S6 Plasma Polymers - Candidates for Biomedical Application

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Due to the fact that polymers are applied to design low-weight devices and to realize different geometries very easily, plasma polymerized thin films are mainly deposited onto polymeric substrates. Plasma Polymerization is used since more than 40 years to develop thin films for different kinds of applications. At least since the sixties of the last century these films are used in the fields of medicine and pharmacy.It is a characteristic property of plasma polymerized films that they show strong adhesion to polymer substrates due to creation of radical sites at the interface when deposition starts. Thus thin layers with good adhesion, a defined amount of chemical functionalities and stability to sterilization processes are generated. This fits to the needs for medical application.

In principle plasma processing offers different approaches for the deposition of thin films with a variable amount of functionalities available for reaction with bio-molecules. Advantages and disadvantages of the different deposition strategies will be discussed.

The interaction of biological systems with materials can be divided in three categories. First, the interaction with bio-molecules. Here the binding of molecules with specific activities on one hand and the minimizing of unspecific protein adsorption on the other hand can be influenced by thin plasma polymers deposited on medical devices. Second, the interaction between bacteria and surfaces can be modulated via deposition of thin films with bacteriostatic or bacteriocidic properties on devices. Third, the interaction of surfaces with mammalian cells can also be influenced to enhance the cell growth and cell proliferation for the development of test kits or implants. In this contribution examples for these three categories will be shortly reviewed.

Beside the preparation of the mentioned films also the analytical tools necessary for film development and control of its properties are stressed in this contribution. A correlation between physico-chemical properties of the applied plasma polymerized films and the biological requirements will be tried.

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S1 The Control of an Unstable Plasma Configuration – the Tokamak

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The tokamak plasmas are intrinsically unstable systems due to both their geometry and magnetic configuration. In the past, these instabilities have been (or simply not!) controlled by passive conductive structures like thick copper shells or analog electronic feedback devices.

New machines typically with plasma currents above 100kA are more demanding on control because the power involved does not leave any margin for error and passive control is impracticable due to its size. If plasma control is not achievable, major disruptions may occur with strong damage on the walls and forces on the structural components. For example ITER itself will only support 10 to 20 disruptions.

Presently the migration of active analog controllers to digital platforms is becoming common giving more powerful control on the process to the end user, due to the advent of fast parallel processing capabilities in hardware embedded systems. Indeed, this approach permits to solve direct physics driven equations instead of the engineering PID models or other custom solutions. Moreover those approaches permit to introduce perturbations or other stimulus to the actuators simply by software modification, eliminating special design by hardware for experiments.

The Compass tokamak for instance is being refurbished with such modern systems. This will give to Compass the capability to serve as a test bed of these systems in the perspective of ITER and DEMO. In this talk the state of the art of the underlying technology for plasma control based on this paradigm will be address and the new challengers rose by the emerging machines. In particular, the new developments done at IST to propose a modern fashion technology based on ATCA crates and ADCs with local processor power availability will be addressed to show that is possible to use Compass as a “proof of concept” for ITER.

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S4 Cavity Ring Down Spectroscopy Measurements of NO_3 Radical Produced by Plasma Chemical Reaction with Atmospheric Pressure Dielectric Barrier Discharges

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Cavity Ring Down Spectroscopy (CRDS) is one of the most powerful tool to perform quantitative measurements of trace molecules. Accurate determination of trace gas and radical concentrations is needed to advance in understanding of chemical processes. We have focused our attention on detection of nitrate radical, NO_3. NO_3 is a relevant radical in atmospheric science field due to the importance in the oxidation of pollutants as well as in various plasma chemical processes. Nitrate radical is usually detected by means of the strong absorption in the electronic B←X band in the 600-700 nm region, with peak cross section of the order of 10^{-17} cm^2/molecule. In this paper we report on NO_3 trace laboratory measurements performed by means of continuous wave (cw)-CRDS based on External Cavity Tuneable Diode Laser. Our apparatus is currently able to detect an NO_3 minimum concentration of 0.1 ppb at atmospheric pressure.

We have investigated plasma-chemical sources producing NO_3 based on atmospheric dielectric barrier discharge (DBD) for testing the sensitivity of the CRDS technique as well as to have insights on some reaction mechanism forming NO_3 in discharge and post-discharge. A coaxial Dielectric Barrier Discharge configuration fed with gas mixture based on N_2, O_2, NO has been used to this purpose.

The most abundant source of nitrate radical was based on the reaction of ozone produced by an O_2 DBD with known quantities of a gas mixture composed of N_2 and NO trace injected downstream. The NO_3 production was limited only by the ozone production and the NO traces present in the gas mixture, and the production of NO_3 could be varied by changing the discharge parameters(from few ppb up to few ppm). The source was also characterized by means of more conventional absorption measurements due to the high production of NO_3 obtained in this way. In order to understand the chemical reaction involved in the production, parallel investigation were conducted in an optical cell on NO_3, O_3, NO_2 monitored by conventional absorption spectroscopy and on NO conversion monitored by Laser Induced Fluorescence.

The nitrate radical was detected also in the stream of an atmospheric pressure DBD fed with $N_2/NO/O_2$ gas mixture. In this case the production of NO_3 was lower than in the reaction of NO with O_3 and cavity ring down is needed to detect efficiently the production of NO_3.

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S3 Plasma-Based X-ray Laser at 21 nm for Multidisciplinary Applications

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An overview of recent advances in development and applications of currently the most energetic X-ray laser at 21 nm will be presented. The unique parameters of this half-cavity based X-ray laser such as record output energy of 10 mJ, highly symmetric beam, robustness and reproducibility, have made it possible to carry out a number of multidisciplinary scientific projects featuring novel applications of coherent X-ray radiation. They include probing of dense plasmas, transmission measurements of intense X-ray radiation, ablative micropatterning of solids, study of X-ray Thomson scattering from dense plasmas, visualization of nanometric transient perturbation of optical surfaces, measurements of ablation rates of thin foils heated by infrared pulses, molecular radiobiology, and studies of 2D plasma hydrodynamics in the regime of sequential illumination which indicates further room for boosting the X-ray laser output beyond 10 mJ. Finally, we report on the development of ultrafast coherent X-ray beamline based on kHz, table-top high-order harmonic generation in noble gases capable to deliver fully coherent, femtosecond, and tunable X-ray beam in the 13 - 35 nm spectral range, intended for seeding the Ne-like Zn plasma amplifier.

This research benefited from support of the Czech Science Foundation (202/05/2316, 202/07/J008), from the Czech Republic’s Academy of Sciences (KAN300100702), the Centers of Fundamental Research (LC528) of the Czech Ministry of Education, and the Access to Research Infrastructures activity in the 6th Framework Programme of the EU (RII3-CT-2003-506350, Laserlab Europe).

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S3 Acceleration of Ions from Solid Targets Irradiated by Short Intense Laser Pulses

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Emission of energetic ion beams from the surface of thin foil targets irradiated by short intense laser pulses has been demonstrated in experiments and simulations. These ion beams are attracting much attention in recent years because of a wide range of their potential applications covering radiography imaging, radioisotope production, isochoric heating, cancer therapy etc. For practical realization of these applications, it is important to be able to efficiently produce collimated beams of high energy ions with possibly quasi-monoenergetic distribution.

Linearly polarized laser radiation accelerates electrons to very high velocities and these electron form a sheath layer on the rear side of thin targets where preferentially protons are accelerated. This so called Target Normal Sheath Acceleration (TNSA) process is responsible for acceleration of ions in most experiments and the energy spectrum of the resulting fast ion beam is usually exponential. The efficiency of the TNSA process and the energy of accelerated ions may be increased by using special kinds of targets, which enhance the laser energy coupling into fast electrons (e.g. targets with special surface structures) or which reduce the lateral transport of the absorbed energy (mass-limited targets). The concentration of fast electrons and the amplitude of the electrostatic field in the surface sheath may also increase due to electron recirculation in ultrathin foils. In targets consisting of two ion species heavier ions facilitate formation of quasi-monoenergetic bunch of lighter ions.

A novel ion acceleration process relying on the circularly polarized laser radiation has been demonstrated in recent simulations. Fast electron production by circularly polarized light is inefficient due to the absence of the oscillatory component of the ponderomotive force. Ion acceleration takes place in the radiation pressure dominant regime on the target front side, where the electrostatic field is induced. The acceleration process is accompanied by the ballistic evolution of the target itself, most ions attain the same velocity in the laser propagation direction and it may be possible to accelerate the whole ultrathin foil as a compact dense block of quasi-neutral plasma. This mechanism enables to obtain quasi-monoenergetic ion beams and in the targets consisting of multiple ion species it may be efficient in terms of the laser energy transferred in particular to heavier ions.

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S3 Laser Plasma Research at the PALS Research Centre – the Present and the Future

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The PALS Research Centre, a Laserlab-Europe member, has been serving the European laser community since September 2000. Its key facility, the terawatt kJ-class iodine laser system is exploited in a large variety of target experiments at focused laser beam intensities of up to 10^{16} W/cm^2, for studying the interaction of high-intensity laser radiation with matter and for pumping plasma-based high-intensity soft x-ray lasers in particular. In the paper a survey of both the domestic and external projects performed at PALS during the last two years and of their selected results will be given.

Among the experimental results highlighted in the paper various applications of the PALS record-brightness zinc soft x-ray laser will be mentioned on the first place, namely its use in laboratory astrophysical experiments, in x-ray ablation and solid-state-density plasma studies. Encouraging results have been obtained also at testing new soft-x-ray laser schemes, as well as at feasibility studies of the Thomson x-ray scattering for diagnostics of high-density plasmas.

The second group of PALS experiments was aimed at development of laser ion and radiation sources for various scientific and technological applications. Systematic studies of the ion acceleration in the expanding plasma plum performed at PALS, together with sophisticated ion diagnostics used, contributed to better understanding of the role of a manifold of non-linear processes leading to acceleration of highly charged high-Z ions to high energies. In particular, they revealed a crucial role of the initial target irradiation geometry.

Further, the results achieved at investigation of ablation processes governing the interaction a high intensity laser radiation with various types of structured targets will be discussed. This category includes e.g. experiments on laser imprint smoothing by low-density foam layers, on ablative acceleration of macroparticles, and on laser production of plasma jets. Remarkably stable high-density supersonic plasma jets were launched at PALS by using a novel original method developed there last year, which may find its use in both the laboratory astrophysics and ICF research. Quite recently, a world-unique series of experimental results on interaction of high-Z plasma jets with ambient gas has been obtained at PALS, which supplies rich material for comparing the experiment with theoretical models.

The high quality laser plasma research performed at PALS up to now, together with the new facility options under preparation, such as auxiliary diagnostic short-pulse and x-ray beam lines, gave base for the PALS active participation at the preparations phases of the laser facilities HiPER (High Power Laser for Energy Research) and ELI (Extreme Light Infrastructure) having started recently in accordance with the ESFRI Roadmap for Pan-European infrastructures. The PALS role at developing these new powerful tools of the hot dense matter research will be discussed in the last part of the paper.

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S3 Coulomb Explosion of a Cluster with Two Ion Species

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Recent progress in laser and nanomaterial technologies opens up opportunities of creation intense multi-terrawatt femtosecond laser pulses and construction of unique nanoscale targets (clusters). This give reasons for study of physics of Coulomb explosion (CE) and ions acceleration up to multi-MeV energies in the interaction of short laser pulses with clusters. Understanding of laser triggered ion explosions is essentially important because of its possible applications as a neutron sources, x-ray sources, applications in proton radiography and isotope production. Number of experiments planed in near future aims the detail studies of laser pulse interaction with submicron mass-limited targets.

For targets that are smaller than the laser skin depth, instantaneous ionization give rise to cluster explosion that may occur when electron energy in laser field is well above the energy of Coulomb attraction by ions. Typically, the energy spectra of accelerated ions is rather broad and terminates with an abrupt upper cutoff. But observation of a group of monoenergetic light ions has been already reported for microplasmas composed of heavy and light ions. The formation of a group of monoenergetic ions occurs from an initially homogeneous target that is different from often discussed bilayered spherical cluster with heavy ion core and ultrathin light ion coating. Naturally, substantial simplification of the nanotarget design without particle monochromaticity loss may enable significant advances in developing high-energy ion sources for different applications. This is why the case of homogeneous cluster composed of heavy and light ions is of a special interest. Light ions, expanding faster than heavy ones, concentrate on the cluster front and are well accelerated by back heavy ions. This results to a formation of nearly monoenergetic light ion spectrum.

In this report we present an analytical study of CE of a spherical cluster consisting of heavy and light ions for the case when the total charge of light ions is much lesser than the one of heavy ions. Such expansion can serve as a source of monoenergetic ions, with high monochromaticity. Monoenergetic ions participate in multi-flows that cannot be studied with pure hydrodynamic approach and requires kinetic description. Spectral and space-temporal distributions of light ions are found. We conclude that interaction of relativistic high contrast laser pulses with cluster gas-jets may produce unique plasmas with ion temperature in the multi-MeV range.

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S3 Experimental Studies of Emission of Highly Charged Au-ions and of X-rays from the Laser-Produced Plasma at High Laser Intensities

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The PALS iodine high-power laser system in Prague was used for the studies of the extreme characteristics of the Au ions, emitted from a laser-produced plasma at various experimental conditions. These studies were performed with the fundamental (λ = 1.315 μm) and the 3rd harmonic (λ = 0.438 μm) frequencies, with laser energies up to ~ 400 J in a pulse length < 300 ps (laser intensity up to 5×10^{16} W/cm^2), at various angles of the target irradiation, and at variable focus positions. The focus setting (the position of the minimum focus spot with regard to the target surface) determines not only the nominal laser intensity, but also the conditions of the laser beam interactions with the plasma, produced by the laser pulse irradiating the target. The plasma created by the front part of a long (> 100 ps) laser pulse, with which the main part of the pulse interacts, can be regarded as a kind of pre-plasma. The interaction of laser radiation of intensities above ~1×10^{14} W/cm^2 with pre-formed plasma significantly increases the charge state and energy of the produced ions due to participation of various non-linear effects, including ponderomotive, relativistic, or magnetic self-focusing.

Au ions with charge states around 57+ and with the kinetic energy in the region of ~100 MeV were recorded. The dependence of the emitted ions on the angle of laser irradiation of target was followed, too. Simultaneously, the emission of X-rays was investigated and correlated with an ion generation. Ion collectors and cylindrical electrostatic ion energy analyzer were used for the ion diagnostics. Semiconductor photodiodes, thermoluminiscent diodes and diamond detectors, all with various filters, monitored the X-ray radiation produced. The results are discussed and compared with those obtained with Ta target.

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S3 RZLINE + THERMOS-BEELINE - a New Numerical Instrument for Modeling of Dynamics of Strongly Radiating Plasmas

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Combination of use of two-dimensional (r, z) Euler MHD code RZLINE and newly developed code THERMOS-BEELINE have been used for modeling of laser produced Sn plasma as possible source of EUV radiation (13,5 nm) for next generation of projection lithography.

Existing RZLINE code was improved by incorporation of extended description of solid state targets (presumably tin droplets) ablation process. The code includes energy and mass flows to and from target (droplet) surface due to thermo-conductivity, evaporation-condensation processes, radiation fluxes in all considered spectral groups, calculation of temperature profile in the droplet.

THERMOS-BEELINE code allows self-consistent calculation of level kinetics and radiation transport for different plasma configurations. New essential feature - radiation transport of overlapped spectral lines with arbitrary optical thickness and usage of realistic line profiles. Calculations are basing on extended and verified atomic database for low-Z materials (H, He, O) and also for Xe, Sn and their mixtures.

Modeling was fulfilled for conditions typical for some industrial prototypes of EUV source for lithography and also for experiments with EUV radiating LPP plasma in ISAN. An approximation using 100 spectral groups was generally used. These calculations include corrections on experimentally verified position of strong Sn lines, especially those which are close to in-band EUV region. It was shown that this essential for calculation speeding up approach gives results which are in a good agreement with more precise 5000 groups approximations.

Using post-processing procedure it is possible to calculate high resolution EUV spectra in the spectral range 80-250. It allows predicting full doze of radiation in narrow spectral band passing through set of multi-layer mirrors in the lithographic device – so called “in band” EUV signal. Comparison of numerical modeling and experiments has been done for a number of important parameters as next:

- time dependence of in-band EUV radiation
- spectra in wide EUV region
- EUV source sizes
- energy anisotropy of fast Sn ion
- mean ion charge of fast Sn ion

Good agreement shows that RZLINE - THERMOS-BEELINE combination is a powerful instrument for LPP where radiation plays an essential role.

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S3 Interaction Laser Plasma Ions of Al, Ti with Surfaces Al and CuBe

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The development of effective ion implantations, local element analyzers, high-power ion sources, lasers based on multi-charged-ion transition, plasma lasers stimulate not only study of ionization composition of the laser plasma, and also study of interaction multiply charged laser plasma ions with solid states.

We adduce results of study to electronic emission with surfaces Al and CuBe at influence multiply charged ions Al, Ti with charge number Z = 1 - 8 and energy E = 1.0 keV - 200.0 keV. The experimental installation consists of laser mass-spectrometer (Poverhnost, 1996, N 6, pp.93-95 and Zh. Tekh. Fiz., 2002, vol. 72, N 8, pp.89-94.). Mass (m), charge (Z) and energy (E) spectrums of multiply charged laser plasma ions Al, Ti studied depending on parameters of laser radiation.

The investigation of influence multiply charged laser plasma ions with solids was found some regularity to electron generation depending on energy, charge number, intensities, and masses multiply charged ions, and also from element composition secondary target. It was found experimentally that, strong temporary correlation between flow pulses of multiply charged ions and secondary electrons that, is indicative of absence role the thermal processes in emission phenomena. Study of output electrons depending on E and Z multiply charged ions are installed that, under comparatively low energy multiply charged ions all charge number ($E \leq 5.0$ keV) and high energy ($E \geq 75.0$ keV) ions with $Z \geq 3$ is absent charge dependency of coefficient to secondary electron emission Al and, CuBe under influence ions Al, Ti with energy $40 \leq E \geq 75$ keV. In range of multiply charged laser plasma ions energy of E = 2.0 keV ÷ 200.0 keV change the coefficient to secondary electron emission has a nonlinear character with one maximum in E = 50 keV is shown. From obtained results it follows important conclusion about that, in emission under the action of laser plasma ion will become to contribute not free, but bounded electrons of the lattice. Probably also observable contribution to emission will become to contribute and own electrons bombarding laser plasma ions.

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S3 Free Electron Laser with Electromagnetic Wiggler Guided by Ion Channel and Uniform Axial Magnetic Field

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By using equations of motion of electron beam and field equations, a set of coupled nonlinear differential equation is derived in slowly varying envelope approximation for a single pass free electron laser with electromagnetic wiggler, uniform axial magnetic field and ion-channel guiding. The electron beam propagates with a relativistic velocity, ions are assumed immobile and slippage is ignored. Numerical simulations are performed with and without ion channel, for electromagnetic wiggler. A comparison is made with the result of propagation of the electron beam in magnetostatic wiggler. Calculations are made for the saturation length, bunching parameter and output power.

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S4 Novel Concept of Electric Discharge Oxygen-Iodine Laser

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A new advanced concept of discharge oxygen-iodine laser (DOIL) is presented. The concept includes a supersonic DOIL (the laser wavelength of 1315 nm) with a combination of a discharge singlet oxygen generator (DSOG) and a discharge atomic iodine generator (DAIG). Our latest DSOG, denoted as the DSOG-6, comes out from a proposed original physical method of singlet oxygen (SO) generation for a DOIL. This novel method is based on a fast mixing of hybrid argon plasma jet of DC electric arc and radio-frequency (RF) discharge with a neutral molecular oxygen stream. This unique method is an alternative to the chemical generation of SO for a chemical oxygen-iodine laser (COIL) and also to the classic high-frequency discharge methods used since the first successful experimental demonstration of a DOIL in 2004. The main effort in the world is concentrated now on searching a more efficient DSOG with a higher SO yield attainable at higher pressures. Compared to a COIL, the DOIL would have several advantages: no dangerous chemicals, a longer period of operation, and reduced dimensions and weight. The goal of our effort is achievement of DOIL oscillations by this new discharge technique, which should provide the SO yields exceeding 30% at the total pressures higher than 10 Torr. Employing this method the DOIL could be scaled up at a reasonable price. Our latest DAIG, denoted as the DAIG-2, comes out from a proposed original physical method of atomic iodine (AI) generation for a DOIL and COIL. The proposed method is based on cw/pulsed RF discharge dissociation of iodine donors directly inside a laser iodine injector. This enables an enhanced assistance of UV light and immediate supersonic injection of atomic iodine into the laser cavity. Our method substitutes the classic dissociation of molecular iodine by energy of singlet oxygen, which saves its energy for laser generation and so can increase the laser efficiency. This unique method also significantly minimizes AI losses by its recombination, and losses by premature SO quenching. It would increase the laser power by ~25% in COIL, and 2 to 3 times in DOIL at no increase in iodine laser pumping by SO. This method of atomic iodine generation is promising alternative to a chemical generation and also a more efficient alternative to other published discharge methods. Compared to the chemical method, this proposed discharge method does not use dangerous gases such as chlorine or fluorine, and a fraction of AI could be produced also in an excited lasing state. Both the subsystems DSOG-6 and DAIG-2 will be used simultaneously in our future supersonic DOIL scheduled for the end of 2009.

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S4 Complex Burning Plasmas: Kinetic Processes and Novel Phenomena

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Multi-component plasma systems involving solid or liquid particles are widely investigated for past years in the atmosphere, in the physics of low temperature plasma, in the material science, and in the plasma based technologies. These particles besides the ions and electrons represent a charged component that strongly complicates the plasma phenomena and affects the properties of ionised gases. One of the important representatives of such systems is the burning plasma. Despite the combustion plasmas have much in common with the conventional discharge dusty plasmas they demonstrates a few specific features: an absence of external electric field, a high rate of chemi-ionization reactions, an existence of both positively and negatively charged clusters and particles, relatively high temperature (1500-2500 K), a strong coupling of gaseous and particulate species, and a broad range of particle sizes (2-100 nm in diameter).

This work is focused on the comprehensive analysis of the kinetic processes responsible for the formation of charged and neutral carbon clusters and particles during combustion of hydrocarbons with air in laminar flames and in practical devices such as aero-engine and energetic machine combustors. A considerable attention is paid to study the coagulation of clusters and particles in combustion plasmas. The novel tendencies in the coagulation growth of particles have been revealed. The enhancement of charged-charged, charged-neutral, and neutral-neutral particle interaction is considered for free-molecular and continual modes in a detailed manner. It is demonstrated that the exerting of Van-der-Waals, Coulomb, and image forces may considerably enhance the coagulation rate.

The novel kinetic model has been developed to deeper understanding the processes of gaseous and particulate charged species formation. The model takes into account the kinetics of formations of primary clusters, incident particles, ions and electrons, surface growth and coagulation of clusters and particles, attachment of ions and electrons to particles, and thermal ionization of particles. The novel data on the ion composition in flames and inside the aero-engine combustor are reported. The analysis based on the comparison of the computed results and experimental data proves that the formation of polydisperse ensemble of positively and negatively charged particles in hydrocarbon/air flames is caused by an attachment of ions and electrons to primary and secondary formed particles and coagulation of charged-charged and charged-neutral particles. The image forces exerting between charged and neutral particle are of extremely important in the formation of charged particles in the flame. The calculations exhibited that the Boltzmann charge distribution for small size particles with diameter d<20 nm is not established in flames. For large size particles (d>20 nm) the Boltzmann distribution may exist at long distances downstream the flame front. It was also shown that the thermoemission does not play a significant role in the formation of charged soot particles in hydrocarbon/air flames as was believed previously. Some new experimental and model results which exhibit the important role of the particle charging in the deposition of polar molecules on the soot particles surface inside the aero-engine combustor that results in the activation of some fraction of soot particles to be contrail nuclei directly inside the combustor are reported.

This research has been supported by the Russian Foundation for Basic Research (grant 08-01-00808).

S4 Rotation Inversion of Dust Plasma Structures in Magnetic Fields in a DC Discharge

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Effect of magnetic field on formation and dynamical characteristics of dust plasma structures confined in electrostatic trap in the axial region of strata in dc glow discharge has been investigated. Experiments were carried out in discharge tube of inner radius 1.8 cm filled with neon at pressures ~10^{-1} Torr with discharge currents ~10^{-4} A. The grains 5.5 μm in diameter levitated in axial region of the vertical dc discharge and formed ordered structures. In the axial magnetic field, they rotate in the horizontal plane about the vertical symmetry axis of the discharge. The rotation seems to be a rigid-body one: the angular velocity of all the grains is the same. In low magnetic fields ($B \sim 10^2$ G) the angular velocity of the dusty cloud is directed against the magnetic field. With increase in the field, rotation is decelerated and terminated at 500 G. In the field $B \approx 600$ G the dusty structure was rotated in opposite direct. With the further increase in the magnetic field up to 700 G dust grains went to the discharge periphery with the continuation of the movement around the axis.

We present an explanation of the rotation inversion of the dust plasma structures. The ions azimuthally drift in the crossed axial magnetic field and radial azimuthal electric field, and the dust plasma structure rotation is due to the ion drag force. In the uniform rotation, the ion drag force is balanced by the friction one with the neutral gas of atoms. As a result, we obtain an approximate dependence of the dust grain angular velocity on the magnetic field. The velocity direction is defined by the direction of the ambipolar electric field. The rotation inversion can be caused by (i) a change in the sign of the radial component of the ion density gradient dn_i/dr and (ii) magnetization of electrons to a degree such that their mobility becomes lower than the ion mobility. However, if the velocity inversion would be related with the (ii) reason, the destruction of the potential trap confining the dusty structure should be expected. But this destruction is observed at higher magnetic fields ($B \approx 700$ G) than $B \approx$ 500 G at which the rotation inversion occurs. The rotation inversion is likely attributed to a change in the direction of the diffusion plasma flux: the derivative dn_i/dr near the structure becomes positive. In this case, dn_i/dr outside the dusty structure remains negative and the trap continues to exist. It is known that plasma recombination occurs on the surface of dust grains; i.e., the plasma is absorbed by the dusty structure. At low magnetic fields, the radial ion diffusion flux from the axis (where the dust structure is placed) to walls prevails over the flux absorbed by the dust grains structure. As the magnetic field increases, the plasma is magnetized and the radial flux toward the wall decreases. At a certain B value (at 500 G in our experiment), the total flux on the dust structure becomes larger than the flux generated in the volume of the dust structure. Therefore, the inversion of the radial ion flux occurs in the central discharge region and leads to the change in the rotation direction of dust grains structure. With the further increase in magnetic field the inversion region of the diffusion flux is expanded, the potential trap disappears, and the dusty structure decays (at $B \approx 700$ G), the grains go to the discharge periphery.

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S4 The Boltzmann Equation Analysis of Spatial Relaxation of the Electrons in Low-Temperature Plasmas

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A multi-term solution of the Boltzmann equation has been developed and used to investigate the spatial relaxation of charged-particle swarms under the influence of electric and magnetic fields crossed at arbitrary angles. We employ a ‘two-temperature’ Burnett function representation of operators in velocity space in the Boltzmann equation while the configuration space is represented by a finite mesh of points. The resulting system of coupled differential equation is solved using a combined pseudo-spectral and finite difference method. Spatial relaxation profiles are presented for electrons in conservative model and real gases and are benchmarked against the results obtained by a Monte Carlo simulation technique. The comparison validates the basis of our transport theory as well as the numerical integrity of both approaches.

In recent years the study of spatial relaxation of the electrons in neutral gases under the action of electric field has been the subject of detailed kinetic studies. While these studies are tremendously important from the point of view of fundamental physics, the modern non-hydrodynamic studies of spatial relaxation of the electrons are motivated by the need to understand the electron kinetics in low-temperature plasmas, especially in the neighbourhood of sources and boundaries. Another issue that is highly relevant for modelling plasmas is to consider the effects of a magnetic field. In most cases, the effect of a magnetic field on spatial relaxation of electrons is being neglected or at best some effective/equivalent electric field only approximations are being applied. In this work we show that the application of a magnetic field significantly alters the spatial relaxation profiles. Both the spatial relaxation lengths and period of oscillations can be modified by the action of a magnetic field. In addition to an orthogonal field configuration, we consider the spatial relaxation for an arbitrary field configuration. It has been shown that the angle between the fields has an ability to control the relaxation process of various transport properties. Aside from the relaxation processes, we discuss the influence of a magnetic field and angle between the fields on the steady-state values of various transport properties. As an illustrative example, it has been shown that $(\mathbf{E}\times\mathbf{B})\times\mathbf{B}$ average velocity component is comparable with the $\mathbf{E}$ and $\mathbf{E}\times\mathbf{B}$ average velocity components but yet it is common in the literature for plasma modellers to fail to include this quantity in their models. We believe that modelling of the magnetically assisted/enhanced plasma reactors can greatly benefit from this study.

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S4 Molecular Dynamic Simulation of Plasma Sputtering of an Electrolyte Cathode by Low Energy O_2^+ Ions

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Process of solution components transfer into plasma zone under the action of ion bombardment is played a primary role in sustenance of a glow discharge with an electrolyte cathode. In the present work the case of O_2^+ ions (energy 50-500 eV) incident normal to the planar surface of an electrolyte cathode was under investigation by means of molecular dynamic method. The simulation of water sputtering initiated by ion impact is carried out in NVE ensemble at GROMACS software version 3.2 [21] with time step 0.8 fs on time interval from 100 to 350 ps. In the process of calculations the output file of the trajectory of all particles containing their coordinates velocities and forces was recorded after every 250 steps of integration. The file was used for calculating the sputtering yield of H_2O molecules, number of destroyed hydrogen bonds, determined from the geometric criterion as well as the energy distribution of sputtered molecules. The data on the sputtering yield of H_2O molecules per one incident ion and energy consumption on sputtering one molecule are presented in table №1. Statistical error for the sputtering yield was generally less than 10%.

Table 1. The sputtering yield of water molecules and energy consumption on transport of one H_2O molecule at various energies of incident ion O_2^+.

Ion energy, (eV)	Sputtering yield, (molecules)	Energy consumption, (eV)
50	2±0.3	25
100	9±1.35	11.1
200	37±5.6	5.38
300	73±11	4.1
400	117±17.6	3.43
500	174±26.1	2.87

As result it was shown that the sputtering yield can reach so much value as 174 molecules per one incident ion. The energy (E_{trans}) for transfer of one H_2O molecule in a gas phase exponentially decrease with an increase in the energy of the incident ion according to the law $E_{trans} = 4.97 * \exp\left(-\frac{E_{ion}}{63.48}\right) + 26.5 * \exp\left(-\frac{E_{ion}}{4.89}\right) + 2.577$ [eV]. It reaches stationary value on the order of 2.58 eV per sputtered molecule at the energy of ion above 500 eV. This value is sufficiently close to one received in experiments where estimations E_{trans} to the transfer of one molecule of water to gas phase about 1 eV was made. At the incident ion energy above 300 eV local destruction of a liquid structure in the area of impact with rupture of a large quantity of hydrogen bonds in water is observed. The energy distribution of molecules sputtered from an electrolyte cathode is considerably differed from one in case of metal cathode sputtering. The results of simulations can be used for construction of accurate model of the glow discharge with liquid electrodes.

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S4 Linking Fluid and Kinetic Parameters near the Plasma-Sheath Boundary in Collision-Free Plasmas with Warm Ion Sources

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In this work we investigate how fluid plasma parameters are related to the kinetic plasma properties for plasmas with warm ion sources and finite Debye lengths. This is an important issue in applying *fluid* codes to experimental, technological and fusion plasmas. Such codes are applicable only up to the plasma-sheath boundary (also called "plasma edge" or "sheath entrance") and cannot be extended to the material boundaries themselves. This is because the sheath region is far from thermodynamic equilibrium and hence can be correctly described only in terms of some *kinetic* model. Since, accordingly, the boundary conditions for a plasma modeled in the fluid description should be defined at the plasma-sheath boundary (rather than at the material one), this boundary needs to be appropriately identified. However, identifying such a boundary and calculating the hydrodynamic parameters there is a demanding task which up to now has been solved only approximately and for a limited number of plasma discharge scenarios (i.e., particle and energy production and loss mechanisms). The plasma edge can be *precisely* defined only in the asymptotic two-scale limit ($\lambda_D/L \to 0$, with λ_D the Debye length and L the presheath scale length), in which it manifests itself as a singularity if represented on the plasma scale (as, e.g., in the famous fluid Tonks-Langmuir (1929) model of a quasi-neutral plasma with "cold" ions), and as lying at infinity if represented on the sheath scale (as in Bohm's (1949) derivation of his well-known criterion for the critical ion velocity required for the existence of a monotonic sheath). Bohm's result was later generalized to cases with warm ions and more general electron densities $n_e(\Phi)$ in the form $u_i \geq \sqrt{k\left(T_e^* + \gamma T_i\right)/m_i}$, where k is Boltzmann's constant, m_i is the ion mass, u_i is the ion directional (fluid) velocity, T_e^* is the electron "screening" temperature (defined by $T_e^* = en_e/(kdn_e/d\Phi)$), T_i is the ion effective temperature, and γ is the ion "polytropic" coefficient (defined by $dp_i/dz = \gamma kT_i dn_i/dz$), with all quantities taken at the plasma-sheath boundary. While during the last half-century γ was assumed to be constant in all fluid plasma models, it has been recognized only recently that γ is a spatially varying quantity rather than a global constant. Kuhn et al. (2006) have shown by predominantly analytical means that in the asymptotic two-scale limit $\gamma(z)$ exhibits a sharp peak exactly at the plasma-sheath boundary, whereas Jelić at al. (2007) have found by means of analytic calculations and particle-in-cell (PIC) simulations that for finite Debye lengths this peak is smoothed but still remains an excellent means of identifying the plasma-sheath boundary and calculating the related fluid plasma parameters, provided the shape of the "cold" ion velocity distribution ($T_i \ll T_e$) at the plasma-sheath boundary is known. In this paper we present representative PIC simulation results, discuss their range of applicability, and compare them with the corresponding results obtained in the asymptotic two-scale limit.

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