Institutions of the Russian Academy of Sciences
Joint Institute for High Temperatures RAS
Institute of Problems of Chemical Physics RAS
Kabardino-Balkarian State University

XXV International Conference on

Equations of State for Matter

March 1–6, 2010, Elbrus, Russia

Book of Abstracts

Moscow & Chernogolovka & Nalchik, 2010

The book consists of the abstracts of oral and poster contributions to the XXV International Conference on Equations of State for Matter (March 1–6, 2010, 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: equations of state and constitutive equations for matter under extreme conditions; shock waves and detonation physics; experimental methods of diagnostics of ultrafast processes; interaction of intense laser, x-ray and microwave radiation, powerful ion and electron beams with matter; techniques of intense energy fluxes generation; low-temperature plasma physics; issues of physics and power engineering, technology projects.

The conference is held under financial support of the Russian Academy of Sciences and the Russian Foundation for Basic Research (grant No. 10-02-06043).

Edited by academician Fortov V.E., Karamurzov B.S., Temrokov A.I., Efremov V.P., Khishchenko K.V., Sultanov V.G., Levashov P.R., Kanel G.I., Iosilevski I.L., Milyavskiy V.V., Mintsev V.B., Petrov O.F., Savintsev A.P., Shpatakovskaya G.V.

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MATTER UNDER EXTREME CONDITIONS PROBED WITH A FREE-ELECTRON-LASER: TIMEX PROJECT

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The expected capabilities of the new free-electron-laser sources under development all around the world open the way to investigate fundamental properties of condensed matter under extreme conditions. The free-electron-laser pulses are expected to be able to pump systems into warm/hot dense matter regime with an unprecedented temporal resolution. In particular, the Fermi@Elettra source (Trieste, Italy) will deliver 0.1–1 ps pulses in the 10–100 eV range and a program (TIMEX) for investigating matter under the extreme conditions generated by the pulses is currently active. TIMEX concerns the construction of an end-station dedicated to the investigation of liquid and solid phases under extreme and excited or metastable conditions. We expect to be able to perform ultrafast time-resolved studies of the optical and soft x-ray properties of matter providing information on sample surfaces, or accessing microscopic electronic and dynamical structure information on excited states. In particular, direct access to points of the phase space beyond those probed by traditional shock-wave techniques, with high repetition rates and possibility of high statistics, makes these new possibilities particularly exciting for exploring states of matter presently inaccessible and put to a test equation of state in a wide range of densities and temperatures.

X-RAY DIFFRACTION UNDER HIGH PRESSURE AND TEMPERATURE USING A NOVEL LABORATORY SETUP

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In recent times, we have developed several original experimental equipments for in-house x-ray diffraction and electroresistance measurements under static high-pressure and high-temperature conditions with a large-volume cell. In this communication we discuss some important technical

features and possibilities of the equipments as well as typical data collected at high pressures. In particular, we will show energy-dispersive x-ray diffraction patterns collected with a rotating anode source of composite samples under pressure (WC anvil recessed geometry). These data under high pressure and temperature conditions are shown to be useful for checking and improving present knowledge about the equation of state of solid systems. The relevance of these experiments to the exploitation of the potential of high-pressure set-ups available at synchrotron radiation facilities is emphasized.

PROBLEMS IN SHOCK WAVE REDUCED ISOTHERMS

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Shock Wave Reduced Isotherms (SWRI) are commonly considered as most reliable EOS data for the realization of a practical pressure scale also with respect to the calibration of the ruby luminescence line shift as secondary pressure scale. A detailed comparison of published SWRI for Cu, Au and Al with EOS derived from thermo-physical data at low pressure illustrates various deficiencies in the procedure commonly used to obtain SWRIs. In addition to recently discussed corrections for deviatoric stresses, effects from uncertainties in the theoretically derived Grueneisen parameters, contributions form dispersion in the Grueneisen parameters, phonon anharmonicity, and structural defects related to premelting are taken into account to support more accurate EOS formulations on the basis of low pressure thermo-physical data.

ELECTRONIC ORIGIN OF THE INCOMMENSURATE MODULATION IN THE STRUCTURE OF PHOSPHORUS IV

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Recent high-pressure x-ray diffraction studies revealed unusual structures with incommensurate modulation (IM) in some simple elements [1]. IM structures were found in the elements of group VII (I and Br) and group VI (S, Se and Te). Very recently, an IM structure was found in a light group

V element phosphorous in the phase P-IV stable in the pressure range 107–137 GPa [2]. This phase is intermediate between simple cubic and simple hexagonal structures that have atomic coordination equal 6 and 8, respectively. All IM structures were observed when elements become metallic. This implies 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 [3]. We consider 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 [4]. For the phase P-IV with the base-centered orthorhombic structure, oC2, we consider a commensurate approximant with an 11-fold supercell along the c-axis and a modulation wave vector equal 3/11 which is close to the experimentally observed value of 0.267. Atomic shifts due to the modulation result in appearance of satellite reflections and hence in a formation of additional Brillouin zone planes. The stability of this IM structure is attributed to the lowering of the electronic band structure energy due to Brillouin zone—Fermi surface interaction. Similar approach is also applied to the IM structure of the group VI elements.

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SPIN CROSSOVER AND INSULATOR-METAL TRANSITIONS UNDER HIGH PRESSURE

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A review of recent study of spin crossovers and electronic transitions under high pressure up to 200 GPa in Mott insulators is given. Transitions have been studied by a number of SI using methods like Synchrotron Mossbauer Spectroscopy (SMS) and XES in $FeBO_3$, $GdFe_3(BO_3)_4$, $BiFeO_3$

[1], as well as by conventional optical absorption and resistivity measurements. All synchrotron experiments have been carried out in APS, ANL, USA. With pressure increasing the high spin (HS) state of Fe^{+3} ion with $S = 5/2$ becomes unstable to the spin crossover in the low spin (LS) state with $S = 1/2$, the critical pressure for Fe oxides is $P_c \sim 50$ GPa. The crossover results in electronic transformation also, in some oxides ($FeBO_3$, $GdFe_3(BO_3)_4$ and other) the insulator-semiconductor transformation with sharp decrease of the energy gap E_g from 3 eV to 1 ev takes place, in $BiFeO_3$ the metallization occurs just after spin crossover. This variety of electronic transitions cannot be understood as the Mott-Hubbard transition in conventional Hubbard model. In the realistic multiorbital Hubbard model we have calculated the effective Hubbard parameter, that determines the Mott-Hubbard insulator gap

$$U_{\text{eff}}(d^5) = E_0(d^6) + E_0(d^4) - 2E_0(d^5).$$

Due to the spin crossovers in d^4, d^5, and d^6 configurations there are sharp changes in the pressure dependence of U_{eff} [2]. The theory explains why spin crossover in $BiFeO_3$ results in metallization, and in $FeBO_3$ to semiconductor with metallization at higher pressure about 200 GPa. Theoretical prediction of the spin crossover and insulator-semiconductor transformation in $GdFe_3(BO_3)_4$ has been confirmed by XES and optical measurements. This work is supported by the Program 3.1 OFN RAS Strong electron correlations, and integration project 40 of SO RAN—UrO RAN.

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UNUSUAL PROPERTIES OF LIQUID HYDROGEN AT MEGABAR PRESSURE

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We present a model of a quantum conductive fluid which is formed as a molecular crystal hydrogen subjected to melting at megabar pressures. This model explains recently observed melting anomalies. The model is based on cell approach that takes into account the contribution of localized state. We show that at $T \leq 13000$ K, the fluid after the melting

can exist in a metastable state with a density $\sim$ 2.3 g/cc, and possibly can retain this state after the depressurization. The issue of hydrogen state at megabar pressures is one of the great problems in condensed matter physics, astrophysics, also important the general understanding of the behavior of matter at extreme conditions. At low temperatures and pressures, hydrogen is a molecular solid or fluid. At high pressures above 100 GPa, hydrogen is supposed to undergo a transition to a highly conducting state. This fact has been verified theoretically and experimentally, with noteworthy development including measurements of melting temperature at extremely high pressures ($\sim$ 300–400 GPa) obtained in diamond anvil cells, and a calculations, an analysis of the melting line predicted a peak at 80 GPa and 900 K. Furthermore, at higher temperatures they found a transition from molecular to nonmolecular hydrogen, with a negative slope. Here we show that at pressures 100–600 GPa, when average distances between protons (ions) become comparable with the internuclear distances in molecule or molecular ion), the MS state is thermodynamically not the most advantageous. A more disordering state, namely quantum conducting liquid (QCL) can compete with it. It is suggested that every ion is localized in the Wigner-Seitz cells, the charge of which is screening completely. There is a domain in the center of this cell, where own electron of hydrogen atom is localized for the most part. The probability density of this electron (VA) is distributed non-uniformly over the cell and describe by the wave function of the hydrogen ground state. Screening leads to admixing of free-like (FL) electron states, which are on the cell periphery mainly and distributed uniformly. We calculate the cell energy taking into account the kinetic energy of VA and FL electrons, the interaction of these electrons with the central ion, electron-electron and exchange interactions. We can neglect the thermal contribution of the electrons in thermodynamical functions in comparison with the proton contribution. The latter is calculated in the hard sphere approach. The hard sphere diameter is found as an average size of the cell.

WIDE-RANGE EOS MODELS

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The physical properties of hot dense matter over a broad domain of the phase diagram are of interest in astrophysics, planetary physics, power engineering, controlled thermonuclear fusion, impulse technologies, engin-

ery, and other applications. The present report reviews the current state of art of investigations at high pressures, high temperatures. It includes results of static and dynamic experiments and modern theories and their possibilities and role in understanding of materials properties in a wide range of the phase diagram.

Experimental techniques for high pressures and high energy density cumulation, the drivers of intense shock waves, and methods for the fast diagnostics of high-energy matter are considered. It is pointed out that the available high pressure and temperature information covers a broad range of the phase diagram, but only irregularly and, as a rule, is not thermodynamically complete; its generalization can be done only in the form of a thermodynamically complete EOS. The main goal of EOS development is its usage in gas dynamic codes. Physical and mathematical demands and limitations to EOS are duscussed. Main principles of EOS construction are described in the historical perspective.

As a practical example, construction of multi-phase EOS for tungsten is presented. The model's results are shown for numerous shock-wave data, the high–pressure melting and evaporation regions and the critical point of tungsten.

MULTIPHASE EQUATIONS OF STATE FOR METALS UNDER HIGH ENERGY DENSITY CONDITIONS

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A new 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 for different materials (potassium, tin, cerium and others) are shown in comparison with available experimental data at high energy densities.

GLOBAL COLD CURVE. NEW REPRESENTATION FOR ZERO-TEMPERATURE ISOTHERM

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Non-standard representation for Global Cold Curve /GCC/ (isotherm $T = 0$) is under discussion. The main point is that chemical potential of substance plays role of ruling parameter in basic GCC-dependence $U = U(\mu)$ of internal energy on density in contrast to the standard form $U = U(\rho)$. This substitution changes radically low-density ("gaseous") part of GCC. Namely: (i) physically meaningless part of standard cold curve ($U(\rho)$ at $\rho \to 0$), which corresponds to absolutely non-stable thermodynamic states, disappears from new GCC, $U = U(\mu)$; (ii) New stable branch of cold curve comes in GCC. It corresponds to thermodynamically stable states only and describes in simple, schematic way the thermodynamics of gas-like plasma as combination of all ionization and dissociation processes available for equilibrium plasma system at finite temperature. This simplified schematic form for thermal and caloric Equations of State (EoS) in the limit $T \to 0$ is under discussion [1–3]. The binding energies of all available complexes (atomic, molecular and ionic) in their ground states with addition of the sublimation energy of the gas-crystal phase transition ("energy scale" [1–3]) are the only quantities that display themselves in meaningful details of this new gaseous part for zero-temperature isotherm (GCC). Another meaningful portion of the zero-temperature isotherm corresponds to a metatstable gaseous state (supercooled vapor).

The considered gaseous portion of the zero-temperature isotherm can be conjugated naturally with the corresponding zero-temperature isotherm (cold curve) of the condensed phase. This united zero-temperature isotherm (GCC) contains no any meaningless part, in particular, one corresponding to thermodynamically unstable states (an artificial portion of cold curve between gaseous and crystalline spinodals).

The simple, schematic structure, which is typical for new form of cold curve in ultra-low densities, appears again in ultra-high densities, which is typical for interiors of compact stars (neutron star crust). It looks as if low-temperature thermodynamics in ultra-low and in ultra-high densities has the same remarkably primitive structure by the same physical reason.

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CLUSTER EXPANSION FOR A STRONGLY COUPLED MULTICOMPONENT QUARK PLASMA

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A nonlocal chiral quark model for the description of mesonic correlations (bound and scattering states) in a strongly coupled quark plasma [1] is generalized to include heavy quark flavors and their bound states: heavy mesons and quarkonia. Applying cluster expansion techniques of nonideal plasmas [2], a generalized Beth-Uhlenbeck equation of state is given and a system of quantum kinetic equations for mesonic bound states in a strongly coupled multicomponent quark plasma is derived which allows to discuss flavor equilibration as well as hadronization prozesses.

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

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We develop a path integral Monte Carlo (PIMC) approach to the strongly coupled quark-gluon plasma (QGP) which self-consistently takes into account the Fermi (Bose) statistics of quarks (gluons) and quantum degeneracy. This method has been successfully applied to strongly coupled electrodynamic plasmas before. Examples are partially ionized dense hydrogen plasmas where liquid-like and crystalline behavior was observed. Moreover, also partial ionization effects and pressure ionization could be

studied from first principles. The same methods have been applied also to electron-hole plasmas in semiconductors, including excitonic bound states, which have many similarities to the QGP due to the smaller mass differences as compared to electron-ion plasmas.

In this work we present first PIMC simulations of nonideal quark-gluon plasma. The main goal is to test this approach for an ability to reproduce the equation of state known from exact quantum-chromodynamics (lattice) calculations. To this end we use the simplest model of a QGP consisting of quarks, antiquarks and gluons interacting via a color Coulomb potential with several approximations for the temperature dependence of the quasiparticle masses. We report surprisingly good agreement with the lattice data for one of the parameter sets, which gives us confidence that the model correctly captures main properties of the nonideal QGP. We also calculate thermodynamic properties and pair distribution functions in the range of temperatures from 1 to 3 of the critical temperature ($T_c = 175$ MeV) and concentrations from 1 to 5 particles in 1 fm^{-3}.

BARYON STOPPING AT RHIC AND LHC ENERGIES

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Strong chromofields developed at early stages of relativistic heavy-ion collisions give rise to the collective deceleration of net baryons from colliding nuclei. It has been solved classical equations of motion for baryonic slabs under the action of time-dependent chromofield. It has been studied sensitivity of the slab trajectories and their final rapidities to the initial strength and decay pattern of the chromofield as well as to the back reaction of produced plasma. This mechanism can naturally explain significant baryon stopping observed at RHIC corresponding to an average rapidity loss $\langle \delta y \rangle \approx 2$. Using a Bjorken-like hydrodynamical model with particle production source it was also studied the evolution of partonic plasma produced as the result of chromofield decay. Due to the delayed formation and expansion of plasma its maximum energy density is much lower than the initial energy density of the chromofield. It is shown that the net-baryon and produced parton distributions are strongly correlated in the rapidity space. It was tried different functional forms of the chromofield decay to reproduce the shape of net-baryon rapidity distributions meausured by BRAHMS colaboration. The best fit of data is observed for the power-law decay of chromofield with initial chromofield energy density of about

$\epsilon_f = 30$ GeV/fm^3. Predictions of baryon stopping for Pb + Pb collisions at LHC energies were also made.

THE PHYSICAL MODEL OF THE GRAVITATIONAL COLLAPSE OF THE IRON-OXYGEN STELLAR CORE, THE NEUTRINO LUMINOSITY, AND SUPERNOVA

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It is known that the Supernova explosion (SN) type II is the gravitational collapse of the central core of the massive star after the finishing of its evolution. The kinetic energy of SN is well known from the optical investigations. The rich physics of the processes of the collapse is also known [1]. But the mechanism of the explosion still is not learnt during 40 years.

We compute the collapse of a $\sim 1.4 M_\odot$ iron-oxygen stellar core in the frame 1D model [2, 3]. The equation of state takes into account photon equilibrium radiation, a mixture of Fermi gases of the free nucleons and ideal gases of Fe, He nuclei in equilibrium relative to nuclear reactions, and an electron-positron gas. The problem includes the Bolzmann kinetic equations for neutrinos. Neutrinos take part in the weak interactions with free nucleons and nuclei. We started from near equilibrium $P \propto \rho^{1+1/n}$ polytropes with $n = 3$. We evaluated the task till the establishing of the neutron star in the final state. The solution yielded neutrino light curves. The computed light curves exhibit narrow peaks with character widths of 10 ms with the maximum luminosity 10^{54} ergs/s due to the shock wave arising at the collapse. Part of the energy of the neutrino radiation is adsorbed by the stellar envelope. But this value $\sim 10^{50}$ one order less than the SN. Probably to achieve the accordance with the investigations we need take into account 3D consideration [4, 5].

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THE SCALING TRANSFORMATION AND PHENOMENOLOGICAL EQUATION OF STELLAR MATERIAL DISTRIBUTION

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Investigations of the distributions of the stellar material quantities from the center of a star to its surface are based on different models. We formulate and solve variational problem about energy minimum of the hydrogen-helium plasma ball. The total energy is a function of radial distribution of material density and consists mainly of gravitational and thermal energy. If the energy processes inside such system are steady-state, they can be described phenomenological using two dimensionless parameters, which determine the possible spectrum of non-polytrophic models of stellar structure. We utilize scaling transformation of the radial variable $r = R\xi$, where R is the scaling parameter of the dimension of length, ξ is the dimensionless variable. One can obtain from Euler's equation an ODE for integral function of relative mass distribution of the steady-state star:

$$\left(1 + a\xi + b\xi^2\right) N'' - \frac{2}{\xi}\left(1 + \frac{a}{4}\xi - \frac{b}{2}\xi^2\right) N' + \eta\xi^{-2/3}(N')^{1/3}N = 0. \quad (1)$$

Solution of the Eq. (1) has to satisfy the natural boundary conditions $N(0) = 0$ and $N(\infty) = 1$. Dimensionless coefficient η is a function of density in the star center.

Nonlinear equation (1) gives phenomenological description of the internal structure of steady-state stars of the Main Sequence, dimensionless parameters a and b are the adjusting parameters connected with the thermodynamic conditions inside a star.

Equation (1) for the fixed values of the parameters a and b with the boundary conditions is subject of numerical calculations. Numerically calculated value of reduced radius of a star ξ_m is connected with photosphere radius R_p as $R_p = R_0\xi_m$. This relation allows to draw an equilibrium value of scaling parameter R_0 and to calculate radial distributions of some thermodynamic parameters such as pressure and temperature.

In particularly, numerical calculation leads to the value η about 17, if $a = 0.5$ and $b = 18$. Radial distributions of the density, pressure, and temperature as well as they values in the middle of the Sun ($\rho_0 = 1.58 \cdot 10^{55}$ kg/m^3, $p_0 = 2.61 \cdot 10^{16}$ Pa, and $T_0 = 2.03 \cdot 10^7$ K) agrees well with the known data.

RADIATIVE UNRESOLVED SPECTRA ATOMIC MODEL

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The main problem for modeling of multicharged plasma of mid and high Z materials is connected with huge number of overlapped spectral lines. As usually in this case level kinetics is strongly coupled with radiation and simple models using escape-factor are applicable only in a narrow region of plasma parameters. It is also obvious that the detailed atomic physics approaches can not be applied to hydrodynamics calculations. It is convenient to use an appropriately reduced atomic model where the ion states and transitions are accounted for by using special averaging procedure. The model must be comparatively simple and computationally efficient.

The radiative unresolved spectra atomic model (RUSAM) is defined by three most important variables: number of ions with different multiplicity ($\sim$ 10 ions), groups of united ion states ($\sim$ 5–10 superstates per ion) and photon energy intervals ($\sim$ 100–200 intervals). The main idea is to connect the level kinetics with chosen energy grid for photons. The detailed spectrum for transitions between superstates is folded into given photon energy mesh and can be refolded if needed. For every state and every energy interval the effective oscillator strengths (including collisional transitions) are calculated and memorized. When solving the reduced system of level kinetics equations the influence of radiation is calculated using transition contribution to all energy intervals.

The proposed method is very fast and allows in-line calculation of ion composition, EOS, opacity and emissivity coefficients for nonstationary, non-LTE multicharged plasmas of mid and high Z materials.

ABOUT FIELD-EMISSION FROM QUANTUM SYSTEM

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The electron field emission from a quantum system is considered. Two methods of the emission current calculation are compared: Bardeen transfer Hamiltonian (BTH) and semiclassical wave function. Within the BTH formalism the tunneling current is given by

$$I = \frac{4\pi e}{\hbar} \sum_{Em,A} |M_{Em,A}|^2 f(E_{Em})[1 - f(E_A + eV)]\delta(E_A - E_{Em}) \qquad (1)$$

with $M_{Em,A}$ being the tunneling matrix element,

$$M_{Em,A} = \frac{\hbar^2}{2m} \int_{x=x_0} dzdy \left(\Psi^*_{Em}(\mathbf{r}) \frac{\partial}{\partial x} \Psi_A(\mathbf{r}) - \Psi_A(\mathbf{r}) \frac{\partial}{\partial x} (\Psi^*_{Em}(\mathbf{r}) \right). \quad (2)$$

Here Ψ_{Em} and Ψ_A are the emitter and anode particle wave functions correspondingly. The integral in the equation (2) is performed along any plane $x = x_0$ entirely in the classically forbidden barrier region. The sum in the Eq.(1) is calculated over all the states of the emitter and anode with equal energies. $f(E) = (1 + e^{(E-\mu)/T)})^{-1}$ – the Fermi distribution function, μ is the chemical potential.

Another expression for the tunneling current is derived using the semiclassical 3D wave function. The field emission current is equal to

$$I = \frac{2e}{m} \sum_{Em} f(E_{Em}) \int_{\Sigma_0} d\Sigma_0 \mathbf{e}(\mathbf{r}_0) |\mathbf{p}_0(\mathbf{r}_0)| |\Psi_{Em}(\mathbf{r}_0)|^2 e^{-\frac{2}{\hbar} \mathrm{Im} S_0(\mathbf{r}_0, \mathbf{r}_{exit})}. \quad (3)$$

Here both $\mathbf{r}_0$ and the barrier exit point $\mathbf{r}_{exit}$ belong to the same trajectory of particle motion with initial condition $\mathbf{r} = \mathbf{r}_0, \mathbf{p} = \mathbf{p}_0(\mathbf{r}_0)$; $d\Gamma$ is an arc element along the trajectory, $\mathbf{p}(\mathbf{r}) = \nabla S_0(\mathbf{r})$, $S_0(\mathbf{r}) = \int_{\mathbf{r}_0}^{\mathbf{r}} d\Gamma p$, $\mathbf{e} = \mathbf{p}/p$, $p(\mathbf{r}) = \sqrt{2m(E_{Em} - U(\mathbf{r}))}$, the gradient of Ψ_{Em} phase is equal to $\mathbf{p}_0(\mathbf{r}_0)$. The surface Σ_0 is inside the barrier region.

In the paper the calculation of the field-emission current from the metal surface [1] is discussed. It is shown the coincidence of the both methods results.

This work was supported in part by Union State Programme SKIF-GRID (project 209P420) and the Russian Foundation for Basic Research (project 08-01-00291)

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IONIZATION DEGREE IN THOMAS–FERMI AND DFT MODELS

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In this work the degree of ionization of dense plasma is investigated for metals (Al, Ni). There were used and compared two finite-temperature models: Thomas–Fermi and density functional theory (DFT) in pseudopotential approximation (VASP) [1, 2]. Density of states and electron density distribution were used for the estimation of ionization degree. In addition, thermodynamic parameters of the electron subsystem were calculated and analyzed. Results obtained might be useful for investigation of interaction of femtosecond lasers with matter. The work has been done under the financial support of the Russian Foundation for Basic Research, grants 08-08-01055 and 09-08-01129.

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HEAT CAPACITY AND THERMAL PRESSURE OF ELECTRONS IN Al AND W CRYSTALS

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We discuss electron pressure and heat capacity calculations as functions of electron temperature T_e and crystal density. FP-LMTO computations were carried out for non-moving ions at $T_i = 0$. We consider Al and W crystals and compare the results of our calculations with data obtained by some equations of state.

FIRST-PRINCIPLE CALCULATIONS OF SHOCK HUGONIOT OF ALUMINUM NEAR MELTING CURVE

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In this work we present quantum molecular dynamic calculations of shock Hugoniot of aluminum near the melting curve. This is interesting for the refinement of the parameters on melting along the shock Hugoniot. We calculated isotherms of liquid aluminum by the VASP [1, 2] code and then solved the Hugoniot equation to obtain the Hugoniot. We used up to 100 particles in our calculations and the number of time steps enough to guarantee the accuracy better than the experimental error. We compared our results with available shock-wave experimental data and wide-range multiphase equation of state of aluminum. The work has been doing under RFBR financial support, grant 08-08-01055.

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FREE ENERGY AND MELTING CURVE OF SODIUM AT HIGH PRESSURE

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A description of the thermodynamic properties in the semiempirical free energy form of sodium and its melt is presented up to high pressure. The intersecting line of chemical potential surfaces of bcc-Na and liquid sodium is calculated in the pressure-temperature-chemical potential space. This line represents a melting curve of sodium at the pressures from -1.3 GPa to 60 GPa and the temperatures 140–1000 K. The melting curve is convex and practically coincides with an experimental melting curve of dense sodium. The calculated nonmonotonic melting curve of sodium together with the similarly earlier calculated convex melting curve of diamond, uranium dioxide and bcc-Ca permits to consider a melting curve of solids as a superposition of convex melting curves sites.

This work was partially supported by the Presidium of the Russian Academy of Sciences within the Program of Basic Research “Thermal

Physics and Mechanics of Extreme Energy Effects and Physics of Strongly Compressed Matter".

PRESSURE INDUCED METAL-SEMICONDUCTOR TRANSITION IN SHOCKED MOLTEN SODIUM

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The liquid sodium attracts attention due to the series of pressure-induced structural and electronic transitions. In this study a multi-shock technique and a computer code simulation were used for investigations of electrophysical and thermodynamics properties of dense molten sodium up to pressure greater than 200 GPa. The multi-shock data shows that the volume-temperature sodium conductivity dependence changes at ≈ 30 GPa. The theoretical results of Raty et al. [1] are used to interpret this change as the pressure induced metal-semiconductor transition in shocked molten sodium. This study was partially supported by the Presidium of the Russian Academy of Sciences within the Program of Basic Research "Thermal Physics and Mechanics of Extreme Energy Effects and Physics of Strongly Compressed Matter"

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EQUATIONS OF STATE OF CRYSTAL SYSTEM AND CALCULATION OF INTRINSIC PRESSURE IN METALS WITH BODY-CENTERED CUBIC LATTICE AND FACE-CENTERED CUBIC LATTICE

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We studied the singular model of crystal system in which atoms stands on single level with equal density of particles

$$\upsilon = Ad^3 \approx \frac{V}{N}, \tag{1}$$

A—constant, d—unit cell constant, V—crystal system volume. Constant A describes symmetry of crystal latitude. For body-centered cubic lattice—$A = 0.5$, for face-centered cubic lattice $A = 0.25$. Equations of state for this singular model allow us to equate in explicit expression compressibility

$$B = \frac{1}{K} = -\frac{1}{V} \cdot \frac{\partial V}{\partial P} \tag{2}$$

and volume coefficient of thermal dilatation

$$\beta = 3\alpha = \frac{1}{V} \cdot \frac{\partial V}{\partial T} \tag{3}$$

offer in explicit form. Formula (2) and (3) is allowed to calculate volume v and constant A with known value β, B and d [1, 2]. Direct correlation of constant A with its crystallographic values gives possibility to argue degree of credibility of selected model. Also we calculate the intrinsic pressure P in metals with body-centered cubic lattice and face-centered cubic lattice at a temperature of 300K. Computational result proves accordance of constant A with its crystallographic value. We note the high level of intrinsic pressure in metals.

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DISSOCIATION OF MOLECULES IN SHOCK-COMPRESSED FLUID

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We have studied the thermodynamic properties of several dense molecular liquids with account for the molecules dissociation under high pressures (30–100 GPa) and high temperatures (3–5 kK). Dissociation was observed in shock-wave experiments in these molecular liquids (H_2, D_2, N_2, O_2, CO). The traditional mechanisms of thermal dissociation are not applicable at the temperatures considered. A new way of the molecules dissociation is supposed. This method takes into account the influence of surrounding particles on the interatomic potential in a particular molecule.

First of all this influence is connected with appearance of atoms in the coordination sphere of a molecule, which initially have been produced by the thermal dissociation. Interaction of external atom on molecular atoms will lead to strong deformation of interatomic potential in a molecule and as consequence to dissociation energy decrease and to essential reduction of the partition function of a molecule. This phenomenon is analogous to the well known effect of atom ionization in strong electric field. We have obtained simple analytical expressions for Helmholtz free energy on the basis of the fluid variation theory. We have chosen the hard spheres system as the reference one. The critical point parameters and the sphere diameter have been obtained by minimization of Helmholtz free energy with use of parameters of interaction potential (ϵ, σ). The thermodynamic functions of the compressed dissociating liquids and their ionic composition have been calculated. We have compared our Hugoniot curves with available experiments. Our results are in agreement with these data within the measurement error.

ELECTRONIC TEMPERATURE-DEPENDENT POTENTIALS FOR ATOMISTIC SIMULATION

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In this work the creation of the electronic temperature-dependent potentials for an atomistic simulation was performed by method force-matching [1]. The method leads to new electronic temperature-dependent potentials which are obtained on the basis of synthesis of quantum and statistical mechanics. The method allows creating correct potentials for temperature-dependent processes such as phase transitions, deformation at different temperature and fracturing at high temperature. The data about necessary range of pressure and temperature and the investigated phases build into potentials on initial stage of creation of potentials. Potentials for the following substances were created: aluminum, iron and silicon. The calculation of melting curve by two-phases simulation method [2] was performed for investigated substances. The results for all mentioned substances were discussed. The comparison to the experimental data was performed.

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STUDY OF ELECTRONIC STRUCTURE AND CONDUCTIVITY OF LIQUID METALLIC SODIUM UNDER HIGH PRESSURE AND TEMPERATURE

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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. Also phase transitions and evolution of electronic structure are examined. Electrical conductivity for some values of pressure and temperatures is calculated.

CRYSTALLIZATION OF ALUMINUM MELT. MOLECULAR DYNAMICS STUDY

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Molecular dynamics study of cooling of aluminum melt is carried out. Aluminum is described by a form of embedded atom method potential.

The system was first equilibrated at T=2000K, which is above the melting temperature of aluminum. Then the velocities of particles were gradually rescaled until the system reached $T = 300K$.

Influence of teh cooling rate on the final state of the system is studied. At cooling rates below $10^{12}s^{-1}$ the melt eventually crystallizes. At higher cooling rates the melt freezes into an amorphous structure.

Structural analysis of amorphous aluminum based on coordination number and angle distribution of atoms is performed. The results show the existence of the ordered (solid-like) and disordered (liquid-like) subsystems.

The crystallization kinetics is studied. Crystal nucleation rate is found as a function of temperature. Critical nucleus size is estimated from the MD simulations. The results are compared with the predictions of classical nucleation theory.

COMPUTATIONAL MODELING OF CYLINDRICAL LINER COLLAPSING DYNAMIC (IRON, CUPRUM, TANTALUM, ALUMINIUM)

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The calculation of magneto hydrodynamic task of cylindrical liner collapsing with magnetic field inside is coupled with a number of hardship. One of these hardships is exact description of electromagnetic properties of material along with thermodynamic. In present work method and substantiations of electro conductivity selection are considered. For description of gas dynamics of liner motion in strong magnetic field calculations were performed with help of bundled software MAG [1], which was supplemented by broadband EOS of substances [2] and real significances of Fe, Cu, Ta and Al electro conductivities at high pressures and temperatures. Equations of hydrodynamics were approximated by difference equations system on regular grid of explicit finite-difference scheme "cross". Equations of field—by completely conservative difference scheme, and were solved by streaming run method [3],[4]. Contact boundaries of medium regions coincide with the boundaries of counting cells. Velocities, coordinates, electromagnetic field are calculated in grid node (on the boundaries of cells), residual values cover the centre of cells. Description of electro conductivity was based on famous data of stationary measurements electro conductivity for temperature and pressure dependences [5]. Calculations and their comparisons were performed for follow cases: without magnetic field, with infinite elector conductivity and with approximated electro conductivity. Received phase diagram of liner material behavior was shown that liner material is heated sufficiently quickly, but not enough for melting. Performed calculations showed no anomalous. But calculations for Fe showed anomalous sharp bend on profile of magnetic induction value dependence from time. It is explained by phase change in liner material, which begins from inside the liner and moves to the boundary. At the moment of appearance it on internal liner surface the magnetic field as though "fall" into liner.

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INFLUENCE OF MACROPARAMETERS ON THE INITIAL STAGE OF VORTEX CASCADES FORMATION

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We present new results obtained in numerical modeling of the vortex cascade phenomenon in an unstable shear flow. We investigate initial stage of the onset of the turbulence in 3D free shear flows of an ideal compressible gas. Development of the cascade of instabilities is initiated by pre-set random or harmonic disturbances of initial velocity. We used different initial conditions: (1) velocity along z-direction has low amplitude random disturbance inside the shear layer; (2) velocity along z-direction is equal $W = \mathrm{Ampl} \cdot \sin(2\pi x)\cos(\pi y)$ and velocity along x-direction is equal $U = \mathrm{Ampl} \cdot \sin(2\pi x)\cos(\pi y)$. We proved that harmonic initial velocity disturbance can initiate turbulent flow pattern similar to the case when disturbance is random. This proves that the existence of the vortex cascade is not an accidental phenomena and can develop itself in case of regular initial disturbance of the velocity.

We analyzed the influence on the shear flow provided by various initial conditions, dimensions of the integration domain. We have identified conditions that lead to formation of the vortex cascade. The cascade comes into existence in case the following conditions are met: (1) the width of the channel is more than $\pi/4$ in x-direction; (2) the length of the channel is more than $7\pi/4$ in y-direction; (3) the amplitude of initial disturbances of velocity is more than 2% of the shear velocity. We investigated the distribution of the turbulent energy. It is shown, that as the flow is transformed into a turbulent mode, the energy is gradually transferred from large structures to smaller ones and at the end finally dissipates into the heat, in correspondence with Richardson–Kolmogorov theory. It proves, that the instability is formed as a result of a decay of a vortex cascade structure.

EQUATIONS OF STATE OF MOLECULAR FULLERITES C_{60} AND C_{70}

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Equation of state and behavior of elastic properties of materials under pressure provide crucial information about interatomic interactions. Experimental data is of great importance and is used for verification of theoretical models of interatomic or intermolecular forces in substance. Here we present *in-situ* ultrasonic study of the elastic moduli and the equation of state of polycrystalline fullerites C_{60} and C_{70} (77–340 K, up to 2.5 GPa) complemented with structural *in-situ* X-ray diffraction study (295 K, up to 6.25 GPa).

Analysis of dependencies of elastic moduli of C_{60} reveals significant increase of the non-central forces negative contribution to the shear modulus under pressure. This contribution is associated with mutual intramolecular deformations due to molecular interactions as non-point objects. The independent measurements of the density allowed the comparison of adiabatic (ultrasonic) and isothermal (from EOS) bulk moduli. Behavior of B_S and B_T dependencies of C_{60} under pressure differ appreciably, although the thermodynamic difference calculated from the empirical intermolecular central potential is less than 1% [1]. Dependence $B_T(p)$ for 295 K is in good agreement with accurate data from X-ray diffraction study and agrees well with data of previous studies [2, 3], while pressure derivative of $B_S(p)$ corresponds to the calculation based on the empirical potential [1]. The nature of this difference is discussed and molecular deformations considered as the possible reason for such behavior of bulk moduli dependencies. An additional argument is obtained from the structural study – there is a hysteresis of EOS of C_{60} under compression and decompression.

The study of fullerite C_{70} reveals that its elasticity behaviour is less complicated than that of C_{60}. The $B_T(p)$ and $B_S(p)$ dependencies show quite similar behaviour and are close to those known (e.g. [4]).

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CONDUCTIVITY OF CARBON MATERIALS (FULLERITE, GRAPHITE AND SINGLE-WALL CARBON NANOTUBES) AT PRESSURES 20–50 GPa

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Conductivity of fullerite C_{60}, graphite and single-wall carbon nanotubes (SWNT) have been studied at pressures 20–50 GPa and temperatures 77–400 K. The kinetics of resistivity of C_{60} at changing pressure was also studied.

Resistivity peculiarities were identified with the known phase transitions of fullerite. Successive phase transitions of fullerite C_{60} appeared in the course of HPHT treatment were accompanied by changes in resistance, which can be of quite different magnitude (from hundreds Ohm to hundreds MOhm) and of different temperature dependence. Critical pressures for the transitions depended on conditions and duration of preliminary HPHT treatment. This fact, as well as smeared character of the transitions is connected with long relaxation time, which was found to be about 140 min.

Three types of SWNT samples were investigated: samples produced by the graphite thermal dispersion method (SWNT percentage is 40 %), the chemical vapor deposition method (SWNT percentage is 80 %) and HiPco method (SWNT percentage is 90 %).

Electric properties of the samples under high pressure were dependent on SWNT percentage. The electric characteristics of SWNT samples remained of the same character with the increasing of SWNT percentage, but the additional features appeared (intermediate region on the temperature dependences of resistance; additional extremums in the baric dependences of activation energy in the pressure range of 40–45 GPa). Thus, the dependences obtained are connected with electric characteristics of SWNT and not with the impurities contained in the sample. The irreversible changes of the electric properties of the samples observed in the pressure range 27–45 GPa can be connected with both the structure modification and partial destruction of the sample.

This work was supported in part by RFBR grant 09-02-01316 and by Federal program “Scientic and research and educational personnel of the innovation Russia” to 2009–2013.

STUDIES OF ELECTRICAL PROPERTIES OF GRAPHITE AND GRAPHITE–ZIRCONIUM OXIDE MIXTURES UNDER PRESSURE UP TO 45 GPa

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The aim of the work was to study the electrical properties (thermoelectric power and impedance) of high-purity graphite and graphite- zirconium oxide mixtures of at pressures up to 45 GPa.

Measurements were performed in high-pressure chamber (HPC) with a diamond anvil cell of synthetic polycrystalline diamond (black diamond) [1]. These anvils are of high electrical conductivity and can be used as electrical contacts to the sample.

Measurement of the thermoelectric power have performed with the pressure steps of 0.5–10 GPa. At every step, the measuring time was as long as that for the thermoelectric power to reach the stationary value up to maximum pressure of 45 GPa. The measurements were performed in a similar way at increasing and decreasing pressure. In the pressure range from 16 to 30 GPa, the sharp change in the TEDS value was observed, this may be evidence of a phase transition in this range of pressures at room temperature, which is confirmed by previous data obtained at d.c. conditions. This transition is irreversible (at lower pressure thermoelectric power does not return to its original state). Impedance measurements were carried out by means of RLC-2000 impedance analyzer at room temperature in the frequency range of 1–200 kHz. The impedance features found for all samples at pressures of 18 to 32GPa confirm also the existence of the phase transition in this pressure range. The transition is irreversible similar to the previous finding.

This work was supported by RFBR grant No. 09-02-01316 and by state contract number P645 of Federal program "Scientific and research and educational personnel of the innovation Russia" to 2009–2013.

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ELECTRICAL PROPERTIES OF NANOCRYSTALLINE ZrO_2 AT HIGH PRESSURE

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We studied correlation between the crystallite size of zirconia and resistance at the pressures 22–50 GPa and temperatures 77–400 K. Nanocrystalline praseodymium doped zirconia powders were produced using a microwave driven hydrothermal process under pressures up to 8 GPa. 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.

At a pressures of about 30–37 GPa the zirconia resistance decreases by 3–4 orders of magnitude. It is found that the transition pressure of zirconia depends on crystallite size.The smaller the crystals the smaller the transition pressure. The reduction of transition pressure was observed to 10 nm. However at 10 nm the transition pressure rises steeply.

It is possible to suspect, that the surface effects essentially change zirconia conductivity mechanism at high pressures.

At the pressure of about 40–48 GPa anomalies in the pressure dependence of the resistance and of the parameters which depend on the concentration, mobility, and activation energy of the charge carriers are found. This permit to suppose the high-pressure induced phase transformation at 40–48 GPa.

Furthermore we obtain that the activation energy depends on the crystallite size. The smaller the crystals the higher activation energy.

We studied relaxation processes in zirconia under the high pressures and the room temperature.The analysis of experimental data has shown that the time function of electric resistance most precisely described by exponential function. It can be seen, that relaxation times depend on pressure and crystallite size.

PECULIARITY OF PRESSURE AND TEMPERATURE DEPENDENCES THE ION-CONDUCTOR SULPHIDE OF SILVER ELECTRICAL PROPERTIES

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The abstract is devoted to investigation of an influence of unstoichiometry and a doping on the electrical properties of the chalcogenides in the system Ag-Ge-As-S. The multi-component chalcogenides $AgGe_{1+x}As_{1-x}S_3$ ($x = 0.4$–0.7) were synthesized and certificated. The electrical properties of these materials at pressure up to 42 GPa and temperatures 78K-400 K were studied. The synthesized compounds have metal color, a blistered break and crystal inclusions were absent at the microscopic study. X-ray powder diffraction patterns of compounds are typical for glasses of the systems Ag-Ge-As-S [1]. High pressures at 15–42 GPa have been generated in the cell with synthetic carbonado-type diamond anvils of the "rounded cone-plane" type [2]. The researches of the electrical properties of the materials both at high pressure and at low temperatures carried out by a method of an impedance spectroscopy with the use of the investigated-analyser of impedance RLC-2000 in the frequency range of 1kHz-200 kHz. It was determined from a research of the temperature dependences of conductivity and dielectric permittivity that the materials are ionic conductors. The temperatures of a start of the ionic transfer in compounds belong to a range 170–200 K and the parts of the ionic component conductivity are 40–70% depending on the composition and the structure. As a result of investigation hodographs of impedance, baric dependences of resistance and tangent dielectric losses angle at pressure 15 GPa-42 GPa were analyzed. The baric intervals of essential changes of electrical properties of materials were observed at pressure 27–35 GPa. The changes are irreversible in all under study materials. The comparative analysis of an influence of the structure on range of change of electrical properties for $AgGe_{1+x}As_{1-x}S_3$ ($x = 0$, 0.1, 0.4–0.7, 0.9) was carried out. The researches were supported in part by RFBR grant No. 09-02-01316 and by Federal program "Scientific and research and educational personnel of the innovation Russia" to 2009–2013.

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BARIC IMPEDANCE SPECTROSCOPY OF MULTI-COMPONENT IONIC SEMICONDUCTORS

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The solid ionic conductors with mobile ions Ag^+ and Cu^+ are perspective materials for miniature sensors and gages. Properties of these materials make possible to use them in a broad interval of frequencies, temperatures and pressures [1, 2]. The purpose of this work is research of electrical and thermoelectrical properties of the amorphous and crystal chalcogenides from the systems $(GeSe)_{1-x}(CuAsSe_2)_x$, $(GeS)_{1-x}(CuAsS_2)_x$ and $Ag_{1-x}Cu_xGeAsSe_3$ at pressures up to 50 GPa.

The compounds were synthesized by melting stoichiometric quantities of the elements in evacuated and filled helium or argon silica tubes. X-ray diffraction experiments and a qualification of the materials have been performed by means of a diffractometer *Shimadzu XRD 6000*.

The electrical properties have been investigated by an impedance spectroscopy. The high pressures from 12 up to 50 GPa have been generated in the cell with synthetic carbonado-type diamond anvils of the "rounded cone-plane" type. For a creation of a temperature gradient one of the anvils was warmed. The device allows simultaneously to register the pressure, the temperature of anvils and the electric signal from the sample. The baric dependences of a thermoemf, an impedance, an admittance and a tangent of loss angle at an increase and a decrease of pressure were analyzed.

In compounds with ionic conductivity an increase of a resistance and a decrease of ionic conductivity with a pressure increase may be explained by a lattice contraction and a reduction of an activation volume of the motion. The some compounds for example $Ag_{1-x}Cu_xGeAsSe_3$, $x = 0.5$, exhibit both electronic and ionic conductivities. In these materials the real part of an admittance and a tangent of the loss angle increased exponentially with pressure from 12 up to 50 GPa.

The researches were supported in part by RFBR grant No. 09-02-01316 and by Federal program "Scientific and research and educational personnel of the innovation Russia" to 2009–2013.

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ELECTRORESISTANCE OF MATERIALS FROM SYSTEM Cu-Ag-Ge-As-Se AT TEMPERATURES 78–400 K AND PRESSURE UP TO 42 GPa

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The purpose of this work is investigation of influences of low temperatures and high pressure on the conductivity of $Cu_{1-x}Ag_xGeAsSe_3$ ($x = 0.85$, 0.9). These compounds received from practically 100% ionic conductor $AgGeAsSe_3$ by replacement of a part of silver atoms by copper atoms. Difracrogramms are typical for glasses from the systems Ag-Ge-As-S and Ag-Ge-As-Se. The researches of electric resistance were carried out by a method of impedance spectroscopy with the use of investigated-analyser of impedance RLC-2000 in the frequency range 1 kHz–200 kHz at temperatures 78–400 K and at pressures 10–42 GPa. D.c. dependences of resistance from time of material $Cu_{1-x}Ag_xGeAsSe_3$ with $x = 0.9$ in the cells with different electrodes (graphite, silver and copper) were investigated. High pressures at 15–45 GPa have been generated in the cell with synthetic carbonado-type diamond anvils of the "rounded cone-plane" type. The dependences of the resistance from time on an alternating current are activation type. From investigation of the dependences of the resistance from time on a direct current in the cells with blocking the ion component electrodes, with the copper and silver ion filters the contributions of different carriers to the conductivity were determined. For compound with $x = 0.9$ the share of electronic conductivity is 0.08, the shares of conductivity on silver and copper cations are 0.83 and 0.09 accordingly. In a cell with copper electrodes at a change of a polarity of a constant voltage the local maximums on the dependences of conductance on time were observed and in a cell with graphite electrodes the monotonous decrease of a conductance was observed.Such distinction in behaviour can be connected that the copper electrodes are partially convertible on ions Cu^+, that causes complex processes in near electrode layers of a sample and on the border a sample/copper electrode. At the pressure increase the real part of an impedance has a maximum in some range of pressure and

then sharply decreases on 1–2 order. The appreciable changes of the real part are observed for the samples with $x = 0.85$ and $x = 0.9$ in the ranges of pressures 30–32 GPa and 36–38 GPa accordingly.

The researches were supported in part by RFBR grant No. 09-02-01316 and by Federal program "Scientific and research and educational personnel of the innovation Russia" to 2009–2013.

ELECTRICAL PROPERTIES OF THE NEW HIGH PRESSURE PEROVSKITE-LIKE PHASE $CaCoCu_2V_4O_{12}$

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Within the family of perovskite-like compounds, the materials of general formula $ACu_3B_4O_{12}$, where A – mono-, di-, tri-, or tetracharged cation or a vacancy, element B–Ti, Mn, Ge, Ru, Ti+Ta(Nb, Sb), V, are of considerable interest because of electric and magneticproperties [1–4] and an extremely high dielectric constant. The purpose of research was a study of the electrical properties of a new compound $CaCoCu_2V_4O_{12}$ in a broad range of the frequencies, temperatures and pressures.

A new perovskite-like compound $CaCoCu_2V_4O_{12}$ have been synthesized at pressure 7 GPa and temperature 1100°C during 15 min in the high pressure cell of "toroid" type. The oxide crystallizes in a cubic symmetry (sp. gr *Im-3*, $Z = 2$), with the lattice parameter $a = 0.73015(5)$ nm. The electrical properties were investigated on a direct current and by a method of impedance spectroscopy in the frequency range between 1 kHz and 200 kHz at temperatures between 10 and 400 K at a pressure up to 50 GPa. All of the temperature dependent electrical measurements were carried out in the dark and in an evacuated closed-cycle helium cryostat. High pressure from 12 GPa to 50 GPa has been generated in the diamond anvil cell with anvils of the "rounded cone-plane" type made of synthetic carbonado-type diamonds.

Metal type of the temperature dependence of conductivity in the range 10–300 K is established. A temperature hysteresis of a conductivity was observed around 25 K. The analysis of the baric dependences of an admittance and a loss angle indicates a possibility of reversible structure change in the pressure interval 29–32 GPa.

The researches were supported in part by Federal program "Scientific and research and educational personnel of the innovation Russia" to 2009–

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PHASE TRANSFORMATION OF MATTER AT EXTREME ENERGY CONDITIONS

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Experiments on pulse generator MIG (maximum current 2.5 MA, rise time 100 ns) have been performed with purpose of obtaining of diamond-like carbon. Before experiments the MHD calculations have been carried on. The calculations showed that at compression of copper tubes with diameter of 2–4 mm filled with carbon powder the conditions for diamond-like carbon synthesis can be satisfied. After each shot on MIG generator the resulting product was analyzed with transmission electron microscope EM-125. This analysis has showed that all loaded carbon was transformed to cubic carbon Pm3m with lattice distance $a = 0.5545$ nm and face-centered cubic lattice with $a = 0.3694$ nm. The carbon crystal size was measured to be 5–25 nm.

THE OVERCOOLED LIQUID CARBON AND THE METASTABLE DIAMOND COEXISTENCE LINE: EXPERIMENTAL BACKGROUND AND THERMODYNAMIC CALCULATIONS

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Metastable matter states are the integral part of the phase diagrams and are realized specifically in the liquid state rapid quenching processes. In our experiments graphite was melted and liquid carbon was solidified under the isobaric condition at the pressure 0.012 GPa. Series of the metastable (under the normal conditions) phase such as diamond, carbine, glassy-carbon and superdense phase C8 formation was shown in [1]. The overcooled liquid and the metastable solid phase coexistence thermodynamics was considered (the diamond formation was taken for example). The overcooled liquid carbon and the metastable diamond coexistence line was plotted for the first time in the wide parameter region below the diamond-graphite-liquid carbon triple point (∼12 GPa). Plotted pressure-temperature dependence is based on the Simon equation. Validity of the diamond melting lines obtained experimentally (by Bundy) and by the molecular-dynamic simulation methods are analyzed using unified approach, based on the received data [2].

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VAPOR–LIQUID–SOLID MECHANISM OF THE CARBON VAPOR CONDENSATION ON THE GRAPHITE AND DIAMOND

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One of the most important problem, that is associated with the carbon phase transitions, is the search for the diamond new obtaining method.

In the present work the possibility of the diamond epitaxial building-up on the diamond substrate from the carbon vapor with the parameters above the carbon triple point graphite-liquid-vapor (4800 K, 10.7 MPa) is considered for the first time. Experimental background for the problem statement was the earlier fulfilled investigations, that showed: (1) carbon vapor deposition (with mentioned parameters) on the graphite results in the liquid phase formation according to the vapor-liquid-crystal mechanism; (2) overcooled liquid carbon solidifies into the graphite and into the series of the metastable under normal condition carbon forms: carbine, diamond, glassy-carbon, superdense C8 phase.

It was supposed that diamond substrate exerts orienting influence on the solidified carbon structure and shifts equilibrium to the metastable diamond formation in preference. Experiments of the carbon vapor deposition on the diamond were carried out in support of this fact. Carbon vapor was obtained by the graphite laser evaporation under the pressure 15–30 MPa. Obtained drop-shaped condensate microscopic and structural investigations are shown.

THE SURFACE TENSION ESTIMATION OF THE IONIC MELTS NEAR A CURVE OF COEXISTENCE

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An analysis of nucleation processes [1] that occur during a vapor-liquid phase transition and temperature fluctuations that take place in clusters of stable phases is employed to derive a semiempirical relation between the capillary and thermophysical characteristic of substances. Such nucleation-fluctuation approach [2, 3] allows to estimation of the surface tension (ST) in a wide temperature interval not only for metals [3] ((1) at $K = 0.39$),

but also for the ionic melts ((1) and (2) at $K = 1$). It is shown on an example of alkaline metals halogeneds (AMH): a non-linear dependence (2) – for rubidium and caesium halogeneds, the linear dependence (1) – for the others AMH).

$$\sigma = \sigma_0 \left(1 + k\frac{T_0 - T}{T_{tr}}\right), \tag{1}$$

$$\sigma = \sigma_0 \left[1 + k\frac{T_0 - T}{T_{tr}} \left(1 + k\frac{T_0 - T}{T_{tr}}\right)\right], \tag{2}$$

here T_0 is the temperature of phase transition, σ_0 – the surface tension at T_0, T_{tr} – the temperature of a triple point of substance, T – temperature of substance. σ_0 is calculated [2] from experimental data on the molar volume, on the heat of the phase transition and the isobaric specific heat of a fluid.

Relationships (1) and (2) are checked up for one point on a curve of coexistence, under normal conditions and represent the ST of the majority of metals and AMH from melting point up to boiling point. The consent between calculated values and the observational values of the temperature derivatives of ST is satisfactory also.

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MODELING OF INTERATOMIC INTERACTION

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In the work the question of modeling of interatomic interaction in ionic dielectrics and gases has been studied. For a number of applications Thomas–Fermi–Dirac model does not give a satisfactory result. The basic source of an error is the expression of kinetic energy leading to an error in calculation of exchange energy. Besides, the energy of electronic correlation is not considered. At calculations of pair potentials for the systems with the filled covers we were guided by the model offered by Gordon and Kim that showed suitability of formalism of a method of electronic density

functional for a considerable quantity of systems and in a big interval of interatomic distances.

Two substantial positions of Gordon–Kim model, in application to the interaction of atoms with the filled external covers, consist in the fact that the electronic density is represented in the form of the sum of two separate densities, and the Coulomb part of the interaction potential cannot be described in approaching the "nearly homogeneous electronic gas". With the use of the given potentials pressure of transition, equilibrium interionic distances and cohesive energy of both phases (B1 and B2) at 0 K have been calculated. Comparing the results received within the limits of the method of electronic density functional, it is possible to notice that the offered model qualitatively improves coincidence of the results of calculations with the experimental data.

For numerical atomic particles interaction processes modeling in a solid and in gas by method of Monte-Carlo it is necessary to define a number of basic stochastic variables adequately describing processes of particles dispersion. The basic characteristic at the description of atomic particles elastic interaction processes is the corner of dispersion which defines power losses and the subsequent character of their movement. It connects among themselves an aiming parameter, interatomic potential of interaction and energy of relative movement of particles.

Integration of the expression for a dispersion corner in an analytical aspect can be carried out only for the potential of rigid spheres and for a number of exponential power potentials and their linear combinations. The analysis of the results of statistical modeling shows that the offered mathematical model of quasi-rigid spheres describes correctly enough processes of elastic dispersion of atoms in the gas medium and the displaced atoms in a solid.

TITANIUM OPTICAL PROPERTIES DURING THE GROWTH OF OXIDE FILM: COMPUTER MODELING

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As known, metals in air media are heated and oxidized under the influence of intense energy fluxes. When an oxide film is being grown upon the surface of a metal, the optical behaviors of the system "oxide film–metal surface" change drastically depending on the time of the film formation, film thickness, and optical properties of the oxide film and the metal [1].

Such variation in emissivity constitutes a serious problem that is known to cause large temperature errors in radiation thermometry.

This report considers a metal substrate having an optically smooth surface on which oxide film is grown. The reflection model was obtained by solving Maxwell's equations as a boundary problem composed from parallel media layers of air, an oxide film, and a metal (two ray interference) [2, 3]. Then the expression of spectral normal emissivity was derived from the reflection model by using Kirchhoff's law as a function of oxide film thickness, optical constants (refractive indexes) of the metal and oxide films. Optical constants m_i was taken from [4].

Dependences on reflectivity, emissivity and brightness (radiance) temperature of the system "oxide film–metal surface" as a function of film thickness and wavelength were obtained by computer experiment for titanium.

It is shown that the brightness (radiance) temperature can be used to estimate thickness of the new oxide film, time of its formation and a refractive index of the film.

Application of the obtained results for the process of oxidation of titanium in air during subsecond resistive heating is discussed also.

This work was supported partly by the Russian Foundation for Basic Researches (grant 07-08-00708-a).

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DIRECT MEASUREMENTS OF TEMPERATURE FIELDS DURING SUBSECOND LASER HEATING OF REFRACTORY SUBSTANCES

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Experimental study of phase diagrams of multicomponent systems by laser heating is based on the analysis of thermograms obtained by means

of optical pyrometers during the processes of heating and cooling. The viewing spot of the pyrometers is small in diameter and it is placed in the isothermal area in the centre of the laser focal spot being more than 10 times greater than the pyrometer spot. Though fairly much information is obtained by means of these pyrometers, the point temperature measurements do not provide full insight into the complicated processes of melting and crystallization in multicomponent system. Therefore, it is quite logical that high-speed registration of temperature fields of the specimen surface must be the next step, necessary for the understanding of the processes of melting and crystallization. Here, measurements have to be performed at temperatures up to 3500 K with temporal resolution of about 1 ms.

In present work high-speed video camera based on CMOS-sensor is used for measurements of temperature fields. This camera supports high spatial resolution (1280x500 pixel) at the frame rate 1000 1/s with amplitude resolution of video signal of 8 bits. Since this camera being device intended for getting information at mainly qualitative level, necessary study of the linearity with proper correction of video signal amplification and offset is carried out.

In order to reduce dynamic range of the input video signal the wavelength 870 nm close to the red boundary of the camera sensitivity was chosen for measurements. This wavelength differs from the wavelength 656 nm common for temperature scale transfer in pyrometric ribbon temperature lamps. Therefore, for temperature calibration at 870 nm well-known literature values for tungsten emissivity were used. Difference in sensitivity over camera pixels is compensated using highly homogeneous light source on the basis of integrating sphere.

Main characteristics of the device and the results of dynamic measurements of temperature fields in course of crystallization of refractory oxides are presented. It is stressed that in spite of relatively low amplitude resolution of video signal, the thermogram recorded by the CMOS video camera for the centre of hot spot almost coincides with the thermogram obtained by virtue of high-speed precision micropyrometer.

NORMAL SPECTRAL EMISSIVITY (AT 650 NM) OF REFRACTORY METALS AT THE MELTING BY A THIN PLATE METHOD

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The Infinitely Thin Plate (ITP) method has been used to determine the normal spectral emissivity (at 650 nm) at the melting point of refractory metals: niobium, molybdenum, tantalum and tungsten. A schematic of the working section of the ITP method consists of the sample in the form of thin plate with thickness H, the laser with beam diameter $d_1 \gg H$ and optical pyrometer, for which the diameter of the sighting spot d_2 , obeys $H \ll d_2 \ll d_1$. The determination normal spectral emissivity is based on the using Planck's law along with the knowledge of the true melting temperature. Data and plots of the radiance temperature of refractory metals as a function of time are presented in this paper. There is good agreement with the highest values thus far published. The method of infinitely thin plate can be recommended as a basis of the device for realization high temperature reference for use in relation to optical temperature measurements.

Work is executed with financial support of the Russian fund of basic researches, the Russian Federal Property Fund grant No. 07-08-00670-a.

ATOMISTIC SIMULATION OF THE INTERACTION OF ELECTROLYTE WITH GRAPHITE NANOSTRUCTURES IN ADVANCED SUPERCAPACITORS

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Carbon supercapacitors represent a promising energy storage devices based on liquid electrolyte ion adsorption on the surface of highly porous carbon [1]. The presence of a developed surface with a pore size down to nanometers provides more contact surface area per unit mass. Optimization of this kind of technology requires detailed understanding of the physics of the electrical double layer formation, its behavior during supercapacitor charging and discharging, information on the mechanisms of diffusion of the electrolyte in nanopores.

The level of development of methods of classical and quantum molecular dynamics and the use of parallel high performance computing allow one to build realistic models of such processes. The most precise characteristics of electrolyte solutions can be calculated with the use of ab initio molecular dynamics in the framework of DFT [2]. Such an approach allows studying the interaction of the ion subsystem of the electrolyte with the surface of carbon material. Including of carbon in the model gives the opportunity to consider the peculiarities of adsorption of electrolyte components at the phase boundary. In particular it suggests a strong adsorption of alkali metal ions on the surface of carbon material. It is found that the carbon material electron-hole plasma determines the capacity of the system. The ratio of the ion subsystem capacity and full system capacity has the order of $C_e/C \sim \Delta U_e > 4$ where U is the full potential drop superimposed on the system. The maximum capacity of the carbon electrode of pure defect-free graphite is estimated $C_{max} \sim 22$ F/cm^3.

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MOLECULAR DYNAMICS SIMULATION OF METHANE HYDRATE

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Methane hydrate is a clathrate compound in which molecules of methane are trapped within the crystal structure of water ice. These compounds are perspective source of fuel in the future. But methane is a powerful greenhouse gas, so, the destruction of methane hydrates may lead to rise of temperature[1].

In this work we study properties of sI methane hydrate structure. The model of a cubic unit cell of the sI structure was created consists of two dodecahedrons and 6 tetrakaidecahedrons. The SPC/E and TIP4P/2005 potentials were used to describe water and a united-atom with all-atom potentials for methane molecules. Parameters in Lennard-Jones potential for the interaction of water-methane were chosen according to rules of the Lorentz-Berthelot[2].The range of temperatures and pressures resulting in

a spontaneous decay of the sI structure were determined. The kinetics of the decay process was described.

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MODEL OF THE INCOMPLETE PHASE TRANSITIONS OF GAS HYDRATES IN POROUS MEDIA

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It is well known that, when confined to narrow pores, fluids can be subjected to very high internal (capillary) pressure. High capillary pressure results in changes in the temperature/pressure conditions where phase transitions take place. Existing theoretical and experimental studies suggest that the phase equilibrium of gas hydrates in the porous media strongly depends on the capillary effects [1]. In the porous media with multi-scale porosity these effects can lead to the coexistence of gas hydrate and the products of its dissociation (gas and water) in a wide region on the $P-T$ plane. If the pore sizes are sufficiently large the region deforms to the phase equilibrium curve which follows from Gibbs theory for pure crystalline hydrate.

A model of such incomplete phase transitions of gas hydrates in the porous media is being developed on the basis of general principles of constitutive equations of the porous medium. It is proposed that the nondeformable skeleton is capable to exchange mass, momentum and energy with the fluids [2]. Skeleton potential takes into account the surface energy, the latent energy of phase transition and temperature dependence. The thermodynamically consistent kinetic equation is formulated. Conditions of the beginning and the end of phase transition are found.

The model is applied to the problem of hydrate dissociation that is initiated by decrease in the pore pressure at the boundary of the porous media containing gas hydrate and water. New similarity solutions of the one-dimensional problem are obtained. 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 on the parameters

of the model is investigated.

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SKELETON BEHAVIOR DUE TO GAS-HYDRATES DISSOCIATION

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Gas-hydrates is a perspective sources of hydrocarbons. Fortunately gas-hydrates development is accompanied by some difficulties connected with gas-hydrates dissociation. One of them is strength deviation of rock. When gas-hydrates fasten grains of skeleton together elastic solid skeleton can transform in to granular or visco-plastic media due to gas-hydrates dissociation. Consequences of these phenomena can be disastrous and can have a form of borehole instability, reservoir consolidation, dramatic decline of permeability. Adequate model of these phenomena should combine approaches of visco-plastic media mechanics, theory of phase transformation and multiphase flow.

In this work gas-hydrates dissociation is described by scalar parameter of dissociation degree. The state of constitutive equations of porous medium with gas-hydrates is completed by kinetic law governing the evolution of this dissociation parameter. A one-dimensional problem of porous medium consolidation due to gas-hydrates dissociation under external stress is considered. It is assumed that skeleton is initially elastic and becomes visco-plastic when dissociation parameter achieves critical value.

ANALYSIS OF MODERN MODELS FOR DESCRIPTION OF THE DENSITY ON THE LIQUID–GAS COEXISTENCE CURVE

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Some models of properties, F = (the desities, ρ_l, ρ_g, the order parameter, f_s, the coexistence curve diameter, f_d) are considered in the report; among them there ara equations suggested by Vorob'ev [1], 2009, Anisimov, 1990, Abdulagatov, 2007, et al. They are taken to compare with reliable experimental data of a wide row of substances (HFC 134a, HFC 143a, HFC 236ea, H_2O, NH_3, CH_4, SF_6, alcohols, ethers, metals et al). One more analytical form of F is investigated. It has a combined structure with scaling and regular parts

$$F(\tau, D, B) = F(\tau, D, B)_{scale} + F(\tau, B)_{reg}\,. \qquad (1)$$

Here D = (α, β, Δ, T_c, ρ_c)—critical characteristics, τ= 1 - T/T_c—a relative distance of T from the critical temperature, T_c, B—amplitudes. Model (1) is described in [2]. The degree laws of the scaling theory were taken into account to express scaling part of ρ_l, ρ_g . Adjustable coefficients, B, D, of model (1) have to be determined by fitting F to the input data sets those are formed in the temperature interval from the triple point up to T_c. Criterions, S1, S2, Sc, are taken into account: S1 represents RMS deviation of measured ρ_l, ρ_g values from (1) , τ=(0... 0.1), S2 represents RMS deviation of measured data from (1) in the whole temperature region. A compromise criterion Sc is chosen as a middle value of S1 and S2. Calculated ρ_l, ρ_g values (1) correlate with the measured data in acceptable limits including such accurate sources as Wagner data for H_2O, CH_4 and SF_6.

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SCALING MODELS OF THE SATURATION PRESSURE IN A WIDE TEMPERATURE REGION

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Some models of the saturation pressure (P_s) are analyzed in the report, among them there ara equations suggested by Xiang, 1996, Wagner, 1996, Wu, 2005, Abdulagatov, 2007, Park, 2009, et al. The models are taken to compare with reliable experimental data of several substances (HFC 134a, HFC 143a, HFC 236ea, H_2O, NH_3, CH_4, SF_6, alcohols, ethers). One more analytical form of F is considered. It has a combined structure with scaling and regular parts

$$Ps(\tau, D, B) = Ps(\tau, D, B)_{scale} + Ps(\tau, B)_{reg}\,. \qquad (1)$$

This Model is written as

$$\ln(P_s/P_c) = B_1\tau^{(2-\alpha)} + B_2\tau^{(2-\alpha+\Delta)} + B_3\tau^{(2-\alpha+2\Delta)} + B_4\tau + B_5\tau^5 + B_6\tau^7 + B_7\tau^9. \qquad (2)$$

Here $D = (\alpha, \Delta, T_c, P_c)$—critical characteristics, $\tau = 1 - T/T_c$—a relative distance of T from the critical temperature, T_c, B—amplitudes. Model (2) is got by the authors [1]. The degree laws of the scaling theory were taken into account to express $P_{s_{scale}}$ that included first four terms of (2). Adjustable coefficients, B, D, of model (2) have to be determined by fitting F to the input data sets those are formed in the temperature interval from the triple point T_tr up to T_c and include reliable experimental results. Criterions, S1, S2, Sc, are taken into account: S1 represents RMS deviation of measured Ps exp values from Ps_{scale} in the critical region, τ=(0... 0.1), S2 represents a RMS deviation of measured data from Ps (2) in the whole temperature interval. A compromise criterion Sc is chosen as a middle value of S1 and S2. Combined models of P_s are built for the substances mentioned. Calculated P_s values correlate with the measured data in acceptable limits in the interval from T_{tr} to T_c. For example in the case of H_2O, SF_6 and CH_4 there are got small criterions $S_c = 0.018$–0.025% in comparisons with Wagner sources.

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SOLIDIFICATION OF MOLTEN METALS AND LIQUIDS INDUCED BY WAVES OF SHOCK, QUASI-ISENTROPIC AND ISENTROPIC COMPRESSION

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Solidification almost all investigated liquids at isothermal compression was revealed still by Bridgman. In usual conditions crystallization represents rather slow process consisting of a stage of origin of the centers of crystallization and growth of grains in a liquid matrix. Both stages are determined both quantity of overcooling of a liquid, and time of a thermal relaxation of the latent heat of melting. Behind front of a wave of compression it is possible to expect both a non-equilibrium metastable condition of substance, and a condition with partial or full formation of a solid phase. Fast crystallization at dynamic compression and transition in an equilibrium solid condition are connected to an opportunity of fast diffusion of the latent heat of melting.

Crossing by the shock adiabatic curve that is starting with a condition in the range of a liquid phase, curve melting was observed on occasion for shock waves of rather low intensity. Thus in initial area of pressure growth of pressure on a shock adiabatic curve occurred basically due to compression, and having warmed up substances was small enough. Adiabatic curves of quasi-isentropic repeated shock compression and also isentropic compression for waves with ramp front of increase the pressure which are starting with area of an initial liquid condition, cross monotonously growing curve of melting at any reference temperature of liquid substance.

The major factors influencing crystallization of metal melts and liquids are investigated. Results of studying of solidification for tin and bismuth melts, and also for liquids taking place in a normal initial condition (mercury, water, four-chloride carbon, and benzene) are considered at shock, quasi-isentropic and isentropic compression. The restrictions resulting in realization of process of crystallization are specified. For mercury the equations of state liquid and solid phases are received, allowed to extrapolate a curve of melting and shock adiabatic curve up to pressure about 50 GPa, adequate to the available data on viscosity at shock compression. Measurement of viscosity of water and mercury is considered at the

shock compression, corresponding to a two-phase condition with different concentration of solid particles.

SHOCK PROPAGATION AND STRENGTH PROPERTIES OF SAPPHIRE

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The shock-wave response of sapphire of seven orientations (c, d , r, n, s, g, m) which correspond to the angles between the load direction and the c-axis varying from 0 to 90 degrees was investigated with the goal to find optimal conditions of its use as a window material. In the experiments at shock stresses in a range from 16 GPa up to 85 GPa the VISAR particle velocity histories were recorded using LiF windows. In most cases measured waveforms are noisy as a result of heterogeneity of deformation. The measured HEL values depend on peak shock stress and direction of shock compression. Highest HEL values reaching 24 GPa have been recorded at shock loading along c-axis and perpendicularly to it (c- and m-directions) whereas shock compression along the s-direction is accompanied with smallest heterogeneity of the deformation and smallest rise time in plastic shock wave. Results of experiments with varying transversal stresses admit to conclude that inelastic deformation of sapphire begins in ductile mode and leads to fracture and fragmentation as a result of interaction of shear bands or twins.

POLYMORPHIC TRANSFORMATION OF GRAPHITE AT DIFFERENT STRUCTURE TO THE DIAMOND-LIKE PHASE UNDER SHOCK COMPRESSION

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Investigation of influence of the structure characteristics of graphite on parameters of its polymorphous transformation to diamond-like phase was carried out. The graphite of two structure states—pressed graphite and highly oriented pyrolytic graphite with different crystal mosaic spread were studied with the goal to verify possible mechanisms of the graphite-

diamond transformation. The materials tested were highly ordered synthetic graphite plates with mosaic spread of 0.4 and 1.7 degrees and samples prepared by pressing of powders of highly ordered pure graphite and several kinds of natural graphite. In experiments the VISAR wave profiles were measured using the LiF windows in the transformation pressure region. It has been found the orientation of the graphite basal planes concerning compression direction significantly affects the detected pressure of the transformation and its rate. The value of the transformation pressure for graphite with more ideal crystal lattice is higher than for pressed graphites. Results of the measurements show that means shifts in basal planes complicate high-rate graphite–diamond transformation. It was found also the transformation pressure increases and the transformation rate decreases as the degree of three-dimensional ordering of graphite decreases.

TWO-PHASE BOUNDARY DETERMINATION BY ISENTROPIC EXPANSION OF SHOCK-COMPRESSED POROUS SAMPLES

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For many metals the high-temperature part of evaporation curve reaches a plasma region, so the strong variation of electron component properties represents a significant problem for both theoretical and semi-empirical description of near- critical point states. Thus the experimental data on metal properties in this region is important for improvement of various equations of state.

It this work experimental data (temperature, pressure, expansion velocity) were obtained for isentropic expansion on shock-compressed initially porous samples of metal (W, Cu, Nb) in the optically transparent barrier media (He at different initial pressure). The states along expansion trajectories, entering into two-phase region close to critical point of liquid-gas transition, were studied. The temperature and rarefaction velocity of the surface of expanded metal was registered by fast multi channel optical pyrometer. It has been shown, that the registration of temperature-time profile during unloading and expansion of porous sample in barrier gas provides the understanding of released state (two-phase mix or one-phase). Thus, it is become possible to trace a boundary of two-phase region and

make estimations of critical point position in pressure-temperature diagram.

MANGANIN GAUGE UNDER MEGABAR SHOCK PRESSURES

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Manganin gauge is widely used for registration of pressure in shock waves. The manganin gauge technique based on the resistance test of manganin placed in the transmitting medium which prevents a shunting of the gauge. There are many calibration electrical resistance dependences on pressure where environment conductivity can be neglected. However under megabar shock pressures (and accordingly high temperatures) environment becomes to some conductivity and the shunting effects are appeared. We have executed calibration experiments in megabar pressure range. Shock loading is realized by high velocity stainless projectiles. Pressures were defined by means of handbook Hugoniots and preliminary measured projectile velocity. Teflon was used as a transmitting medium. The electrical signals were registered by high-frequency oscilloscope. The projectile velocity was measured with help of VISAR technique. The results are compared with the literaturery manganin electric response data up to megabar pressure in various transmitting. This work was partially supported by the Government Contract No. 2.552.11.7090.

THE ELECTRIC RESPONSE OF THE SHOCK-COMPRESSED MAGNESIUM HYDRIDE MgH_2

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Recently researches of hydrides of alkali and alkali earth metals at high pressures involve special have attracted considerable attention. This fact is connected with two problems. First, in these materials occurrence of superconducting properties for the account of chemically compressed hydrogen [1] is expected. Secondly, electrophysical properties of hydrides high-pressure phases of alkali and alkali earth metals are of interest for

hydrogen materials science [2]. In the present work the shock-wave experiments on measurement electrical conductivity of high pressure phases of magnesium hydride have been made executed at quasiisentropic compression up to 60 GPa. Identification of a condition of the hydride of magnesium state in experiments was made on the basis of calculations of phase trajectories loading a material in the area of existence of polymorphic phases including high-pressure phases of magnesium hydride (γ and α MgH_2, hP1 and hP2 [3]). It is shown that occurrence of magnesium hydride electrical conductivity occurs in the field of existence of high-pressure hP2 phase.

This work was partially supported by the Presidium of the Russian Academy of Sciences within the Program of Basic Research "Thermal Physics and Mechanics of Extreme Energy Effects and Physics of Strongly Compressed Matter".

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STABILITY OF CRYSTAL STRUCTURE OF FULLERENES UNDER SHOCK WAVE COMPRESSION

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The experimental study of properties of carbon nanostructures including fullerenes under extreme conditions of high pressures and temperatures presents both fundamental and applied interest. It is known that high pressures stimulate a number of physico-chemical transformations in fullerenes, which take place under the conditions of both static [1] and dynamic [2] loading. Shock wave compression is characterized by a short process duration (usually about one microsecond), an increase in the substance temperature, and high deformation rates. Therefore it is possible to expect that, other new states of fullerenes will be achieved under such conditions. At the present work structural and molecular states of some representatives of fullerenes was investigated under shock wave loading. Recovery experiments on monocrystal C_{60}, C_{70} fullerenes and a monocrystal powder

of fullerene hydride $C_{60}H_{36}$ after multi-shock compression up to 28 GPa have been carried out. It is shown by results of x-ray diffraction and absorption spectra of initial and recovery samples of fullerenes, that studied monocrystal fullerenes materials under shock wave compression keep their molecular and crystal structure in the investigated area of pressure and temperatures.

The work is supported by the program of Presidium of Russian Academy of Sciences "Thermophysics and mechanics of extreme power influences and physics of strongly compressed substance".

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TO THE DIFFERENCE OF ROCK-FORMING MINERALS TRANSFORMATIONS IN THE COURSE OF PLANAR STEPWICE AND CONVERGING SPHERICAL SHOCK COMPRESSION

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Character of rock-forming minerals (clinoamphibole, plagioclase, clinopyroxene, scapolite) transformations in conditions of planar stepwise shock compression and under the converging spherical shock compression has been compared. Significant differences in shock metamorphic changes of minerals in these two types of shock experiments have been revealed. Under the spherical shock compression amphibole undergo shock-thermal decomposition with forming of andesine, amphibole and metallic mineral aggregate at 40 GPa already. Under the stepwise shock wave compression it does not happen even at 52 GPa. The same is observed for clinopyroxene that reveals just mechanical transformations in conditions of step-like shock compression even at 52 GPa. Under the spherical shock compression in the range of 40–60 GPa it transforms to the aggregate of plagioclase, amphibole, clinopyroxene and magnetite. Scapolite under the stepwise shock wave compression becomes amorphous but does not undergo any chemical transformations in all explored pressure range. Under the spher-

ical shock compression in the same pressure rage bringing of Si, Fe, K and carrying out of Al and Na is observed in scapolite. Earlier comparisons of minerals transformations under the spherical shock compression with their shock-metamorphic changes in impact structures show good agreement of experimental data to the natural data (but it is necessary to take into account that the correct pressure definition is the big problem of the spherical shock compression experiments). The question is: how may we use a stepwise shock-wave compression as a method of modeling of natural impact processes and under which conditions may we use the results of stepwise shock experiments (for example, well-known geobarometer based on shock metamorphism of quartz). The work was supported by RFBR (09-05-00211).

DYNAMICS OF FRACTURE OF CERAMICS WITH POROUS STRUCTURE AT SHOCK WAVE LOADING

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Dynamics of fracture of a porous alumina and zirconia nanoceramics at meso-scale level under shock pulse with amplitudes below 10 GPa of sub microsecond duration was investigated by the method of 3D computer simulation. The two-level computational model was applied to the description of mechanical behavior of the structured ceramics. The influence of a porous structure and the shape of pores on the nanoceramics damage behind a shock were studied. It is shown that the Hugoniot elastic limit (HEL) a oxide nanoceramics depends not only on the porosity, but also a porosity structure. Under shock compression the fracture of solid phase of nanoceramics arises at local areas near to the largest pores or pore clusters. The start of damage accumulation has a barrier character. The stress, at which the local damage begins to increase, corresponds to the HEL. At same integrated porosity the oxide ceramics with the pore clusters possesses a smaller limit of elasticity, than analogous ceramics with a uniform distribution of micropores of a comparable size. Evolution of damage zones near to pore clusters leads to formation of the mesocracks parting volume of a material on blocks. Sizes of blocks surpass medial sizes of grain and are comparable to distance between pore clusters. Formation of blocks is accompanied by occurrence of a bimodal distribution of particles velocity at mesoscopical level. Process of fragmentation of oxide nanoceramics depends on the shift and rotation of formed blocks. Pores

and the pore clusters which are present at initial structure of materials are hindrances to extending of the meso cracks formed in a solid phase of nanoceramics behind a shock wave. Therefore the fracture wave can not form in the ceramics under shock waves below of 10 GPa. Porous clusters with nanopores in the grain boundaries cause the decreasing of the shear strength of oxide nanoceramics.

DAMAGE OF NANOCOMPOSITES UNDER PULSE LOADING

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Mechanical behavior of nanocomposite materials under intensive dynamic loading is not studied in detail. This problem is important today because modern nanocomposite materials possess unique combination of strength and functional capabilities. The damage evolution of Cu-Al_2O_3, Cu-TiB_2 nanocomposites under impulse loadings with amplitudes up to 5 GPa was studied by computer simulation method. The two-level model for prediction of mechanical behavior of composite materials with the ultrafine grained (UFG) copper matrix, strengthened by ceramic particles with size near 100 nm under intensive microsecond impulse impact is offered. Models of structures of nanocomposites were developed on basis of the data of microscopic researches. Nanocomposites with concentration of particles less than 20 The dynamic fracture of nanocomposites is preceded the inelastic strain localization and the formation of a block structure behind of shock wave front. The effective block size depends on shock wave amplitude and essentially exceeds the average size of ceramic particles. Results of numerical simulation testify the formation of nonuniform strain and stress fields, particle velocity distribution on mesolevel behind the shock wave front. This nonuniformity causes the formation of species of damage zones. Damages appear at the interface boundary of a matrix and particles. But the loss of macroscopic strength of nanocomposites caused confluence of local damage zones of matrix. The damage on boundaries of blocks is related with the limit of localized inelastic strain of UFG copper matrix. Results of numerical simulation testify the spall strength of investigated nanocomposites can increases with growth on concentration of ceramic particles and decreasing of their sizes.

STRUCTURAL-SCALING TRANSITIONS AND LONG RANGE CONSTITUTIVE MODELS FOR SHOCKED MATERIAL

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Numerical simulations of metals and alloys during explosively driven deformation and high velocity impacts require a physically realistic models of plastic constitutive behavior. The main difficulty in constructing of such a model is the wide range of mechanical and thermodynamical conditions that can occur in solid flow processes of interest; plastic strains of several hundred percent, plastic strain rates up to 10^{11} s^{-1} (hypervelocity impact, pressures exceeding 10GPa, and temperatures up to melt. In particular, plastic constitutive models based on thermally activated glide are restricted in applications to strain rates $< 10^5$ s^{-1}.

The dynamic response of materials depends on its current microstructural state, which is characterized by its current grain distribution, dislocation density, dislocation network structure. A constitutive relation depends in general on the complete set of internal variables that represent the microstructural state. The continuum models employ internal state variables, is constructed using a sophisticated homogenization procedure relating to internal state to the continuum response, includes a model for microstructure evolution, and requires complete microstructure characterization for its utilization. A step in this direction has been taken by Follansbee and Kocks who developed a constitutive model employing the mechanical threshold stress as structure parameter related to thermally activated dislocation motion. However, thermal activation is no longer controlling at high stresses, but instead dislocation drag mechanisms are expected to predominate. MTS-PTW model was proposed in [1] to incorporate the transition in rate controlling mechanism by joining the Arrhenius form onto a power law dependence at very high strain rates. The MTS-PTW model is applicable at strain rates spanning the range 10^{-3}–10^{12} s^{-1}. This was achieved by merging the flow properties of metals in the strong-shock-wave limit, where nonlinear dislocation drag effects are expected to predominate with the thermal activation regime. The model developed in [2], [3] links the mechanisms of structural relaxation with the multiscale kinetics in mesodefect ensembles (structural scaling transition-SST), and the mechanisms of plastic flow and damage-failure transtions. The comparative analysis of MTS-PTW and SST models allowed us to es-

tablish the linkage of hardening law, hardening saturation stress and yield stress in thermal activation regime with non-linearity of non-equilibrium thermodynamic potential (free energy), to propose interpretation of the universality of structured plastic wave, transition to the overdriven-shock regime.

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MULTISCALE KINETICS OF EVOLUTION OF MESODEFECTS, STAGING AND STATISTICAL REGULARITIES OF FAILURE UNDER INTENSIVE LOADING

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The problems of failure under intensive loading are related to the solution of the fundamental problems of the qualitative difference in the behavior of materials in brittle and viscous states, transitions between which are realized during the variation in loading intensity. The study of the mesodefect ensemble behavior [1, 2] revealed the specific features of failure as a multiscale process of mesodefect evolution within the framework of a new class of critical phenomena—structural-scaling transitions. The phenomenological theory based on the Ginzburg-Landau approach allowed us to determine the type of collective modes of mesodefect ensembles defining the localization of failure and to justify its stages.

A series of experiments [2, 1] were performed to study the stages of failure under dynamic crack propagation in PMMA, fragmentation of glass specimens subjected to dynamic loading, initiation of failure waves in quartz glass specimens, distribution of failure zones during the spall formation in armko-iron and vanadium under impact-wave loading. The correlation between the stages of dynamic crack propagation and the stages of fragmentation process is shown. The resonance nature of failure wave initiation caused by the blow-up dissipative structures in the microshear ensemble is substantiated. In order to find features of structural-scaling

transitions the correlation analysis of damage in the vicinity of the spall zone in recovered armko-iron and vanadium specimens was performed. Fragmentation regularities were investigated in the experiments with sectional glass specimens loaded according to the direct-impact scheme under covering conditions. The statistic analysis of mass distribution was carried out by weighing the fragments using an electronic balance HR-202i. The scaling of fracture surfaces was investigated using 3D optical profiler and AFM.

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NUMERICAL SIMULATION AND EXPERIMENTAL INVESTIGATION OF SPALL FAILURE IN METALS UNDER SHOCK COMPRESSION

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The developed statistical model of solid with mesoscopic defects [1] was applied to investigation of the failure phenomena. Plate impact experiments were conducted to verify the model.

Equations [2, 3] describing the linkage of relaxation mechanisms with the structural-scaling transitions in defect ensemble were solved numerically for the statement of plate impact test. The spall at the middle of the specimen corresponds to the blow-up regime.

Experiments were carried out in Institute of Continuous Media Mechanics. The diameter of the targets was 90–100 mm and thickness was 5–10 mm. Materials under investigation were pure iron and vanadium. Free surface velocity profile shows typical profile with reverberation. But after the reverberation an additional jumps of the free surface velocity were observed on the vanadium specimen. On the front and rear surface of the vanadium a lattice of cracks was observed. We suppose, that mentioned surface velocity jumps are related to the cracking of the specimen after spallation. In order to investigate transition from damage to failure specimens were subjected to low amplitude shock [2]. Recovered specimen was

sectioned by electroerosion cutter. Structure of the recovered specimen was investigated and correlation properties were measured in order to find evidence of self-consistent structural transition. The correlation analysis in terms of the Hurst exponent supported the long-range correlation as the precursor of spall failure.

The research was supported by the projects of the Russian Foundation for Basic Research (No. 09-01-92441, 08-01-00699) and contract 82617-000-03-35 between LANL and Sarov Laboratories Corporation.

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DISLOCATIONS AND MICRO-CRACKS KINETICS IN PLASTICITY AND FRACTURE OF METALS AT HIGH DEFORMATION RATES

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Plasticity and fracture are essential parts of the metal response on intensive action, such as high-speed impact, irradiation by powerful beams of charged particles or laser irradiation. Suitable models of plasticity and fracture are required for simulations of such fast processes, as well as suitable equation of state for target substance. A question of special interest is the substance response at high deformation rates, provided by sub-nanosecond electron irradiation pulses or ultra-short laser pulses.

The plasticity and fracture of metals have been treated through the kinetics of their microscopic carriers—dislocations and micro-cracks. Dislocation kinetics and its influence on stresses in target have been described basing on the well-known results in dislocation theory [1–4]. The micro-cracks nucleation equation has been written basing on the thermofluctuation approach. The micro-crack growth equation has been formulated basing on Lagrange formalism. The complete equations system consists of the continuum mechanics equations, the kinetics equations for dis-

locations and micro-cracks, the feed-back relations between dislocations, micro-cracks and stresses in target, and the equation of state. The formulated mathematical model allows simulating of the metal target response on intensive action at high deformation rates. Calculation results of metals plasticity and fracture under the action of shock waves and intense electron and ion irradiation have been presented in paper in comparison with experimental data [5].

The work was supported by RFBR, grant No. 09-08-00521.

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MECHANICAL AND PLASTIC PROPERTIES OF MONOCRYSTALLIC IRON

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The purpose of this work is to study the plastic properties of bcc iron at the atomic level, the identification of mechanisms of plastic deformation of bcc lattice and the comparison of the results with the results obtained for the fcc metals.

Although most of the metals in ordinary conditions have lattice, study of the properties of bcc metals is of great interest since such widely used in industry, construction and engineering metals as iron, chromium, molybdenum, cesium, barium, niobium, rubidium possess bcc lattice. But despite the practical importance of studying the properties of bcc metals (especially iron, accounting for 95% of worldwide metal production), relatively few articles are devoted to this topic.

Mechanisms of distribution of defects (particularly dislocations, determining the plastic properties of the crystal) in the fcc and bcc crystals can be essentially different. In particular, the glide systems in bcc lattices are more diverse as glide planes are usually the most densely packed planes and in contrast to the fcc lattice, where the {111} planes are by far most

densely packed, we have several planes with very similar packing density in bcc crystals, namely {111}, {112} and {123}.

Studying the properties of iron begins with a study of the behavior of artificially created spherical cavity inside a stretched monocrystal of iron. Depending on the degree of stretching of the crystal and the size of the embryo there can be different scenarios. There is a critical size of the embryo, at which the transition from collapse to the growth of the cavity occurs (by analogy with boiling and condensing processes).

Calculations are performed on the cluster of Moscow Institute of Physics and Technology "MIPT-60" using the software package LAMMPS.

CALCULATION OF A STRONG SHOCK WAVE EXIT ON THE SURFACE OF METAL HAVING MICRODEFECTS

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Modeling of a strong shock wave (SW) exit to flat metal surface free of defects is well known and is described by 1D hydrodynamics. But, as shown in work [1], the account of micro-defects, such as bubbles, micro-cracks, borders of crystals inside and micro-roughness of a surface, leads to that the substance after SW exit on a surface expands non-uniformly, micro-jets are formed. In experimental work [1] the distribution ejecta particles in the sizes by the method of high-speed shooting, and in work [2] with use piezoelectric gauges are shown. In both cases grooves with the set sizes of an order 1–10 microns have been put on surfaces. In the present work the results of 2D numerical simulations of an exit of a strong SW on a free surface of iron and copper with the set micro roughness are discussed. The roughness modeled by grooves with depth 1 and 10 microns and corner 90°in plane and in axial symmetry cases. The carried out calculations have shown distribution of temperature on such surface, presence of long living jets which move with certain speed. The obtained data allows to estimate temperature, mass and speed of metal ejecta at the set surface roughness.

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PECULIARITIES OF STRONG SHOCK WAVE EMERGING FREE SURFACE OF A METAL

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In the experiments when the shock wave emerges at the free surface of shock-compressed targets the microparticle jet and vapour of target material were observed with the measured velocity exceeding the shock wave velocity in a gas adjacent to the target (D. S. Sorenson, 2002). The results of spectroscopic study of optical emission of target at expansion into gas and into vacuum and measurements of expansion velocities are presented.

The measurements are made with the arrangement, which include fast time-resolved spectrometer and explosive generators for plane shock wave. In the experiments the spectra of target material were recorded.

The velocity up to 10 km/s, above the calculated velocity of shock wave was observed.

The effective temperature of target radiation was measured.

NUMERICAL MODELING OF THE CUMULATIVE EFFECT IN THE MICROCHANNEL OF THE EXPLOSIVE

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Numerical modeling of the cumulative effect of the detonation products in the microchannel of the explosive (PETN) and numerical modeling of the detonation transfer with the cumulative jets consisting of the detonation products were made. The agreement with the detonation wave entering the microchannel experiment was achieved. For hydrodynamic calculations SPH method in plain two-dimensional approximation was used.

HIGH-ORDER GODUNOV METHOD IN LAGRANGIAN COORDINATES FOR SIMULATION OF SHOCK WAVE EXPERIMENTS

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We present a hydrodynamic code that implements a piecewise parabolic Godunov method in Lagrangian coordinates [1]. The computational scheme is proved to be of 3d order in space and of 2nd order in time. The ideal liquid dynamics equations representing the conservation of mass, momentum and energy are solved. The system is closed with wide-range multiphase equations of state. Simple destruction criterion is introduced to destroy matter when specified level of negative pressure is reached. The hydrocode under discussion is freely available through web-interface at http://www.ihed.ras.ru/rusbank/gassim. We illustrate the application of the hydrocode for the simulation of shock wave experiments. The experiments of D. Shakhray *et al.* [2, 3] on measuring of electrical conductivity of shock-compressed light metals were chosen for comparison and analysis. Numerical simulations were carried out via the web-interface.

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DYNAMICS OF METAL WIRE DISPERSION UNDER ELECTRICAL EXPOSITION

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Formation of nanosize particles under the electrical pulse dispersion of metal wires was investigated. Calculations were carried out within the frame of the molecular dynamics method. The potentials based on the embedded atom method were used to describe interatomic interactions. 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 wire whereas a free surface was simulated along the rest two directions.

It was supposed that temperature changed nonuniformly in the cross section of the metal wire. At that the atomic velocity distribution along the wire cross section was assigned so that temperature reached the maximum in the center and decreased to the face side of the wire linearly. The maximum heating temperature at different simulations were varied within the interval from 10 000K to 25 000K.

It was shown that the explosion process of metal wires was characterized by stages. Each stage was studied in detail. Main processes which were responsible for the reply of the simulated copper wire were analyzed. It was found that the increase of the metal wire heating temperature led to: 1) the decrease of time interval, which was necessary to reach the maximum of the cluster number; 2) the increase of the cluster number at the last stage of the metal wire dispersion; 3) the decrease of an average cluster size at the last stage.

It was shown that the internal structure weakly influences on the metal wire behavior under the electrical explosion. The peculiarities of the dispersion process and nanoparticle formation were investigated under the synchronic metal wire explosion.

INFLUENCE OF DEFECTS ON FRACTURE KINETICS: MOLECULAR DYNAMICS STUDY

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The kinetics of fracture under high strain rate tension ($> 10^6$ s^{-1}) and corresponding dynamic strength are studied on the example of single and polycrystalline aluminum. The influence of defects (grain boundaries, stacking faults, deformation twins and nanosize pores) is analyzed basing on the results of molecular dynamics simulations within the embedded atom method model for interatomic interactions in metals.

The simulations of uniform triaxial stretching at constant strain rate have revealed that the presence of defects in single crystal makes the dependence of the spall strength on strain rate much stronger than in an ideal crystal at low temperatures.

The critical stresses for nucleation of pore or melting are found for crystals with defects at different temperatures. Considerable overheating is observed in MD simulations in the case of a single crystal, even in the

presence of stacking faults, dislocations and voids. However the premelting of grain boundaries takes place. The width of the amorphous liquid-like layer at grain boundaries increases when the state of matter approaches the melting curve in the stretching process. The tensile strength of the homogeneous liquid is comparable to that of the single crystal at elevated temperatures. But the liquid layer formed provides a decrease of the critical stress for growth of pores along grain boundaries. It can provide the decrease of the spall strength of polycrystals at the approach to the melting curve in agreement with experimental data on shock wave loading.

ATOMISTIC SIMULATION OF PLASTIC DEFORMATION AND FRACTURE IN CERAMICS

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The work is devoted to molecular dynamics (MD) simulation of microscopic mechanisms of plastic deformation and fracture in ceramics on the example 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 potential is tested by the quantum-mechanics calculations of the energy formation of defects during the sliding along three plane slip: prism slip plane ($\langle 10\bar{1}0\rangle \{1\bar{2}10\}$), pyramidal slip plane ($1/3\,\langle 10\bar{1}0\rangle \{\bar{1}012\}$) and basal slip plane ($1/3\,\langle 11\bar{2}0\rangle \{0001\}$). The results are in an agreement with each other. MD simulations of shock-wave loading were carried out for different orientations of crystallographic directions. The analysis of structure transformations demonstrates the mechanisms of plastic deformation similar to the experiments. The defect structure activates the void formation under stretching in the release wave. The spall strength was estimated.

This work was partially supported by the RFBR-09-08-01116-a, RFBR-09-08-12161-ofi-m grants, RAS programs 11, 12.

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THERMODYNAMICS OF LASER DRIVEN DETONATION

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Laser-induced core damage remains a limiting factor of laser energy transport by fiber glass. There are two type of propagation of laser-induced damage in core [1, 2]. Slow mode is called "burning", another mode is corresponding to fast propagation regime (laser driven detonation). In the present paper the structure of destruction process with high velocities under intensive laser beam has been investigated. These regimes were detected and measured at all investigated diameters of fiber glass core 1.5–10 μm. Plasma and destruction waves in fiber glass core (mode diameter 5.8 μm) were recorded up to 40 W/μm^2 with exposition time 2 ns. Registrations show that dense plasma propagation exists in zone of crack initiations. Measurements of temperatures for both "start–stop" points and process of propagating were carried out. The measured radiating temperature for detonation-like regime was 9000 K. Equation of state gives evaluation of local pressure in core as 50–100 kbar. The measured temperature let us to calculate decomposition products of SiO_2 plasma in core using IVTANTHERMO software package (see also http://www.ihed.ras.ru/∼thermo).

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GROWTH OF NANOPARTICLES OF CONDENSED CARBON AT DETONATION OF HIGH EXPLOSIVES

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Small-angle X-ray scattering (SAXS) is investigated via registering the diffraction signal from a sample in the small-angle area. This method is

widely used for analysis of the structure of disperse systems. Application of highly-periodic synchrotron radiation (SR) from the accelerator complex VEPP-3 to measuring SAXS with exposures of 1 ns (and cycle of 250 ns) makes it possible to trace development of the signal in the course of detonation of high explosives. Analysis of the development allows determination of the sizes of resulting particles of condensed carbon as well as size variations in time after the detonation wave has passed. Pressed charges of TNT, TNT/RDX (15 mm in diameter) and TATB (20 mm in diameter) were under study. It follows from the results that there are 2.5–3 nm nanoparticles registered immediately beyond the detonation front in TNT/RDX and TNT. The particle sizes increase up to 4.5–5 nm in time 3 μs. Judging from the amplitude of integral SAXS in TNT/RDX, the nanoparticles are mostly nanodiamonds and those in TNT consist of graphite and soot. As for TATB, nanoparticles of 1.5 nm in diameter are registered at the detonation front. Then the particle size is increasing weakly and reaches the value d=2.6 nm by the instant t=4 μs. Judging from the SAXS signal amplitude, there is no trace of nanodiamonds in the products of TATB explosion.

STRUCTURAL HETEROGENEITY OF DETONATION DIAMOND-CONTAINING MATERIAL

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The object of the research was detonation diamond-containing material (DCM) or so-called detonation nanodiamond. The material was separated into the fractions. Raman and infrared (IR) spectra and X-ray diffraction patterns (XRD) of some fractions were obtained. The experiments showed that the distribution of sp3 (diamond) grains was of complicated character. The fine particles contained small amount of the diamond grains or did not contain at all.

SPEED OF A DETONATION POWDER AND WATER-FILLED RDX

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Some aspects of the use of water-powdered RDX (GOST 20395–74) mixes in explosive experiments are discussed in this report. Measurements of the velocity of detonation are presented also. Mixes with mass contents of RDX from 0.6 up to 1.0 served as research objects. A charge formed by the filling of thin-walled (0.75 mm) glass cylinders with a diameter of 16–36 mm and a length of 200–1000 mm with the preliminary prepared mix. Special procedures on condensation or pumping out of the mix was not used, therefore the charges could contain few air inclusions with a size up to 2–3 mm. The final density of charges in the experiments was within the limits of 1.063–1.475 g/cm^3. Accuracy of a charge density definition was not worse than 0.5%.

Definition of the velocity carried out with the use of x-t diagrams received by comparison of 16 photos of detonation front luminous. Photos received with the use of high-speed digital chamber Cordin 222–16 at an exposition of 30–50 ns. The moments of gate opening of the digital chamber were registered by means of pulse digital oscilloscope LeCroy WP 7100A with an accuracy not worse than 1 ns. The photos were processed with the use of Microsoft Office Visio software. Resulting accuracy depend on base of measurements and was within the limits of 0.5–1.0%. Accuracy of measurements is confirmed by good agreement between the received and literary data on the velocity of detonation of powdered RDX with the apparent density (1.0630 g/cm^3). Experimental x-t diagrams for mixes have linear character that specifies uniformity of a mix density over the charge length.

Literary data on the velocity of detonation of water-containing RDX are scanty and can not be used for verification of experimental results. Therefore the analysis of theoretical models for detonation velocity of RDX with inert additives has been made. Cartograms for an estimation of the detonation speed of water-containing RDX are constructed on the basis of these models. Cartograms give values of the detonation velocity depending on the real density of the charge and the component ratio. In the report the degree of the experimental and theoretical data conformity is discussed. The obtained results give an opportunity to use the simplified process of

water-containing RDX mixes preparation for the formation of charges of any forms.

NUMERICAL STUDY OF STABILITY OF CONVERGING SHOCK WAVES IN THERMODYNAMICALLY NON-IDEAL MEDIA

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The problem of the stability of the converging shock waves has two aspects. The first is connected with the cylindrical or spherical shape of converging shocks and approves itself by polygonal/polyhedral front structure. This aspect has been studied by many authors. The second conditioned by thermodynamic non-ideality influence is poorly known although it may be of importance (see [1] for the plane shock wave behavior). The examples of such influence are considered in this work.

The nonlinear behavior of the converging shock waves in the medium described by the model equation of state [1] has been studied. The Hugoniot chosen for calculations contains the region of the shock ambiguous representation conditioned by fulfillment of the linear criterion of the plane shock wave instability $L > 1 + 2M$. Calculations have shown that the 'entering' of converging shock wave into the region of ambiguous representation leads to its splitting into two oppositely directed shocks, one of which is converging. The splitting is accompanied by the sharp pressure increase behind the converging shock wave.

The other example results from the two-dimensional simulations of converging shock wave with equation of state accounting for hard-sphere repulsion in Carnahan-Starling [2] approximation. The simulations have been conducted in inviscid formulation using moving grid algorithm. The results obtained have been compared with the results for ideal gas in which converging shocks are known to be unstable.

Calculations have shown stabilizing effect when pre-shock state is characterized by rather high packing fraction η_0. Formation of polygonal structure characterized by presence of triple-wave configurations on the shock wave surface is shifted to higher values of inverse radius and pressure. 'Forth mode' perturbation of the cylindrical converging shock wave is found to be decreasing at initial packing fraction $\eta_0 = 1/3$.

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THE SHOCK WAVE STRUCTURE IN EQUILIBRIUM MIXTURE OF RADIATION AND FULLY IONIZED GAS

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The complete theory of the shock wave (SW) structure was formulated for heat-conducting inviscid medium, typical for thermonuclear temperatures that are about tens and hundred millions degrees. For such temperatures the radiation transfer of energy ('radiant heat-conducting') is incomparably more important then all impulse transfer ways. Under thermonuclear temperatures the medium consists of completely ionized atoms, electrons and radiation, at that the last one can contribute significantly not only to energy transfer but also to thermodynamic parameters of medium. From incoming in the state equations constants and gas density in front of the SW it is possible to make up combinations whose dimensions are the same to that of all parameters incoming in the state equations and in integral conversation laws that describe structure of the SW. If to take them for scales of thermodynamic parametres and velocity, then in the dimensionless form various media will differ in only the relation of the specific heat capacities of gas γ or the constant $\varepsilon = (\gamma - 1)/(\gamma + 1)$.

In the context of this model the SW structure analysis means to find out its features for the following values of parameters: $0 \le \varepsilon \le 0.5$, $a_0 \le D \le \infty$ and $0 \le \sigma = T_0^3/3 \le \infty$, where D, T_0 and a_0 – dimensionless velocity of SW, temperature and sonic speed of the medium in front of SW. Executed analysis consisted of three stages, for which: 1. In the state equations it is possible to neglect radiative addends (RA); 2. On accounting RA SW moves through the cold background; ($\sigma = T_0 = a_0 = 0$); 3. On accounting RA the background is warm ($\sigma > 0$). It is found out, when SW structure is continuous and when it contains a finite or an infinite 'harbinger' and an isothermal shock (IS). When $\sigma \ge \sigma_{**}(\varepsilon)$ there is no IS for any $a_0(\sigma, \varepsilon) \le D \le \infty$, thus the SW structure is continuous and asymptotic in the both sides of the SW. For $\sigma < \sigma_{**}(\varepsilon)$ function $D_{*2}(\sigma, \varepsilon) > D_{*1}(\sigma, \varepsilon) > a_0(\sigma, \varepsilon)$ that define the SW structure were calculated. When $a_0(\sigma, \varepsilon) < D < D_{*1}(\sigma, \varepsilon)$ or $D > D_{*2}(\sigma, \varepsilon)$ then the SW structure is continuous and asymptotic in the both sides of the SW as it

is in case when $\sigma \geq \sigma_{**}(\varepsilon)$. For $D_{*1}(\sigma,\varepsilon) < D < D_{*2}(\sigma,\varepsilon)$ structures with IS and asymptotic harbinger are realized. In case of 'switching' when $D = D_{*1}(\sigma,\varepsilon)$ or $D = D_{*2}(\sigma,\varepsilon)$ there is no IS but asymptotic structure takes place only in front of the SW.

The work is carried out at support of RFBR (08-01-00178), State Program of LSSS (SS-3876.2008.1) and AVCPRNPVSh (2.1.1/200).

ATTAINMENT OF EXTREME TEMPERATURES AND DENSITIES IN COMPRESSION BY A SHOCK WAVE AND NON-SELF-SIMILAR CENTERED WAVE AND A COLLAPSE OF AN EMPTY SPHERICAL CAVITY WITH CHANGE OF MEDIUM PROPERTIES BEHIND THE REFLECTED SHOCK WAVE

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Under the fast intense compression in time, much less than transit time of a sound wave through not compressed volume, temperatures and the densities required for realization controlled inertial confinement fusion (ICF) are reached. Attainment of such conditions by purely gas-dynamic means is probable if effects of the shock wave (SW) going to an axis or to the centre of symmetry (SC) and following it non-self-similar centered compression wave (CCW) are combined. At ICF temperatures 10^7-10^8 K every gas is quasi-neutral plasma of electrons and one-atomic ions, and radiation contributes greatly to pressure and internal energy. Therefore such a mix of ions, electrons and radiation differs from PG with $\gamma = 5/3$. But in PG approach effects noted above can be considered by turning from $\gamma = 5/3$ to $1 < \gamma \leq 5/3$. In case radiation prevails, the mixture of gas and radiation behaves like PG with $\gamma = 4/3$. Region $\gamma > 5/3$ is of certain interest. The solution with focusing CCW in SC at the moment of SW arrival there, constructed in [1] for $\gamma \leq 5/3$, proved to be valid only for $\gamma < \gamma_* \approx 1.909$ or 1.870 in cylindrical and spherical cases, respectively. In accordance with [1], focus of compression waves close to SC being placed, the flow almost everywhere indistinguishable from the flow at compression with focusing in SC is realized. The simulations by the method of characteristics are performed using such a replacement for $1 < \gamma \leq 3$ have shown that the dependences on the time of radius of the piston and density on it are close to the power ones.

Physical and mathematical character features of the problem on re-

flection SW from a SC and collapse of an empty spherical cavity [2] are similar. Therewith, high temperatures behind SW, going from SC, are also reached. It may cause change of the phase state of the medium.

The work is carried out at support of RFBR (08-01-00178), State Program LSSS (SS-3876.2008.1) and AVCPRNPVS (2.1.1/200).

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SMALL AND LARGE SCALE MOTION INTERACTION IN WALL TURBULENCE

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Recent trend in the study of turbulence aims in representing the complex, multiscaled, random fields of turbulent motion as organized motion of some elementary structures which are referred as coherent structures or eddies. There is a hope that understanding the kinematics and dynamics of the structures of coherent eddies in fundamental turbulent flows like, for instance, pipe flow or zero pressure boundary layer flow (ZPBL), may constitute a foundation on which to understand more complex wall flows and significantly advance the development of ideas for scaling, manipulating and controlling wall turbulence [1, 2, 3].

In this work, to shed light on possible mechanisms of momentum transfer in constant momentum zones discovered by [4], as well as to provide more thorough evidence for the organization of hairpin packets in wall turbulence, Tomographic PIV measurements of the ZPBL in a water tunnel were carried out at two different Reynolds numbers based on the momentum thickness: 1400 and 4500 respectively. In a measurement domain of 80 x 65 mm (1.2 x 1 boundary layer thickness) in wall-normal and spanwise directions and of 5 mm thickness in streamwise direction several hundred instantaneous u-v-w vector fields were obtained. The accuracy of each vector measurements was better than 1% of the free steam velocity, and the spatial resolution ranged from 16 to 48 viscous wall units, depending on the Reynolds number and the interrogation parameters. Thus, both large scale and small scale motion were captured with sufficient resolution.

The final paper will include a quantitative estimate of the small and large scale motion dynamics and a comparison with DNS data.

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INVESTIGATION OF THE SOOT GROWTH AT ACETYLENE PYROLISIS BEHIND SHOCK WAVES BY LASER-INDUCED INCANDESCENCE AND LASER LIGHT EXTINCTION

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Experimental investigation of soot growth at acetylene pyrolysis is important for development of soot formation models in combustion and carbon nanoparticles synthesis [1, 2]. Experiments were carried out in the shock tube with inner diameter of 50 mm. In this work laser light extinction and laser-induced incandescence (LII) were applied simultaneously for observation of soot volume fraction, and soot particle sizes during their growth at acetylene pyrolysis behind reflected shock waves. The final sizes of soot particles were analyzed by transmission electron microscopy (TEM). Several series of experiments with the mixture of 3 % C_2H_2 diluted in Ar in the temperature range of 1600–2300 K and pressure range of 5.5–8.5 bar were carried out. Soot particles size time profiles during their growth were measured by LII at the fixed temperatures. The temperature dependences of soot yield and final soot particles sizes having bell-shaped form were found and the influence of pressure of the surrounding gas on the maximum of soot yield was investigated. The main kinetic characteristics of soot formation—the induction times and the rate constants of soot growth for soot volume fraction and for soot particle sizes were analyzed. The comparison of the soot particles sizes obtained by LII at the latest stages of their growth with TEM data was carried out. Based on this comparison, the heat release during soot formation and their properties are discussed.

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CHARGING OF CARBON NANOPARTICLES FORMED DURING SHOCK WAVE PYROLYSIS OF CCl_4

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This work continues the study of kinetics of charging of carbon nanoparticles [1], formed at pyrolysis of various carbonaceous substances behind shock waves. Experiments behind the reflected shock waves at the temperatures from 1500 to 3200 K in the mixtures 0–5% CCl_4 in argon were carried out. To take into account the influence of chlorine on kinetics of process of charging of carbon nanoparticles the addition measurements of electrons concentration in argon with the small additive of chlorine were carried out. A considerable decrease of concentration of free electrons, arising at thermal ionization of a natural impurity of sodium, in the presence of carbon nanoparticles is revealed. In a mixture of 5% CCl_4 in argon a final concentration of negatively charged particles in plasma was approximately at 100 times less than in pure argon. Modeling of kinetics of charging of carbon particles taking into account a step-by-step ionization of sodium and subsequent recombination of free electrons and ions on a surface of particles [2] is carried out. Both the experimental and modeling results show that the final concentration of the charged particles in most cases is much higher, than free electrons concentration. This fact means that electrostatic properties of gas-particle mixtures are completely determined by the charged particles.

This work is supported by Russian Academy of Sciences and RFBR.

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FAST RESPONSE TIME PHOTOEMISSION MEASUREMENTS OF TEMPERATURE AT PYROLYSIS OF ETHYLENE BEHIND THE SHOCK WAVE

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The study of processes proceeding in shock tubes requires temperature measurement with a time resolution up to 10^{-6} s. This problem intricate in itself can be aggravated by the fact that it is impossible to determine the emissivity of object when a temperature rate changes up to 10^8 K/s. The both problems are being solved when temperature is measured by the photoemission method [1],[2].

Photoemission method is one of the kinds of pyrometry of spectral distribution, when temperature is found from the partial radiation flux ratio, and is based on the energy photoelectron distribution depending on photon energy.

The photoelectron multiplier (PEM) is used as a radiation detector and at the same time as an analyzer of the photoelectron energy distribution in the photocathode region. The separation of photoelectrons is realized due to retarding field of modulator.

The electron ratio of different energies measured in a constant retarding field and without it characterizes change in photoelectrons distribution. This value is determined as a ratio of levels of modulated and nonmodulated PEM signal $k = U_0/U_{mod}$ and does not vary with light flux within the linearity limits of the light characteristic of the PEM. The temperature is the function of the k ratio.

The method was applied for recording instantaneous temperature measurements with 1-microsecond time resolution of carbon submicron particles formed at pyrolysis of ethylene-argon mixture (5% C_2H_4 - 95%Ar) behind reflected shock wave at temperatures 2100–3100 K. At the beginning of registration the temperature of particles was higher by about 500–800 K than the gas temperature, but it decreased fast and became lower by about 350–500 K than the last one. The temperature rate change is about $(2–4)\cdot10^6$ K/s [3].

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EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF ACOUSTIC FIELD ON THE IGNITION AND FLAME PROPAGATION IN PROPAN–BUTAN–AIR MIX

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This paper concerns of the experimental investigation of acoustic field influence on the ignition and flame propagation through stationary propane-butane-air mix ignited with an electric spark. The experiments were carried out in the shock tube equipped with light sensors and pressure transducers so as to measure flame speed with and without acoustics for different fuel-air equivalence ratio mixes.

The development of the flame front turbulence is caused by different reasons: hydrodynamic influences or collisions of propagating flame with obstacles. It is well known that flame is liable to acoustic influence [1] causes acceleration of developed flame [2]. Flame front turbulization causes gas mixing and flame surface increase that results in diffusion and heat conduction intensification and eventually leads to deflagration to detonation transition [3]. The shorter the sound wavelength the greater the effect of acoustic influence [4].

However in case of small flame area the mixing and heat transfer increase shifts the balance between heat release due to chemical reactions and heat outflow into cold gas. Due to this the heat outflow exceeds heat release and the temperature of the reacting gas falls [4]. This could possibly leads to quenching the reaction. Such a processes are possible only at initial stage of combustion—ignition—when the reaction area is small and the heat did not begin to release yet.

During the experiments the dependence between flame speed and acoustic field presence was obtained. This effect occurs to be strongly depends on the ignition spark energy.

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EXPERIMENTAL INVESTIGATION OF HYDROGEN IGNITION AT THE DISCHARGE INTO CHANNEL FILLED WITH AIR

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Last years hydrogen is concerning as a prospective environment-friendly fuel. For the safe utilization of hydrogen it is necessary to know conditions for the ignition of hydrogen leaks. Investigation of hydrogen ignition at the discharge into channels of different geometry is essential task of hydrogen safety. At different experiments, delay times of hydrogen ignition may vary on the order of value at the same temperature, also there is the difference from calculated values [1]. Diffusion mechanism of hydrogen ignition is of special interest because it doesn't require preliminary mixing.

Investigation of hydrogen self-ignition at the release through pressure relief devices (PRD) is of practical interest. A pressure relief device (PRD) is a safety device that protects against failure of a pressure containment system by releasing some or all of the gaseous or liquid contents [2]. The rate of release has to be fast enough to prevent a failure of the containment system. For a full container in a hydrogen vehicle the release can last up to 5 minutes.

In the paper, self-ignition of high-pressure hydrogen releases into model of PRD is investigated experimentally. Dependences of hydrogen diffusion ignition delay time on temperatures behind the reflected shock waves are presented in the exponential form. Also in this paper there is a comparison between the data obtained, results for jet injection of hydrogen into oxidizer by [3] and for ignition of H_2+O_2 mixture by weak shock wave [4]. In this paper suggested an explanation of divergences in different experiments.

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THE EFFECT OF BURST DISK OPENING ON COMBUSTIBLE MIXTURE FORMATION PRECEEDING HYDROGEN SPONTANEOUS IGNITION

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It is well known that release of compressed hydrogen into atmospheric air can be spontaneously ignited even for low hydrogen pressures. Up to date little research has been devoted to studying the effect of the burst disk rupture process on the formation of combustible mixture and subsequently on the spontaneous ignition of hydrogen. Recently the experimental investigation of spontaneous ignition was reported in [1]. In current work, the burst-disk rupture process is modeled using University of Ulster LES model and the effect of mixing is investigated. The paper will compare the process of combustible mixture formation in the pressure relief device when the burst disk is opening in time versus instant opening.

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EXPERIMENTAL INVESTIGATION INFLUENCE OF DIAPHRAGM RUPTURE RATE ON SPONTANEOUS IGNITION OF HYDROGEN

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In present work self-ignition of hydrogen discharged into 18 mm diameter circle channel was investigated. Required condition for hydrogen self-ignition is to maintain the high temperature for a time long enough for hydroden and air to mix on the contact surface and inflammation to take place. Hydrogen self-ignition occurs owing to the formation of a shock wave in front of a high-pressure hydrogen gas propagating in the tube. Temperature increase, as a result of this shock wave, leads to the ignition of hydrogen-air mixture formed on contact surface.

The conditions in the shock wave strongly depends on diaphragm rupture rate[1]. That was mesured in the present work. Original optical technique was used for measuring diaphragm rupture rate. Conditions for hydrogen ignition was experimentally defined in dependance of diaphragm rupture rate. The experiments were carried out with different pressures up to 150 atm in high pressure chamber.

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INVESTIGATIONS OF COMBUSTION AND EXPLOSION OF HYDROGEN-AIR MIXTURES IN THE LARGE SPHERICAL VOLUMES

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An installation is made for study of evolution of a spherical flame in gas mixture with a volume of 7 to 30 m^3 as well as for investigations of

possibility of regulation of combustion and explosion of gas mixtures by small addition of chemically active substance components. The investigated gas mixture is contained in a spherical volume bounded by a thin rubber envelope. The mixture is initiated in the center of sphere. A special measuring bar is located in the reaction volume for realization of gas mixture initiation, for measuring of parameters and velocities of propagation of blast waves and flame front. The measuring bar is a long (1.5 m) rectangular box with outer cross section 80x60 mm. One of the wide sides is flat. The opposite side is inclined to it; together form a wedge with vertex angle of 15°and wedge spike is directed in the center of sphere. The other bar end is connected with sleeve on which the rubber envelope neck is mounted. The cables from sensors and from blast line are brought out of the reaction volume through the openings in the sleeve. There are 4 pairs of sensors in the wide flap side: impulse pressure sensors (PCB Piezotronics, USA) for registration of propagation of blast waves and photodiodes or ionization sensors for registration of flame front moving. The experiments are performed on study of various regimes of hydrogen-air mixtures combustion.

FLAME EVOLUTION WITHIN CLOSED VOLUMES

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Combustion gasdynamics within closed volumes studying is a basis for the optimum fuel combustion regimes design. This optimality is necessary when engine combustion chamber or other energy-producing technical system is elaborating. It defines permanent interest in gaseous combustion within channels and tubes. A number of studies gave a sufficiently detailed numerical analysis of non-linear combustion modes evolving within opened and semi-opened channels. The results allowed to explain fundamental trends of non-steady transient combustion regimes—acceleration and transition to detonation [1]. However flame dynamics within closed volumes (channels) is determined by much more complex combination of physical processes. This issue is less reported in contemporary literature. Equally with intrinsic Darrieus-Landau (DL) instability flame front is affected by acoustic waves generated by propagating flame itself and repeatedly reflected from the channel walls [2]. In this case flame propagates in conditions of upwind flows and permanently growing pressure due to energy release within closed volume. Combined influence of DL-instability

and acoustic perturbations creates sufficiently complex evolution of the flame front propagating through the channel.

This paper numerically examines a flame propagation process within closed channel filled with hydrogen combustible mixture. Calculations were based on phys-mathematical model accounting convective transport, heat conductivity, multicomponent diffusivity and energy release due to chemical reactions [1]. Transport coefficients and equations of state for multicomponent combustible mixture and combustion products were calculated according to real mixture parameters. Hydrogen oxidation kinetics were described by proved reduced scheme of nine reactions.

Numerically obtained results agree qualitatively with experimental data. It is shown that flame interaction with acoustic waves and weak shocks generated within volume causes flame front oscillations growth that in turn results in flame speed increase. The peak speed values are observed in the vicinity of the walls and can achieve values of tens and hundreds of laminar speeds. These oscillations increases with channel width. Theoretical estimations of averaged flame speed within closed channel coincides with one-dimensional numerical results when flame front is approximately unperturbed. In real case geometrical factors considerably define instabilities rates, their stabilization or enhancement under acoustic wave influence. Numerical experiments show qualitative pattern of flame propagation and quantitative parameters of the process to be sufficiently dependent on thermodynamical parameters and especially on chemical kinetics of real combustible mixtures.

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FLAME IN CHANNEL PROPAGATION REGIMES: MIXTURE CHEMISTRY AND HEAT OUTFLOW FACTORS

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The paper examines a fundamental problem concerning flame propagation through semi-opened channel filled with combustible gaseous mixture. The aim of such investigation is to understand mechanisms and to

propose methods of non-stationary combustion regimes control. In the paper an accelerating flame is assumed to be the main phenomena to be examined. One of the basic mechanisms responsible for flame acceleration is a deformation of the flame due to the hydrodynamic instability of the flame front—Darrieus-Landau instability (DLI) [1]. Most vividly DLI is observed in the flames that propagate in channels with smooth walls [2]. Flame instability evolution and corresponding acceleration are determined by numerous inner and outer factors. However the leading roles belong to flame interaction with non-uniform gas flow and combustion products cooling. It was signed as early as 1940-ies [3], however non-steady combustion gasdynamic modeling became accessible not long ago (since powerful computational resources appeared). To achieve comprehensive examination of such complex process, that in addition is stiff dependent on initial conditions (mixture composition), one has to use numerical approaches based on detailed mathematical models. In this paper we used full gasdynamic model of viscous heat-conductive compressible multicomponent mixture of hydrogen with oxygen or with air. The equations of state for real multicomponent mixture and detailed chemical kinetics scheme of nine equations were used.

Flame and nearby flow dynamic analysis allowed to determine four fundamental regimes of flame propagation: planar flame, curved stationary flame, accelerating concave flame and accelerating tulip flame. The basic parameters defining flame shape and corresponding propagation regime are: mixture chemical composition, channel geometry (channel width), accounting of flow interaction with viscous boundary layer and accounting of heat outflow through channel side walls. Thus, for example, the most unstable regime of accelerating tulip flame takes place in near-stoichiometric hydrogen-oxygen mixture. Deviation out from this composition or even oxygen replacement by the air cause process stabilization and shaping of nearly stable concave flame. The main obtained result is detailed description of relative affects of hydrodynamical and chemical factors. It allows to extract leading factors features and roles in combustion evolution within channels. All the numerical results are verified utilizing experimantal and theoretical criterions [3].

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THE STATISTICAL CORRELATED PARAMETERS OF AXIALLY TURBULIZED MEDIUM INSIDE COMBUSTION CHAMBER OF SPARK-IGNITION EGINE

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Axially-symmetrical turbulence being natural generalization of homogeneous isotropic case are progressing in problems with one detailed direction, as for instance flow into compression chamber of piston engine. Experimental and theoretical investigations have started at the middle of last century. And its are being high continued to present day [1], [2], [3].

The numerical simulation results of air-ethanol gas mixture dynamic into combustion chamber of piston engine have been introduced in this work. For numerical simulation the two-dimensional model of combustion of ethanolair mixture was used. The gas dynamic transport of viscous gas, oxidation kinetics of ethanol, multicomponent diffusion and heat conduction [4] were included to this model. For multicomponent mixture and combustion products the equations of state for real gases [5] were used. Instead of direct calculations of turbulent pulsations the series of the similar computations were carried out. They distinct with weak perturbation of initial conditions. Here the instantaneous speed distinct from ensemble-averaged speed distribution were used as turbulence pulsations. The statistical properties of turbulized medium induced by piston movement were described in terms of integral correlated scales of speed distribution. The effect of piston placement and speed to correlated parameters was considered. Variations of correlated characteristics under ignition and during combustion of gas mixture were investigated. The qualitative conformity (quantitative for some parameters) of computational modeling results and results of physical measurements [3] was obtained.

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THE SIMPLE MODEL FOR DIFFERENT COMPOSITION EXPLOSIVE CHARGES TEMPERATURE DYNAMIC UNDER HEATING ANALYSIS

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The goal of this work is the explosive charges behavior under exterior heating research. For the decomposition peculiarity of different composition explosive charges research the heat conduction and heat generation equations for one-dimensional case of reaction proceeds with a effective value of heat of reaction and thermokinetic parameters has been used. The dependence of specific heat capacity from temperature is taken in form, what allowed to take into account the temperature and the heat of fusion. Commonly in similar cases the solution of this equation received with thermokinetic parameters for one-stage decomposition processes of homogeneous explosive charges is used.

In this paper we presents two models for the effective value of heat of reaction and rate decomposition calculations for two types of charges. The first model is suppose that explosive charge is consists from a mixture of two individual components, decomposes with deferent values of heat of reaction and thermokinetic parameters. The temperature of two mixture components are suppose equal and interaction between reaction productions of components is consider absent. The heat conduction of the mixture components is determined with equation by Odelevskiy. The second model is consider that explosive charge is consists from a homogeneous explosive, witch has a explicit two stage decomposition reaction. The first stage with its own values of heat of reaction and thermokinetic parameters is descried the conversion of the initial substance in intermediate productions. The second stage also with its own values of heat of reaction and thermokinetic parameters is descried the conversion of the intermediate productions in final productions. In the model we supposed that each calculation unit cell has initial substance, intermediate products and final products. The temperature of three components in each calculation unit cell are considered equal for equal time.

ROLE OF CONDENSATION ENERGY IN ACETYLENE DETONATION

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Formation of the detonation waves of condensation of carbon nanoparticles at self-decomposition C_2H_2, initiated by a shock wave, was experimentally observed. The steady detonation-like wave of self-decomposition of acetylene was initiated by a shock wave at the pressures about 30 bar. The basic kinetic characteristics of process of pyrolysis of acetylene and following growth of nanoparticles—induction time and a rate constant of particle formation, are determined. An interconnection of various stages of process with a heat release of condensation is analyzed. It is shown that induction time of particle formation is not accompanied by a noticeable heat release. The following stage of carbon nanoparticle formation, accompanied by an essential heat release, proceeds extremely fast in regime so-called "explosive condensation". The analysis of the obtained data on kinetics of particle formation has shown that the bottleneck of process, determining the possibility of formation of a detonation wave of condensation in C_2H_2 is the secondary reactions of growth of large poly-hydrocarbon molecules. The increase in pressure leads to narrowing of this zone and collapse of whole process to a detonation wave of condensation.

TREATMENT OF ICCD-CAMERA RECORDS ON DEVELOPMENT OF DETONATION WAVE OF CONDENSATION

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Recently the first experimental observation of detonation wave driven by the energy of condensation of supersaturated carbon vapor has been reported [1]. Carbon vapor was formed behind the shock wave by the fast decomposition of unstable carbon suboxide C_3O_2. The following process of explosive condensation, accompanied by the essential heat release led to amplification of a shock wave and its transition to a detonation wave. In this work the process of formation of detonation wave of condensation was investigated using ICCD-camera ("Streak Star-II", LaVision GMbH) records of shock wave propagation. Measurements were performed in a

70 mm inner diameter shock tube through rectangular 5 mm $\times$ 160 mm sapphire windows. Experiments have shown that development of a detonation wave takes place in a distance of 50 $\div$ 100 mm from the tube end. This process is accompanied by the acceleration of a shock wave from about 1000 m/s up to 1500 m/s and appearance of the sharp pressure peaks up to 200% higher the values registered behind the initial shock wave. ICCD-camera records of distance-time resolved radiation intensity presented the bright pictures of formation behind the shock wave the secondary wave of condensation, moving much faster than the shock wave. The following combining of these two waves resulted in formation of a detonation wave. Computer treatment of obtained records provided the quantitative information about the behavior of the main physical parameters during the process of development of detonation wave of condensation.

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ABOUT PRINCIPLES CALCULATION CHARACTERISTIC OF CONDENSE AND GASEOUS SYSTEMS

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In this work we investigated differences and analogys process of detonation solid and gaseous systems. Calculations of detonation parameters had been devoted considerable quantity works. Legacy thermodynamical methods of similar calculations founded hydrodynamic of equation for detonation velocity. In this work we investigated appropriateness parameters of detonation from velocity of sound solid and gaseous systems. In this paper have been introduced calculations of detonation parameters gaseous systems on basis of generalized Voskoboynikov's shock adiabat.

DETONATION FORMATION IN FLOW OF METHANE-AIR MIXTURE

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Possibility of deflagration-to-detonation transition in flow of methane-air mixture was investigated experimentally in a narrow shock tube $D/\lambda = 0.3$, where D – internal diameter of the tube, λ – detonation cell width.

Stoichiometric mixture of methane with air was created in the tube directly. There to a synchronous separate injection of air and methane was used. Velocity of the mixture was 35 m/s. Initiation of deflagration was accomplished by an electrical discharge. Energy release in the gap was a function of a capacitor energy. The last was changed form 10 to 300 J. At the same time the energy for direct initiation of detonation was 10–100 MJ [1].

Required acceleration of a flame front was provided by turbulizing elements. Ring obstacles and extended chamber were used not only for turbulization of the flow but for additional compression of the flame under multi reflection of weak shock waves before the flame. Definite displacement of a set of these obstacles can sufficiently reduce the deflagration-to-detonation distance [2]. The influence of extended chambers on detonation formation was investigated in detail in [3]. In addition to turbulizing elements in the tube preliminary turbulence because of the flow existed.

Optimal dimensions and positions of the ring obstacles along the axis of the tube were obtained at which maximum velocity of the flame front 1300 m/s was observed.

Initial conditions for mixing was obtain at which strong retonation wave with parameters of Chapmen-Jouget detonation was observed.

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INSTABILITY OF DETONATION WAVES IN NITROMETHANE/METHANOL AND FEFO/NITROBENZENE

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The initial rate of decomposition of liquid high explosives (HE) can change by means of inert solvent addition to HE. The experimental investigation of reaction zone structure was conducted for detonation waves in nitromethane/methanol (NM/M) and (bis-(2-fluoro-2,2-dinitroethyl)formal)/ nitrobenzene (FEFO/NB) solutions. The wave profiles were registered by laser interferometer VISAR. The laser beam was reflected from Al foil placed between the charge and water window.

NM with the initial density of 1.14 g/cm^3 and detonation velocity of 6.3 km/s was used. On obtained profiles the velocity peak is registered in reaction zone with 50 ns time duration. The detonation wave instability did not observed for NM, the velocity profiles were recorded during the long time and reproducibility of experimental results was good enough. At 5% of methanol the velocity profile is practically such as one for NM with feebly marked high-frequency oscillations. At methanol concentration increase up to 10% oscillations amplitude rises. In solutions with 20% methanol the velocity disturbances are so considerable, that intensity of reflected laser beam decreases up to zero at the moment of shock wave coming on the 7 microns Al foil-water window boundary. The critical methanol concentration was equal to 35%.

FEFO with 1.60 g/cm^3 initial density and detonation velocity of 7.5 km/s was used. Measured velocity profiles both in chemical reaction zone and in unloading wave is strongly oscillating with typical oscillations amplitude about 50 m/s. It means that detonation front is unstable and heterogeneities size is comparable with the foil thickness (7 microns). Averaged velocity profile corresponds to ZND theory with the reaction time of 350 ns. At low NB concentrations (10–20%) stabilization of front is observed. Perhaps such unusual character of change of reaction zone structure is caused by partial reaction of HE directly in shock wave front in a pure FEFO. When the NB concentration increases up to 30% high-frequency oscillations in particle velocity profiles appear again. The critical NB concentration in FEFO/NB solution is equal to 45%.

DEVELOPMENT OF APPROACH AND TECHNIQUE FOR INVESTIGATION OF IGNITION NEARBY LIMITS

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The exact prediction of chain reaction initiation behind shock waves nearby limits is a quite difficult task up to now. The laboratory technique for such kind of investigations is under the development currently. At least two problems should be mentioned for example. First, the so called "negative temperature coefficient" in cold ignition, described in [1]. Second, the detonation threshold shift caused by a small admixture of Xe atoms in detonative mixtures [2] and time delay reduction of self ignition of combustible gas mixtures after the replacement of relatively heavy carrying gas by the lighter one [3]. Objective reason for difficulties it is caused by the increasing influence of different types of instabilities nearby thresholds of ignition and detonation and consequent reason for the inaccuracy of rate constants measurements. The use of measurements carried out far off the threshold can not totally improve the situation until all elementary stages of chain initiation are known exactly. In other words, the rate constants extracted from the experimental measurements are always attributed to any hypothetical reaction mechanism. But even $H_2 + O_2$ mixture ignition detailed mechanism is under discussion up to now. The approach for clear recognizing the influence of nonequilibrium processes in shock wave front on the chemical kinetic behind the front was elaborated and applied in this work.

The principal ideas of experimental approach as well as their technical realization implemented to the problem of investigation of ignition nearby limits and first results, are represented in the work.

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SPECIFIC MECHANISMS OF INFLUENCE OF HIGH PRESSURE ON RATES OF MONOMOLECULAR REACTIONS

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A general mechanism of influence of high pressure on rates of monomolecular reactions is connected with change of a "free volume" of substances with the change of pressure. It performs both in liquid, solid, and gaseous states and does not depend on specific features of structures of substances. According to the "free-volume" mechanism, the high pressure brakes chemical reaction. At the same time, presence of specific features of structures of molecules can lead to the occurrence of specific mechanisms of influence of high pressure on rates of chemical reactions. In the present work, deformational, polarizing and conformational mechanisms are considered. If the initial molecule is deformed on reaction co-ordinate under the influence of pressure, it leads to decrease in activation energy on the value of elastic energy of deformation of a molecule. Experimentally it appears as square-law dependence of logarithm of the rate constant of the reaction on pressure. The deformational mechanism causes increase in speed of a chemical reaction with increase in pressure. Molecules of energetic materials, products of their degradation and activated complexes, are as a rule polar particles. Under influence of their electric fields, an electric polarization of environmental molecules takes place. Dependence of dielectric polarization on pressure leads to the dependence of rates of chemical reactions on pressure. Besides, it is necessary to consider the dependence of dielectric polarization on rates of processes. For activated complexes it is necessary to apply only to the electronic polarization, and for long-living particles both electronic and orientational polarization should be taken into consideration. In the processes of monomolecular thermal degradation of energetic materials, the electric phenomena lead to acceleration of chemical reactions, and values of these effects are as a rule of much more braking influence of a high pressure according to the "free-volume" mechanism. In case if the substance can exist in forms of several conformers, for example RDX and HMX, the change of properties of different conformers under the influence of pressure, and mainly the change of ratio of concentrations of conformers depending upon pressure, can lead to a complicated dependence of rates of monomolecular reactions of their thermodecomposition on pressure. Probably, unusual dependence of rates

of thermodecomposition of RDX and HMX on pressure is caused by the conformational mechanism of the reaction.

ENHANCEMENT OF PULSE DETONATION ENGINE WITH EJECTOR

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The possibility of using of an ejector for increase of a thrust of a pulse detonation engine and influence of geometrical parameters of the ejector were investigated by experimentally and numerically.

The fact that the increase in the thrust with using of the ejector is in certain cases of the stationary regime possible are shown in [1]. The same was shown in one-impulse regime[2]. In present work thrust was created due to the periodic combustion of stoichiometric hydrogen-air mixture in the detonation regime. The continuous valueless separate supply of fuel into the combustion chamber and ignition of the obtained mixture by an electrical spark were used. The deflagration to detonation transiton was recorded in this case at a distance of 100 tube diameters in the chamber with diameter 16 mm. At the end of the chamber the ejector was arranged with parameters S_1/S_2=2 (S_1—area fo the nozzle, S_2—area of the chamber) and length 150 mm. The position of ejector relative to exit nozzle was changed.

The numerical calculation showed that the ejection flow was capable to have an effect on the thrust.

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THRUST CHARACTERISTICS OF A PULSE DETONATION ENGINE

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Pulse detonation engines are considered to be a perspective jet systems in aerospace applications. Effects of nozzles of different length and shape on the propultion performance of pulsed detonation engines were given in [1].

Characteristics of model of pulse detonation engine in periodic regime of stoichiometric hydrogen-air mixture combustion were obtained at present work. Specific impulse and thrust dependences on cross section area of a nozzle was received experimentally.

The model of engine consisted of a combustion chamber, which provided continued separate feed of fuel in the chamber and intermixing, nozzle. Detonable mixture was ignited by an electric spark. Deflagration to detonation was achieved at the distance up to 100 tube diameters. Internal diameter of the combustion chamber was 16 mm, and nozzles with diameters from 16mm to 53mm were used.

It was observed that the increase of cross section area of the nozzle brought to increase of thrust and fuel consumption. However, there was an optimal diameter of the nozzle 28 mm (1.8 tube diameters) at which a maximum specific impulse was obtained.

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COMPARISON OF FIRE-HAZARDOUS ZONES IN ACCIDENTAL RELEASES OF COMBUSTIBLE GASES BY RUSSIA'S TECHNIQUES AND DNV METHODS

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Modeling and simulation large scale accidents, including different explosion, is directly connected with modern industry development. Numerical assessment of fire-hazardous zones resulting in accidental releases of combustible gases or volatile liquids vapors in a necessary step in the fire risk analysis. For solving this problem we had used two numerical techniques for hazardous zones calculation. In Russia such calculations should be done using the following management directives:

Method of determining the calculated values of fire risk in industry [1], RD 03-409-01 [2], RD-03-26-2007 [3], STO Gazprom 2-2.3-351-2009 [4]. But there is independent approach. Recently Norwegian DNV (Det Norske Veritas) methods and software pretend to play the role of world-accepted standard. Purpose of this work is to compare calculations results using both techniques. We compared five emergency scenarios:

- Drift of air-fuel mixture clouds - Explosion or combustion of clouds - Fire of spill surface - Fire jet - Fireball

In general it may be noted that there is rather good agreement between the calculations results using DNV methods and recommended Russian's techniques. Disagreements were not exceeding 20%. This coincidence is explained due to the both methods used the similar physical approaches. For example energy release type (detonation of deflagration) depends on the space encumbering. In both models the cloud drift estimation takes into account a possibility of drop-gaseous mixtures formation with effective density more than air one ("heavy gas"). Heat emission calculations use the similar flame surface models. However simulations show difference between calculating air-fuel mixture cloud drift distance (the size of the zone of gas contamination) by means [1] in comparison with [2] and [3].

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EXPERIMENTAL INVESTIGATION OF FEMTOSECOND LASER DRIVEN SHOCK WAVE DYNAMICS IN Al TARGET

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In present paper, femtosecond laser driven shock waves were studied experimentally. The mass velocity and shock velocity were measured. Combination of pump-probe scheme and interferometric microscopy was used to determine displacement of a target backside at the moment when shock wave leaves the target. Experiments were made in the laboratory of JIHT RAS. Femtosecond laser pulses were generated by Ti:Saphire laser system with repetition rate of 1 kHz. Experimental data for Al targets with different thickness (0.35, 0.5, 0.76 and 1.2 μm) were collected in order to better investigate shock waves propagation mechanisms. Phase of complex reflectivity coefficient was registered. Dependence of target surface displacement versus time was determined for Al targets. Using these measurements mass velocity and shock velocity can be calculated easily by calculation using well known relations [1, 2]. In our case corresponding velocities have magnitudes of $u_p = (0.3 \pm 0.05)$ km/sec and $u_{sh} = (8.3 \pm 0.5)$ km/sec, while pressure was found to be $P_{sh} = (0.3 \pm 0.05)$ GPa. Shock wave velocity was previously estimated theoretically [3] and our experimental result is in the good agreement with this theoretical value.

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INVESTIGATION OF TWO-TEMPERATURE RELAXATION IN THIN FOIL ON A GLASS SUBSTRATE INITIATED BY THE ACTION OF ULTRASHORT LASER PULSE

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Under the action of ultrashort laser pulse a metal target transfers into two-temperature warm state with ititial solod state density. It triggers than a chain of hydrodynamic and kinetic processes—melting, expansion, stretching, creation of tensile stress and transition into metastable state. In our case a pulse propagates through a glass substrate and illuminates an aluminum foil deposited on a glass. Several foils with different thicknesses d_f from 350 to 1200 nm have been used. The smallest thickness d_f was taken of the order of the heat penetration depth $d_T = 100$–200 nm in bulk Al. Dynamics of the d_T-layer affects the time dependence $\Delta x_{\rm rear}(t)$ describing motion of a rear side of a foil. The d_T-layer and the rear side of a foil are coupled through acoustic waves propagating between them. We compare numerical and experimental dependencies $\Delta x_{\rm rear}(t)$. The experimental investigations of the dynamics of rear side of foil were made using the pump-probe technique. The comparison of the results of hydrodynamics and molecular dynamics simulation with experimental data allows us shed light on the two-temperature processes occurring inside the heated layer d_T.

ELECTRON COLLISION FREQUENCY AND HEAT CONDUCTIVITY IN METALS UP TO THE ELECTRON TEMPERATURES COMPARED WITH THE FERMI TEMPERATURE

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When ultrashort laser pulse acts onto the metal it creates a two-temperature state within the irradiation absorbtion depth of a metal target. Electron temperature T_e essentially exceeds the ion temperature T_i.

This state of a target matter is kept during some time interval (from several picoseconds to some tens picoseconds depending on the type of a metal). Two-temperature stage of the interaction of a laser irradiation with metals is very important because it is just this stage which is characterized by the energy transfer from electrons to ions with their temperature relaxation. Electron-ion energy relaxation is simultaneously attended by the heat transfer from the surface into the bulk target (mainly through the electron heat conductivity) so that the heated layer of a metal target is formed for the most part during the two-temperature stage. This heated layer of a target, its thickness and state of a matter in it are of importance in the subsequent expansion of a target matter with its hydrodynamic motion, phase transitions and ablation. Dynamics of the energy transfer from electrons to ions, heat propagation into the bulk metal are essentially depend on the corresponding kinetic coefficients. These coefficients are rather well studied for the ordinary matter with moderate electron temperature but are known very bad for the condensed matter state with electrons having temperatures compared with the Fermi temperature. Estimation of such intrinsic characteristics of a condensed matter as the electron-phonon coupling constant for the electron-ion energy exchange G and electron heat conductivity coefficient $\varkappa$ is of first importance in a true evaluation of a heated layer state and consequently in the obtaining the realistic ablation pattern when using the hydrodynamics or molecular dynamics simulation of a matter expansion. We have calculated the electron heat conductivity coefficient in the wide range of the electron temperature including the electron-ion and electron-electron scattering. For the electron-electron collision frequency calculation is made which is applicable in the range of electron temperatures less or comparable to the Fermi temperature as in contrast to the ordinary $\sim T_e^2$ dependence on the electron temperature at low temperatures. The theory is applied to the estimation of the electron heat conductivity coefficient of simple metals with s- and p- conduction electrons.

COMPARATIVE STUDY OF QUANTUM STATISTICAL AND KINETIC MODELS OF PERMITTIVITY OF LASER PRODUCED PLASMAS

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Knowledge on the permittivity ε and effective electronic collision frequency ν_{ef} in plasmas, created at the surface of solid targets under action of intense laser pulses, are necessary for the description of laser energy absorption and optical properties of the heated target. For peak laser intensities $I_L \gtrsim 10^{14}\mathrm{W/cm^2}$, the plasma undergoes a complex evolution from metallic state to the state of strongly coupled plasma or warm dense matter (WDM) and further to the state of weakly coupled plasmas. Subsequently, wide range models for ε and ν_{ef} should be elaborated.

In the region of WDM, i.e., at temperatures of the order of $T \sim 0.1 \div 10^2\mathrm{eV}$ and densities of the order of solid ones, the effects of strong coupling, such as electron correlations, dynamical screening and strong collisions with large-angle scattering should be taken into account for theoretical description of ε and ν_{ef}. For the reaction of the system to laser radiation, this is done within linear response of quantum statistics (QS). Transport coefficients and absorption are expressed by equilibrium correlation functions which are calculated with the help of the Greens functions technique.

Calculations of ε and ν_{ef} by QS theory are compared with results obtained by a wide range semi-empirical model, which is derived on the base of kinetic equation. It contains numerical parameters obtained from comparison of theoretical calculations with experimental results. In the range of weakly coupled plasmas and for optical laser frequencies, good agreement of QS and semi-empirical theories is demonstrated. In the region of WDM, both theories give qualitatively similar behavior of ε as function of density and temperature of a plasma, but quantitatively different numerical values. The reasons for numerical differences are discussed and the consequences for applications are considered.

LASER WAKEFIELD DYNAMICS IN GUIDING STRUCTURES

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The interaction of short, intense laser pulses with plasmas produces large amplitude wakes. The high field amplitude associated with these wake waves can be used to accelerate particles to high energies over very short lengths compared to conventional accelerator technology. The control of the characteristics of the electron beam as it is accelerated is crucial for achieving a usable laser-plasma accelerator unit. It is linked to the control of the accelerating electric field structure over several centimetres in a plasma. Diagnostics providing a detailed knowledge of the field structure and time evolution are therefore important for the progress of accelerator development.

The general approach to the spectrum modifications of the laser pulse interacting with matter is elaborated and used for spectral diagnostics of laser wakefield generation in guiding structures [1]. Analytical predictions of the laser frequency red shift due to the wakefield excited in the capillary waveguide are confirmed by self-consistent modeling results. The role of ionization blue shift, and nonlinear laser pulse and wakefield dynamics on the spectrum modification is analyzed for recent experiments .

The results of last experiments on the of plasma waves excitation over a length of up to 8 centimeters are demonstrated and analyzed using laser guiding of intense laser pulses through hydrogen filled glass capillaries. The plasma waves are diagnosed by spectral analysis of the transmitted laser radiation. The dependence of the spectral red shift, as well as the spectra measured at moderate pressures, is in excellent agreement with simulation results [2]. The longitudinal accelerating field inferred from the simulations is in the range 1–10 GV/m.

This work was supported in part by the Programs on fundamental research of Russian Academy of Sciences and by the Russian Foundation for Basic Research—CNRS PICS program (grant 07-02-92160).

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OPTIMIZATION OF K-ALPHA YIELD FROM THE TARGET COVERED WITH SPHERICAL CLUSTERS IRRADIATED BY FEMTOSECOND LASER PULSE

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We present the model for calculations of characteristic x-ray yield against laser pulse intensity and angle of incidence, taking into account cluster size and laser power absorption by fast electrons. Average energy and number of hot electrons at nonrelativistic intensities were calculated in accordance with analytic Brunel model, applicable if amplitude of electron oscillation in the driving electric field is small in comparison with cluster radius R. Structure of driving electric field normal to the cluster surface was evaluated according to Mie's theory. Driving field depletion was taken into consideration by means of absorption cross section computation.

Almost threefold enhancement of hard x-ray yield in comparison with the case of plain Cu target is demonstrated. There is a maximum in x-ray yield dependence on cluster size in the range of $\rho = k_0 R \approx 1 - -2$, with k_0 being laser wave number. This maximum is determined by decrease of driving field with growth of cluster size for $\rho \gg 1$ and depletion of scattered field for $\rho \lessapprox 1$. Increase of K-alpha yield with rise of hade is the most pronounced for the indicated range of ρ.

This work was supported in part by the program on Fundamental Researches of Russian Academy of Sciences and by Russian Foundation for Basic Research—CNRS PICS program (grant 07-02-92160).

MONOENERGETIC WAKEFIELD ACCELERATION OF ELECTRON BUNCHES

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The progress in laser-plasma accelerators depends substantially on the possibility to provide extended quasi-monoenergetic acceleration of short electron bunches. The inhomogeneity of a comparatively short wavelength

laser wakefield usually tends to increase the energy spread of finite length electron bunches, but at the same time it can lead to the effects of electron bunching in the energy distribution in certain conditions of bunch injection in nonlinear wakefield. The process of trapping and acceleration of a nonmonoenergetic electron bunch of finite length is investigated analytically in terms of a one-dimensional model, and relevant three-dimensional simulations are performed. The bunch is assumed to be injected into the region ahead of the laser pulse generating moderately nonlinear wakefield, the injection energy being such that the electron velocities are lower than the wave phase velocity. The study is aimed at clarifying how the spatial and energy parameters of the injected bunch in the trapping and acceleration stages depend on its initial length and energy spread. The injection conditions are discussed under which the electrons of a nonmonoenergetic bunch can be accelerated to high energies and the energy spread of the bunch electrons after acceleration is weakly sensitive to their initial energy spread.

GENERATION OF QUASISTATIC MAGNETIC FIELDS IN THE INTERACTION OF COUNTERPROPAGATING LASER PULSES IN A UNDERDENSE PLASMAS

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The effect of generation of quasistatic magnetic fields in the interaction of counterpropagating moderate intensity laser pulses in a low-density plasma is considered. The mechanism for generating quasistatic magnetic fields is associated with the growth of small-scale plasma waves excited in the region of overlap of the pulses under the action of the averaged ponderomotive forces. It has been shown that, in the interaction of laser pulses of different durations, long-lived magnetic fields with nonzero azimuthal components are generated. We have investigated the spatial structure of the magnetic fields and have shown that the spatial scales on which the field decreases from its maximum strength to zero are comparable to the sizes of the region where the small-scale plasma waves are localized. It has also been shown that the magnetic field generated in the interaction between two pulses is substantially stronger than that generated in the wake wave of a single laser pulse. In addition, we have investigated the structure of the magnetic field lines, as well as of the lines of the total constant electric current.

INVESTIGATION OF HARD X-RAY GENERATION FROM SOLID TARGET IRRADIATED WITH fs-LASER PULSES

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In this paper we present results of experiments on hard x-ray generation in the MeV range by interaction intense femtosecond laser pulses with solid target.

The experiments were performed with the multiterawatt femtosecond Ti:sapphire laser system at the JIHT RAS that delivers 40-fs, 250-mJ pulses at a repetition rate of 10 Hz at at a central wavelength of 800 nm.

In the experiments we used massive target made of copper. Focused laser intensity on the target surface is varied from 10^{17} to 10^{18} W/cm^2. The MeV bremsstrahlung yield in an energy range from 500 keV to 5 MeV was measured using scintillation detector SSDI37 based on the FEU-97 PMT. In the experiments we found a nanosecond prepulse effect on the yield of hard X-rays depending on the angle of observation.

EVALUATION OF SASE XFEL BEAM PARAMETERS USING HIGH-RESOLUTION DIFFRACTION IMAGES OBTAINED ON LiF CRYSTALS

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High resolution images of coherent X-ray beam were measured during study of SASE FEL emission at Spring-8 synchrotron radiation facility. In these experiments far field 2D source intensity distribution was registered on LiF crystal detector together with local near field diffraction images of 1D or 2D regular structures, which disturbed a small fraction of the incident X-ray wavefield. Measured intensity is connected with X-ray beam parameters. For instance far field intensity distribution is closely related to the FEL generation process. At the same time local diffraction images of very small objects (wires) uniformly distributed across the wavefront does not depend on spatial coherence function of the beam, and thus can be used for the estimation of harmonic intensities in the spectum of FEL X-ray emission.

INFLUNCE OF THE INTERACTION ANGLE OF THE LASER RADIATION ON THE CHARACTERISTICS OF THE LASER-PRODUCED PLASMA IONS

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It is known that laser source of ions is capable to provide highest intensity of multi-charged ions to inject into many elements of various accelerators [1]. For the practical applications one should be able to extend the ions impulse keeping the intensity and the change of ions unchanged. Several methods have been proposed [2] for the extension of the intensity of laser-plasma ions.

In this work we investigate the influence of the interaction angle of the laser radiation on the parameters of laser-produced plasma ions. The effect of the interaction angle of the laser radiation was also studied in [2]. However, the results in the present work considerably differ from the ones in [2] which might be due to the initial experimental conditions. We have studied the effect of the interaction angle of the laser radiation on the formation process of the multi-charged plasma ions systematically at the same initial conditions. Experiments were conducted in the mass-spectrometer with the intensity of the laser radiation $q = 10^8$–10^{12} W/cm^2 (the details of the experimental setup is given in [2]).

Analysis of the experimental result shows that the interaction angle is one of the key parameters control the efficiency of physical processes during the absorption of the laser radiation, ionization and expansion of plasma beams; in order to increase the maximal charge and energy of ions a special condition is necessary at which resonance absorption of the heating electromagnetic radiation by the plasma takes places.

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TEMPERATURE DYNAMICS OF METALS UNDER MILLISECOND LASER IRRADIATION

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Temperature dynamics of laser heating the surface of thin (30–400 μm) metal samples (W, Mo, Ta and Ti) has been studied. The measurements of temperature were carried our by photoemission method [1]. According to Wien law, temperature increase shifts the maximum of spectral distribution of radiation to the range of short wavelengths. So, it is possible to determine the temperature by analyzing the energy distribution of photoelectrons emitted under target irradiation.Photoelectron modulation at frequencies exceeding 1 MHz is very feasible. This allows measurements of fast phenomena and target emissivity has weak affect on the results of measurements [2]. It permits to measure a temperature when temperature variation is 10^8 K/s. A theoretical procedural error of the method is 0.3% but the accuracy of signal measurements is 5%.

The samples were irradiated by a Nd:glass laser pulses of about 1 ms duration with energy density from 15 up to 120 J/cm^2.The region of measured temperature was 1200. . . 3000 K. The experimental were carried out at high reproducibility of the laser parameters and measurements results. Temperature dynamics was investigated for different energy densities for each sample. Time delays between temperature maximums of the irradiated surface and back side of samples were obtained. The measurements were carried out in air and in argon environment. Time resolution of 1 μs showed that device measures temperature synchronously with about 10 microsecond periodic slight fluctuations in laser radiation intensity. For comparison, temperature dynamics of laser heating Si and C samples also has been carried out.

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LASER-STIMULATED THERMODIFFUSION PROCESSES IN Ge/Si HETEROSTRUCTURES WITH QUANTUM DOTS

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Recently, the experimental studies of laser modification of Ge/Si heterostructures with quantum dots (QD) had been carried out with the use of optical pyrometry and Raman spectroscopy methods. It was found that nanosecond laser processing results in a narrower distribution of QD over their sizes. The suggestion has been made that this effect is due to a local melting of QD. In this work we submit the results of numerical simulation of thermodiffusion processes in Ge/Si heterostructures with quantum dots under nanosecond laser pulse irradiation. Two types of heterostructures (with one layer of quantum dots (QD) and with vertically stacked quantum dots (VSQD) irradiated by ruby laser pulses with 80 ns (FWHM) duration were simulated.

Two approache based on Stephan and kinetic models [1] are used for simulation of laser heating and melting of heterostructures. The dependences of optical and thermo physical parameters on temperature and phase state are taking into account both for the matrix and for the quantum dots. The time dependences of the temperature at the surface of the structure and also at the depth of QD layer location were calculated. The threshold laser energy densities for the onset of QD melting and Si melting were found. The peak surface and QD layer temperatures as a function of irradiation energy density were obtained too. The calculation results obtained by use of both models are compared and the advantages and lacks of each model are discussed.

Diffusion phenomena (mass transfer) results in the change of QD composition and hence they influence on the QD melting temperature. The data about change of QD composition during laser processing and time of QD dilution in Si matrix for different regime of irradiation are analyzed. Calculated results are in a reasonable agreement with surface temperature measured by using optical pyrometry and with the experimental data on the change of QD compositions which were obtained from Raman spectroscopy investigation of as-grown and laser modified structures.

This work was particularly supported by RFFI (No. 08-02-00121-a), by BRFFI (No. F09SO-015) and by Program of Nanotechnology Department

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NANOSECOND LASER ABLATION OF SILICON IN AMBIENT GAS AND NANOCLUSTERS FORMATION

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Nanosecond laser ablation is one of the most promising ways of semiconductor nanocluster formation [1]. Commonly it is supposed that coalescence is of minor importance in nanoparticle synthesis and nucleation stage mainly determines distribution of clusters over sizes. It means that the cluster size is defined by the vapor supercooling. In the present report spatio-temporal dependences of thermodynamic parameters and supercooling of the vapor ejected from the laser irradiated surface have been numerically explored. Thermal processes in target under nanosecond laser single pulse irradiation were simulated with the use of heat conduction equation taking into account the formation of melting layer at the surface. The system of gas dynamics one-dimensional equations describing the spreading of evaporation products were numerically calculated by use of two-step Lax-Wendroff scheme. The boundary condition for heat conduction equation is specifying by the condition of the energy balance at the interface between condensed and gas phases. Gas dynamics boundary conditions take into account jumps of temperature and other hydrodynamic parameters in Knudsen layer and gas condensation at the target surface. The developed algorithm considers ionization of gas phase and screening of laser radiation due to absorption of electromagnetic radiation in plasma formed. The coefficient of light absorption in gas due to photoionization and bremsstrahlung effect was determined on the basis of Kramers-Unsöld formular. Calculations were performed for silicon irradiated by a single ruby laser pulses with FWHM of 80 ns and fluence in the range of 5–10 J/cm^2 in vacuum and in argon atmosphere with pressure in the range from 0.001 up to 1 atm. From the calculations it follows that supercooling achieves pick value near the outside boundary of Knudsen layer and its value slightly increases with increasing the ambient gas preasure. Calculated results are in a reasonable agreement with the surface temperature

measured by optical pyrometry. The conditions of nanoparticles formation due to condensation in gas phase were discussed.

This work was particularly supported by RFFI (No. 08-02-90024, 09-02-00888), by BRFFI (No. F08R-174).

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INVESTIGATION OF IRON NANOPARTICLE GROWTH AT PULSE Kr-F EXCIMER LASER PHOTOLYSIS OF $Fe(CO)_5$ BY LASER-INDUCED INCANDESCENCE AND LASER LIGHT EXTINCTION

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Transition metal nanoparticles are extensively studied due to their potential applications as the catalysts in many chemical processes, carbon nanotube synthesis, and the fillers for magnetic fluids and others. UV-photolysis of $Fe(CO)_5$ is an efficient way for synthesis of iron nanoparticles [1]. In the previous study [2] iron nanoparticles were synthesized using the excimer Ar-F laser (193 nm). In this work the excimer Kr-F laser (248 nm) was used for nanoparticles synthesis. Adaptation of longer wavelength for $Fe(CO)_5$ photolysis allows to decrease the requirements for emission source and to avoid an appearance of carbon admixtures inside nanoparticles, which can be generated as a result of photo-dissociation of CO ligands at photon energy higher than 6 eV. The new experimental data of kinetics of iron nanoparticles growth in dependences on the kind and pressure of surrounding gases (He, Ar, Xe) and initial concentration of $Fe(CO)_5$ were obtained and analyzed. The measurements of iron nanoparticle volume fraction were performed using laser light extinction method on a wavelength 633 nm. The particles sizes time behavior during their formation process was measured by laser-induced incandescense (LII). Final iron particle sizes and their structure were analyzed by transmission electron microscopy (TEM). The process of iron particle formation in investigated conditions could be divided onto three stages: nucleation and fast surface growth of small clusters up to 1 nm (70 atoms) within the time of 1–25 μs; further surface growth and coagulation of clusters up to 2–3 nm and coagulation of large nanoparticles up to 5–12 nm, which were studied by TEM. The iron nanoparticle properties extracted by comparison LII and TEM data are discussed.

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MECHANISM OF ABLATION DAMPING IN FEMTOSECOND DOUBLE PULSE EXPERIMENTS

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In this paper we report the physical reasons of a curious decrease in the crater depth observed for picosecond delays in experiments with femtosecond double pulses [1]. Detailed hydrodynamic modeling shows that the ablation mechanism is damped when the delay between the pulses exceeds the electron-ion relaxation time. In this case, the interaction of the second laser pulse with the expanding target material leads to the formation of the second shock wave which suppress the rarefaction wave created by the first pulse. The evidence of this effect follows from the analysis of pressure and density profiles obtained for different delays between the pulses.

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MDMT HYDRODYNAMICAL CODE AND THE LASER ABLATION SIMULATIONS

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We are developing the multidimensional multitemperature hydrodynamical code suitable for simulations of different process at experiments with high energy density in the matter [1]. Together with the carrying of gas transfer the code can describe such process as electron conduction, radiation processes, the energy exchange between components, and the kinetic of the reactions [2], [3], [4], [5]. The code uses splitting on physical processes on separate time steps. The hydrodynamical part of the

code is based on the Godunov type scheme [6]. We developed the effective Riemann problem solver for the case of the real gas with the different temperatures of its components.

As an example of the code application we consider the problem about the ablated matter expansion under the action of ultrashort laser pulse. Such task in the hydrodynamical formulation should take into account different temperatures of ions and electrons, energy exchange, equation of state of the real gas [7]. This application is useful for our code test. Multidimensional simulations can be interesting for focused beams [10].

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OOPIC PRO POSSIBILITIES FOR VARIOUS HIGH ENERGY DENSITY PROBLEMS

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OOPIC Pro [1, 2] is a parallel object-oriented particle-in cell code for plasma simulations. OOPIC PRO is written in C++, and includes graphical user interface (GUI).

OOPIC Pro models two spatial dimensions in both Cartesian x, y and cylindrical r, z geometry, including all three velocity components, with both electrostatic and electromagnetic models available. All three components of both the electric and the magnetic fields are modeled, but there is no spatial variation along the ignored coordinate. The code includes a fully relativistic model for inertial particles, as well as a Boltzmann model for inertialess electrons.

OOPIC Pro also includes volumetric and surface plasma injection, including thermionic and field emission models. Particle statistics can be

collected at arbitrary surfaces, and field and particle data can be averaged over arbitrary volumes and surfaces. A Monte Carlo collision (MCC) technique [3] allows multiple background gases at arbitrary partial pressures.

In this work the code is applied to a number of test problems, including beam-plasma wake-field acceleration, plasma radiation, interaction of laser radiation with plasma, tunneling ionization etc. Performance capabilities of the code are also tested. The advantages and drawbacks of the code are discussed.

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FEATURES OF LASER DESTRUCTION OF GLASSES AND IONIC CRYSTALS

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The laser radiation of high intensity can result in to destructions of transparent solids.

The analysis of similar phenomena is imperative for transparent solids—glasses, organic dielectrics and crystals. Such mediums are integral members of lasers (active elements, substrate of mirrors), non-linear converters of a laser radiation, systems of haul and formation of a laser beams (prism, lenses etc.).

It is most expedient to section destructions arising in transparent bodies under operating of nanosecond laser impulses, into destructions arising in ideal clean mediums, and destructions conditioned by additives. In these cases the mechanisms of destruction are various. In clean medium it is an optical destruction qualitatively similar to a scintilla (an electron avalanche) in gas; in mediums with additives—destruction, bound with heating of additives at absorption of radiation. According to this approach, distinguish a threshold of an improper laser destruction conditioned by destruction on defects, additives, actuations, and threshold of an own destruction instituted light stability of extreme clean material.

The optical destruction of transparent dielectrics in real conditions is

usually determined by destruction on technological absorptive actuations or self-focusing of laser radiation. The self-focusing results in uncontrolled increase of a power density in an irradiated volume, and the destruction is determined by interplay of a laser field with a matrix of dielectric.

For a light destruction of an inorganic glass and ionic crystals by nanosecond laser impulses such features are fair: relation to pulse duration, higher values of a threshold of light destruction as contrasted to by organic materials, dispersion of values of light strength, higher light strength of a volume as contrasted to by surface, proximity of thresholds of light destruction by nanosecond laser impulses and static voltage destruction.

Light destruction and the phase changes at intensive effects are studied not only in numerous experiments, but also serve object of simulation and different idealized calculations.

The different views on the causes and regularity of a laser destruction in ionic crystals take place. The conventional mechanism of a destruction can be approved only after a cycle of new experimental activities, conjugate with simulation and idealized calculations.

OPTICAL BREAKDOWN OF ALKALI HALIDE CRYSTALS

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The development of laser engineering, in particular, the technology of generation of high-power light fluxes, is slowed by the fact that, under the action of high-intensity laser radiation, optical breakdown-induced irreversible laser radiation, optical breakdown-induced irreversible changes occur in laser optical elements. Interest in the optical breakdown effect in transparent dielectrics is determined primarily by the practical needs of laser technology, since the problems of focusing and transmitting high-power laser pulses cannot be solved without knowledge of the mechanisms of laser damage of dielectrics. Laser damage is also of independent scientific interest as one of the fundamental problems of the physics of the interaction of intense electro-magnetic radiation with matter. This paper proposes a mechanism of optical breakdown of extremely pure solid dielectrics that is associated with a stepwise narrowing of the energy gap, i.e., with The metallization of a dielectric in the intense field of a laser light wave. The metallization theory is considered using the formalism of the electron-density functional. It is shown that the metallization of a di-

electric in the region of its interaction with laser radiation is substantiated mechanism of laser damage of wide-gap dielectrics. Calculations of the radiation pressure produced by high-power laser radiation and the pressure of extreme bulk compression at witch the dielectric energy-gap width becomes zero and which is calculated on the basis of the self-consistent statistical electron theory of ionic crystals have shown that these pressures are of the same order of magnitude.

NANOSTRUCTURED GLASS FILMS LASER ABLATION DESTRUCTION STUDIES

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The nanostructured solid films with 500 nanometers and lesser dimension play the great role in the nanophotonics and other nanooptics technological applications. Such a films laser cutting was based on the laser ablation under power laser pulse on the glass 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 1 up to 50 J/cm2.

Therefore this report goal is the time dynamics of the films laser ablation destruction versus the incident laser radiation intensity and its time irradiating decay dependencies for our experimental conditions. The important problem in this study is the laser plasma plume formation on the target surface [2]. recording procedure. The experimental laser ablation station detail description was given earlier in [1, 4].The YAG: Nd laser radiation with pulse duration of 10 ns and energy up to 0.3 J at 1064 nm wavelength beam was focused by the special objective on the film surface. The laser plasma emission intensity was measured by the minispectrometer in the wavelength range 400...1000 nm synchronized by the laser pulse with the time decay up to 5 μs. The threshold energy density Q_T have been derived from the dependences of breakdown probability P versus laser pulse energy density Q when the probability P is equal to 0.5 as in our earlier work [1, 2]. But the laser ablation process is too complex for the poor description in terms of the thermal process without of plasma formation and its interaction with irradiating laser pulse [3]. And the laser pulse absorption increases in plasma plume due to this absorption was depended from plume flight away process.

The laser plasma integral emission pulse spectral distribution time dy-

namics experimental studies can serve as the additional confirmation of this fact because these spectra were not equivalent to the black body ones. And this plasma integral emission time decay was equal to that of the polymer targets as earlier in [2].

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SIMULATION OF RADIATION DEFECT GENERATION AND EVOLUTION IN CRYSTAL MATERIALS

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The study of the structural damage generation and evolution in materials under irradiation represents a great scientific and practical interest from the point of view of the long-term prediction of the metal and alloys mechanical properties.

The given paper presents the mechanisms of the radiation defect generation and evolution in the crystal lattice under irradiation. Calculations were carried out applying to the vanadium crystallite both with ideal and grain boundary structure. The simulated crystallites had a parallelepiped shape. The symmetric tilt grain boundaries with different energy were chosen for the investigation. Interatomic interactions were described on the base of the Finnis-Sinclair approximation. Used potentials allowed describing with high accuracy many mechanical and physical properties which are very important for the atomic cascade simulations. The periodic boundary conditions in all directions were used at atomic cascade simulations. The number of atoms in the vanadium crystallite varied from 65 000 upto 3 000 000 depending on the primary knocked atom energy. Dynamics of the Frenkel pairs at the different atomic cascade stages was analyzed. Cluster sizes formed by point defects were calculated.

It was shown for the crystallites with grain boundaries that sufficient part of radiation defects including the large size clusters was accumulated inside the grain boundary region. The grain boundary resists the atomic

cascade propagation into the crystal bulk. The number of the radiation defects in the grain boundary region depends on the primary knocked atom remoteness from the boundary as well as its energy. It should be noted that the grain boundary becomes the impassable obstacle on the atomic cascade propagation if the primary knocked atom energy is less than certain threshold value. The obtained results represent the scientific and practical interest from the point view of the material behavior under irradiation.

SHOCK WAVES EXCITED IN WATER BY OPTICAL BREAKDOWN

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The experimental set-up for study of generation processes of shock waves in liquids by means of the optical breakdown within the laser beam with diffraction divergence compensated (Besselian beam) is described. The optical breakdown was realized along an axicon lens focal length when a pump laser (1.06 mkm, 5 J, 6–8 ns) was focused in a water sample. The breakdown phase, shock waves formation and their propagation were monitored using shadow photography technique. An expanded beam of a diagnostic laser as a backlighting source passed through the water, then an image of region under investigation was relayed by lens on photocathode of a intensified charge coupled device (ICCD) comprising a CCD-sensor and a gated image intensifier.

A set of time-resolved shadowgraph pictures with various delays between the laser and the shadowgram was obtained. At the initial stage a nearly continuous channel of small and dense bubbles formed by the pump laser was observed. Each centre of breakdown originated a spherical shock wave. These waves expanded out from bubbles heavily overlapping already not far from an axis and created a cylindrical shock wave.

The work was partially supported by Russian Foundation for Basic Research (Project 08-08-00199).

THE DARRIEUS-LANDAU INSTABILITY IN FAST DEFLAGRATION AND LASER ABLATION

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Main characteristics of the linear Darrieus–Landau instability in the laser ablation flow are investigated. The dispersion relation of the instability is found numerically as a solution to an eigenvalue stability problem taking into account continuous structure of the flow. The results are compared to the classical Darrieus–Landau instability of a usual slow flame. The difference between two cases is due to specific features of laser ablation: high plasma compression and strong temperature dependence of electron thermal conduction. It is demonstrated that the Darrieus–Landau instability in laser ablation is much stronger than in the classical case. Particularly, the maximal growth rate of perturbations in laser ablation is about three times larger than for slow flames. The characteristic length scale of the Darrieus–Landau instability in the ablation flow is comparable to the total distance from the ablation zone to the critical zone of laser light absorption. Possibility of experimental observations of the Darrieus–Landau instability in laser ablation is discussed.

EXCITED STATES OF WARM DENSE MATTER

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There is a number of papers treating WDM produced with fs X-ray lasers (see e.g. [1] and references therein). They call the state of matter produced as even a "new form of plasma" [2]. WDM produced with lasers is most widely discussed. However there are other sources of WDM generation as well. High intense ion beams are considered in [1]. WDM nanochannel is formed at propagation of a fast single ion through condensed matter [3]. Great amount of deposited energy in nanosecond exploding wires is suggested to explain by creation of strongly nonequilibrium solid-state-density plasma [4]. Similarity and diversity of WDM states produced are discussed in this work.

Some important properties of the matter are similar for a short time for all above mentioned methods of WDM production. It is a transient state of non-equilibrium, uniform plasmas. It is quasi-stationary with respect to

bulk electrons There is no reference to nonideality, both ideal and nonideal plasmas can be formed. Lifetime limiting processes are electron-phonon exchange, recombination, collisional electron cooling etc. Plasma formed in WDM retains solid state density and has two temperatures. Electron temperature is about tens eV. Ions remain to be cold and keep original crystallographic positions. However electron band structure and phonon dispersion are changed due to inverse influence of the electron excitation [5, 6]. Redistribution of the electron density after the electron temperature increase can result in the paradoxical hardening of the lattice. The ion cores survive after ionization of outer shells. Their excited state populations are changing. Spectral lines are emitted by the ion cores embedded in electron plasma environment which influences the spectra strongly. The suppression of spectral lines in WDM is discussed. The main differences between different WDM states are discussed.

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STABILITY OF LiF CRYSTAL IN THE WARM DENSE MATTER STATE

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The finite temperature density functional theory approach is deployed for description of the fcc LiF crystal in a two-temperature warm dense matter state with hot electrons and cold lattice that is formed after ultrafast energy deposition. The lattice stability and the interatomic bonding at elevated electronic temperatures are studied. The excitation of the electronic subsystem at temperatures $T_e \sim 3$ eV results in the loss of mechanical stability of the fcc LiF lattice that is manifested as an appearance

of the soft acoustic phonon mode and should probably lead to non-thermal melting. The corresponding redistribution of the electronic density implies that the originally strongly ionic interatomic interaction becomes more of covalent character with the rise of electronic temperature.

ELECTRON-PHONON RELAXATION IN METALS UNDER NONEQUILIBRIUM EXCITATIONS OF THE ELECTRON SUBSYSTEM

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The values of the electron-phonon coupling factor of matter under different temperatures are very important for the treatment of the results obtained in the experiments on very fast energy contribution to the matter. There are different ways to produce such a contribution: femtosecond laser pulse, passing of heavy ions through the matter and others. And in each of these experiments the special state of matter appears in which ions of the crystallic lattice are "cold" and their temperature is about hundreds of K while the electrons are "hot" and their temperature can reach several eVs. This special state of matter is also known as "warm dense matter" [1]. The evolution of such states is determined to a large extent by the rate of the energy exchange between electrons and ions, i.e. by the electron-phonon coupling factor.

In the present work we determine the temperature dependencies of the electron-phonon coupling factor for Al, Ag and W using methods of the density functional theory. The intensity of the electron-phonon interaction can be calculated using the values of the electron and phonon densities of states [2]. The first quantity is calculated using VASP package [3] while the second one is determined with the small displacements method [4]. It is shown that the temperature dependencies of the electron-phonon coupling factor may be described without taking into account of change of the electronic structure and the phonon spectra only for electron temperatures below 1 eV. Under higher temperatures it is observed the lattice hardening. It is significant that for silver and tungsten the electron density of states also changes and the electron-phonon coupling factor increases. It is shown that for these two metals it is necessary to take into account the changes in the electron and phonon densities of states for the electron temperatures above 1–2 eV.

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NUMERICAL MODELING OF EXPERIMENTAL CONDITIONS FOR DETERMINATION OF THE EQUATION OF STATE FOR LOW-DENSITY VOLUME-STRUCTURED MEDIA

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The simulating of the "foam" matter influence on the heterogeneity smoothing in laser interaction with target materials is considered. It's suggested to construct the effective EOS of the "foam" using both theoretical and experimental foundations. The data of laser-wave experiments to clarify the "foam" EOS in the range of $P = 4$–6 Mbar are analysed and simulated using the code DIANA in more wide range of pressures. The obtained "foam" EOS and other results are dicussed.

SOFT X-RAY SOURCE BASED ON TABLE-TOP MINI GENERATOR

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The MINI-generator, a 340 kA peak current, 170 ns risetime,40–50 kV, pulsed power generator with energy storage of 1 kJ, was designed and built at the High Current Electronic Institute (Tomsk, Russia). The generator is 45 cm diameter, 33 cm high and weights 70 kg. The main goal was to design a table-top generator for use with X pinches to create a point source of soft x-ray radiation for radiography of plasma and biological objects. The first experiments with X-pinch loads performed in Lebedev Physical Institute (Moscow, Russia) showed that the MINI-generator has very high efficiency in transformation of a stored energy to radiated energy of an X-pinch hot spots in the range of 1 to 5 μm diameter, depending on the photon energy range.

FEMTOSECOND LASER PLASMA X-RAY SOURCE FOR MICROSTRUCTURE IMAGING UNDER AIR CONDITIONS

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The development of methods and tools for sensitive and inexpensive diagnostics of low-contrast objects and microstructures becomes important aim for the purposes of material science, medicine and high energy density physics. According to these demands X-ray emission and possibility of obtaining radiography images with laser plasma X-ray source operating at atmospheric pressure and room temperature is investigated.

Tabletop Ti:Sapph 40 fs 1 kHz 100 μJ laser and bulk metal targets were used to produce X-ray emission in spectral range of 3–10 keV. The spectra, yield and size of X-ray source were measured under different experimental conditions.

The sufficient yield of characteristic X-ray radiation in K_α and K_β spectral lines of Cu is registered. Laser plasma temperature was determined according to bremsstrahlung spectra analysis. It is concluded X-ray radiation of solid target is caused mainly by fast electrons generation in area of ambient gas breakdown. It is shown hot electrons are generated in breakdown area, and then they make the impact in X-ray generation at solid target surface.

Due to this effect X-ray source of up to 10 keV energy photons are produced effectively even by relatively low laser intensity $< 10^{15}$ W/cm^2. The source was applied for absorption imaging of thin films and low-contrast biological samples in different photon energy range. In the obtained data the features with 5–10 μm thickness as well as internal structure of 500 μm samples are distinguished even for the case of low Z material. The spatial resolution of 25–30 μm is provided. Also, the ability to perform phase enhanced imaging is demonstrated.

The advantages of the proposed method are in short-pulsed backlighting source, spectral range tunability; and sensitivity to weakly-absorbed or micron-thin details. Main feature is in convenient setup of investigated object within air environment. Thus, *in vitro* diagnostics or life samples and production control of thin films becomes possible.

Work was supported in part by RFBR Grant # 09-02-92482-MSCS-

a, Program of fundamental research of RAS Presidium # 27 and CRDF BRHE project # Y5-P-11-02.

DEVELOPMENT OF LASER BASED ION RADIOGRAPHY METHODS APPLIED FOR HIGH ENERGY DENSITY MEASUREMENTS AND MICROSTRUCTURE ANALYSIS

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Present day investigations of high energy density processes initiated by powerful laser pulses are overviewed. It is concluded the further progress in this field demands of upgrade and application of different sensitive diagnostic methods. As we shown in recent experiments on LULI2000 laser in Ecole Polytechnique, the source of both characteristic X-rays and several-MeV protons can be generated by intense picosecond laser pulse in metal foils. The source was successfully applied in investigations and radiography imaging of laboratory astrophysics plasma phenomena. Numerical simulation codes were applied to interpret radiography imaging data and to measure different parameters of plasma structures and internal electromagnetic fields. However for a number of tasks in HED experiments, there is important aim to increase the brightness and penetrability of probe radiation and/or to reduce the demands on initiating laser. It is suggested to apply submicron structure cluster target in order to effectively convert laser pulse energy and generate both ions and X-rays with higher yield and energy. We studied the interaction of J-LITE femtosecond laser in KPSI JAEA with gas cluster targets. The advantages of gas cluster target are in easy creation, fast replacement, absence of debris, and tunability of cluster size and density. Laser pulses providing moderate 10^{17} W/cm^2 radiation intensity were absorbed in supersonic jet of the mixed He and CO_2 gases. By this way the intense isotropic source of multicharged ions with energy above 300 keV and total yield of 10^8 ions per shot was produced. High contrast ion radiography images were obtained to be sensitive to 100 nm change of object thickness. As well, bright isotropic partially coherent source 0.2–10 keV X-ray photons was obtained, that allows to register phase-contrast images of extremely thin objects with 50 nm spatial resolution. It will allow the imaging of low-contrast structures in plasma such

as jets, vortexes, shock waves etc during their propagation in ambient media. The developed source is recommended to be applied in radiography measurements on HED conducted on powerful laser facilities. Work was supported in parts by RAS Presidium programs #12 and #27, CRDF BRHE project #Y5-P-11-02, and RF State contract #02.740.11.0236

HIGH ENERGY PROTON MICROSCOPY AS A DIAGNOSTIC TOOL FOR EXTREME STATES OF MATTER

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Radiographic study of matter using high energy proton beams is the unique experimental technique for investigation of dynamic material properties under extreme conditions of high pressures and strain rates. Facilities for proton radiography have been build in Los Alamos National Laboratory (LANL) in USA, Institute for Theoretical and Experimental Physics (ITEP) in Russia and recently in Institute for High Energy Physics, also in Russia. These facilities provide the dynamic measurement of properties of matter under extreme conditions with typical spatial resolution of about 100 to 300 μm.

The next step in the development of the proton radiography is the introduction of proton microscopy which can provide greater spatial resolution through the use of magnetooptical magnifiers. LANL facility already has that capability. At the ITEP the proton microscopy facility has been commissioned at 800 MeV beam line in 2009. Its spatial resolution was measured for a variety of test objects to be about 50 μm. The construction of radiographic facility at 3 GeV beam line at the ITEP is also planned.

Recently an international collaboration was formed to develop a new high energy proton microscopy capability for the study of dynamic material properties at the Facility for Anti-proton and Ion Research (FAIR) located at GSI Helmholtzzentrum fur Schwerionenforschung in Darmstadt, Germany. This new facility with proton beam energy of 4.5 GeV will provide radiographic imaging of dynamic systems with unprecedented spatial, temporal and density resolution, resulting in a fundamental understanding of material properties in extreme states at new length scales.

RESEARCH OF PROPERTIES AND STRUCTURE OF THIN FILMS RECEIVED AT MAGNETRON SPUTTERING OF A GRAPHITE TARGET

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Now the great interest to ultraviolet electronics is shown. Ultra-violet (UV) radiation receivers are applied in medicine, power and other branches of technics. As a material for the thin-film receiver of ultra-violet radiation serve wide-band gap semiconductors, on the basis of GaP, ZnS et al.. Recently attention of researchers involve various allotropic forms of carbon as receiver UV material. It is considered that perspective are diamond and carbine.

Earlier in work [1] we have considered results of experimental realisation of a method of sedimentation of carbon films in process magnetron sputtering of a graphite target in atmosphere of especially pure argon and photoactivation adatoms carbon on growth substrate surfaces. Conditions of stable reception of thin transparent films by thickness of an order 0.25 microns have been defined.

In the presented work the phase structure, surface structure, and also dependence of electroresistance on temperature are investigated. It is shown that the spectrum of combinational dispersion of light (Raman spectroscopy) removed on transparent films which have been put on glass, sapphire, the titan corresponds to diamondlike (DLC) structures. At heating of a substrate to temperature 1000 K films which Raman-spectrum have been received specifies in presence at films carbine. Formation ordered columnar structures focused perpendicularly growth surfaces is noted at sedimentation of films DLC on a amorphous substrate with application of activation of process by a tungsten thread. Possibility of use of a method of photoactivation adatoms carbon on growth surfaces for management allotropic structure of besieged films is discussed.

Work is executed with financial support of the Russian fund of basic researches, the Russian Federal Property Fund grant No. 07-08-12170-ofi and Fund of support of young scientific ITES JITH the Russian Academy of Sciences for 2008.

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A MAGNETIC CUMULATIVE GENERATOR WITH OUTPUT ELECTRICAL PULSE HAVING STEEP FAST-HEAD FRONT

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To feed an inductive load ≈ 0.1 μHs with an electrical pulse with steep fast-head front (a leading edge no more 3 μs), the alternate solution can be used: a magnetic-cumulative generator with magnetic flux trapping (MCG FT) with a primary circuit being switched off.

Theoretical and experimental results are presented for actual magnetic flux losses, coefficient of perfection, losses in the contact point of, and also for open switch resistance. The maximum parameters of the device picked on the basis of the executed calculations.

MCG FT has been designed and investigated with cutout of a primary circuit. Generators were tested for a model loading by inductance 1.16 μH. An explosive open switch cuts out a current by amplitude 3 MA no more than 3 μs, that ensured front of a build-up of a voltage pulse on a loading ≈ 2 μs. The intercepted magnetic flux in primary circuit was 0.086 Wb, the electrical pulse in a loading has been registered with parameters: energy 86.3 kJ, a magnetic flux of 0.45 Wb. Coefficient of flux conservation — 0.6. The leading edge of the current and the shape of the voltage on the load have matched to desired values. The tests under consideration have demonstrated a high performance and an opportunity of MCG FT application in the power supply of the impulse plasma accelerator.

EXPERIMENTAL RESEARCHES AND CALCULATIONS OF MAGNETIC-CUMULATIVE GENERATOR WITH CONE SECTIONS

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Calculations and experimental researches of new magnetic-cumulative generators where the last sections are carried out as direct and return

cones are conducted. It has allowed to increase a current in loading from $0.1I_{max}$ to $0.9I_{max}$ during 20 μs without application of switched off and switched on explosive keys. The calculations have shown that absence of an explosive switch off in the circuit of the generator of the suggested schema and uncontrollable arrester in loading circuit raises the efficiency of energy transfer to loading. Use of the generator with such geometry lead to effective velocity increase of the liner sliding on a spiral in comparison with cylindrical geometry. It entails to increase the generator power. It is important, that in such generators the increase of the liner sliding on a spiral isn't achieved due to use of more powerful HE with the greater detonation velocity, but due to an optimum cones spirals angle.

Results of experimental researches of functioning magnetic-cumulative generators of the suggested design on modeling loading $L_H = 0.17$ μH are shown in this work. The electric pulse by energy $E_H = 2100$ kJ is registered at initial energy of generator $E_0 = 90$ kJ in loading.

FIRST RESULTS OF MAGNETICALLY INDUCED ABSORPTION INVESTIGATIONS

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In the report the first results on the experimental investigation of magnetically induced gas sorption on the surface of polymers in strong impulse magnetic field are presented. The methodology of experiment is described. Influence of a magnetic field on parameters of absorption of gases is revealed. The cited data on absorption of steams of iodine show is abnormal a long life of the absorbed layer received at strong magnetic fields action. The possibility of using the magnetically induced sorption effect in the medical application is shown.

EXCITATIONS IN BILAYER GRAPHENE IN HIGH MAGNETIC FIELD

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The charge-density excitations in bilayer graphene at the filling-factor $\nu \ll 1$ at small momenta are considered in the frame of the Hartree-Fock approximation. The presence of small asymmetry of graphene layers is included. The dependence of the magnetoplasmon energy on the bilayer ground state is shown. The energy splitting proportional to $\sqrt{H}$ for the symmetric case with half-filled zero-energy levels is found both for bilayer and monolayer graphene.

Recent experimental progress has allowed the fabrication and study of monolayer and bilayer graphene. The electronic band structure of these objects is gapless and has a chirality. The monolayer has Dirac-type spectrum with linear dispersion and chirality exhibiting Berry phase π. In magnetic field there is zero-energy Landay level, fourfold degenerate due to two spins and two valleys. The bilayer graphene is the unique object which combines the parabolic dispersion law of quasiparticles with their chirality exhibiting Berry phase 2π. In magnetic field there is a double-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 is eightfold degenerate. For the bilayer with small asymmetry there are four weakly split two-fold levels, close to zero.

The charge-density excitations at small momenta are considered in the frame of the Hartree-Fock approximation. The case of filling-factor $\nu \ll 1$ is considered. The presence of small asymmetry of graphene layers is included. The energy of the magnetoplasmon excitations is considered and the strong dependence of the energy on the form of the bilayer ground state is shown. In asymmetric bilayer taking into account spin we have four transitions with equal energies. Energy splitting due to asymmetry is absent, only additional shift takes place.In the case of symmetric ground state with half-filled 0 and 1 for each valley and spin there are two combined transitions splitted in energy. This splitting for combined electron-hole transitions from half-filled level is not specific to bilayer graphene. For monolayer graphene with filling-factor $\nu = 0$ the value of splitting is practically the same as for bilayer graphene. If this splitting would be observed it would be the evidence of Coulomb interaction in graphene.

THE MECHANISM AND PARAMETERS OF THERMAL DESTRUCTION OF THE TITAN AT FAST RESISTIVE HEATING IN THE AIR ENVIRONMENT

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In the conditions of combined visual and pyrometric diagnostics features of destroying heating of a titanic tube are studied by a powerful impulse of an electric current. Experiences are spent on samples of industrial titan VT 1–0 in the air environment of atmospheric pressure. The geometry of the sample with a slot-hole cavity of a black body is used. Thermogram of true temperature of process it was studied by means of the high-speed monochromatic pyrometer which has been adjusted on a pyrometric crack. The additional pyrometry was provided by means of high-speed digital camera "Sprint". Time charts of intensity for three lengths of waves (506, 559, 636 nm.) were used for definition correspond ing brightness temperatures on the basis of camera graduation on a temperature lamp of SI-10-300.

In this work the phase of destruction is studied along with the information typical for such kind of experiments about the characteristics of the example. It is shown that the phase of destruction has quasi-explosive character Having the density of heating current 100 A/m^2 explosive de struction is fixed near upper current supply on 798 ms of experiment. The evolution of the explosive destruction can be understood if we concede that in the zone of top electrode running off melt of titan downwards gradually reduces the area of current-carrying section. At constancy of the current in the line the density of the current in this section grows, and activate the sharp rise of the density thermal flux and consequently to intensive growth of local temperature. Process of heating the isobar. Therefore scattering of products of destruction can be obliged to boiling up of the liquid titan at the set pressure.

In this work the information about the temperatures of solidus, liquidus is given. It was not possible to measure boiling up temperature. We can say only that it is higher then, the maximum temperature fixed by the videocamera, made 2500 K.

We can do the conclusion that the particles of the titan oxide melt are presented along with metal melt.The trace structure, the possible sizes and condition of the condensed phase of products of combustion are analyzed.

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NUMERICAL MODELING OF HOMOGENOUS NUCLEATION IN GAS-DYNAMICAL CODES

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Physical models of homogeneous nucleation are intensively developed from the middle of the last century [1, 2, 3]. Considerably smaller number of researches is devoted to numerical realizations of these models [4, 5]. In many respects it is caused by great volumes of calculations which are required for finding a function of nucleuses size distribution. Actually adding of nucleation kinetics models in gas-dynamical code increases dimension of a solved problem by unit.

Nucleuses number evolution is described by analogy with gases kinetic theory. In the issue we have infinite system of ordinary different equations [3]. Using of continuous function of nucleuses size distribution leads to Fokker-Plank equation (it is named Frenkel-Zeldovich equation [1, 2] if we consider nucleation problem). It is known that nucleation problem solution [1] included quasi- equilibrium distribution of precritical sizes nucleuses is applied for long processes [3].

In present work nucleation different models is considered. Appropriate mathematical problems (they are system of ordinary different equations [3], Fokker-Plank equation; quasi- equilibrium solution [1] of nucleation problem) are solved by numerical methods. Using of implicit finite-difference schemes allows reaching of quasi- stationary nucleation regimes. Comparison results of different nucleation models solutions are presented. Workability regions of these models are determined.

The simplified variants of the numerical models that allow to making calculations of homogeneous nucleation in multidimensional cases with sufficient accuracy for practice are offered.

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THE PROBLEM-DIRECTED DATABASE FOR CALCULATION OF COMBINED THERMAL AND MECHANICAL ACTIONS OF RADIATIONS AND PARTICLES

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Medley sets of the material property data are required for numerical modeling of combined action of radiations and particles having various physical nature on airframe [1, 2]. Search of this data in available extensive databases of optical, thermodynamic and mechanical constructional materials properties is laborious and long work and, as a rule, is accompanied by errors. Creation of the small database directed on the decision of a concrete problem is represented expedient. Certainly such database requires own interface.

The offered database consists of three basic blocks: interactions sections and coefficients (for example, dependences of factors of superficial absorption on length of a wave and temperature) described radiations and particles interaction with constructional materials; dependences of thermal-physic characteristics (a thermal capacity, heat conductivity, speed of thermal ablation) from temperature; dependences of deformational-strength characteristics from temperature.

Functional dependences (from temperature, energy of quanta etc.) are broke into characteristic areas, in each of which they are approximated by polynoms. Storage of only these polynoms factors essentially reduces database volume. In additives it accelerates extraction of the data from a database. The own database interface that facilitate input, test, reorganize and extract of the accumulated data is developed.

Use practice of the created database has shown its efficiency and application convenience at consequences calculations of combined thermal and mechanical actions of radiations and particles on carrier elements of vehicle designs.

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OHMIC HEATING CALCULATION FOR CARBON PLASTICS STRUCTURES AT A LIGHTNING DIRECT STROKE

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Carbon plastics elements of designs find the increasing application in aircraft construction [1, 2]. First of all, it is caused by specific deformational-strength characteristics of carbon plastics. These characteristics are essentially above corresponding values for aluminium alloys are traditionally used in the plane. However lower conductivity (in comparison with aluminium in 500 times) of these materials increases vulnerability to direct action of a lightning. New calculative-experimental methods are required for development of lightning strike protection for carbon aircraft structures and securement of safe flights.

One of principal causes of design damage at a lightning direct stroke is ohmic heating of a material by currents passing through it [3]. In present work the method of calculation of ohmic heating multilayered carbon plastics elements of an aircraft structures is offered at a lightning direct stroke. The problem is considered in quasistationary statement. It is supposed that materials of a multilayered construction are orthotropous. Calculations results are represented for final carbon plastic part of a wing in two-dimensional geometry. It is received that temperature rise as a result of ohmic heating considered construction can make some hundreds degrees at lightning stroke parameters.

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THE RESEARCH OF POROUS STRUCTURE AND ELECTROCHEMICAL PARAMETERS OF NANOCOMPOSITE CARBON MATERIALS FOR ELECTROCHEMICAL DOUBLE LAYER CAPACITORS

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Electrochemical double layer capacitors (EDLC) allow to realize modes of accumulation and return of energy with high speeds of charge and discharge. EDLC consists of two porous electrodes divided by the separator with electrolyte. The process of energy storage in EDLC is carried out at the expense of charge division into two electrodes with big potential difference between them. The potential difference is usually defined by the value of decomposition voltage of electrolyte. This value lies around 1.23 V for water electrolytes and around 2.5–4 V for organic electrolytes. The processes occurring in a double electric layer (DEL) in the boundary of two conductors are similar to those in the usual capacitor. In this case the distance between electrodes contains some internuclear lengths. Actually one electrode is presented by electrons in an electronic conductor, and the second – by positive ions of electrolyte, sorbed on a surface of an electronic conductor. On the second electrode the layer is formed at the expense of pauperization of electrons in the electronic conductor and sorption of negative ions of electrolyte. Thus, it is necessary to provide the possibly big surface of contact of electrolyte with an electronic conductor for achievement of the maximum capacity. Therefore nanoporous carbon materials are usually used as an electronic conductor. The liquid electrolyte is usually concluded in the porous polymeric or asbestos separator dividing electrodes in order to avoid short circuit. For increase of the energy reserved by the supercapacitors organic electrolytes with high voltage decomposition are used. The method of equilibrium drying investigates nanoporous structure of activated coals and carbon fabrics, coals received from carbides of metals. Research of electrochemical properties of the given structures in the experimental single-cell is given. Correlations between parameters of porous structure and capacity of supercapacitors on the basis of the given materials are established.

ROLE OF HOMOGENIZATION IN FAST POROUS MEDIUM HEATING

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Energy deposition in porous media plays important role in high energy densities physics applications such as inertial confinement fusion research and spaceship protections. Usually the medium has density in the range 0.001–0.1 g/cm^3 and pore size from several nanometers to hundreds of microns. The matter is typically heated at the nanosecond time scale over the whole volume, e.g. by means of ion beams or X-ray.

We propose that the media could exhibit non-trivial behavior during the early stages of the heating while the general pore structure is still intact. It should be noted that while the average density of the medium could be made almost arbitrary low, its structural elements retain the solid density. Effective and the basic thermodynamical and stopping properties of such solid media are at the mesoscale. Thus the energy deposition and the following hydrodynamical flows are like the ablation of the irradiated solid medium. The resulting flows could be as fast as hundreds km/s, especially if the pores are large enough to allow the flows to develop. If the above holds, in the history of the irradiated medium will be a moment when a small portion of its matter will be accelerated to considerable velocities without any apparent macroscopic flows. When these flows collapse inside the pore voids. Later on collapses will produce the "hot spots" with thermodynamical parameters far exceeding anything for the averaged energy deposition throughout the medium.

Because the direct measurements of the flows inside the pores are difficult we propose the physical modeling scheme where the 3D pore collapse is substituted with 1D collapse of the flows from the fast heated thin foils. This approach makes the direct observation of the heated matter expansion and collapse practical.

We used thin aluminum foils as the medium model because aluminum has quite accurate equation-of-state for the wide range of parameters. Pulsed electron beam was used as the energy source. The obtained experimental results were used for 1D numerical and analytical modeling [1, 2]

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ELECTROPHYSICAL CHARACTERISTICS OF THE MATERIAL RTP-200 UNDER EXTREME HEAT LOADS

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Some effects of high-temperature aerodynamic heating on electrophysical characteristics of heat-shield materials for aerospace applications are studied experimentally.

If the intensity of aerodynamic heating is high enough the heat-shield materials or materials of the body of aerospace vehicles undergoing the thermo-mechanical destruction due to melting, vaporization, carbonization, etc. These physical-chemical transformations can essentially change some electrophysical characteristics of material RTP-200 and in particular influence its ability to transmit radio waves.

Effect of additional attenuation of microwave radiation (1.2–1.6 GHz), used in GLONASS positioning system, by RTP-200 material is studied in three steps. At first, the factor of its transparency to the microwave radiation is studied for original material. Then, the material is exposed to the heat flux similar to the aerodynamic one.

At the first stage the degree of attenuation of the microwave radiation by a plate of RTP-200 material is measured. Microwave measurements of the material dielectric properties are performed using broadband vector network analyzer (R&S ZVA24) equipped by lens horn antennas. This, so-called quasioptical technique is based on frequency dependence measurements of the complex transmission coefficient of an electromagnetic wave through the sample located between two horns with using of time-domain technique to prevent spurious reflections in a circuit. At the second stage the complex variation of aerodynamic heat flux at different flight-pass intervals is simulated by radiation of power CW YAG-laser, ($\lambda = 1064$ nm). Laser power in the range of 200 to 3000 W is applied for the simulation whereas its needed time variation has been analyzed previously using suitable mathematical modeling. At the third stage the degree of attenuation of the microwave radiation by partially destructed plate of RTP-200 is defined. It turns out that the microwave attenuation by RTP-200 material in the GLONASS frequency band is increased approximately by 1 dB due

to the influence of simulated aerodynamic heating. This increase in attenuation is due to the evident partial carbonization of the thin layer on the material surface exposed to the high heat flux.

STRENGTH OF THE CONIC COVER AT EXTREME THERMAL LOADINGS

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Strength of a thin-walled composite conic cover in the conditions of aerodynamic heating and influence of high-energy radiation (HR) with constant level of a stream is numerically investigated. Two variants of influence are considered: along an axis of symmetry of object and on its lateral surface. The temperature field was defined with the account of ablation of weight at physical and chemical transformations (PCT). Energy losses on PCT were considered integrally through the surface temperature. For definition of the thermal pressure caused by non-uniform heating on a thickness of a wall, the interfaced problem of thermal elasticity was solved.

It is shown that at influence on a lateral surface more weight is carried away more weights, than at axial influence. It is established that the maximum stretching pressure correspond to the moment of the beginning of action of HR. They are observed on some depth of a nasal part of object and on a surface of a conic part. Position of a maximum of compressing pressure is located inside of a wall of object and in the course of heating moves deep into in process of distribution of heat at the expense of heat conductivity. Change of stretching pressure with compressing pressure is caused by temperature dependence of factor of linear expansion of a material of the case. The maximum of compressing pressure is necessary in the range of temperatures 200–300°C where the greatest change of factor of linear expansion is observed. Strong expansion of heated up to 200–300°C part of the case is damped, on the one hand, by heated to high temperatures (> 1000°C) near-surface layers, where linear expansion coefficient is negative, on the other hand—relatively weakly heated ($\leqslant 200$°C) deeper layers of the case. Such situation causes compressing pressure. Thus stretching pressure approximately in 1.5 times there are less than compressing.

EXPRESS METHOD FOR DETERMINATION OF NEUTRON FLUX WITH ENERGY MORE THAN 0.1 MeV ON RESEARCH REACTORS

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The algorithm of operative definition flux neutrons with energy more than 0.1 MeV ($F_{0.1}$), being one of the basic controllable sizes at tests of products of electronic techniques on radiating firmness, is presented in the report. The method is based on use of natrium and sulphuric detectors, co-operating with neutrons on reactions $Na^{23}(n,\gamma)Na^{24}$ and $S^{32}(n,p)P^{32}$.

Flux neutrons in working premises of research reactors can be presented in the form of superposition straight (not disseminated, F_{st}) and disseminated (F_{dis}) radiations, i.e. $F_{0.1} = F_{st} + F_{dis}$. The contribution of disseminated neutrons with energy more than 3 MeV in the reactor premises is very small, on this reason the share (ϵ) of straight neutrons in this energy interval is practically constant on all distances from an active zone of a reactor. Hence, flux of straight neutrons is possible to define on the following dependence: $F_{st} = F_3/\epsilon$, where F_3—flux neutrons with energy more than 3 MeV, measured by the sulphuric detector, the effective threshold of registration of neutrons at which is equal 3 MeV.

The basic part of disseminated neutrons is the slowed down neutrons with energy less than 3 MeV, therefore for definition flux disseminated neutrons it is expedient to use of detectors above thermal (with energy more than 0.5 eV) the neutrons, which sensitivity inversely proportional their speeds. Such detectors concern Dy^{164}, P^{31}, Na^{23} etc. In the mixed neutron flux above thermal neutrons can be separated from thermal with the help cadmium the screen. Cadmium absorbs practically all neutrons with energy less than 0.5 eV. In this connection, activity of the detector covered with cadmium is caused only above thermal by neutrons. The difference of activities detectors ($A - A_{\mathrm{Cd}}$), not covered and covered with cadmium, characterises flux thermal neutrons. For the natrium detectors flux disseminated neutrons it is possible to define under the formula: $F_{dis} = 0.58KA_{\mathrm{Cd}}$, where $K = F_T/(A - A_{\mathrm{Cd}})$—the factor, defined by an irradiation of detectors in the field of thermal neutrons; F_T—flux of thermal neutrons. Full flux neutrons (straight and disseminated) with energy more than 0.1 MeV it will be equal $F_{0.1} = F_3/\epsilon + 0.58KA_{\mathrm{Cd}}$.

The given method is successfully used on a research reactor the PRIZ at dosimetric maintenance of experimental works.

A CONVENIENT METHOD OF HIGH-ENERGY PULSE ELECTRON BEAMS DOSIMETRY, BASED ON MEASURING THE VOLUME OF GASEOUS PRODUCTS OF ACETONE RADIOLYSIS

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High energy electron beams (HEEBs) are used to initiate processes in the gaseous phase and condensed state. Study of energy parameters of interact processes of HEEB with compounds requires accurate and reproducible methods of dosimetry. Ideally, the dosimetric system should be closest to the properties of the target studied objects. In this message a method of pulse HEEB dosimetry using a simple and reliable method of measuring the volume of gaseous products acetone radiolysis is reported. Testing cell used for measurement has the diameter of 18 mm and thickness of 0.4 mm. One side of the cell was closed by 10 μm titanium foil and used for the input tested beam. The method of dosimetry was developed with the use of electron accelerator RADAN forming the beam of electrons with a duration of 3–4 ns, energy electrons 180 keV, beam current 300–600 A. The studies showed that at doses of 100–5000 kGy a dependence of evolved gases on the dose is described to almost ideal linear law. Influence of impurities and mechanism of radiolysis in the dosimetric cells has been studied . The key products of acetone radiolysis in the cell was identified. A method of gas chromatography/mass-spectrometry (GC/MS) was used for research of conversion products of organic compounds processed by HHEB.

The work was performed at partial financial support of the Presidium of Ural Branch of RAS within the framework of the complex program of the Presidium of RAS “Thermophysics and Mechanics of Extremal Energy Actions and Physics of the Highly-Compressed Matter”.

ENGINEERING METHODS COMPLEX FOR STRUCTURE OPTIMIZATION OF HETEROGENEOUS MODERN COVERINGS FOR PROTECTION AGAINST HIGH-INTENSITY IONIZING RADIATION FLUXES

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Heterogeneous coverings (GC) having dispersed microspherical fillers [1] are used for vehicle protection from mechanical and thermal actions of high-intensity ionizing radiation (IR) streams [2, 3]. Such coverings having set protective characteristics are created by means of a variation in structural parameters of these fillers. Structure definition of such coverings is possible only by means of the solution of an optimizing problem and use of engineering calculation methods of IR action parameters. Dynamic programming methods are used for optimum search.

The engineering methods complex consists of parametrical methods of calculation of energy absorption characteristics and algorithms of an estimation of thermal and mechanical IR actions parameters. The method of an elementary cell [2] is used for calculation of an initial pressure profile formed in GC. Energy absorption profiles realized in GC components are calculated by a hybrid method. Photons transfer is realized by Monte-Carlo method but energy redistribution by secondary electrons is determined analytically. According to this point of view incuts method [2] is used. It is suppose that IR flux insignificantly changes within heterogeneous material elementary cell that is photon run length is more then microsphere dimen-sions. Angular distributions of secondary electrons born in interaction processes (photo-absorbing and Compton scattering) are supposed isotropic.

Calculations results of rational structure parameters for GC having glass or carbon microspheres (they are covered heavy metals: tungsten or nickel) are presented.

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MICROWAVE SYNTHESIS OF NANOSELENIUM WITH SURFACTANT TEMPLATING

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Nanosized structures of selenium and its derivatives are very interesting and promising nowadays. There are its potential applications in electronics in field effect transistors,in medicine for nanobiomaterials, anticancer agents, in energetics for productions of thin film solar cells and fuel cells. The microwave synthesis of nanoselenium is the very promising and effective. For applications it necessary to have nanoparticles of uniform but different sizes. The widespread approach is the templating with surfactants . But its selection is the mostly empirical. Mechanism of its action is understandable but not predictable, because the most laws of nanoscience are unknown yet. We had began this research to find the mechanism of stabilization of selenium nanoparticles in microwave process of its production. Oxyethylated alkylphenols were used, as stabilazing and templating agents. The reaction mixture of solutions of polymers, surfactants, selenium compounds and reducer was treated in microwave oven. Obtained solutions of nanocomposites were dried and investigated with electron and optical microscopy, x-ray diffraction ,optical spectroscopy (uv-vis).

THE ANALYSIS OF THE UNIVERSAL MODEL OF OPTIMIZATION OF TECHNICAL DIAGNOSTIC PROCEDURES FOR POWER PLANTS

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The aim of mathematical model is to choose diagnostic parameters which condition knowledge of allowed level of reliability and determined analytic expression which corresponds to precisely described condition of hydroelectric power plant components complex. Model of technical diagnostic procedures optimization is a specific approach to the problematics of preventive maintaining according to condition, and it is related to the conception of condition parameters change which represent abase for optimal solution for procedures of tehnical diagnostic of power plant components. It also makes direct relations between the law of condition

parameter change and reliability of the observed power plant components complex.

The optimal model analysis includes methodology with help of block diagram in determining the safety of integral components functioning of analyzed hydro plants complexes. The methodology included monitoring system construction optimization and algorithm for constructing the model for diagnostic parameters determining [1]. The components are arranged by complexes, from turbine working circuit to waken, taking their functionality and intention, so reduction of complex structures of block diagrams was done.

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THE ANALYSIS OF POSSIBILITIES OF QUALITATIVE CHANGE OF ASTEROID 99942 APOPHIS ORBIT

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According to astronomical observations and to calculations results asteroid Apophis will fly in 2029 at 40000 km distance from the Earth centre without its collision. However the know collision risk can take place in 2036 [1]. Therefore the number of the researches devoted to the analysis of an orbit correction problem grows. The correction purpose is collision prevention in 2036 and only. But forecasting of consequences of such correction for the long time period after 2036 is not obviously possible. As a result the final solution of a problem of asteroid Apophis by means of its deviation from a collision orbit will not be reached.

In the present work as the purpose the problem of qualitative change of an asteroid orbit with the termination of its independent movement in solar system is put. In addition instead of passive protection tactics variant of use of an asteroid is considered for statement of large-scale space experiment on shock action by an asteroid on the Moon.

Moon use as a natural space board was offered in [2]. Correction of an asteroid Apophis orbit when we have result of collision with the Moon in 2036 is considered in [3]. Let's notice that high-speed impact on the Moon surface was already used for carrying out of physical experiments [4]. The development of space scale will allow solving a complex of physical

questions concerning the Moon. In particular, it is definition of its composition and internal conformation. Moon sounding by impact seismic waves is demanded by an establishment of gauges from the Moon underside in relation to a impact zone. The fence of transient vapor plume test and registration of radiation from an impact zone is expedient for spending from the Moon sputnik having orbit parameters providing a information maximum.

Possibilities to use thermo-nuclear effect and impact kinetic action for proposed change of asteroid orbit are estimated.

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THERMODYNAMIC PROPERTIES AND CONDUCTIVITY OF MULTIPLE SHOCK COMPRESSED HELIUM ALONG 130 GPa ISOBAR

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Measurements of thermodynamic properties and electrical conductivity of helium compressed with shock wave reverberation technique up to pressure of 130 GPa were performed. Explosively driven steel plate with velocities of 5.3 km/s was used to impact experimental assemble filled by gaseous helium at temperature about 78 K and pressure in the range of 3–20 MPa. Shock wave velocities and brightness temperatures of helium were measured by fast optical pyrometer. Electrical resistance of a shocked helium layer was measured simultaneously with optical pyrometer records by three electrode resistance measuring system. Helium conductivity in the states of maximal compression was traced along investigated isobar. Semiempirical helium EOS was constructed including ionization in Debye model. 1D hydrocode simulation of the process of compression results were compared with measured experimental information. Work was supported by RFBR grant No 09-02-01257-a.

THE INVESTIGATION OF POLARIZED REFLECTIVITY PROPERTIES OF STRONGLY CORRELATED PLASMA

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The research of transitive layer of explosively driven dense plasma can be carried out using the technique of inclined probing by polarized electromagnetic waves. Angular dependence of s- and p-polarized reflectivities at several wavelengths can be used in the integration of Maxwell equations to construct the spatial profile of the density of charge carriers.

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 $\lambda =$ 1064 nm and $\lambda = 694$ nm.

To generate a strongly nonideal plasma we used a dynamic method, based on compression and irreversible heating of the gas in front of a high-power ionizing wave and to measure the dense xenon plasma polarized reflectivity coefficient, the pulsed $Y_3Al_5O_{12}$:Nd^{3+}+KTP and Al_2O_3:Cr^{3+} laser system with electro-optical shutter was used. The measurements of polarized reflectivity coefficients of explosively driven dense plasmas have been carried out at incident angles up to $\theta = 65$ degrees simultaneously for s- and p-polarization, respectively.

The thermodynamic parameters of the plasma were determined from the measured shock wave velocity. Working with a grand canonical ensemble, virial corrections have been taken into account due to charge-charge interactions (Debye approximation). Short-range repulsion of heavy particles was considered within the framework of a soft sphere model. In accordance with these calculations, the free electron density $n_e = 7.1{\cdot}10^{21}$ cm^{-3} has been obtained at the wavelengths of $\lambda = 1064$ nm and $n_e = 7.8{\cdot}10^{21}$ cm^{-3} at the wavelengths of $\lambda = 694$ nm. During the experiments, the plasma density up to $\rho = 2.8$ g·cm^{-3}, pressure up to $P = 12$ GPa and temperature up to $T = 32000$ K were realized. Under these conditions, the plasma is non-degenerate and can be characterized by the nonideality parameter $\Gamma = 1.8$.

The integration of Maxwell equations are based on an interpolation formula for dc conductivity, obtained from a systematic quantum statistical treatment of different limiting cases.

PRESSURE FLUCTUATIONS IN NONIDEAL PLASMA: PRECURSOR OF THE PLASMA PHASE TRANSITION

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An assumption about the plasma phase transition (PPT) is advanced in [1, 2] by analogy with the Van der Waals equation where the phase transition origin is a result of the balance between 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. However contrary to real gases there are ex-

cited atoms in low temperature plasmas. The restriction of the discrete spectrum in the atomic partition function depends on the charge number density. Gryaznov and Iosilevskiy [3, 4] noted 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 [3, 4]. We guess that it is more logical to apply the fluctuation approach [5] 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 studied. The fully ionized plasma region is found where pressure fluctuation distribution can be approximated by the superposition of two Gauss distribution functions. It should be noted that this region of plasma parameters lies out of the area of the abovementioned stabilized factor action. The result could be considered as a precursor of the PPT.

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NONEQUILIBRIUM DISTRIBUTIONS FUNCTION OF ELECTRON AND TEMPERATURE DEPENDENCE FOR RECOMBINATION COEFFICIENT IN ULTRACOLD PLASMA

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Nonequilibrium distributions function of electron has been calculated in positive and negative aria of energy at temperature, and nonideality parameter $\gamma = \beta\dot{e}^2\dot{e}n^{1/3} = 0.1 - 0.9$. In [1] we have calculated distribution functions in energy range $E = (-2kT) - (2kT)$ by molecular dynamic

method. This function has joined with distributions function from balance equations system at $E = -2kT$ [2]. As a result we have calculated recombination coefficient and it dependence of temperature in nonequilibrium ultracold plasma. In region $\gamma \sin 0.1$ our calculations agree with Gurevich-Pitaevskiy recombination coefficient [3] and temperature dependence $T^{-9/2}$. Calculated recombination coefficient is less than Gurevich-Pitaevskiy recombination coefficient at $\gamma \sim 0.1$.

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KINETICS OF ATOM EXCITED STATES IN LOW TEMPERATURE PLASMA

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Stepwise atom ionization, three body recombination of electrons and ions in a low temperature plasma and evolution of atoms over excited states after two-step laser excitation of an atomic gas results from subsequent collisions of the atom with electrons and radiation of excited atoms. In a low temperature plasma, kinetics of excited atoms is described by the classical scheme BKW [1] that includes transitions between atom excited states in collisions with plasma electrons along with radiative transitions from these states. This scheme was used in detail for three-body electron-ion recombination in a hydrogen plasma [1, 2] where it is based on classical cross sections for the transition rates between excited states by electron impact. But the classical approach does not valid for transitions including the ground and lowest excited atom states, and the rate of excitation from the ground state depends on the energy electron distribution function [3]. In addition, atoms with several electron shells contain many excited states, so that transitions from these states has a quantum character.

We use the block model for the BKW scheme [1] where the states with nearby excitation energies are joined in one block. For example, in the case of an argon plasma 4 states $2s_5$, $2s_4$, $2s_3$, $2s_2$, are joined in one block, 10 states $2p_n$ are joined in other block. Other excited states are considered as hydrogen-like ones with taking into account the quantum

defects of these states, and classical formulas are used for transitions involving these states. Joining of $2s_n$ and $2p_n$ states in separate blocks is justified because the rate of state mixing $\sim 10^{-7} cm^3/s$ by electron impact is large compared to the rates of collision transitions in other atom states. Using experimental rate constants for collision transitions involving states of a given block, we reduce the rates for states of a given block to the block rates with the statistical average inside a block, and this statistics accounts for radiative transitions from the states of a given block at low electron number densities.

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MAGNETRON GENERATION OF METAL CLUSTERS IN PULSE REGIME

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An effective method of generation of metal clusters in magnetron discharge is effective because of a high rate of cathode erosion in magnetron discharge [1, 2]. In the stationary regime, the efficiency of conversion of metal atoms in metal clusters is $\sim 1\%$, because the process of cluster formation from metal atoms proceeds at not high temperatures and hence the optimal discharge power is restricted. On the other hand, magnetron discharge requires a low buffer gas pressure, and the basic channel of loss of metal atoms is their attachment to the walls of the discharge chamber.

In order to increase the efficiency of conversion of metal atoms in metal clusters we suggest the pulse method of cluster generation. Then after a current pulse that lasts $\sim 10^{-5}$ s and proceeds at a low pressure of a buffer gas, an additional buffer gas is injected in a magnetron chamber near the walls. Therefore relaxation of a buffer gas with metal atoms that consists in a decrease of the gas temperature and diffusion of metal atoms towards the walls of the magnetron chamber, proceeds at a high pressure of a buffer gas. As a result, the ratio of the rates of cluster formation and departure of metal atoms to the walls increases compared to the stationary case. We analyze the kinetics of relaxation of a buffer gas with metal atoms under

pulse conditions. This analysis shows that the efficiency of conversion of metal atoms into metal clusters in the pulse regime exceeds that in the stationary regime in several times.

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SELF-CONSISTENT FIELD NEAR THE CHARGED PARTICLE LOCATED IN IONIZED GAS

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In a dusty plasma, micron-sized particles are located in a weakly ionized gas, and a particle charge influences on a surrounding plasma, so that a self-consistent field is formed in a vicinity of each particle [1, 2]. In the case of a dense gas when the mean free path of ions and electrons is small compared to a size of the field action, the current of ions and electrons to the particle surface is given by the Fuks formula [3]. The equality of currents of electrons and ions allows one to find the spatial distribution of ions and electrons, so that their number density trends to zero in the particle vicinity and the particle field decreases at large distances according to the Debye formula.

In the case of a rare buffer gas when the mean free path of ions and electrons is large compared to a size of the field action, screening of a self-consistent field of a charged micron-sized particle located in an ionized gas is determined by ions only, and along with free ions, trapped ions are of importance for screening of the particle field [4]. According to dynamics of ion motion in a self-consistent particle field [5], trapped ions are formed not close to the particle as a result of the charge exchange process involving the ion under consideration and a buffer gas atom. A subsequent charge exchange process with participation of a trapped ion leads to transition in a more close orbit or to ion capture by the particle. From this it follows that if a size of the action of a self-consistent particle field is not small and trapped ions exists, the number density of trapped ions exceeds that of free ions.

We derive formulas for the number densities of free and trapped ions separately in two cases when screening of the particle field is determined by free or trapped ions such that the number density of free ions tends

to the number density N_0 of electrons and ions of an unperturbed plasma far from the particle and the number density of trapped ions tends to zero at the boundary of the self-consistent field region. On the basis of these formulas, the algorithm is worked out for determination of a size l of the self-consistent field region such that the total charge of ions in this region due to free and trapped ions is equal to the particle charge. The accuracy of determination of the ion number densities in the region of a self-consistent field may be obtained from comparison of the results of the above two limiting cases and is estimated as 10%. We obtain that formula for the particle charge [6] is independent of screening of the particle field. One can explain this that the particle charge is determined by the equality of electron and ion currents which are originated far from the particle where its field is screened. We also establish the similarity law for the self-consistent particle field, so that this field is identical at distances R/r_0 at identical values of the parameter $N_0 r_0^2$, where R is a distance from the particle, r_0 is the particle radius. The role of trapped ions increases when the number density N_0 of electrons and ions of an unperturbed plasma becomes small, and this is of importance for dusty plasmas of the solar system which result from interaction of the solar wind with a dust, as it takes place in comet tails, Saturn and Jupiter rings.

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INVESTIGATIONS OF STRONGLY COUPLED DUSTY PLASMAS IN LIQUID STATE: LABORATORY AND MICROGRAVITY EXPERIMENTS

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The particles are usually charged negatively in gas-discharge plasmas by collecting electrons and ions. The combined effect of interaction between the particles and the ambient plasma as well as between the particles themselves leads to the formation of various complex plasma states ranging from gaseous plasma to liquid plasma and plasma crystals.

Results of experimental study of the dusty plasma kinematic viscosity and the diffusion are presented. Experimental examination of the Einstein-Stokes relation between the viscosity and diffusion constants is carried out. The results are given of an experimental investigation of heat transport processes in fluid dusty structures under different conditions: for discharge in argon, and for discharge in air under an action of electron beam. The analysis of steady-state and unsteady-state heat transfer is used to obtain the coefficients of thermal conductivity and thermal diffusivity. The results of the experimental study of mass-transfer processes are presented for dust systems, forming in laboratory plasma of a rf capacitive discharge. A method for simultaneous determination of dusty plasma parameters, such as the kinetic temperature of the grains, their friction coefficient, and characteristic oscillation frequency, is suggested. The coupling parameter of the system under study and the minimal values of the grain charges are estimated.

The measurements in dusty plasma were carried out to find the region of validity of approximate relation in statistical theory of liquid states. New results from the recent experiments using the Plasma Kristall-4 onboard of the parabolic flight plane A-300 Zero-G will be presented. These are: the formation of a boundary-free dust cluster due to attractive forces caused by ion uxes in a bulk plasma region; structural and dynamics properties of dusty plasma clouds containing elongated dust particles; initiation of solitary wave in dusty plasma by electrical manipulative electrode; 3D ordering of dust cloud in pure dc discharge and 'alternative' dc discharge. Physical models of the observed phenomena are discussed. This work was supported by the Grant CRDF RUP2-2891-MO-07, the NWO project 047.017.039 and by Research Program of the Presidium of the Russian

Academy of Sciences Thermophysics and Mechanics of Extreme Power Actions and Physics of Highly Compressed Matter.

COULOMB CLUSTER CONFINED IN A MAGNETIC TRAP

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Recently we have proposed to use a magnetic trap, based on the known possibility of the levitation of diamagnetic bodies in a nonuniform steady-state magnetic field, for confinement of clusters of charged diamagnetic particles [1, 2]. The electric charges of particles in the cluster are responsible for only interparticle Coulomb interaction, while their levitation and confinement in the trap are due to diamagnetic properties of the particle matter. This approach is an alternative for formation of dusty plasma structures in electric discharges for experimental study of strongly coupled clusters and systems. We have experimentally and theoretically shown the principal possibility of creation of such a trap.

We continue investigations of Coulomb clusters of diamagnetic particles in a magnetic trap. In this communication we present new results obtained by means of corresponding theoretical model. Parameters of the magnetic trap formed in the experimental setup described in [1, 2] have been found. We present dependences of the width and depth of potential well on magnetic field. The particle charge q has been estimated by three ways. For graphite particles with the size of the order of 10^{-2} cm, we find $q \sim 10^6$ elementary charges. Orientation of clusters consisting of two particles in the trap and its dependence on the magnetic field value and direction, is analyzed.

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INFLUENCE OF CONFINEMENT FIELD ANISOTROPY ON STRUCTURE OF DUSTY PLASMA SYSTEM

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A dependence of dusty plasma structure on anisotropy value of a confinement field was investigated on the base of the molecular dynamics method. Dust particles were characterized by the same density as melamine formaldehyde and had a shape of sphere with diameters of 7.1 μm. The simulated dusty plasma system was confined by the electrical force in the horizontal plane and by combination of electrical and gravity forces. The Yukawa potential was used to describe the interparticle interaction. A screening parameter of the interparticle interaction was determined by adjusting the interparticle distances to experimental data.

The simulation showed that the dusty plasma shape and structure sufficiently depended not only on anisotropy value of the confinement field but also on the dust particle number of the simulated system. The dusty plasma system represented a Coulomb ball with a typical shell structure in the background state for 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. At the same time the simulated system tended to the transition from the plane to bulk shape and to form the shell structure in the background state at increase of the dust particle number.

ABNORMAL KINETIC ENERGY OF DUST PARTICLES IN A GAS-DISCHARGE PLASMA

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A mechanism of the increase of the average kinetic energy of charged dust particles in gas discharge plasmas is suggested. Particle charge fluctuation is the reason for the appearance of forced resonance, which heats vertical oscillations. The energy transfer from vertical oscillations to the horizontal ones is based on the parametric resonance. It arises because of the overlapping of the eigenfrequency range of the horizontal oscillations in a dust particle cluster with the eigenfrequency range of particle vertical oscillations in near-electrode plasmas. The combination of the

parametric resonance and the forced resonance explains the high kinetic temperature of dust particles. The theoretical assumptions are confirmed by simulation of dust particles motion in the near-electrode layer plasma of gas discharge. The estimated frequency, amplitude and kinetic energy are close to the experimental values.

LONG-RANGE ASYMPTOTICS OF INTERGRAIN INTERACTION POTENTIAL IN EXTENDED DUSTY PLASMA STRUCTURES OF RF-DISCHARGE

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Here we present the results of determining of pair interaction potential in dusty plasma of rf-discharge. The analysis of intergrain interactions was carried out for the extended quasi-2D structures forming the sheath region. Under the experimental conditions the observed dusty structures changed from the weakly correlated fluids to the strongly coupled system. The dust positions were registered with a high-speed video camera. The video-record was processed by the special software, which allowed the identification of coordinates and displacements for each particle in the field of video-system view. The analysis of pare interaction potential was carried out by a new technique [1], based on a solution of the inverse Langevin problem. This technique has a wide spatial range of identification of interaction potential and also allows determining the friction coefficient and the external confining potential. Far asymptotic behaviour of the obtained potential for extended dust clouds is in a good accordance with the Coulomb interaction of grains ($\phi(l) \propto l^{-1}$). Meanwhile at short distances the intergrain potential has the Yukawa type dependence. The obtained long-range power asymptotics may be related to an influence of ionic plasma components [2], or can provides a proof of validity of the Wigner-Seitz-cell model in the ordered systems [3]. To make a comparison the reconstruction of the pair potential was also carried out from the available information on the pair correlation function on the base of the approximate integral relations of statistical physics [4].

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THERMODYNAMIC CHARACTERISTICS OF NON-IDEAL THREE-DIMENSIONAL SYSTEMS WITH ISOTROPIC PAIR INTERACTION POTENTIAL

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Here we present the results of numerical study of thermodynamic characteristics (such as the energy density, the thermal coefficient of pressure, the isothermal compressibility and the heat capacity) for non-ideal dissipative systems with Yukawa interaction potential. We considered non-ideal three-dimensional systems of the particles interacting with isotropic potentials. The case of Yukawa potential within a wide range of parameters typical for the laboratory dusty plasma experiments is considered particularly. The calculations were performed by Langevin molecular dynamic method.

In this work, the simple analytical approximation is presented for the energy densities of the two- and three-dimensional non-ideal systems, that was obtained with a help of the semi-empirical "jumps" theory developed for molecular fluids, and based on the analogies between solid and liquid state of matter The parameters of proposed approximation were obtained using the best fitting of the numerical calculations of energy density by analytical curves.

The mentioned approximation was used for the determination of analytical expressions for the pressures, the thermal coefficient of pressure, the isothermal compressibility and the heat capacity on base of the thermodynamics relations. To test a suitability of proposed approximation of energy density for a correct determination of the heat capacity, the calculation of the heat capacity was performed both in numerical experiment and from the analytical approximation. The comparisons of obtained results with the numerical calculations have shown that the proposed approximations can be used for the description of thermodynamic properties in analyzed non-ideal dissipative systems. We also note that results of the present study may be adapted to obtain the suitable approximations for the thermodynamic functions of the non-ideal systems with various types of pair interactions.

DIFFUSION CONSTANT AND ENERGY DENSITY OF NON-IDEAL SYSTEMS WITH ISOTROPIC PAIR INTERACTION POTENTIALS

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In this paper we present the results of numerical study of such transfer characteristic as the diffusion constant and its relation to energy density for non-ideal dissipative systems with screened coulomb pair interaction potential. We considered non-ideal three-dimensional systems of the particles interacting with isotropic potentials. The case of Yukawa potential within a wide range of parameters typical for the laboratory dusty plasma experiments is under study.

The calculations were performed by Langevin molecular dynamic method. In this work, the simple analytical approximation is presented for the energy densities of the two- and three-dimensional non-ideal systems. It was obtained with help of the semi-empirical jumps theory applied to molecular fluids and based on the analogies between solid and liquid state of matter.

The above mentioned approximation was used to determine the analytical expression for diffusion constant using well known thermodynamics relations. To test a suitability of proposed approximation of energy density for a correct determination of diffusion constant its values were both calculated in numerical experiment and from the analytical approximation.

The comparisons of obtained results with the numerical calculations illustrate that the proposed approximation can be used for the description of transfer properties in analyzed non-ideal dissipative systems. We also note that results of the present study may be applied to obtain suitable approximations for the transfer properties of non-ideal systems with various types of pair interaction potentials.

DIAGNOSTICS AND OPTIMISATION OF OPERATING MODES OF THE GENERATOR OF LOW TEMPERATURE ARGON PLASMA MICROPLASTER FOR MEDICAL APPLICATIONS

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Use of plasma in medicine was connected with its thermal effect on a processed surface until nowadays. However, non-isothermal plasma influence has been of great interest resently because of a possibility of its application for obtaining of various semilethal effects: sterilisations, healing of wounds, cell detachment, etc. We present methods of optical and probe diagnostics of low temperature plasma, created by microwave generator with frequency of 2.45 GHz at rather low power ($\sim$ 150 W) in a stream of inert gas of argon. The measurements of the floating potential of plasma by probe method were obtained. Spatial distribution of a brightness temperature in plasma, profile of gas temperature, vibrational-rotational spectrum of high resolution behind the microwave torch were derived. The estimation and adaptation of parametres of a plasma stream (temperature, speed of a stream and ionic compound) according to medikotechnical requirements were obtained. Research results had shown an efficiency of low temperature argon plasma effect on biological objects in vitro and in vivo for disinfecting and healing of the festering wounds, providing by irradiation during 10–15 min destruction of about 80% of pathogenic microorganisms on a wounded surface and destruction of 99.9% of cultivated pathogenic microorganisms in the absence of affecting influence on cells and mammal tissue in vitro.

THE INVESTIGATION OF THE RADIATION SPECTRA 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 because it gives the unique opportunities for experimental research of strongly coupled systems as well as for developing the new dusty plasma technologies of creating the new composite materials.

The presented work deals with the experimental investigation of dust particles radiation under the direct influence of electron beam. The experiments were carried out with particles made of different materials and with various forms and sizes (10–100 microns) in the air atmosphere at pressures 0.2 and 0.12 Torr; the current of electron beam was 10 mA and 2.6 mA correspondingly. The energy of electrons was about 25 keV and electron beam diameter was about 6 mm. Under the action of electron beam the dust particles began to radiate.

As the reasons of radiation, the thermal emission and the luminescence were considered. A good fit of the gray-body radiation spectrum to the experimental data is obtained. The heating was investigated analytically, the estimated temperature of the surface of dust particles is found to be about 2000 K.

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EXPERIMENTAL STUDY OF SELF-SUSTAINED OSCILLATION PROCESS IN DUSTY PLASMA INDUCED BY LASER RADIATION

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The presented work deals with the experimental investigation of oscillations of dusty macroparticles induced by the laser radiation. A dusty plasma structure was observed in the near-electrode layer of RF discharge (power 5 W), buffer gas-air (pressure 0.1 Torr). The experiments were carried out with carbon particles (56–71 micron). The laser beam was injected in the plasma volume perpendicularly to the dusty plasma structure and focused on a single particle. It was discovered, that the oscillations of dusty particles evolved by two distinct ways: 1) fast fading (lifetime less than 1 s.), 2) long-lived self-maintained oscillations (lifetime greater than half a minute). The preliminary analysis of experimental data was completed. The value of the typical oscillation frequency was 25 Hz.

EVOLUTION OF DUSTY PLASMA INSTABILITIES IN A GLOW DIRECT CURRENT 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. Using special programs coordinates of dusty particles were recovered after processing video data. Structure and dynamical characteristics of dusty plasma structures were obtained in a wide range discharge parameters. A dependence between interparticle distance in different parts of dusty structure and parameters of glow discharge was measured, also a dependence between frequencies of oscillations and the gas pressure for structures with self-excited oscillations was measured. For dusty structures with vortices the profile of an average kinetic energy and a profile of concentration were calculated and plotted. To explain mechanism of an instabilities initiation analyze of theoretical models have already existed was done.

ON THE ION DRIFT IN GAS MIXTURES

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The electric field causes ion drift and, in the case of a high electric field strength, the average ion velocity (drift velocity) can be high in comparison with the thermal velocity of gas atoms. The ion mobility coefficient depends on both the field strength and gas parameters (temperature, pressure, composition). The mobility coefficients are usually well known for weak fields and much worse known for strong fields. In the latter case, the velocity distribution function of ions deviate from the equilibrium Maxwellian distribution and the dependence of the mobility coefficient on the field strength arises. In addition to the determination of the ion drift velocity, an important problem is the determination of the ratio between the directed velocity and random thermal velocity of ions. Namely this problem was considered in previous papers, where it was shown that it is impossible to achieve a supersonic ion flux with a Mach number larger than two due to the ion heating effect. Let us consider ion drift in a mixture of different gases, bearing in mind the possibilities arising for experiments with dusty plasma. The ion flux characteristics, i.e., the degree of ion heating and the relation between longitudinal and transverse temperatures, can be varied by choosing the mixture composition. This makes it possible to predict the strong effect of the gas composition on characteristics of plasma-dust structures in discharges. More specifically, to determine the features caused by the supersonic nature of the flux, i.e., ion focusing, anisotropy of the interaction of dust particles, and others. The results of the calculation allow the following conclusions.

(i) In the case of heavy ion drift in light gas, ion heating is suppressed in an electric field and a supersonic ion flux arises at rather high electric field strengths.

(ii) In the case of ion drift in mixtures of gases with close properties (atomic mass and ionization potential), the ratio between longitudinal and transverse temperatures changes due to decreasing the frequency of collision with resonant charge exchange.

(iii) In the case of light ion drift in heavy gas, the drift velocity significantly decreases, and an ion flux with small Mach numbers can arise.

The main goal is to attract researchers attention to new possibilities of dusty plasma studies, e.g., to experiments with dusty plasma in discharges

in mixtures He-Hg, He-Xe, He-Kr, He-Ar, Ne-Ar-Kr, K-Xe, Na-Xe, and K-Kr. Other combinations are also possible.

HYDRODYNAMIC MODEL OF THE POSITIVE COLUMN WITH DUST PARTICLES

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In recent years the large number of well developed theoretical models for the description of RF discharge plasma in the presence of dust particles, were developed [1]. The local characteristics of such complex plasma around the dust particle, the charge gain and interaction between dust particles may be now described rather correctly using adequate assumptions on the plasma parameters. Nevertheless, the change of plasma parameters under the presence of dust is studied not sufficiently up to now and usually drops out of the consideration.

The influence of dust component on the DC discharge plasma is described as the first step to solve the self-consistent problem of complex plasma description. The DC discharge plasma is described in frames of diffusion approximation, combined with OML approximation for dust component. The problem is solved for the dust particles of 2 μm radius, embedded into the gomogenious glow discharge column with diameter of 16 mm at air pressure $P = 0.5$ Torr, current $I = 0.5 \div 3$ mA, particle concentration n_d up to $1.0 \cdot 10^5$ cm^{-3}.

The current-voltage characteristics for discharge with and without dust are calculated and compared with the available experimental measurements [2], [3]. The radial distributions of plasma components, as well as electric field and particle charges are calculated. It is shown that the higher is the current, the higher is stability of the discharge against the disturbing action of dust. The current-voltage characteristics represent the experimentally observed falling down with the increase of the discharge current. The particle charge values range about $(4.0 \pm 1.5) \cdot 10^3$ e, that agrees well with the experimental data.

The higher is the particles concentration, the lower is the radial electric field inside the dust cloud. When the dust concentration attains some critical value, the radial electric field changes the directionin some regions inside the dust cloud. In that region, the corresponding force acts on the dust particles, tending to change their positions. This force has not been

taken into account in this work, and will be included in the model as the next step.

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DENSE DUST CLOUDS FORMATION IN CRYOGENIC PLASMA OF GLOW DISCHARGE IN NEON

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Characteristics of dust structures depend on Debye radius, therefore its change under cooling of dust plasma leads to the reduction of distance between particles and to the increase of dust structure density [1].

For the first time, the formation of dust structures from 4.14 μm MF particles in a neon glow discharge with current $I = 0.01 \div 3$ mA at gas pressure $P = 0.2 \div 1.1$ Torr (at $T = 295$ K) and temperature of liquid nitrogen was studied experimentally. The temperature of a wall of the 16.5 mm i.d. discharge tube was adjusted in the range 77.4÷300 K. The initial distance between dust particles in the structure at $T = 295$ K and $P = 0.5$ Torr was about 300 μm, depending on a discharge current. It was revealed, that the reduction of gas temperature leads to the appearance of longitudinal fluctuations of particles and reduction of inter-particle distances. At a $T = 200$ K and $I = 0.6$ mA, the inter-particle distances reduced down to $50 \div 60$ μm in the centre, and 150÷200 μm at the edges of the structure, from the initial distance ~ 280 μm at 295 K. The reduction of T down to 77 K resulted to the inter-particle distance reduction down to 25÷37 μm. In this case the vertical fluctuations of particles with amplitude up to 150 μm were observed. Under increase of P and I, the average distances between particles changes slightly, but the dependence of the dust cloud shape on the discharge current remains the same. The reduction of P leads to the reduction of the quantity of particles in dust cloud and to the stratification of the cloud, with the formation of dense clusters of 3÷4 particles (in the longitudinal direction), with distances of 125÷150 μm between clusters and 25÷40 μm between particles in cluster. The similar effect of agglomeration was observed earlier in our experi-

ments with dust particles in the glow discharge in air at $T = 77$ K. The voltage-current characteristics of a positive column with dust particles at cryogenic temperatures differs essentially from that at room temperature. This distinction should be explained by the dust particles influence on concentrations and space distributions of electrons and ions in the discharge, analyzed in [2], as well as by the increase of the role of atomic metastable states in the course of ionization at low temperatures.

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MATHEMATICAL SIMULATION OF THE RADIATIVE PROPERTIES OF THE NUCLEAR-INDUCED PLASMA

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The application of the fine particles containing uranium for nuclear pumping of the gaseous active medium could increase a part of the energy carried out by the fission products from the condensed phase into the gas medium in comparison with the traditionally used methods of the heterogeneous nuclear pumping. Then it would be possible to make grounds to increase approximately by an order the efficiency of transformation of the kinetic energy of the fission products into the energy of the coherent optical radiation in the gaseous medium radiated by neutrons and containing nanoclusters of the uranium compounds. The present work is devoted for developing the theory of the kinetic processes and simulation of the radiative properties of the nuclear-induced dusty plasma. We performed the theoretical study of an influence of nano and micro-clusters of the fission material on the kinetic processes in the dusty plasma. As a result of the consideration of the medium kinetics it has been shown that the fine particles of the fission products could significantly influence the kinetic processes in the nuclear-induced gaseous plasma. Besides we studied an influence of nano and micro-clusters on the component composition of the medium in the dependence of their concentration and sizes for conditions of specific energy input powers character for the nuclear pumping. The main goal of the work is to evaluate an influence of the dusty component on the kinetic processes taking place in the given medium especially on the processes of population and settlement of the upper and lower levels

of the first negative nitrogen system (for helium-nitrogen-hydrogen dusty plasma, wave lengths are 391.4 nm and 427.8 nm). It should be mentioned that at present time this medium is the only gaseous active medium for the laser with the nuclear pumping allowing to obtain the laser radiation in the ultra-violet spectrum region.

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 inves-

tigate dynamics of the dust particles behavior and to choose a perspective geometry of the laser-active element.

NUMERICAL MODELING OF THE DUSTY PLASMA IN THE DC DISCHARGE

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The simulation results of the dc discharge positive column with dusty cloud are presented. The comparison with experimental data obtained in the PK-4 experiments is discussed.

DEBYE'S PLASMA OBSERVATION IN DUST PLASMA EXPERIMENTS

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Since the time isothermal dust plasma was studied that can be considered as the start of Debye's isothermal plasma research 10 years have passed. Though, the possibility of existence of this plasma type is not universally recognized. Furthermore there is no uniform system of classification of this plasma type, that resist of experimental and theoretical results representation. In this work the system of terms presented in [2–5] is used. Work [1] gives rise to many theoretical researches whose main aim is to find out the nature of Debye's atoms interaction using the conditions [1]. According to correspondence of analytical and calculation results the interaction potential of two Debye's atoms reaches minimum at distance of two Debye's radius.

The common item in [6] and [4] is the idea that result force acting from first Debye's atom to dust particle of another Debye's atom is calculated as the sum of the forces that act on the core from the electric field generated by first Debye's atom and the force acting from the polarized space charge of second Debye's atom to the its own core. In analytical researches [6] the influence of first Debye's atom on dust particle of second Debye's atom was taken into account by the idea of rigid constraint between spherical symmetric charged sheath and dust particle. In [4] sheath polarization of two Debye's atoms was taken into account and force acting on dust particle

of second Debye's atom was sum of forces that act from first polarized Debye's atom and its own deformed charged sheath.

The defect in [4] and [6] is that the problem of Debye's atoms interaction was solved in conditions of equilibrium distribution of electric field potential and concentrations of ions and electrons. Though, in real conditions there is electron and ion sink on dust particles. The problem of two Debye's atoms interaction with electron and ion sink on dust particle was solved in [7, 8] and also it was shown that in these conditions Debye's atoms attract to each other forming Debye's molecules and Debye's substance.

For the first time the existence of the Debye's plasma was experimentally validated in [9] in conditions of distant high-frequency discharge afterglow that produced dust plasma in interelectrode gap.

In work the analysis of different isothermal dust plasmas (or close to this condition) with electron and ion sink on dust particles is carried out. It was find out that Debye's plasma (Debye's substance) forms in dust plasma produced by products of radioactive decay. Special attention is given to analyses of correctness of results.

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EXPERIMENTAL STUDY OF A FLOW OF LIQUID UNDER ACTION OF AN ARC DISCHARGE AND JET OF POWDER GASES

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Results of research of flow of transformer oil and water under action of an electric arc with energy 10–100 kJ and jets of powder gases with enthalpy up to 500 kJ are presented. In the arc the current built up to 5–50 kA in time 1–5 ms that is characteristic for the arc discharge arising due to internal short circuit in high-voltage oil-filled electric equipment. Arc duration was 3–20 ms. The current and the voltage of the arc, chamber walls pressure, pressure in a gas cavity above a liquid were measured in experiments. High-speed photography of the discharge and liquid-gas surface was spent. It has been established, that there is no essential difference in characteristics of the discharge in water and in oil. It has been shown, that pressure in an extending gas-vapor bubble is about 10 MPa.

Powder gases have been received at burning powder in weight of 100–200 g in the high pressure chamber. Then gases have extended in Laval nozzle. Gas producing factor of gunpowder was 0.9 l/g. Pressure in the combustion chamber was about 600 MPa, pressure in jet at the liquid inlet (oil or water) was 10–30 MPa. Duration of jet influence on the liquid was 30–60 ms. In these experiments pressure was measured in characteristic points of the chamber. High-speed photography of liquid motion under action of a gas jet was spent.

The received results testify that at it is possible to provide hydraulic similarity of force action on a liquid of a gas jet and an electric arc. It may be provided by appropriate choice of a design of the powder gases generator. Accordingly, such generator can be used at the tests of the high-voltage oil-filled equipment on explosion safety.

PLASMA CHANNEL STRUCTURE DURING THE HIGH-VOLTAGE GENERATOR WITH THE PICOSECOND PULSE FRONT DISCHARGE TO THE MICROWIRES

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In our experiments high-voltage impulse generator (HVIG) "RADAN-220" with the characteristic impedance of 50Ω was discharged to the inhomogeneous 15 cm long coaxial line (vacuum camera), where to the center conductor there were placed 5 mm long microwires of Cu (20 μm in diameter), W (24.5 μm in diameter) and Ni (25 μm in diameter). HVIG parameters: voltage pulse amplitude was of about 220 kV; pulse rise time— 200 – −500 ps; energy stored in the generator – 1 J. Pressure in the camera varied from 10^{-4} mm Hg to 1 atm. The input voltage in the vacuum camera was measured via the capacitance voltage divider installed into the vacuum oil, and the electric current via shunt with the impedance $R_{sh} = 0.4\ \Omega$. Signals from both shunt and divider were registered by the four-channel digital Tektronix oscilloscope with 1 GHz bandwidth. It is revealed that the maximal current value is defined by the effective characteristic impedance and reaches 2.2 kA. It is also shown that for same conditions the form of the current does not virtually depend on the microwire material. The integral survey of the discharge via the DSLR camera Canon 450D with super close-up rings system, the discharge continuous sweep survey via the AGAT "SF-3M" camera, integral spectrum registration via the MS 257 spectrograph and the electron microscopy of the surface of the exploded microwires tails were also carried out.

It has been revealed that the microwires destruction process depends on the ambient gas pressure and on the thermal-field processes at the surface of microwires. The integral pictures of the discharge show the channel structure to be not one-dimensional, and also vortex and helical structures, clear luminous spots and plasma (electron) jets presence. It has been revealed that there is a reduced pressures range without any microwire destruction which divides two regions with different destruction mechanisms and corresponding oscilloscope records of current waveforms.

The work is carried out under the partial financial support of the RFBR (grant No. 10-08-00961-a), the Presidium of UB RAS within the integration projects, carried out by joint efforts of UB, SB and FEB of RAS, and also within the Program for basic research of the Presidium of RAS "Ther-

mal physics and mechanics of extreme energetic interactions and physics of strongly compressed matter".

RESEARCH OF HIGH-TEMPERATURE AREA FORMATION IN DISCHARGE CHANNEL IN DENSE HYDROGEN UNDER CHARACTERISTICS OF SOFT X-RAY RADIATION

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A self-constricted discharge in hydrogen initiated by wire explosion is studied experimentally at initial pressure up to 10 MPa and current amplitude up to 1.6 MA with current raise rate $dJ/dt = 10^9 - 10^{11}$ A/s. Duration of current first half-cycle was of 100–150 μs. A two-channel self-SXR detecting system is described. It is established, that temperature of central area of the discharge channel grows with increase in initial pressure of hydrogen. It is shown, that in the discharge channel surrounded with dense environment, an axial high-temperature area is formed owing to radiation capture. At an instant of maximal contraction of the channel X-ray quanta of the greatest energy are radiated, and temperature of plasma can achieve ~ 500 eV.

This work was supported in part by the Russian Foundation for Basic research (project nos. 8-08-00449a, 10-08-00739a).

INVESTIGATION OF VORTEX WAKE INDUCED BY DIELECTRIC BARRIER DISCHARGE

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In this experimental work the airflow, induced by asymmetrical dielectric barrier discharge (DBD) [1], was investigated. The peculiarity of the asymmetrical DBD is the presence of huge gradient of electrical potential in area, where the ionization of air, discharge and glow of plasma occur. Along the surface of discharger the airflow appears, and it induces the vortex near the discharger initiation area. The velocity magnitude of air

jet induced by DBD is sufficient enough to affect on flow pattern around the body placed in the subsonic airflow [2].

The visualization of airflow and vortex was performed by optical methods – high speed schlieren and 2D planar particle image velocimetry (PIV). The power supplying to discharger was provided by high voltage AC/AC-converter with variable amplitude of output voltage 0–5 kV and with the frequency 60 kHz. The investigation was carried out in two stages. At first the investigation of steady near-wall airflow was performed after the several seconds after discharge initiation. The instantaneous distribution of velocity in the near-wall airflow was obtained with the spatial resolution 0.1 mm. Then the high speed visualization and velocity distribution measurement were carried out in the airflow during 0–10 ms afterdis charge initiation with the spatial resolution 0.1 mm and time step 0.1 ms. The evolution of vortex structure was obtained with the different amplitude of voltage, applied to discharger.

The comparison of two visualization techniques was carried out. The parameters of airflow development depending on the amplitude of voltage, applied to discharger, were obtained.

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THE PROGRESS OF COMBINED OPENING SWITCH FOR PROJECT OF GENERATORS ON INDUCTIVE STORAGES

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The article proposes a fundamentally new approach to the problem of breaking high currents of 100 kA or more. The vacuum discharger and the vacuum interrupter differ significantly in the rate of electric strength recovery, size of electrode erosion and etc. This is due to the difference in the type of the discharge. In the report considered we suggested that to align these values the current I should be closed through the spark gap prior to moving the electrodes of the vacuum interrupter; at this its value is above the initial by ΔI (ΔI-current, $\Delta I/I_0 = (5 \div 10) \times 10^{-2}$). The excess ΔI-current flows through the vacuum interrupter, but in the reverse direction. In the course of moving the electrodes apart, the ΔI-

current falls to zero with a time constant $t = L/R$, where L and R are the inductance of the contour (vacuum interrupter – spark gap) and resistance of the discharge of the discharge gap, respectively. This makes it possible to quickly recover the electric strength of the gap between the contacts, substantially reduce the electrode erosion and significantly decrease the breaking voltage of the ΔI-current. At the final stage the discharge of the countercurrent battery recovers the vacuum strength of the discharge gap [1, 2, 3, 4, 5].

Such method of current breaking allows for the effective interruption of direct currents of high power. The method was developed in terms of the combination current breaker (vacuum interrupter and plasma opening switch). Spark gap is replaced to mobile plasma gap in design of combination opening switch. The article considers

– construction of switch;

– described of action steps;

– energy characteristics of circuit in the context to progress of conception pulsed generators based on inductive storage.

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PECULIARITIES OF ARC IGNITION WITH "SELF-HEATING" OF GRAPHITE

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The "self-heating" of the carbon is implied a monotonic increase of the temperature and resistance of sample with the fixed heating current. The growth of the temperature causes to the appearance of the arc discharge. In our experiments the maximum temperature of graphite before the arc ignition was about 3.25 kK. The samples were made of rod of spectral graphite, which had annular groove by a diameter of 3 mm and the length

of 20 mm. The samples were heated in argon at pressure of 10–100 kPa. The arc has initiated from the sharp jump of the voltage on the sample from 10–12 V to 30 V, and then the discharge along the surface has been occurred. The visible gap between two parts of sample was not observed at the initial moment. The intensive transfer of graphite between cathodic and anodic part of the sample at this time took place, and the anode diameter has increased by 10–30%. The visible gap between the cathode and the anode has appeared approximately through 1 s after the jump of the voltage. This gap could repeatedly overlap as a result the transfer of the graphite between the electrodes. The connection between the anode and the cathode before being finally destroyed could exist to 10 sec. The jumper between the electrodes took the form of the liquid bridge. High-speed film made it possible to fix the formation of the liquid drop with a diameter of 1 mm before the final destruction of the electrode connection. The voltage on the connection was about 25 V, in this case the oscillogram of voltage showed the sharp breakdowns, when voltage decreased to 10–15 V. Breakdowns with duration less than 1 msec followed each other with the period approximately 0.3 sec. After formation the electrodes separation the anode had the smooth drop-shaped form, the cathode geometry was close to the cone. The maximum cathode temperature was 3.0–3.2 kK at the arc current of 100–150 A, the maximum anode temperature was 3.3–3.6 kK. After arc the surface of electrodes were coated by the nanostructures, which were similar the strings with a diameter of 10–60 nm and by the length of 1–3 microns or the plates with the size about 1 micron. Probably, strings represent a bunch of nanotubes. The appearance of flat structures is similar graphene.

FAST-COLLECTIVE ELECTROSTATIC-OSCILLATIONS INFLUENCE ON THE GENERATION OF RUNAWAY-ELECTRONS BEAM IN ATMOSPHERIC GAS-DISCHARGE

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The fast termination of the run-away electrons beam in picosecond gas-filled diode is considered. The voltage pulse amplitude is about several hundreds of kilovolts, its duration — several hundreds of picoseconds. Whereas the duration of accelerated in run-away regime electrons beam is about tens of picosecond 10 ps $< t_b <$ 100 ps, the beam current $\sim$0.1–

10 A. Gas pressure is atmospheric. Cathode-anode distance is about 1 cm, therefore the dense plasma from the cathode cannot reach the anode plate within the ∼100 ps, and short-circuiting does not occur. As it can be easily estimated from voltage pulse parameters, the minimal electric field strength in the gap is about 100 kV/cm, what is only few times lower than critical field for run-away in the gas (for used nitrogen ∼450 kV/cm, for hydrogen ∼180 kV/cm). Therefore the fast termination of the run-away electrons acceleration in these extremely highvoltage conditions is of interest.

As a possible mechanism of such termination the collisionless collective plasma processes based on the Langmuir-oscillations are offered. It is shown that in the observed range 10–100 ps lies the build-up time of the following processes. 1) The virtual-cathode oscillation (at the plasma density $n \sim 3 \cdot 10^{10}$–$3 \cdot 10^{12}$ cm^{-3}). 2) The Buneman-instability (at the plasma density $n \sim 3 \cdot 10^{13}$–$3 \cdot 10^{15}$ cm^{-3}). 3) The beam-instability (at the plasma density $n > 10^{16}$ cm^{-3}). Therefore the collective plasma processes indeed can be the required mechanism of picosecond fast-electrons beam termination.

It is clear that the developing of all the discussed collective mechanisms depends on the density. The faster plasma and beam densities increase, the faster an instability build-up will occur. Therefore, the lower/bigger neutral gas pressure, the longer/shorter the beam duration. Similarly, the use of more easily ionizing gas (e.g. Cs vapor 3.89 eV) will lead to the fast-electrons beam shortening, and vise versa. Both these suggestions can be examined experimentally. It should be noted that the emission processes at the cathode will define not only the moment of the fast-electrons beam occurrence, but also the rate of the density ionization-growth, i.e. the time of instability build-up and the beam duration.

DYNAMICS OF A DENSE CATHODE SPOT PLASMA IN APPLIED TANGENTIAL MAGNETIC FIELD

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The plasma dynamics of a cathode spot cell in an applied tangential to the cathode surface magnetic field is considered in frames of the ecton model. It is shown that due to the dense metal plasma expansion across magnetic field plasma polarization occurs, what lead to an additional positive space charge formation at the “retrograde” (i.e. anti-Amperian) side

of plasma ball, and — negative space charge at the Amperian side. Therefore the probability of the new explosive center formation increases at the retrograde side, as well as it decreases at the Amperian side.

It should be noted that the polarization current is much less than the ion Bohm current in the core of explosive center (there the plasma density is more than 10^{20} cm^{-3}, space size $\sim 10^{-4}$ cm). But the Bohm current to the surface decreases as r^{-2}, together with plasma density. Let us to subdivide spot plasma to three regions: inner one — with most of density, there magnetic field influence is almost negligible ($n > 10^{20}$ cm^{-3}, $r < 10^{-4}$ cm), outer one — there plasma is rare enough for $\omega_e \tau_e \sim 1$ and MHD-instability can build up ($n < 10^{15} - 10^{16}$ cm^{-3}, $r > 10^{-2}$ cm), and the middle region. The polarization due to the transverse plasma expansion should be considered in the middle region.

The enhancement/decreasing of a space charge was taken into account by Mackeowen-like equation by enhancement/decreasing of ion-density at the sheath boundary. Then the Fowler-Nordheim expression was used for field-emission current density evaluation j. The time delay of a new explosive center occurring tec was estimated by integral of action h: $t_{ec} \sim h/j^2$. The explosive center motion velocity was defined as $L/10$ ns, where L — the length from the center where t_{ec} is less than 10 ns. Estimated by this type directed spot velocity v_{retr} is about $v_{retr} \sim B$, where v_{retr} =[cm/s], B =[Gs]. It should be noted that the random motion of a cathode spots with velocity $v_{diff} \sim 10^4$cm/s is prevailing until magnetic field reaches $\sim$1 T. Then the velocity of a retrograde motion becomes comparable with the random motion one: $v_{retr} \sim v_{diff} \sim 10^4$ cm/s.

THE WORK FUNCTION OF A CATHODE AT THE INITIAL STAGE OF EXPLOSIVE ELECTRON EMISSION

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Practically in all cases, high-power electron beams are produced with the use of explosive emission cathodes. Of interest are investigations of the expanding cathode plasma, its characteristics, and the velocity of motion of the plasma front at the initial stage of explosive emission, when we deal with essentially nonideal high-density plasma.

The goal of the work was to construct a self-consistent model based on the electron density functional theory [1] which would allow one to predict the work function of the cathode plasma in the range of densities from

the metal density (10^{23} cm^{-3}) to the density of the cathode spot plasma ($\sim 10^{18}$-10^{20} cm^{-3}) and in the range of electron temperatures from zero to $\sim$5 eV.

The work function was calculated, like in the study of Lang and Kohn [2], in the LDA approximation [3] with the use of a uniform positive background model with the difference that we considered the states of the electron system at finite temperatures. Calculations have been performed for a copper cathode. It has been shown that as the concentration of free charge carriers at the front the cathode flare is decreased from $\sim 10^{23}$ to 10^{20} cm^{-3}, the work function of the plasma decreases to about one fifth. The use of the model developed encounters difficulties when the temperature dependence of the work function is calculated for temperatures above $\sim$6000 K. This is related to the occurrence of an appreciable thermal electron emission current and, hence, to the buildup of the space charge of emitted electrons. Application of an external field substantially reduces the space charge in vacuum. In this case, the work function increases with temperature for any electron density due to the square-law decrease of the electron subsystem chemical potential. The results obtained will be used in constructing closed models and in simulating the operation of explosive-emission centers with self-consistent calculations of emission characteristics.

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EXPERIMENTAL AND NUMERICAL STUDY OF DISTRIBUTION OF PLASMAS IN THE DISCHARGE CHANNEL UPON ALUMINUM WIRE EXPLOSION

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Distribution of matter in the discharge channel formed upon a nanosecond electrical explosion of a Al wire in vacuum was studied. Simultaneous use of optical, UV, and X ray diagnostics made it possible to distinguish qualitatively different regions of the discharge channel, such as the current-carrying layers and the region occupied by a weakly conducting cold plasma. Several series of experiments with 25 μm diameter 12 mm long wires were performed. The charging voltage and the current amplitude were $U_0 = 20$ kV and $I_{max} \sim 10$ kA [1]. Shadow and schlieren images of the discharge channel were obtained using optical probing at the second harmonic of a YAG: Nd^{+3} laser ($\lambda = 0.532$ μm, $\tau \sim 10$ ns).

The simulations were performed by RAZRYAD-2.5 [2] implementing Braginskii model of two-temperature magneto hydrodynamics and devised on the base of homogeneous conservative implicit finite-difference MHD schemes. Multigroup spectral approximation is applied for the radiation energy transport computation with the use of diffusion model or ray-tracing method based on a model of Shuster and Schwartzshild. Heat- and electro- conductivity anisotropy in magnetic field is taken into account. The code allows utilization of data tables for thermal and optical matter properties. Aluminum thermal and optical properties data tables [3] were applied in the computations under consideration. We have investigated the influence of the radiative energy transfer upon the matter parameters distribution and the electric current density in the discharge channel. Numerical results are analyzed via comparison with experimental.

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INFRARED LASING IN Ar-Xe-PLASMA CREATED BY A NON-SELF-SUSTAINED DISCHARGE

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Production of Ar-Xe-lasers with a high average lasing power has two significant problems: formation of powerful rep-rated pumping pulses of electron beam and non-self-sustained discharge and heating of gas mixture. A device presented in [1] allows to solve the both problems.

This report presents the results of experiments on electron-beam and non-self-sustained-discharge pumping of Ar-Xe-laser in a regime of single pulses with the use of the above device. 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.

The parameters of obtained lasing pulses are as follows: maximum pulsed lasing power at wavelength of 1.73 micrometer is 50 kW; half-height lasing pulse duration is 130 ns; energy of single lasing pulse is 6 mJ.

The experiments [2] showed that limitation of lasing power during frequency pumping of Ar-Xe-laser is explained by heating of working gas mixture. So an effective cooling of the gas mixture in close cycle by a liquid nitrogen is necessary. Our device [1] will allow to cool gas mixture during frequency pumping and to obtain high average lasing power.

The work is supported by RFBR (project No. 08-08-00505a).

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MONOCHROMATIC X-RAY GENERATOR FOR METROLOGICAL SUPPLEMENT OF PLASMA DIAGNOSTIC

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In this paper an information about X-ray generator CC607 developed at RIPT is presented. The generator is intended for calibration and measuring of characteristics of X-ray detectors, filters, mirrors and other X-ray converters in order to acknowledge that it is satisfies to all requirements of plasma diagmostics. The generator consists of vacuumable x-ray tube, sample ionisation chamber, masuring chamber, pumping system, high voltage power sources and controls. X-ray tube can be easily disassembled for repairing and maintenace. It has direct-heating cathode, capstan anode head, series of selectable filters and monitors. While powered with 0.7 to 15 kV the X-ray tube provides static generation of 12 separeted lines of characteristic radiation, that is uniformly distributed in the range from 0.07 to 8 keV. For monitoring radiation generated it uses x-ray diode with Au cathode for energies less than 0.3 keV. For greater energies there are diamond x-ray detector.

The sample ionisation chamber is intended for absolute measuring of energy density of radiation at exit of the x-ray tube and it's used for periodical measuring of sensitivity of monitors. Ionisation chambers is filled with highly pure argon or nitrogen under preassure from 1 torr to 1 atm. Maximum density of flow of x-ray quantums is at least $5*10^9$ quantum/(s*sm^2), purity of lines generated is not worse than 75%. Exit window has diameter of 10 mm, radiation is emited horisontaly.

Design of measuring chamber allows calibration of six detectors simultaneously during one period of mesurment without breaking of vacuum. Calibration can be carried with all 12 lines one next to another. Diameter of detector must not exceed 20 mm. Cooling of detectors with liquid nitrogen is also available. Callibration error does not exceed 15% if signal-to-dark-current ratio is greater than 0.5.

INVESTIGATION OF SOLID PARTICLE PARAMETERS IN HIGH-TEMPERATURE FLOWS USING HIGH-SPEED VISUALIZATION SYSTEMS

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Heterogeneous plasma flows are widely used for heating the particles and plasma spraying [1]. Wide temperature and dynamic range realized in plasma jets and the possibility of using different working gases allow combining phase and chemical transformations in a single technological process to ensure the desired modification of the initial powders and coating materials with a given structure [1].

This paper reports on methods for monitoring the particle parameters during plasma spraying and establishing the dependency of the main parameters of the sprayed particles starting from the plasma parameters and operating modes of the plasma jet, as well as obtaining distributions of these parameters in different areas of the plasma jet. Using high-speed video equipment and specially designed IR cameras, the measurements has been performed of the velocity fields and acceleration of Al_2O_3 particles in heterogeneous plasma jet interaction area with the surface of the target using a plasma spraying installation. A comparative analysis of the heating efficiency of carbon and Al_2O_3 particles sized from 20 to 100 microns in high-current plasma generator with the expanding anode channel at atmospheric pressure was completed.

The next stage of development of new coal combustion technologies and coal gasification are new plasma-fuel systems (PFS), which are the pulverized-coal burners, equipped with plasma generators, and combined plasma gasifiers for thermal power plants. PFSs provide oilless burning initiation of coal-fired boilers, coal-dust flame stabilization and simultaneously increase fuel combustion efficiency and decrease formation of nitrogen oxides.

The system described in this paper can be used to control the parameters of carbon particles during combustion of coal-fired power plants and coal gasifiers. High-speed visualization of heterogeneous flows allows determining the following parameters: velocity of particles in the jet, distribution and changes in particle sizes and the particles temperature.

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THE INFLUENCE OF ELECTRON-ATOM INTERACTION ON THE CONDUCTIVITY AND COMPOSITION OF NOBLE GASES UNDER HIGH PRESSURES

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The properties of noble gases (Ar, Xe, Kr) under high pressures have been studied intensively during several dozen years [1, 2]. One of the most frequently used techniques to study different wide-ranged characteristics theoretically is the generalized chemical models (GCM), which are based on the law of mass action. Recently the integral equations (IE) of the liquids theory were applied to the description of atom-atom interaction within GCM [3]. It was shown that this is dominating interaction, which leads to changes in properties of the substance in hand from dielectric to metallic with the increase of densities. In particular the conductivity at the density $\sim$ several g/cm^3 rises abruptly to the Ioffe–Regel value [2]. Up to this density the neutral particles dominate, so the interaction between atoms and charged particles is of minor importance. But at higher densities, when the conductivity grows, the interaction between neutrals (atoms—a) and charges (electrons—e, ions—i) begins more important. The contribution of e–a and i–a interactions to the free energy are usually described by the second virial coefficient for some polarization potential ($U(r) \sim \alpha/(2r^4)$, $r \to \infty$). At $r \to 0$ the potential is supposed to be $U(r) \sim$ const. It is the case for almost all calculations [1–3]. But the virial approximation can be incorrect when the numbers of charged particles are comparable with the neutrals. Besides it is known that in noble gases at low temperatures e-a potential should include the interaction between the electron and atom core [4]. I.e. $U_{ea}(r) = \infty$ at $r < r_c$, where r_c is the core radius. The presence of core can shift the ionization potential significantly [4]. Consequently, the first aim of this work was to take into account the influence of atom core. The second aim was to apply integral equations to the charge–atom interactions just like it has been done for atom–atom interaction. The results of our calculations were compared with available experimental and theoretical data.

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SIAS — Scientific Industrial Association "Sintez", Moscow, Russia

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SNL — Sandia National Laboratories, Albuquerque, United States

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SPbSU LTFT — Saint-Petersburg State University of Low Temperature and Food Technology, Saint-Petersburg, Russia

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SRC RF TRINITI — State Research Center of the Russian Federation – Troitsk Institute for Innovation and Fusion Research, Troitsk, Moscow Region, Russia

SSC RF IPPE — Federal State Unitary Enterprise "State Scientific Centre of the Russian Federation – A. I. Leypunsky Institute for Physics and Power Engineering", Obninsk, Russia

SSC RF ITEP — State Scientific Center of the Russian Federation – Alikhanov Institute for Theoretical and Experimental Physics, Bolshaya Cheremushkinskaya 25, Moscow 117218, Russia

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SUT — Sharif University of Technology, Tehran, Iran

SWCMRC KU — Shock Wave and Condensed Matter Research Center, Kumamoto University, Kumamoto, Japan

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TC Schlumberger — Technology Company Schlumberger, Moscow, Russia

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