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Experimental Investigation on Laser – Plasma Coupling in the Shock Ignition Regime at PALS

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In the context of Inertial Confinement Fusion, Shock Ignition (SsI) is a promising approach to reach the ignition and burning of a thermonuclear fuel pellet. It consists of a two-steps scheme, where ignition is achieved by a strong converging shock wave launched by a laser spike at an intensity $I\lambda^2 > 10^{16}$ $\mathrm{Wcm^{-2}\mu m^2}$ at the end of the compression phase. Its attractiveness relies mainly in the high potential gains leading to a lower laser energy needed for the fuel ignition.

In this intensity regime, however, laser-plasma interaction is strongly affected by the growth of a variety of parametric instabilities, including stimulated Raman scattering (SRS), Brillouin scattering (SBS) and Two Plasmon Decay (TPD), leading to the waste of a considerable amount of laser energy and to the generation of fast electrons, which could produce a detrimental preheating of the compressed fuel.

To investigate laser-plasma coupling in the SI regime, several measurement campaigns have been carried out at the Prague Asterix Laser Facility (PALS). A strong shock has been produced by focusing a laser spike at intensities 10^{15} – 10^{16} $\mathrm{Wcm^{-2}}$ (250 ps, 438 nm and 1315 nm) on an extended plasma corona, which was created by a previous laser pulse at intensity $I \sim 7\cdot10^{13}$ $\mathrm{Wcm^{-2}}$ (250 ps, 1315 nm).

The pre-plasma temperature and density were inferred by x-ray spectroscopy, ion diagnostics and interferometry. Parametric instabilities were investigated by calorimetry and spectroscopy of the backscattered radiation in the full angular range; the emission peaks at (3/2)ω, ω

and ω/2 emission provided information on TPD, SBS and SRS, respectively. Kα spectroscopy was utilized to investigate fast electron generation. Finally, the shock pressure produced by the laser spike was derived by shock breakout chronometry and by the morphology of craters formed in massive targets.
The main results of these experimental campaigns, with a particular emphasis to the relevance of parametric instabilities, are here presented [P. Koester et al., Recent results from experimental studies on laser–plasma coupling in a shock ignition relevant regime, Plasma Physics and Controlled Fusion, 55, 124045 (2013); D. Batani et al., Generation of high pressure shocks relevant to the shock-ignition intensity regime, Phys. Plasmas 21, 032710 (2014); T Pisarczyk, Pre-plasma effect on energy transfer from laser beam to shock wave generated in solid target, 21, 012708 (2014)]. The obtained results are critically discussed in the perspective of SI and future directions of investigation are suggested.

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The Path towards GW Soft X-ray Lasers.

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Ultra-intense X-ray sources have opened new avenues by creating new states of matter, probing or imaging most intimate component of living or inert matter or realizing movies of samples excited by ultra-fast sources. Within the panorama of available ultra-intense X-ray sources, free-electron lasers have a strong leadership by delivering pulses combining femtosecond duration and 10's of µJ to mJ energy. However, these sources remain highly expensive by reaching more than 1B$, limiting their number to a few worldwide.
Since the first successful demonstration of amplification of high harmonic pulse in a low density plasma in 2003 [Zeitoun, P. et al. A high-intensity highly coherent soft X-ray femtosecond laser seeded by a high harmonic beam. Nature 431, 426–429 (2004)] and high density in 2008 [Wang, Y. et al. Phase-coherent, injection-seeded, table-top soft-X-ray lasers at 18.9 nm and 13.9 nm. Nature Photon. 2, 94–98 (2008).], we have develop extensive numerical studies aiming at finding path for generating mJ, fs, fully coherent laser-pumped soft x-ray lasers.
We have first used 2D hydrodynamic code to optimize the plasma amplifier conditions when pumped by a combination of long and short infrared pulses. In best case, plasmas may store up to 0.4 mJ in the population inversion.
On a second step, we developed a time-dependant Maxwell-Bloch model enabling to describe accurately the temporal structure of the soft x-ray pulse all along its amplification. We observed that at best, pulses of 80 fs and only 20 µJ might be generated with table-top lasers. We thus studied the seminal experiment of Ditmire's et al [Ditmire, T. et al. Amplification of XUV harmonic radiation in a gallium amplifier. Phys. Rev. A51, R4337–R4340 (1995)] who seeded the first plasma. This peculiar experiment was using kJ and ns laser to create long life duration plasma. We retrieved and explained for the first time the experimental result (amplified spontaneous emission 1,000 times stronger than amplified

seed). We thus proposed and fully modelled the transposition of the so-called Chirped Pulse Amplification (CPA) in the soft X-ray range, showing that 6 mJ, 200 fs, fully coherent soft X-ray pulse is accessible with compact pump lasers [E. Oliva et al, A proposal for multi-tens of GW fully coherent femtosecond soft X-ray lasers, Nat. Phot., 6, 767 (2012)].

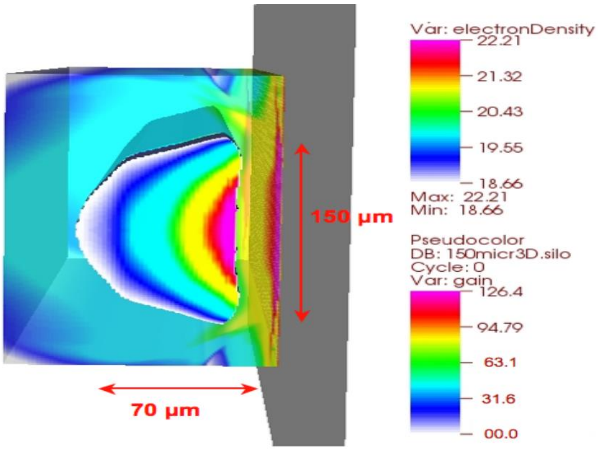

Fig. 1: Image in false colours of plasma created by two laser pulses and the gain region.

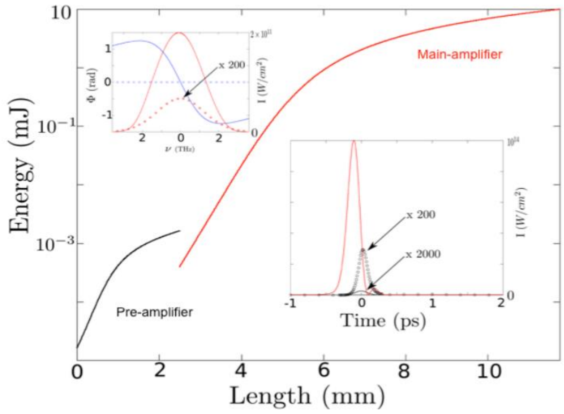

Fig. 2: Energy vs plasma length for the X-ray CPA.

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Edge Plasma Studies in the COMPASS Tokamak

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The COMPASS tokamak is an experimental device operated in divertor plasma configuration with ITER-like plasma cross-section. Recently, an H-mode has been achieved in COMPASS. The H-mode is generated by an increase of the plasma current above 240 kA or a pulse of Neutral Beam Injection (NBI) heating system. The L-H transition is characterized by a sudden decrease of Da signal as well as its fluctuations. The H-mode is accompanied by characteristic plasma instabilities (Edge Localized Modes – ELMs) with frequencies in the range of 80 – 2 000 Hz or exhibits so called ELM-free periods.
This contribution will present a characterization of edge plasma during H-mode in COMPASS with a focus on the ELM classification. In addition, the characterization of ELM parameters using different probe techniques will be provided. Examples of edge electron temperature and density profiles measured by High Resolution Thomson scattering diagnostics will be also presented.

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Simulation of Damage of Metallic Plasma Facing Armor under Transients in Tokamaks

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Tungsten (W) is planned as plasma-facing components (PFCs) in the ITER divertor and as the main PFC material of future tokamak DEMO. Uncontrolled transients, such as ELMs, VDEs, disruptions have the potential to drive significant erosion of PFC surfaces by vaporization and melting. Melt motion followed by melt splashing of metallic armour can be very serious, leading to deterioration of surface topology, and decrease in PFC lifetime.
In the paper recent using of melt motion code MEMOS for calculation of PFC erosion in the tokamaks is described. Recent simulations of W-melt motion performed for the tokamak multi-transient experiments demonstrated as good agreement with measurements of target profile as importance of J´Bforce generated by thermo-current. Significant melt erosion of PFC surfaces after plasma and runaway electron heat loads onto the misaligned edges between armour mono-blocks is numerically demonstrated for expected tokamak transients.

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Multi-Mirror Linear Trap for Fusion Plasma Confinement: Status and Future

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The paper reviews recent results obtained on the Multiple Mirror Trap GOL-3. It is an 11 m-long solenoid with axially-periodical magnetic field. In the basic operation regime the solenoid consists of 52 cells with $B_{max}/B_{min} = 4.8/3.2$ T. Deuterium plasma of $10^{20} – 10^{22}$ m^{-3} density is heated up to ~2 keV ion temperatures at confinement time ~1 ms by a high power relativistic electron beam. In general, achieved plasma parameters support our vision of a multiple mirror trap as the alternative path to a fusion reactor with betha ~1. Project of a new linear trap with multiple mirror plugs is in progress in Novosibirsk BINP. Several new experiments in support of the fusion program based on linear machines are presented. An intense electron beam source of a new type, based on a gaseous arc plasma emitter, was developed and experiments with this beam are carried out; the new data on plasma rotation, electromagnetic radiation and plasma-surface interaction in the GOL-3 will be presented.

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Performance of Tungsten as Divertor Material in Future Fusion Devices

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Tungsten as a plasma facing material (PFM) in the divertor region of a fusion device like ITER has to withstand severe environmental conditions such as high thermal loads and particle fluxes. These exposure conditions may cause a deterioration of the heat removal capability

of the material and/or component. In order to ensure that designs of tungsten components are suitable for an application under such exposure conditions detailed qualification programs are required. Especially the high steady state and transient thermal loads, simulated with electron beam and linear plasma devices, induce a wide range of modifications and damages on the PFM surface as well as in the component.
Open issues are the performance of materials under high cycle transients, after/during neutron irradiation, after recrystallization, and under simultaneous particle fluxes (D/T/He). For DEMO new technologies are required and investigations towards the materials resistance against much higher neutron doses.

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Plasma Focus as an Effective Tool for Laboratory Simulation of Astrophysical Jets

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Cosmic jets of different nature are one of the most striking phenomena in astrophysics. There are many models of their origin, however, their verification, for understandable reasons, is extremely difficult or impossible in principle (black holes). One of the possible solutions is a laboratory simulation, which, subject to certain similarity laws, allows performing experiments which are difficult to implement under natural conditions. One of the laboratory facilities allowing to carry out such simulation is the facility of plasma focus type (PF). For this goal the PF-3-facility (Kurchatov Institute, Moscow) was adapted. The advantages of PF for laboratory simulation and first experimental results on studies of plasma jet formation and its propagation through background plasma are discussed.

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Experimental Characterization of an Overdense Plasma Excited by Electron Bernstein Waves Heating in a Compact, Plasma-Based Ion Source

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Electron Cyclotron Resonance Ion Sources (ECRIS) are compact plasma-based machines able to feed particle accelerators with high intensity beams of multicharged ions. ECRIS plasmas are density limited since sustained by E.M. waves propagation up to a cutoff density value. In the past the only way to improve ECRIS performances has been to increase microwave

frequency and magnetic field strength satisfying ECR condition. A different plasma heating mechanism is being applied at INFN-LNS. It is based on Electron Bernstein Waves (EBW), i.e. electrostatic waves which do not suffer any density cutoff. The research has been based on the detection of the peculiar signatures of EBW formation and following absorption: the overcoming of cutoff density, the observation of non-linear heating and the electro-magnetic spectrum broadening. The three signatures have been simultaneously revealed for the first time in a compact device, in different magnetic configurations and above a fixed power threshold.

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Advanced Plasma Diagnostics Tools for Ion Source Development

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In Electron Cyclotron Resonance Ion Sources (ECRIS) a dense and hot plasma is confined by magnetic fields and resonantly heated by microwaves in the 2.45–28 GHz frequency range. The ECRIS development path has been traced on the roadmap of magnetic field, microwave source frequency and power boosting. This trend is approaching saturation due to technological constraints. One limiting factor consists is the few types of diagnostics tools so far designed and installed on such compact machines due to difficult accessibility of the plasma chamber. In order to improve microwave-to-plasma coupling, we are developing diagnostics tools spanning across the entire electromagnetic spectrum, from microwave interferometry to X-ray spectroscopy. In the last year these methods have started to be implemented at LNS, including high resolution X-ray spectroscopy and spatially-resolved X-ray spectroscopy made by quasi-optical methods (pin-hole cameras). Obtained results will be shown and discussed.

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A Path Forward for Fusion: Thermoelectric Liquid Metal Plasma Facing Structures

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The divertor region of a tokamaks experience extreme heat fluxes which lead to intolerable levels of damage. To ensure an adequate lifetime, such structures could be constructed out of flowing molten materials. Lithium is the obvious choice since it is low Z and allows low-recycling regimes which enable a larger portion of the core to reach fusion-relevant temperatures.

The Liquid-Metal Infused Trenches (LiMIT) concept [D.N. Ruzic, et. al., Nucl. Fusion 51(2011) 10200] is a plasma facing structure which employs thermoelectric magneto-

hydrodynamics to self-propel lithium through a series of trenches. The combination of an incident heat flux and a magnetic field provide the driving mechanism for the flow. A limiter based on this concept was designed and placed at the bottom of the HT-7 tokamak resulting in a positive effect.
Recent results from the experiments at Illinois will be described and a path forward for fusion utilizing this concept will be discussed.

This research has been supported by the US Department of Energy.

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Dynamics of W and Be Dust in Fusion Devices; Experiments and Modelling

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We report on experiments with injection of artificially introduced dust (for transport studies) and exposure of samples with pre-adhered dust particles (for remobilization studies) in tokamak, reversed field pinch and linear configurations. The experiments enable calibration of the physical models employed in the MIGRAINe dust dynamics code [S. Ratynskaia, L. Vignitchouk, P. Tolias et al. (2013) Nucl. Fusion 53 1230021-3; I. Bykov, L. Vignitchouk, S. Ratynskaia et al. (2014) Plasma Phys. Control. Fusion 56 035014; P. Tolias (2014) Plasma Phys. Control. Fusion 56 (in print)]. We discuss new models of dust-surface collisions and aspects of dust-plasma interaction implemented in the code. The specific processes concerned are: restitution coefficients (dependencies on the grain size and temperature), secondary electron emission, electron backscattering, sputtering and ion reflection, ion neutralization in the vicinity of metal surfaces and vapor cloud dynamics.

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Study of Bifurcation Based L-H Transition Using Fixed Points Stability Analysis

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An L-H transition in tokamak plasma is studied using the bifurcation concept. 2 field (heat/particle) transport equations with both neoclassical and turbulent effects are solved simultaneously. The flow shear is used as transport suppression mechanism, which is assumed to affect only the turbulent channel and is a function of both pressure and density gradients, hence coupling the two transport equations. Moreover, both transport equations are reformed into energy and particle flow equations in order to analyze fixed points stability of local plasma. It is found that a sudden increase of local pressure/density gradients can occur at critical fluxes, exhibiting the L-H transition. Also the local fixed points analysis implies that the plasma takes much longer time to evolve in H-mode than in L-mode. The timescales ratio is proportional to the ratio of turbulent over neoclassical transports. The effects of toroidal flow on the bifurcation picture of L-H transition are also studied.

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Model for Predicting Toroidal Rotation Based on Neoclassical Theory and Toroidal Momentum in Tokamak Plasmas

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A theory-based model for predicting toroidal rotation velocity is developed based on two mechanisms: toroidal momentum from torque due to auxiliary heating and toroidal rotation from neoclassical theory. For the torque from auxiliary heating, it includes NBI, ICRF, and LH. This toroidal velocity model is implemented in 1.5D BALDUR integrated predictive modeling code and is used to evolve plasma current,temperature,and density profiles for 4 JET optimized shear discharges. These simulations are carried out with a combination of Mixed Bohm/gyro-Bohm core transport and NCLASS neoclassical transport model.It is found that the predicted toroidal rotation profiles are in a range of the experimental data, with an RMS below 25 % for 4 JET optimized shear discharges. In addition, agreement for ion and electron temperature and density profiles can be satisfactory achieved. It is also found that the ITB formation is observed at a location similar to those found in the experiments for all simulations.

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Spectroscopy Diagnostics Based on NBI in EAST Tokamak

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Several spectroscopy diagnostics based on heating neutral beam injection (NBI) have been recently developed in EAST tokamak, i.e. the Charge eXchange Recombination Spectroscopy (CXRS), direct current Beam Emission Spectroscopy (DC-BES), alternating current Beam Emission Spectroscopy (AC-BES), Fast-Ion Dα (FIDA) and Motional Stark effect (MSE) diagnostics. These diagnostics provide tools for some important plasma parameters, such as a 1 M resolution plasma density signal. Physical plan in the next EAST experiment is presented, together with an idea of Ultrafast-CXRS diagnostic system in the nearly future.

This research has been supported by the National Magnetic Confinement Fusion Science Program of China (No.2012BG101001).

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Active Spectroscopic Methods Monitoring of Active Species in Atmospheric Radio Frequency Plasma

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Rf-DBD plasma of 13.56 MHz generated in between two electrodes with a size of 50 × 50 mm at pressure range from sub-atmospheric (300 mbar) to atmospheric (1100 mbar) and power of 20-80 W is studied by optical emission spectroscopy (OES) and absorption spectroscopy (AS). The gas temperature and electron density is estimated from the OES. AS is used to record the absolute density of Ar^* metastable and resonance states by measuring absorption signal of 794.8, 800.8, 811.53, and 750.4 nm. Laser-induced fluorescence (LIF) and two-photon absorption laser-induced fluorescence (TALIF) spectroscopy are the major techniques that have direct access to the ground state populations. The present work uses the time resolved LIF and TALIF spectroscopy to investigate the temporal behavior of laser excited states in the atmospheric pressure RF plasma jet, sustained in Ar/0.3 % H_2O or 0.3 % O_2 mixtures, with a special attention devoted to the proper interpretation of the LIF and TALIF results.

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Research of Low Temperature Dusty Plasma System under Microgravity Conditions

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Dusty plasmas are low temperature plasmas consisting of electrons, ions, neutral gas atoms, and charged dust particles. The research of dusty plasmas under microgravity conditions provide new insights and allows to observe phenomena, which are suppressed under gravity conditions on Earth. We will present some results of the dusty plasma studies under icrogravity conditions obtained with the help of PK-3 Plus laboratory.

Due to the manipulation of the interaction potential between the microparticles it is possible to initiate a phase transition from an isotropic plasma fluid into an electrorheological plasma. The investigation of interpenetration of two clouds of different grain sizes allows to study lane formation phenomenon at the kinetic level. The crystal-liquid phase transition was obtained in large 3D isotropic dusty plasma system. Besides, we studied transition from the homogeneous crystallization to the heterogeneous crystallization (propagation of crystallization fronts).

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Influence of Voltage Supply Pulse Duration on Characteristics of DBD in Atmospheric Air

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The volume dielectric barrier discharge in atmospheric air in a plane-parallel electrode arrangement with alumina ceramic barrier was studied. Unipolar square pulses with amplitude of 16 kV and pulse repetition rate of 30 Hz were applied to the electrodes. The duration of the applied pulses was varied from 600 ns to 6 ms during the experiment. Two discharge pulses were observed in the waveforms at rising and falling edges of the applied voltage pulse. It was found experimentally that with varying the voltage pulse duration the current pulse amplitude of the first discharge stayed constant, whereas the amplitude of the second discharge increased with the voltage pulse elongation. The growth of the second current peak also strongly affects the peak power of this discharge. The peak power of the second discharge increased nearly twice with increasing the voltage pulse duration.

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Control of Plasma Density in Plasma Layer near High-Speed Body by Electric and Magnetic Fields

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When a space vehicle re-enters the atmosphere at a high velocity, a layer of ionized gas is formed around it. This layer shields the radio signal transmission to and from the vehicle. This phenomenon, the so-called radio transmission "blackout", was observed during the first re-entry phase of space flights. The gas temperature in the layer between the bow shock wave and the vehicle surface can reach 10^4 K, and the gas becomes ionized, thus forming a plasma layer in the vicinity of the vehicle surface. For a typical re-entry trajectory the plasma frequency in this layer can be much higher than 10^9 Hz. In this report computational modelling and experimental results of the method of mitigation of radio transmission blackout during a flight at a high velocity in crossed electric and magnetic field are presented. Results show that a decrease in the plasma frequency can be obtained by applying electric and magnetic fields to the ionized layer near the model surface.

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Electrical Discharge in Water Assisted By a Shock Wave

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New method of generation of an electrical discharge in water with shock wave assistance is proposed. A high voltage pulse is applied to a pair of electrodes at a time when the shock wave is passing between them. The shock wave creates favourable conditions for the electrical breakdown. Two electrode configurations were used: pin-to-pin and plate-to-plate. If the electric field is lower then the critical breakdown field in pin-to-pin geometry, the corona discharge is observed on the anode and no spark is generated. The shock wave used at this condition enhances the breakdown process and underwater spark is generated. Plate-to-plate geometry is characterised by the homogeneous electric field with magnitude under the critical value of an electrical breakdown. The use of shock wave leads to the electrical breakdown between plate electrodes.

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Non-equilibrium Plasma Emission Properties of EUV and Soft X-ray Sources

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Discharge and laser produced plasmas used in EUV and soft X-ray sources are non-equilibrium. Understanding of behaviour of such plasma and the results on modelling of sources depend on kinetic and spectral parameters of plasma. Mismatch between actual plasma conditions and its theoretical estimations leads to incorrect evaluation of parameters and to impossibility of optimisation of sources. Modelling of emission properties of Xe, N, Zr and Kr plasmas is carried out in the approach for kinetic parameters of non-equilibrium plasma, incl. interaction processes with arbitrary electron distribution, based on Hartree-Fock-Slater model. Non-equilibrium kinetic modeling demonstrates high sensitivity of ionization and emission properties of plasma to a presence of high energy electrons and to the accuracy of cross-sections of processes. Efficiencies of light sources in required bands are discussed. Optimal plasma conditions for substantial increase (×10) of emission intensity are proposed.

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Ion Phase-Space Resolved Plasma Fluctuations

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Measurement of velocity distribution functions not only permits the determination of density, current, and temperature, but correlated fluctuations of the distribution function enable more direct determination of plasma transport coefficients. We will discuss measurement of the two-point correlation function $< f(x,v,t)\, f(x',v',t') >$ for ions in a cylindrical magnetized Argon RF gas discharge that are resolved in time $t - t'$ and in position and in the velocity component parallel the the magnetic field. Typical plasma parameters in the singly ionized discharge are $T_e \sim 4$ eV, $T_i \sim 0.1$ eV, $n_e \sim 10^{10}$ cm^{-3}, with B = 0.1 T. Two independently movable periscopes are used to collect light from laser-induced fluorescence of metastable Argon with excitation at 611 nm and 668 nm. This technique allows the measurement of correlation functions with large signal-to-noise, and the estimation of transport coefficients.

This research has been supported by the Supported by US Department of Energy DOE-FG02_99ER54543.

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Design and Implementation of Gas Puff Imaging Diagnostic to Investigate 2D Plasma Turbulence in the COMPASS Tokamak

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In tokamaks, the particle and energy transport strongly depends on the level of turbulent fluctuations of the plasma parameters. Investigations have shown that those fluctuations correspond to large amplitude bursts due to intermittent structures, which propagate in both the radial and poloidal directions at the same time. In the COMPASS tokamak with ITER-like plasma shape, these phenomena can be studied by a comprehensive set of diagnostics. However, these diagnostics usually provide only 1D information on the transport behavior. The gas puff imaging technique represents an interesting alternative allowing 2D measurements of turbulent structures by imaging the emission of a controlled neutral gas puff using a fast camera. Gas puffs are injected in the SOL region to visualize the plasma turbulence increasing the contrast and light emission. We report on the design and implementation of such a new diagnostic for COMPASS. The first tests of the optical and injection systems will be shown.

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Change of Tungsten Structure under the ITER ELM-like Repetitive Plasma Loads

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Tungsten treated by the double forging method is very perspective material for armor of ITER divertor. The behavior of such material under transient heat loads is critical issue for realization of ITER project. Tungsten targets have been irradiated by repetitive hydrogen plasma loads relevant to ITER ELM in quasi-stationary plasma accelerator QSPA Kh-50. Heat load on tungsten surfaces was 0.45 MJ/m^2, which was between the cracking and melting thresholds of tungsten. Pulse duration is 0.25 ms. Number of plasma pulses achieved 400. XRD method is used for analyzing structure and evolution of residual stresses. SEM analyze has been used for study of exposed surface. Plasma loads cause the formation of tensile residual macro-stresses up to 300 MPa in surface layer after the first irradiation. Further plasma irradiation led to annealing the structural defects and some relaxation of residual stress. Macro-cracks appeared in the surface layer as result of thermo stress relaxation

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Comparison of Cooling Schemes for High Heat Flux Components Cooling in Fusion Reactors

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About 20 % of the energy released by plasma in fusion reactor, turns ultimately out to be surface heat load on the Plasma facing components (PFC’s) and the heat fluxes on these components (e.g. First wall, Divertor, Neutral beam injectors etc.) can range from 1 to several MW/m^2. In order to handle such high heat fluxes and prevent damage, in the recent past several coolants are proposed such as water, helium and liquid metals along with different ways of enhancing the heat transfer coefficient, such as swirl tubes, hypervapotrons, Jet cooling, pin-fins arrays, 2D, 3D roughness in different combinations with the coolants. Among these concepts water and helium are most preferred because of several advantages that these coolants

possess. This paper analyzes different ways of enhancing heat transfer using helium and water for cooling of PFC's and then conclusions are drawn to decide the best choice of coolant, for usage in near and long term applications.

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Lithium Beam Diagnostic on the COMPASS Tokamak

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The new beam emission spectroscopy (BES) diagnostic using neutral lithium beam has been designed and installed on the COMPASS tokamak. The principle of this diagnostic is injection of accelerated lithium beam with energies 30 – 60 keV and detection of light emitted by collisionally excited Li atoms. Apart from a routine density profile reconstruction, the diagnostic is useful for investigation of the turbulent plasma behavior in the edge/scrape-off layer (SOL) plasma on the base of detected light fluctuations. Therefore there are two detection systems, the charged coupled device (CCD) camera used for density profile reconstructions with time resolution of 10ms, and the array of avalanche photodiode detectors (APDs) for fluctuation measurements. Spatial resolution of both detection systems is about 1 – 2 cm. The presentation will cover design of the diagnostic system as well as first density profile reconstructions.

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Comparison between 2D Turbulent Model ESEL and Experimental Data from ASDEX Upgrade and COMPASS Tokamaks

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The dynamics of edge tokamak plasma transport is dominated by electrostatic 2D interchange instability, driven by intrinsic pressure gradient and magnetic field curvature at the outboard side. 2D computer turbulent model ESEL simulates this plasma boundary as three interacting fluid fields of electron temperature, density and vorticity. This paper directly benchmarks the model output with experimental data obtained by both Langmuir and ball-pen probe measurements from two tokamaks. As a result, the simulation quite well matches spatial profiles of mean plasma potential and temperature, the level of density fluctuations and in regions far from separatrix probability distributions of both density and plasma potential. Large discrepancy is found, however, especially in the level of plasma potential and temperature fluctuations and that spatial profile of density in the ESEL gets close to experiment only for highest density plasma.

This research has been supported by the P205/12/2327.

Quartz Crystal Microbalance Measurements for In-situ Evaluation of Dust Inventory in Fusion Devices

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To realize in-situ evaluation of dust inventory in fusion devices, we have developed quartz crystal microbalances equipped with a cluster-eliminating filter, by which we can discriminate mass deposition rate of dust particles from film deposition. Dust particles were generated due to interactions between a grounded graphite target and H_2plasmas produced with a helicon discharge device. The ion density is 4.1×10^{10} cm^{-3} for 500 W and 2.8×10^{12} cm^{-3} for 1100 W, respectively. The space potential is 30 V. Deposition rate measurements with the filter show that the net flux of deposition precursors for 500 W is 1/10 of that for 1100 W. Deposition rate measurements without the filter show deposition of dust particles and deposition precursors is dominant for 1100 W while etching rate due to H atoms surpasses deposition rate for 500 W. These results suggest that our method offers information of the flux of H atoms as well as deposition precursors and dust particles.

This research has been supported by the This research was supported by General Coordinated Research Grant from the National Institute for Fusion Science Grant Numbers NIFS12KLPF020 and NIFS12KLPF022 and MEXT KAKENHI Grant Number 21110005.

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Measurement of Plasma Filaments Electromagnetic Properties with U-probe in the COMPASS Tokamak

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A complex electrostatic-magnetic probe diagnostics, so-called ‘U-probe’, has been installed on COMPASS. Probe composes of two identical towers. Each tower houses 3 radially spaced sets of 3D coils, triple probe and rake probe. The U-probe measures electric and magnetic properties of the filamentary structures in the plasma scrape-off layer with high temporal resolution. The probe head is installed close to divertor region on manipulator allowing adjustment of radial position on the shot-to-shot basis. The U-probe was operated in different L-mode and H-mode plasmas, even with NBI heating. This work describes first results of the U-probe measurements concerning the SOL plasma instabilities and current filaments. Propagating filamentary structures has been identified onVfloat, Isat and magnetic coil signals. We were able to detect ELMs inner structure as a composition of filaments. Electromagnetic features of these filamentary structures were investigated in detail.

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Evaluation of First Wall Heat Flux Asymmetries Due to Magnetic Perturbations for a Range of ITER Scenaria

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Resonant magnetic perturbations (RMPs) are one method of edge localized mode (ELM) control and energy loss suppression. However the RMPs application can cause other side effects as formation of helical flux channels outside the main strike points (called footprints), which can lead to damage of wall. Hence the need of proper estimations of wall heat fluxes. These estimations have been done in previous studies only for a few cases due the time difficulty of complex 3D transport models. The estimation of heat fluxes can be approximated with Melnikov integral method with much less time complexity. These calculations for concrete ITER scenarios will be presented. Calculation is compared with ERGOS model of field line tracking in a sample scenario. Based on Melnikov integral calculation and known function of heat flux in scrape-off layer the wall heat fluxes and footprint positions can be calculated. The analysis and optimum RMPs configuration for various scenarios will be presented.

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Interaction of Spatially Localized LHW with Banana Particles

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We studied the interaction of electrons with spatially localized lower hybrid waves, we considered as a zero approximation the unperturbed constant velocity of electrons, for simplicity circulating along the circular magnetic field line. The basic stochastic interaction appeared on nonlinear resonant frequencies of the interaction. We anticipate there the possibility to accelerate electrons to higher velocities (even to relativistic velocities) than corresponds to the quasilinear theory.
In our last paper we tried to support this phenomenon again by means of numerical simulation. In spite of the fact, that large acceleration has been really found, we were not able to reach the experimentally detected values due to lack of overlapping of resonances for higher velocities. The corresponding velocity distance between two neighboring nonlinear resonances was the main ground, limiting the maximal stochastic acceleration. To cancel this closure, the appearing of further resonances with smaller velocity distances could be a solution. They may appear, leaving the pure 1D approximation. One from these possibilities is offered by the existence of banana motion, generally in tokamak appearing.
In our next work, we shall estimate the broadening of resonances, using analytical formula for bananas. Nevertheless, two basic expressions, banana frequency and banana ammplitude are results of severe approximations. The banana frequency is strogly nonlinear (there appear elliptic integrals, reminding mathematical pendulum) and its simple expression can by no means represent the whole problem offered by the banana dynamics. Mereover, since there appear a set of new parameters, that the corresponing dynamics has 3D character, we see the only way in the computer simulation of corresponing 3D dynamics of Hamiltonian in its toroidal version.

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Scrape-off Layer Width of Parallel Heat Flux on Tokamak COMPASS

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Edge plasmas in the divertor configuration were studied on the COMPASS tokamak. The dependence of the decay length of the parallel heat flux $q_{||}$ was measured at different values of plasma current and line-averaged density. We have found that $q_{||}$ decreases with both the plasma current and the line-averaged density, which is in agreement with previous results achieved on the JET tokamak.

This work was performed in the frame of the IAEA Joint experiments 2013 and also supported by EURATOM and carried out within the framework of the European Fusion Development Agreement. IST activities received financial support from "Fundação para a Ciência e Tecnologia" through project Pest-OE/SADG/LA0010/2013. The work was also supported by the project GAP205/12/2327 of the Czech Grant agency. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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Investigation of Intermittent Burst Characteristics for Better Understanding of Plasma Turbulent Transport in Tokamaks

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Investigation of plasma turbulent transport is important issue of fusion research. For this purpose plasma density fluctuations recorded by Langmuir probes are studied. We proposed new method of fluctuation analysis. Large amplitude positive fluctuations – bursts of plasma density are selected by threshold method and their temporal characteristics – burst rate, inter-burst time and burst duration are calculated. Study of their radial dependence improves our understanding of turbulent transport in tokamaks. Using this method we demonstrated experimentally on CASTOR tokamak that electrode biasing splits large coherent structures into smaller ones thus reducing turbulent transport [I. Nanobashvili et al., Phys. Plas. 16, 022309, 2009]. The method also allowed to find on TEXTOR tokamak that in some regimes modification of burst characteristics by dynamic ergodic divertor is quite close to modifications caused by electrode biasing [I. Nanobashvili, ECA, 37D, 2013].

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First Results on the Effect of Magnetic Perturbations on Edge Plasma at the COMPASS Tokamak

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Edge localized modes (ELMs) can significantly reduce the lifetime of ITER plasma-facing components, if not mitigated. Magnetic perturbations (MPs) have shown their potential for ELM control on several tokamaks, and coils for their generation are proposed for inclusion in the ITER design. The COMPASS tokamak (R = 0.56 m, a = 0.2 m), which is operated in divertor plasma configuration with ITER-like plasma cross-section, has achieved stable ohmic as well as NBI assisted H-mode discharges with type III ELMs, ELM free periods, and larger ELMs carrying about 5 % of the plasma energy. It is equipped with a rich set of perturbation coils with n = 2 symmetry.

This contribution will present a study of the effect of MPs on edge plasma by means of fast visible cameras (one with tangential view at the X point) and by divertor probes. In particular, we will focus on the divertor footprints formed by the MPs. The results will be compared to synthetic data based on the vacuum magnetic field model.

This research has been supported by the Czech Science Foundation, grant P205-11-2341, by the Ministry of Education, Youth and Sports project LM2011021, and by EURATOM.

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Evolution of Electron Temperature and Density Profiles in Edge Transport Barrier in the COMPASS Tokamak

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High-resolution Thomson scattering system on the COMPASS tokamak (R = 0.56 m, a = 0.2 m, divertor plasma configuration with ITER-like plasma cross-section) provides electron temperature and density profiles. The spatial resolution in the edge plasma region (~a/100) is optimized for edge transport barrier studies. Formation of characteristic edge profiles (pedestals) is observed during high-confinement mode, i.e. the core electron temperature and density are raised up by the value of pedestal height. Both the T_e and n_e pedestals are well-fitted by a modified hyperbolic tangent (mtanh) function. In this contribution, a fitting technique of the core profiles of electron temperature and pressure during H-mode is also described. Electron temperature and density on top of pedestal are statistically processed to find a possible signature for various types of H-modes. Pedestal stability with respect to peeling-balooning modes for experimental profiles will be evaluated.

This research has been supported by the Czech Science Foundation, grant P203-14-35260S, by the Ministry of Education, Youth and Sports project LM2011021, and by EURATOM.

The Influence of Secondary Electron Emission on the Floating Potential of Tokamak-Born Dust

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Dust production and its transport into the core plasma is an important issue for magnetic confinement fusion. Dust grains are charged by various processes, such as the collection of plasma particles and electron emissions, and their charge influences the dynamics of the dust. This paper presents the results of calculations of the surface potential of dust grains in a Maxwellian plasma. Our calculations include the charging balance of a secondary electron emission (SEE) from the dust. The numerical model that we have used accounts for the influence of backscattered electrons and takes into account the effects of grain size, material, and it is also able to handle both spherical and non-spherical grains. We discuss the role of the SEE under tokamak conditions and show that the SEE is a leasing process for the grains crossing the scrape-off layer from the edge to core plasma. The results of our calculations are relevant for materials related to fusion experiments in ITER.

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Time-Resolved Measurements of Electron Temperature and Density in Low Pressure Plasma Induced by Short Pulses of EUV Radiation

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We report on the measurements in the plasma induced at low pressures 3 – 100 Pa in hydrogen by submicrosecond pulses of extreme ultraviolet radiation at wavelength of 13.5 nm. This plasma was demonstrated to have a lifetime of a few microseconds. Langmuir probes were used to study temporal dynamics of electron temperature and density at submicrosecond resolution. Plasma densities of several 10^8 cm^{-3} and electron temperatures of several eV were measured.

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Volume Discharge in Helium nearby Atmospheric Pressure: Uniformity and Stability

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We have experimentally studied electric and time-spatial characteristics of volume discharge and transition from a volume burning stage to a channel stage nearby atmospheric pressure. We have shown that in conditions of strong preliminary ionization the discharge has a volume

structure of the current in a wide range of initial voltage, and the duration of this stage decreases with the growth of current density and gas pressure.

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Non-Stationary Optical Transmission Spectra of Inhomogeneous Plasma of Nanosecond Electrical Discharges near Narrow Spectral Absorption Lines

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Non-stationary optical plasma transmission spectra of high-speed ionization waves in cylindrical plasma waveguides filled with neon gas in the pressure range of 1 ÷ 60 Torr have been experimentally investigated. The analysis of the results obtained in the experimental study of transmission spectra of nanosecond discharge plasma shows that in the propagation of laser irradiation at an angle to the axis of the plasma waveguide, the classical ratio for absorption by Beer-Lambert law is shifting.

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Dielectric Barrier Discharges Diagnostics in Asymmetric Electrodes Arrangement

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Dielectric barrier discharges (DBD) are one of the most popular sources of non-equilibrium (low temperature) plasmas, and still find new fields for applications. That is why it is important to investigate them carefully and thoroughly. Our present approach focuses on the usage of a single barrier inside the measuring chamber. When a one-sided barrier is used it causes an asymmetry due to the difference of electrode material. In our case the barrier is a barium titanate ($BaTiO_3$) ceramic doped with lanthanum and neodymium which serves as the cathode in the positive half-period. The metallic electrode is the cathode in the negative half-period. The purpose is to analyze the discharge processes in neighbouring half-periods of alternating current voltage and to examine and discuss the influence of this asymmetry on the barrier discharges properties by means of electrical (current and light characteristics, charge-voltage loops, Paschen curves) and optical measurements (N_2 and N_2^+ spectra).

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Production and Removal of Dust Particles in Methane Plasma

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Dust particles are produced in plasmas containing CH species which are used in production of nanometer and/or micrometer particles, deposition on several processing and fusion materials. We have developed a large rectangular RF device, called TReD (Transport and Removal experiments of Device), whose size is 44 × 50 × 120 cm^3. Methane RF is generated for the production of dust particles with CH species, which are levitated in sheath potential. Properties of dust plasma produced by methane are analyzed by cylindrical electric probes. Levitated dusts are transported by three phase electric curtain electrodes and movement of dusts is observed by a fast camera with frames of 198,000 /sec. For the real time measurement of the produced dust particles, we have developed the following devices: one is a modified capacitive diaphragm (CDG) gauge which was firstly suggested by ITER team, and the other is a light-to-voltage sensor system.

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The Characteristics of the Lamp the Barrier Discharge in Mixtures of Ar-CCl_4-H_2O and Ar-Kr-CCl_4

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In the spectral region $\Delta\lambda = (140 - 350)$ nm, the ArCl*, Cl_2* and OH* bands were observed in the spectra of the barrier discharge in the Ar-CCl_4-H_2O mixture. To obtain maximal intensities of the ArCl(B→X), OH(A→X) and Cl_2(D'-A') molecular emission band at 175 nm, 309 nm and 258 nm, the optimal CCl_4vapor pressure should be 10 to 20 Pa. At the partial pressure p(Kr) = (0.3 – 1.3) kPa, the spectra contained the ArCl(B→X), KrCl(D→X), KrCl(B→X), and Cl_2(D'-A') bands. The introduction of krypton (p(Kr) $\leq$ 1.3 kPa) neither significantly decreases nor increases the total intensity of the UV– VUV molecular bands, but only redistributes their intensities between each other. An increase in the partial pressure of krypton (from 1.2 kPa to 6.6 kPa) considerably decreases the ArCl(B→X) band intensity due to the substitution of argon by krypton atoms upon formation of argon and krypton chlorides.

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Energy Efficiency of Planar Discharge for Industrial Applications

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The Diffuse Coplanar Surface Barrier Discharge (DCSBD) is a special type of dielectric barrier discharge, that was developed by the research group of prof. Cernak. The DCSBD discharge works at atmospheric pressure in open air or in different working gases. Plasma treatment using DCSBD discharge changes properties of the various materials; the discharge is applicable in treatment of planar surfaces for its high homogeneity and narrow plasma layer. The surface of the standard DCSBD discharge has the size 8 × 20 cm. The DCSBD device is extensively used in industry with input powers over 400 W for high uniformity. For its industrial applications we decided to measure energy efficiency of the plasma source, therefore, we measured the input power of the plasma generator and the power of the DCSBD discharge using an oscilloscope. In our work we did calculations for different oscilloscope parametersto estimate errors of our measurements linked to experimental setup.

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Strong Plasma Emission from Merged Neighboring Atmospheric Pressure Plasma Jets

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Strong atmospheric plasma emissions were achieved by plasma focusing effect using a circular array configuration in the ambient air. Two plasma modes, an intense plasma mode and the well-collimated plasma mode, were found to exist in the same plasma array structure under a change of experimental parameters such as gas flow rate and distance between two electrodes. The plasma focusing effect produced in adjacent atmospheric pressure plasma jets is also optimized by controls of gas mixture and gas flow rate. The central tube has an isolated gas connection from outer tubes, allowing the device to be used with variable flow rates and gas mixtures. As a result, it was observed that the plasma emission generated by an argon central flow with helium outer flows is strongly improved only if the argon central flow rate is high enough above 1 slm. It means that a plasma array device can be tuned to produce higher intense plasma than is available via static flow rates.

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Comparison of Ag Nanocluster Films Deposited by Sputter Deposition and Gas Aggregation Nanocluster Source

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Metal/plasma polymer nanocomposites are used in various technological applications. The key step in the production of such materials is formation of metallic nanoclusters. This may be achieved e.g. by sputter deposition from metallic targets or by use of nanoparticle sources.

In this study we compare both of these techniques. Ag nanostructured surfaces were prepared either by DC magnetron sputtering at pressure of 3 Pa or by gas aggregation source (GAS) of nanoclusters operated at pressure 28 Pa in the aggregation chamber. It is shown that in case of sputter deposition, the morphology and optical properties of prepared films is dependent on the substrate material and deposition time. In contrast, no significant changes in morphology were observed for films produced using GAS in dependence on the substrate material. The films were composed of individual nanoclusters and the deposition time affects only the amount of nanoclusters on the surface and intensity of anomalous absorption peak.

This research has been supported by the grant GACR 13-09853S from the Grant Agency of the Czech Republic.

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Emission of Mercury Monobromide Exciplex in Gas Discharge Plasma Based on Mixture of Mercury Dibromide Vapor with Argon and Helium

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Gas discharge plasma based on mixture of mercury dibromide vapor with gases is the working medium of coherent and spontaneous sources of radiation emitting in blue-green spectral range was investigated. The raise of emission power of mercury monobromide molecule is observed with the increase of argon and helium partial pressures from the value 104 to 114 and 122 kPa. Further increase of argon and helium partial pressures to 122 and 130 kPa reduces the emission power. The shift of the emission power maximum in the range of lower pressures in mixture with argon was also observed. The emission power of argon value was increased on 30 % in comparison with the mixture of mercury dibromide vapor with helium. The reduced electric field was equal to $E/N = 20\,\mathrm{Td}$ for the total density of the mixture components $(N) = 1.85 \times 10^{25}\ \mathrm{m}^{-3}$, at which the maximum emission intensity of $HgBr^*$ exciplex molecules was observed.

* * *

Influence of Plasma on the Surface Tension of the Liquids

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Previous research of plasma-liquid systems with vortex and reverse vortex flow showed that discharge plasma influences surface tension of the liquids. Based on the observations, surface tension at the liquid-plasma interface has lower value in comparison to a liquid without contact with plasma. To study this influence group conducted the series of experiments using four liquids with different conductivity and viscosity and the negative corona discharge as the source of charged particles. In the corona discharge plasma, temperature of heavy particles is close to the room temperature, which prevents surface tension from changing in response to heating. The system has a wolfram tip as a cathode and a stainless steel plate as an anode. A liquid drop is positioned on the anode surface under the cathode tip. Liquids used in the experiments are vacuum oil, rapeseed oil, distilled water and bioglycerol (crude glycerol left after biodiesel production).

Influence of Ambient Temperature on Functioning of Dielectric Barrier Discharge Ozone Generator

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Ozone has due to its high relative speed of reactions with chemical and biological species many applications. Generation of ozone by electrical discharge is a complex process, which apart on electrical parameters of the discharge depends also on temperature. The temperature can be associated with the balance of the discharge heat generation and the heat removal. The heat removal from the discharge chamber can be, except of the cooling of the chamber, also affected by input and output of air to or from the discharge chamber. For surface dielectric barrier discharge in air we investigated concentration of produced ozone as a function of average discharge power for temperatures 15 °C and 24 °C, which are the values at which are most frequently functioning commercial ozonizers. We found, that even small increase of air temperature from 15 °C to 24 °C decreases for particular discharge power ozone concentration to about 60 % of its original value.

This research has been supported by the TA CR under contract TA03010098.

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Nitritation of GaAs in Ar/N_2 RF Discharge: Electrical and Spectral Characteristics of Plasma

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The aim of the work is to find out optimal experimental conditions for nitritation of GaAs sample exposed to the flow of argon/nitrogen plasma products. Ar / 0 – 5 % N_2 discharge was ignited with 40 MHz generator at pressure p = 20 Torr in the quartz tube of 1.2 cm diameter. Nitritation of GaAs (100) sample, fixed on the heatable mount, was performed at tube outlet ca 5 cm downstream from active plasma region. From electrical characteristics current, i, voltage, u, and phase shift between i-u were recorded and based on this data input power, electron concentration and reduced electric field strength were calculated. Spectra were recorded from lateral direction of the tube as a function of input power and N_2 concentration. From the spectral data gas temperature and absolute densities of Ar 1s state atoms were estimated. Photoelectron spectroscopy (XPS) was used to examine GaAs surface nitritation efficiency as a function of substrate temperature and N_2 concentration in the mixture.

This research has been supported by the Estonian Archimedes Foundation financed by EU.

* * *

Deposition of Al_xO_y Nanoclusters by Gas Aggregation Source

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Aluminium oxide nanoclusters were deposited using gas aggregation cluster source. DC, water-cooled, planar magnetron equipped with 3 mm thick Al target (purity 99.99 %) was operated at constant current mode (200 mA). As a working gas argon was used with small admixtures of oxygen. The total pressure in the gas aggregation chamber was kept constant and equal to 40 Pa. Series of experiments with step by step addition of oxygen were performed. Deposition process was monitored by means of the optical emission spectroscopy in different parts of the aggregation chamber while the deposition rate was simultaneously measured by quartz crystal microbalance. It was found that both the deposition rate and temporal stability of nanoclusters production are strongly dependent on oxygen to argon ratio. Morphology, chemical composition and optical properties of nanocluster films deposited at optimized conditions were subsequently characterized by SEM, XPS and UV-Vis spectrophotometry.

This research has been supported by the grant GACR 13-09853S from Czech Science Foundation.

* * *

Decomposition of Atrazine Traces in Water by Plasma Discharge

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Organic pollutants take a prominent place amongst the contaminants of emerging concern. Some of these pollutants are known to be hazardous in relatively small concentrations. Modern wastewater treatment plants are not able to remove or decompose the persistent contaminants efficiently. Therefore, more efficient advanced oxidation processes need to be developed. Plasma discharge in contact with water is a promising technique, since it generates highly reactive plasma species near or in the water solution. In our experiments, atrazine, a persistent and hazardous pesticide, is chosen as a model micropollutant for decomposition in different reactors, based on either DBD discharge or diaphragm discharge. Its by-products and the efficiency of its degradation are measured by means of GC-MS and HPLC-MS. Hydrogen peroxide measurements are performed to characterize the reactors for specific experimental configurations. The results for the different reactors are compared with each other.

* * *

Comparative Measurements of the Plasma Potential by Ball-Pen and Langmuir Probe in Magnetized Low-temperature Plasma

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The recently developed ball-pen probe presents a promising tool for direct measurement of the plasma potential. In comparison with emissive and Langmuir probe, its advantages are a robust construction and simple interpretation of the data. It has been experimentally proved at many tokamak-like devices and, recently, also in low-temperature magnetized plasma. In this contribution we present results of comparative measurements of the plasma potential by ball-pen and Langmuir probe performed in a cylindrical magnetron DC discharge. The experiments were made at argon pressure 1 – 20 Pa, magnetic field 20 – 40 mT and discharge current 50 – 100 mA. The floating potential of ball-pen probe was measured using a high-input-impedance voltage follower. The plasma potential by Langmuir probe was estimated as an abscissa of the inflection point in the I-V characteristic. Preliminary experiments indicated a reasonable correspondence of the plasma potential at a certain set of experimental conditions.

This research has been supported by the Czech Science Foundation, grant P205/11/2341, by the CEEPUS Network AT-0063, by the Grant Agency of Charles University, grant No.604612, by the Ministry of Education, Youth and Sports of the Czech Republic, project LM2011021 and by EURATOM.

* * *

Plasma Kinetic Theory as a Basis of Diagnostic Methods

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One basic result of plasma kinetic theory is the spectral densities of fluctuations, measurable in both laboratory and space plasmas. A class of diagnostics based on plasma fluctuations can be described in a unifying manner within the Klimontovich approach; measurements of ion density fluctuations, electric field fluctuations, plasma scattering of radiation. In dusty plasmas, a drastic enhancement of the low-frequency part of the power spectrum of fluctuations has been predicted and its use as a dust diagnostic suggested. It stems from the screening clouds around the massive “nearly immobile” highly charged grains. For experimental tests of fluctuation theory in ideal/dusty plasmas, the ideal environment is that of stable quiescent plasma. However, most laboratory plasmas exhibit spatial fine structures. Rare exceptions are the brush cathode discharges. Such a device has recently been built at CNR-Bari.

* * *

Electrostatic Ion Thrusters – Towards Predictive Modeling

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The development of optimized electrostatic ion thrusters for space propulsion is until now a trial-and-error procedure. The need for expensive prototypes, extensive testing and iterative improvements is non-optimal in terms of time and costs. In other fields of research modeling is used to minimize the number of iterations, replacing real prototypes by virtual prototypes tested in numerical test environments. A typical example for this is car industry and the development of new car models, where numerical wind tunnels replace more and more real tests. Based on integrated models, combining self-consistent kinetic plasma models with plasma-wall interaction modules a new quality in the description of electrostatic thrusters can be reached. These open the perspective for predictive modeling in this field. This will be discussed for the example of the HEMP (High Efficiency Multistage Plasma) thruster patented by Thales Electron Devices.

This research has been supported by the German Space Agency.

* * *

Nonlinear Self-Organized Structures in Plasmas with Negative Ions

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The main principles of transport in multicomponent plasmas are described. Because the bulk plasma is charged positively to keep electrons together with positive ions, negative ions are confined by electrostatic fields inside the plasma and they flow from the plasma periphery toward the center. A nonlinear dependence of the negative ion flow velocity on their density results in the formation of steep gradients of negative ion density. Addition of negative ions makes the plasma afterglow a two stage process. In the first stage, the negative ions are trapped inside the plasma and only electrons and positive ions can reach the walls. At the second stage, electrons quickly leave the plasma, and an ion–ion plasma forms. The complex structure of the radio frequency sheath in strongly electronegative gases is also reviewed. Similar phenomena are observed in dusty plasmas. A possible relevance to ball lightning is discussed.

This research has been supported by the US Department of Energy.

* * *

Measurement of Forces Exerted on Surfaces by Particle Beams and Plasmas

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Plasma-wall interaction in plasmas usually involves electric currents and heat fluxes that can easily be measured. In contrast, the momentum transfer to a wall is typically very small and its measurement is correspondingly difficult. The situation is different, when there is a strong plasma flow [Makrinich and Fruchtman, Phys. Plasmas 16, 043507 (2009)] or in an ion beam [Trottenberg et al., Plasma Phys. Controlled Fusion 54, 124005 (2012)]. In this contribution, instruments are shown which are able to measure forces exerted on surfaces by particle beams and plasmas. In beams, the investigation of sputtering related momentum transfer is of special interest. A recent plasma experiment is presented, where a small plane target is mounted at the end of a pendulum force probe. The target is integrated into the wall, so that it becomes part of the wall without disturbing the plane geometry. The measured forces are surprisingly high. First interpretations of the data will be presented.

This research has been supported by the German Aerospace Center (DLR) under grant 50 RS 1301.

* * *

Streamers and Nanosecond Pulsed Discharges: Theory and Experiments

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and Eindhoven Univ. Techn., Eindhoven, The Netherlands

In this talk I will review our recent work on streamer discharges, with an emphasis on discharges in air. Based on experiments, theory and simulations on multiple scales in space and time, our understanding is now becoming more and more quantitative.
Given the broad attention on scientific plagiarism in the Dutch media, I will not give partial results away here, and republish them later in the international reviewed journals.
Results that I will discuss will include

1. Microscopic particle modelling of pulsed electric breakdown above and below the breakdown field in air [A. B. Sun, J. Teunissen, U. Ebert, Why isolated streamer discharges hardly exist above the breakdown field in atmospheric air, Geophys. Res. Lett. 40, 2417 (2013); A. B. Sun, J. Teunissen, U. Ebert, "Electrodeless inception of pulsed air discharges above and below the breakdown field", revised for J. Phys. D: Appl. Phys.],
2. Macroscopic corona models with large streamer numbers in so-called dielectric breakdown models, but now with finite streamer conductivity and consistent charge transport [A. Luque and U. Ebert, "Growing discharge trees with self-consistent charge transport: the collective dynamics of streamers", New Journal of Physics 16, 013039 (2014)],
3. Experiments on the dependence of the morphology of positive streamers on repetition rate, gas composition and radioactivity [S. Nijdam, E. Takahashi, A.H. Markosyan, U. Ebert, "Investigation of positive streamers by double-pulse experiments, effects of repetition rate and gas mixture", Plasma Sources Sci. Technol.23, 025008 (2014), S. Nijdam, G. Wormeester, E.M. van Veldhuizen, U. Ebert, "Probing background ionization: Positive streamers with a varying pulse repetition rate and with a radioactive admixture", J. Phys.D: Appl. Phys.44, 455201 (2011)], accompanied by theoretical understanding,
4. Experiments on metre long positive and negative discharges, showing a large streamer corona with transition to leader, and strong X-ray pulses within a particular stage of the discharge [P. O. Kochkin, A.P.J. van Deursen, U. Ebert, "Experimental study of the spatio-temporal development of metre-scale negative discharge in air", J. Phys. D: Appl. Phys. 47, 145203 (2014), P. O. Kochkin, C.V. Nguyen, A.P.J. van Deursen, U. Ebert, "Experimental study of hard X-rays emitted from meter-scale positive discharges in air", J. Phys. D.: Appl. Phys.45, 425202 (2012)].

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Mechanics of GeV-range Electron Beam Generation in Preplasma by Relativistic Laser Radiation

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Recent experiments and modeling [S. D. Baton et al., PoP 15, 042706 (2008); B. S. Paradkar et al., PRE 83, 046401 (2011); B. S. Paradkar et al., PoP 19, 060703 (2012)] have shown that the large-scale preplasma alters the LPI dynamics and the fast electron energies appears to be much larger than that predicted by ponderomotive scaling. The reason for this is the Fermi-like acceleration of electrons caused by the synergistic effects of electron interactions with both deep electrostatic potential well, formed in preplasma, and laser radiation [3]. We have carried out comprehensive simulations and confirmed that the most energetic electrons are generated in the course of the interactions of electrons with both electrostatic potential well in preplasma and laser radiation. We performed experiments on the Texas Petawatt Laser to validate modeling predictions. Both experimental results and comparison with simulations will be presented at the meeting.

This research has been supported by the US DOE grant DE-NA0001858 at UCSD.

* * *

3D Ion and Electron Mapping of a Droplet-Based Laser-Produced Plasma Measured Using a Motorized Array of Langmuir Probes

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Droplet-based laser-produced plasmas (LPPS) are promising light sources for EUV lithography. At the Laboratory for Energy Conversion, ETH Zürich, a new drople-based LPP source, ALPSII, has been recently built. Micro-sized tin droplets are used as target material to reduce the formation of plasma debris, which damages the light source collection optics. In order to mitigate the plasma debris and ensure the life-time of these optics, it is essential to understand the temporal and the spatial plasma dynamics. With the use of a new diagnostics tool, namely a multiple array of motorized Langmuir probes, these dynamics are studied, for the first time, in terms of ion and electron energy distribution around the droplet plasma. These measurements reveal an anisotropic distribution of the ion kinetic energy and flux around the target. Analysis of the probe signals yields estimated for the electron density and temperature. Comparisons with numerical simulations are also discussed.

* * *

Particle Emission in Relativistic Laser-Droplet Interactions

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Particle acceleration from nm-sized solid density droplets illuminated by a 2-cycle ultraintense laser pulse has been studied with realistic 2D PIC simulations. Attosecond electron bunches are emitted, whose angular pattern departs from Mie theory when droplets radii satisfy the condition $\delta_r < R < 10\delta_r$ ($\delta_r = \gamma^{1/2}\delta$ is the plasma relativistic skin depth). Induced transparency is proposed to explain why this transition regime is not recognizable as Mie theory (valid for $R >> \delta$) or dipole approximation ($R < \delta << \lambda$). The bunches are initially emitted from the surface following the nonlinear ponderomotive scattering model and then interact in vacuum with the laser ponderomotive pressure. The final emission angles and energy spectra of the bunches are determined. The remaining hot electrons generate an ambipolar field around the ion core, which undergoes a hydrodynamic expansion.

* * *

Physics of Laser Plasmas on Stages of Explosive Instability and Strong Magnetic Fields Quantization

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Experimental and theoretical investigations of fundamental properties (ultra short nonlinear phenomena) in laser produced plasmas had been carried out. The complex laser diagnostics (laser interferometer, picosecond momentary absorption photography, X-ray streak camera RFR-4, Imacon-486 end etc.) with high spatial and temporal resolutions were applied in natural experiments. For theoretical investigation we used the computer code “ZEVS-2D” (based on system equations of radiative magneto hydrodynamics with taken into account real properties of matter in wide ranges of density and effective temperatures of electrons and ions). It had been shown that in stage of explosive instability the generation of quasi stationary super strong electric and magnetic fields takes place, which accompanied by extremely high growth of ion temperatures (and acceleration part of ions up to GeV energies) as well as quantization of strong magnetic fields in small long living “plasma droplets”.

* * *

Effect of Third Harmonic Generation on the Growth Rate of Raman Forward Scattering of an X-mode Laser Pulse in Magnetized Cold Plasma

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Nonlinear Raman forward scattering (NRFS) in the propagation of an X-mode laser pulse in a magnet-ized cold plasma channel is analyzed for the third harmonic scattered waves. 3rd harmonic nonlinear wave equation is set up to obtain the coupling equations and dispersion relation of excited upper-hybrid wave. Using Fourier transforming and matching condition, the nonlinear growth rate of third harmonic NRFS is analytically calculated. It is shown that unlike the fundamental NRFS, the growth rate of third harmonic NRFS instability increases by increasing the external magnetic field.

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Ion Aceleration from Self-Similar Expansio of a Non-Quasi-Neutral Plasma into Vacuum

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We obtain a new self-similar solution which describes the expansion of a finite plasma mass into vacuum with a full account of charge separation effects. The solution exist only when the ratio $\Lambda = R/\lambda_D$ of the plasma scale length R to the Debye length λ_D is invariant under the condition $T_e(t) \propto [n_e(t)]^{1-2/\nu}$, where $\nu = 1, 2, 3$, corresponds respectively, to the planar, cylindrical and spherical expansion geometries.
The ion fluid is assumed to have a finite radial extension $0 \le r \le R\xi_f$. The functions Niand v_i/R are defined only inside the interval $0 \le \xi \le \xi_f$. The electron fluid, on the contrary, extends to infinity and the functions ϕ, Neand ve/R are defined for all $0 \le \xi < \infty$.
For $\Lambda \gg 1$ the position of the ion front and the maximum energy εimáxof accelerated ions are calculate: in particular, for $\nu = 3$ one finds $\varepsilon_{imáx} = 2ZT_{eo}W(\Lambda^2/2)$, where W is the Lambert function.

* * *

Density Transition Baserd Resonant Second Harmonic Generation in Plasma

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We propose a scheme of resonant second harmonic generation of a relativistic self-focusing laser in plasma under density transition. Relativistic self-focusing of laser beam causes electron redistribution from high intensity to low intensity region by ponderomotive force and a transverse intensity gradient is created in plasma which can generate a plasma wave at the pump wave frequency. The second harmonic undergoes periodic focusing in the plasma channel created by the fundamental wave. The normalized second-harmonic amplitude varies periodically with distance and attains maximum value in the focal region. Enhancement in the second harmonic amplitude on the account of relativistic self-focusing of laser in plasma under density ramp is seen. Plasma density ramp plays an important role in self-focusing which leads to enhance the second harmonic generation in plasma.

* * *

Relativistic and Ponderomotive Nonlinearities in Propagation of Laser Beam through Quantum Plasma

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In present work, using the recently developed quantum hydrodynamic (QHD) model, we study the combined effects of the ponderomotive and relativistic nonlinearities of the laser beam propagating through the high density quantum plasma. Further, we study the effect of non-linearities on the modulation instability. The effects associated with the Fermi pressure, the Bohm potential and the electron spin have been taken into account. The quasistatic approximation (QSA) has been used and the analysis proceeds using the source dependent expansion (SDE) technique. The effects observed in the present study have relevance to the environments of dense astrophysical plasmas (eg. neutron stars, magnetostars, etc.) as well as to the next generation laser plasma compression (LBPC) experiments where the electro-magnetic wave intensities can reach extremely high values.

This research has been supported by the CSIR, India.

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Surface Hardening of Instrumental Steels under Pulsed Electron-Beams Treatment in a Vacuum.

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Features of formation ofborides VB_2 and W_2B_5 on the surface of instrumental steels U8A and R18 under the influence of intense electron beams in pulsed mode were investigated. Electron beams are used as the initiator and heating source of self-propagating high temperature synthesis (SHS) of refractory borides VB_2 and W_2B_5. Mechanicalproperties of the layerswere studied. Wear properties theselayers were testedwith respect tosteel 45.

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Plasma System for Toxic Ash Processing

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Ash from combustion of fossil fuels is a superfine powder polluted with heavy metals. Vitrification is one of the most promising ways to protect the environment from pollution with highly toxic dispersed materials. We propose the use of plasma technology for vitrification of toxic ash. An experimental plasma set was designed and manufactured. As a result ash process-sing, we receive solid chemically resistant material with a low rate of leaching. The material is environmentally friendly and can be stored for a long time or used as a filling compound in construction.

This research has been supported by Energy Research Institute, King Abdulaziz City for Science and Technology and Luikov Heat and Mass Transfer Institute of the National Academy of Science of Belarus, Project KACST-HMTI/12.

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Characterization of PECVD Nitrogen Doped Amorphous Silicon Carbide Thin Films Irradiated with Neutrons

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The SiC(N) film were deposited on Si wafer by PECVD technology using SiH_4, CH_4, NH_3 and H_2 gases. The concentration of elements in film was determined using RBS and ERD method. Chemical compositions were analyzed by FTIR. Raman measurements of the a-SiC(N) films were performed using a Raman microscope with 532 nm laser. Irradiation of samples with neutrons to a total fluencies A (7.9×10^{14} cm^{-2}), B (5×10^{15} cm^{-2}) and C (3.4×10^{16} cm^{-2}) was performed. The films contain silicon, carbon, hydrogen, nitrogen and small amount of oxygen. No significance effect on the IR spectra after neutron irradiation was observed. Raman spectroscopy results of SiC(N) films showed decreasing of Raman band feature intensity after neutron irradiation and slightly decreased with increased neutron fluencies. The current-voltage characteristics of samples before and after neutron irradiation were measured. The measured current of the films increased after irradiation with neutrons and rise up with neutron fluencies.

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* * *

3D Integrated Micro-solution Plasma for The Treatment of Water - Effects of Discharge Gases -

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Methylene blue molecules in aqueous solution have been decomposed by using a novel 3D integrated micro-solution plasma reactor operated with Ar and He gases. Energy efficiency for methylene-blue de-composition in the case of Ar is relatively higher than that in the case of He. This result suggests that cheaper Ar gas has brought about superior performance in water purification. In both cases of Ar and He, methylene-blue decomposition efficiency is one order of magnitude higher than that of conventional so-lution plasma.

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Metal Nanocluster Formation in Pulsed Systems

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Metal nanoclusters, i.e., aggregates of atoms in the nanometer size scale (10–100 nm), gain deserved interest in many technological applications. Hence, formation of different metal clusters (e.g. Cu, Ti, Pt, Si, Ag, Co, Au) and nanocomposites has been recently studied. Clusters can be formed in systems that combine magnetron sputtering with subsequent condensation of sputtered metal atoms in the gas phase. We report recent results of research in novel pulsed systems that allow to control the energy transport and the sputtered atom thermalisation needed for efficient cluster growth. (i) The first configuration utilizes pulsed magnetron sputtering operated in wide range of discharge frequencies 100 Hz – 100 kHz. (ii) The second configuration employs pulsed gas aggregation cluster source fed by argon that is delivered in short pulses repeated with low frequency. It is demonstrated that cluster mass/size and cluster mass flux well corresponds with the pulse frequencies.

This research has been supported by the Deutsche Forschungsgemeinschaft (DFG) through SFB/TR 24 “Complex Plasmas” project and by Czech Grant Agency GACR project P108/12/1941.

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Control of the Particle Flux and Energy at the Substrate in an Inverted Cylindrical Magnetron Reactor for Plasma PVD

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Inverted cylindrical magnetrons (ICM) are often used for coating complex shaped objects. In such configurations, the substrate is inherently surrounded by the plasma and therefore the energy flux of the impinging particles represents the main contribution to the substrate heating which is a limiting factor for the deposition process. This work concerns a DC driven ICM configuration subjected to several constraints: the substrate can't be cooled, its surface area is small compared to the cathode and its imposed potential is ground, thus itself constituting the anode of the setup. The most important substrate heating factors are highlighted and a mean to raise the plasma potential by positively polarizing an additional electrode is proposed. This new surface generates a redistribution of the current and, consequently, regulates the electron flux on the substrate. The obtained results are shown as a function of electrode bias and discussed in terms of impact on the substrate heating.

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* * *

Dynamics of Compression Plasma Flows Interaction with Solid Targets

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Due to a capability to generate high energy plasma flows, magnetoplasma compressors offer an effective tool for modification of surface properties of various materials. In this report, the results of numerical simulation of compression plasma flows interaction with solid targets are presented. The proposed 2D model is based on coarse-particle method with account for magnetic field. Energy transfer by radiation is calculated with provision for spectral composition of radiation. This approach makes it possible to describe dynamics and structure of partially ionized plasma flows in quasi-stationary high-current plasma accelerators. As a result of numerical simulation, distributions of all plasma parameters were calculated. As of now, our model is the only one which allows the description of compression plasma flow parameters with detailed account for all main effecting factors. The model can be applied for plasma accelerators with complex geometries and any gases as working media.

* * *

Simulation of Electrical Arcs in Circuit Breaker

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Eaton is a power management company providing safe, reliable, efficient, and sustainable power management solutions for our global customers. In the Eaton European's Innovation Center in Roztoky, Prague we conduct electrical arcs (thermal plasma) simulation with focus on Circuit breaker applications. State of the art simulation is essential to reduce development, time to enhance performance, and increase reliability of circuit breakers. Not only the electrical arc itself, but also mechanism, materials, magnetics, thermodynamics, gas flow, and interactions with the electrical grid are key factors for realistic arc simulation. Several differential equations and empirically established modes and coefficients describe the physics of electrical arc and its environment. However, verification through laboratory experiments is essential to validate the model. Actual arc movies of an interrupting circuit breaker will be shown and compared to simulation results.

* * *

An Approach to Plasma Wake Studying

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Complex, conforming methods for investigation of plasma turbulent wakes are advanced and discussed. From the one hand, this is one-dimensional model of wake. From the other hand, this is study based on two-point velocity measurement. According to two-parametric model advanced, there are four global modes of two-cylinder wake. They are: the asymetric mode with von-Karman Street behind one cylinder is damped; the symmetric mode of two in-phase synchronized streets; two anti-phase synchronized streets; and two streets being synchronized by the angle distinct from 0 and π. According to the model there is a parameters aria where modes 2 and 3 alternate. The domains of attraction for these two modes was found. A two-point velocity transducer was created for this study. First data for two-cylinder wake have been obtained. These data as a whole agree with the model derivations (with regard to wake turbulence account).

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* * *

Transport and Optical Properties of Dense Non-Equilibrium Aluminum Plasma

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Transport and optical properties of liquid aluminum in the two-temperature regime were investigated in this work. At first transport and optical properties were obtained in the ab initio calculation. Ab initio calculation is based on the quantum molecular dynamics, density functional theory and the Kubo-Greenwood formula. Then semiempirical model of transport and optical properties was built based on the results of ab initio calculations. Ab initio results may also be well described by the Drude theory with the expression for the relaxation time determined in this work. The results were compared with the other models of transport and optical properties. Most of the models are reduced in the low temperature limit to the Drude expression with different expressions for the relaxation time. The Bloch-Grüneisen expression is commonly used for solid phase and for liquid phase as well. In this work we have shown that the Bloch-Grüneisen expression is incorrect for liquid phase.

* * *

Development of Dielectric Barrier Discharge Instabilities in Ne/Xe Excimer Lamp

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The objective of this work is to study the DBD instabilities in front of the dielectrics to eliminate their growth. In particularly, these instabilities will affect the discharge homogeneity and the excimer lamp efficiency. Different parameters have been investigated to understand the filaments and the streamers development in the sheath region under the operation conditions of UV light sources. These parameters are: the electric field, ions and electrons density which are calculated using one-dimensional model based on transport equations of electrons and ions coupled to Poisson equation for a parallel-plate DBD reactor.

* * *

Measurement of Target Currents Generated during the Interaction of Terawatt Laser with Solid Targets

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During the interaction of an intensive laser beam with a solid target, the electrons and ions are accelerated and the target becomes charged. As a consequence, an electrical current is flowing throw the target. The dependence of the target current on laser beam energy was measured at the iodine 3-TW kJ-class Prague Asterix Laser System (PALS) with pulse duration of about 350 ps. The measurement was performed with several kinds of target material. The short current pulses were registered with magnetic probe. Current pulse maxima achieve up to 2.5 kA and duration of the pulses is of about 0.5 ns (FWHM). This current could contribute to the high intensive broad-band electromagnetic noise accompanying all high-power laser experiments.

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* * *

Thermal Plasma Flow Modeling of Non-Transferred Arc Operating in Air at Non-Atmospheric Pressure

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Steady magnetohydrodynamic equations under axis-symmetric assumption incorporated with turbulence model are solved to predict the thermal plasma flow inside a DC torch with well-type electrodes operating in air at working pressure up to 3 bar. The simulation based on a parallelized Cartesian-grid based finite volume approach suggests that the plasma core becomes more restricted and gives a small arc length between electrodes as the working pressure grows, especially in the low current condition. In the typical case of 160 A and 140 L/min, the average gas temperature of thermal plasma can decline from 6200 K to 4000 K as long as the pressure is tripled from the atmospheric one. The average axial velocity of plasma flow is estimated to accelerate from 35 m/s to 300 m/s provided the pressure drops from 3 bar to atmospheric environment. The rise of operating pressure has negative impact on enhancing temperature and flow velocity of thermal plasma due to the energy loss at high pressure.

* * *

Emission from Electromagnetically Driven Solitons in Inhomogeneous Magnetized Plasma

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Nonlinear dynamics effects connected with the electromagnetically driven solitons of nonlinear Schrödinger equation (NSE) in inhomogeneous plasmas were studied numerically in [Kochetov A. V. et. al.: Physica D, 152-153, 723 (2001); Adv. Space Research, 29, 1369 (2002); Adv. Space Research, 38, 2490 (2006)]. In present paper we apply the NSE for inhomogeneous magnetized plasma to study the O mode dynamics by reason of resonance soliton emission converting to electromagnetic waves at the turning point [V. A. Mironov et.al: Sov. Phys. JETP, 67, No. 3 (1987)]. It allowed us to specify the correlation between soliton features and evolution of electrodynamical indexes. This numerical study should be useful for the understanding the nonlinear interaction of intense radio waves with ionosphere.

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* * *

Polymers Containing Cu Nanoparticles Irradiated by Laser to Enhance the Ion Acceleration

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Target Normal Sheath Acceleration method was employed at Prague Asterix Laser System Laboratory (PALS) to accelerate ions from laser-generated plasma at intensities above 10^{15} W/cm^2. Laser parameters, laser irradiation conditions and target geometry and composition control the plasma properties and the electric field of ion acceleration. Cu nanoparticles have been deposited and embedded into polymers in order to induce resonant absorption effects of the laser radiation, increase the plasma electron density and enhance the proton and ion accelerations. The hydrogenated targets containing nanostructures show a significant increment of the ion kinetic energy with respect to that of the pure polymer. Protons above 3.0 MeV can be accelerated in forward direction. The optimal target thickness, the maximum acceleration energy and the angular distribution of emitted particles have been measured using ion collectors, X-ray CCD streak cameras, SiC detectors and Thomson-Parabola Spectrometer.

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* * *

New 3-frame Femtosecond Plasma-Probing Techniques at the PALS Research Infrastructure

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In experiments with high-power lasers the plasma generation on the target surface starts at intensities as low as 10^9 W/cm^2, in case of the PALS laser ~1.5 ns prior to the pulse intensity maximum. The laser pulse rise time is long enough for development of many kinds of non-linear plasma instabilities, which may significantly affect the evolution of plasma corona at later stages of the interaction.
The femtosecond probing techniques developed recently at the PALS Research Infrastructure enables obtaining detailed information on the dynamic processes in the laser-produced plasma plume. Introducing the femtosecond Ti:Sa laser beam into a 3-frame recording system allows to capture three interferometric or shadowgraphic pictures of expanding plasma during a single laser shot. The time delay between frames is variable from 300 ps to 3 ns. The upgraded femto-second probing techniques are already helping to reveal fast changing structures in the initial phase of laser-plasma interaction.

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Pulsed Laser Deposition of FeS: a Spectroscopic Study

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In this work, we report the effect of laser pulse energy and target-substrate distance on the pulsed laser deposition (PLD) from ferrous sulfide (FeS) target in vacuum. During deposition with 1064 nm pulsed Nd:YAG laser, not intentionally heated Cu, Al and Ta substrates are used. The plasma plume emission is characterized by optical emission spectroscopy with temporal and spatial resolution. Thus the spatial distribution of the detected plasma species and their propagation velocities are obtained. The in-situ characterization of the ablation plume indicates the presence of both, Fe and S atomic and ion emission lines, which are used for the calculation of the plasma parameters: excitation temperature and electron number density. The obtained deposits at different laser pulse energies and distances are investigated by scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDX). A correlation between the observed structure and the plasma parameters is discussed.

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Self-Focusing of Intense Laser Beam in Magnetized Quantum Plasma

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In the present paper, we have analyzed the effect of the magnetic field on self-focusing property of an intense laser pulse propagating in a cold homogenous quantum plasma. The magnetic field is transverse to the electric vector and the direction of propagation of the radiation field. The study is motivated by the fact that transverse magnetic fields are generated in the laser-plasma interaction and in many applications, modification of the propagation characteristics of the laser beam due to the presence of these fields becomes important. We focus on the recently developed quantum hydrodynamic model (QHD), where the quantum-statistical pressure, quantum Bohm potential and the electron-spin effects have been taken into account.

This research has been supported by the UGC, India.

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Propagation of Extraordinary Laser Beam in Cold Magnetized Plasma

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This article studies the evolution of spot-size of an intense extraordinary laser beam in cold, transversely magnetized plasma. Due to the relativistic nonlinearity, the plasma dynamic is modified in the presence of transversely magnetic filed. In order to specify the evolution of the spot size of extraordinary laser beam, nonlinear current density is set up and the source dependent expansion method is used. It is shown that enhancing the external magnetic field decreases the spot-size of laser beam significantly, and thus the self-focusing effect becomes more important due to the extraordinary property of laser beam.

* * *

Relativistic Propagation of Electromagnetic Beam at the Interface of Underdense and Overdense Plasma

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In this paper we presents relativistic propagation of electromagnetic beam at the interface of underdense and overdense plasma. The nonlinearity in the dielectric function arises on account of relativistic variation of mass. An appropriate expression for the nonlinear dielectric constant has been used to study electromagnetic beam propagation at the interface of underdense and overdense plasma. The variation of beamwidth parameter with distance of propagation, self-trapping condition and critical power has been evaluated. Numerical estimates are made for underdense and overdense interface for typical values of relativistic beam-plasma interaction process. Since the relativistic mechanism is instantaneous, this theory is applicable to understanding of self-focusing and propagation of electro-magnetic beam in underdense and overdense plasma.

* * *

Physics of the Laser "Magnetoms"

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The soliton-like solutions for quasi-static magnetic and electric fields had been obtained in numerical solution of Maxwell equations in matter under an intense laser radiation influence, when thermo-magnetic and explosive instabilities took place. What physical objects correspond to such solutions in reality? Such objects are very similar to quasi atoms with high number of electrons and ions – "magnetoms" with freezing super strong magnetic fields. In the vicinity of such systems (in micron or submicrons regions) as in atoms, there are very high pressures, electric and magnetic fields, and effective ion temperatures (in keV or MeV ranges in dependence from total energy input). Under these conditions a very high internal energy concentration takes place. This phenomenon can be accompanied by the observed effect of quantization of strong magnetic fields in laser plasmas.

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Laser Plasmas as Short Living Holograms and Crystals

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Experimentally demonstrated the possibility of plasma hologram creation by using two laser beams: for plasma production we used the Nd:YAG-laser (with intensity in the focal spot I >> 1.E14 W/cm^2 , frequency of repetition of main pulses 4 Hz, with energies of main pulses E >> 100 mJ, half-pulse duration t = 100 ps, with wavelength l = 1.06 mm) and for hologram reproduction we used continuum low intensive He-Ne laser (standard, wavelength 632 nm). During plasma creation we can produce not only plasma holograms with images of solid-state metallic targets but also short living plasma crystal, by using which in turn we could observed the effect of multiplication.

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Hydrogenated Targets for High Energy Proton Generation from Laser Irradiating in TNSA Regime

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Polyethylene based thin targets have been irradiated in high vacuum and in TNSA (Target Normal Sheath Acceleration) regime by using the Asterix laser at PALS facility at the fundamental wavelength and pulse energy of about 600 J. The plasma produced in forward direction has peculiar characteristics depending on the laser irradiation conditions and on the target composition and geometry. Particular attention has been given to the optical properties of the polymer and to promising nanostructures embedded into polymer increasing the laser absorbance. Proton kinetic energies from hundreds of keV up to about 5 MeV have been obtained by looking for the optimal conditions for improving the electric field driving the ion acceleration.

This research has been supported by the PALS (Prague Asterix Laser System) laboratory and by the LASERLAB- Europe project N. pals001823.

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Theory and Simulations of Laser-Plasma Generation of Tunable Few-cycle Mid-infrared Pulses

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We examine a new method for generation of the coherent few-cycle mid-infrared pulses. The method utilizes the gas ionization by ultrashort incommensurate two-color laser pulses. These incommensurate pulses contain the fields at two different frequencies. One of the frequencies is detuned from the doubled value of the other one. We calculate both analytically and numerically the electron current which is excited by such two-color pulse in a gas during ionization and find out that the low-frequency component of that current can have central frequency in the mid-infrared range, which can be controlled by tuning the frequency of the weaker optical field. We estimate energy radiated by that current and discuss the possibilities of employing the phenomenon for creating the tunable source of coherent few-cycle mid-infrared pulses.

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Spectroscopic Measurement of Laser-Induced Tin Plasma in Presence of a Magnetic Field

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Optical emission spectroscopic studies have been carried out on a laser-produced tin plasma in the presence of 0.5 T parallel magnetic field. Plasma was generated by focusing 1.064 μm Nd:YAG laser pulses onto a solid density, planar tin target in vacuum at a laser irradiance of 1×1011 W/cm^2. Estimates of the electron temperature and density were made by assuming Boltzmann distributed population levels and Stark broadened singly ionized tin spectral lines, respectively in the presence and absence of *B* field. The temperature measurement showed an increase of a factor of 1.5 with application of 0.5 T magnetic field. However the plasma density is found to be reduced with application of a magnetic field.

This work was supported in part by the US National Science Foundation (PIRE project) and the Academy of Sciences of the Czech Republic and the Czech Republic's Ministry of Education, Youth and Sports, under Projects HiLASE (CZ.1.05/2.1.00/01.0027), DPSSLasers (CZ.1.07/2.3.00/20.0143), and Postdok (CZ.1.07/2.3.00/30.0057), co-financed from the European Regional Development Fund.

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Application of Glow-Discharge Plasma for Structure-Phase Modification of Cutting Carbide Ceramics

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Great attention is currently given to the design, development and improvement of the various methods of cutting tool modification and treatment in glow-discharge plasma is among of these methods.
The subject of this investigation was oxide-carbide ceramics containing Al_2O_3 and TiC which was exposed to glow-discharge plasma treatment. It was shown that after plasma treatment of working surface of cutting plates made of oxidecarbide ceramics wear resistance is 1.5 – 2.5 higher than for nonirradiated ones. By means of metallographic and X-ray spectrometry analysis we found out that during plasma processing block-fragmented structure was formed due to ion bombardment and carbon was redistributed in bulk and at the boundaries due to radiation-enhanced diffusion. X-ray spectrometry study showed that plasma processing leads to the formation of solid solution of aluminium carbide Al_4C_3 with hexagonal crystal lattice. Plasma processing also changes parameters of titanium carbide crystal lattice.

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Inactivation of *Candida albicans* Growth Indirectly Treated by Gliding Arc

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Bactericidal and fungicidal effect of non-thermal plasma, generated by different types of discharges at atmospheric pressure are being intensively studied. We distinguish between the direct and indirect plasma treatment. The gliding arc usage for the direct treatment is problematic due to an electrode configuration. Another problem is that the high temperature of a stream can destroy the substrate. On the other hand, the indirect treatment can be a perspective tool for inactivation of germs.
The indirect plasma treatment of a contaminated surface was studied using the AC gliding arc discharge in air. The gliding arc was realized in two cone electrode system with an ignition zone interelectrode distance of 3 mm. The active species produced by the discharge were carried by the air flow toward an agar plate through a non-conductive nozzle. Agar plate was

inoculated by 10^6 CFU Candida albicans suspension. The preservation of a plate overheat was realized by a plate rotation. The gas temperature at the nozzle exhaust did not exceed 50 °C.

This research has been supported by the Czech Technical University in Prague grant SGS13/194/OHK3/3T/13.

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Indium Nanoparticle Synthesis Using Plasmas in Water for Nanoparticle Transport Analysis in Living Body

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Indium nanoparticles can be employed for studying kinetics of nanoparticles in the living body because the body does not contain In. Here we report synthesis of In nanoparticles using plasmas in water. In rod electrode and In plate electrode were immersed into pure water. Discharges were generated by applying pulsed voltage between the electrodes. The discharge voltage and frequency was 9.2 kV and 10 kHz, respectively. From the discharges, emissions of In, O, H, and OH were observed. In emission suggests In atoms exist in plasmas and contribute to In nanoparticle formation. The electron density was around 10^{17} /cm^3 deduced from Stark broadening of H emission. TEM observation revealed that nanoparticles exist in the supernatant collected after the 3 min discharge. The primary nanoparticle size was around 7 nm. EDX measurements show the nanoparticles consist of In and O. These results show that In nanoparticles were successfully produced using plasmas in water.

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New Possibilities of Low Temperature Atmospheric Plasma Jets for Biomedical Applications

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This work will show 2 possibilities for use of cold atmospheric plasma jets in biomedical fields. One part will focus on direct plasma interactions with microorganisms which cause skin infections, tested in vitro on agar plates, for potential use in the new medical sector of plasma medicine. 2 jet systems were tested with varied process gases (Air, N_2, Ar) and treatment parameters. The results have shown in general strong inhibitory effects but also a dependency of the used gas and its reactive plasma species (OES). The 2nd part presents the deposition of composite layers with high antimicrobial activity using such a plasma jet arrangement as well. Different chemical precursors are induced into the plasma, one able to form SiOx structures and one to form and embed Ag, Cu or ZnO NPs in-situ in the growing films. Applied on textiles for use as wound dressings and modified Ti alloys

as substitute materials the layers showed high antibacterial but non-cytotoxic behaviour in standard tests.

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Cleaning of Well Screens Using Strong Shock Wave Generated by Pulsed Spark Discharge in Water

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Water wells clogged by various reasons can be improved by the application of appropriate rehabilitation methods, exending their life. In this paper, we have investigated the field applicability of well cleaning using high-voltage pulsed discharge technique. The field test has been performed in a water well for bank filtration located near Anseong-cheon (river) in Korea. Prior to the treatment, Johnson-type screens installed in the middle of the water well have lefted untreated almost a year to be detereriorated by biochemical processes. During the treatment, the maximum shock pressure of up to 180 bar is delivered to the surface of well screens with an initial energy of 490 J. Investigation of well screens with an underwater camera clearly shows that the strong shock pressure generated by underwater spark discharge can effectively remove almost all incrustations formed in the well screens, proving the field applicability of the present technique.

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