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The book consists of the abstracts of oral and poster contributions to the XXVI International Conference on Interaction of Intense Energy Fluxes with Matter (March 1–6, 2011, Elbrus, Kabardino-Balkaria, Russia). The reports are devoted to the modern investigations in the field of physics of extreme states of matter. The following questions are covered: interaction of intense laser, x-ray and microwave radiation, powerful ion and electron beams with matter; techniques of intense energy fluxes generation; experimental methods of diagnostics of ultrafast processes; shock waves, detonation and combustion physics; equations of state and constitutive equations for matter under extreme conditions at high pressures and temperatures; low-temperature plasma physics; issues of physics and power engineering, technology projects.

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HIGH ENERGY ELECTRONS AND CHARACTERISTIC X-RAYS UNDER THE ACTION OF RELATIVISTIC INTENSE SHORT LASER PULSES ON METALS

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In the interaction of high intensity laser pulses with a solid, collective absorption mechanisms transfer part of the laser energy into hot electrons, which are accelerated to multi-keV energies and penetrate into the cold solid behind the surface plasma, where they generate characteristic x-rays via K-shell ionization. These energetic photons with energies above 20 keV can be used for monochromatic backlighting of high Z targets (Al–Pb) heated by heavy ion beams in future experiments at GSI. To optimize x-ray source using the possibilities given by the PHELIX-laser facility at GSI, variations and control of the PHELIX-laser contrast are planned to be done by using thin foils placed in front of the x-ray target for reduction of the nanosecond ASE prepulse interaction with the target. As x-ray target material, thin electrically isolated foils of Ag (E_{K_a}= 21 keV) will be used in order to provide the electron-flux recirculation. Current capabilities of PHELIX provide possibilities for fundamental investigations of mechanisms of the laser energy transformation to the component of high energy electrons in the important region of relativistic laser intensities.

In order to describe planned experiments with intense laser pulses acting upon solid targets, we develop the model, which includes description of the laser energy absorption, ionization, heating and expansion of target substance, the electron-ion relaxation and the ponderomotive force. For completeness of the model the two-temperature equation of state is used for each substance under consideration. To take into account real properties of metals, we suggest models of optical and transport properties of plasma, which are valid in the range from solid density degenerate plasma to ideal one and permit to include into consideration available phenomenological data on the initial metal state of a target. This code was employed in a pilot 1-D modelling of the transparency of thin foil to analyze a possibility to vary the PHELIX prepulse on the x-ray target. Substantial reduction

of the laser prepulse is demonstrated. Obtained results permit to plan experiments using PHELIX with a variable prepulse and controllable preplasma production on the x-ray target for investigation and optimization of the hot electron generation and K_a emission.

INTERACTION OF INTENSE EUV PULSES WITH MATTER

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Extreme ultraviolet (EUV) is strongly absorbed in any kind of matter. A single EUV photon is capable to ionize any atom or molecule. The resulting photoelectron carries enough energy to break any chemical bond. It means that the EUV radiation regardless of its intensity can modify molecular structures of chemical compounds. In case of sufficiently high intensity the bond breaking leads to efficient material ablation.

In this work interaction of intense EUV pulses with different materials was investigated. The EUV source used for the investigation is based on a double-stream gas-puff target created in a vacuum chamber synchronously with the pumping laser pulse. The gas puff target is irradiated with 3 ns Nd:YAG laser pulses with energy of 0.8 J and repetition rate of 10 Hz. The target is formed by pulsed injection of Kr, Xe or a KrXe mixture into a hollow stream of helium. The EUV radiation is focused using a grazing incidence gold-plated ellipsoidal collector. Spectrum of the reflected radiation consists of a narrow feature with maximum at 10–11 nm and a long-wavelength tail up to 70 nm. Different kinds of materials, mainly chemical compounds, were irradiated in a focal plane of the EUV collector with a single or multiple EUV pulses. The resulting craters formed after irradiation and morphology of the micro- or nanostructures were investigated using scanning electron microscopy (SEM) or atomic force microscopy (AFM). The ablation products were investigated using mass spectrometry (QMS) for the molecular mass range up to 512 amu. Additionally X-ray photoelectron spectroscopy (XPS) was employed for investigation of chemical changes in the near surface layer of material samples after irradiation.

In case of some materials, especially organic polymers, efficient ablation or strong surface modification could be noticed. Thickness of the material layer removed from the polymer surface during irradiation was comparable to the EUV absorption depth without any signs of melting in

the resulting craters. It suggests that the mechanism responsible for the material ablation is rather bond breaking than thermal effects. In case of some other materials ablation was rather weak but strong changes of the surface morphology or chemical structure could be observed. In these cases different kinds of micro- or nanostructures in the near surface layers were formed. Usually the structures were created after irradiation with multiple pulses but in some cases a single pulse was sufficient.

MODELLING OF LASER PRODUCED PLASMA SOURCE OF RADIATION AT THE WAVELENGTH 6.7 NM FOR FUTURE LITHOGRAPHY

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The 2D RHD Eulerian code RZLINE was developed for modelling the interaction of laser beams with matter.

The code makes possible self-consistent calculation of level kinetics and radiation transport for different plasma configurations arising from extreme heating by laser pulse. It includes processes of evaporation and condensation, absorption and reflection of laser beam, opacity effects and so on.

An efficiency of different plasma sources of radiation in extreme ultraviolet spectral region is investigated by using the code RZLINE. We have calculated the detailed spectra of laser produced Gd and Tb plasmas with Nd and CO_2 laser beams at different pulse energies, pulse durations and power densities (different focal spots) for plate and droplet targets. The conversion efficiency, anisotropy of radiation, size of source and other characteristics of the source were obtained in a wide range of input parameters at different wavelengths in 6.5—6.9 nm region.

The calculated data are compared with experiment.

WIDE-RANGE MODEL FOR PERMITTIVITY OF STRONGLY-COUPLED PLASMA

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Different applications of laser-matter interactions require reliable models for optical properties of laser produced plasma, which are determined by permittivity ε.

Based on kinetic and linear response of quantum statistics (QS) theories, a semi-empirical wide-range interpolation model for permittivity of strongly coupled aluminum plasmas is proposed. Known limiting cases for ε of high-temperature weakly coupled plasma and for could degenerate metallic plasma are reproduced. In the later case, contributions of interband transitions into permittivity of aluminum through Huttner semi-empirical model [1] are incorporated. Being based on QS theory, the model accounts for the effects of strong coupling, such as electron correlations, dynamical screening and strong collisions with large-angle scattering [2].

From the practical viewpoint, the proposed model can be used in hydrodynamic codes for simulations of laser-matter interaction.

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SUPERCRITICAL FLUIDS, PHASE EXPLOSIONS AND SHOCK WAVES DRIVEN BY SHORT AND ULTRASHORT LASER PULSES

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Single-shot macroscopic femtosecond laser ablation of graphite was studied in a broad laser fluence range using pump self-reflection, time-resolved optical reflection microscopy, non-contact ultrasonic and optical

surface profilometric measurements. At moderate laser fluences these studies revealed ultrafast formation of a dense, strongly-heated (supercritical) carbon phase, which expands on a fluence-dependent picosecond timescale in the form of a point-like three-dimensional explosion, driving a multi-GPa shock wave and providing unexpectedly deep single-shot craters. At higher laser fluences the critical electron-ion plasma is formed instantaneously during the pump pulse, with its strong plasma absorption initiating a TPa-level shock wave.

Likewise, removal rate, air shock and ablative recoil pressure parameters were measured as a function of laser intensity during 532-nm 20-ns laser ablation of graphite. Surface vaporization of molten graphite at low intensities was observed to transform into its near-critical phase explosion above some threshold intensity in the form of a drastic, correlated rise of removal rate, air shock and ablative recoil pressure magnitudes. Just above this threshold the explosive mass removal ended up with saturation of the removal rate, much slower increase of the air and recoil pressure magnitudes, and appearance of a visible surface plasma spark. In this regime, the measured the source plasma shock pressure demonstrates a sub-linear trend, indicating the sub-critical character of the plasma. The strict coincidence of the phase explosion, providing high (kbar) hydrodynamic pressures of ablation products, and the ignition of ablative laser plasma in the carbon plume may indicate the ablative pressure-dependent character of the underlying optical breakdown at the high plume pressures, initiating the plasma formation. The experimental data evidence that the spatiotemporal extension of the plasma in the laser plume and ambient air during the heating laser pulse is supported by fast lateral electron and radiative heat conduction (laser-supported combustion wave regime), rather than by propagation of a strong shock wave (laser-supported detonation wave regime).

CHARACTERIZATION OF CONDENSED MATTER FEMTOSECOND LASER ABLATION WITH COMBINED INTERFEROMETRY TECHNIQUE

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Low power dissipation rates and target shielding absence during ultrashort laser irradiation results in high efficient laser ablation. Development

of fiber optics leading to compact, efficient and easy to use femtosecond laser systems creation makes use of ultrashort laser pulses more accessible, even for on-board utilization. Ultrashort laser-matter interaction processes and laser-induced ablation plume dynamics detailed characterization is necessary for prospective femtosecond laser ablation technologies development. This is impossible without the use of precise diagnostic techniques.

Pulsed laser interferometry is a powerful diagnostic technique for laser-matter interaction processes characterization, but is often underused due to its complexity or due to some uncertainties in obtained data. Laser ablation processes simultaneous investigation both at target surface and in ablation plume leads to significant diagnostic performance increase. We have recently proposed a combined interferometry technique [1, 2], where Michelson interferometer is used to observe thermophysical processes at solid target surface and Mach-Zehnder interferometer for plume characterization with μm spatial and sub-ps temporal resolution. Data directly obtained using this technique regard to ablation crater shape (giving ablated volume and mass) and ablation plume refraction and extinction coefficients distribution (giving electron number density and absorption (inverse bremsstrahlung + photoionization) rate). Using these data combination atomic number density, static and full pressure and temperature, particle velocity distributions, plasma average ionization rate, plume momentum and kinetic energy can be evaluated.

The results of combined interferometry data treatment are presented for metal (Ti, Nb, Mo, Zr) and polymer (PTFE, POM) targets under effect of femtosecond (45–70 fs) laser pulses (266, 400, 800 nm) in vacuum. Obtained data are compared to previously published results of the analogous parameters non-resolving spectroscopic evaluation.

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ELASTIC-PLASTIC PHENOMENA AND PROPAGATION OF STRONG SHOCK WAVES UNDER THE ACTION OF FEMTOSECOND LASER PULSES

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The splitting of the acoustic disturbance into an elastic precursor and a plastic wave is one of the most important phenomena in the physics of shock waves in solids. Recently, numerical simulations and femtosecond laser experiments revealed the existence of elastic shock waves at pressures $p \sim 10$ GPa at 1–2 orders of magnitude greater than the dynamic elastic limit (superelasticity). And at these relatively high pressures, the plastic wave is absent.

The use of the experimental results together with molecular dynamic simulations provided an opportunity to explore the elastic properties of crystals of aluminum at the extreme values of shear stresses, comparable in amplitude to the shear modulus. This allowed for the first time to extend the elastic Hugoniot into the region of metastable states at extremely high pressures, 1–2 orders of magnitude higher than normally accepted values for the dynamic elastic limit. It is shown that ultra-elastic, extra high pressure shock wave precedes the formation of well-known two-wave structure of the elastic precursor and a plastic shock wave. It was found that the transient elastic precursor survives even under conditions, when the pressure achieves the enormous value of $p \sim 1$ Mbar after the plastic front (for such a jump melting of metal starts). Note that the neglect of superelasticity has led to a misinterpretation of previous laser experiments.

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HEAT PROPAGATION IN METALS IRRADIATED BY A FEMTOSECOND PULSE CONSIDERING THE MELTING KINETICS

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Commonly, in order to solve the problem of heat transfer, the Stefan problem is used. The melting area is supposed to be thin infinitely. In

present work, it is shown that this statement is not valid concerning ultrashort laser pulse action on metals. Computational modeling based on electron heat-transfer equation considering the electron-ion exchange and a multiphase equation of state has been carried out. In the first variant the melting kinetics has not been taken into account, in the second variant it has. In both cases a finite-thickness melting area has been obtained. The influence of the melting kinetics on the thermodynamic functions is analyzed in relation to femtosecond laser pulse interaction with aluminum.

ACTION OF FEMTOSECOND SINGLE AND DOUBLE PULSES ON METALLIC FOILS: HYDRODYNAMIC AND COMBINED APPROACHES

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In this work we simulate the action of femtosecond laser pulses on a metallic foil. Two approaches are used: the two-temperature one-velocity hydrodynamic model [1] and the combined model [2] which is based upon the molecular dynamics method for the ions and the heat conductivity equation for the electrons. In these two models the electron-phonon coupling and electron heat conductivity are taken into account. In the hydrodynamic model we use a multi-phase equation of state, while in the combined model the properties of matter are described by the embedded atom potential. We neglect ionization in both models.

Hydrodynamic model correctly describes the absorption of the laser radiation and evolution of electron and ion subsystems, but the decomposition of matter is considered only roughly. The combined model, on the other hand, doesn't take into account the contribution of electrons into pressure, as well as the kinetic energy of electrons, but the defragmentation of the foil is represented rather realistically. The results obtained by two methods are analyzed for aluminum both for single and double femtosecond pulses. We offer the ways of improvement of the combined model.

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EMISSION OF TERAHERTZ WAVES IN THE INTERACTION OF A SHORT LASER PULSE WITH AN UNDERDENSE PLASMA SLAB

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The present paper gives a analytic study of the excitation of terahertz electromagnetic radiation when a short laser pulse is incident from vacuum on a underdense plasma slab. A new mechanism for generating terahertz radiation is considered that is associated with the growth of an antisymmetric leaking mode of the slab under the action of the ponderomotive forces of the pulse. The spatiotemporal distribution of terahertz waves is investigated and it is shown that they propagate into vacuum in the form of electromagnetic field pulses with a frequency close to the plasma frequency and a duration equal to the reciprocal of the damping rate of the antisymmetric leaking mode of the plasma slab. The angular, spectral, and energy parameters of the terahertz radiation are investigated. It is shown that the radiation energy is emitted predominantly along the normal to the slab boundary into a cone the angle of which decreases as the size of the focal spot of the laser pulse increases. It is demonstrated that, for a short laser pulse, the terahertz radiation spectrum has a sharp peak at the plasma frequency and that this peak narrows substantially with increasing the pulse spot size. As the laser pulse duration increases, the spectral line at the plasma frequency disappears and a broad peak arises at a frequency comparable to the reciprocal of the pulse duration. The total energy of the terahertz radiation is calculated and its dependence on the size of the focal spot of the laser pulse and on the thickness of the plasma slab is examined. It is shown that terahertz waves are excited most efficiently when the pulse length is comparable to the slab thickness. A comparison with earlier results shows that, for a laser pulse with large transverse sizes, the radiation energy from the slab is much higher than the energy emitted by a plasma half-space. According to the estimates presented here, the interaction of a femtosecond laser pulse with gas jets can generate megawatt-level terahertz radiation power.

NON-LINEAR EFFECTS IN THE FIELD OF INTENSE LASERS AND RADIATION OF RELATIVISTIC ELECTRONS

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Within the frame of classical electrodynamics we study the interaction of intense laser beams with ultra relativistic electrons. In contrast with pure quantum approach based on Volkov solutions of Dirac equation [1, 2] we develop theoretically formalism based on the classical theory of radiation of relativistic electrons somewhat similar to that of [3, 4]. The approach permits one to take into account the nonlinear effects of high harmonic generation using relatively simple expressions. By this approach we calculate in analytical form the radiation spectrum for the case of linear polarized plane wave interacting with relativistic electrons. Finally we show, that in the limit of high intensity of the laser beam the radiation formulas simplify essentially and the spectrum becomes of synchrotron nature. Such the synchrotron approximation turns out to describe the radiation spectrum perfectly for $\nu_0 \geq 2$, where ν_0 is an invariant laser field parameter.

We restrict ourselves by the case when the whole spectrum lies in the region when $\hbar\omega \ll E$, $E = mc^2\gamma$ is electron energy, $\gamma = (1-\beta^2)^{-1/2}$ is a Lorentz factor, $\beta = v/c$, v is electron's velocity and c is the velocity of light. So we do not take into account the effects of quantum recoil due to photon emission [5, 6]. Our consideration makes use a well developed technique from the theory of channeling radiation [7]. We do not consider also the secondary destructive factor of mutual refraction of electrons and intense laser beam.

It is shown that the shape of the radiation spectrum is is defined by to invariants—ν_0 and parameter a depending on electron energy.

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INTERACTION OF RELATIVISTIC ELECTRONS AND POSITRONS WITH STRONG LASER FIELDS AND ELECTROSTATIC FIELDS OF ORIENTED CRYSTALS

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Strong laser fields with field parameters $\nu_0 > 1$ produce high harmonics in the radiation spectra of electrons and positrons moving at some angle to the wave vector of these fields. QED approach based on calculation of probabilities of laser beam multi photon absorption by moving electron followed by radiation of a single hard photon was developed in detail by many authors (see a review article [1]). Another way to study such phenomena is to start from the well developed theory of radiation of moving electron in an external field [2]. It has been shown recently that in the important case of ultra relativistic motion the corresponding formulas simplify significantly [3–6].

Formulas for radiation spectrum of relativistic electrons channeling in oriented crystals have the similar form [7]. Nevertheless, these two types of radiation have important differences. In the present work we study this difference in detail. We show that in contrast with the laser case channeled electrons possess an additional mechanism for generating high harmonics—the anharmonism of the transverse motion, whereas the motion of an electron in the field of a plane wave is essentially harmonic. In channeling a much wider class of transverse trajectories exists, including an infinite transverse motion (quasichanneling). The nonlinear effects of high harmonic generation become weaker with increase of electron energy in the laser case, whereas for channeled electrons it becomes stronger.

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MODELLING OF CHARACTERISTIC X-RAY YIELD UNDER THE VACUUM HEATING OF HOT ELECTRONS BY A FEMTOSECOND LASER PULSE

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Enhancement of characteristic x-ray yield from a metal foil, coated with spherical clusters, irradiated by a Gaussian femtosecond laser beam, is investigated depending on the cluster size, laser pulse intensity and the foil thickness [1]. To give insight on the influence of the hot electron energy distribution upon the K_α yield, the calculations were carried out both for the hot electrons, accelerated in accordance with the Brunel model, and for Maxwellian distribution of hot electrons, which temperature was related with the average electron energy. Existence of an interval of cluster sizes with respect to the laser wavelength, in which the number of emitted photons from the foil with clustered surface exceeds one from the polished foil, and increase of K_α yield with growth of the laser field angle of incidence is most pronounced, is shown. Indicated enhancement of K_α yield correlates with increase of the energy absorption by fast electrons which produce x rays.

This model was applied for interpretation of increase in K_α x-ray line emission obtained under irradiation of a metal foil covered with metal rods with surface number density about 10^8 rods/cm^2 ($\approx 20\%$ of the solid density), each of 0.5 μm in diameter and about 1 μm of height, as an approximate description of the surface with rods of low aspect ratio modified by prepulses [2]. Calculated ratio of K_α yields from the polished foils of 31 μm and 8 μm thicknesses reproduce well the experimental value under the assumption of Maxwellian distribution of hot electrons. Measured relative increase in x-ray yield from the foil of 8 μm thickness with clustered surface is best fitted by hemispheric clusters of 0.5 μm diameter.

Calculations according to this model demonstrated satisfactory agreement with the measurements of K_α yield from a massive iron target in the interval of peak intensities 5×10^{16}–2×10^{17} W cm^{-2} of p-polarized

femtosecond laser pulse with wavelength 1.24 μm under fixed angle of incidence 45° [3].

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MONOENERGETIC ACCELERATION OF ELECTRONS, TRAPPING BY WAKEFIELD FROM WIDE AND LONG ELECTRON BEAM

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The acceleration process of electrons from the wide and long electron beam, injected in a wakefield of a high strength, generated by short powerful laser pulse, propagating in the plasma channel, is analysed. The actuality of the problem is caused by that modern injectors cannot prepare short enough electron bunches with small emitance and energy spread, the most suitable for monoenergetic laser wakefield acceleration. The injection scheme is investigated, in which the electron bunch with the sizes much more than the characteristic sizes of a wakefield from a laser pulse is injected in the plasma channel simultaneously with a laser pulse. Energy of injected electrons is such, that the electron velocities are lower than the wave phase velocity. For the decision of a problem of monoenergetic electron acceleration it is offered to combine effect of focusing of electron trajectories [1] in phase space in the course of their acceleration with effect, so-called "cutting" by wake wave of group of electrons [2] at their trapping from a wide and long injected electron beam. The formation process of a compact bunch of electron, trapping from the maximum wakefield potential area, is investigated by means of numerical modelling. It is shown, that in certain conditions at the further acceleration of the bunch the trajectories of electrons are focused in small enough area of the phase space, providing sufficient compensation of the initial spread of electrons in injection energy and coordinate. It is shown by means of the simulation, that in laser-plasma system with the parametres typical for nowadays existing equipment it is possible to generate and accelerate a bunch of electrons to energy in some GeV with small energy spread (0.4%).

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PIC SIMULATION OF LASER WAKEFIELD ACCELERATION OF ELECTRONS IN PONDEROMOTIVE APPROXIMATION

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An acceleration of electron bunch in laser wakefield is simulated in the work. The PIC-code WAKE is used to model the wakefield. This code is based on the quasistatic approximation, which assumes that the laser pulse and its wakefield are undisturbed during the transit time of plasma electrons through the pulse. The injection of electrons in plasma is taken into consideration by the use of the module, in which equations of the relativistic electron in the wakefield are solved. The acceleration of the electron bunch up to several GeV is investigated.

MeV PROTON GENERATION BY A MODERATE ULTRA-SHORT LASER INTERACTION WITH H_2O NANO-WIRE TARGETS

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Compact sources of high energy protons (50–500 MeV) are expected to be key technology in a wide range of scientific applications. Particularly promising is the target normal sheath acceleration (TNSA) scheme], holding record level of 67 MeV protons generated by a Peta-Watt laser. In general, laser intensity exceeding 10^{18} W/cm^2 is required to produce MeV level protons.

Now we report on the first generation of 5.5–7.5 MeV protons by modest laser intensities (4.5×10^{17} W/cm^2) interacting with H_2O nano-wires (snow) deposited on a Sapphire substrate. In this setup, the plasma near the tip of the nano-wire is subject to locally enhanced laser intensity with high spatial gradients, and confined charge separation is obtained. Electrostatic fields of extremely high intensities are produced, and protons are accelerated to MeV-level energies. Nano-wire engineered targets will relax the demand of peak energy from laser based sources.

ATOMISTIC SIMULATION OF LASER ABLATION OF GOLD FILMS

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At the present time there are no models of laser ablation which are taking into account the effects on the atomistic level (phase transitions, the mechanism of destruction) and the accurate effect of the hot electronic subsystem on the ionic one (electron pressure and electron-ion relaxation). One of the aims of the work was to develop an interatomic potential for gold, depending on the electron temperature. This potential allows taking into consideration the electron pressure in atomistic simulations. The developed potential was included in a hybrid two-temperature model [1, 2] to simulate the processes of ablation and non-equilibrium melting of gold films under pulsed laser irradiation. The creation of the electronic-temperature-dependent potentials for an atomistic simulation was performed by force-matching method [3].

Simulation of laser ablation was performed at different values of energy deposition and film thickness. The various mechanisms of destruction of the crystal during the ablation were examined. The influence of geometric parameters of the absorbing medium on the characteristics of the ablation was studied. In addition the nonequilibrium process of gold melting under the influence of pulsed laser was investigated. The comparison to the experimental data was performed.

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EVOLUTION OF METALS AFTER NONEQUILIBRIUM EXCITATIONS OF THE ELECTRON SUBSYSTEM

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In the work we consider warm dense matter—the state between heated condensed matter and plasma. It may be generated in different ways: by strong short laser irradiation of metal, during the electrical explosion of conductors, in the matter of cathode during heavy-current pulse discharge etc. For all general mechanisms of warm dense matter formation it is common that the two-temperature state is formed right after initial energy deposit. In this state the temperature of electron subsystem is significantly higher than the one of the ions. Actually, we can consider such systems as if all the energy absorbed during excitation was absorbed by the electron subsystem while lattice remained practically unaffected.

The evolution of such states after energy deposit is determined by the rate of electron-phonon energy exchange and the electron and lattice heat capacities. Theoretical approaches, initially developed in the superconductivity physics, allows to calculate these quantities using basic microscopic characteristics of matter such as electron and phonon densities of states.

We calculate the dependencies of densities of states and the electron-phonon coupling constant for Al, Ag, Au and W on the electron temperature in the range from 0 to 4 eV. It gives the values of the electron-phonon coupling factor, electron and lattice heat capacity in the same range of electronic temperatures. The electron DOS is calculated using VASP package [1], phonon DOS—using PHON utility [2] and the electron-phonon coupling constant is calculated with Quantum Espresso distribution [3]. Obtained values are compared with the ones from the work [4] in which changes in densities of states weren't taken into account. The results show that for the electron temperatures higher than 1 eV considered quantities may change significantly and their values for ground state can't be applied to the description of the system with strongly superheated electrons. It is also shown that relaxation times for the two-temperature state may differ for an order of magnitude for different metals depending on their electronic structure and lattice properties.

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DYNAMICS OF NANOPULSED LASER INDUCED INFRARED RADIATION OF SILICON

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Effects of a ruby laser irradiation of Si crystal surface at pulse duration of 80 ns (FWHM) have been studied at the laser energy density W varied from 0.8 to 3.2 J/cm^2 in the spot of 4 mm in diameter at W inhomogeneity not more than $\pm 5\%$. Near infrared (IR) radiation of the laser heated area was detected in 0.9–1.15 μm spectral region by means of a photoelectric (pyrometric) sensor with a multiplier phototube as IR-detector. Also, reflected from the area a probe radiation flux ($\lambda = 0.53$ μm) was detected by another multiplier phototube in order to observe the laser-induced melting of Si. Output signals of the radiation detectors were simultaneously recorded by two-beam oscilloscope.

Under the experimental conditions the surface melting of Si crystal is reached if $W > 1$ J/cm^2. IR-radiation signals recorded at $W = 0.8$–1 J/cm^2 repeat the form and duration of the laser affecting pulse. IR-radiation intencity culminates to the moment of the laser power peak. This radiation is laser-stimulated recombination luminescence (RL) of Si, at that its intensity is well above the same of thermal IR-radiation (TR) emitted by the heated layer.

At larger values of W in the dynamics of detected radiation the quenching of RL takes place at premelting stage and then TR of arising liquid phase is recorded. Under W= 2.6 and 3.2 J/cm^2 well-defined maximum of TR intensity is observed at the moment of attainment of molten surface peak temperature T_p which is equal to 1950 K and 2100 K, correspondingly, as it follows from the measurement results at the effective wavelenghth $\lambda_e = 1.04$ μm in this case.

Obtained data on T_p as a function of W agree with similar measurements [1], carried out at $\lambda_e = 0.53$ and 0.86 μm. The dynamics of IR-radiation at the stage of solidification of the melted Si layer is qualitatively the same in comparison with dynamics of visible thermal radiation of Si [2].

This work was supported by BRFFI (Project F09SO-015).

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MODEL CALCULATION OF THE MELTING TEMPERATURE OF Ge NANOCLUSTERS IN Si AT PULSED LASER HEATING

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Recently the possibility to manage the properties of quantum dots (QDs) by pulsed laser treatment has been shown. The laser treatment of Ge nanoclusters embedded in Si matrix was considered. It was shown that laser irradiation may produce changes in composition and size of QDs and also in distribution of QD over sizes. In the most attractive regimes of laser treatment energy densities of laser radiation should be sufficiently large to melt quantum dots and on the other hand not be so much to result in dissolving them in Si matrix. Thus, in order to define optimal conditions of laser treatment of QD it is very important to know melting temperature of embedded nanoclusters depending on their size, composition, shape and others parameters.

This work is devoted to the study of melting temperature of embedded nanoclusters under conditions of laser irradiation. Hut and dome nanoclusters are studied. The ratio of height to base was 1:10 in the first case, and 1:5 in the second one. We showed that thermodynamic description of phase transitions and temperatures is valid for QDs under consideration.

Two phenomenological approaches were used for the description of size dependence of T_m. In the first approach T_m is determined by the entropy of thermal crystal vibrations. The entropy depends on nanocrystal size, shape and properties of nanocrystal–matrix interface. The dependence of T_m for two different shapes of nanocrystals (hut- and dome- clusters) on size was obtained. In the second approach it is assumed that T_m is proportional to nanocluster cohesion energy. The data obtained by use of both approaches are compared. Tm increases from 1215 K up to 1250 K for Ge dome-clusters and from 1220 K up to 1285 K for Ge hut-clusters with reduction of base size from 50 to 5 nm.

The joint influence of lattice mismatch, thermoelastic stresses, QD composition and QD size on QD melting temperature are discussed. Temperature dynamics in QDs under conditions of laser treatment was inves-

tigated by numerical simulation taking into account QD melting temperature change.

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STUDY OF IMPACT-PARAMETER DEPENDENCE OF INELASTIC ENERGY LOSS IN SILICON

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In this work, we describe a new computer code for the inelastic energy loss as a function of the impact parameter for projectiles. The calculation are performed by using Monte Carlo simulations, each event characterized by choosing the distance between electron and projectile b determined by using the random procedure ξ_n. We compare simulated data with those obtained by other authors using theoretical and experimental methods.

PERIODICAL STRUCTURE DIFFRACTION APPLICATION FOR SOFT X-RAY LASER PULSES PROPERTIES DETERMINATION

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X-ray lasers is the rapidly growing technology recently. There are many methods of short X-ray laser pulses generation : high-order harmonics of femtosecond lasers, x-ray plasma lasers, x-ray free electron lasers. Such x-ray lasers are used for matter heating, for nanometer resolution imaging etc. X-ray lasers employment optimization significantly depend on generated beam quality. Creation of high-performance diagnostics methods that allow to measure spatial distribution of spectral and coherence beam properties is necessary to improve beam quality. In this paper method that permit to get this properties for one laser flash is described.

Self-amplified spontaneous emission-free electron laser (SPring-8 Compact SASE Source) [1] was used for soft X-ray laser pulses generation. Laser pulse with energy up to 11 mkJ, duration of 300 fs and wavelength of 51–62 nm propagated through vacuum system. At 16 m away from

the source the mesh with period of 350 mkm and the wire thickness of 36 mkm was placed. 26 mm away from the mesh the LiF crystal detector was placed. This detector had high dynamical registration range, high apprehensibility which allow to register the soft X-ray emission with 0.6 mkm resolution for one laser flash [2]. Diffraction pattern obtained by the detector from each cell then was compared with diffraction pattern obtained by means of numerical simulation. Chosen model parameters for optimal coincidence with experimental data we can restore real beam parameters for each cell.

In this studying experimentally and theoretically was shown that introduced method allow to measure the intensity, coherence and spectral behaviour of soft X-ray laser beam distribution across the beam profile with accuracy better than 10 %.

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ABLATION OF LITHIUM FLUORIDE DIELECTRIC CRYSTAL BY THE SHORT PULSES OF X-RAY PLASMA LASER AND EXTREME ULTRAVIOLET FREE ELECTRON LASER

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We presented experimental and theoretical studies of ablation of condensed matter by extreme ultraviolet (EUV) and X-ray lasers (XRL). Results obtained by the use of two different soft XRL are compared. The first XRL is the collision Ag-plasma laser with pulse duration 7 ps and laser photon energy 89.3 eV, while the second one is EUV free electron laser (EUV-FEL) with pulse duration 0.3 ps and energy of photon 20.2 eV. Investigation of interaction of irradiation from these two types of XRL with the wide gap lithium fluoride (LiF) dielectric shows that ablation thresholds in both cases are approximately the same. Ablation threshold for

XRL interacting with dielectric appears to be significantly lower than the threshold of ablation when ultrashort laser pulse of optical frequency range interacts with the metal surface. The similarity between the two XRL is due to the short pulse durations of both XRL. They are shorter than, or comparable with the acoustic time, which is necessary for sound to travel through an attenuation depth. These short pulses create thermomechanical stresses which are the reason for spallative ablation in the dielectric as well as it takes place in metals. Thermomechanics and negative pressure define character of ablation at relatively low fluences of the order of ablation threshold. At such fluences, heating is moderate and matter remains in condensed state where cohesive properties are dynamically important. At higher fluences, XRL transfers the heated layer into the gaseous state where cohesion phenomenon is not significant. A theory presented explains a slow growth of ablated mass with a fluence when the short x-ray laser irradiation interacts with the dielectric target as a result of transition from the spallative ablation near threshold value of a fluence to the evaporative ablation at high fluences.

INVESTIGATION PARAMETERS 2T-STATE INTO SODIUM CHLORIDE

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Influence by ultrashort laser pulses creates in crystals a condition with two temperatures, so-called, a 2T-state, at which $T_e \gg T_i$, where T_e, T_i— electron and ion temperatures. Duration 2T- state is essential enough, for example, 1–10 ps in a number of systems [1].

The 2T-state is very important, as on it there is a 2T-relaxation to transfer of laser energy to ions and, basically, the layer of warming up playing the important role in subsequent dynamics is formed. Kinetic coefficients of the condensed matter with hot electron at present are insufficiently studied, basically, the phenomenological dependences made from asymptotics at low and high temperature T_e are applied. The first calculation of heat conductivity from the kinetic equation, fair for area low $T_e \ll T_F$ (T_F—Fermi's temperature) and moderated $T_e < T_F$ temperatures, is presented in work [2].

2T-state is a subject of many fundamental researches which are essential because thermodynamic (for example, electronic pressure) and kinetic (for example, conductivity) the data about a 2T-state is necessary for

understanding of the processes arising at influence by femtosecond laser pulses on materials and for corresponding calculations.

To the crystals subjected to influence of radiation of the femtosecond laser, at the initial stage of equilibrium process methods of calculation of the electronic structure, developed for a case of zero temperatures [3] can be applied.

These methods, for example, for sodium chloride, irradiated with femtosecond laser pulses [4], it is possible to calculate an electronic thermal capacity at normal density and based kernels for various electron temperature, and as pressure depending on compression at electron temperature and the ions, equal to zero.

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CALCULATION OF HEAT FLOWS IN SODIUM CHLORIDE

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To estimate time borders of applicability of the formula offered by authors [1], for calculation of transitional temperature on an active interval, the member who shows time dependence is enough to estimate: $\exp\left(-\mu_n^2 t/\tau\right)$, where μ_n—eigenvalue of parameter μ with number n; t—running time; $\tau_0 = l^2/\alpha$—characteristic time of the problem, making sense time of stationary thermodiffusion; l—length of the homogeneous isotropic heat-conducting sample, α—thermal diffusivity [1].

As the sample we consider NaCl ($l = 10^{-2}\,m$), $\alpha = \kappa/\rho c$, where κ—thermal conductivity, ρ—density, c—specific heat.

For NaCl at $T = 273$ K: $\kappa = 1.15$ W/m^2·K, $\rho = 2.76 \cdot 10^3$ kg/m^3, $c = 854$ J/kg·K [2]. Then $\alpha = 6.206 \cdot 10^{-3}$ m^2/s, $\tau_0 = 0.016$ s. In degree exponent the relation of running time to characteristic time of the problem is defining: $t/\tau_0 = 0.63$ for a pulse 10 ms, for shorter pulses $t/\tau_0 \ll 1$. Eigenvalue μ_n of parameter μ at any n of the order of 10. Thus, offered in [1] formula it is possible to use for calculation of transitional temperature

on an active interval for pulses of the order of ms. For shorter pulses it is necessary to carry out the analysis of other works.

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RESEARCH OF AVALANCHE IONISATION IN FUSED QUARTZ

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The first works on breakdown transparent dielectrics and high energy-gap semiconductors by powerful laser radiation have appeared still in the sixties [1]. Though, the variety and complexity of physical processes, and high practical value does research in the field still actual.

In the offered work one of aspects—generation of nonequilibrium electron–hole pairs by intensive laser radiation with energy of quantum $\hbar\omega$, which more, than energy of excitation of bound electron state in atom, but smaller in comparison with width of forbidden zone U_{eff} is presented. Apparently, in most cases occurrence of a considerable quantity of nonequilibrium carriers of a charge under the influence of a powerful light wave serves as the reason (precondition) of dielectric destruction. In early works it was specified that at breakdown occurrence in very pure transparent dielectric a dominant role two mechanisms of generation of nonequilibrium electron-hole pairs—avalanche ionization and multiphoton band-to-band play transitions.

For electron density calculation ρ, created in the environment under the influence of a light field, we will take advantage of the equation [2]

$$\frac{d\rho}{dt} = W + \frac{\sigma}{U_{\text{eff}}}\rho I - \frac{\rho}{\tau_r}. \tag{1}$$

Component W considers the photoionization contribution, σ—section of return brake absorption, U_{eff}—width the forbidden zone of dielectric, τ_r—trapping time of electron by defects of a lattice in a solid. As follows from (1), effective time of avalanche ionization can be certain as

$$\tau_l = \frac{U_{\text{eff}}}{\sigma I}. \tag{2}$$

At typical for fused quartz values $\sigma \approx 1.32 \cdot 10^{-18}$ cm^2 (by $\lambda \approx 900$ nm), $I \approx 1$ TW/cm^2, $U_{\text{eff}} = 9$ eV effective time of avalanche ionisation silicon dioxide $\tau_l = 1.1$ ps.

We suppose that in transition from nano- to picosecond range formation of avalanche ionization can be slowed down and in this area other processes can play the important role of initiation of breakdown.

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INVESTIGATIONS OF LASER PLUME GENERATED BY LASER MICROSECOND PULSE ON THE SAPPHIRE TARGET

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Understanding of aluminum burning in water steam process isn't possible without elementary processes which in it proceed understanding. Key elementary process is condensed phase formation process, this work has been devoted to this research.

The experimental complex is presented. The complex allows to irradiate an investigated surface of the target established in the chamber from stainless steel, light with length of a wave 10.6 microns (CO_2 the laser) as in high vacuum (1.3×10^{-5} Pa) as in the set gas atmosphere (to 1 atm). A laser torch luminescence diagnostics system provide registration of optical spectra composed from the torch component and used high-speed electron-optical chambers K008 and K011 is made by BIFO Company, spectrograph-monochromator iHR 320. Management of experiment, registration of results and their processing was made by operating computer. A chamber K008 use allowed to obtain as an integrated spectrum on time, as to cut out separate spectral lines and to develop them in time. A chamber K011 (9-personnel with the minimum time of exposition of 100 nanoseconds and a delay between shots also 100 ns) was used for registration of integrated radiation of the torch. The system allowed to obtain the spatially-resolved spectra of the torch in a range of lengths of

waves of 380–800 nanometers. A special design was used for installation of flat samples (plate of glass by TS) on which surface from a gas phase the products formed as a result of laser heating of a target were condensed. After experiment surface of target and samples were investigated by means of a scanning electronic microscope and a nuclear power microscope Smena.

As a target plates of optical sapphire (Al_2O_3) were used. Spatially time distribution of products of a laser torch (aluminum ions, Al, O, AlO), formed in oxidizing (O_2), regenerative (H_2), neutral (Ar, He) atmospheres is investigated. Approaches to a temperature estimation gasofase components making a laser torch are developed, and the technique of studying of products of their condensation on a surface of glass samples is fulfilled.

EXPERIMENTAL INVESTIGATION OF THE DIAMOND AUTOEPITAXIAL GROWTH FROM LIQUID CARBON

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Progress in science is related to the search for new materials, as well as known substance new obtaining methods. There are various obtaining methods of the diamond, and only the potential of melting methods insufficiently investigated.

The possibility of diamond epitaxial growth on the diamond substrate from the liquid carbon in the isobaric gas-static conditions with 30 MPa pressure was experimentally demonstrated for the first time. Liquid carbon was obtained as the result of the laser remelting of the microdisperse graphite islands held by the adhesive on the substrate—the edge of natural diamond crystal. The diamond original surface was formed by pyramidal growth hillocks, with steps oriented along the edges of the octahedron (111), as well as the tetrahedral cavities—trigon. Trigons are known to be strictly oriented in the direction opposite to the octahedron edge and are formed as the result of the peculiar growth discordance. Remelted island surface is the well known "cobble structure" consisting of graphite densely packed hexagonal crystals and strikingly different from the flaky structure of the islands before melting.

In the solidified carbon from the contact area of the liquid carbon and the substrate transparent crystal inclusions were detected, protruding above the original diamond. Crystal surface also had a form of "cobble structure" due to the different types of instabilities in the growth process,

but from flattened crystals with octahedral faceting. It is important to note that such surface morphology has nothing to do with the diamond original surface, that proves transparent particle growth origin. Raman spectrum of the particles contained diamond narrow line 1332 cm^{-1}, as well as graphite-like sp_2 strongly disordered nanographite with crystallite size around 5 nm was identified, while the characteristic size of the transparent crystal crystalline regions was 100 nm. Thus, the new-formed crystals, as well as the diamond substrate are characterized by the line 1332 cm^{-1}, i.e. the diamond. Their orientation on the diamond substrate surface was similar to the trigon orientation, that indicates the autoepitaxial growth character. Possible methods to improve the efficiency of the diamond autoepitaxial growth, including the use of amorphous carbon for the liquid carbon production and the initial substrate optimal orientation are discussed.

THE RESEARCH OF THE GRAPHITE MELTING PROCESS BY THE LASER HEATING

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In spite of the fact that the attempts of the carbon studying in the melted condition have almost century history, some fundamental properties of liquid carbon are still unsolved. It is established, for example, that liquid carbon has an abnormal low density and heat conductivity near to a triple point and high electroresistance which decreases with the pressure increase. However, it is not possible to define the change character of the liquid carbon properties in the pressure range of 100 to 10000 bar more precisely. One of the factors, creating difficulties for the optical supervision over the graphite melting process, is the strong evaporation leading to the formation of the soot at the volume condensation of the vapor in the rather cold inert gas. The temperature of the soot particles at their formation rises approximately to 4000 K, that creates complexities in the interpretation of the measurements (for example, temperatures of a surface of a liquid). The purpose of the present work is to increase the accuracy and reliability of the measurements by applying the equipment that allows operating the heating process with the use of the preliminary mathematical experiment modeling. Also, some methods of the optical measurements for studying graphite melting process not applied earlier are used.

Heating of the sample is carried out by the laser impulse. A Nd-YAG laser is used with a pulse duration in the range of 100–200 ms and power 3 kW. The sample of the high density graphite is located in the optical cell with the pressure of inert gas about 3000 bar. To increase the reliability of the liquid phase detection the system based on the laser illumination of the heated surface, operating on the wave-length 532 nanometers, is used. The change of the surface temperature is fixed by a high-speed micro pyrometer on wave-length 650 nanometers.

In the present work graphite melting temperatures in a range of pressure 100–3000 bar are reported, the behavior of the liquid carbon is discussed on the basis of comparison experimental thermo grams and the data of mathematical modeling, results of the analysis of the melted substance are reported.

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THE BEHAVOIR OF GRAPHITE MELTING AT SUBSECUND LASER HEATING UNDER CONTROLLED ISOBARIC CONDITIONS

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The behavior of carbon at high temperatures and pressures was investigated for several decades. But a number of questions, concerning solid graphite melting, evaporation of liquid, sublimation of solid are still unsolved or are controversial. The main aim of this work is further improvement of methods of experimental study of graphite using of laser hitting. Basic difference of this work vs. [1] is in using high power Nd-YAG laser with constant beam power, with arbitrary varying power, with time constant 1 ms. The last make it possible to set the pulse shape, with duration of the order of tens millisecond. High repeatability of pulse shape and maximum of power beam, make it possible to reach better results than in [1]. Graphite specimens are placed in a high-pressure chamber, and heated by laser pulses. By means of a gas membrane compressor, the chamber is filled with a neutral gas up to 1000 bar pressure. A high speed brightness pyrometer, operating 650 nm wavelengths with constant time 10 ms, is used for the temperature measurements. The measuring spot of pyrometer is small (0.5 mm diameter) compared to the size of the heated surface

(about 2 mm diameter), therefore the temperature error due to possibly existing radial temperature gradients is negligible. Experimental heating tomograms of carbon at different pressures of neutral gas and at different laser pulses are shown in this work. The features of graphite melting at high pressures are discussed in this work.

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MATHEMATIC MODEL FOR HEAT TRANSMISSION THROUGH MODIFIED GRAPHITE MATERIALS INFLUENCED WITH LASER RADIATION

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The research aim was to create modified graphite materials for protecting various objects from high-energy laser radiation. We investigate modified graphite formed as a result of implantation atomic or molecular layers of various chemical agents between graphite layers (crystals). Thermo-dilative graphite is a product of fast decomposition process then layer graphite compounds are under exposure to power thermal flux. Radical change of modified graphite crystal structure is caused by intensive enlargement of gaseous decomposition products. Hexagonal layers draw apart along axis "c" with crystals increasing up to two orders without considerable change in structure and size along others axes.

Samples were made from caoutchouc binding with 20 and 40% content of modified graphite. Experimental researches were fulfilled at facility mentioned in [1].

We propose to use the way described in [2, 3] to calculate laser radiation exposure to modified graphite materials. Such materials are regarded as porous two-phases single-temperature reactive medium that includes solid material and gaseous decomposition products. Heaving is accompanied by solid material loss. Comparative evaluation was made to check calculations and experiment results.

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GLASS PLATE WITH NANOSTRUCTURED GLASS FILM LASER DESTRUCTION STUDIES

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The nanostructured solid films with 50 nanometers and lesser dimension for the glass plate optical property modification play the great role in the nanophotonics and other nanooptics technological applications. The glass plates with Such a films laser cutting was based on the laser ablation under power laser pulse on the glass film surface and its studies are the important scientific problem [1, 2]. It demands the detail studies of the glass films target threshold parameters dynamics at the laser ablation destruction in the laser pulse energy density from 10 up to 500 J/cm^2.

This report goal is the various chemical composition films laser ablation destruction dynamics versus the incident laser radiation intensity dependencies for our experimental conditions. The nanostructured glass films were created by the plate plunging into the film formatting solution of 2.5 mass % (Bi_2O_3 + TiO_2 + Fe_2O_3). The composite was burned in air at the 4500C in a half an hour. The film formatting solution viscosity value has been measured by the capillare method, the film structure—by the electron microscopic study and their refractive index and thickness have been controlled by the ellipsometry [3]. The iron oxide molar composition in all the films was constant and was equal to 25% but Bi_2O_3 and TiO_2 concentration were changed accordingly from 10 up to 70 and from 65 to 5% with the concentration different of 10%. These composite samples have been burned and modified by the applied regime with the sequenced its parameters measurements.

The experimental laser ablation station as in [1, 2] the YAG: Nd laser radiation with pulse duration of 100 μs and energy up to 4.5 J at 1064

nm wavelength beam was focused by the special objective on the film surface. The threshold energy density QT have been derived from the laser plasma emission appearance due to this plasma emission intensity measuring by the mini-spectrometer in the wavelength range 400 . . . 1000 nm synchronized by the laser pulse with the time decay up to 5 μs.

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INVESTIGATION OF LASER INTERACTION WITH LOW-DENSITY POROUS MEDIA ON MISHEN FACILITY

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The prime goals of Mishen facility research program on interaction of powerful (10^{13}–10^{14} W/cm^2) laser pulses with low-density (0.5–30 mg/cm^3) porous media are briefly discussed. Utilization of these materials in laser fusion targets and in targets for powerful laser-plasma sources is considered recently as a very promising approach. The experimental program as well as the used optical and X-ray diagnostics are described. The results are presented obtained in experimental investigations of laser light absorption, production of high temperature plasma, and subsequent plasma homogenization in plane porous agar $(C_{12}H_{18}O_9)_n$ samples of different average densities. The data on measured plasma electron and ion temperatures as a function of sample average density and laser power are presented also. The experimental data are in a good agreement with the theoretical predictions.

NONUNIFORM COMPRESSION AND BURN OF LASER ICF TARGETS

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One of the principle, may be the most important question in the theoretical and experimental studies of the laser ICF problems (LF) is a problem of the hydrodynamics instabilities development at a target compression, because it leads to a neutron yield reduction. This problem makes one to construct the complex many-beams systems for a target irradiation, for example, Omega (LLE RU) or NIF (LLNL), where the many amount of beams are used (60–192).

So, it seems, that as well as a theoretical investigations of an incarnate hydrodynamics instabilities, and the effect its development in laser targets. The present theories of a turbulent mixing in a distant sense only are applied to a LF targets, which have a their specific. More of them, it is usually, that as an experience shows, it is often not the zone width, but a large scale violation of a symmetry, which connected with a diversity (in space and in time) the temperature and density maximums.

In this paper the observation of the existence ideas about the experimental and theoretical study this problem is presented. It concerns a mathematical modeling role as well as a question: what a completeness of our images, that computer can gives. We have presented the principles and a theory of the mixing zone evolution in the laser targets taking into account their specific features (short time of a deceleration, spherical geometry of the shells convergence, compressibility of a matter). The main conclusions are illustrated by through simulation examples. These simulations based on 3D codes authors elaborated.

EXPLODING WIRES IN THE STRONG EXTERNAL MAGNETIC FIELD WHICH IS QUICKLY FALLING DOWN

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The study of the plasma formed in the strong external magnetic field which is quickly falling down is very interesting for many basic and applied problems concerning induced gas discharges and interactions of intense energy fluxes with matter. The effective input of energy into plasma is possible, if the amplitude of the magnetic pressure of the external field essentially surpasses the gas kinetic pressure of plasma, and the speed of the field recession is sufficient for exciting the intensive induced gas discharge. Experimental results for two modes are presented: in the first one the electric explosion of a linear wire inside of the solenoid was made; in the second mode the electric explosion of wire spirals was made. In all experiments copper exploding wire having diameter from 0.4 up to 0.5 mm were used. Installation had the condenser battery 80 nF charged up to a voltage of 350 V; the amplitude of a primary current could get 8 kA. In the first of the mentioned modes the solenoid was connected consistently with the exploding wire, and at the explosion of the wire there was a disconnection of a contour with a current. As a result the formed plasma incorporated some part of energy of the magnetic field of the solenoid. This solenoid had 40 coils of a wire in diameter of 1 mm reeled up on dielectric skeleton in diameter of 16 mm and length 40 mm. In the second mode of experiments two parallel spirals with the right and left windings were used which reserved enough big magnetic energy before the disintegration of wires. Each of the spirals had 20 coils; the diameter of spirals was made 4 mm and the length of 20 mm. Estimation of the absorbed energy by plasma has been made on amplitude of a signal of the photo detector installed on distance about 400 mm from exploding wires. Experiments have shown the essentially higher intensity signal of the photo detector at explosion of wires in an external strong and quickly falling down magnetic field in comparison with experiments without an external field. Sometimes at electric explosion of spirals a plasma clot had being forming which had lifetime about 0.5 seconds.

DISTRIBUTION OF MATTER PARAMETERS UPON EXPLOSION OF AN ALUMINUM WIRE

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There has been investigated the distribution dynamics of matter in the discharge channel upon nanosecond explosion of single aluminum wires in vacuum. A series of experiments were performed with a charge voltage $U_0 = 20$ kV and current amplitude $I_{max} \sim 8$ kA having a current rate of rise $dI/dt \sim 40$ A/ns when exploding wires of 25-μm diameter and 12-mm length. Optical shadows and Shlieren images of the discharge channel were obtained using optical probing at the second harmonic of a YAG:Nd^{+3} laser (wavelength 532 nm and pulse length ~ 70 ps); also, ultraviolet images of the discharge channel were obtained by means of a 4-frame camera with microchannel plate. Simulations of the explosion of an aluminum wire, including and beginning with a cold start, were carried out; the results of numerical calculations are compared with experimental data.

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SIMULATION OF SYNCHRONOUS ELECTRIC PULSED DISPERSION OF METAL WIRES

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Properties of metal, alloy and ceramic nanopowders are largely determined not only by the size of the resulting nanoparticles but also by the degree of their activation and peculiarities of their internal. The size of nanoparticles manufactured by most technologies is tens of nanometers or more. A promising process for the synthesis of nanopowders of predetermined composition is the method of electric pulsed dispersion. The purpose of this work is to investigate fracture dynamics of metal wires having perfect crystal structure with respect to spatial temperature distribution in the course of the electric dispersion process. Simulation of parameter high rate loading influence (heating rate, loading duration) on

internal structure and sizes of generated nanoparticles under metal wire dispersion as well as investigation of synchronous dispersion of metal wires were carried out on the base of the molecular dynamics method. The potentials based on the embedded atom method were used to describe interatomic interactions in copper nanowires. These potentials allow describing the surface properties, defect structure energy, elastic characteristics and a number of other features to a high accuracy, which are critical for the simulation of the electric pulsed dispersion. The simulation was applied to the cylindrical shape copper wire with the ideal structure. The periodical conditions were used along the cylindrical axis of the metal wires whereas a free surface was simulated along the rest two directions. The results showed that an increase of loading duration weakly affected on number of generated nanoparticles. Simulation of synchronous electric dispersion of metal wires showed that not only number of nanoparticles but also their internal structure and sizes strongly depended on distance between wires, in particular, the less distance between wires than less number of generated nanoparticles and larger their sizes. The work was supported by RAS Scientific Program 21 "Basis of fundamental investigations of nanotechnologies and nanomaterials".

TECHNOLOGY OF THE COMBINED PULSE-PLASMA WORK-HARDENING OF HARD-ALLOY TOOLPIECE

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Know-how of the combined ion-plasma technology consists of the simultaneous use of two methods of plasma treatment of surface of solid: treatments by powerful ionic bunches (PIB) of carbon and by ion-plasma causing of covering in the method of condensation with ionic bombardment (CIB). Technology is worked out as it applies to accelerating of powerful ionic bunches of "Temp-6", modernized by means of placing in his working chamber of the module of for causing of ion-plasma coverage and system of fall-over of reactionary gases.

Experiments are executed on standards of carboloy MC221. At the combined treatment next operations were conducted: (1) cleaning and activating of surface by means of influence of 1 pulse C^+ ($n = 1$, energy of ions of $E = 300$ keV, closeness of ionic current of $j = 120$ A/cm^2); (2) overcoating of sublayer of titanium (0.5 μm thick); (3) overcoating of TiN of 2–3 μm thick (current of arc 100 A, tension on a cathode 160 V,

pressure of nitrogen in a chamber 0.6 Pa); (4) ionic interfusion of material of coverage with the surface of material by means of PIB ($n = 3$, energy of ions of $E = 300$ keV, closeness of ionic current of $j = 150$ A/cm^2).

X-ray analysis of the modified superficial layer showed the presence of phases of WC, TiC, δ-TiN, α-Co and α-Ti. As a result of influence of bunch of ions in the superficial layer of carboloy, composition structures is formed, providing the decline of coefficient of friction, increase of microhardness and wearproofness of surface.

The results of model tests of cutting hard-alloy plates of tangential type (from the carboloy MC221) showed at the draft sharpening of carriage wheelpairs, that application of technology of the combined treatment on the basis of impulsive ion-plasma influence provides the increase of firmness of instrument in 2.5 times.

PULSED TREATMENTS IN MODERN MICROELECTRONICS

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Pulsed thermal treatments of semiconductor structures have been widely used in microelectronics since 1980th to eliminate post-implantation defects, create highly doped epitaxial layers, synthesize compounds, form contacts, etc. The process requires various sources of pulsed radiations (first of all lasers and flash lamps) in a wide range of power density and treatment duration. The work analyses the non-stationary temperature fields in the semiconductor structures caused by intensive light, electron and ion beam irradiations in a wide duration range from 10^{-9} to 10^{1} s. Physical mechanisms of energy absorption and transformation as well as phase and structural transitions in irradiated materials are considered. In the nanosecond duration range characterized by the liquid-phase mechanism, conditions for the fast local crystallization without growth defects leading to the formation of highly concentrated solid solutions and the oriented compounds are realized. The pulsed light treatments of micro-milli- and second durations are the most widely used. They provide good compatibility with planar technology in microelectronics and are currently described by a steady term—Rapid Thermal Annealing. The process is accompanied by the solid-phase elimination of defects, high electrical impurity activation, diffusion suppression. The schemes and technological possibilities of the laser treatments by rapidly scanning beams of contin-

uous laser radiation (Spike Laser Annealing) are illustrated. Using of the specially focused laser beams allows to provide pulsed high-temperature processing without considerable temperature gradients and impurity diffusion. The perspectives of the development of the pulsed methods when going over to nanometer (about 10 nm) technologies in microelectronics and creation of new functional materials and structures are considered.

PULSED BEAM SYNTHESIS OF NANOCRYSTALLINE IRON DISILICIDE FILMS FOR SILICON MICRO- AND OPTOELECTRONICS

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In recent years the actual problem of micro- and optoelectronics is the creation of efficient Si-based light emitters operating in the telecommunication range of 1.5–1.6 micron. One of the perspective materials for the fabrication of light emitting diodes is semiconducting iron disilicide ($(\beta$-$FeSi_2$) which has luminescent properties in this spectral range. In this work the technology for the creation of triple Si/β-$FeSi_2$/Si heterostructures (with β-$FeSi_2$ nanocrystals in active region) is demonstrated and their structural, optical and electrical properties are investigated. At the first stage of heterostructure fabrication silicon monocrystals were implanted by iron ions (Fe^+) with energy E = 40 keV and fluence F = 6x10^{15}-6x10^{16} cm^{-2} (concentration N = 1–10 at. perc. in 100-nm layer). At the second stage the implanted Si layers were subjected to pulsed treatments by intense laser (λ = 0.69 micron) or ion (C^+, E = 300 keV) beams of nanosecond duration (τ = 50–80 ns) for Si crystallization and synthesis of iron silicide. At the third stage the surface of the implanted crystals was cleaned in ultra high vacuum at 800°C and covered by epitaxial Si film with thickness of 300–500 nm by molecular-beam epitaxy method. At the different stages of fabrication process the crystallinity, phase composition, surface morphology, Fe depth distribution, photoluminescence and electrical parameters of Si/β-$FeSi_2$/Si heterostructures were studied. The optimum parameters of ion implantation, pulsed and thermal annealing which resulted in to formation of oriented β-$FeSi_2$ nanocrystals emitting light in the near infrared range and growth of epitaxial Si films with increased conductivity and carrier mobility are determined.

A WAY OF PRODUCING GRAPHENE BY PROTON BOMBARDMENT OF GRAPHITE SAMPLES

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Proton bombardment of graphite samples produced graphene on their surfaces. Samples were graphite rods having 6mm in diameter and 100mm in length. Cut-outs were made in the middle of each rod. Cut-outs were 20mm long and 3mm in diameter. Proton exposures were $4 \cdot 10^{15}$ and $2 \cdot 10^{16}$ protons per square cm in high-vacuum environment. Samples surface topography was investigated with a scanning cantilever Veeco Dimension V microscope and a raster electron FEI Quanta 600 FEG microscope. As the study showed, the graphene structures had surface areas of about 20 square microns.

ELECTRON-HOLE ASYMMETRY IN EXCITATIONS OF BILAYER GRAPHENE IN HIGH MAGNETIC FIELD

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The bilayer graphene is the unique object which combines the parabolic dispersion law of quasiparticles with their chirality. This parabolic dispersion becomes linear far from zero energy point. The tight-binding Hamiltonian for electrons taking into account only nearest-neighbor transitions gives the spectrum which is symmetryic around zero energy. In magnetic field there is a two-fold degenerate zero-energy Landay level incorporating two different orbital states with the same energy. Taking into account spin and valley degeneracies, the zero-energy Landau level in a bilayer is eight-fold degenerate. For the bilayer with small asymmetry there are four weakly split two-fold levels, close to zero.

Inter-Landau-level transitions in the clean (neutral) bilayer graphene at high perpendicular magnetic field have been studied taking into account the next- nearest-neighbor transitions and energy difference between dimer and non-dimer sites. This assumption results in the asymmetry of electron spectrum around zero-energy point. The infuence of Coulomb interaction and layer asymmetry are included. It is shown that asymmetry in cyclotron

resonance of of clean bilayer graphene depends on magnetic field. At lower magnetic fields the energy splitting in the spectrum is due to electron-hole one-particle asymmetry, at higher magnetic fields the energy splitting in the spectrum is due to Coulomb interaction.

SPONTANEOUS FORMATION OF QUANTUM WALLS DURING CRYSTALLIZATION OF SiC

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Formation and properties of structure defects, arising during crystallization of SiC in a condition of the vapor phase reaction in the high temperature resistive reactor, are discussed in the paper. Interest to the generation of such defects is caused by their unique properties, giving a possibility to realize a high quantum yield of the recombination emission. SiC is a unique material due to its temperature and chemical stability. The high temperature conductivity and the reasonable electron mobility allow using it in the high power electronics. The same properties make it a perspective material for the high power light emitters. However, due to its indirect energy band, SiC demonstrates a low relative efficiency of the recombination radiation. Light emission is a phonon mediated process with a low probability. This work is devoted to a comparative analysis of the efficient radiation arising at the structural defects and their structural properties. On the basis of experimental data the model is suggested for realization of the effective light emitter on SiC material.

CATALYSIS OF IMPURITY COALESCENCE BY QUANTIZED VORTICES IN SUPERFLUID HELIUM

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Any guest nanoparticle suspended in superfluid helium has the affinity to quantized vortex. Such a concentrating in practically 1-D core of vortices causes a tremendous acceleration of coagulation process. Practically whole condensation proceeds then in the vortices and its primary products should be nanowires. This phenomenon has been firstly observed for hydrogen embedded into HeII [1, 2] and then it was used for producing

metallic nanowires. The materials were sputtered by pulsed laser from the targets submersed in liquid helium at $T = 1.6$ K. In accordance with the prediction [2] the long (up to 1 cm length) metallic nanowires grown HeII were attached by metallic bonds to the tips of electrodes to which the generating them vortices were pinned. This effect allows carrying out the electrical studies of metals just at low temperature. The nanowires made of conductive gold and copper [4, 5], ferromagnetic nickel and superconductive lead, tin, and indium [3, 6] were grown and investigated. Electron microscopy of the filaments heated up to room temperature has shown that they represented the bundle of the nanowires connected by point contacts. The nanowires had the diameter of 2–7 nm and they consisted of conjunct monocrystals having regular structure. The bundles of nanowires just grown at $T = 1.6$ K metallically closed two neighboring electrodes spaced by 3 mm and consequently closed the electrical circuit. Being conductors of metallic type they demonstrated the strong size effect inherent for nanowires, namely strong growth of specific resistivity and, for superconductors, the transformation and temperature shift of phase transition. Due to their high length and small radius the bundles of nanowires demonstrated powerful field-induced electron emission at rather low voltage and represented such a way the prototype of effective cold cathodes. The crystalline structure of nanowires and nanospheres evidenced that they were molten inside HeII during their growth. The explosion of stressed under cooling metallic spheres initiated by e-beam has been observed.

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PREDICTION OF HIGH-POWER PULSED HEATING OF A POROUS BLOCK CONTAINING KEROGEN

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The development of hard-to-extract hydrocarbon reserves becomes important at the prospect of exhaustion of easily accessible sources of hydrocarbons. These include the deposits such as a kerogen containing formations. The kerogen is able to decompose with the formation of light oil fractions as a result of pyrolysis reaction. The extraction of hydrocarbons from such deposits will require a high-power pulsed heating, which is necessary for pyrolysis reaction and distributed damaging of the porous skeleton. The main processes are: pulsed thermal action, pyrolysis reaction of the kerogen in porous medium, distributed damaging of the skeleton due to the damage accumulation caused by the pressure increase and heating [1], flow of the pyrolysis products through the medium with variable permeability, heat transfer. For this problem it was used the thermodynamically consistent theory of saturated porous medium [2], [3]. The medium is considered consisting of two interacting continua (fluid and skeleton) which can exchange mass, momentum and energy. The main assumptions are as follows: the skeleton is assumed to be elastic and damaging; the permeability is considered as a power function of porosity; the kinetic equation with reaction rate constant of Arrenius type is used for modeling the pyrolysis; the damage is assumed to be a linear function of state parameters. The equations for energy porous pressure, skeleton deformations and kinetic equations for reaction and damage accumulation has been solved to predict consequences of pulsed heating of porous block containing kerogen. It was investigated the output of oil from porous block with various methods of heating.

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WIDE-SIZE ELEMENTARY CELL OF THE HETEROGENEOUS MATERIALS WITH THE COLLAPSING DISPERSE BINDING

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Methods of the communication description of effective heterogeneous materials (HM) properties with characteristics of their components represent considerable practical interest. For a long time these methods intensively develop. With reference to mechanical ionizing radiation (IR) action on the condensed heterogeneous environments the construction of the equations describing HM behavior at a stage of formation of a pressure profile in a target was realized in [1].

In the present work the method of defining equations construction in case of the temperature nonequilibrium HM is offered. Wide-size nonequilibrium model of an elementary HM cell having dispersed filler is constructed. This construction is realized proceeding from the assumptions accepted in [2]. Calculation of stress relaxation within an elementary cell is based on the solution of two-dimensional equations system for elastic-plastic equilibrium in cylindrical coordinates. This system is, added by wide-rise EOS of HM components. The offered wide-size HM cell model allows calculating behavior of a material in all representing practical interest range of absorbed energy density (as small energy contributions when elastic-plastic current is impotent and big energy contribution when phase transitions are determinative). These calculations become taking into account heat exchange influence between HM on process of a quasistatic establishment of stress fields.

The great attention at construction of HM cell model is given to the account of structural features of the multilayer microspherical fillers. These fillers are used in heterogeneous coverings for protection from IR. Stability loss (it takes place for thin microspheres with the small relation of a thickness to radius), destruction and irreversible microspheres collapse are considered.

Calculations results of stress profiles in heterogeneous coverings having dispersed filler from glass and carbon microspheres ((these microspheres have coverings consisting from tungsten and nickel)) are discussed.

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MODELLING METHODS FOR MECHANICAL RADIATIONS ACTIONS ON THE THIN-WALLED

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Now mechanical radiation action (MRA) of various spectrum ranges on matter [1, 2] is enough studied in detail. However isn't obviously possible that experimental research of MRA consequences on designs of space-rocket technics. In work on the basis of MRA analysis various wave lengths, fluxes density streams, external conditions and properties of constructional materials requirements to characteristics of non-stationary loadings which are necessary for reproducing at strength tests of the designs working in the conditions of an irradiation are formulated. Proceeding from these requirements, the complex of explosive gasdynamic devices is offered. This complex allows to modeling MRA from an optical spectrum to rigid x-ray ranges on large-sized thin-walled cases of designs. Directions and problems of the further development for modeling MRA explosives are formulated. In a final work part the methodology [3] carrying out of tests of composite designs on durability by means of explosives is offered. Experimental researches results of r of the empty and filled thin-walled composite cases in the conditions of their functioning [4, 5] are resulted. Possible causes of infringement of working capacity of designs depending on levels and duration of lateral non-stationary loadings influencing them are discussed.

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DEFINITION OF RATIONAL PARAMETERS OF HETEROGENEOUS COVERINGS STRUCTURE FOR PROTECTION OF THIN-WALLED MULTILAYERED DESIGNS AGAINST JOINT THERMAL AND MECHANICAL ACTIONS OF RADIATIONS AND PARTICLES

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Despite variety of the physical processes accompanying influence of intensive radiations and particles streams having various physical nature, destruction of thin-walled bearing designs occurs as a result of heating, change of a thickness at thermal ablation, a splitting off and also under the action of the non-stationary pressure formed on a design surface. Thus at definition of rational coverings parameters the problems solution is required in following three concerning independent directions.

1. Numerical modeling of radiations and particles transposition in atmosphere and in multilayered heterogeneous barriers to calculate energy allocation taking place in designs;
2. Calculation of parameters of thermal and mechanical actions of intensive radiations and particles fluxes;
3. Numerical modeling of deformation, loss of stability and destruction of non-uniformly warm thin-walled design from a variable (owing to non-uniformity of ablation and thickness of a splitting off) thickness under the action of non-stationary loading.

For the solution of the first and second groups of problems authors have a set of the original techniques [1] developed during several tens of years. The essential moment is working out of a universal numerical code [2] for the third direction.

To notice that the approach accepted in work at which rational coverings parameters are defined on the basis of the data on parameters of protected design reaction realized on radiations and particles action is new. As a rule, the covering is optimized separately from a protected design at aprioristic preset values of factors of passage and as much as possible admissible impulses of the pressure formed in a covering.

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RECOMMENDATIONS FOR COMPOSITION AND STRUCTURE OF HETEROGENEOUS COVERINGS FOR PROTECTION AGAINST THERMOMECHANICAL ACTION OF IONIZING RADIATION

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It follows from works [1–3] that heterogeneous coverings have hypersensibility of ionizing radiation (IR) action parameters to their composition and structure. At a design stage this circumstance demands carrying out of preliminary numerical researches for definition of rational sheetings parameters. In case of IR influence the scientifically-methodical technique is intensively developed for numerical modeling of physical processes in composite structures of various types [3, 4]. Now this technique has sufficient accuracy that allows carrying out calculations of IR energy absorption and wave processes in structured materials.

Multiple calculations of thermomechanical action have been carried out. These calculations had the purpose of a choice of rational parameters for coverings having structure and characteristics gradient. Such coverings enjoy the big capabilities for variability of structures elements. At calculations the numerical code [2] was used.

As calculations results composition and structure recommendations for heterogeneous new generation coverings are formulated. Rational coverings parameters to correspond concrete characteristics of fluxes of Plankś radiation are considered.

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ATOMIC CASCADE NUCLEATION AND DEVELOPMENT IN V ALLOYS UNDER RADIATION LOADING

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Investigations into structural damage to materials under irradiation are of particular interest for long-term predictions of changes in their mechanical properties. Primary evidence for the radiation effect is generation of atomic displacement cascades responsible for radiation-induced structural defects, formation of microstructures, and changes in the physical-mechanical properties of materials.

In present work the study of structural defect nucleation and development which arising as a result of atomic cascades in V based alloys under radiation effect is represented. The investigation was carried out on the base of molecular dynamics method with use of multiparticle interatomic potentials calculated in the scope of modified embedded atom method. The V-4Ti-4Cr alloy was considered as a model material. At that simulated crystallites as with ideal structural so with grain boundary were used. In the calculations special type symmetrical tilled boundaries were used. In order to simulate atomic cascades generation primary knocked atom (PKA) was supplied with the energies in the range of 1–10 kEv. For each PKA energy crystallite size was determined in such a way to exclude self-action of atomic cascades from the one hand and to minimize calculation time from the other hand.

Calculations showed that structural defects (Fraenkel pairs) began to arise after atomic cascades were generated. Some Fraenkel pairs could join into clusters. It should be noted that the presence of grain boundaries substantially affect the structural material response under irradiation loading. In particularly the number of stable defects formed late in the relaxation stage depended on the distance of the PKA from the grain boundary: the greater the distance the smaller the number of defects generated in the crystallite. As the distance from the grain boundary increased, the number of defects tended to a value characteristic of the material with ideal

structure. There was a threshold energy-dependent distance of the PKA from the interface: starting with this threshold distance this type of grain boundary becomes an insurmountable obstacle for atomic displacement cascades generated by a PKA of lower energy.

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THERMOLUNISCENCE DOSIMETRIC DETECTOR BASED ON SYNTHETIC DIAMOND

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Several types of thermoluminescence detectors are currently used in the individual dosimetry, but a selection of detectors with optimal characteristics is required for the solution of certain dosimetric tasks.

Thermoluminescence of diamond is known for long time; however it has not wide practical application in dosimetry owing to high cost of material as a main reason. Essential advance in a creation of synthetic diamonds has been achieved last years. Since 2000 y. quality of producing diamond material has been comparable with quality of the most clear natural crystals, some of the laboratories get diamond material better quality than natural diamonds. Cost of the synthetic diamond material became available, that gives the capability of the creation of diamond thermoluminescence dosimeters for the wide application in the systems of the individual dosimetric monitoring.

This work is dedicated to research the possibility of creation TL dosimeter based on synthetic diamond material. Influence of the different doped centers typical for synthetic and natural diamonds on the thermoluminescence intensity is studied in this work. The experimental set-up based on the high sensitive photomultiplier was built to record thermoluminescence curves. Glow curves for the different types of diamond samples are shown.

In terms of thermoluminescence analysis of the experimental material was produced the sample of synthetic diamond with required properties and TL detector using this diamond as a basis was created. The complete research of the dosimetric characteristics of this sample was conducted, the estimation of activation energy was made and linearity of this detector in the range of radiation dose from 0.001 to 10 Gy was shown. Under the radiation dose more than 10 Gy the detector response is not linear and it saturates under the dose of 200 Gy.

The experiments shown that diamond as a thermoluminescence dosimeter has a high sensitivity compared with a serial TL dosimeters (DTG-4 for instance). High sensitivity of diamond TL detector in principle is allowed to record a natural background radiation with less than day exposition. Low-nitrogen samples (type 2a) with some inherent defects of lattice (expected dislocations) are most appropriate to create TL diamond detectors.

HYDROGEN INFLUENCE ON CARBON PARTICLE FORMATION IN MICROWAVE FLOW REACTOR

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Hydrogen presents in variable concentrations at carbon particle formation process from hydrocarbons pyrolysis. Current kinetic models suppose an important role of hydrogen during soot particle growth. Quantitative knowledge about the influence of hydrogen, however, is missing. In this study carbon nanoparticles were formed during plasma-heated flow-reactor pyrolysis of hydrocarbons. This process is characterized by high temperature (about 6000 K [1]) and continuous generation of carbon material. A molecular beam sampling system was used to extract particles as well as gas molecules from the reactive source. The sample is rapidly expanded into the free-molecular regime. This expansion leads to a temperature drop, thus freezing all chemical and physical processes almost completely. This molecular beam technique is regarded to be non-intrusive. The center of the hypersonic jet is cut out by a skimmer and propagates as a "particle loaded" molecular beam into the high-vacuum chamber where the particulate fraction can be analyzed by means of a particle mass spectrometer (PMS) described in detail in [2]. It allows determining the particle mass distribution by combining measured particle kinetic energy and particle velocity. Furthermore, formed particles were collected on grids and analyzed by transmission electron microscopy (TEM). Mixtures of hydrocarbon precursors (CH_4, C_2H_2, C_2H_4) with and without hydrogen additives in argon were investigated. The concentration of each precursor was varied as well as $[H_2]/[C_xH_y]$ ratio. It was observed that hydrogen addition does not influence final particle sizes. Only weak influence of hydrocarbon concentration was found. TEM measurements are resulted in larger mean particle size than PMS. The difference can be explained by the fact that

particles were assumed spherical when processing results of PMS measurements, but real particles formed under investigated conditions can have non-spherical shape. The particle properties are discussed.

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MICROWAVE INDUCED TRANSFORMATIONS OF SELENIUM POLYMERIC NANOCOMPOSITES

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Nanoselenium structures and its derivatives still remain the attractive subjects of investigations in many laboratories of the world. Its present and future applications are very wide. There are the scope of research works in medicine, electronics, photonics, power-engeneering etc. Selenium has a number of modifications. For some applications in electronics and photonics the most interesting is the nanocrystalline hexagonal gray semiconductor selenium. The usual way of such synthesis is the heating of amorphous modifications polymer or surfactant stabilized nanoselenium or ultrasound treatment [1, 2]. It was very interesting for us to use microwave treatment of dried films of polymeric selenium nanocomposites for study the process of transformations and crystallization of amorphous red selenium into gray hexagonal semiconductor nanocrystalline form. This research is pioneers one, there is no any communications about such work. Nanocomposite films were prepared with the same way as mentioned in our previous communication [3]. Samples received were treated in microwave oven in different gas atmosphere. For detection of their changes optical microscopy, laser scanning confocal microscopy, electron scanning microscopy, Raman spectroscopy, X-ray study were used.

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INTERACTION OF A HIGH ENERGY ELECTRON BEAM WITH ORGANIC COMPOUNDS IN THE CONDENSED STATE: RESEARCH OF PRODUCTS BY A GC/MS METHOD

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The experimental technique for research of interaction of a pulsed high-energy electron beam on organic compounds is developed. For the researches the portable electron accelerator RADAN with the following parameters was used: electron energy—180 keV, beam current—400 A, pulse duration—3 ns, pulse repetition rate—up to 10 Hz. The experimental cell allowed to process thin layers of organic materials in a liquid or solid state. For the analysis of volatile products the method of gas chromatography with mass-selective detector (GC/MS) was used. Correlation of chromatographic peaks with definite compounds was made with the aid of mass-spectral data bases NIST. Researches of some compounds were carried out: hydrocarbons, its halogen-derivatives, and other functionally replaced derivatives (carbonyl compounds, etc.). It is shown that process of interaction of high energy electron beam is accompanied by change of structure of organic molecules in the following basic directions:

1. Binding of carbon skeletons of molecules to dimer-like structures;
2. Breaking of a molecules carbon skeletons;
3. Eliminating of hydrogen atoms with formation of molecular hydrogen. Also low-molecular products such as CO, CO_2, CH_4, etc.
4. Eliminating of active atomic halogen from halogen-derivatives with subsequent its reaction with walls of a reactor or elimination of hydrogen from a molecule of a starting compound.

This radiolysis technique allows to carry out operative researches of objects and does not demand application of radioactive materials. With the use of corresponding calibration it is possible to receive power parameters of plasma-chemical yields.

The received data will be useful for:

1. Researches of radiation stability of materials and researches of corrosion stability of constructional materials during by processing with halogenated compounds.

2. Modification of physical and chemical properties of matter.
3. Development of new technologies of recycling of important ecotoxines, such as halogenated compounds (polychloro-bipheniles, chlorophenoles, dioxines, etc).

The work is supported by RFBR (project No. 10–08–01085a).

STRAIN RATE AND TEMPERATURE EFFECTS ON THE FLOW STRESS AND STRENGTH OF METALS UNDER SHOCK-WAVE LOADING AND APPROACHING THE IDEAL STRENGTH

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Recent studies of response of metals and alloys to shock-wave loading at elevated temperatures disclosed new phenomena which could be expected but had not been discussed previously. It is well known that, under normal conditions, the yield strength of materials decreases with heating. However, the shock-wave measurements at elevated temperatures show that the influence of temperature on the yield stress at very high strain rates in some cases may be opposite to that at low and moderate strain rates. An anomalous growth of the dynamic yield strength was observed for several metals and interpreted as an evidence of a transition in the rate-controlling mechanism from the dislocation motion aided by thermal fluctuations to the phonon drag mechanism of over-barrier motion. At the same time, the dynamic yield stress of high-strength metals and alloys decrease monotonically or is maintained practically constant with heating.

With the goal to systematize temperature effects we performed measurement of decay of the elastic precursor wave and the rise time of plastic shock wave in commercial aluminum AD1 and magnesium Ma2 at shock compression at normal and elevated (up to 900 K) temperatures. These data and the data from femtosecond laser shock experiments have been treated in terms of strain rate and strain dependences of the flow stress. It has been found the dependences are much weaker than expected ones for the phonon drag mechanism and the characteristic viscosity decreases with development of plastic deformation. The new and published earlier data are discussed in terms of relationships of different mechanisms of plastic deformation and on this base requirements to constitutive models for high strain rates are formulated. The yield stress and tensile strength data at shortest load durations are discussed in terms of approaching ultimate shear and tensile strength of metals.

SPALL STRENGTH OF Al BY HIGH SPEED TENSION IN SHOCK WAVE

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In the present report ultrashort laser driven shock waves were studied experimentally. The source of femtosecond laser pulses was Ti:Sapphire laser system, generated pulses of 300 fs duration and energy up to 2.5 mJ. The pump-probe technique combined with interferometric microscopy was used for determination of the displacement of rear surface of a target with an accuracy of several nanometers and temporal resolution of 10^{-13} s [1]. In the experiment the Al films of the different thicknesses 500, 750 and 1200 nm, deposited on a glass substrate was used. Using rear surface time velocity history the spall strength of aluminum films equal to the value $\sigma_{spall} \sim$(6.8±1.1} GPa at the record strain rate of 10^9 s^{-1} was determined.

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THE INFLUENCE OF THE METALLIC ADDITIONS IN THE GRAPHITE POWDER ON PARAMETERS OF POLYMORPHOUS TRANSFORMATION TO DIAMOND

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The investigation of influence of the metallic powders, as additions to graphite powder, on parameters of polymorphous transformation of graphite to diamond was carried out. The tested samples, consisting of the graphite (5% rhombohedral crystal structure)/aluminium powder mixture and graphite (5% rhombohedral crystal structure)/copper powder mixture in different concentrations were loaded. The concentrations of the metallic addition to sample mass were 30% and 50% for aluminum powder and 81%, 65% and 44% for copper powder. Uniaxial shock loading of mixture graphite samples were created with a plane aluminum impactor of 5mm thickness accelerated by explosive facilities up to velocity of 3.15 km/s. In the experiments, VISAR laser-Doppler velocimeter was used for recording the particle velocity history of interface between the sample and LiF win-

dow. For mixture graphite/aluminum, the phase transition pressure was found 21.53 GPa and 20.37 GPa for the concentration 50/50 and 70/30, correspondingly. For graphite samples with copper additions, the transition pressure of graphite to diamond is higher in comparison with pure graphite samples and it equals to 27.3 GPa and 22.67 GPa for the concentration 35/65 and 56/44, respectively.

SHOCK-INDUCED TRANSFORMATIONS OF ROCK-FORMING MINERALS IN CONDITIONS OF STEPWISE SHOCK COMPRESSION OF SOUTHERN URAL'S QWARTZ-FELDSPAR-BIOTITE-GARNET SCHIST

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Rock-forming minerals (garnet 40–45 vol. %, biotite 20–25 vol. %, quartz 5–10 vol. %, potash feldspar and plagioclase 10–15 vol. %) transformations in conditions of planar stepwise shock compression have been studied with the use of recovery assemblies of planar geometry. Experimental samples have been taken from Southern Ural (Russia). The maximal shock pressures in experimental samples were equal 26, 36 and 52 GPa were attained upon a few reverberations of the waves between the walls of the recovery ampoule (stepwise shock compression) (see [1] for details). The recovered samples were examined by the methods of optical and scanning electron microscopy (SEM), microprobe analysis, and X-ray phase analysis (XPA).

Diverse minerals reveal different degree and various types of transformations: mechanical (fissuring, amorphization and etc.) and chemical (bringing and carrying out of different compounds). The strongest transformations (both mechanical and chemical) were observed in potash feldspar and plagioclase. These minerals undergo strong amorphization at 26 GPa already: at this pressure most part of plagioclase (89 weight %) and potash feldspar (94 weight %) become amorphous. Plagioclase chemical transformations are equal to results of earlier stepwise shock compression experiments [1]. The greater shock compression is, the more potash feldspar chemical transformations result in K carrying out. Biotite also reveals strong mechanical (stripes of contortion, partial melting) and chemical (for melted biotes only) transformations. Garnet reveals mechanical transformations only. Chemical changes of garnet result in dispersion of

chemical composition growth. The work was supported by RFBR (09–05–00211).

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YTTRIA-DOPED TETRAGONAL ZIRCONIA: TECHNOLOGY OF MANUFACTURING, STRUCTURE, MECHANICAL PROPERTIES AND SHOCK BEHAVIOUR

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High-density, hard and durable, wear-resistant refractory materials based on partially stabilized zirconium dioxide (PSZD) are among the most perspective ceramics of new generation, having a complex of high performance behavior. High strength properties of PSZD ceramics are based on PSZD transformation reinforcement mechanism, which happens due to polymorphous transition of the tetragonal phase into the monoclinic phase, initiated in a stress field.

We have introduced a new technology of manufacturing ceramics based on zirconium dioxide, partially stabilized by yttria, out of fine-grained powders, obtained by a heterophased chemical deposition method. The main properties of the manufactured ceramics have been characterized by us: density of 5.79 $\mathrm{g\,cm^{-3}}$, bending strength of $\sim$ 800 MPa, crack resistance of $\sim 8\ \mathrm{MPa\,m^{0.5}}$, microhardness of $\sim$ 15 GPa and others. The microstructure and phase structure have been also investigated. The average size of sintered ceramic grains was 0.6 micron. It was established that the investigated ceramics consisted of 93 mass % tetragonal and 7 mass % monoclinic phase and had X-ray density of 6.18 $\mathrm{g\,cm^{-3}}$. We have also obtained longitudinal and transversal sonic speed relation to the frequency range of 1.25–10 MHz. The measurements have shown dispersion occurrence. There was established a fair quantity of monoclinic phase appearing after a mechanical effect. At dynamic loading the PSZD ceramics had shown high efficiency in Hugoniot elastic limit and spall strength.

ALUMINUM-FULLERENE COMPOSITE PRODUCED BY HIGH-PRESSURE TORSION

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Al–C_{60} fullerene composites were produced with the use of severe plastic deformation (SPD) through high-pressure torsion. Al and C_{60} powders were mechanically mixed and preliminary compacted using piston-cylinder pressure cell. The preliminary compacted specimens (compacts) had a diameter of 10 mm and a thickness of 1 mm. The compacts were placed between anvils of HPT machine, subjected to high pressure, and then the upper anvil was rotated with respect to the lover anvil at a rotation speed of 1 rpm. Rotation was terminated after 5 turns. Mass fraction of C_{60} fullerene in the composites was 10, 20 and 30%. In addition, reference specimens were produced only of pure Al ASD-6 and only of pure C_{60} powders. In the latter case, rotation was terminated after 3 turns because of extrusion of the material from the cavity. In order to study SPD-induced transformations in detail, two of specimens containing 20% of C_{60} were produced with the use of reduced SPD procedure (two and three terns only). Microstructure of the specimens was characterized with the use of x-ray diffraction, atomic force microscopy, electron microscopy and Raman spectroscopy. Spatial-resolved maps of chemical composition of the specimens were studied, too.

According to x-ray data, an apparent grain size of aluminum crystals in the composite specimens decreases with the SPD intensity. Aluminum crystals on the surfaces of all specimens had preferable orientation. Microhardness of the specimens was up to 2.5 GPa and seems to be determined by the properties of the metal matrix. Raman spectroscopy reveals that C_{60} molecules were not damaged by SPD. The work was supported by the Swedish Institute (00906–2009) and RFBR.

METALLIZATION OF MONOXIDE MnO UNDER HIGH SHOCK PRESSURE AND TEMPERATURE

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It is known that in many substances metal-insulator transitions can not be explained by the one-electron band theory and usually associated with electron interaction. For example in compounds of transition and rare earth metals the electrons of internal partially filled d- or f-shells are localized in the ionic core. Their transfer to the neighboring ions that is required for the appearance of metallic conduction is impossible due to the large loss in energy-electron interaction. Substances which are insulators for this reason (Mott insulators) and the insulator-metal transition in such systems are widely studied under static conditions using the diamond anvil cell basically at room temperature [1]. This paper presents experimental data of metallization of manganese oxide under high shock pressures and temperatures (multiple-shock compression). The electrical properties of manganese monoxide MnO investigated using advanced techniques of step shock compression in little-studied region of pressures up to 100 GPa and temperatures up to 4000 K. The experimental data of electrical conductivity with their mathematical modeling can marked the insulator-metal transition of manganese oxide in the previously unexplored area of temperatures and pressures.

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CONDUCTIVITY OF SHOCKED DENSE PHASE MAGNESIUM HYDRIDE AND ITS EQUATION OF STATE UP TO 150 GPa

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Magnesium hydride MgH_2 has been intensely studied as one of the most promising materials for hydrogen storage. The large hydrogen content of MgH_2 leads to other interesting properties. As noted [1] the "light" hydrides such as SiH_4, AlH_3, or MgH_2 might also be high-Tc superconductors. Recently possible metallization of alane at high pressure along the quasiisentrpeic compression up to 100 GPa has been investigated experimentally [2]. The results obtained are sufficiently encouraging to prompt similar studies of MgH2 as well in wider range of pressure and temperatures. In this work transition possibility to the conducting condition of magnesium hydride due to "chemical precompression" of hydrogen in molecule MgH_2 was investigated. High pressures and temperatures were obtained with an explosive device, which accelerates the metallic impactor up to 3 km/s. Use of a step mode loading has allowed lowering an irreversible shock wave heating up of the sample. The sample represented the pressed tablet in diameter of 8 mm and thickness of 0.5 mm with initial resistance more than 10 MOhm. On received values it is calculated specific electrical conductivity of the sample.

The equation of state was constructed on high pressure ithoherms [3]. Using the constructed equations of state of dense phase MgH_2 the temperatures and volumes of shock compressed samples have been calculated. In the experiments at pressure 100–145 GPa temperatures 2000–2500 K were reached. In experiments with magnesium hydride occurrence electrical conductivity about 0.01 (Ohm·cm) is registered at pressure 110 GPa since which conductivity of the sample becomes comparable with conductivity manganin shunt.

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FRACTIONAL RESISTANCE CHANGE OF SHOCKED POLYMER ENVIRONMENT IN CONDUCTIVITY EXPERIMENTS UP TO 150 GPa

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The conductivity of organic composition composed by Teflon film with Vacuum Leak Sealant (TVS) is investigated under high multiple shock up to 150 GPa. The measuring cell of conductivity duplicates the measuring cell for fractional resistance change δ of manganin gauge in [1, 2]. But in contrast to this in present work the manganin transducer is considered as shunt resistor for TVS environment. The shunt is cemented with the Vacuum Sealant (TY 38.401–58–172–96 in Russian) between two sheets of Tefon films. So the manganin shunt was encapsulated into TVS environment with effective resistance R_e. Our data on coincides with [1, 3–5] up to 40–70 GPa. So the environment, the gauge shape, a composition of manganin, manner (single shock or multiple shock regime) have little or no effect on function δ(P) in this shock pressure range. But our data are significantly below the data [3] in 80–120 GPa pressure range. We assume that a Vistal environment in [3] is remained as a well isolator while the organic materials become the partial conductors. Nevertheless our experiments shows that under these conditions, the fractional resistance change of shocked polymer environment did not fail at pressures as high as 150 GPa. We proposed the calculation of resistance correction based on the electrical properties of TVS environment in megabar pressure range. The results showed that the TVS environment can be used in shock pressure electrical measurement techniques in megabar range provided that the δ(P) of environment is defined.

This study was partially supported by the Presidium RAS Program of Basic Research "Thermal Physics and Mechanics of Extreme Energy Effects and Physics of Strongly Compressed Matter".

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DEFORMATION AND FRACTURE OF BULK NANOSTRUCTURED MATERIALS UNDER SHOCK-WAVE LOADING. COMPUTER SIMULATION ON MESOSCALE LEVELS

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Researches of the last years have allowed to establish that the laws of deformation and fracture of bulk nanostructured and coarse-grained materials are various both in static and in dynamic loading conditions. Development of adequate constitutive equations for the description of mechanical behavior of bulk nanostructured materials at intensive dynamic influences is complicated in consequence of insufficient knowledge about general rules of inelastic deformation and nucleation and growth of cracks. Multi-scale computational model was used for the investigation of deformation and fracture of bulk nanostructured aluminum and magnesium alloys under weak shock waves on mesoscale level. The increment of plastic deformation is defined by the sum of the increments caused by a nucleation and gliding of dislocations, the twinning, meso-blocks movement, and grain boundary sliding. The model takes into account the influence on mechanical properties of alloys an average grains size, grain sizes distribution of and concentration of precipitates. It was obtained the nucleation and gliding of dislocations caused the high attenuation rate of the elastic precursor of nanostructured alloys than in coarse grained counterparts. It was found the effective spall strength of bulk nanostructured aluminium and magnesium alloys with precipitation strengthening is higher in comparison of coarse-grained counterparts.

FRACTURE OF CERAMIC COMPOSITES UNDER PULSE LOADINGS

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The prediction of mechanical behavior ceramic composites under pulse loadings is the complicated problem owing to insufficient knowledge about laws of structure evolution and nucleation and accumulation of damages. Computer simulation of mechanical behavior of oxide ceramic composites at single and repeated pulse influences of submicrosecond duration are presented in the given work. The model of the structured representative volume of oxide composites was developed using the data of microscopic researches. Deformation and damage of structured representative volumes of some oxide composites on meso-scale level were simulated under pulse loadings having amplitudes near several GPa. The critical fracture stress on meso-scale level depends not only on relative volumes of voids and strengthened phases, but also sizes of corresponding structure elements. It was shown that the isolated micro- and meso-scale cracks can be generated in oxide ceramic composites at pulse amplitude less than the Hugoniot elastic limit. In the studied ceramic composites the critical failure stress in spall zone is changed nonmonotonically with growth of the volume concentration of particles partially stabilized tetragonal phase of ZrO_2.

HYDRODYNAMICAL SIMULATION OF THE DESTRUCTION OF SHOCK-LOADED MATTER USING HOMOGENEOUS NUCLEATION MODEL

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Strong shock loading of metals accompanied by melting and destruction was explored by hydrodynamical simulation. The model of nucleation and growth of pores in liquid described in [1] has been chosen to describe the kinetics of fracture. The model considers the homogeneous nucleation to be the major mechanism of nucleation at the conditions arising during high strain-rate ($\sim 10^6$ 1/s) intense shock loading. The kinetic parameters (the nucleation rate) as well as the surface tension and viscosity as functions of pressure and temperature were taken from the molecular dynamic simulation [1]. The voids growth was modeled accurately according to

the Rayleigh-Plesset equation [2]. The characteristic time of kinetic processes turns out to be 50–500 times smaller then that of the hydrodymanic motion of the medium.

The fracture model described above was introduced into Lagrange Godunov 1D hydrodynamical code. The collision and fracture of aluminum plates was simulated and analyzed. Wide-range multiphase equation of state with metastable phases was used.

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MODEL OF FRACTURE OF LIQUID ALUMINIUM BASED ON ATOMISTIC SIMULATIONS

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Under the action of high energy density fluxes the melting of metal is probable and fracture starts in a liquid phase. However the models for description of fracture kinetics in such a conditions reached just for a short time are hard to verify experimentally. The model of fracture of Al melt under high strain rates is presented. The model is based on nucleation and growth kinetics of voids in a melt under tension. Rates of elementary processes of fracture are evaluated from the molecular dynamics (MD) simulations with several embedded atom method potentials and compared with the predictions of theoretical models. Some substance properties used in the models (e.g. surface tension, viscosity) are calculated from independent MD simulations. It gives a possibility to compare theoretical predictions with direct estimations of nucleation and growth kinetics in the scope of one model systems.

Homogeneous nucleation rate is calculated by means of the statistical averaging of the lifetimes of metastable phase under negative pressure in a temperature range from 1000 to 3000 K. Pressure and temperature dependencies of nucleation rate can be approximated in the form of classical nucleation theory. The temperature dependence of the pre-exponential factor is close to Arrhenius and differs substantially from the nucleation theory [1]. The void growth rate is determined by the non-equilibrium MD. The kinetics of void growth is interpreted within the scope of the

hydrodynamic Rayleigh equation. The results are presented analytically and can be used in the hydrocodes.

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ATOMISTIC SIMULATION OF SHOCK-WAVE LOADING OF ALUMINA

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The work is devoted to molecular dynamics (MD) simulation of shock-wave loading of alumina. Single crystal, crystal with the microcrack and nanocrystaline Al_2O_3 are considered. To describe the properties of Al_2O_3 we use the three-body interatomic potential that takes into account the covalent and ionic nature of the bonds [1]. The splitting of shock wave into the elastic and plastic ones is observed. The dependence of the velocity of the elastic wave on the impact velocity is obtained. It is in a good agreement with the experimental results [2]. The influence of the density on the sound speed is considered in the comparison with experiments. The plastic deformation of single alumina crystal is the result of the slipping along the basal, prismatic and pyramidal planes. The mechanism observed depends on the loading direction. The activation stresses are about 30 GPa for basal plane and 16 for prism and pyramidal planes as well as in ab initio calculations [3]. The velocity of the growth of the defects is about 3–4 km/s. Another mechanism of plastic deformation is observed in the crystal with microcrack and nanocrystaline alumina. The growth direction and slip plane do not correspond to the ordinary mechanisms. The velocity of the defect propagation is about 16–18 km/s. The fast propagation of the defects is in agreement with the experimental results [4]. In the rarefaction wave the fracture is observed. It is initiated on the defects which occur during the plastic deformation. The spall strength is estimated.

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EXPERIMENTAL RESEARCH OF MICROMETEORITES IMPACT ON SPACECRAFTS IN LABORATORY ENVIRONMENT

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The problem of protecting spacecrafts from fluxes of meteoritic matter and space garbage is under decision at the stage of designing. Facility test bench was created to investigate construction materials expose to micrometeorites. Meteoritic matter is a quantity of solid bodies with a size from a fraction of a micron to several kilometers in space. Debris in the 1–10 cm size range are especially hazardous to near-Earth space assets because they are not tracked, but can cause fatal damage. Larger objects can usually be tracked and avoided (although this is becoming more difficult with time), while spacecraft shielding is practical for smaller objects. The 1–10 cm debris were created from explosions or mutual collisions and, because of the range of launch latitudes and inclinations of the source objects, their typical velocity in the reference frame of an orbiting spacecraft is 12 km/s. Their density maximizes in the 400 to 1100 km altitude range [1]. Possible impact velocity would be 14 km/s.

Electroheat gun was developed to provide experimental research. Graphite plasma is an electrons source in it. Electron beam is ejected from central aperture in anode and absorbed by charge of hydrocarbon compound. Barrel unit is non-permanent because of 150k atmosphere pressure and 100k–200k degrees in flash chamber. Barrel assembly can be used many times. Graphite charge mass is 40 mg, hydrocarbon compound—60 mg, driven body—50–60 mg. Energy source is capacitance loop with capacity of 300 mkF charged by 20 kV to 60 kJ. Such energy level lets use only one switchboard that has especial construction.

Mentioned parameters allow to archive velocity up to 14.9 km/s for 55 mg aluminum driven body with efficiency of 10%. Target voltage increasing at 50–60 V after collision was found out. It is used to detect velocity value. There are two time marks. The first is plasma flash detected by photodiode then driven body leaves the barrel. The latter is acquired then target voltage increases. Driven body voltage is positive after leaving out the barrel. The target is mounted on insulators. Results analysis shows destruction mechanism has some changes for velocity value more than 14 km/s.

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HIGH VELOCITY IMPACT OF TUNGSTEN ROD PROJECTILES AT A TARGET

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In the work the questions of high velocity deformation of materials of different density are considered. Influence of velocity of contact on change of the form of the rest of high density projectiles during dynamic contact is investigated. The complex approach to research deformation and destruction of tested materials in conditions of an intensive dynamic loading is executed on the basis of experimental, physical and mathematical modeling with the account of shock wave processes. The experiments were carried out on the ballistic stand. At registration of dynamics of high speed interaction, geometrical and cinematic parameters of a projectile before and behind a target were used high speed and X-ray pulse shooting with application of a complex of the measuring and recording equipment on the basis of digital oscillographes PCS1000 and GDS810 with computer data processing. During experiments a number of features of penetration and deformation of tungsten projectiles is revealed at punching a hole in the steel targets of finite thickness. So, at initial velocities of interaction more than 1400 m per sec the rest of a projectile keep integrity behind a target at the expense of steady penetration because of a high difference of dense characteristics of materials. It is proved to be true by the analysis of results of numerical accounts, where a typical kind of a projectile behind a target also is given. Usually in a head part of a projectile a splitting material because of intensive unloading is observed. At low velocities of interaction in experiments is registered intensive plastic deformation of a head part of a projectile, which results in formation of a spherical particle. This phenomenon is reflected on X-ray photo, received in experience at the following entry conditions: a tungsten core by a diameter of 5 mm and length 100 mm; a steel target by thickness of 23 mm; velocity of impact 950 m per sec. At the further decrease of velocity of impact on X-ray photo the interesting phenomenon is registered. Ahead of a spherical particle is gone a tube. The tube has central hole by a diameter about a diameter of a projectile, and external diameters in 2 times more.

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INFLUENCE OF APPLICATION OF VARIOUS STRENGTH CRITERIA ON FRACTURE DEVELOPMENT IN ANISOTROPIC MATERIALS AT DYNAMIC LOADS

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Composite materials have found wide application in all areas of a modern science and technique. It is known that composites, as a rule, possess high degree of anisotropy of elastic and plastic properties. In work influence of modern criteria of strength on modeling of behavior of fragile anisotropic materials at high-speed interaction is considered. At numerical modeling were used the compact projectile from a steel of mark St3 and a target from orthotropic organoplastic. The range of velocities of interaction from 200 to 1000 m/s was considered. Was applied as tensor-polinomial Ashkenazi's criterion, as criteria Vu and Hoffman, allowing to consider various strength on a tension and pressure. The behavior of high-anisotropic material also was compared with behavior of the material, received from initial averaging of all mechanical properties. As a result of research it has been shown that the picture of an is stressedly-deformed condition is defined by interactions of waves of pressure and tension in a target material, and the account of anisotropy of properties of composite materials is necessary for the adequate description of their behavior at dynamic loadings.

FEATURES OF DEFORMATION AND FRACTURE OF BRITTLE ANISOTROPIC MATERIALS AT HIGH-VELOCITY INTERACTION

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Development of technologies of creation of materials with the set characteristics impulses to use features of anisotropy in all modern branches of technics. The effective usage of elements of designs, whose functioning is possible only by optimization on parameters, is impossible without use of

materials with a primary orientation of properties. It is necessary to notice that in the majority of modern works of an axis of coordinates coincide with the main axes of symmetry of a material. The urgency of researches of behavior at blow is defined by requirement for noegenesis about properties and forecasting of reaction for dynamic loading of elements of designs from anisotropic materials.

In research the model of elastic-brittle behavior of a material was used. As criterion of transition of an anisotropic material in the destroyed condition it was used criterion of Vu. Penetration of the steel compact projectile in anisotropic target with various orientation of elastic and strength properties was modelled. The range of velocities of interaction was from 750 to 3000 km/s. It has been shown that application of anisotropic materials with the set gradient of strength properties is an effective method of creation of designs. The low density and high resistibility to high-velocity loadings allow to use organoplastic in a wide spectrum of application.

MODEL FOR THE SPALL STRENGTH CALCULATION IN THE WIDE RANGES OF STRAIN RATES AND TEMPERATURES

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A wide range of strain rates (from 10^4 s^{-1} up to 10^9 s^{-1}) as well as a wide range of temperatures can be reached in substance of target under the action of pulse irradiation (laser irradiation, electron beam action). Certain values depend on irradiation type, pulse duration and target thickness. Therefore, various conditions accompany the spallation of target, including back surface spallation. For example, in case of the electron irradiation and a thick target, the entire target can be heated by beam, the back surface spallation occurs at raised temperature. Thus a model of fracture with accounting of the strain rate and temperature dependences of spall strength is necessary for simulations. Basing on previous works [1, 2], the model of fracture is developed. Fracture is treated as the process of nucleation and growth of micro-cracks. Thermal fluctuations and initial defects in substance are taken into account in description of cracks nucleation. Defects weaken the substance and precipitate formation of cracks in tensile stresses. The accounting of initial defects (which are supposed to be exponentially distributed) makes difference of this model from the previous versions described in [1, 2]. It allows describing of the strain rate

dependence of spall strength in the range of strain rates from 10^4 s^{-1} up to 10^{10} s^{-1}. The results of model testing are presented in comparison with experimental date [3, 4] and molecular dynamics simulations [5, 6] for the strain rate and temperature dependences of the spall strength. The work was supported by RFBR 09–08–00521-a.

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INVESTIGATION OF SHOCK WAVES AND BOILING JETS FORMATION BY TUBE RUPTURE WITH HIGH-ENTHALPY WATER

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The aim of the present work was to researches the processes of formation of the boiling water flow during dectruction of a tube or tank initially filled by water with high pressure (up to 20 MPa) and temperature (up to 320 C). After full or partial tube disruption the water was boiling and then starting to flow out to the external medium with a shock wave formation. Also the rarefaction wave was moving inside the tube. After some time quasi stationary jet of boiling coolant was formed. The physical and mathematical model of the shock wave and jet formation and evolution was suggested. Using this model taking into account thermodynamical non-equilibrium of the liquid-vapor mixture the conjugated computation of the formation of shock wave structures at the initial stage and the quasi-stationary two-phase vapour-liquid jets in the space behind the tube at next stages was performed.

The amplitudes of the shock waves, form and structure of boiling jet on different distances from the tube rupture were calculated. The influence of the temperature and pressure of the water, diameter of the tube, time of tube cross-section opening on the particulars of forming the shock wave and its intensity were revealed by a series of calculations. For example, it is shown, in particular that due to the influence of the explosive boiling the amplitude of the shock wave is increasing with the increasing of initial temperature of water. Also, the numerical investigation of the wave structure arising in the interaction of the shock wave with rigid wall and forming of the reflected wave was conducted. The structure of the shock waves interactions between each other and with a surface is in a good agreement with a general regularities of gas dynamics. The model was proposed to calculate parameters of stationary boiling up liquid jet, form and density of boiling jet were determined.

A good correlation between calculated values and experimental results is demonstrated.

SHOCK WAVE CONVERGENCE TO THE CENTRE OF SYMMETRY AND A COLLAPSE OF AN EMPTY SPHERICAL CAVITY WITH SUBSTANCE COMPRESSIBILITY CHANGE ON THE REFLECTED SHOCK WAVE

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For simulation of taking place at controlled thermonuclear fusion processes, in particular, metal balls are subjected to shock compression. There are often empty spherical cavities in metal balls after it [1, 2]. Intensity of converging shock wave (SW) infinitely increases in the symmetry centres (further—SC) of the balls. But the solution of the classical problem on convergence of SW to SC gives zero gas density only in the SC, in all other points at any moment the density is distinct from zero. Moreover, beyond of SC's small vicinity the density behind reflected SW is almost constant, and at assuming infinitely high radiant heat conductivity behind reflected SW homothermic model is constant behind the reflected SW. But one can resolve this paradox at the account of that substance compressibility in front of and behind the reflected SW can change owing to additional freedom excitation at heating by SW; in perfect gas model it is described by the adiabatic exponent γ change. At appreciable (an order of 10%) change

of γ on SW extending from SC cavity is formed behind it, in self-similar formulation the temperature in it is infinitely high with vanishing density owing to the pressure in the cavity being finite and isotropic.

Physical and mathematical character features of the problem on reflection SW from a SC and collapse of an empty spherical cavity are similar. Therewith, high temperatures behind SW, going from SC, are also reached. It may cause considerable substance compressibility change.

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INFLUENCE OF HARD-SPHERE REPULSION ON STABILITY OF CONVERGING SHOCK WAVES: HYDRODYNAMIC SIMULATION WITH CARNAHAN–STARLING EQUATION OF STATE

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Hydrodynamic simulations of initially perturbed converging shock waves have been performed on moving (collapsing) grids with equation of state accounting for hard-sphere repulsion on the basis of Carnahan-Starling equation of state [1]. Development of the converging shock wave instability connected with breaking of symmetry of radial flow has been studied. In the first series of calculations the flow was assumed to be adiabatic. Dependence upon packing density of hard spheres η in the pre-shocked state, which controls non-ideality, is investigated. The symmetric converging shock waves in the hard-sphere fluid are found to have Guderley type asymptotics $r \sim (-t)^n$, $p \sim r^{-2(1-n)/n}$, where the exponent n depends on both the ratio of specific heats γ, and on the packing fraction η. It was found that the packing fraction has an effect on transverse shock waves formation and evolution. At high pre-shock density $\eta = 1/3$ calculations of cylindrical converging shock wave have shown stability of radial flow with respect to strong perturbations with the smallest angular period $\pi/2$: the polygonal shaped due to strong initial perturbation shock wave

becomes cylindrical near the focus. Calculations with non-adiabatic flow model, which accounts for radiative energy losses as the product of powers of temperature and density, have shown decreasing of cumulation and stabilization of radial flow. The both effects are observed only if the exponent in temperature dependence exceeds some critical value which depends on the packing fraction and γ.

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NUMERICAL INVESTIGATION OF TRIPLE SHOCK CONFIGURATIONS FOR STEADY CASES IN REAL GASES

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The triple shock wave configuration, or the single Mach reflection, is quite typical for the aircraft internal and external aerodynamics.

Configuration consists of an incident wave of given intensity, the reflected shock wave and Mach wave. The location of the waves in the configuration, the angles between the waves and their intensity depends on the free-stream Mach number M, angle of the flow and ratio of specific heats, the height of Mach waves depends also on the flow conditions downstream.

For steady cases in aerodynamics calculations of these configurations are usually carried out for an ideal gas, since the experiments were carried out at the wind tunnel, operating in air with Mach numbers not more than 6. Physical and chemical transformations do not pass behind shock waves under such conditions. However, at high flight speeds, the ratio of specific heats behind the shock waves is reduced. It is known that in the unsteady case, at the impingement of the shock wave on a wedge in a real gas, there may be new forms of reflection to occur [1]. For a steady case the concept has been suggested for the appearance of new modes of flow in real gases [2].

In this paper a numerical study of flow patterns in intakes in air have been done. The patterns on regular reflection and simple Mach reflection have been obtained. Study were carried out by means of the software system STAR-CCM+, designed for solving problems of continuum mechanics. The default Spalart-Allmaras turbulence model and the ideal gas model is used.

Calculation of two and three shock configuration have also been made analytically with shock polar method. The results were compared with experimental data. Good agreement between numerical and experimental results gives the right to use this method for the future studies of new forms of triple shock configuration.

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NET ELECTRIC CONDUCTION OF DETONATION PRODUCTS OF CONDENSED EXPLOSIVES

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High electric conduction of the detonation products of TNT and its compositions with other explosives has no satisfactory physical explanation. We studied the role of the free carbon in the process of the charges transfer in the zone behind the detonation wave.

The molecular dynamics (MD) method was used for the numerical simulation of the free carbon aggregation in the detonation products. Starting from the initial state with approximately homogeneous distribution of the carbon atoms, the formation of carbon nanoparticles of the linear sizes from 10 to 50 atoms occurs in the substance. Then, the clusters of the nanoparticles are formed with the characteristic linear size about 10 particles. The subsequent dynamics depends on the initial concentration of the free carbon in the detonation products. If the carbon volume fraction is 10 percents and higher then the clusters form the net spatial structures of mesoscopic sizes bridging the opposite sides of the simulation region. The carbon nets are electrically conductive that explains the high conductivity of the explosion products of the carbon-rich explosives. The aggregation is done with the formation of separated clusters if the carbon concentration is small.

The electric conductivity of the detonation products were calculated provided that the charge transfer was possible along only the carbon nets. The clusters obtained in the MD simulations were projected onto a spatial cubic lattice having the sizes that are equal to the sizes of the regions of MD simulations. Those bonds of the lattice that were inside the volume

occupied by the cluster were given the conductivity of graphite. The other bonds were considered to be non-conductive. The results of the calculation of the carbon nets are in a good agreement with the well-known experimental data on the conductivity of the detonation products. The percolation model proposed earlier by other authors predicts the zero value of the conductivity if the volume concentration of the free carbon atoms is less than about 25 percents.

The electric conductivity behind the detonation front of emulsion explosive with very low carbon content was studied experimentally. The conductivity of such explosive is shown to be about an order lower than the conductivity of the carbon-rich explosives. This result confirms indirectly the model proposed.

EXCITATION OF THE ELECTRIC FIELD MICRO-STRUCTURES DURING ENERGETIC MATERIALS UNSTEADY COMBUSTION AND WAVES OF NEGATIVE EROSION

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The phenomenon reduction burning rate as a result of blowing energetic material burning surface with low velocity of the combustion products from the same composition refers to effect of negative erosion. A suggested new concept of the phenomenon of negative erosion is developed on the basis of the universal concept of the spatial-periodic micro-structure excitation on the energetic material burning surface. The key to the understanding of this effect is the electro-chemical phenomena in the reactionary zone of burning energetic material. The electric field micro-structures generated in the heated-up liquid-viscous layer of the energetic material gives the program for formation of cellular-pulsating micro-structures in this layer, on the burning surface, and also for excitation of periodic toroidal vortex micro-structures over the burning surface. It is proposed that the phenomenon of excitation of periodic toroidal vortex micro-structures over the burning surface plays a key role in the realization of the phenomenon of negative erosion. Physical laws of excitation of the toroidal vortex micro-structures over the burning surface have been considered during analysis of the extensive experimental results. The near-wall periodic toroidal vortex micro-structures form a circulating layer with a high thermal conductivity, which intensifies the thermal conductivity of the turbulent core of the

flow. The boundary of existence of the phenomenon of negative erosion is determined by stability of toroidal-shaped vortex micro-structures in the stream of the combustion products which is blowing the burning surface. Within suggested concept, the phenomenon of excitation of the waves of negative erosion is considered.

RESEARCH INTO MILLING OF THE DETONATION DIAMOND-CONTAINING MATERIAL

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The aim of the work is research into milling of the particles of detonation diamond-containing material (DCM). It was applied a treatment with speed of up to 2200 rpm, accel., of up to 1000 m/s^2. DCM-1, synthesized in CO_2 atmosphere from TNT/RDX mixture, was investigated. X-Ray Diffraction (XRD) patterns, Raman-scattering, and infrared (IR) spectra of the products for each point were obtained. The experiments showed that the milling changed the structure of the particles. IR-spectra were interpreted from the standpoint of the nitrogen A-defect destruction. It followed from XRD that destruction of the diamond grains took place. Thus, these particles are based on the chemical bonding, and consist of several components. As a first approximation, we assume that the particles are characterized by limited number of diamond grains; it is likely that they locate in the outer layer of the particle. The density gradient is formed by non-symmetrical distribution of diamond grains and molecular groups and fragments.

DYNAMIC EXPERIMENTS AT TWAC-ITEP PROTON MICROSCOPE FACILITY

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In recent years studies of shock and detonation wave phenomena at extreme conditions have been conducted at proton radiography facility developed at the ITEP Terawatt Accelerator (TWAC-ITEP). The 800 MeV proton beam intensity in these experiments is about 10^{10} particles per pulse. A single beam bunch consists of four consequent 70 ± 5 ns long micro bunches with 250 ± 15 ns intervals between them. Ultra-fast CCD cameras with the synchronization with a single proton bunch from accelerator are used for the registration of radiographic images. The spatial resolution of the facility is about 50 μm. For the generation of shock waves in studied objects the energy of high explosives (HE) is used.

Detonation waves in condensed HE were studied as a dynamic test object at the facility. Series of radiographic images of areal density (i.e. density along the proton beam) of detonating HE charges were obtained in those experiments. From these images detonation wave velocities were found and volume density profiles along the axes of charges were reconstructed. The profiles showed good agreement with the known experimental data obtained by other measurement techniques.

Shock-induced dense non-ideal plasma of argon and xenon is also studied at the facility. Shock pressure P in recent argon tests was from 100 to 1000 bars, temperature T was 8–20 kK with non-ideality parameter Γ of about 1. In similar tests with xenon the values of P=4–6.5 kbar, T= 20–25 kK and Γ=1–2.5 were reached. At several proton radiography images for argon the existence of shock waves propagating in it was registered and their velocities were measured. However, in present experimental setup the observed density gradient in these waves is of the same order as the sensitivity of the technique, so the exact values of density jumps in shock

waves cannot be measured by it for now. It is shown that better results can be expected from next planned experiments with denser gas—xenon.

INVESTIGATION OF DETONATION WAVE STRUCTURE IN EMULSION HIGH EXPLOSIVES

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Emulsion high explosives (EHE) are widely used in practice, but the process of EHE detonation is still not sufficiently studied. In particular, the influence of kinetics of decomposition of EHE on its critical diameter of detonation and other detonation properties is not clarified yet. Therefore the investigation of detonation wave structure in EHE charges of different diameters was conducted at proton radiography facility at ITEP-TWAC accelerator [1] and by VISAR laser interferometer technique.

EHE charges with initial density of 1.07 g/cm^3 in polyethylene shells with internal diameter of 15 mm and 20 mm were studied. The length of charges was 75–80 mm. Using obtained proton radiographic images of density distribution the two-dimensional spatial structure of detonation waves was explored, and also curvatures of their fronts and angles of shell expansion were measured. Multi-framing radiographic registration also allowed us to measure detonation velocity. It was 4.6 km/s for 20 mm charges and from 4.0 to 4.4 km/s in different experiments for 15 mm diameter.

The comparison of EHE density profiles obtained from proton radiography images with particle velocity profiles obtained with VISAR laser interferometer for the same targets shows that there can be different detonation regimes in 15 mm and 20 mm diameter charges. The character of density changes behind a detonation wave front shows that the diameter of 20 mm appears to be close to a critical diameter of detonation. For these charges only a steady-state self-sustaining detonation is observed. However, in 15 mm charges different regimes in different experiments were observed, such as a steady-state detonation, a fading shock wave and some kind of intermediate regime of a fast-going detonation-like process with non-ideal front. So it can be concluded that in EHE charges of sub-critical

diameter non-stationary explosive processes that propagate with supersonic velocities can take place.

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NOMOGRAM FOR FORECASTING DETONATION VELOCITY IN WATER-FILLED RDX CHARGES WITH AIR INCLUSIONS

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It is accepted [1], that detonation velocity of a condensed RDX linearly depends on density with a proportionality factor of 3.33 at a density range of 1.0–1.8 g/cm^3. It is obvious, that charges with a density in this range are porous if the density of a RDX monocrystal is 1.806 g/cm^3. That state of the charge can be characterized by the density of packing ρ_{pack}. The density of the charge will increase, if RDX powder will be mixed with water for deciding technological problems. In [2], the method for forecasting the detonation velocity in a mix charge of RDX powder with water. The forecast of the detonation velocity seems authentic for charges with pores completely filled with water, but not for charges with air inclusions. Experimental data for that charges are not found in the literature.

Three-component water-filled charges with air inclusions can be described by the three parameters: the density of the charge ρ_{mix}, the density of packing of the RDX powder ρ_{pack} and the RDX mass fraction α. As a rule the packing density of the RDX powder is known poorly because of bad adhesion of RDX to water and dispersion of parameters of the RDX powder. Consequently, the forecast of the detonation velocity of the charge is doubtful.

In the report the results of X-ray and grain-size studies of the RDX powder and the analysis of influence of these results on packing density of water-filled charges are presented. The method for forecasting the detonation velocity in water-filled charges with air inclusions is discussed and the nomogram for forecasting the velocity is proposed.

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THE ESTIMATION OF CONDITIONS OF EXPERIMENTAL REALIZATION OF AN ELECTRIC DETONATION

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It is known, a detonation is defined as a shock-wave induced transformation of a substance from its initial state to final state. The process of the substance transformation and stability of detonation parameters is supplited by the energy released in the limited zone behind front of a shock wave.

The detonation can be subdivided on chemical one [1], light one (laser breakdown of gases) [2], electronic one (electric breakdown in solid dielectric from the anode) [3] depending on an energy source.

The electric detonation is the overheated chemical detonation with additional energy release in a chemical reaction zone as heat from the proceeding electric current according to terminology [4]. The chemical reaction zone has the thickness δ and appreciable conductivity σ.

The essence of experimental realization of an electric detonation consists in the organization of an additional energy deposition from an external pulse electric source to the chemical reaction zone of condensed explosives.

Required effect of an expected electric detonation can be the increase of detonation velocity D related to dimensionless ratio: $(D_2/D_1)^2 \sim W_2/W_1$. Here $W_1 = \rho Q$-density of the energy allocated (J/m^3), Q-specific chemical energy of HE (J/kg), ρ-density of substance in an energy allocated zone (kg/m^3), $W_2 = (\rho Q + jE\tau)$-total density chemical and thermal energy by an external electric source allocated in chemical reaction zone (J/m^3), j—current density in a energy allocation zone (A/m^2),E-electric field strength in a energy allocation zone (V/m), ρ—energy allocation time (s).

In the given work the estimation of parameters of a pulse source which produces energy flux density S and specific released electric energy Q in quantities corresponding to similar quantities of the chemical energy is submitted.

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MECHANISM OF GASEOUS DETONATION FORMATION

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There are numerous variants of detonation initiation in gaseous combustible mixtures. The most interesting mechanisms of detonation initiation are deflagration-to-detonation transition (DDT) and detonation ignition by the temperature or concentration non-uniformities presenting in the volume filled with combustible mixture. In the later case a spontaneous reactive wave propagating along the gradient of reactivity and the compression wave generated by the exothermic reaction can couple and evolve into a self-sustained detonation wave or produce a flame and a decoupled shock depending on the gradient steepness. There were a lot of attempts to connect the phenomena of DDT with the Zeldovich gradient mechanism however there were no clear understanding of the problem. This paper represents results of the series of numerical simulations of both problems in different setups. In this paper we used full gasdynamic model of viscous heat-conductive compressible multicomponent hydrogen-based mixture. The equations of state for real multicomponent mixture and detailed chemical kinetics scheme were used. Such approach allows us to investigate the qualitative and quantitative differences in the detonation formation process between detailed chemical kinetics and the predictions from one-step models. The obtained results showed that in case of detailed chemical kinetics model the steepest gradient sufficient for detonation initiation is much shallower compared to that predicted from a one-step Arrhenius model for a highly reactive mixture. The obtained result makes questionable applicability of the gradient mechanism as a mechanism of the DDT in channels. On the other hand detailed computational approach allows us to describe DDT phenomena within channels filled with highly re-

active mixtures. We proposed model of detonation formation out from the accelerated flame coupled with the pressure pulse arisen on the flame surface only due to the features of flame acceleration within channel. Thus one can conclude that one of the possible mechanisms of DDT within channels is the generation of the pressure pulse and its localization within reaction zone. And this mechanism is quite similar to the Zeldovich mechanism of detonation formation due to the coupling of the pressure wave and the spontaneous reaction wave. The final conclusion is that the formation of detonation arises out from the structure of reaction zone coupled with the pressure wave independent on how this structure was formed. Needless to say that such a structure has to be stable in the ambient conditions. Otherwise structure would collapse and detonation would not arise.

TRANSIENT COMBUSTION REGIMES IN CHANNELS

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The flame acceleration in channels of different widths and lengths and deflagration-to-detonation transition (DDT) in hydrogen/oxygen mixture are studied using two-dimensional high resolution simulations with a detailed chemical kinetic model. For long channels it is shown that there are 5 main stages of the flame propagation from one of the end-walls: (1) flame propagation due to the hot products expansion out from the ignition area; (2) stage of the flame speed exponential increase due to the development of the instabilities on the flame front; (3) stage of a slower acceleration; (4) stage of the new exponential increase of the flame speed; (5) transition into detonation wave. On the 3rd stage the compression waves produced by the accelerating flame form the shock close to the flame and the unreacted mixture of increased density enters the flame producing a high pressure pulse, which enhances reaction rate and the heat release in the reaction zone with a positive feedback. As a result the pressure pulse grows exponentially. After the flame front achieves locally supersonic speed the pressure pulse occurs to be localized within the reaction zone. It results in super-high rate of the flame acceleration and pressure increase directly in the reaction zone (4). Such a coupling of the supersonic flame and the pressure pulse transforms the flame into detonation wave. For shorter channels the flame propagates in conditions of upwind flows generated behind compression waves and weak shocks generated by the flame and then reflected from the end-wall. Influence of the acoustic perturbations changes

the evolution of the flame front propagating through the channel. In case of the short channels the perturbations begin affect the flame dynamics on the first stages and can even prevent sufficient flame acceleration and detonation formation. There is approximately no influence on the flame dynamics in case when the perturbations begin affect the flame on the very final stage when the pressure pulse is already localized in the reaction zone. In the channels of moderate lengths the influence takes place on the stage when the pressure pulse is already arose but it is not yet localized in the reaction zone. In such conditions the counter running perturbations can flow the pressure pulse out from the reaction zone and prevent detonation formation. However the stronger wave interacts with the flame after reflection from the rear end-wall. Such interaction can trigger a new regime of flame acceleration and transition to detonation. Results of the high resolution simulations are fully consistent with experimental studies of DDT in hydrogen/oxygen gaseous mixtures.

LOW-TEMPERATURE COMBUSTION AND DISPLACEMENT OF OIL IN POROUS MEDIUM

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Displacement in porous medium is considered such that displacing gaseous phase contains oxidizer which reacts with oil fractions. Products of the low-temperature oxidization reaction belong both to liquid and gaseus phase. A reactant-controlled model of the reaction is applied which assumes that oxygen reacts instantaneously with oil upon contact. Propagation of combustion front is studied on the basis of generalized Buckley-Leverett model. Solution to the problem includes front of displacement, region of two phase flow of inert gaseous phase and liquid resident phase containing compaund of light and heavy oil, front of combustion and region of two phase flow of injected gas containing oxidizer and liquid phase which includes products of the reaction in liquid phase. Dependence of the combustion on relative permeability functions is investigated. It is found that the relative permeability functions, particularly cross terms responsible for interation of phases in pore space [1] , have a great influence on the part of oil which reacts during displacement. The result is explained by change of reactant fluxes into the reaction zone.

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QUANTUM PHENOMENA IN INITIATION OF DETONATION WAVES OF CONDENSATION

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In the recent works [1], [2] a new physical phenomenon—formation of detonation wave of condensation has been reported. It was shown that the bottleneck of this phenomenon is the immediate formation of supersaturated carbon vapor behind shock wave in carbon bearing precursors—carbon suboxide or acetylene. The rate constants of this process obey the Arrhenius law:

$$k_f = A \cdot \exp(-\Delta E/RT)$$

where ΔE is the threshold of reaction of precursor ecomposition. And it was noticed that in both precursors at low temperatures and high pressures the rate constants k_f begin to deviate from Arrhenius dependence reflecting the apparent decrease of ΔE. This effect resulted in unpredictable expansion of the low temperature threshold of detonation. In this work an analysis of observed phenomena based on account of quantum corrections to the rate constants of inelastic processes developed in [3] is carried out. An essence of quantum effect is an increase of high energy tail of the momentum distribution function due to quantum uncertainty in the particle energy at high frequency of collisions [4]. Based on these effects the estimations of corrected rate constants of initial reactions of carbon suboxide and acetylene decomposition k_f have been performed. The corrected values of k_f were correlated with the main phenomenological parameter of the rate of detonation formation—an induction time of condensation τ. It was shown that experimentally observed deviations in Arrhenius dependences $\ln \tau \sim \Delta E/RT$ are well described by the quantum corrections presented in [3].

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ESTIMATIONS OF QUANTUM EFFECTS IN IGNITION DELAYS

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Ignition delay τ_{ign} is one of the most important parameters, determining the rates of ignition and the threshold of detonation. In the theory of combustion it is accepted to represent this phenomenological parameter in a form of reversal rate of two-order chemical reaction [1]:

$$\tau_{ign} \times \rho_f = A \exp(\Delta E/RT)$$

where ρ_f is the molar density of fuel, ΔE is the activation energy, which is usually close to the threshold of initial reaction of active radical formation. However one of the main problems of this representation is that at low temperatures experimental data does not agree with the model predictions and apparent values of ΔE become much less calculated values based on experimental data obtained at high temperatures. For example ignition delay of methane ignition at $T > 1200$ K is characterized by $\Delta E = 210$ kJ/mol and at $T < 1200$ K it decreased down to $\Delta E = 84$ kJ/mol [2].

Up to now any plausible explanation of this phenomenon was not suggested. In this work a new interpretation of observed deviation of ignition delays from kinetic modeling based on estimations of quantum corrections to the rate constants of inelastic processes developed in [3] is given. It is shown that experimentally observed non-Arrhenius dependences of ignition delays for hydrogen, methane and syn-gas [4, 5] could be reasonably described by the quantum corrections presented in [3].

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COMPLEX INVESTIGATION OF CCl_4 PYROLYSIS AND SOOT PARTICLE GROWTH BEHIND SHOCK WAVES

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The processes of soot formation during pyrolysis and combustion processes are the subject of steady scientific interest due to their great importance for engines constructions improvement and environmental protection. Along with various hydrocarbons carbon-chlorines CCl_4 and C_2Cl_4 are also used in shock-tube experiments for investigation of soot formation in hydrogen free systems [1, 2]. Kinetic of CCl_4 decomposition is usually described quite simplificated, as a brutto-reaction, or even neglecting in most works concerning soot formation. However, details of small critical clusters formation may be quite important to following soot particle growth.

In present work CCl_4 pyrolysis was investigated using time-of-flight mass-spectrometer, which allows to obtain time profiles of concentration of numerous species during single experiment [3]. Processes of soot formation were observed by registration of time-resolved absorption spectra in range 300–600 nm using high-speed CCD camera. Kinetic scheme of CCl_4 decomposition and secondary products formation was investigated and verificated using experimental data. Importance of C_2Cl_2 formation was demonstrated. It was shown that even at $T_5 = 2900$ K more than 60% of carbon atoms are bound in C_2Cl_2—i.e. never form monoatomic carbon vapor—and main channel of small carbon clusters formation is $CCl_4 \rightarrow CCl_2 \rightarrow C_2Cl_2 \rightarrow C_2$. Relatively slow C_2Cl_2 decomposition is the limitation process of C_2 clusters formation and soot particles growth resulting in bell-shaped dependence of soot yield on temperature. Obtained absorption spectra may be used for analyzing of time evolution of soot particle sizes distribution in combination with other experimental methods and analytical studies providing dependence of carbon particles optical properties on their size.

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HYDROGEN INFLUENCE ON CARBON PARTICLE FORMATION AT ACETYLENE PYROLYSIS BEHIND SHOCK WAVES

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Carbon particle formation is an important process for industry and for the environment. Up to now a kinetic models and mechanisms of carbon particle growth are developed [1]. However, a lot of questions are still opened. One of them is a role of hydrogen in carbon particle formation process. In this work the study of hydrogen addition influence on carbon particle growth at acetylene pyrolysis was performed. Several series of experiments with the mixture of 3% C_2H_2 + 3% H_2 diluted in Ar in the temperature range of 1750–2300 K and pressure range of 6–7.5 bar were carried out behind reflected shock waves. Laser light extinction and laser-induced incandescence (LII) were applied simultaneously for observation of optical density of condensed phase and carbon particle sizes. The samples of obtained particles were analyzed by transmission electron microscopy (TEM). Results of optical density of condensed phase and particle size measurements were compared with data obtained at the pyrolysis of C_2H_2 without hydrogen addition. The temperature dependence of optical density having bell-shaped form was observed. It was found that hydrogen addition decreases maximal optical density by 65%. Final particle sizes formed in mixture with hydrogen addition measured by LII are in a good agreement with TEM data and about 20% smaller than ones obtained without hydrogen. Also, it was observed decrease of particle growth rate and increase of induction time of particle growth as a result of H_2 addition. Weak decrease of particle mean diameter due to hydrogen addition results in decrease of optical density at twice. However particle optical density drop in hydrogen containing mixture run up to three times. It could be explained by influence of reactions of hydrogen addition to active hydrocarbon radicals, formed during acetylene decomposition. It means that some part of carbon atoms remain in gas phase as hydrocarbons, which is plausible at temperatures of about 1900–2000 K. The results of kinetic modeling of this process are discussed.

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EXPERIMENTAL STUDY OF CARBON NANOPARTICLES FORMATION IN THE ATMOSPHERIC PYROLYSIS FLAMES OF C_2H_2 AND C_3O_2

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In works [1, 2] devoted to pyrolysis C_2H_2 and C_3O_2 behind shock waves the kinetic characteristics of process of nanoparticles formation are measured and influence of heat release of condensation on flow parameters behind the reflected shock wave are determined. However, the work time, during which it is possible to obtain the informative data behind shock waves is about 1 ms. In order to increase time of observation for formation of nanoparticles the special design pyrolysis flame has been developed [3]. In present work a process of growth of carbon nanoparticles in pyrolysis flame at atmospheric pressure was experimentally studied. The current temperature and the size of particles during the initial stage of their growth, when the heat release of carbon condensation still affects temperature of particles, are measured. The particle formation process was investigated in the flows of C_2H_2 and $C_2H_2 + C_3O_2$ diluted by N_2. The C/O-ratio of the outer non-sooting C_2H_4/air flame was 0.54. The flame heights could be varied between 60–240 mm above the burner. Laser extinction, scattering and temperature measurements [4] were carried out in the different flame conditions. Flame temperatures were measured by two variants methods—by the emission-absorption spectroscopy at $\lambda = 550$ nm, detecting the temperature of the condensed particles and by the thermo-couple method, detecting the gas temperature. From the extinction measurements a soot volume fraction can be obtained. The combination of laser light scattering and extinction studies were used to derive the particle size and the number density of soot particles. The soot samples were studied in an electron microscope. Obtained results have determined the kinetics of heat release processes during particle condensation.

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EXPERIMENTAL SETUP FOR INVESTIGATION OF SHOCK WAVE STRUCTURE IN GASEOUS AND HETEROGENEOUS MIXTURES

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Experimental study of processes determining the structure of shock wave front is important due to the absence of clear description of intensive nonequilibrium phenomena observed during the propagation of shock waves. Recently, the effects of ionization and charge separation were revealed within the front of weak shock waves (Mach number < 2.5) propagating in gas mixtures containing gases with large difference of masses [1, 2]. The experimental conditions were found at which the interaction of supersonic flow with neutral medium may be observed. For the solution of this task the experimental setup 'Yashma' was developed: 2-diaphragm high vacuum shock tube, generating shock waves with Mach numbers of 1.1–10, pressure of 0.2–300 bar permitting to study gas mixtures containing concentrations of some ppm of reactants in inert gases. This gave the possibility to enlarge the relaxation lengths of heavy molecules in mixtures and measure them precisely by commonly known experimental techniques.

The main parameters and the necessary equipment properties of setup are represented: Laser-Schlieren method for exact measurement of density gradient arrival in measurement cross section of Shock Tube; time-resolved emission spectroscopy on the base of monochromator ACTON-150 and CCD-camera; multi-needle electrostatic probe of high sensitivity to measure free electrons concentrations near the shock wave front.

The preliminary results of study of shock wave propagation in mixtures containing (0.5–0.05)% CCl_4 in He are represented. The measured time profiles of emission and charged particles distributions are represented and compared with simulated ones.

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HYDROGEN EXPLOSION SUPPRESSION IN EXPERIMENTS OF DIFFERENT SCALE

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The problem of hydrogen safety is very important for development of hydrogen power and nuclear power plant safety. There are different ways to suppress hydrogen combustion in a closed volume: creation of inert atmosphere, usage of different types of recombiners, and injection of phlegmatizator substances. The paper presents results of experimental investigations of different phlegmatizator additives and its binary compounds used for full hydrogen combustion suppression. The work was performed in experimental facilities of three different scales (small, medium and large) for normal initial pressure. Small scale experiments were carried out in a tube 1m length, 66mm diameter. Medium scale experiments were carried out in a tube 8m length, 121mm diameter. Large scale experiments were conducted in a polyethelen film cube, total volume of the cube was 10 m^3. Temperature was varied from 20°C to 120°C in experiments of all scale. Twelve individual substances and six binary compounds were tested in a small scale experiments. In a series of small scale experiments three individual halogen containing substances capable of full suppression of hydrogen combustion were found. The minimum concentration of the most effective substance was 11% at 20°C and 14% at 120°C. In a series of medium scale experiments it was found that 12% of the same substance fully suppresses hydrogen combustion at initial temperature of 20°C and 14% at 120°C. Large scale unconfined experiments confirmed the possibility of full combustion suppression at 20°C with 14% of phlegmatizator substance. The minimum concentration of the best binary mixture was found to be 12% at 20°C.

COMBUSTION OF HYDROGEN-AIR MIXTURES IN LARGE SPHERICAL VOLUMES

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Experiments were conducted with spherical gas charges 7 and 14 m^3 in size that initially had been bounded by thin rubber envelope. The mixture is initiated by charges of PETN (0.4 g and 0.8 g) and by the explosion of nichrome wire with energy 8J. The measurements of pressure in blast waves (waves with a short positive phase) at different distances from the point of initiation along the bar, where the detection elements of diagnostic equipment were placed, were taken. Recorded was the glow of the gas charge inside the rubber envelope as well as after destruction of envelope at the stage of the process evolution in a large explosion chamber 13Ya3, in which the reaction volume was placed. Some features of the glow were observed reflecting spatial peculiar character of the dynamics of reactive gases under conditions admitting the origin of ignition points and development of the active combustion. The features of blast wave development from the initiating source for the stoichiometric and lean hydrogen-air mixtures were recorded.

ASYMMETRICAL SIDE LOADS IN OVEREXPANDED DE LAVAL NOZZLE

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Cruise engine of modern rocket operates at different altitudes while carrying useful load at Earth's orbit. This circumstance causes different regimes of supersonic outflow from the nozzle. At start point the ambient pressure has maximum value and overexpanded regime occurs. Under this regime in supersonic jet that goes from the nozzle there is oblique shock wave that starts inside the nozzle. The interaction of oblique shock wave and the boundary layer near the nozzle wall can cause asymmetrical flow separation and therefore additional loads in side direction. This phenomenon is quite dangerous for modern rocket nozzles. Today the experiments with real rocket engines are provided in many laboratories [1–2], where the real conditions of rocket start can be provided. In this work the

problem was considered under relatively low values of ambient pressure, when the overexpanded regime occurs.

The experiments were carried out with de Laval nozzle (Mach number 2) of supersonic wind tunnel ST-4 [3]. The static pressure of jet in outlet cross-section is 0.16 atm., but inlet pressure is 1 atm. The visualization of outgoing air jet was carried out with high speed schlieren imaging and by Particle Image Velocimetry (PIV). Pressure in working chamber and along the nozzle was registered. The critical pressure ratio (n) was obtained when the asymmetrical flow separation occurs. Digital image processing was performed for oblique shocks detection and therefore the separation points on nozzle wall were calculated. The dependence between n and side-loads amplitude was obtained. By the PIV the spatial distribution of velocity vector in airjet behind the nozzle obtained with different values of n.

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APPLICATION OF GAS DETONATION IN THE NARROW CHANNELS FOR A NEEDLELESS DEVICE DEVELOPMENT

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The main difference between current needleless injection devices is an energy source for acceleration of microparticles or jet of medicaments. But all of them have characteristic shortcomings. For example, the devices based on pulse laser focusing are too bulky, ones based on compressed gas can carry out only a few (10–15) injections without recharging and using powder or solid detonation fuel produces unhealthy products of combustion.

In this paper, we consider the applicability of gas detonation as an energy source in the devices for needleless injection. This approach makes it possible to avoid all above mentioned shortcomings but it requires achieving detonation at short distances for the device to be portable. This, in turn, requires using narrow detonation channel.

When the diameter of detonation channel becomes comparable with detonation sell size, dissipative loses into channel walls becomes essential. It reduces the velocity of stationary detonation and limits of existence, and also reduces the limits of deflagration to detonation transition (DDT). It is well known that propagation of detonation wave is impossible in channels with diameter three times less than size of a detonation cell. However, possibility of DDT has been shown by many researchers. It is possible to achieve by flame acceleration at the initial stage of propagation.

In present work DDT in the narrow channel has been achieved by using pre-chamber. Parameters of a detonation wave have been experimentally defined. The estimation and experimental definition of speed of deformation for various diaphragms have been obtained.

Depths of penetration of a jet of medicaments into the model human tissue have been obtained for different diaphragm and detonation parameters. The obtained results have shown the applicability of gas detonation in devices for needleless injections.

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AN EXPERIMENTAL STUDY OF DEFLAGRATION TO DETONATION TRANSITION VIA FLAME PROPAGATION FROM WIDE CHANNEL TO NARROW ONE

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It is well known that stationary detonation in channel is impossible when the channel diameter less than critical value equal to L/3, where L is detonation sell. Critical value of deflagration to detonation transition in straight cylindrical channel occurs to be bigger than one for stationary detonation. In present work the possibility of deflagration to detonation transition in channel with under critical diameter was investigated experimentally for hydrogen-air mixture.

The main reason that prevents deflagration to detonation transition in narrow channel is high heat loses into channel walls comparatively to energy of burning [1], [2] at the initial stage of flame propagation. Due to this stationary regime of slow flame propagation establishes and transition to detonation becomes impossible.

To achieve deflagration to detonation transition in narrow channel wide for-chamber was used. Flame accelerates before the entrance of narrow channel with an additional energy of mixture burning in for-chamber. This increases an amount of mixture burned per time unit and shifts an energy balance between energy of burning and loses and makes transition to detonation possible.

Possibility of DDT in channels with under critical diameter has been showed. Dependence of run up distance on additional energy in 3 mm channel was obtained for different pressures.

Work was supported by Russian Foundation for basic research No. 10-08-00214a.

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ACOUSTIC WAVE INTERACTION WITH DIFFUSION FLAMES

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The research on the influence of acoustic field on the diffusion flame was carried out to obtain new fundamental knowledge for the creation of burners with the ability to control the shape and parameters of flame.

In Suzuki et al. 2007 [1] methane jet flame was ejected vertically upward into the air through a tube and burned under the condition of natural convection. It meanders and diverges into two branches under the influence of sound waves propagating transversely across it. Detailed movement of the jet is examined with a high-speed video camera by means of shadowgraphy.

Methane gas was used as a fuel. The burner is a vertical pipe with an open upper end having an inside diameter $d_{in} = 3$ mm and having a thread at the end of the tool by which the regulated gas supply nozzle was mounted. The length of the pipe is more than 100 times greater than the inner diameter. It were studied 4 nozzles with diameter d_{out}: 0.5 mm, 0.8 mm, 1.25 mm and 2.5 mm, respectively. Floe Reynolds number in a pipe generally takes a value between $Re = 60$ and 70, which corresponds to a flow velocity of 0.33 m/s and 0.38 m/s, respectively.

Bifurcation of flame was observed in the frequency of 3 kHz for d_{out} equal to 1.25 mm. In this case, the flame forked into a plane perpendicular to the place of the source of sound and passing through the axis of the burner. In this case , the wavelength of the acoustic field in methane is equal to 113 mm, which is 90 times greater then the diameter of the outlet nozzle of methane, and consequently the characteristic size of the flame. This suggest that the instability of the jet flame and the whole developing under the influence of higher harmonics of the fundamental tone of acoustic field.

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DELAYS OF SPONTANEOUS DECOMPOSITION OF ACETYLENE DILUTED BY HYDROGEN OR PROPANE–BUTANE

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In the work [1] an inhibition of a spontaneous decomposition of acetylene by admixtures of propane-butane and hydrogen was investigated. It was subsequently shown that the inhibition has both thermal and chain-branch nature [2]. This wave of spontaneous decomposition is called "explosive condensation". Taking to account the energy of condensation for energy balance of self-sustaining wave of decomposition was studied in [3].

An important characteristic in the processes with heat release is the induction period. Despite the fact that the induction period is sufficiently well studied for the detonation waves and for the pyrolysis of hydrocarbons [4], induction period for self-sustaining waves of the spontaneous decomposition of acetylene with the formation of soot still requires detailed study.

Delays of the spontaneous decomposition of acetylene behind the incident and reflected shock waves were measured experimentally in the work. Compression of acetylene was carried out by the detonation of a stoichiometric acetylene-oxygen mixture in the shock tube.

It was shown that the decomposition of acetylene has a self-sustaining nature. Induction periods of polimerisation and condensation in mixtures of acetylene and hydrogen or propane-butane were measured in the range of initial pressure 1–2.5 atm. It was found that there is a minimum value of condensation delay at certain concentrations of the admixtures which is equaled to 30 μs. Dependences of polymerization delays from the concentrations were obtained.

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ON CHARACTERISTICS OF HYDROGEN SELF-IGNITION AT PULSE DISCHARGE INTO CHANNEL WITH AIR

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Characteristics of the diffusion ignition of hydrogen were experimentally studied at a pulse discharge into a channel, filled with air. The ignition of hydrogen occurred on the contact surface of hydrogen discharged into air. The necessary temperature of self-ignition was reached due to heating of air by the shock wave, which appears as a result of the pulse discharge of hydrogen from the high pressure chamber [1]. However, the duration of diaphragm rupture may have the critical effect on the ignition of hydrogen [2], since in this case a system of shock waves appears and regions with thermodynamic parameters exceeding the one-dimensional calculation can be formed [3].

In this work the formation of shock-wave flow structure was studied at the pulse discharge of the jet of compressed hydrogen into the channel. The visualization of the rupture of diaphragms with the use of high-speed video cameras was carried out. Rupture durations of the diaphragms ranged from 10 to 100 μs depending on the material of diaphragm (copper, brass, steel and aluminum), width of channel and initial pressure. Measurements are carried out for the channels of 18 mm and 5 mm diameter.

On the basis of comparison results of diaphragm rupture visualization with the indications of pressure sensors, were discovered three types of stream profiles. They appear in the channel of the larger diameter at a distance 4–5 calibers from the diaphragm. And was investigated the influence of the form of stream profile on the self-ignition/noncombustion of hydrogen.

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SELF-IGNITION OF HYDROGEN IMPULSE JET IN PERFORATED CHANNELS

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There are two effects that tend on hydrogen ignition In the perforated channels. Firstly extra orifice decrease shock wave pressure, leading to gas heating behind the shock wave. Secondly the orifices always have inhomoginities areas where flow velocity decreasing leads to temperature grown in these areas. Appearing of the high temperature area increases ignition. The channels with symmetrical orifices often use in practice because total impulse of flow stays constant.

In this paper parameters was experimentally investigated tends on hydrogen self-ignition process in perforated channels.

Initial conditions leading to ignition in T-shape channel have been investigated. Have obtained ignition time depends on initial pressure of hydrogen. Fact that area where ignition starts and ignition delay differs from the channel shape: strait channel, strait cannel with lateral orifices and T-shape channel have shown experimentally. Lateral orifices cross section area was equaled to the channel's one. Found that Ignition time decreases because of inhomoginities caused by lateral orifices in T-shape channels and in strait cannel with lateral orifices.

In this work strait cannel with lateral orifices with large lateral orifices with cross section area more than channel's one have been investigated. Initial pressures leading to ignition and hydrogen self-ignition time depends on distance till lateral orifices have obtained. Ignition delay of hydrogen depends on cross section area of lateral orifices have shown. Analytical explanation for two studied (before and after orifices) heating have found and compared with experimental data.

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THE TRANSITION FROM COMBUSTION TO DETONATION IN MIXTURE METHANE WITH AIR

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The mixture of methane with air is characterized by the greatest detonation cell size among the hydrocarbons. A width of the cell reaches 270–350 mm , energy of direct initiation of detonation reaches 9–88 MJ/ m^2 [1]. On the other hand, for using the detonation of methane in the devices of crushing, stamping or combusting the withdrawals it is necessary to use the energy of initiation, which does not exceed several joules.

The essential factor, which is capable to considerably reduce predetonation distance, is the presence of obstacles in the channel. The goal of this investigation was the decrease of pre-detonation distance in methane-air mixtures with use of ring obstacles at the interchamber mixing of components in the flow with the speed of 30–40 m/s. The schematic of an experimental setup for investigation of combustion in moving nonpremixed gases is presented in [2].

It was established that optimal number of chamber-inside exists which has an optimum effect of increase of speed of flames motion.

It was found the influence of expansion chamber on the transition from deflagration to detonation. It was observed the possibility of appearance of shock waves which is generated in the expansion chamber when gas mixture was inside them.

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VELOCITY JUMP AT THE SUPER-LAYER IN A TURBULENT BOUNDARY LAYER

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We present an experimental study of the outer edge of a turbulent boundary layer. The goal is to address the question about the main mechanism which is responsible for the entrainment process, i.e. how a turbulent flow is growing and bringing in more fluid into the turbulent motion. For this purpose, we performed Tomographic Particle Image Velocimetry experiments in a water tunnel with a relatively thick boundary layer thickness δ_{99} of 78 mm at a Reynolds number based on the momentum thickness Re_θ of 1370. This enabled us to achieve good spacial resolution of $8U_\tau/\nu$, where U_τ is the friction velocity and ν is kinematic viscosity.

COMPARISON OF KINETIC MODELS OF BIOMASS THERMAL DECOMPOSITION

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In heating of solid hydrocarbon raw materials its decomposition occurs. The products are a solid residual char and volatile components. Basing on the experimental thermogravimetric curves, which represent a dependence of sample weight on its temperature at a given heating rate, one can calculate the kinetic parameters characterizing the process of thermal decomposition. In the present paper the various kinetic models used for this purpose are analysed, the comparison of kinetic parameters obtained with their help is carried out. The thermogravimetric curves measured by thermoanalyzer SDT Q600 for two groups of biomass (wood of different types and agricultural waste) were used as the experimental base. Kinetic parameters were determined by solving the inverse problem. For minimization of the error functional a procedure of coordinate descent was used. The simplest model is a single-channel model in which process the sample decomposition in all temperature range is described by single gross reaction. The rate constant is represented in Arrhenius form. In this case the determined parameters are the reaction order, the activation energy and the pre-exponential factor. Analysis of the computational results has shown that the kinetic parameters for the samples from one group are

rather close to each other but considerably differ from similar parameters for samples from other group. Use of the single-channel model can lead to noticeable computation errors of decomposition rate.

The three-channel model is based on the assumption that the phytogenic organic raw materials consist of three basic components (hemicellulose, cellulose and lignin) which thermal decomposition comes independently from each other. In this case as a result of the inverse problem solution there are determined not only the kinetic parameters characterizing the decomposition of the mentioned components, but also their content in the original sample. Inclusion in the considered scheme of the fourth channel allows to take into account a possible effect of components on each other by formalistic method. The content of components (hemicellulose, cellulose and lignin) in samples of the different organic raw materials, defined along with kinetic parameters, correlates well with results of the chemical analysis known from the literature. In addition the four-channel model describes satisfactorily not only thermogravimetric, but also differential thermogravimetric curves.

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SIMPLE CUBIC AND POST-SIMPLE CUBIC STRUCTURES IN COMPRESSED PHOSPHORUS AND CALCIUM: ELECTRONIC ORIGIN

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Recent high pressure X-ray diffraction studies revealed great variety of new structural modifications for elements from a simple cubic structure (1 atom per unit cell) to very complex structures with incommensurate modulations (IM) in some simple elements [1]. We consider energetical stability of the simple cubic and post-simple cubic structures found under high pressure in Phosphorous [2] and Calcium [3]. Within our approach we evaluate the importance of the two main contributions into the crystal structure energy: electrostatic (Ewald) and electronic (band structure) energies. The latter can be lowered due to a formation of a Brillouin zone plane and an opening of an energy gap at this plane. Under pressure, the band structure energy part becomes more important leading to a formation of complex low-symmetry structures [4]. Using a BRIZ program we examine configurations of the Brillouin zone and Fermi sphere within a nearly-free-electron model in order to analyze the importance of these configurations for the crystal structure energy [5]. Appearance of the simple cubic structure in Calcium at pressures 32–113 GPa made difficulties for theoretical calculation. Our suggestion is to assume an overleap of valence and core electrons leading to increase of the valence electron number for Calcium higher than 2 that is its normal valence at ambient pressure.

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EQUATIONS OF STATE FOR TITANIUM, ZIRCONIUM AND HAFNIUM

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Results of theoretical calculations and experimental measurements of the equation of state (EOS) are discussed and applied to Ti, Zr and Hf. A multi-phase EOS model is presented, accounting for solid, liquid, gas, and plasma states, as well as two-phase regions of melting and evaporation.The EOS's for Ti, Zr and Hf are of practical interest as structural materials for aerospace and atomic industry. The thermodynamic properties and phase diagrams are calculated with the use of this model. Theoretical calculations of thermodynamic properties of the solid, liquid, and plasma phases, and of the critical point, are compared with results of static and dynamic experiments. The analysis deals with thermodynamic properties of solid metal at $T = 0$ and 298 K from theories, static compression experiments in diamond anvil cells, and the information obtained in shock-wave experiments. Thermodynamic data in the liquid state, resulting from traditional thermophysical measurements, "exploding wire" experiments, and evaluations of the critical point are presented. Numerous shock–wave experiments have been done to measure shock adiabats of crystal and porous samples, release isentropes, and sound speed in shocked metal. These data are analyzed in a self-consistent manner together with all other available data at high pressure. The present EOS describes with high accuracy and reliability the complete set of available information.

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MULTIPHASE EQUATION OF STATE FOR SODIUM AT HIGH PRESSURES AND TEMPERATURES

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A semiempirical equation-of-state model for metals is proposed with taking into account polymorphic phase transformations, melting, and evaporation effects over wide range of densities and temperatures. Results of calculations of thermodynamic characteristics and phase diagram

for sodium are presented in comparison with available data from static and shock-wave experiments at high pressures and temperatures.

EQUATION OF STATE OF ALUMINUM BASED ON FIRST-PRINCIPLE CALCULATIONS

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In this work we present quantum molecular dynamics calculations of the shock Hugoniot of solid and porous aluminium and release isentropes of aluminium. We use the VASP code [1] with an ultrasoft pseudopotential [2] and GGA exchange-correlation functional. Up to 108 particles have been used in calculations which have been done on up to 150 processors. For the principle Hugoniot of aluminium we solve the Hugoniot equation numerically. To calculate release isentropes we use Zel'dovich's approach [3] and integrate an ordinary differential equation for the temperature thus restoring all thermodynamic parameters. The results of our calculations are in good agreement with experimental data. Consequently, quantum molecular dynamics data can be effectively used for calibration of wide-range equations of state in conditions of lack of experimental information. This work has been doing under RFBR financial support, grant 09–08–01129.

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"PHASE FREEZEOUT" IN ISENTROPICALLY EXPANDING MATTER

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Features of isentropic expansion of warm dense matter (WDM) created by intense energy fluxes (strong shock compression or instant isochoric heating by laser or heavy ions) are under discussion in situation when (i)— thermodynamic trajectory of such expansion crosses binodal of liquid-gas

phase transition, and (*ii*)—expansion within the two-phase region is going on along equilibrium branch (not metastable one) of the two-phase mixture isentrope. It is known for the flat case (Anisimov, Inogamov and Rethfeld) that because of sharp break of the expansion-isentrope at the binodal (boiling) point (in P-V plane) i.e. high jump of sound velocity in this point, there appears extended zone (layer) of uniformity for expanding material with constant thermodynamic parameters, which correspond just to the state on this binodal of boiling liquid. It is important that because of self-similarity of such expansion (in flat case) this zone has remarkable property—it contains $finite$ and $fixed$ part of whole expanding material. Even more, in the case of expansion of semi-infinite WDM sample the size of this uniform layer of boiling liquid tends to infinity! This remarkable property makes it possible (at leas formally) to discuss this type of isentropic WDM expansion as a tool for *generation* (and subsequent diagnostics) of $extended\ uniform$ state of the matter *exactly* on *binodal* (and even in *critical point*) for the case when parameters of this binodal (and/or thermophysical properties on it) are not known. Besides, it is natural to use for this regime of expansion the term: "phase freeze-out". It is similar to the terms "chemical freeze-out" and "kinetic freeze-out", which are widely used in interpretation of quark-hardon transformations during the expansion of products for ultra-high energy ionic collisions in supercolliders. Perspective of such phase freeze-out appearance is discussed in connection with isentropic expansion of quark-gluon "fireball", created by mentioned above huge ionic collision.

General hydrodynamic scheme of adiabatic movements for the case of more complicated *stack target* (as an ensemble of well positioned plates or foils) under instant isochoric heating (for example, by heavy ion beam) is considered as natural elaboration of mentioned above simple initial idea of phase freeze-out. Hydrodynamics of such WDM stack is expected to be a descending sequence of alternate isentropic expansions and shock compressions. Thermodynamic aspects of such combined hydrodynamic regime ("reverberation") are discussed for intermediate and final stages.

ANOMALOUS SCENARIO FOR SPINODAL DECOMPOSITION OF DEEP METASTABLE MELTING IN THE ZERO-TEMPERAURE LIMIT

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Hypothetical scenarios for termination of deep metastable melting in the zero-temperature limit ($T \to 0$) are under discussion. The analysis based on study of features for combination of phase transitions in modified non-standard version of one-component plasma model on uniformly compressible background—OCP($\sim$) [1, 2]. In contrast to the widely accepted scenarios of metastable melting termination in rare gases [3] and metals [4], when metastable melting curve actually reaches the "cold curve" of matter (isotherm $T = 0$), present work studies more plausible scenario titled as "spinodal decomposition" of deep metastable melting. The basic point of this scenario [5] is unavoidable intersection at finite temperature ($T > 0$) of the metastable liquid freezing boundary with the liquid spinodal curve of liquid-gas phase transition. It meens that at lower temperature liquid phase is absolutely unstable. I.e. crystal phase have no more where to melt. In addition to two mentioned above scenarios of metastable melting termination (MMT) two else non-standard scenarios for MMT are under present discussion. Both have been also studied at the base of OCP($\sim$) model [5]. In first scenario (**A**) hypothetical *unique global crystal-fluid phase coexistence* is realized as smooth superposition of boiling and sublimation processes (with no critical point at all). In second scenario (**B**) anomalous non-standard type of spinodal decomposition is realized, where *solid binodal* (metastable crystal melting boundary) intersects *gaseous spinodal* for gas-liquid phase transition.

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BOUNDARIES OF THERMODYNAMIC STABILITY FOR WIDE-RANGE INTERPOLATIVE EOS OF ELECTRON-IONIC PLASMA

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Boundaries for thermodynamic instability of well-known wide-range analytic approximations for equations of state (EOS) of strongly non-ideal fully ionized electron-ionic plasmas, widely used in astrophysical applications (A.Potekhin and G.Chabrier), are under discussion. Different thermodynamic parameters have been calculated in wide range of temperature and pressure. Boundaries for violation of thermodynamic stability conditions were revealed through these calculations. The region of thermodynamic instability proved to be close to the set of phase transitions boundaries, calculated previously in less sophisticated approximations (Iosilevskiy and Chigvintsev) for so-called "associationless" (modified) model of one- and two-component electron-ionic plasma on uniformly compressible compensating background. Perspectives for calculation of the simplest model for non-congruent phase transition in so-called BIM—"binary ionic mixture" is under discussion in frames of present and previous approximations for phase transitions in BIM-model.

FEATURES OF GAS–LIQUID PHASE TRANSITION IN SILICA SiO_2

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High-temperature phase diagrams in thermal and caloric planes for ρ–T, H–T, and P–T dependences as being predicted via different theoretical equations of state are under discussion. Predictions of different theoretical approaches are examined: traditional quasi-chemical representation

(code SAHA-IV [1]), improved wide-range semi-empirical EOS (MPQeos-JWGU [2]), direct numerical simulation via ionic-MD [4] and ab initio approach (DFT/MD [3]). Theoretical H–T and P–T dependences have been compared with experimental data [5] and Handbook recommendations [6]. Ab initio data for compressed liquid SiO2 [3] were extrapolated for reconstruction of zero-pressure isobar in ρ–T plane. Approximation by the Guggenheim formula was used for reconstruction of ρ–T liquid binodal in whole temperature range from $T = 0$ up to the critical point for EOS-s [1] and [4]. Parametres of so-called Zeno-line ($PV/RT = 1$) were calculated for EOS [4] for discussion.

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LIFETIME OF METASTABLE STATES IN ION-BEAM IRRADIATED SiO_2 FOILS

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The lifetime of the liquid-vapor metastable state within the quasi-static expansion of volumetrically heated foils was calculated. For this purpose an equation-of-state model for homogeneous mixtures of elements based on the model QEOS and the corresponding code MPQeos with an improved cold curve and liquid-vapor phase coexistence data routine was developed. A hydrodynamic calculation including the decomposition process from superheated liquid metastable to liquid-vapor phase equilibrium state was done for an ion-beam heated thin foil made of fused silica (SiO_2). In this case it is found that the transition happens practically instantaneously well into the irradiation phase. Besides their general importance the calculations were done in order to plan an experiment at GSI with a novel

ion-beam target scheme based on a stack made of thin foils. Within this experiment equation-of-state data near the boiling curve will be determined. Furthermore, the subject of non-congruent phase transitions can also be addressed.

PATH INTEGRAL MONTE CARLO SIMULATION OF EQUATION OF STATE OF STRONGLY COUPLED QUARK-GLUON PLASMA

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There are different approaches to study quark-gluon plasma (QGP). The most fundamental way is based upon the quantum chromodynamics (QCD) and requires enormous amount of computations. On the other hand, a semi-classical approach neglects quantum effects in QGP. In this work a strongly coupled quark-gluon plasma of heavy constituent quasiparticles is studied by a path-integral Monte-Carlo method. This approach is a quantum generalization of the model developed by Gelman, Shuryak and Zahed [1]. It is shown that this method is able to reproduce the QCD lattice equation of state and also yields valuable insight into the internal structure of the QGP. The results indicate that the QGP reveals liquid-like rather than gas-like properties. At temperatures just above the critical one it was found that bound quark-antiquark states still survive. These states are bound by effective string-like forces and turns out to be colorless. At the temperature as large as twice the critical one no bound states are observed. Quantum effects turned out to be of prime importance in these simulations.

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MODEL OF FIRST ORDER PHASE TRANSITION FROM HADRON GAS TO QUARK–GLUON PLASMA

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Relativistic heavy ion collisions give a tool for theoretic and experimental studying properties of strongly interacting matter [1, 2]. At heavy ion collisions, hadron resonance gas and quark–gluon plasma appear. To understand behavior of matter in such conditions, equations of state of hadronic and quark–gluon phases are necessary. Stage of hadron gas formation at heavy ion collisions is most studied nowadays. There are a lot of statistical thermal models based on conservation laws in heavy ion collisions, which describe thermodynamic properties of hadron resonance gas quite well. To calculate equation of state for hadron gas in this work, we use grand-canonical ensemble and excluded volume corrections [3, 4]. Properties of quark–gluon phase are described by MIT Bag model [4–6]. Gluons and light quarks are considered as massless particles, strange quarks are taken into account with a nonzero mass. According to charges conservation lows, we have calculated kaon–pion multiplicity ratio for central collisions and thermodynamic parameters for phase transition of hadron gas to quark-gluon plasma. Results qualitatively described experimental data [7, 8].

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SHOCK HUGONIOT AND DISSOCIATIVE PHASE TRANSITION OF HYDROGEN AND DEUTERIUM

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The dissociation phenomenon in the shock wave compression of molecular liquids (H_2, D_2, N_2, O_2, CO) was detected in experiments at high pressure (30–150 GPa) and rather low temperatures (5–8 kK). The usual mechanism of thermal dissociation is not applicable to describe the phenomenon of observable dissociation because of temperatures are low in comparison with dissociation energies of molecules (5–7 eV). We have supposed that interaction between free atoms in a dissociating atomic-molecular mixture is caused by the collective quantum cohesive energy, that analogous the binding energy of atoms in alkali metals. The Wigner-Seitz approximation is used for cohesive energy calculation. We have obtained approximate solution of Schrodinger equation for ground state of quasi-atomic liquid. The derivation of wave function on the bound of the Wigner-Seitz cell is equivalent to zero. The received energy of the ground state decreases under compression (increases in absolute value) in comparison with energy of the ground state of hydrogen atom. Obtained energy is agreed with available numerical calculations. The atom radius also decreases. The cohesive energy is sum of the ground state energy and the Fermi kinetic energy of the delocalized electrons. The fraction of these electrons is proportional to a square of a wave function of the ground state on a cell bound [2]. The presence of the collective cohesive energy between the free atoms with a minimum allows to speak about possibility of quasi-liquid behavior of the atomic component in the dissociated atomic-molecular mixture. Preliminary calculations have shown, that within the frameworks of our hypothesis the transition to the dissociated state has the character of the first-order phase transition—the transition from the molecular fluid in a atomic liquid with critical temperature $\sim$ 10 kK and density jump for hydrogen (0.7–1) g/cm^3 at temperature 4 kK. The received results qualitatively agreed with density jump on deuterium Hugoniot, fixed in the recent experiments carried out in Sarov [2]. We compared our results with numerical data of *ab initio* calculations also.

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MODEL CALCULATION OF DYNAMIC EFFECTS ON POROUS MATERIALS AND MIXES UNDER HIGH ENERGY DENSITY CONDITIONS

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In this work results are presented on development of the model of calculation of shock-wave load of porous environments and mixtures of powders taking into account the presence of air in pores. The model is based on the assumption that under a shock-wave load all mixture components including gas in pores are in a thermal equilibrium.

To describe the behavior of the condensed phases, the equations of the state of type of Mie-Gruneisen are used. The Mie-Gruneisen function is considered as the function depending on temperature only as follows:

$$\Gamma(T) = ((\Gamma(T_0) - \Gamma(T_\infty))^{-1} + C * (T - T_0))^{-1} + \Gamma(T_\infty)$$

where parameters T_0, T_∞, C are chosen due to the condition of accordance of calculation shock adiabat to the known experimental results for every material. This type of Mie-Gruneisen function allowed to expand the range of reliable description of shock adiabat of both monolithic and porous matters and mixtures.

After selection of parameters for monolithic materials and verification of description of conduct of porous matters, rotining good applicability in the wide range of porosity, the calculations of mixtures have been conducted for two hard phases, using the parameters of components only. Supplementing the proper equalizations shock adiabatic have been built also for the greater amount of components, in particular for triple alloys and mixtures

Based on the calculations, the offered model well confirms the results of experiments on the double compression of continuous and porous materials and mixtures shock waves, Calculated shock adiabat given phase transition. Calculation of unloading isentropic of monolithic and porous standards up to the moment of evaporation also well corresponds to the experiment.

ATOMIC MECHANISMS OF STRUCTURE-PHASE TRANSFORMATIONS IN TITANIUM CRYSTALLITE UNDER DEFORMATION

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The investigations of nucleation and evolution of plastic deformation in hexagonal close-packed phase of a titanium crystallite under uniaxial tension are carried out. Influence of loading rate on generation of local structure-phase transformations in crystallite is studied. It is shown that these transformations lead to abrupt decreasing of potential energy of simulated crystallite. It is revealed that increasing of loading rate results in growth of threshold deformation value at which local structure-phase transformations are nucleated. Influence of interface boundaries, phase composition and temperature on peculiarities of nucleation and evolution of plastic deformation in loaded crystallite is studied. Rearrangements of atomic structure in the region of local structure-phase transformations are analyzed. It is shown that local structural rearrangements of atoms, near which structure-phase transformations are nucleated, are characterized by atomic structure reconstruction between first and second coordination spheres.

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INVESTIGATION OF THERMAL ENERGY TRANSFORMATION INTO MECHANICAL ONE BY THIN-FILM METALLIC NANOSTRUCTURES

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Molecular dynamics simulation of nanostructure behavior under heating is carried out. These structures are formed by self-rolling of nanothickness bilayer metallic films. The interatomic interactions are described by potentials obtained by the embedded atom method. The calculation data are shown that simulated non-closed nanostructures can transform the supplied thermal energy into the mechanical oscillations of its free edges. The influence of heating rate and duration, medium viscosity prop-

erties on kinematical characteristics of simulated nanostructures is investigated. It is shown that choosing of such parameters as mass and size of initial bilayer films can considerably change the oscillation amplitude and frequency of heated nanostructures. The efficiency estimation of thermal energy transformation, supplied to non-closed nanostructures, into mechanical oscillation of their free edges under heating is carried out. The typical structural changes responsible for the formation of nanostructures made of initial bilayer films and for their behavior under thermal action are investigated.

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RADIATION INDUCED DAMAGE AND EVOLUTION OF DEFECTS IN Mo

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The strength and mechanical properties of nuclear fuel pellets as well as structural materials of nuclear reactors essentially depend on the influence of neutron irradiation and the corresponding time evolution of the material microstructure. Molecular dynamics method is a useful tool for studying the production of primary defects in the cascades: both the mechanisms of formation and the structure of defects can be analyzed.

In this work the formation of defects in bcc Mo lattice as a result of high-energy Xe bombardment is studied via atomistic simulation with a new interatomic potential developed using the force matching ab initio based approach. Defects evolution in the Xe track is described. Diffusion and interaction of interstitials and vacancies are analyzed. Only small interstitial atom clusters form directly in the track. Larger clusters grow only via aggregation at temperatures up to 2000 K. Stable forms of clusters demonstrate one-dimensional diffusion with a very high diffusion coefficient. Point vacancies have much lower diffusivity and do not aggregate. The possibility of a large prismatic vacancy loop formation near the impact surface is revealed.

MOLECULAR DYNAMICS SIMULATION OF THERMOPHYSICAL PROPERTIES OF LIQUID AND SOLID URANIUM

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New interatomic potential for liquid uranium was constructed using molecular dynamics (MD) and embedded atom method (EAM) [1]. The potential was fitted to the structural and thermophysical properties of liquid and bcc uranium, including density, enthalphy (both at the temperatures up to 5000 K), bulk modulus at 1406 K and also pressure-volume dependence along the Hugoniot curve up to 220 GPa [2]. The effect of electronic excitation arising in uranium at the high temperatures was took in account during the construction of the potential. The new method allowing to account the electronic excitation during the MD calculations was introduced. The values of corresponding electronic contributions to potential energy and heat capacity of uranium were estimated. The MD model built with the potential obtained gives good agreement with the experimental source data and allows to predict thermophysical properties and structure of uranium at high pressures and temperatures. The melting curve of uranium was calculated by two-phases simulation method [3] and the comparison with the experimental data is performed.

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CONDUCTIVITY OF LIQUID METALLIC SODIUM UNDER HIGH PRESSURE AND TEMPERATURE

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The shockwave experiment provide possibility to reach high pressures and temperatures. However the constrained data could be obtained and mostly the information would be indirect. The goal of calculation is to provide more data than in experiments to understand the phenomenon more precisely.

Properties of liquid metallic sodium are studied by means of Quantum Molecular Dynamics (QMD) under pressures up to 250 GPa and temperatures up to 3000 K. In this range of pressures and temperatures EOS is obtained and electronic structure is analyzed. After the ground state is obtained electrical conductivity is calculatied via Greenwood-Kubo formalism.

FIRST-PRINCIPLE CALCULATIONS OF OPTICAL CONDUCTIVITY OF ALUMINUM

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The present work deals with ab initio calculation of optical conductivity of aluminium. Ionic configurations for different densities and temperatures are obtained during quantum molecular dynamics (QMD) simulation. For each configuration optical conductivity is calculated using the Kubo-Greenwood formula [1]. Special attention is paid to the orthogonality of wave functions and the number of bands to provide for correct and accurate results. The simulation is performed using the VASP code (Vienna ab initio simulation package) [2]. DC conductivity is obtained by interpolation of optical conductivity to zero frequency. The values of DC conductivity are compared with experimental data [3].

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KINETICS OF CRYSTAL NUCLEATION IN SUPERCOOLED ALUMINUM MELT AND CALCULATION OF CRYSTAL-MELT FREE ENERGY

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Kinetics of crystal nucleation in supercooled aluminum melt is studied by molecular dynamics (MD) method. The melt is described by embedded atom method (EAM) potential. The dependence of crystal nucleation rate on pressure and temperature is obtained.

We considered homogeneous nucleation of crystal in supercooled melt at constant temperature and density. It is shown, that in independent MD simulations corresponding to the same (T, ρ) the lifetimes of homogeneous melt are different, i.e. crystal nucleation occurs at a random moment of time. We performed a number of MD simulations for each point (T, ρ) in order to calculate the average lifetime of homogeneous liquid phase in simulation cell. The nucleation rate is defined as $J = 1/N \langle t \rangle$, where N is the number of atoms in the simulation cell, $\langle t \rangle$ is the average lifetime for given (T, ρ).

The dependencies of the nucleation rate on pressure at $T = 670$ K and $T = 750$ K are obtained. They are fitted using the formulas of the classical nucleation theory (CNT) [1]. The values of crystal-melt interface free energies γ are fitted to have the best approximation of MD data by analytical expressions.

We have also made an attempt to calculate the crystal-melt free energies directly from MD simulations using the capillary fluctuations method [2]. The calculations of interface free energies are performed for two-phase system at the melting curve in the temperature range 1000–1250 K. The values of free energy are calculated for different orientation of interface relative to crystalline directions. The results show slight anisotropy of interface free energies.

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VITRIFICATION OF ALUMINUM MELT. MOLECULAR DYNAMICS STUDY

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Molecular dynamics study of transition from liquid aluminum into amorphous solid state is carried out.

Aluminum is described by a form of embedded atom method potential. The system was first equilibrated at $T = 1500$ K, which is above the melting temperature of aluminum. Then the velocities of atoms were gradually rescaled until the system reached $T = 300$ K.

Influence of cooling rate on the final state of the system is studied. MD simulations were held for cooling rates from 10^{12} K/s to 10^{13} K/s. At cooling rates below 10^{12} K/s the melt eventually crystallizes. At higher cooling rates the melt freezes into an amorphous structure.

Structural analysis of amorphous aluminum based on radial distribution function of atoms is performed. Splitting of the second peak is used as a criterion for the amorphous structure.

The results show the temperature of vitrifying and final pressure in glass depends on cooling rate. The pressure is performed as a function of temperature during the cooling process. At cooling rate higher than 10^{13} K/s the final amorphous state is nonequilibrium and relaxation time is approximately 200 ps.

The results are compared with the common data.

THE MELTING TEMPERATURE OF BULK CRYSTALLINE SILICON IN THE PRESSURE RANGE FROM −1 TO 3 GPa: MOLECULAR DYNAMIC SIMULATION

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For the calculations of the temperature and pressure along the crystalline silicon melting line the two-phase simulation method, well-known in molecular dynamics, was used. Calculations were performed within the bounds of the classical molecular dynamics, the software package LAMMPS (Large-scale Atomic/Molecular Massively Parallel Simulator) was used. Initial simulation cell contained 5184 atoms of Si. Special two-phase simulation scenario provided the strict control of the two phase pres-

ence in the cell. Four classical potentials were chosen to describe the interaction between the atoms: the Stillinger-Weber classic potential and three bond-order type interatomic potentials based upon the modified Tertsoff classic potential form. The investigations of the crystalline silicon melting line were held in the pressure range from -1 to 3 GPa. For the Stillinger-Weber potential [1] and for the Tertsoff potential in Kumagai-Izumi-Hara-Sakai modification [2] good agreement with experimental data [3] of the crystalline Si melting temperature in the range from 0 to 3 GPa was obtained.

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MOLECULAR DYNAMIC SIMULATIONS OF CONDENSED MATTER AND NONIDEAL PLASMA ON GPU

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The method of molecular dynamics (MD) is widely used to study dynamic properties of the condensed matter [1] and nonideal electron-ion plasmas [2]. In particular an approach to study the relaxation of metastable states is developed [3]. These states play essential role in the impulse loading processes such as shock compression, laser ablation, etc. Herewith we discuss GPU performances for different interaction potentials and report on the results for crystallization of the supercooled Al melt.

Our simulation code is based on the open source HOOMD package where we added the implementations of the short-ranged Embedded Atom Method (EAM) for metals and the long-ranged Coulomb potential with erf-like corrections at short distances for nonideal plasmas. The EAM is a semiempirical many body potential which provides appropriate description for the atomic interactions in solids. The EAM implementation on GPU is not straightforward as the interaction between each atom pair depends not only on the interparticle distance but also on the induced electron density. It requires to calculate the electron densities first, store them in an temporary array, synchronize all GPU threads and perform the final loop to sum up the total forces. Moreover the EAM data is typically defined

via tabulated functions so an interpolation is needed. The same comes to the short range part of the interaction potential for charged particles. We used the hardware texture interpolation for this purpose.

As a result we obtained 55 and 180 times performance gain for a single MD run comparing NVIDIA GTX480 GPU and Intel Xeon E5520 CPU for EAM and Coulomb potentials respectively. Usage of multiple GPUs allows us to obtain more precise results due to statistical averaging over en ensemble of initial conditions.

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STABILITY OF METHANE AND HYDROGEN HYDRATES FROM ATOMISTIC MODELLING AND SIMULATION

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Gas hydrates are clathrate compounds in which molecules of gas are trapped within the crystal structure of water ice. They form when constituents come into contact at low temperature and high pressure. Physical properties of hydrates give rise to numerous applications in the broad areas of energy and climate effects. Methane hydrates contain large amount of hydrocarbons and considered as perspective source of fuel in the future. They typically form at temperatures less than 300 K and pressures more than 5 bar. Hydrogen hydrates can be used for hydrogen storage and transportation. The formation of the sII hydrogen hydrates requires high pressures in the range of 1800–6000 bar. At these pressures hydrogen hydrates become stable up to room temperature but at ambient pressures hydrogen hydrates are only stable for lower temperatures (less then 140 K). Binary sII hydrates of H_2 and tetrahydrofurane (THF) are formed at much lower pressures.

Gas hydrates are studied intensively last years. However there are still many unresolved questions in the modelling of these compounds. We performed molecular dynamic simulations for studing sI methane and sII H_2+THF hydrates. In our simulations we compared different interaction

potential for gas and water molecules and extensively checked the size effect on the modelling results using the large-scale calculations with the LAMMPS and GROMACS package. We calculated metastable hydrate stability boundary, elastic properties and thermal conductivity of the hydrate at different cage occupancies. The three-phase coexistence line is also determined. It was established that the stability boundary curve behavior is very similar to the experimental three-phase coexistence line. Local mechanisms of the planar crystal-liquid interface motion during melting and crystallization processes were studied as well as the mechanisms of the homogeneous nucleation at the hydrate decay at high degrees of metastability.

MODELING OF METHANE HYDRATE DISSOCIATION IN POROUS MEDIUM UNDER HEATING AND DEPRESSURIZATION

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Methane hydrates are considered as a potential energy resource for the 21st century because a large amount of methane is trapped in hydrate reservoirs [1]. Production of gas from natural methane hydrates is complicated problem, because in natural conditions it is mixed with soil particles in porous layers possessing small permeability. An accurate physical based model is required to predict thermo-hydro-mechanical behavior as well as to evaluate the perspective production methods. The model has to describe following associated phenomena: phase behavior of gas hydrates in porous media, multiphase filtration under conditions of variable permeability, degradation of strength of skeleton due to hydrate dissociation and consolidation phenomenon. In the present work, the phase behavior of the methane hydrates is described on the basis of the model of incomplete phase transitions of gas hydrates in porous media [2]. Generalized Darcy s low is applied to predict multiphase filtration; kinetic model of one-dimensional consolidation is formulated. Self-similar solutions of one-dimensional problems are analyzed in formulations which simulate technologies of gas extraction from porous layer containing methane hydrate by depressurization and heating methods. These solutions are characterized by the presence of incomplete hydrate dissociation regions which width increases in time as $t^{1/2}$.Dependence of the solutions is investigated

upon parameters of the problem: initial permeability, porosity, boundary conditions.

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ON RECOVERY OF TRUE HEATED BODY TEMPERATURE VIA THERMAL RADIATION SPECTRUM: SIMULATION OF MEASUREMENTS IN SPECTRUM WINDOW

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Computer simulation of emitted radiation intensity spectrum of tantalum body (object) was carried out. Simulation measurements occurred in a narrow spectral window, which moved along the spectrum with the given step. In this way it searches for spectral ranges at which the dependence of the emissivity (or its logarithm) on the wavelength was simple and fairly accurate in particular linear. In the case of a successful search for the specified spectral range desired temperature was determined for the spectral window on the method of least squares. If the emissivity (or its logarithm) is linearly dependent on the wavelength, it is possible for an alternative assessment of the desired temperature. In this case, the desired temperature is determined to change the convexity of the spectral emissivity dependence in the process of selecting its numerical value from the values smaller than the true temperature value to values higher than the true temperature value. This method is simple, does not require the solution of the system of equations and can significantly narrow temperature range to which belongs to the desired temperature.

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INFRARED IRRADIATION FROM BODIES WITH COMPLEX GEOMETRY

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In the present work carried out investigations of the spatial distribution infrared irradiation fluxes emitted from surfaces of bodies with complex geometry. The goal of research work was developing efficiency and reliable instrument for accurate predictions irradiated energy emitted from complex surfaces. Existing software (for example TERM, PATRAN) allow to calculate heat exchange between different bodies with an assumption diffuse emitting surfaces, but can not calculate spatial distributions of the emitted irradiation fluxes.

As the approximate model for the directional dependencies of radiation was selected zonal method described well in [1]. Complex geometry emitting surfaces require to take in account direct, scattered and reflected irradiation fluxes. Emitter with given geometry divide into elementary areas and irradiation from each elementary area summarize together on each of elementary areas of summation sphere. It is important to take into account radius and number of elementary areas dividing the summation sphere, because in some cases arise the problem of the stabilization of the indicatrix (spatial distribution in solid angle). During investigation was found the optimal rate between summation sphere's elementary area and emitter's elementary area, which approximately equal 3. There is in the realized algorithm, specular reflected infrared energy calculate with Lambert law, but the distribution of the energy reflected from specular elements calculate in according with Z. Hori reflection model [2].

The program was validated by series of the numerical experiments. Simple geometry emitters with well known spatial distribution of the emitted and reflected energy were selected as testing emitters.

The calculation of the spatial distribution of the energy irradiated from complex emitters is the first step to perspective goal of determination irradiation fluxes in high- energy turbulent gas flows absorbing and emitting radiative heat fluxes. This problem is more complex and it require to solve not only radiation transport equation.

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INVESTIGATION OF THERMODYNAMIC PROPERTIES OF CRYSTALS OF INERT GASES

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Equilibrium interionic distance, binding energy of the lattice and the bulk modulus have been calculated for a series of crystals of inert gases (CIG) with the use of pair potentials obtained in [1–2]. The lattice energy CIG is written as the Lennard–Jones (6–12).

The potential of CIG was conducted in the additive approximation based on three focal areas.

The results of the calculated cohesive gomoatomnyh and heteroatomic crystals characteristics of inert gases show a systematic improvement of results in terms of proximity to the experiment compared with the model of the Gordon-Kim.

Table 1. The binding energy U_{cr}, the equilibrium interionic distance r, the bulk modulus B.

crystal	U_{cr},$\cdot 10^{-20}$ J			r, Å			$B\cdot 10^9$ Pa		
He	0.500	0.537		2.289	2.398		4.12	4.02	
Ne	0.448	0.481	0.323	2.96	3.05	3.13	1.47	1.23	1.1
Ar	1.512	1.503	1.290	3.575	3.97	3.75	3.98	2.84	2.7
Kr	2.373	2.132	1.774	3.864	3.902	3.99	3.73	3.67	3.5
HeNe	0.454	0.487		2.594	2.714		2.94	3.04	
HeAr	0.752	0.791		2.997	3.030		3.15	2.21	
HeKr	0.831	0.92		3.23	3.42		2.79	2.84	
NeAr	0.597	0.675		3.40	3.37		1.71	1.99	
NeKr	0.629	0.696		3.63	3.564		1.48	1.73	
ArKr	1.851	1.745		3.75	3.71		3.96	3.87	

In the first column of Table 1 shows the results obtained in the framework of the GK [1–2], the second column—the results of our model, and the third—the experimental results [3, 4]. For heteroatomic crystals of inert gases results in numbers.

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NEW PHASE FORMATION PERCOLATION MECHANISM

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Presented work offers the model of a new phase formation, basing on the theory of the percolation and a similarity hypothesis under construction. They are successfully used in the theory of phase transitions of the second sort. Within the limits of this approach change character of phase transition entropy and spasmodic character of transformation receive their explanation.

According to our model phase transition starts to develop in surface area of a crystal. It is known that external pressure changes parity between the particles radiuses composing an elementary cell that leads to crystal system change since more close-packed structure becomes energetically more favorable. Similar transformation can occur with great probability on a crystal surface. As a result there is a germ of a new phase which represents macroscopical formation with denumerable number of particles (cluster). Origin of clusters occurs stochastically near to defective areas of a surface.

While the distance between two the two nearest clusters less than some critical, characterised in the radius of correlation ρ which is defined according to expression $\frac{4\pi}{3}\rho^3 = \overline{n}\nu$ ($\overline{n}$—an average of knots in cluster, ν—the average volume falling to a particle in cluster), a critical share of volume ξ of a new phase is insufficient for new cluster formation. There is critical value ξ_c of volume of the new phase, defined by means of criterion of the fusion offered in the work: $(E/kT)^{3/2}\exp(-E/kT) = \text{const}$, where with a critical share of free volume $\xi = \frac{\nu-\nu_0}{\nu_0}$ (ν_0—the volume falling to one particle in a crystal close T_{pl} in the field of free of defects), distributed in the form of vacancies: $\xi = \exp(-E/kT)$, energy of formation of vacancy E is connected as follows $\xi_c = \frac{\Delta_0}{\nu_0}\left(\frac{z}{1.5}\right)^{1/a\cdot z}$, where Δ_0—the free volume falling to a molecule in a liquid, z—coordination number, a—lattice parameter. The given criterion of a lattice transformation, in frameworks of

percolation approach, allows considering the peculiarity of thermalphysic properties of substances with identical types of lattices. At $\xi = \xi_c$ clusters merge begins which leads to formation of the percolation channel—infinite cluster. Merge of the last forms a thin film of a new phase. Further process develops into the sample, leading to occurrence of a new phase clustered areas over all dimensions of the crystal.

DIMENSIONAL EFFECTS FOR DIELECTRIC NANOPARTICLES

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It is known, that physical and chemical properties of substances considerably vary at the change of the sizes of their particles within a range of 10 to 100 nanometers. The effects observed in this case are accounted for the surface influence a on crystal properties. At a particle size reduction the share of surface atoms increases. Anomalies of particles structure are observed and they are expressed in the change of internuclear distances, root-mean-square statistical and dynamic displacement of atoms from positions of balance, stabilisation of new phases and updatings etc. Such changes are usually called dimensional effects. The most widely dimensional effects are studied for metals, in a smaller measure—for ionic crystals. Surface energy σ_r dependence on the size of a particle predetermines the connection between fusion temperature of a particle and its size:

$$\sigma\,(r) \approx \sigma_\infty(1 - 2\delta/r),$$

where σ_∞ corresponds to an infinite surface, r—radius nanoparticle, δ—thickness of a surface layer. By analogy to expression for a surface tension [1] of a liquid drop since in a case nanoparticles these quantities are equivalent. Owing to the big number of surface atoms in nanoparticle there is a number of consequences, for example, dependence fusion temperature on the size of nanoparticles. As reduction of the nanoparticle sizes lead to increasing in a share of energy surface, accordingly, to dependence of fusion temperature on the nanoparticles size. There are data, that in an isotropic crystal of simple substance in the size of 10 nanometers the number of surface atoms makes 1 % from the general number of atoms, and for nanocrystallites alkali halide crystal the specific contribution of surface energy makes not less than 30 % of full thermodynamic potential [2].

In this connection, the account of superficial contributions to thermodynamic potential is necessary at definition of thermodynamic parametres nanocrystallite.

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PROGNOSIS OF MAGNETIC AND ELECTRICAL PROPERTIES OF FERROPERICLASE IN THE EARTH LOWER MANTLE

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In the depth of 1000–3000 km typical pressure is 50–200 GPa and temperature 2000–3000 K. The ferropericlase $Mg_{1-x}Fe_x$ is the second most abundant mineral (about 30%) of the Earth's lower mantle after the (Mg, Fe)SiO_3 perovskite. It is magnetic and electrical properties under megabar pressure are important both for geophysics and condensed matter physics. Recently the high spin (HS)-low spin (LS) transition in the ferropericlase has been found under high pressure experiments with diamond anvil cells with the critical pressure $P_c = 55$ GPa [1–3]. The LS state is stable above P_c at the pressures typical for the Earth mantle.

With pressure increasing the HS state of Fe^{+2} ion with $S = 2$ becomes unstable to the spin crossover in the LS state with $S = 0$ resulting in the diamagnetic properties at low temperatures. At high temperature spin fluctuations across the spin gap $E_s = E_{\rm HS} - E_{\rm LS}$ is possible. Based on the experimental data we calculate the pressure dependence of the spin gap. We predict a maximum in the temperature dependence of the magnetic susceptibility at $T_s = E_s/k_B$, where k_B is the Boltzman constant.

The electrical properties are determined by a charge gap E_g which is also pressure dependent. At the critical point Pc both spin and charge gap are zero, metallization is possible in the vicinity of the critical point. Electrical resistivity dependence on pressure has minimum at P_c.

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INFLUENCE OF THE COMPOSITION AND THE TEMPERATURE ON DYNAMICS OF IONS IN CHALCOGENIDE GLASSES

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Influence of the composition and the temperature on the mean-squared displacement of silver mobile ions in glassy chalcogenide ion conductors have been analyzed. From the electrical conductivity spectra, measured in a broad frequency range, we have derived the characteristic distances which contain information on the spatial extent of the nonrandom ion hopping. Values of the mean-squared displacement was obtained by using of the linear–response theory and Kubo formulas which connect macroscopic parameters (transport coefficients) and microscopic parameters (equilibrium time correlation functions of corresponding fluxes) of the statistical system. Fourier analysis with the complex conductivity function was applied to obtain the time dependent mean-squared displacement of mobile ions.

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CONDUCTIVITY AND MAGNETORESISTANCE OF AMMONIUM IODIDE AT HIGH PRESSURES

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The aim of this work is to study the effect of high pressures up to 50 GPa on conductivity and magnetoresistance of ammonium iodide (NH_4I), to determine the conditions and characteristic times of formation of different high-pressure phases in dependence of the duration and sequence of pressure/temperature treatments and to compare the results for NH_4I with those for previously studied ammonium halides NH_4X (X: F, Cl, Br).

We have found earlier [1] that critical pressures P_C for the transitions from low-ohmic to high-ohmic states are different for different ammonium halides (40, 25–27 and 15 GPa for NH_4F, NH_4Cl, and NH_4Br, respectively), correlate with cation-anion distances and don‘t depend on preliminary HPHT treatments. The similar transition in NH_4I was found to appear at the critical pressure of 8–10 GPa. The linear dependence of critical pressures on cation-anion distances may indicate the same type of structure transformations in all investigated ammonium halides.

Some additional features in conductivity of NH_4I were found at pressures of 20–35 GPa. They have slightly smoothed at applying transverse magnetic field. The negative magnetoresistance was observed.

Usually, an evidence for an existence of phase transitions has been obtained from microscopic structure analysis, i.e. X-ray or Raman-scattering measurements. The data obtained in this work show that some information can be obtained from transport measurements.

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ELECTRICAL CONDUCTIVITY OF CARBON NANOTUBES UNDER HIGH PRESSURE

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According to theoretical data, single wall carbon nanotubes (SWNT) demonstrate a high structural stability to 35 GPa [1]. As it was shown in [2], Raman spectra have an addition peak at high pressures $P > 20$ GPa that can be connected with phase transitions in SWNT at $P \simeq 20$ GPa, although the question about their electrical properties was still open. Here we report on the electrical properties of SWNT at pressures up to 45 GPa. High pressure was generated in diamond anvil cell. The anvils are made of synthetic diamond "carbonado" and can be used as electrical contacts to samples.

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EFFECTS OF HIGH PRESSURES AND MAGNETIC FIELDS ON ELECTRIC PROPERTIES $(PbSe)_{0.8}(AgAsSe_2)_{0.2}$

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Multi-component chalcogenides of a silver are known as perspective materials for the scientific and applied purposes [1, 2]. In the search of the materials with ionic conductivity and ferroelectric properties new chalcogenid $(PbSe)_{0.8}(AgAsSe_2)_{0.2}$ were synthesized. The purpose of this work is investigation of electrical properties of synthesized material in the field of frequencies up to 200 kHz at pressure up to 48 GPa and magnetic fields up to 1 T.

The material have metal colour and shine. According to X-ray analysis, the synthesized material is a mixture of two phases PbSe and $AgAsSe_2$. Measurements were made on powdered samples. The researches of electric resistance were carried out by a method of impedance spectroscopy with the use of investigated-analyser of impedance RLC-2000. Resistance at constant current was measured from the voltage drop across the sample. High pressures have been generated in the cell with synthetic carbonado-type diamond anvils of the "rounded cone-plane" type [3].

At normal pressure the sample is ferroelectric with a Curie temperature near 200 K. Electrical conductivity of semiconductor type, at temperatures 190–210 K there is a change of activation energy.

Sample resistance decreases with increasing pressure and weakly depend on the frequency. Resistance after unloading is several times greater than the resistance to loading. At pressures 20 GPa in the sample significant changes in electrical properties observed.

As the result of investigation were found

1. In the sample there is partially reversible phase transition at pressures of 18–22 GPa. Compared to $AgPbAsSe_3$ the phase-transition is shifted to lower pressures.
2. The magnetic field has no appreciable effect on the electrical properties at pressures up to 18 GPa and after 26 GPa.

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ELECTRICAL PROPERTIES OF THE NEW HIGH PRESSURE PEROVSKITE-LIKE PHASE $Gd_{0.73}Cu_3V_4O_{12}$

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The aim of this work was to study electrical properties of a new perovskite-like compound $Gd_{0.73}Cu_3V_4O_{12}$ from the system $A_xCu_3V_4O_{12}$ [1, 2] in the temperature interval from 10 to 300 K at atmospheric pressure. Synthesis of the compound was carried out at high pressures and

high temperatures in the high pressure cell of "toroid" type [1]. The oxide crystallizes in a cubic symmetry (sp. gr *Im-3*, $Z = 2$), with the lattice parameter $a = 7.2939(2)$ Å. The electrical properties were examined on a direct current and by a method of impedance spectroscopy in the frequency range between 1 kHz and 200 kHz. The temperature dependent electrical measurements were carried out in the dark and in an evacuated closed-cycle helium cryostat.

The temperature versus conductivity dependence is of a semiconductor type in the considered temperature range. The temperature hysteresis of a conductivity was observed around 50 K.

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RELAXATION PROCESSES IN ZrO_2 AT HIGH PRESSURES

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It is well known that materials electrical properties changed in time after pressure treatment.

The relaxation processes in ZrO_2 has been studied at the pressures in range 22–50 GPa by measurements of high-pressure electrical relaxation of the resistance on time. Size of crystallites changed from 10 to 500 nm.

The dc resistance measurements were carried out in a diamond anvil cell rounded cone-plane type. We found times dependence of resistance at different pressure for all samples.

The electrical relaxation in nanocrystalline praseodymium doped zirconium powders and in the bulk material sample of zirconium has been measured in the pressure range 35.5 and 50 GPa. The time dependence of electric resistance most precisely described by exponential function up to

pressure 44–45.5 GPa. After pressure treatment higher than 45.5 GPa the character of the relaxation changed and resistance increases with increasing time.

The baric dependencies of the characteristic relaxation times for nanosamples with the crystallite sizes of 10 and 12 nanometers and for a polycrystalline sample have their anomaly between 42 and 44 GPa. The latter leads us to suppose the presence of considerable changes in the electronic structure of ZrO_2 at this pressure.

ELECTRICAL CONDUCTIVITY OF THE CERIA BASED CERAMICS

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Ceria is a high refractory oxide. Its melting point is more 2900 K. It has no any polymorphic transformations and it is not interact with water and alkali. So that it is suitable to produce the ceramic materials.

Sintered ceria ceramics has a high electrical conductivity at temperatures more than 1100 K. It is partially reduce in low oxygen atmosphere. Reduction of CeO_2 to compositions $CeO_{1.97-1.99}$ is sharply increase its conductivity. This increasing of electroconductivity is due to by transformation of part Ce^{4+} ions to Ce^{3+} ions. Another way of increasing of electroconductivity is introducing in cation lattice of ceria the penta valence ions. Introducing of Me_2O_5 in a CeO_2 matrix leads to reducing same Ce^{4+} ions to Ce^{3+} (from condition of electroneutraluty of lattice). This effect is due to an increasing of CeO_2 electrical conductivity. We investigated the system CeO_2–Ta_2O_5, and mixture ceria with india.

Usually, the conductivity grow limited by boundaries of existing single phase solid solution. By X-ray analysis single phase solid solution CeO_2–Ta_2O_5 content to 2.2% Ta_2O_5.

Electroconductivity of the all ceramics compositions in air and in combustion products atmosphere with various values of excess oxidizing coefficient (1.2; 0.9; 0.7) by two- and four- probe method in temperature interval 300–1900 K were investigated.

Pure ceria at 1100 K in air has conductivity 10 $Om \cdot m^{-1}$. $CeO_{1.98-1.95}$ and CeO_2–2.5% Ta_2O_5 at temperatures lower than 1000 K have conductivities on several orders of the magnitude higher than pure one. At temperatures more than 1700 K all curves aspire to draw together. It is evidence that own ceria conductivity is predominate at these temperatures.

For compositions with 2% Ta_2O_5 and more, conductivity in combustion products atmosphere was approximately the same as conductivity in air, but pure ceria considerably increased its conductivity (for two orders of the magnitude).

The conductivity of mixture 70mol.% CeO_2–30 mol.% In_2O_3 was investigated in temperature interval 300–1700 K. Its conductivity for 1.5–2 orders of the magnitude higher than conductivity of solid solution CeO_2–Ta_2O_5 and defined by india content.

So that, the ceria based ceramics can be used as electroconducting part of high temperature heater.

STATISTICAL CHARACTERICTICS OF FREE SHEAR TURBULENCE AND RELEIGH–TEYLOR INSTABILITY

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Two versions of hydrodynamic instabilities, caused by RTI or shear flow, are studied in details by means of three-dimensional calculations. The simulations are based on the concept of independence of large ordered structures from small-scaled developed turbulence (Kolmogorov's concept). The known assumption of Kholmogorov about existence of the inertial interval of wave numbers, within which energy is neither produced nor dissipates, but only transferred to large wave numbers, is proved. The energy is drawn from the large-scale motion and is transferred to ever decreasing scales until it dissipates within the small-scale interval of motion [1, 2].

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EXPERIMENTAL STUDIES OF OSCILLATIONS IN SYSTEM THREE-COMPONENT HYDROCARBON MIXTURES–THE POROUS MEDIUM IN THE CONDITIONS OF PHASE CHANGE

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Gas condensate represents a complex mixture of methane and higher derivatives of methane series with high methane content. At condensate extraction from a productive layer there is a pressure reduction near the borehole. The gascondensate in the bottom zone is partially condensed and forms a retrograde liquid filling pore space and prevents the gas phase outflow. Physical modeling of the formation of gas-condensate plug was carried out at the experimental facility PLAST. Gas condensate was simulated by a methane n butane binary mixture under the thermo baric conditions of real strata pressure up to 20 MPa and temperature up to 320 K. As a result of the experiments the gas condensate plug has been received. Oscillation character of process of a filtration of a model binary mixture in pore space has been found out and methods of influence on the gas-condensate plug for its destruction and increase of gascondensate output are suggested [1]. It is the objective of the present study to perform experimental investigation of the effects of formation and destruction of gascondensate plug using a methane propane n butane ternary mixture as a physical model of gas condensate and compare with the results obtained using binary mixtures. The results of experiments submitted in the present work confirm possibility of modeling of formation gas-condensate plug using of a ternary hydrocarbon mixtures. Essentially processes of a filtration of two and a threecomponent mixtures don't differ, but time of formation of a gascondensate plug and the period of own oscillations of process are various. But for all that the threecomponent mixtures are closer on thermodynamic properties to a real gas condensate stratum. Filtration oscillations in system a threecomponent hydrocarbon mixtures the porous medium in the conditions of phase change are investigated. Values of parameters of this process depending on concentration of components and pressure difference on an experimental facility are obtained. Work is supported by RFBR 10-08-00595a.

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CALCULATION OF PHASE EQUILIBRIUM OF MULTICOMPONENT HYDROCARBON MIXTURES

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For the calculation of the hydrocarbon mixture in the vapor and liquid phases it was used four-coefficiented generalized cubic equation of state Van-der-Waals type, designed specifically for natural oil and gas mixtures at pressures up to 100 MPa and temperatures up to 200°C. In this equation of state the coefficients are determined by the properties of components forming a mixture and parts of these components in the mixture. The algorithm of calculation of phase equilibrium of multicomponent hydrocarbon mixtures by a method of successive approximations is presented.

The phase diagrams of two-and three-component mixtures and multicomponent mixtures, whose composition corresponds to that of real gas-condensate deposits were obtained. Calculated diagrams for the binary mixture of butane–n-butane are consistent with reference data. The error in the determination of phase compositions is not more than 7%.

The calculations suggest the following conclusions: the beginning of the condensation pressure of hydrocarbon mixtures is strongly dependent on the composition of this mixture: the higher proportion of heavy hydrocarbons, the higher the pressure. In addition, obtained for three-and multicomponent systems, phase diagrams show that such mixtures behave like a binary hydrocarbon mixtures.

The pressure of condensation beginning of multicomponent hydrocarbon mixtures of the real gas condensate deposits, for which calculations were made, does not exceed 180 atm. Also in these mixtures there is a large two-phase zone. Thus, these mixtures possess satisfactory parameters for realization on experimental installation of filtration process in the porous medium.

The developed model can be incorporated into the overall mathematical model of filtration of hydrocarbon mixtures in a porous medium.

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EXPERIMENTAL RESEARCH OF CONDENSATE PLUG FORMATION PLACE IN A MODEL OF GAS CONDENSATE STRATUM

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The technique of two-component two-phase flow studies of the hydrocarbon mixture in a physical model of gas-condensate stratum on the example of a methane-n-butane mixture is proposed. This mixture is the simplest model of gas condensate representing a complex mixture of methane and higher derivatives of methane series with high methane content. The phase diagram of such a mixture contains a region in which at pressure decrease formation of the retrograde liquid evaporating with the further decreasing of pressure, so-called "retrograde area" is possible.

At condensate extraction from a productive layer there is a pressure reduction near the borehole. The gas-condensate in the bottom zone is partially condensed and forms a retrograde liquid filling pore space and prevents the gas phase outflow.

Results of mathematical modeling of this phenomenon by means of specially developed program PLAST show that in a place of formation of a plug the sharp increase in a gradient of pressure will be observed. Physical modeling of the formation of gas-condensate plug was conducted at the experimental facility PLAST.

Place of formation of condensate plug in the pore space of the experimental area of physical stratum model is proposed to determine the change of pressure gradient along the length of the experimental area. The sharp increase in the pressure gradient can be measured using strain gauge method of pressure measurement.

For carrying out of measurements the single resistive-strain sensors connected under the semibridge scheme, have been chosen. Signals from the amplifier Spider-8 were output on the computer and processed by the program HBM Catman 5.0 Release 3. Eight pairs strain sensors were uniformly distributed along the length of the experimental area. As a result of experiments to test the method of strain measurements in the motion model gas (nitrogen) through a porous environment in the experimental area linear pressure distribution was obtained.

As a result of experiments on technique of tensometric measurements linear distribution of pressure at movement of modeling gas (nitrogen) through the porous environment in an experimental site was obtained.

Measurement error was 2%, while the calculated pressure gradient at the moment of formation of gas condensate plug in the process of filtering a mixture of methane-n-butane overreaches 20%.

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THE INFORMATION ABOUT THERMOPHYSICAL PROPERTIES ON THE INTERNET: TENDENCIES AND PROBLEMS

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Different Internet-resources are analyzed. They contain an information about thermophysical properties of different working mediums [1]. We consider thermophysical calculations those are connected with power plants (a binary geothermal power plant, a steam gas power station et al.). The calculations are devoted to such criteria Z of a thermodynamic cycle as a coefficient of performance (COP), works of turbines, L, a received heat, Q, et al. It is significant in these calculations: 1) an usage of thermophysical properties R which are placed on the Internet, 2) an attraction of some Internet—resources which give the possibility to determine properties R and criteria Z. There are studied in this report: 1) resources TF or text files those contain values of properties R = (P, T, v, h-enthalpy, s-entropy), 2) resources EF or closed objects those contain exe-files and are purposed for calculation of properties R, 3) resources EA or open objects. The third form is the most complicated Internet-object that is named as EA resource and contains an interactive open algorithm. A user can, for example, calculate properties R applying entrance parameters, P, T, for a specified substance. We underline that EA resource gives an essential additional information to an user in comparison with that of EF resource. The information includes: 1) mathematical formulas (MF) of a calculation of properties R, 2) an algorithm of calculation which is realized in the open resource. The user can copy in the case: numerical results, Z, R, 2) MF equations. Authors have created the Internet-portal Thermal Engineering [2]. A user can choose EA resources and fulfills some thermophysical modeling of criteria connected with power plants. Users apply the resource and for example calculate thermodynamic properties R of the water. under certain boundary conditions. This EA resource is

based on formulation IF-97 which contains about a hundred of MF equations. Interesting applied tasks and problems are analyzed in a connection with modeling criteria Z of power plants.

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POROUS CARBON MATERIALS FOR ELECTROCHEMICAL DOUBLE-LAYER CAPACITORS

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Growing energy demands lead to search of new, ecologically safe energy sources and to optimize energy consumption from the existing ones. One of the main pollution source for large city agglomerations atmosphere are vehicles powered by internal combustion engine (diesel-type especially). Many car companies nowadays are working on hybrid and pure electrical vehicles for cities. The important part of such vehicle is power source, usually based on lithium-ion batteries (LIB) because of their high efficiency and specific parameters suitable for transport applications. Power source must be compact, efficient, relatively cheap, have long lifetime. Increase LIB lifetime and decrease of their amount can be reached by introduction of electrochemical double-layer capacitors (EDLC) for acceleration and braking energy recuperation. In such hybrid power source LIB provides energy for nominal power and EDLC compensates transition processes.

Hybrid scheme can be also applied to power plants based on renewable or traditional energy resources for peak-shaving, power quality improvement and grid frequency regulation.

Single electrochemical EDLC cell includes two current collectors, two electrodes divided by filled with aqueous or organic electrolyte. Current collectors also divide one cell from another and connect them in series electrically. On the boundary between electronic and ionic conductor (electrode/electrolyte boundary) charge separation occurs under applied external voltage. Energy capacity of such capacitor is proportional to boundary surface area – area of electrode available to electrolyte molecules. Usually corrosion-resistive and conductive carbon materials – carbon cloth, nanotubes, activated charcoal, and graphite-like structures are used as electrode materials.

In this report complex investigation of several types of carbon materials porous structure has been carried out. Laboratory techniques for electrodes formation are developed. Experimental electrochemical EDLC cells with different electrode materials – activated charcoal, carbon cloth, non-woven carbon fabric have been assembled and tested.

One can conclude that choice of adequate porous activated charcoals allows to increase specific parameters compared with traditional clothes or non-woven fabrics.

ABOUT FIELD IONIZATION OF ALUMINIUM CLUSTERS

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It is discussed a field ionization of the spherical metal clusters with a soft self-consistent potential by the example of the aluminium clusters Al_N. It is used the jellium model, Woods-Saxon potential and semiclassical approach.

The special features of the electron spectra in the small aluminium clusters Al_N ($N \leq N_F$) in a ground state have been shown in the paper [1]: there is an orbitally quasi-degenerate energy region: $\varepsilon_{nl} \simeq \varepsilon_{n0}$. The region position in the spectrum depends on the cluster size N: when increasing size the degenerate region "rises" to higher energies. The calculations [1] in the Woods-Saxon potential for aluminium (atomic units)

$$U(r) = -U_0 \left[1 + \exp \frac{r-R}{a}\right]^{-1}, \; R = r_s N_e^{1/3}, \; N_e = wN$$

$$w = 3, \; U_0 = 0.5319, \; a = 2.7, \; r_s = 2.07$$

predict $N_F = 57$. So all the clusters Al_N with $N > N_F$ have no the filled degenerate region in a ground state.

This size dependence is supposed to manifest itself in a field ionization of the clusters. To verify the supposition we use a semiclassical expression [2] for a total charge current from a spherical system due to an outer stationary electric field.

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POLARIZED REFLECTIVITY PROPERTIES OF EXPLOSIVELY DRIVEN DENSE PLASMA

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For further development of nonideal plasma physics, investigations of its electronic subsystem properties appear to be crucial. The analysis of the response of dense plasma to electromagnetic waves of moderate intensity can be used as a tool to investigate the validity of the physical models describing the behavior of matter under extreme conditions, high temperatures and pressures.

The results of new experiments on reflectivity of polarized light on nonideal xenon plasma are presented. The study of polarized reflectivity properties of plasma was accomplished using laser light of wavelength λ_{las} = 1064 nm and λ_{las} = 694 nm.

In order to measure the dense xenon plasma polarized reflectivity coefficient, the pulsed YAG, ruby laser system with electro-optical shutter and four-channel pulse high-speed device has been used. The device allows to measure the intensity of the reflected laser beam for four azimuthal angles and was equipped with filters for selection of frequency of probing. The measurements of polarized reflectivity coefficients of explosively driven dense plasmas have been carried out at incident angles up to θ = 70 degrees simultaneously for s- and p-polarization, respectively.

For determination of the equilibrium properties of explosively driven plasma, appropriate gas dynamics calculations were carried out. The plasma composition was calculated within a chemical picture [1]. During the experiments, the plasma density up to $\rho = 2.8$ g/cm^3, pressure up to $P = 14$ GPa and temperature up to $T = 33000$ K were realized. Under these conditions, the plasma is non-degenerate.

The integration of Maxwell equations are based on an interpolation formula for dc conductivity [2] taking into account electron-atom scattering and temperature variation in the plasma transitive layer.

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THE COMPARISON OF GENERALIZED CHEMICAL AND "CELL" MODELS IN APPLICATION TO THE HELIUM IONIZATION UNDER PRESSURE

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The processes of ionization of noble gases under high pressures have been investigated during several dozen years both in measurements and in theoretical models [1, 2]. During this process (at high compressions) a gas becomes a conducting medium although it is a dielectric under normal conditions. So this phenomenon is often referred to as the dielectric-metal transition. There are various theoretical approaches to its description. But all of them can be divided into two groups. First one is so called generalized chemical models (GCM), where a medium is considered as a mixture of several kinds of particles—electrons, positive ions, neutral atoms (see [1–4]. The second group is so called "cell" models [5], which suppose that a substance is consisted of the neutral cells. Inside the cell the electron component is described by different quantum statistical techniques (Hartree-Fock, DFT etc). While GCMs originate from famous Saha model which is correct for weakly coupled plasmas with classical particles, the cell models are initially applied to dense media with strong interparticle interactions. So it is interesting to compare both approaches in the "intermediate" region. This region exactly corresponds to the area where one can observe the transition of noble gases to the conducting state mentioned above. In this work the average charge of ion for helium was calculated, using one of "cell" models considered in [5]. Then this average charge have been compared with the ionization degree obtained by means of recently developed variant of GCM model [3]. We have also calculated the conductivity in the transition region using the ionization data of both approaches and made the comparison with available measurements.

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DETERMINATION OF ELECTRONS TEMPERATURE AND CONCENTRATION IN AN ULTRACOLD PLASMA BY MEASURING POPULATIONS OF EXCITED STATES

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For a weakly nonideal nonequilibrium low-temperature plasma, where the kinetics of the transitions of excited atoms is determined by collisions with electrons in 1973 [1] developed a method for calculating the temperature T_e and free electron concentration n_e based on measuring population of excited states n_k. Then, this method has been extended to experimental practice [2]

This method of determining free electrons temperature and concentration can also be used for a plasma with a temperature T_e = 1–5 K, in which recombination is due mostly to collisions with electrons. However, recombination in such ultracold plasma has its own characteristics.

The first feature is that in an ultracold plasma levels, which energy is the order of T_e, correspond to the principal quantum numbers in range of $p = 50$–400. The second one is that due to recombination non-ideality can vary from strong to weak. At the same coupling parameter $\gamma_e = e^2 n_e^{1/2}/T_e$ varies from values much larger to values much less than unity.

In papers [3, 4], we model an ultracold hydrogen equilibrium plasma, where we have calculated by molecular dynamics nonequilibrium distribution function of electron energy for different densities and temperatures. The presence of the calculated distribution functions for different temperatures of quasiequilibrium Rydberg states allows to use at certain modifications, as described above, the method for determining the temperature T_e and the concentration of free electrons n_e from the measured excited states population n_k. The analysis of experimental data for a weakly nonideal ultracold plasma [5] is reported. Obtained agreement with calculations by other methods [6].

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THE INFLUENCE OF UNIFORM MAGNETIC FIELD ON THE ELECTRON DISTRIBUTION FUNCTION AND RECOMBINATION IN AN ULTRACOLD PLASMA

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The influence of uniform magnetic field on the electron distribution function in a plasma is significant, when the Larmor radius is much smaller than electron mean free path. In case of low-temperature plasma with electron energy of several thousand degrees and above, this requires magnetic fields with the induction of hundreds Tesla. At the same time ultracold plasma with electron energy at 10 K or less required magnetic field of a few Tesla. The problem of the influence of magnetic field on the recombination processes was formulated in experiments on antihydrogen [1, 2], since this experiment was carried out at low temperatures and in magnetic field with induction of a few Tesla.

In this paper, the method of molecular dynamics for ultracold plasma model developed in [3, 4], which takes into account the influence of magnetic field on the equation of motion of particles, calculated nonequilibrium distribution function of electron energy as a function of temperature and magnetic field for a fixed initial density charged particles. We also analyze the effect of the magnetic field on the recombination of nonequilibrium ultracold plasma.

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RECOMBINATION IN STRONGLY COUPLED ION PLASMA OF THE GAS DISCHARGE AFTERGLOW

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The goal of this work is to study recombination processes in plasmas of positive and negative singly charged ions. Experimental results [1] for the afterglow of gas discharge show a strong suppression of the recombination rate compared to the classical model. Ion plasmas consisting of fluorine or sulfur fluorides are investigated. The deviation the results from predicted ones by the classical model for the recombination rate are observed with increase of plasma nonideality parameter.

Explanation of this deviation is possible within the framework of the approach based on the use of molecular dynamics modeling and simulation, which allows for detailed description of the interaction between ions and their recombination [2]. Electron-ion plasmas are considered in [2]. The theory turns out to be in a satisfactory agreement with the experimental results for ultracold plasmas and plasmas of pulse discharges in water. The formula for the recombination rate [2] can be applied to ion plasmas as well. In this case we obtain:

$$K\tau = \begin{cases} 0.3 \cdot \Gamma^{9/2} & \text{for} \quad \Gamma < 0.488 \\ 0.3 \cdot \Gamma^{9/2} \exp[4.5 \cdot (0.488 - \Gamma)] & \text{for} \quad \Gamma > 0.488 \end{cases} \tag{1}$$

where $\Gamma = (4\pi/3)^{1/3} e^2 n^{1/3}/kT$ is nonideality parameter, n is number density of ions of one sign $\tau = (\pi m/e^2 n)^{1/2}$, m is a reduced mass of ions.

The recombination rate obtained for sulfur hexafluoride [1] is still less than that predicted by the equation (1). The explanation for this effect can be done under the assumption of the ion solvatation and that the recombination process in strongly coupled ion plasmas occurs in two stages. The first stage is a reversible formation of an unstable cluster, in which two ions are separated by solvated molecules. The second stage is a transition of two ions to a tight ion pair with its subsequent recombination. Due to the activation barrier in the latter process the second stage is the limiting one.

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ABNORMAL PRESSURE FLUCTUATIONS IN CLASSICAL NONIDEAL PLASMA

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The hypothesis of the plasma phase transition (PPT) is advanced in [1, 2] by analogy with the Van der Waals equation. The first order phase transition is a result of the balance be-tween long-range attraction and short-range repulsion. Coulomb interaction between charges is a long-range and effectively attractive one because of the plasma polarization. An effective repulsion at short distances even for an electron-proton pair is of the quantum nature. How-ever contrary to real gases there are excited atoms in low temperature plasmas. The restriction of the discrete spectrum in the atomic partition function depends on the charge number den-sity. It was noted [3] that this dependence results in the appearance of a new term in the equation of state. The term is equivalent to the effective repulsion. Therefore this factor is able to suppress or influence the PPT.

The chemical plasma model is used in [1–3]. We guess that it is more logical to apply the fluctuation approach [4] which provides the self-consistent joint description of free and weakly bound electron states without their separation. The molecular dynamics method is used. The electron-ion interaction is described by the density and temperature-independent cutoff Coulomb potential. Fluctuations of pressure of singly ionized nonideal plasma are stud-ied. Two main abnormal features of pressure fluctuation distribution are observed. (a) The fully ionized plasma region is found where pressure fluctuation distribution dramatically dif-fers from normal distribution and can be approximated by the superposition of two Gauss dis-tribution functions. (b) There is also a region of plasma parameters where negative instanta-neous values of pressure are observed. It should be noted that these regions of plasma parame-ters lay out of the area of the abovementioned stabilized factor action. The results could be considered as a precursor of the PPT.

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MD SIMULATION OF IONIC LIQUIDS. CALCULATION OF EQUILIBRIUM PROPERTIES AND DYNAMIC CHARACTERISTICS

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Ionic liquids are usually organic salts with melting temperatures below 100°C [1]. They are widely used as promising electrolytes for supercapacitors. This application of ionic liquids is the main motivation of the research involved.

Using classical molecular dynamics method two ionic liquids are studied: 1-buthyl-3-methylimidazolium tetrafluoroborate ($[bmim]^+[BF_4]^-$) and N,N,N-triethyl-N-methylammonium tetrafluoroborate ($[tema]^+[BF_4]^-$). These liquids represent different types of ionic liquids—in $[tema]^+$ cation charge is localized but in $[bmim]^+$ charge is delocalized. For both liquids the temperature dependence of the diffusion, viscosity and electric conductivity coefficients are calculated on the basis of proposed in literature potentials [2, 3].

Also stochastic properties of real molecules are studied. The dynamic memory times corresponding to different degrees of freedom—center of mass translation, rotation, bond stretching, angle oscillations etc—are estimated. It is an extension of the work conducted for Lennard-Jones particles [4].

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MIXED SCENARIO OF THE CHARGED LIQUID HELIUM RECONSTRUCTION

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Discussed in the paper is the mixed scenario of charged liquid surface reconstruction when the surface 2D charge density is close to the saturation. The basic building block of arising honeycomb structure is shown to be a modified multielectron dimple.

STRONGLY COUPLED SYSTEMS OF DUST IN PLASMA AND TRAP: CHARGING, FORCES AND INTERACTIONS

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Dusty plasma is a complex object capable of self-organization, which has been subjected to intensive investigation during the last fifteen years. Dusty plasma is a unique laboratory tool for the investigation of the physics of systems with strong Coulomb interaction. A typical feature of dusty plasma is the strong interaction between charged dust particles, which may result in formation of ordered structures of liquid and crystal types accessible to observe them at kinetic level, i.e. at level of behavior of separate particles of medium.

In present work dusty plasma in a dc gas discharge is considered at low (cryogenic) temperatures of the gas. The formation of dusty plasma structures consisting of monodisperse particles ($d = 5.44$ μm) in a dc glow discharge is experimentally investigated at cryogenic temperatures in the range from 4.2 to 77 K. The ion velocity distribution function and the charging of dust particles at cryogenic temperatures are calculated using the molecular dynamics method.

For confinement and investigation of strongly coupled systems of charged dust particles, we propose to use a trap based on the known possibility of the levitation of diamagnetic bodies in a nonuniform steady-state magnetic field. An experimental setup is described, which is capable of forming and confining clusters of charge graphite particles sized 100 to 300 μm in magnetic field $B \sim 1$ T and $|\nabla B| \sim 10$ T/cm. It is inferred that it will be possible to form stable 3D structures containing several thou-

sands macroparticles under terrestrial conditions by using fields $B > 10$ T, and under microgravity conditions by using fields $B \sim 0.1$ T.

The superhigh charging of dust particles under direct stimulation by an electron beam is experimentally investigated. The energy of beam electrons amounts to 25 keV, with the typical diameter of macroparticles employed in the experiment of 100 μm. The charge acquired by a dust particle amounts to $5 \cdot 10^7$ electron charges, which is more than two orders of magnitude higher than the values of the charge of dust particles in gas discharges.

This work was supported by the Research Program of the Presidium of the Russian Academy of Sciences "Fundamentals of Basic Studies of Nanotechnologies and Nanomaterials" and by the Russian Foundation for Basic Research, Project No. 10–02–90056 and Project No. 10–02–01428.

EQUILIBRIUM STRUCTURAL PROPERTIES OF QUASI-TWO-DIMENSIONAL CRYSTAL SYSTEMS

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The pair correlation functions and the dynamics of mean square displacements of particles were studied theoretically and experimentally for quasi-two-dimensional crystal systems. In theoretical part of the work the basic attention is given to the systems with the screened Coulomb potential that is of particular interest in the context of investigation of dusty plasma. The experiments were carried out in plasma of a capacitive radio-frequency (RF-) discharge in argon with melamine-formaldehyde dust particles 12.74 microns in diameter.

Information on the pair correlation functions is necessary for calculations of various structural, thermodynamic and transport characteristics from the known formulas of statistical theory. This information may be also useful for a prediction of the different phase transition in non-ideal systems.

Here, a simple model for reconstruction of the pair correlation functions, $g(r)$ (where r is the distance between two particles), is proposed for a wide range of strongly correlated systems. This model is based on the relation between a value of the root-mean-square displacement of particle from its equilibrium position and a value of coupling parameter in non-ideal structures. The various empirical rules for the fluid-solid phase

transition in two-dimensional systems (Lindemann's and Hansen's criterions, the split of the second peak of $g(r)$ etc.) are discussed.

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THE FORMATION OF DUST LAYERS IN RF DISCHARGE

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In the present work we experimentally studied the conditions of formation of monolayer and multilayer dusty plasma systems in rf-discharge. Experiments were provided for argon (with pressure 0.05–0.3 Torr) with dust particles of melamineformaldehyde 12.74 microns in diameter and discharge power of about 2–40 W.

We revealed that the formation of a new dust layer occurs either with decrease of the discharge power while pressure of buffer gas is constant, or with decrease of the pressure while discharge power is constant. In both cases this process is connected with decrease of a gradient of vertical electric field.

For monolayer and multilayer dust systems we obtained profiles of velocities and particle displacement, there kinetic energies, spatial correlation functions and dynamic characteristics. Parameters of a steady levitation of monolayer dusty plasma structures in plasma of rf-discharge and conditions of formation of a new dust layer were defined. We made a comparison of the experiment with numerical and theoretical data. New experimental data concerning features of formation of configuration phase transition in quasi two-dimensional dusty plasma systems was obtained.

POSITIONAL AND ORIENTATIONAL CONFIGURATIONS OF ASYMMETRIC CHARGED DUST PARTICLES IN AN ELECTRIC TRAP

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Most studies on the properties of dusty plasmas deal with spherical grains. It is only rather recently that experiments have appeared with dust grains of highly asymmetric (cylindrical) shape [1]- [3]. Dust-plasma systems with such grains possess a far broader spectrum of possible states, specifically, along with conventional crystalline and liquid phases, there may be various phases with different degrees of orientational and positional grain ordering. The formation of such structures is governed largely by the electric field distribution within the discharge chamber, which is usually a cylinder. The observed spatial orientation of cylindrical grains is often unexplainable by the existing theoretical models [3] and can be rather diverse: the grains can be oriented horizontally, vertically, or at a certain angle to the axis of the gas-discharge chamber and the orientation can change from the center of the dust structure to its periphery.

The purpose of the given work was to determine the conditions for the formation of different positional and orientational configurations of uniformly charged cylindrical dust grains in an external electric field of a cylindrically symmetric trap. These conditions have been found to be determined by the ratio of the field gradients in the trap. The effect of the nonuniform charge density distribution on the dynamics of a cylindrical dust grain in an external electric field has been analyzed.

The results obtained can be useful in developing new techinques for contactless diagnostics of the parameters of gas-discharge plasma [4], e.g., in measuring electric fields in gas-discharge chambers. In contrast to measurements with spherical dust grains, those in experiments with cylindrical grains make it possible to reveal even a slight asymmetry in the design of gas-discharge tubes, a factor changing the symmetry of the electric field due to the change in the preferred orientation of microcylinders [1].

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THE DYNAMICS OF DUST MACROPARTICLES NEAR THE VACANCY IN THE DUSTY PLASMA CRYSTAL

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Research of the evolution of defects in ordered dusty plasma structures are of interest from the point of view of understanding the structural and dynamical properties of strongly nonideal systems as well as phase transitions and transport processes in such systems. It is necessary to notice that studying of influence of laser radiation on dusty plasma formations is of interest from the applied point of view, allowing to manipulate both the single dust particles and their ensembles. During the study of viscoplastic properties of dusty plasma crystals and its structural characteristics hydrodynamic flow of dusty plasma crystal was obtained. The flow mechanism was generation and following annihilation of boundary misfit dislocations. Experimental works devoted to study of dislocations in the dusty plasma structures have appeared recently in the scientific literature, but the generation and dynamics of another type of crystal defects is studied not enough. These defects are vacancies in the dusty plasma crystal. In presented work the experimental research of vacancies in crystalline dusty plasma structures was studied.

The experiments were carried out in high-frequency capacitive discharge in air atmosphere at a pressure 9–15 Pa. The discharge power was 8–12 W. The plastic (MF) microspheres of 12.17 microns in diameter were used. A dusty plasma crystal was created, and then one of its particles was removed from the structure. The evolution of vacancies was researched. The relaxation times of the vacancies were about 0.2–0.4 s. The data about dynamics of individual particles of the crystal structure located near the defect were obtained. Velocity dependencies on time of particles and their initial accelerations were determined. On the basis of the following data the interaction force of the particles in dusty plasma structure. It was equal to 8–15 ndyn and was about several percent from the gravity force acting on dust particles. Also the dynamics of particles ejected by a laser beam from a dusty plasma structures was studied.

AUTO-OSCILLATIONS OF A SINGLE PARTICLES INITIATED BY LASER RADIATION IN DUSTY PLASMA STRUCTURES

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During the last several years series of experiments devoted to the studying of the laser influence on dusty plasma structures in the high-frequency discharge plasma were carried out. It was shown that flows of dusty particles can be created for both liquid and crystalline phase states by means of a laser radiation. In this case laser radiation affects the big ensembles of dust particles. In continuation of this work experiments deal with studying of influence of laser radiation on the dusty plasma structures were performed. Vertical auto-oscillations of single particles were obtained.

Experiments were carried out in high-frequency capacitive discharge in air atmosphere at a pressure 0.1 torr. The discharge power was 5 W. The graphite dust particles of 60 μm in diameter were used in our experiments. Initiation of the oscillations was produced by a laser pulse. Movements of macroparticles were recorded by the video camera. The amplitude of oscillations was about 1 mm, frequency 20 Hz.

It was suggested that the mechanism of the maintenance of the oscillation connected with the difference between the charge of the moving particles and the charge of particles at rest. A model of the oscillations near electrode layer was constructed. This model takes into account the recharging of particles. On the basis of this model the conditions of self-oscillation mode, was determined depending on the parameters of the surrounding plasma.

CHARGING OF PARTICLES BY ELECTRON BEAMS OF DIFFERENT ENERGIES

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The presented work deals with the experimental investigation of charging of dust particles under the direct electron beam action. Two series of experiments under various conditions with 100 μm alumina particles are presented. Experimental technique that allows to digress from the way

of particle charging and to obtain the magnitude of the particle charge is described. The estimations of the charge acquired by individual macroparticle gives $1.6 \cdot 10^7$ elementary charges at pressure of air 10^{-3} Torr and energy of electrons 30.8 keV, and $5 \cdot 10^7$ e at pressure 10^{-4} Torr and energy of electrons 25 keV. Mechanisms of charging of dust particles are discussed. Influence of energy of beam electrons, gas pressure, and size of dust particles is considered.

THE INVESTIGATION OF HEATING AND CHARGING OF DUST PARTICLES UNDER THE ELECTRON BEAM ACTION

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The studying of the dusty plasma properties under the electron beam action is of great interest as this domain is of interest both from fundamental point of view (investigation of structures with extremely high coupling parameter, astrophysical tasks) and from such important practical problems as developing the new dusty plasma technologies of creating the new composite materials and spacecraft engines.

The presented work deals with the experimental investigation of dust particles motion and radiation under the direct influence of electron beam. The experiments were carried out with Al_2O_3 particles with characteristic sizes of 100 micron in the air atmosphere at pressures $\sim 10^{-3}$ mbar, the current of electron beam varied from 1 mA to 50 mA. The energy of electrons was in the range from 30 keV to 50 keV. Under the action of electron beam the dust particles began to radiate. So the radiation spectrum was registered by spectrometer with the optical resolution of 1.5 nm (FWHM). The particles motion was registered by camera and high-speed video camera (200 fps).

The analysis of particles spectral and motion experimental data was performed. The particles velocity distribution was built. In various series of experiments the charge was estimated, the characteristic value $Q \sim 10^7 e$.

MECHANISMS OF THE ROTATION OF DUSTY PLASMA STRUCTURES IN STRATIFIED DISCHARGES UNDER ACTION OF AN AXIAL MAGNETIC FIELD

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Rotation of dusty plasma structures levitating in strata of dc glow discharges under action of an axial magnetic field was observed in a number of experiments. Velocity and direction of the rotation were depended on the magnetic field. Usually, in a weak field the angular velocity and magnetic field vectors were oppositely directed, however as the field increased the velocity direction changed. In the present communication, we consider different mechanisms acting on dust particles in a magnetic field that can lead to their rotation in dc discharges. The main acting forces are the ion drag and neutral gas friction. However, the direction of these forces can be different in different conditions. We discuss the mechanisms of the appearance of these forces, their dependence on the magnetic field, and their direction. We show that the combination of the forces can lead to the rotation inversion as the magnetic field increases. Moreover, the mechanisms of the inversion can be different in different conditions.

"WARMING" OF DUST PARTICLES MOTION IN GAS DISCHARGE PLASMA

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The phenomenon of acceleration of dust particles motion in gas discharge plasma is studied. The dust particle kinetic energy exceeds both own temperature of dust particle and temperatures of electrons and ions. The mechanism of energy transfer from an external source to dusty particles kinetic energy in plasma is investigated and its influence on the spectrum of particles motion is discussed. The subsequent steps of the increase of the average kinetic energy of charged dust particles in gas discharge plasmas are suggested. Equations of dust particles 3D motion in gas discharge with account of charge fluctuations, features of near electrode layer and their influence on dust particle charge are formulated. The molecular dynamics simulations of dust particle system are performed. The combination of stochastic particle charge fluctuation and electric field

gradient in near-electrode plasma results in the dust particle forced vertical oscillations. Resonance arises due to the intersection of the range of vertical oscillations eigen frequencies with a range of charge fluctuation frequencies. The joint action of the parametric resonance and the forced oscillations explains the high kinetic temperature of dust particles. The estimated frequency, amplitude and kinetic temperature are close to the experimental values. The question of the validity of using the term "temperatures" to describe the vertical and horizontal kinetic energy of dust particles is considered. Some subsystems of plasma-dust systems are in partial equilibrium, which allows us to use the term "kinetic temperature" for these subsystems. For various system parameters several modes are implemented. It is necessary to apply different types of kinetic temperatures for different modes.

THE ENERGY TRANSFER IN THE SYSTEM OF DUST PARTICLES IN GAS DISCHARGE PLASMA

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There is a significant difference in dust particles motion along the vertical and horizontal axes under certain conditions. The mechanism of energy transfer from discharge to dust particles motion is divided into several parts. Warming up of dust particles vertical oscillations is considered separately from the heating of horizontal oscillation, as these processes are determined by several different phenomena due to near-electrode layer anisotropy. The energy transfer from vertical to horizontal oscillations is investigated separately. The outflow of energy from the dust particles oscillations due to friction on the neutral gas is also taken into account.

The system of dust particles in plasma of gas discharge near-electrode layer is considered with involving the theory of parametric resonance and forced oscillation. It is necessary to consider the fluctuations of the charge of dust particles and features of gas discharge near-electrode layer for a full accounting of all possibilities of energy transfer in the system of dust particles in the plasma. The dust particles charge fluctuates over time, depending on proximity to the electrode and the proximity to other charged particles. It is shown that energy transfer from vertical to horizontal oscillations can be based on the phenomenon of parametric resonance. Resonance arises due to the intersection of a range of horizontal oscillations natural frequencies with a range of vertical oscillations frequencies. The

joint action of the parametric resonance and the forced oscillations explains the high kinetic temperature of dust particles. Consideration of dust particles horizontal and vertical oscillations separately reveals the possibility of two different average kinetic temperature oscillations of dust particles. Molecular dynamics method confirms the theoretical calculations.

NUMERICAL ANALYSIS OF THERMAL CONDUCTIVITY FOR DUST IN COMPLEX PLASMA

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This paper concerns problems connected with thermal conductivity calculation on the basis of only the dusty system's microstate information by means of Green-Kubo formulas for transport coefficients. 2D-systems are studied. The methodology of thermal conductivity regaining is developed and discussed with perspective to apply it for processing data of experiments with dusty plasma. The results of computer simulation of dusty component theoretical model for wide range of dusty component parameters usual for RF-discharge experiments are discussed. Comparison with analytical estimation and experimental independent measuring of thermal conductivity coefficient is presented.

INFLUENCE OF NANOPARTICLES ON AFTERGLOW IN RADIO FREQUENCY CAPACITIVE DISCHARGE

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After switching off the plasma of the radio frequency discharge decays due to ambipolar diffusion process. The characteristic time of plasma relaxation is different for pristine and dusty plasma since the effective surface for electrons and ions loss in dusty plasma is substantially larger. Additionally the negatively charged massive nanoparticles visibly affect the diffusion process. In this work we study the plasma relaxation in discharge afterglow with using PIC MCC method for different gas pressures. The simulations are performed for discharge in pure argon and in Ar/C_2H_2 mixture with/without a monodisperse ensemble of nanoparticles ranging from 70 to 150 nm in size. The charge of nanoparticles is calculated from

the balance equation for electron and ion flux on the nanoparticle surface. The charge of nanoparticles varies over the discharge volume and decreases with time. It is shown that the characteristic time of plasma decay becomes less with decreasing gas pressure and the presence of nanoparticles essentially enhances the rate of plasma decay.

INFLUENCE OF DUST PARTICLES ON THE GAS DISCHARGE

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Dust particles in the gas-discharge plasma can make a significant impact on its properties (a plasma density, a current, a distribution of ions and an electron velocity and an electric field distribution) and its average properties (an average field along the tube and a field distribution along the radius of the tube). In the present work an experimental investigation of the effect of dust on the discharge characteristics is presented. We measured current-voltage characteristics of dc glow discharge in neon at a pressure 0.1 Torr. A tube diameter and a height of the tube were 4.8 cm and 135 cm correspondingly.

Current-voltage characteristics were measured in two cases: in pure gas without injected dust particles and with CeO_2 dust particles, which in total number of 10^5 particles levitated in electrostatic traps stratified discharge. Experiments had shown a strong influence of dust particles on the value of discharge current. Estimations of the discharge characteristics with dust particles and without it were obtained.

In the analysis of the experimental data Monte Carlo simulation of electron drift in the pure gas and in the presence of dust particles levitating in strata was carried out. Different characteristics, like a drift velocity, an average energy and an energy distribution function, were calculated. Also the calculation of the features of the neon ion drift, like an effective temperature and a drift velocity, was carried out. The obtained characteristics of the electron and ion flows were used to calculate the parameters of dusty plasma—electron density, the charge of the dust particles, dust charge fluctuations and the number of bound ions, the recombination flow of ions and electrons on one particle.

On the basis of the calculations and experimental data one could conclude that there is a substantial influence of dust on the conductivity of the

positive column of a stratified discharge. The analysis of the simulation results showed, the main reason for the reduction of conductivity of the positive column was a plasma recombination on dust particles, rather than an increase in resistance due to scattering of electrons on the negatively charged dust particles.

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EXPERIMENTAL DETERMINATION OF DUST PARTICLES CHARGES IN A DUSTY PLASMA

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A method for measuring the interactions of charged dust particles within a three-dimensional dust cloud is presented [1]. Stereoscopic optical system to observe the process of interaction and to determinate the distance between dust particles is suggested and developed. High speed videocamera is used in measurings. First results of image acquisition is presented.

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BEHAVIOR OF DUST PLASMA CLUSTERS UNDER ELECTRIC PULSED LOADING

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Behavior of dust plasma cluster, having 14 dust particles, under electric pulsed loading was investigated. This dust plasma cluster was chosen in order to compare obtained results with available experimental data for the same cluster type. The radius of dust particles was equal to 3.585 μm and the charge value was equal to 2660e. The next phenomenological scheme was suggested for the description of dust particle charge changing after electric nanopulsed loading. During 0.05 ms after electric nanopulsed loading the dust particle charges increased linearly 1.3 times from initial

value, then during 0.15 ms particle charges decreased exponentially to initial ones.

The results showed that character of oscillation substantially depended on both friction coefficient of surrounding environment and frequency of electric pulsed loading. It should be noted that without taking into account friction of surrounding environment the dust particle oscillations had character of pulsation near resonance frequency while in other cases dust particle oscillations reached maximum which value depended on frequency of electric pulsed loading and friction properties of surrounding environment. The oscillation amplitude of dust particle cluster linearly depended on charge particle value under electric pulsed loading. Gain-frequency characteristics of dust particle cluster were in good agreement with available experimental data.

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SINGLE- AND BICOMPONENT DUST PLASMA CLUSTERS IN ANISOTROPIC CONFINEMENT FIELD

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Research of the dependency dust plasma cluster structure on confinement field anisotropy was conducted. The interparticle interaction was described by Debye-Huckel potential. It was shown that confinement field anisotropy greatly affects shape and structure of dust plasma clusters.

The single-component dust plasma cluster represented a Coulomb ball with a typical shell structure in the ground state in the spherically symmetric confinement field. The simulated system tended to the transition from a bulk to plane shape at the decrease of the horizontal confinement field component to compare with vertical one. Increasing of the horizontal confinement field component leads to the decrease of the horizontal size of the dust plasma clusters and in the limiting case dust plasma particles form vertical chain. At the same time the simulated system tended to the transition from the plane to bulk shape and formation of the shell structure in the ground state at the increase of the dust particle number.

It was shown that the structure of the bicomponent dust plasma cluster as well as single-component dust plasma one depends substantially on confinement field anisotropy, but this dependence had a few peculiarities:

particles of different sorts were segregated by height due to size and charge differences; volumes occupied by particles of different sorts were divided by "forbidden zone"; structure of the bicomponent dust plasma cluster was symmetric with respect to the center of the "forbidden zone". It should be noted that the structure of the bicomponent dust plasma cluster was varied by confinement field anisotropy change in the same manner as the structure of single-component dusty plasma cluster one.

The work was supported by RAS Scientific Program "Thermal physics and mechanics of extreme energetic interactions and physics of strongly compressed matter".

DINAMIC DUST PARTICLE CONFINEMENT IN NUCLEAR-STIMULATED PLASMA

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Experimental research of argon-xenon medium and numerical simulation of nuclear-stimulated plasma properties that were carried out in [1, 2] shows the ability of forming of ordered structures and dust crystals that consists of charged micron Uranus or Uranus oxide particles in argon-xenon medium. This allows us to carry out effective direct conversion of nuclear energy into the optical radiation.

In work the ability of using of Paul trap or quadrupole trap for dust particle confinement in study region.

For numerical simulation of dust particles behavior in this work the case with potential forces that act on dust particles is considered, the pressure of gas medium is taken into account by viscosity magnitude.

In considered model the equation of dust particle motion in given potential field is reduced to Langevin equation:

$$m_d \frac{d^2 r_i}{d^2 t} = F_{tr}(t, r_i) + F_{int}(r_i) - 6\pi\eta R_d \frac{dr_i}{dt} + F_i^{Br} + F_{mg},$$

where $i = 1N_d$, N_d—number of dust particles, R_d—dust particle radius, $\eta = 0.02$–0.002 mPa $\cdot$ sec—dynamic viscosity, $F_{tr}(t, ri) = -grad(U_i)$—force of external electric fields that compensate gravity force, F^{Br}—stochastic delta correlated forces that describe dust particles and plasma particles impacts, F_{mg}—dust particle weight, $F_{int}(r_i) = -grad(U_i)$—forces that act on dust particle from another dust particles, U—potential

energy of dust particle interaction between each other that takes into account shielding of dust particles. Detailed description of numerical method is given in [3]. All test computings were carried out for one dust particle in harmonic trap $V(x) = \omega\frac{x^2}{2}$. Calculated results agree with analytical solutions in limits of digital error.

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MATHEMATICAL SIMULATION OF A PROCESS OF THE DUSTY COMPONENT ORDERING IN THE NUCLEAR-INDUCED PLASMA OF THE LASER-ACTIVE ELEMENT

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The key task in the problem of a creation of powerful nuclear-optical energy converters is a developing of the effective laser-active element that is the facility in which a transformation of the fission energy into the laser radiation energy directly takes place. It is suggested to use in the laser elements of the new generation the fission material distributed along the volume of the laser element in a form of dust particles. In this case all products of the fission process participate in the pumping of the laser-active medium. The rigid limitations on the geometrical sizes of the laser-active element will be removed. It will be possible to control a pumping power independently on an impulse of the sparking reactor with the help of a density of the dust particles containing uranium. It becomes possible to change one laser-active medium to another without any changes of a construction of the laser element. The aim of the work is to make the scientific and technical basis on the technology of laser-active elements of new generation on the base of dusty plasma structures. In this case the efficiency of the straight transformation of the nuclear energy into the energy of the

optical radiation is significantly greater in comparison with the present-day analogues. The results of the mathematical simulation of processes of stabilization and ordering of the dusty component in the nuclear-induced plasma are presented. The simulation was performed by the Brownian dynamics method. We took into consideration the evolution of the dust particles randomly distributed along the laser-active element volume to the stationary state with the aim to reveal stable dusty structures formed in the gaseous laser-active medium. The mathematical model was used as well to investigate dynamics of the dust particles behavior and to choose a perspective geometry of the laser-active element.

TWO-DIMENSIONAL MODEL OF KINETIC PROCESSES IN URANIUM FISSION FRAGMENTS TRACKS OF INTO GASEOUS PLASMA WITH NANOCLASTERS

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The two-dimensional multi component model of non-homogeneous kinetic processes in fission fragments track in the dusty plasma of the noble gases was developed. The system of nonlinear integral differential equations describing the space-time evolution of dusty plasma of the noble gases in a track of fission fragments is derived. The model includes the space-time evolutionary equations for electron velocity distribution function, concentration both various gaseous and dusty component of plasma and Poisson equation for the electric field. The method of the solution and algorithm for parallel calculations of rigid differential equations system describing kinetic processes in the fission fragments track in gaseous plasma with nanoclasters is developed. The program complex for mathematical simulation was developed.

The track structure effects for a space-time evolution of fission fragment excited dusty argon plasma and data about of a space-time fluctuations both concentration of various component of plasma and charge distribution on dusty particles and electric field strength were obtained by the methods of numerical simulation.

STATIONARY PRE-BREAKDOWN VOLT-AMPERE CHARACTERISTICS OF WEAKLY-IONIZED MEDIUMS

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For the first time discrepancies from the Ohm Law for weakly ionized mediums in pre-breakdown stationary electric fields of the plane capacitor have been experimentally revealed by Poole [1]. Frenkel [2] showed theoretically the exponential growth of a conductivity of the mediums discussed with an increase of the field intensity module using the Arrhenius type equation for dependence of a volume ionization velocity on temperature. It has been shown [3] that for application of the Frenkel formula both for isothermal and non-isothermal regimes it is sufficiently to have a fulfillment of the quasi-neutrality of the mediums in the weak and prebreakdown electric fields. In this case in the isothermal regimes for the plane high-voltage capacitor the Frenkel exponential volt-ampere characteristic that is proved by experiments follows from the law of the charge conservation. In the case of a spherical capacitor the much more complicated ordinary differential equation of the first order to determine a steady-state distribution of the electric field potential in the interelectrode gap has been obtained. From the analytical solution that we obtained in [4] a linearity of the volt-ampere characteristic for the weak fields and its squareness in the prebreakdown fields follow. These facts are in an agreement with the experimental results of different authors. In the case of the cylindrical high-voltage capacitor the similar problem converges to the nonintegrable analytical problem. We developed an algorithm of a numerical integration. The results of the calculation of stationary volt-ampere characteristics using this algorithm approved a linearity of these characteristics in the weak fields and the squareness in the non-uniform prebreakdown fields for the case of the cylindrical symmetry. The experimental verification of the solution obtained was performed. The experiment was made in the cylindrical cell with a 49 mm diameter. The 0.1 mm diameter wire was stretched along the cell axis. The potential that was positive in relation to a wall was applied to the wire. The volt-ampere characteristic obtained is quite well described by the received numerical solution.

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EXPERIMENTAL RESEARCH OF DUSTY PLASMA STRUCTURES UNDER THE INFLUENCE OF NANOSECOND ELECTRIC PULSES

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Within researching processes of appearance of ordered structures and phase transitions in non-ideal dusty plasma the behavior of dust structures under the influence of nanosecond electric pulses in the DC glow discharge has been studied. The search of resonance effects, stabilization and precipitation of dust structures is carried out. Experiments of influence by nanosecond electric pulses with frequencies from 4 to 300 Hz were carried out. Basing on the analysis of the particle fluctuation amplitude the resonant frequency of 7.1 Hz was found out. The investigation of mechanism of particles fluctuations was of great interest. It was discovered that nanosecond impulses change the background plasma near the particle, and don't get an impact on the displacement of particles. In our previous experiments with the RF discharge a stabilization of particles was observed at a pulsed repetition frequency of 16 Hz. The similar experiment has been made in the DC glow discharge. The stabilization of self-excited fluctuations and waves was observed at frequency of pulses of 200 Hz. Such behavior of particles happens because the imposing of the capacitor nanosecond discharge forms an additional local ionization of plasma and artificial striation in which the dust cloud is stabilized. The further increase of a repetition frequency of nanosecond pulses caused the effect of precipitation of the particles. It was caused by the dusty plasma trap destruction. The resonant frequency for a dust structure in the glow discharge was discovered experimentally. The effect of stabilization of dusty plasma structure was found out. The frequency at which a stabilization of the dust structure is fixed was defined. The method of separation of particles was offered.

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INVESTIGATION OF TRAP'S PARAMETERS IN DC GLOW DISCHARGE BY MEANS OF OPTICAL METHODS

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Dust structures are often observed and investigated levitating in the striations of a dc glow discharge, which are usually produced by step change of discharge's tube diameter. The investigation of striations by means of Langmuir probe is difficult due to high disturbances. Optical methods of research, such as laser spectroscopy by means of tunable diode laser and absorption of intrinsic emission, give accurate parameters of the trap, for instance low concentration of metastable atoms and their temperature. Such important parameters for discharge's simulation are obtained and discussed in this article.

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DUSTY PLASMA INSTABILITIES IN CRYOGENIC DC DISCHARGE

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The experimental research was carried out on the basis of setup of a glow direct current discharge. Different types of dusty plasma instabilities were observed (self-excited oscillations, vortices and complex oscillations). Conditions of initiation instabilities were determined. Different parameters, like discharge current, gas pressure, particle concentration and gas temperature were varied in a wide range. Using special program coordinates of dusty particles were obtained after processing video data. Structure and dynamical characteristics of dusty plasma structures were obtained. Dependence between interparticle distance in different parts of dusty structure and different parameters of glow discharge was measured.

Besides, dependence between frequencies of oscillations and the gas pressure for structures with self-excited oscillations was presented. Density wave front speed was estimated.

During the experiments influence of gas temperature on the dusty plasma instabilities was investigated. Temperature was varied from the room temperature to the temperature of liquid nitrogen (77.4 K). The main result consists in decreasing of self-excited oscillation frequency with the decreasing of gas temperature. It seems that decreasing of gas temperature could lead to damping of self-excited oscillations. The profile of an average kinetic energy and a profile of concentration for dusty structures with vortices were calculated. To explain the mechanism of an instability initiation the theoretical model based on existence of a radial charge gradient of dust particles was used. Using experimental data some estimations of this charge gradient were done.

DUST PARTICLES INFLUENCE ON CRYOGENIC PLASMA OF GLOW DISCHARGE IN NEON

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The experimental study of influence of dust particles on parameters of positive column of glow discharge in neon at cryogenic temperature is presented. Melamine formaldehyde particles of 4.14 μm diameter were introduced in discharge maintained at liquid nitrogen temperature in the discharge tube of 16.5 mm i.d. cooled in optical cryostat. The neon pressure range was 0.14–1.4 torr, measured at room temperature.

The optical images of dust structures, current-voltage characteristics of positive column of discharge and temperature of discharge tube wall were registered. The character of dust particles influence on plasma parameters and change of dust cloud shape versus discharge current are similar to those at room temperature [1]. Nevertheless, unlike experiments at room temperature, the dust structures with central zone free of particles were not registered in cryogenic plasma at the same currents. The dependence of distance between particles versus discharge current at cryogenic temperatures is absent. Cooling of gas was followed by initiation of longitudinal oscillations of dust particles and increase of particles density in dust structure. The discharge with dust particles was ignited at current of 2 mA, after that current was increased up to 3 mA and then diminished back to 2 mA. As a result, some part of dust particles precipitated from dust cloud.

Finally, the lower voltage of the positive column was observed, which was due to the lower losses of plasma electrons on dust particles. The number of particles confined in discharge decreased with current due to the thermophoretic force action, which push particles out of the electrostatic trap formed by strata, towards the wall of the discharge tube [1].

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STUDY OF GLOW DISCHARGE POSITIVE COLUMN WITH DUST PARTICLES

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Experimental and numerical study of positive column of glow discharge with dispersed particles was motivated by the need to simulate plasma parameters and electric field configuration changes induced by cloud of particles. Dust clouds of micron size particles were developed and studied in the positive column of a glow discharge in air at pressure of 0.1–0.6 torr and discharge current of 0.1–3 mA. For simulations the numerical model of influence of dust cloud with the specified geometric parameters on gas discharge, represented in details in [1], was applied. Plasma of positive column and dust component were described in terms of diffusion model and OML approximation correspondingly. The distribution of dust particles in discharge was simulated by a blurred step function with size and concentration independent of discharge current and gas pressure. The radial distributions of plasma components calculated for different values of particle concentration, discharge current and gas pressure, reflect the change of electric field in presence of dust cloud. When concentration of particles attains sufficient value, the efficiency of particle surface absorption becomes comparable with diffusive losses of electrons on walls of discharge tube leading to the situation when the electron concentration on outer face of dust cloud becomes higher than in the center of discharge tube. At some critical concentration of dust particles, the radial electric field changes its direction towards the axis of the tube in some region inside the dust cloud. Experimentally measured and simulated current-voltage characteristics of discharge with and without dust component show the increase of the positive column electric field strength in the presence of dust particles and the

higher stability of discharge against disturbing action of dust particles at high currents.

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FACTORS OF LOW TEMPERATURE NON-THERMAL ATMOSPHERIC PLASMA INFLUENCE ON THE BIOLOGICAL OBJECTS

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For the investigations of low temperature non-thermal atmospheric plasma flow influence on the biological objects, diagnostics of the plasma torch was carried out. Influence of plasma flow on bacteria was investigated *in vitro.* Main factors influencing on the biological objects are active radicals and oxides (O_3, OH, NO et al.), UV radiation, electrons and ions, heated gas flow.

Spectral diagnostics of low temperature atmospheric plasma was carried out and radiation spectrums of near-electrode region of plasma were obtained. There were detected emission spectra lines, such as N_2, Ar, OH, O_2, NO. To research a contribution to a medical effect of UV radiation number of experiments with special quartz-crystal filters was carried out. Using quartz-crystal filters made it possible to eliminate all main influences except UV radiation effect. Spectrophotometric methods based on measuring and analysis of absorbance and transmission spectrums were used to measure optical density and transmission coefficient of filters. It turned out that plasma flow influence on bacteria in vitro without any filters led to a high decontamination effect. The efficiency of agar surface decontamination after 2 minutes exposition ranged between 97.2–99.2% for Pseudomonas aeruginosa and 71.0–99.4% of Staphylococcus aureus in dependence on a strain. The effectiveness of decontamination was rose when exposition time was increased, thus after 5 minutes exposition the effectiveness was 100% for P. aeruginosa and 71.0- 99.4% for S. aureus, that depended on a strain.

It turned out that plasma flow influence on bacteria in vitro with using quartz-crystal filters led to decreasing of the effectiveness of the decontamination by tenfold and more. Thus, o low temperature non-thermal atmospheric plasma flow influence demonstrated a significant bactericidal effect against opportunistic pathogens while a relative contribution of UV was less than 10%.

EFFECTIVENESS OF NONTHERMAL PLASMA AGAINST INTRACELLULAR BACTERIA: A NOVEL SPHERE OF APPLICATION?

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Nonthermal plasma was shown to be bactericidal for Gram-positive and Gram-negative bacteria. The sphere of plasma applications would further increase if its bactericidal effect spreads to intracellular bacteria. Intracellular pathogens are common causative agents of local infections of mucous surfaces and members of wound polymicrobial communities. Gram-negative bacteria of the family Chlamydophilia are obligate intracellular pathogens and opportunistic pathogens in chronic skin ulcers and other inflammatory skin conditions. All experiments were performed with argon plasma produced by the MicroPlaSter device. A bactericidal effect of nonthermal plasma was studied at major stages of the chlamydiae lifecycle including infectious extracellular elementary bodies (EBs) in water suspension; EBs attached to the cell surface during the process internalization into the cells; actively multiplying intracellular bacteria (reticulate bodies, RBs) that form in 24 h after infection; intracellular EBs formed in infected cells in 48 h after infection of the McCoy cells.

Obtained results demonstrated that both extracellular and intracellular Chlamydia forms are highly sensitive to plasma treatment. About 0.01% bacteria survived treatment. The noticeable effect of plasma treatments on intracellular bacteria raised the question concerning susceptibility of host eukaryotic cells to argon plasma. In 24 h after 2 minutes treatment, about 35% drop in the amount of viable epithelial McCoy cells was observed in regarding to control cells. There was no difference in viability between in-

fected and non-infected cells. Thus, plasma might effective in elimination of intracellular bacteria. Upon development of endoscopic plasma sources, this might spread plasma applications in medicine up to treatment of urogenital and pulmonary infections.

THE STUDY OF NON-THERMAL ARGON PLASMA IN DIFFERENT BIOLOGICAL MODELS

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Non-thermal (low-temperature) physical plasma is under intensive study as an alternative approach to control superficial wound and skin infections when the effectiveness of chemical agents is weak due to natural pathogen or biofilm resistance. The purpose of this study was to test the bactericidal effects against pathogenic bacteria in different biological models. Overall, Gram-negative bacteria were more susceptible to plasma treatment than Gram-positive bacteria. For the Gram-negative bacteria Pseudomonas aeruginosa, Burkholderia cenocepacia and Escherichia coli, there were no survivors among the initial 105 c.f.u. after a 5 min plasma treatment. The susceptibility of Gram-positive bacteria was species- and strain-specific. Streptococcus pyogenes was the most resistant. Staphylococcus aureus had a strain-dependent resistance with 0 and 10% survival from 105 c.f.u. of the Sa 78 and ATCC 6538 strains, respectively. S. epidermidis and Enterococcus faecium had medium resistance. Non-ionized argon gas was not bactericidal. Biofilms partly protected bacteria, with the efficiency of protection dependent on biofilm thickness. Bacteria in deeper biofilm layers survived better after the plasma treatment. A rat model of a superficial slash wound infected with P. aeruginosa and the plasma-sensitive Staphylococcus aureus strain Sa 78 was used to assess the efficiency of argon plasma treatment. A 10 min treatment significantly reduced bacterial loads on the wound surface. A 5-day course of daily plasma treatments eliminated P. aeruginosa from the plasma-treated ani-

mals 2 days earlier than from the control ones. A statistically significant increase in the rate of wound closure was observed in plasma-treated animals after the third day of the course. Wound healing in plasma-treated animals slowed down after the course had been completed. Overall, the results show considerable potential for non-thermal argon plasma in eliminating pathogenic bacteria from biofilms and wound surfaces.

GAS HEATING BY ACOUSTIC WAVES IN HIGH PRESSURE MEGAAMPERE DISCHARGES

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Earlier analysis of soft X-ray intensity oscillations in the discharges with the initial hydrogen pressures of 5–7 MPa showed that it could be caused by periodic changes in the diameter of the discharge channel [1]. In continuation of these studies the diameter of the current zone was defined. The experimental changes in the diameter correspond to the calculated estimations. It was established that the oscillation period is proportional to the square root of the atomic number of the initiating wire material. This fact is an argument that the diameter variations of the discharge channel with the metal vapors are associated with aligned magnetic and gaskinetic pressure.

In go over to the initial pressure of 80–160 MPa, which are created by adiabatic compression [2], there are the amplitude of acoustic pressure on the discharge chamber wall increasing and the growth of voltage fluctuations in the discharge simultaneous with it. The amplitude of pressure fluctuations at the wall reaches 150 MPa and voltage jump is of ~ 3 kV. According to estimations, it is correspond to the discharge channel radius changing from 0.35 cm to 0.20 cm. This oscillations are several times more then at an initial pressure of 5–35 MPa.

Estimations of channel parameters by its conductivity and pressure for the copper plasma at a current amplitude of 500 kA and an initial pressure of hydrogen in the chamber 110 MPa give $T \sim 1.0 \times 10^5$ K; $n_i \sim 2 \times 10^{20}$ cm^{-3} and the average ion charge $z = 2.6$. Power balance for the initial pressure of 80–160 MPa at the time of maximum discharge current shows that about half embedded electrical power in the channel goes into heating the gas in the chamber by acoustic waves. The work

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ECTON MECHANISM OF UNIPOLAR ARCING AT A NANOSTRUCTURED FIRST WALL UNDER ELM-PLASMA POWER LOAD

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The recent experiments on initiation of a unipolar arc at a tungsten surface with nanostructure under the action of the ELM (edge localized mode) power load [1, 2] are considered in frames of the ecton model [3]. The power load of about 1 MW/cm^2 produced by a laser pulse (0.6 ms, 5 MJ/m^2) corresponds to the ELM type-I. The net-like fiber-form nanostructure of a few microns thickness was formed at a tungsten plate by a He-plasma action at a NAGDIS-II linear device ($T_e \sim 6$ eV and $n_{pl} \sim 2 \cdot 10^{13}$ cm^{-3}). The surface temperature is about 1900 K. The action of a laser pulse on the nanostructured surface lead to the prompt, stable unipolar arc ignition.

We have shown that the ignition of a unipolar arc represent itself the initiation of explosive emission centers at the surface and the nanosecond emissive pulses—ectons, similarly to the vacuum arc. The arcs sustainment is the continuous initiation of a new explosive emission center leading to the consequence of the emission pulses—ectons. This initiation is provided by an intense explosive-plasma (10^{20} cm^{-3}, 2 eV) interaction with the surface. This is the reason for the formation of numerous microcraters, that were observed in all experiments on unipolar arcs.

The arc burning duration depends on the initiation condition—the more the total current, and hence the number of a explosive emission center functioning simultaneously, the longer the arc life time. It is known that the ectons arise mainly at microprotrusions and impurities present on the electrode surface. The cleaner and smoother the surface, the greater the energy necessary for the initiation of an arc and the worse the conditions for its self-sustainment.

The agreement between the experimental data and the model predictions testifies, in our opinion, to the key part of ecton processes in the phenomenon of unipolar arcing.

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PARTICLE KINETICS TRACING AT A SPECIFIED EXTERNAL FIELDS AND COLLISIONS

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Multipurpose numerical algorithm for particle kinetics analyzing at a given external field and plasma and neutral gas density distribution was designed. Such type of numerical analysis of "exact" solution of particle motion equation is of substantial interest for various plasma physics phenomena: for example—acceleration of electrons in runaway regime in plasmas and pulsed electrical discharges; particles drift trajectories at non-adiabatic regions near field nulls in magnetic confinement systems stabilized by a strong field lines curvature (plasma compressibility); motion of electrons in dense plasmas expanding across a magnetic field, etc.

Magnetic field geometry is given by a circular current rings array arbitrarily arranged. Special interpolation procedure is applied for field calculation acceleration. The inaccuracy of interpolation method is less than 10^{-5}–10^{-4} from the Biot-Savart law.

The collision processes are taken into account by a continuous decelerating force, which is most adequate for plasma-collisions with prevailing of low-angle scattering. The elastic scattering is taken into account as diffusion by the transverse velocities in the phase space.

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EXPERIMENTAL RESEARCH OF ELECTRIC ARC IN PLASMA TORCH WITH SECTIONED ANODE

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Experimental investigations were performed on test facility consisted of plasma generator with cylindrical sectioned output electrode (anode), electric feed system, water cooling system and gas-dynamic circuit with heat exchanger and exhaust ventilation [1, 2].

Nitrogen was used as orifice gas. Experiments were performed for different gas flow rates (1, 1.5 and 2 gr/sec) and electric current nominal values (125–300 A). Arc voltage drop and electric current through each section was measured during experiment. Magnitude of time step was 11microseconds.

In addition approximate values of electric field intensity were calculated. On figure 2 electric field intensity for different regimes is represented. Obtained results have good agreement with experimental data of other authors [3].

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THE HIGH-CURRENT ARC DISCARGE IN TRANSFORMER OIL

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Results of experimental researches of the pulse arc discharge at duration of burning of 3–20 ms and the maximal current up to 50 kA are presented. These conditions are characteristic for an initial stage of the discharge arising in the high-voltage oil-filled electrotechnical equipment as a result of internal short circuit.

Experiments were spent in the discharge chamber with total volume of 61 l. The volume of oil was 35 l and the remaining volume was filled with nitrogen at atmospheric pressure. The discharge was arisen at electric explosion of a copper wire with diameter of 0.1 mm, connecting parallel electrodes with diameter of 15–24 mm. The distance between electrodes was changed from 20 to 48 mm. The released energy in the arc discharge reached about 100 kJ. The diagnostic system included measurement of a current and a voltage of the discharge, pressure in oil and in nitrogen. The video shooting with a speed up to 1200 frames per second of development of the discharge and liquid-gas surface was spent. Propagation of the discharge to oil was registered by means of potential probes.

The maximal pressure in the liquids reached about 2 MPa. It has been measured on distance of 0.2 m from area of burning of the discharge. This pressure increased with the rate about 1 MPa/msec. Characteristic value of electric field strength in an arc column was about 0.2 kV/cm. Gas producing factor in an arc was about 110 l/MJ. The composition of the gases which have occurred due to oil decomposition in the arc discharge was defined. Estimations of plasma parameters in extending gas-vapor bubble are presented. It was shown, that characteristic value of pressure of plasma was about 10 MPa.

NANOSECOND HIGH-VOLTAGE DISCHARGE IN NON-HOMOGENEOUS GAS

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High-speed mixing of gases at injection fuel into oxidant is one of the actual problems of plasma-assisted combustion. Submicrosecond filament discharge can be used to initiate turbulent gas motion and vorticity to solve this problem. Thereby studying of the geometrical form and localization of impulse submicrosecond discharge closely to the boundary of two gases becomes actual.

One of the feature of this discharge is high level of energy deposition density. Typical discharge parameters are as follows, discharge current $I = 1$–3 kA, energy release $E = 1$–3 J, duration $t = 30$–100 ns. These experiments revealed interesting effect: the discharge tend to propagate along the boundary flow-jet. The particular detailed mechanism of this effect is not clear now. Study of localization of pulse discharge closely to the boundary of two gases was fulfilled to clarify the mechanism of this effect. Experimental scheme allows the visualization of streamer phase of discharge propagation by gas-dynamics disturbances that are caused by streamer channels.

Series of experiments with the different electrodes configurations were done. Discharge propagates precisely along the boundary in case of setting both electrodes at the jet border. The discharge channel becomes straight in this configuration in opposition to similar configuration without jet. In case of discharge propagation along the border electrical characteristic of discharge (energy deposition, breakdowns voltage, channel resistance) are close to such characteristics in still air. Electrical measurements are supposed to give qualitative information about discharge channel gas composition.

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REP-RATED Ar-Xe-LASER PUMPED BY A NON-SELF-SUSTAINED DISCHARGE IN GAS FLOW

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Effective lasing in Ar-Xe-mixtures pumped by rep-rated electron beams and discharges is connected with certain difficulties. The experiments [1] and [2] showed that limitation of lasing power at wavelength of 1.73 micrometer during rep-rated pumping of Ar-Xe-laser is explained by heating of working gas mixture. Our device used in [2] has allowed us to cool gas mixture during rep-rated pumping and to obtain higher average lasing power.

In the experiments an electron beam and non-self-sustained discharge initiated by electron beam in gas mixture Ar:Xe=200:1 at an atmospheric pressure have the following parameters: energy of beam electrons up to 170 keV, beam current up to 24 A, beam half-height pulse duration 7 ns, beam cross-section 20 cm per 3 cm, voltage at the discharge gap 10 kV, discharge current up to 1100 A, discharge half-height pulse duration 110 ns, electron beam and discharge pulse repetition rate up to 50 Hz. The installation provides an effective cooling of the gas mixture in close cycle by a liquid nitrogen during rep-rated pumping.

Experiments without circulation of gas mixture showed that already with a pulse repetition rate of 1 Hz not an increase, but a sharp decrease in both the energy of separate laser pulse and the average lasing power was observed. A gradual increase in temperature of the gas mixture was observed too.

During experiments with various speeds of the circulation of the gas mixture it was explained that an increase in the speed of the circulation leads to an increase in the linear section of the dependence of the average power of generation on the pulse repetition rate and to a considerable increase in the values of the average power of laser radiation. Maximum average power of lasing (55 mW) was reached during the pumping with a pulse repetition rate of 10 Hz and with the speed of circulation 1 m/s.

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INVESTIGATION OF THE AIRFLOW INDUCED BY DIELECTRIC BARRIER DISCHARGE IN QUIESCENT AIR

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Nowadays the dielectric barrier discharge (DBD) [1] has many applications, for example in ozone producing devices, in plasma aerodynamics, in vortex generators and as pressure sensor. Very promising is its application in flow control devices near the surface of an aircraft [2], particularly to prevent flow separation. There is additional flow weakly ionized air when voltage is applied. Nowadays the dependence between the airflow velocity and amplitude of applied voltage is well studied in stationary case. But the gas-dynamic processes occurring at the initial time after energizing the DBD-discharger (or actuator) are not investigated to the end.

The experimental investigation of dielectric barrier discharge was presented in this work. One of the goals of this experimental work was the visualization of the gas-dynamics structures, created by asymmetric DBD. The initiation of DBD in quiescent air was visualized by two main diagnostic techniques. The first is schlieren and second technique is the particle image velocimetry (PIV). Visualization of air flow near the place of initiation of the discharge was carried out. The structure of vortex flow in steady and unsteady flow of air was considered. With the help of schlieren and PIV methods the velocity of the vortices was measured. A comparison of PIV-measurements based on the method of particles, and high-speed schlieren visualization was made. A linear dependence of the average current consumption during initiation into the air from the voltage amplitude was obtained. During the process of measurement of the velocity distribution in the main vortices in the nonstationary case, it was found that there is a secondary vortex near the edge of the external electrode. For the dynamical properties of vortices to be described the time dependence of the vorticity was experimentally obtained. The experiment showed that the magnitude of vorticity near the edge of the outer electrode in magnitude coincides with the vorticity core of the vortex, but opposite direction.

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STABILIZATION OF LAMINAR METHANE-AIR FLAME BY NANOSECOND DISCHARGE

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An influence of plasma of nanosecond discharge on characteristics of laminar methane-air flame is theoretically studied. The premixed flame model solves a set of the basic differential equations which describe dynamics of a flame, using implicit final methods of separation. This model is applied to determine the characteristic flame velocity at the specified pressure and initial temperature. In this case there are no heat losses (by definition), and thus temperatures could be calculated from the energy equation. A flame velocity depends partially on heat transport and temperature distribution. The reactor model is based on the numerical solution of the Boltzmann's kinetic equation for distribution function for electrons energy in low-temperature plasma, on determination of the electronically-excited reaction rate constants and on calculation of drift electron speed, average electron energy, the electron diffusion constant, etc. Mixture content in plasma changes according to chemical and vibrational kinetics. The mechanism of methane combustion is selected [1]. The results of calculations have confirmed experimental data [2], [3] where plasma partially converts fuel in after-discharge zone to incomplete combustion products CO, H_2, CH_2O, C_2H_4O, C_2H_6, H_2O. An influence of the certain reactive species, yielded as a result of plasma influence, on a flame and impact of nanosecond discharge on premixed laminar methane-air flame are considered. It is established that the effect of heat release in the reactions of conversion has more influence on a flame velocity than chemical activating; at low initial temperatures ($T < 700$ K) plasma influence brings the same effect for flame velocity as thermal heating.

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STRUCTURE OF AMORPHOUS CARBON PRODUCED BY HIGH-VOLTAGE ELECTRIC DISCHARGE TECHNOLOGY IN ORGANIC LIQUIDS

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New high-energy electric discharge technologies for production of carbon nanomaterials, containing fullerene-like clusters of the C_{60}–C_{70} type, nanotubes, nanodiamonds and amorphous carbon (AC), using the methods of electrical explosion of graphite rods and electric breakdown of organic liquids (EBOL) are elaborated [1, 2]. The EBOL technology gives an opportunity to produce an AC in amounts required for industrial application.

The structure of the synthesized from different organic liquids (benzene, hexane, cyclohexane, etc.) carbon powders is studied by the electron microscopy, Raman spectroscopy and X-ray analysis. Raman spectra are typical to AC materials and they are characterized by a large intensity ratio I_D/I_G (~ 0.9), what indicates on significant structural disorder. The synthesized AC powders possess a complex hierarchical structure with a size of individual components of the order of 30–50 nm and specific surface area of ~ 150 m^2/g. It is found, the Raman spectra of AC produced from cyclohexane (C_6H_{12}) are similar that of nanodiamonds. This fact testifies to the diamond-like type of short-range order, what was confirmed by the RDF calculations. We found that the type of short-range order of AC produced by EBOL technology is primarily determined by the degree of hybridization of carbon atoms in the molecule of the working liquid: in the case of hydrocarbons with sp^2-hybridization, AC have the graphite-like type of short-range order, in the case of working liquid with sp^3-hybridization—diamond-like one. A structure of the organic molecule plays an important role, because AC with predominance diamond-like type of short-range order is synthesized only in the case of cyclohexane, a molecule which is similar to a hexaatomic ring in the crystalline structure of diamond.

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REVERSE CROWN DISCHARGE IN AEROSOL MEDIUM IN ELECTROFILTERS

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Efficiency of the technological gases clearing from the solid particles process depends on a regime of the high power supplies [1]. Sedimentation of the solid particles with high specific electric resistance of $\rho \geq 108$ Om·m, leads to low charge providing layer formation on the gathering electrode. This dust layer is the most difficultly caught because of the reverse crown appearance [2]. The negative charge was collected on this layer surface. At the critical potential value achievement in this layer the micro breakdowns arise at this layer accompanied by the positive ions emission into the inter electrode space. This phenomenon has got the name "reverse crown" [1], which sharply reduces overall performance of the real electrofilter. The experiments for the size and sign of the ionic stream in the interelectrode space measurement for the determination of the reverse crown quantitative influence on the processes in the electrofilter at the high specific electric resistance particles clearing have been made. The experimental layout has constructed with the sensitive element which has been connected to the mass measuring instrument. All of the experiments has been fulfilled during the reverse crown in the interelectrode space and it have been stated that It depends on physical and chemical particles flow properties and the efficiency of the gases clearing decreases in the interelectrode space by the ions of both signs.

It is necessary to reduce the reverse crown power for the degree of gases clearing increasing, for example, by changing the form of a wave of supplied power—through one period power, a pulse power, a sign-variable power.

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TWO STEPS BREAKER WITH FORCED SWITCHING AS OF GIGAWATT TECHNOLOGY

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Modern of electric brake systems have widely characteristics as of current, voltage, power and time of acting. Commutation equipment is used in electrical networks of AC and DC. At megawatt power, resource of breaker is 10.000 acts of reliability switching. Therefore combination vacuum interrupter and vacuum switch as source pulsed power is often used in industrial technologies [1–3].

With increase of power of breaker system, for example gigawatt level, it resource is decreasing before 100 acts and less. The two steps breakers based on ordinary circuit is not solving problem. It connected with initial stages of breaker, as namely, arc is not moved until of little gap between electrodes. It is cause of high erosion of electrodes, because in this moment the through electrodes flowing full of current [4, 5].

To overcome of this problems is offered to consideration the two steps opening switch based on forced transfer of current from first step to next [6–8]. While through first step is flowing only 3–5% from full current but opposite direction. It lets decrease erosion and time recovery of electrical strength of gap. Thus it is decreased size of breaker, increase of resource of more 10.000 acts of real switching off.

Offered technical solution lets to develop problems to connected with gigawatt pulsed technology based on inductive storage energy such so microwave, ELM launch, pulsed radar, geophysical research, power lasers, at al. The several features of parameters of breakers under application of technology is offered in this paper.

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MANAGEMENT OF INTANGIBLE ASSETS IN ESTABLISHMENTS OF THE RUSSIAN ACADEMY OF SCIENCES

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Management features of intangible assets created in scientific institutions are analyzed at deducing on the market of innovative results of intellectual activity, including in the form of uniform technologies. Main objective of the management is to extract the maximum benefit from their use for the organization and the motivation of scientists which are authors of innovative works by intangible assets reduction. Utilitarian questions of cession rights process on uniform technologies are considered at important stages of application activity. Cost estimation method of the uniform technology taking into account the object features, the brand of creator, a stage of readiness for industrial use and market conditions of innovative technologies is offered. It is shown that in some cases, the cost estimation of results of intellectual activity define a mechanism of management and a policy of scientific organizations concerning results of intellectual activity and intangible assets.

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SPbSPU — Saint-Petersburg State Polytechnic University, Saint-Petersburg, Russia

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