rates of mutual rearrangement of the monomeric forms in layers formed by evaporation are higher than in the spin-coated layers and markedly exceed the rate of change in the substrate temperature. The results obtained show that the relative temperature changes in the component compositions and optical densities for PC solutions and molecular layers are close. At the same time, compared with the isomer composition of the solution, the layer composition is rearranged considerably slower (during few tens of minutes).

The thermally stimulated changes in the optical properties of polymethine solutions and layers can be used for recording of temperature distribution in various areas of a sample. The most suitable spectral regions for probing by the absorption method are regions of bleaching in the band maximum of the stable all-trans isomer and regions of a long-wavelength induced absorption of a gamma-cis isomer. The sensitivity of both optical techniques of recording of the temperature changes in a wide temperature range is nearly the same. These methods make temperature stabilization of a sample not necessary. The comparison of the relative changes in D and fluorescence intensities of the solutions at the same change of the temperature shows that the fluorescence changes are considerably (two-fold) larger. So, the large sensitivity and rather high fluorescence yield make fluorescence method more preferable for recording the temperature distribution in solutions.

We constructed an installation to visualize IR image through isomerization quenching of fluorescence of screen based on multiatomic molecules. It includes a He-Ne laser as fluorescence excitation source, a CO_2 laser as IR radiation source, optical systems of excitation of screen fluorescence (in the visible region) and construction of an IR image, a black and white videocamera, and a CCD array photodetector connected to a computer via the special “Studio” program. With this installation, the IR-visible image reconstruction resulted from quenching of the fluorescence of screen was obtained.

PS2_37 Photoacoustic study of liquid explosive boiling on absorbing targets by pairs of short laser pulses

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Besides the various practical issues of the laser-induced superheating of liquids in contact with solid surface followed by explosive phase transitions, these phenomena are also of significant fundamental interest in view of peculiarities of non-equilibrium phase transitions. We investigated such processes using acoustic registration of pressure pulses induced by pairs of laser pulses following each other with nanosecond delays. The research aimed to trace dynamic properties of vapor cavity using the second laser pulse as a probe.

The absorbing target was covered by acoustically thick later of transparent liquid (water, acetone, alcohol) and exposed to short nanosecond pulses (2 ns) on YAG:Nd laser. The induced pressure pulses in the target were recorded by fast acoustic transducer based on lithium niobate crystal. Typical bipolar photoacoustic pressure signals were observed with no liquid layer on the target, while monopolar ones was recorded under such layer, which followed the time profile of the exposing laser pulse at low energy level. Increasing of laser energy modified the rear front of the pressure pulse due to explosive boiling.

Additional pressure pulse appeared here in this case duration of which depended on energy level. If the delay between the boiling and probing pulses was fixed, the probing pulse appeared at the same spot either within or after boiling. The shape of pressure signal induced by the probing exposure was of particular interest. It was found that its shape was nearly not affected by explosive boiling and the vapor cavity appearing at the surface in spite of presumably significant variation of density of adjacent layer.

This paradox result is discussed in terms heat and mass transfer across the liquid layer taking into account non-equilibrium kinetics of phase transitions.

The research was partially supported by RFBR grant No 06-08-01440-a.

PS2_38 SRS-gain in AgCl(J) monocrystals under femtosecond Excitation: anomaly large spectral shift and high amplification of weak signals

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Anomaly large spectral Raman scattering shift for ionic crystals and also high amplification coefficient were observed in nominally pure AgCl monocrystals doping by use of concentrated water KJ solution. Investigation of this composition absorption spectra has given an opportunity to value the total concentration of J-ions as 0,1 molar %. Exitonic absorption maximum characteristic for crystal phase of AgJ was observed at $\lambda_{max} = 417$ nm under room temperature. Distinct blue spectral shift of it in relation to known maximum for bulk AgJ crystal ($\lambda_{max} = 420$ nm) is an argument for AgJ crystal nanoparticles formation.

Under excitation by radiation of continuous Ar ion laser at $\lambda = 488$ nm measured spectral Raman shift for the most intensive line was ~2945 cm^{-1} and much exceeded the values for AgCl and AgJ crystal lattices frequencies lying in region 150…400 cm^{-1}. The amplitude of this strong component was an order much more than amplitudes of observed lines corresponding as to low frequencies vibrations of lattices as to weak asymmetric satellites of the strongest line centered about 2835 and 2995 cm^{-1}. Under excitation of samples at IMAPh femtosecond laser spectrometer using 150-fs pulses and $\lambda = 780$ nm the wideband probe radiation was amplified only at Stokes Raman component shifted at 3030 cm^{-1} and twice smaller absorption was observed for symmetrically shifted antiStokes one. Stokes signal amplification was near 2 for 2 mm thickness sample at power density about 10^{11} W/cm^2 and was higher than amplification for KGW crystal 4 mm thickness what has been put at the same place. Such a crystal is known as one of the best solid SRS transformers providing radiation frequency shifts up to 1000 cm^{-1} [1].

Observed combination of anomaly large spectral Raman shift and high SRS amplification can be explained taking into account the fact of AgJ nanocrystals formation and high capability of water molecules to be aggregated on the surface of them. It is also known stimulating influence of high dispersion AgJ phase addenda on AgCl and AgBr crystals photolysis resulting in formation of metallic Ag nanoparticles [2]. To our mind interaction of water hydrogen atoms with heavy Ag atoms and surrounded silver halides ions explains qualitatively the observed significant decrease of Raman shift relatively to pure water one. And finally, the formation of metallic Ag nanoparticles is the key argument for qualitative explanation of observed high SRS amplification in spite to very little impurity concentration, if to take into account well known effect of giant surface enhanced Raman scattering of light by molecules contacting with small metallic particles.

This way a new mechanism of SRS generation was discovered in AgCl(J) monocrystals doped by water molecules which are incorporated in it and aggregated with nanoparticles of AgJ and metallic Ag. Combination of large spectral Raman shift (3030 cm^{-1}) and high SRS amplification is giving a chance for practical use of such compositions as effective solid SRS frequency transformers of femtosecond pulses especially in IR spectral region where they are very stable to action of high power laser beams.

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PS2_39 Low threshold optical breakdown of air near the two transparent dielectric plates under TEA CO_2 laser pulse action

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It is known that action of laser pulse with radiation intensity $q>q^*$ on transparent dielectric surface initiates optical breakdown of gas surrounding the irradiated target. In such a case the threshold of gas breakdown q^* is lower than gas breakdown threshold in the case of the target absence. Appearance of breakdown plasma is accompanied with part of laser pulse absorption, deformation of radiation pulse, passed through target and plasma, and target surface damage.

It is interesting to know if it is possible to initiate breakdown near surface of the second target with identical properties under the action of radiation pulse passed through plasma initiated near the first target. From the standpoint of laser damage to optical materials such a situation can be of practical interest, when a collimated beam passes through optical installation containing a grate number of optical elements made of the same materials.

In experiment TEA CO_2 laser radiation has been focused on front surface of plate made of NaCl. The irradiated area has been refocused with magnification 1/1 on the second identical plate. Raising of probability of breakdown near the second plate has been achieved by focusing on its back surface. Thresholds of breakdown near the both targets have been measured. Conditions at which breakdowns arise near the both plates have been discussed. It has been shown that the second plate damage in the case of breakdowns initiating near the both plates is considerably less than that in the case of breakdown initiating only near the second plate.

Near-field distribution in laser illuminated tip-sample system for nanopatterning

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Two different mechanisms of surface nano-patterning with atomic force microscope (AFM) tip, illuminated by a laser are under discussion: the field-enhancement (FE) model and the thermal induced mechanical contact (TMC) model. Due to the presence of evanescent waves in the optical near-field, the exact calculation of the field distribution of the tip-sample system in micro/nano scales becomes complicated. There is lack of understanding of the asymmetrically illuminated tip-sample system. In this paper, full 3D finite difference time-domain (FDTD) analysis was carried out to investigate the field distribution in different tip-sample systems. The effects of different tip/sample materials (either dielectric or plasmonic material), the gap distance, and laser incidence angles on the field distribution/enhancement have been studied. We have demonstrated two new effects which are helpful in distinguishing between the opposing mechanisms: (1) on the sample surface, the field peak position has a shift away from the tip-axis at large angles of incidence, and (2) the field enhancement depends strongly on the horizontal component (*perpendicular to tip-axis)* of the incident wave instead of the vertical component (*along tip-axis)*. The optimal incident angle is around 30^{o} for the maximum field under the tip. The existence of field-distribution nodes on the 3D tip surface that leads to the in-homogenous heating of the tip is also predicted.

Plasmonic surface nanostructuring by intense femtosecond laser

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In this paper we present theoretical and experimental results on the near field nano-fabrication of the dielectric, semiconductor and metal surface using metal and dielectric nanoparticle array excited by an 800 nm femtosecond laser. The simulations are performed using a finite difference time domain simulation code. The simulated system consists of nanoparticles hexagonally arrayed on different substrate materials – metal, semiconductor and dielectrics.

We demonstrate a new nano-processing technique using the near electromagnetic field around small transparent particle irradiated by femtosecond laser pulse. We fabricate a 2D nano-hole-array with *negative* and *positive* pattern on glass surface by irradiating 790 nm diameter polystyrene (PS) particles monolayer with a femtosecond laser pulse. At the lower laser fluence domain, PS particles act as focusing lens and/or near field enhancer due to Mie scattering; it enables nanohole processing just under the particle (*positive patterning*). Nanoholes with diameter ranging from 84 to 170 nm are fabricated in this regime. At the higher fluence domain, PS particle acts as a mask; while positive nanohole formation disappears, then it enables nano-pattering of the surface at gap areas corresponding to the region between particles (*negative patterning*). Nanoholes with diameter ranging from 65 to 110 nm are fabricated in this case. The switching of *negative* and *positive* nano-pattering by simply controlling the incident laser fluence is experimentally demonstrated for the first time to our knowledge. This new processing is explained by FDTD simulation.

In addition to the above topic several new nanoprocessing using plasmonic effect will be presented together with their textured surface application in nano-tribology.

Photophysics paves intelligent route to nanoscale surface structures

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Recent progress in nanotechnology is based mostly on the “upside-down” paradigm. Notwithstanding with obvious achievements, this approach is inevitably connected with gross energy consumption and material waste. An attractive alternative is “bottom-up” manufacturing. In this case the quantity of raw material required could be considerably reduced. Still, lack of reliable means to manipulate matter at the scale of atoms and molecules impedes progress in this promising direction. One way to get rid of these limitations is to improve our knowledge of photo-induced surface phenomena. In what follows, several possibilities to control metal nanostructure growth through laser illumination is presented.

It is common to describe growth of islands on a dielectric substrate in the framework of Volmer-Weber model. The atoms, first, get trapped on the surface, then, migrate over it, and, finally, develop nucleus of the future island. An elementary opportunity to influence the nucleation stage of the island film deposition is to change the surface number density of the atoms adsorbed on the surface. Laser induced desorption provides a versatile tool for reduction of surface number density of adsorbed atoms at a predetermined pattern on the surface. Another possibility is to employ photoinduced diffusion to redistribute the atoms over the surface avoiding any loss of material delivered at the surface.

Metal nanoparticles attract much interest due to their huge and robust absorption resonances in visible. Local field enhancement in the nanoparticle neighborhood finds many applications as well. Laser light may be used to characterize and, if needed, to reshape the particle in a desired form. Both thermal and nonthermal process that lead to selective changes of nanoparticle shape will be discussed.

Energy transfer of electronic photo-excitations in semiconductor quantum dots

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Effect of nonradiative energy transfer of electronic photo-excitations in solid state is of the most important problem of modern condensed state physics. Investigations of the effect in systems with semiconductor quantum dots have been intensively developed in recent years. Dipole-dipole approximation is common approach for description of energy transfer between quantum dots by means of the Coulomb interaction. Its utilization results in satisfactory results if distance between quantum dots is far more their characteristic sizes. However another case realized frequently in practice, when distance between quantum dot surfaces is comparable or smaller quantum dot sizes, arouses considerable interest. In this case condition permitted to consider quantum dots as point dipoles is violated, therefore taking into account contributions of multipole interactions for calculation of energy transfer probability is necessary.

In this work process of the nonradiative energy transfer has been considered. In result of the process electron and hole in quantum dot with smaller size (donor) recombine while electron-hole pair in quantum dot with larger size (acceptor) is created. Model allow for the total Coulomb potential of interaction between electronic subsystems of quantum dots has been proposed. Such approach has allowed to take into account multipole interactions of all order of values. This point is of fundamental importance for consideration of creation of electronic excitations in dipole-forbidden states where quantum numbers of electron and hole differ in value. Comparison of probabilities for dipole-allowed transfer processes calculated in the framework of the model and in the dipole-dipole approximation has been shown considerable difference of probability values and their dependence on quantum dot distance. Obtained results have been used for calculation of photoluminescence spectra of quantum dots. Dependences of the spectra on distance between donor and acceptor, quantum dot sizes, and relaxation parameters have been analyzed.

New Type of Resonance Light Scattering by Small Particles

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Light scattering by a small particle is one of the most fundamental problems of electrodynamics. This scattering plays an important role in subwavelength optics and related fields, developing in the recent years incrementally [1]. Meanwhile the problem description is still based generally upon treatment of a small scatterer as an electric dipole [2]. Here we show that in certain cases this approximation becomes irrelevant regardless the particle smallness and the conventional Rayleigh scattering is replaced by a principally new type of anomalous scattering. Exhibited by particles from materials with low dissipation rates the anomalous scattering is related to interplay of the radiative and usual dissipative damping [3-7]. It occurs when the radiative damping prevails over the dissipative. The anomalous scattering results in sharp giant optical resonances. The resonances are originated in coupling of the incident light with the plasmon (polariton) modes excited in the particle and have very unusual properties. For example, the characteristic values of electric and magnetic near-fields for the scattered light are singular in the particle size [5]; while energy circulation in the near-field is rather complicated, so that the Poynting vector field includes singular points whose number, types and positions are very sensitive to fine changes in the incident light frequency [4-8]; the scattering cross-sections increase with increase in order of resonance (dipole, quadrupole, etc.) [3, 5-7] and so on. Numerous applications of the phenomenon may be associated with much greater than in the conventional cases amplification of the incident radiation in the near-field and controlled changes of the field with tuning of the incident light frequency.

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Properties of nanohills formed on a surface of Ge, Si and GaAs by laser radiation: quantum confinement effect

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Nanostructures (NSs) are the most investigated object in solid state physics, especially the quantum confinement effect in quantum dots, quantum wires and quantum wells, because in these conditions occur change of conductivity and structure of valence band of a semiconductor. This leads to a crucial change of the semiconductor properties such as: 1.electroconductivity, due to the change of the free charge carrier concentration and mobility of electrons and holes; 2. optical parameters: absorption coefficient, reflectivity index, radiative recombination efficiency; 3. mechanical and heating properties. It allows to control semiconductor properties and to design new electronic and optical devices. Today we have only some very well elaborated methods for formation of nanostructures. They are: molecular beam epitaxy, ion implantation, and laser oblation**.** Therefore, elaboration of new methods for production of NSs in Si, Ge and GaAs is a very important task for nanoelectronics and optoelectronics.

The aim of this study is investigation of nanohills optical properties formed on a surface of semiconductors by laser radiation (LR).

Nanohills on a surface Ge single crystal were formed using basic frequency of Nd:YAG laser radiation at intensity of 30 MW/cm^2. This structure is characterized by patterns related to C_{6i} point group symmetry covering all the surface of the sample by translations symmetry [1]. In the case of Si, the nanohills are formed by the second harmonics of Nd:YAG laser radiation at intensity of 20 MW/cm^2 on the mechanically polished surface. The nanohills form rows on mechanical scratches. Photoluminescence from irradiated surfaces is found in visible range of spectrum. Peculiarities of photoluminescence from Ge and Si nanohills could be explained by Quantum Confinement effect in nanowires with gradual decrease of nanowire diameter from maximum on the plane of a semiconductor surface to minimum on the top of nanohill. It is semiconductor with graded band gap [2]. Photoluminescence from the surface of GaAs single crystal irradiated by the second harmonic of Nd: YAG laser at intensity 7.5MW/cm^2 is characterized by blue shift on 100 nm and increase of its intensity by 10 times in comparison with a nonirradiated sample. A shift of micro-Raman scattering spectra is a good evidence of this suggestion. The calculated minimal diameters of nanowires on the top of nanohills [3] for Ge, Si and GaAs single crystals are 4 nm, 9 nm and 11.5 nm, correspondently.

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Highly Nonlinear Optical Absorption in Quantum Wells and in Wide-Gap Bulk Materials

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New results on optical processes characterized by a high degree of nonlinearity are discussed. Emphasis is placed on such phenomena as the photon avalanche, optical trampoline, multiphoton avalanche, and multiphoton absorption controlled by optical Stark effect.

The photon avalanche effect (PAE) occurs as a result of optical absorption from an excited state and Auger-type transitions. In quantum wells, the PAE allows a fast switching of the material between states with different optical and electrical parameters, with the switching times of 10^{-9}-10^{-11} s. The PAE makes it possible to derive emission at a wavelength 3-5 times shorter than the excitation wavelength [1, 2]. The last-mentioned result can be also achieved at higher intensities via the optical trampoline effect produced by optical transitions from the ground state and Auger-type processes involving photons [3].

Analysis of the pre-threshold generation of electron-hole pairs (EHPs) in wide-gap solids shows that, under certain conditions, the multiphoton avalanche effect (MPAE) [4] plays a dominant role in the generation. The MPAE shows a threshold in excitation intensity and involves Auger-type processes assisted by several photons, along with the cascade of multiphoton transitions. A specific feature of the MPAE is that there exists a region of light intensities j, in which a small increase in j yields a sharp increase in the EHP generation rate and, as a result, the breakdown of the material. A similar effect may result from multiphoton interband absorption controlled by the optical Stark effect [5-8]. The energy band spectrum reconstructed by interaction of electrons with light exhibits new van Hove critical points whose position in the Brillouin zone depends on the light intensity j. If j is changed so that such critical points approach the points of multiphoton resonance between the valence band and conduction band, the EHP generation rate sharply increases.

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Near field properties in vicinity of gold nanoparticle array

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In this work we present theoretical and experimental results on the near field distribution in vicinity of metal nanoparticle array. The simulations are performed using a finite difference time domain simulation code. The simulated system consists of gold nanoparticles with diameter of 200 nm hexagonally arrayed on different substrate materials – metal, semiconductor and dielectrics. The properties of the electromagnetic field in the near field zone are studied for different inter-particle distances and the wavelength dependence of the electric field intensity enhancement factor is obtained for the case of gold substrate. It is found that the field enhancement factor increases with the increase of the inter-particle distance and at the distances longer than the incident wavelength it approaches that of a *single particle*. The near field distribution is also found to be governed by the polarization of the incident radiation.

Some of the obtained dependences are confirmed by the experiment. A femtosecond laser system is used to irradiate gold nanoparticles deposited on metal substrate. The deposition technique used leads to a random particle distribution as clusters with different sizes and single particles are observed in a monolayer. Irradiation of the sample with laser fluence below the threshold for substrate ablation, results in a selective single particle removal, while the particle aggregates remain on the substrate surface. The single particle removal also leads to the hole formation with a characteristic diameter smaller than that of the used particles. The obtained results are in good agreement with the theoretical predictions and confirm the validity of the simulations. The presented study can be a basis for a novel method for precise nanostructuring of different surfaces.

IR laser resonant desorption: selective *vs* clustering regimes

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We present an overview of our recent wavelength-selective desorption studies performed by excitation of vibration modes in the 3 µm spectral range [1]. Our experimental approach is based on the coupling of three techniques:

1. IR laser resonant desorption of the condensed phase with a tuneable (2.7 – 4 µm) ns optical parametric oscillator (OPO) based on a $LiNbO_3$ non-linear crystal.
2. UV multi-photon ionization of the ejecta by using the fourth harmonic (266 nm) of a 10 ns Nd :YAG laser.
3. Reflectron time-of-flight mass spectrometry (TOF-MS) for the mass separation of the ionized particles.

Using this approach we have proven the perfect resonant character of the desorption process mediated by excitation of the O-H (λ=3.1 µm) and C-H (3.3 µm) stretching modes in pure ice and polycyclic aromatic hydrocarbons samples, respectively. Moreover, the resonant character has been employed to desorb cryogenic binary mixtures, involving ice and various organic and inorganic compounds. A surprising selective desorption effect has been demonstrated by comparative IR/IR [2] or IR/visible [3] irradiation studies. Highly preferential desorption of H_2O molecules is observed when in resonance with the O-H mode, in contrast with desorption of (almost exclusively) PAH molecules in the C-H stretching spectral region or with desorption of various metal salts at 532 nm. Increasing the laser fluence and/or analyte concentration led to a loss of selectivity with co-desorption of both components and (eventually) extensive cluster generation. Some possible explanations of the wavelength-selective effect are outlined with respect to non-thermal mechanisms.

Finally, possible analytical and technological applications of the LRD technique will be discussed in several directions, as IR Matrix-Assisted Laser Desorption and Ionization (IR-MALDI), Dry Laser Cleaning (DLC) or selective analysis of complex samples.

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Backscattering under pulse propagation in dielectrics

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As powerful light beam propagates in Kerr medium its self focusing results in nonuniformities in the refraction index due to longitudinal and transverse gradients, a part of the incoming beam gets backward-reflected. This phenomenon is known as nonlinear backscattering. At present, very little is known about it, except for the general belief that it is small. However, small-magnitude mechanisms can have a large effect in nonlinear self-focusing in bulk medium. The study how this effect may influence on the pulse propagation is especially important from the standpoint of large potential applications in modern science and engineering.

In this work we investigate analytically and numerically the nonlinear dynamics of powerful light pulse propagation in Kerr medium with self-reflection from nonlinear focus. Application of the eikonal related to the nonlinear phase increment in the pulsed beam axis allows to reduce Maxwell equations to the set of equations of non-linear Schrödinger type for forward (incident) and backward (reflected) waves. Backscattering process is investigated in dependence on the ratio of input pulse power and critical one for self-focusing. It is found, that when this ratio is 1:1 and more, in spite of the reflected wave intensity is weaker by 2-5 percents than the forward one, it prevents the collapse. At this, the beam waist in the nonlinear focus region is of the order of the radiation wavelength. As analysis shows, the intensity of backward wave can reach more than 10 percents of forward wave when this ratio exceeds 30:1. The beam exhibits a multifoci behavior along the propagation axis. The spectrum changes of the propagating beams are analysed.

3D microfabrication by femtosecond laser direct writing for biophotonic microchips

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The use of a femtosecond (fs) laser facilitated the internal modification of transparent materials due to a multiphoton absorption process. One of the most attractive applications of the internal modification process is optical waveguide writing inside glass. In addition, successive wet chemical etching after the modification can fabricate hollow microstructures three-dimensionally embedded in glass. In this paper, we attempt to integrate the waveguides and the hollow microstructures in a single glass chip for application to biophotonic microchips.

The substrate used in our study is commercially available photostructurable glass (Foturan). The waveguide writing is performed merely by direct writing using tightly focused fs laser beam (775 nm, 150 fs, 1 kHz) in the glass. In the meanwhile, the experimental procedure for formation of the 3D hollow structures consists of (1) 3D direct writing of the glass by the fs laser, (2) baking to form the modified regions at the laser exposed regions, (3) wet etching in dilute HF solution to selectively remove the modified regions, and (4) post annealing to smooth the etched surfaces. Finally, 3D hollow microstructure can be fabricated inside the glass.

By fabrication of the 3D hollow microstructures, a vareiety of microfluidic components, micromechanical components like a microvalve, and microoptical components like a micrimirror, a microlens, and a microlaser are successfully integrated in a glass chip. The optical waveguide can be further integrated into the identical glass chip after the hollow microstructure fabrication. Such an integrated microchip is of great use for biochemical analysis and medical inspection based on photonic sensing.

Another application of the microchips is observation of living bio-cells and microorganisms. The use of microchips possessing different structures and different functions enables biologists to perform dynamic analysis of various kinds of bio-cells and microorganisms very efficiently. We referred these microchips to as nano aquarium.

A Laser Produced Plasma (LPP) source prototype for production of high power EUV radiation

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EUV Lithography for high volume manufacturing is a challenge for the semiconductor industry. Numerous research groups around the world are making dedicated efforts to reach the requirements imposed by the industry. Discharge produced plasma (DPP) and Laser produced plasma (LPP) are the two leading technologies for high power EUV production.

Within the French EXULITE program, we have tested a LPP source prototype. It uses some original concepts - modular laser approach, multi-beam heating of the target, differential pumping, EUV dose control, feed-back loop to avoid long-term drift, ... Six 500-W modules constitute the laser system which are focused on a 50 µm spot in a spider-like configuration. As target we are using a xenon filament jet with a 35 µm diameter.

At a laser repetition rate of 6 kHz we obtained 7.7 W EUV (in 2% bandwidth and 2 PI st.) which represent 0.45 % CE.

Complex beam sculpting with Tunable Acoustic Gradient index lenses

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Rapid shaping of an incident Gaussian laser beam enables local control and spot-to-spot modifications over material properties in pulsed and CW applications. Spatial light modulators have been successfully used for beam sculpting, however in certain applications their associated pixelation, slow switching speeds, and incident power limitations can be undesirable. In this study, we present a novel approach to beam shaping and in particular, Bessel beam formation using a Tunable Acoustic Gradient Index of Refraction (TAG) lens. Bessel beams have the unique properties of nondiffracting and self-healing behavior with a characteristically different intensity profile compared to a focused Gaussian. These features can be beneficial in a variety of laser processing applications such as deep hole drilling, waveguide fabrication, micromachining on non-planar substrates and 3-d manufacturing. Bessel beams are typically created using axicons, diffractive elements, or holographic methods all of which present fundamental limitations to high throughput, tunable operation. In our approach, an amplified ultrasonic signal is used to establish a steady-state density fluctuation within a liquid causing an oscillatory variation in local index of refraction. Light propagating through this liquid produces a Bessel-like beam whose properties primarily depend on driving amplitude, frequency, geometry and liquid properties. When driven with a frequency-modulated signal, arbitrary optical phase modulation patterns can be generated at regular time intervals. The theory behind the lens operation, its degrees of control, experimental results, and applicability to laser-materials processing will be presented.

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