DEVELOPMENT OF ELECTRIC PROBES FOR IMPROVED DIAGNOSTICS CHARACTERIZING FILAMENTARY TRANSPORT IN MID-SIZE TOKAMAKS

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The dynamics of the edge region in magnetically confined plasma is of vital importance for plasma performance and plasma exhaust. A full understanding of this region and particularly the transport through the Scrape-off-Layer is a high priority issue in fusion plasma physics. Probes still offer highly temporal and spatial resolved measurement of plasma fluctuations and transport in the SOL. We are developing probe systems to measure plasma parameters with higher reliability and accuracy. We especially envisage probes for directly measuring the plasma potential (PPP for Plasma Potential Probes). One type of PPP is the electron emissive probe. Another type of PPP is the newly invented Bunker probe which in a magnetized plasma will also float on the plasma potential since due to its geometry the random plasma electron current is strongly reduced until its magnitude is almost equal to that of the ions. This is a necessary condition for the probe to float on the plasma potential. Combinations of such PPPs can be used to measure electric field components necessary for the determination of transport parameters.

PLASMA WALL INTERACTION WITH THE ITER-LIKE FUSION MATERIAL MIX IN JET

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Since installation of the JET ITER-Like Wall (Matthews et al., Phys. Scr. T145 (2011) 014001) more than 30 h of plasma operation with the inertially cooled full tungsten divertor, designed and developed by the Forschungszentrum Julich and IPP Garching (Mertens et al., 2011 Phys. Scr. T145 (2011) 014002), and the beryllium first wall took place. The divertor plasma-facing components PFCs successfully handled harsh tokamak conditions with (i) high surface temperature excursions passing both the tungsten ductile-to-brittle transformation temperature and the re-crystallisation temperature of about 1600 °C multiple times, (ii) ITER-relevant steady-state and transient peak power loads due to more than 1.5 million of edge-localised modes or ELMs, (iii) combined impact of deuterium and intrinsic impurities (C, Be, O) as well as extrinsic seeded impurities like He, Ne, Ar, N_2 and Xe, and (vi) multiple complex conditioning cycles including baking to 320 °C, deuterium glow discharges and ion-cyclotron-radio frequency plasma wall conditioning. Routinely, monitoring discharges have been applied to characterise the long-term evolution of impurity content in the plasma and of the tungsten divertor and first wall performance. Overall the bulk divertor components showed no visible damage and only moderate damage in form of cracking networks and delamination of the W-coating CFC tiles could be observed. The main wall bulk Be tiles showed at areas subjected to direct plasma contact significant damage by melting and erosion due to both high steady state heat flux (apex areas of mid plane limiters during limiter plasma operation) and high transient heat flux (upper dump plate during disruptions).

We present an overview of physics findings obtained from the JET operational campaigns C28–34 (2011–2014) with full tungsten divertor and beryllium first wall including in-situ observations as well as post-mortem analysis of extracted tiles in different interventions. These include on the material side erosion and deposition characteristics (Brezinsek et al., Nucl. Fusion 55 (2015) 063021), material migration and mixing, fuel retention and outgassing (Brezinsek et al., Nucl. Fusion 53 (2013) 083023) as well as power handling (Coenen et al., J. Nucl. Mater. 463 (2015) 78–84). Complementary a brief insight into the plasma compatibility and performance will be given and the conclusions for the next step fusion device ITER will be drawn (Brezinsek et al., J. Nucl. Mater. 463 (2015) 11–21).

THE WENDELSTEIN 7-X STELLARATOR — CONSTRUCTION, COMMISSIONING AND FIRST EXPERIMENTAL EXPERIENCE

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Wendelstein 7-X is an optimized stellarator with superconducting coils aiming at high performance steady-state operation demonstrating basic reactor requirements. To achieve this, the design of the device is based on an elaborate optimization of the plasma confinement and the equilibrium and stability properties, including a viable exhaust concept. The commissioning of Wendelstein 7-X was successfully concluded by a first verification of the vacuum flux surface topology. During the first experimental campaign from December 2015 until March 2016, important physics studies included a first assessment of the basic confinement properties and studies of the core and edge plasma transport. At plasma densities of several $10^{19}\,\mathrm{m}^{-3}$ electron and central ion temperatures up to 10 and 2 keV have been achieved. The further extension of the device focuses on increasing the heating power and power handling capability of the plasma facing components, starting full steady-state operation by 2020.

This research has been supported by the EUROfusion Consortium

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NEW RESULTS IN THE THEORY AND MODELLING OF SHEATHS AND NEAR-ELECTRODE LAYERS IN ARC DISCHARGES

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Near-electrode space-charge sheaths play a crucial role in the physics of most discharges with cold plasmas; in particular, processes in the near-cathode sheath are responsible for formation of single (normal) spots or spot patterns on cathodes of dc glow discharges. The same is true for low-current high-pressure arcs, as was shown experimentally and theoretically in the beginning of the 2000s. On the other hand, near-electrode space-charge sheaths have been routinely neglected in the theory and modelling of high-current high-pressure arc discharges: most of the models rely on the assumption of LTE in the whole discharge gap. Methods of account of near-electrode space-charge sheaths in high-current high-pressure arcs and, more generally, of deviations from LTE occurring near the electrodes have started to appear relatively recently. The aim of this talk is to review these methods with application to cathodes and anodes of high-pressure arcs and cathodes of vacuum arc discharges.

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EFFECT OF HIGH ELECTRON EMITTING SURFACES ON THE CHARACTERISTICS OF DC GLOW DISCHARGES AND FUSION PLASMAS

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The emission of electrons by ion or electron impact is a key element in the basic under-standing of electrical discharges. It plays a fundamental role in the maintenance of glow discharges and it is directly related to the modification of the sheath potential in hot plasmas as those used in Fusion Research. After the first report of the anomalously high secondary electron emission (SEE) from lithium surfaces exposed to a Glow discharge plasma (Oyarzabal et al., J. Nucl. Mater. 452 (2014) 37), insertion of lithium elements into the plasmas of the TJ-II stellarator has proven the important effect that the SEE yield may have in the performance of hot plasmas. On the other hand, in cold plasmas, a coating of lithium at the cathode surface leads to a drastic drop of the potential required to maintain it, thus significantly reducing the power dissipated by the discharge.

In this presentation, a survey of these results will be presented and their implications on cold and hot plasma research will be addressed.

ULTRAHIGH ACCELERATION OF PLASMA BY LASERS FOR AVALANCHE BORON FUSION REACTIONS

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Advancements are reviewed for fusion of protons with ^{11}B (HB11) based on measured elevated gains (Picciotto, Margarone et al., Phys. Rev. X4 (2014) 031030) resulting in a non-thermal avalanche ignition (Lalousis, Hora et al., Laser & Part. Beams 32 (2014) 409), (Hora, Korn et al., Laser & Part. Beams 33 (2015) 607), (Hora et al., arXiv 1510.02465) by ultrahigh intensity laser pulses of picoseconds duation. Ultrahigh acceleration above 10^{20} cm/s^2 for plasma blocks was numerically predicted since 1978 (Hora, Physics of Laser Driven Plasmas. Wiley, New York 1981, p. 178–179) by the dominating force from genera-lizing Maxwell's stress tensor by the dielectric plasma properties of the nonlinear force fNL. The picosecond option resulted in solid density HB11 ignition of fusion similar to DT fusion (Hora, Miley et al., Energy Environ. Sci. 3 (2010) 479). The demonstrated avalanche reaction (Hora, Korn et al., Laser & Part. Beams 33 (2015) 607, Hora et al., arXiv 1510.02465) in combination with laser produced magnetic fields above kiloTesla (Lalousis, Hora et al., Laser & Part. Beams 32 (2014) 409) for cylindrical magnetic trapping resulted in more than GJ energy of alpha particles generated by 30 kJ picoseconds laser pulses.

MAGNETOHYDRODYNAMIC COMPRESSION AND HEATING OF A LASER PRODUCED PLASMA

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The results of an experiment on magnetohydrodynamic compression and heating of a laser produced plasma in vacuum are described. The laser plasma was produced by laser ablation of a copper (Cu) target at 2 Jcm^{-2}. A pulsed magnetic field, with an amplitude of 0.3 T and a period of 2.2 μs, was produced by a 3-turn spiral induction coil placed 10 mm above the ablation spot. The ablation plasma flow through a central aperture in the induction coil was measured using a Langmuir ion probe. Time-resolved imaging revealed that the magnetic field had a strong influence on both the plasma between the coil and the target, and on the plasma which flows through the aperture in the coil. The plasma flow through the coil aperture is strongly pinched due to the Lorentz interaction of the induced current and the coil magnetic field. Heating of the plasma is evidenced by strong enhancement of the overall visible light emission and the appearance of Cu$^+$ line emission.

This research has been supported by the Science Foundation Ireland.

ELECTRON HEATING IN CROSSED LASER BEAMS WITH POSSIBLE FURTHER ACCELERATION IN ION CAVITY

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In this contribution, we explore by numerical PIC modelling electron heating in crossed (main and additional) laser beams propagating in plasma. Thermal electrons with energy of tens of eV are heated to energy up to tens of MeV in the beam crossing region. This rate of heating is qualitatively compatible with single particle motion in two plane waves. The fast electrons can then be injected into an ion cavity in conditions of the bubble LWFA regime. As an example, we consider the plasma density $5 \times 10^{18}\,\mathrm{cm}^{-3}$ and the peak amplitude of the normalized vector potential of the main beam $a_0 = 4$, the intensity of the additional beam being 1 percent of the intensity of the main beam. A bunch of electrons, with a narrow energy spread about the mean value of 400 MeV is obtained after 6 ps of the bubble propagation. In such a very short time, the self-injection did not yet occur.

This research has been supported by the National Grid Infrastructure MetaCentrum.

RELATIVISTIC PLASMA RESONANCE IN LASER-PRODUCED PLASMA

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We present a theoretical investigation of a nonlinear transformation of an electromagnetic wave near the laser-produced plasma critical density, which is based on the renormgroup symmetries method. An analytical stationary solution to the system of equations for relativistic plasma oscillations is found that defines a phase modulation of plasma waves near the plasma resonance region. The spatio-temporal characteristics of the stationary potential electric field and the electrons velocity are described. The spectral analysis of the deduced stationary solution is performed that points to the existence of a power law spectrum for the relativistic plasma electric field. The relativistic plasma wave-breaking conditions are deduced and the influence of the relativistic nonlinearity on the spatial localization of the plasma field is studied. The optimal conditions for acceleration of electrons in the plasma resonance field are discussed.

VACUUM SECONDARY EMISSION FROM AN ULTRASHORT LASER PULSE TIGHTLY FOCUSED BY OFF-AXIS PARABOLIC MIRROR

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Laser-plasma interaction with ultrashort sub-PW laser pulses is a source of high energy electrons, ions as well as secondary radiation, including ultrashort X pulses. One possible scenario of electron acceleration in super strong laser fields is so-called direct electron acceleration. The interaction between the laser beam focused by off-axis parabolic mirror and free electrons is determined by topology of the laser fields in a focal spot. As a result, the direct electron acceleration and corresponding non-linear Thomson scattering (NTS) of laser pulse have energy and spectral characteristics which are different from those for the case of modest focusing, where the laser field components can be described in simplified manner relevant to paraxial approximation. Our results on NTS can be used for diagnostics of the laser pulse characteristic as complimentary to those based on the energy-angular spectra of directly accelerated electrons.

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TWO-PLASMON DECAY INSTABILITY IN WEAKLY RELATIVISTIC LASER PLASMA INTERACTION

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Two-plasmon decay (TPD) instability is a three-wave process in which the incident light wave propagates through the plasma decays into two plasmons which are nearly equal in frequency and hence this process takes place at densities near quarter critical density. The TPD instability has been identified as a source of hot electrons with energies up to 50 keV, which could induce preheat of the fuel in inertial confinement fusion (ICF) experiments.

In this research, TPD instability is examined in laser plasma interaction in the weakly relati-vistic regime. Electron velocity up to third order nonlinearity is calculated and applied in the equation of motion, continuity equation, and wave equation to find the full dispersion relation and temporal growth rate of the TPD instability. The effect of the relativistic motion of plasma electrons on the growth rate of the instability is reported in different wave numbers of the plasmons correspond to their scattering angles.

GENERATION OF MAGNETO-ACOUSTIC WAVES BY LASER-PLASMA INTERACTION

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Electrons can interact with the ion acoustic potential during their evolution, and then can be trapped in the wave potential. Elsewhere, non-thermal electron distribution is turning out to be a characteristic feature of the space plasma. A useful distribution function to model such electrons is the Cairns distribution. It is relevant to say that the simultaneous presence of energetic free electron and trapped electrons in plasma is observed by many applications that may arise during the acceleration mechanisms of electrons and ions, in the context of laser-plasma acceleration In this work, magneto-acoustic waves generation in magnetized plasma where the combined effect of trapped and non-thermal electron are taken into account, are studied. The effects of external magnetic field, trapped electron distribution and non-thermal electron distribution are examined.

This research has been supported by the CDTA.

INFLUENCE OF ELECTRON SOURCES ON THE NEAR-FIELD PLUME IN A MULTISTAGE PLASMA THRUSTER

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In order to obtain a better understanding of the near-field plume of a multistage plasma thruster, the influence of an external electron source is investigated by Particle-In-Cell simulations. The variation of the source position showed a strong influence of the magnetic field configuration on the electron distribution and therefore on the plume plasma. In the second part of this work, higher energetic electrons were injected in order to model collision-induced diffusion in the plume. This broadens the electron distribution, which leads to a more pronounced divergence angle in the angular ion distribution.

This work was supported by the "ITSim - Skalierung von Ionentriebwerken mittels numerischer Simulation" project of the Bavarian State Ministry of Education Science and the Arts and the German Space Agency DLR.

POWER TRANSFER TO GAS HEATING IN MOLECULAR GASES: APPLICATION TO N_2 AND N_2–O_2 PLASMAS

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Electron impact collisions in plasmas discharges containing N_2 or O_2 are responsible for the formation of vibrationally and electronically excited molecules, as well as for their dissociation and ionization. Part of the discharge power spent on these processes is sub-sequently transferred into gas heating through the following mechanisms that take place in the plasma volume: non-resonant V-V energy exchanges, V-T energy exchanges, electron-ion recombination and exothermic chemical reactions. Moreover, if the plasma has boundaries, being for instance produced in a cylindrical tube, the gas can be also heated from the re-combination of N or O atoms at the wall and from the diffusion of molecular and atomic metastables states to the wall. The purpose of this work is to presenta time-dependent model to study the main gas heating mechanisms and temporal evolutionof the gas temperature for different plasma conditions. The power transfer to gas heating is also discussed in detail.

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PRE-BREAKDOWN LUMINOUS WAVE IN COPLANAR BARRIER DISCHARGE

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In physics of dielectric barrier discharges two consecutive phases of discharge dynamics were reported so far. The Townsend phase of discharge formation followed by the ionizing waves propagation (cathode/anode). During the Townsend phase the formation of electron avalanches leads to space charge accumulation and electric field distortion invoking the propagation of ionizing waves leaving the dielectrics charged by surface charges.

In present contribution the new luminous phase of discharge formation is reported in coplanar dielectric barrier discharge, that precedes the Townsend phase of discharge formation. During this phase the luminous cloud was formed above the edge of still negative electrode, just before the change of electrodes polarity. Consequently it spread across the whole electrode surface as a luminous wave. This extremely weak light phenomenon was attributed to surface charge dynamics connected to the recombination of surface charges prior to the next discharge event.

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FEEDBACKS IN THE NON-EQUILIBRIUM OXIDATIVE PLASMA REACTING WITH THE POLYETHYLENE

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This work was aimed at understanding the mechanisms of the processes influencing the physical properties and active species kinetics in the non-equilibrium, oxidative plasma during the interaction with polymer materials. The special attention was attracted to the impact of the gaseous plasma-polymer reaction products on both plasma parameters and surface modification kinetics.

This work was supported by the Russian Foundation for 206 Basic Research (RFBR) (Project No. 16-32-00404).

MICROWAVES GENERATE REACTIVE PLASMA FIGURING FOR ULTRA-PRECISION FABRICATION OF OPTICS

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Microwave plasma aims at providing highly efficient activated energy beams for rapid fabrication of ultra precise optics. The chemical nature of this type of energy beam is targeted at silicon-based materials. In this presentation, we show a novel ADTEC microwave-generated plasma torch design, which is operated at atmospheric pressure. In this study, the plasma torch is fed with either argon or helium carrier gas. The results of a preliminary investigation using Optical Emission Spectroscopy (OES) are reported and discussed. These results show the operating range when the main processing parameters are changed: microwave forward power values, gas flow rates and the types of gasses. Additionally, the results from microwave characterisation experiments are discussed. These results show the energy efficiency and directionality of the ADTEC microwave micro plasma torch.

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AN INVESTIGATION OF INTERACTION FOR ELECTRICAL DISCHARGE AND LIQUID-MOLECULE

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UV Spectra and vibrational spektra of 5-kloro-3-(2-(4-metilpiperazin-1-il)-2-okzoetil)benzo[d]tiyazol-2(3H)-on drug molecule under the effect of atmospheric pressure plasma jet of neon have been analyzed. Since the 1990s, various pharmacological investigations of newly synthesized benzothiazoles demonstrated interesting pharmacological activities and led to the development of new medications for treating diseases. They were taken into account extensively for their antiallergic, anti-inflammatory, antitumor, and analgesic activities. Various benzothiazole compounds are of considerable interest for their diverse pharmaceutical uses and they have a vital role in the synthesis of fused heterocyclic systems. The 2-benzothiazolethiol ring system is important in medicinal chemistry and finds its application in drug development for the treatment of allergies, hypertension, inflammation, schizophrenia and bacterial and HIV infections.

INFLUENCE OF RATIO BETWEEN PLASMA-ACTIVATED AND NON-ACTIVATED AIR ON EFFICIENCY OF PLASMA-CATALYTIC HYDROCARBON REFORMING

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Dynamic plasma system based on the rotating gliding discharge was developed as simple and efficient sources of active components for the purpose of renewable hydrocarbons reforming. The system features separate injection of plasma-activated air and of the fuel mixture into the reactor, which provides high energy-efficiency of plasma injection and control over the conversion processes via the generation of non-equilibrium non-thermal plasma.

The composition of produced plasma and electron, rotational and vibrational temperatures of its components were determined based on plasma emission spectra. The product composition, reforming efficiency, electric energy transformation coefficient and hydrogen energy yield of the reforming process were evaluated. The influence of the air-flow on the reforming properties was investigated. The system is able to convert ethanol into synthesis gas with 80% reforming efficiency and high hydrogen energy yield (approx. 350 g per kWh of electrical energy).

EFFECT OF ELECTRON BEAM IN PLASMA-OPTICAL DEVICE FOR EVAPORATION OF DROPLETS IN CATHODE ARC PLASMA COATING

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Cathodic arc coatings are praised for their high deposition rates. But droplets are presented in arc plasma stream. Droplet weight component is compared with ion component. Droplets do worse properties of deposited films. As a result of droplet removing from flow through separation the deposition rate is greatly reduced. To reduce the negative effect of droplets on the film and to increase the deposition rate the energy effect of electron beam, which formed by double layer, appeared in the plasma-optical system in crossed electrical and magnetic fields in the evaporation of droplets is considered. High-energy electrons appear near the inner cylindrical surface by secondary ion - electron emission. The additional energy pumping by this beam for droplet evaporation is considered in this paper. It is shown that high-energy electrons pump energy up to 9 keV, which are related to one atom, which should be evaporated, and which is sufficient for droplet evaporation.

This research has been supported by the STCU and NANU Agreement 6059.

POWER LOADS CHARACTERIZATION ON A LIMITER WITH MISALIGNED EDGES IN THE COMPASS TOKAMAK

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The presence of leading edges (LE) in the ITER divertor is a major issue because of a near normal incidence of magnetic field lines that can cause melting of the tungsten tiles. The standard geometrical approach of the heat flux distribution around a LE was recently challenged by particle-in-cell (PIC) simulations showing that part of the impinging power load to the side of the LE should be transferred to the top surface.

A special graphite tile with four leading edges with misalignment up to 0.9 mm was installed on the COMPASS inner wall in direct view of a high resolution IR camera (0.25 − 0.5 mm/pixel). 2D PIC simulations of this experiment show mitigation factors 0.5 − 0.8 on the side of gaps and enhancement on the top surface by factor 1.2 − 3. The simulated and the optically approximated power load profiles are used as input to 2D finite element thermal calculations. Reconstructed synthetic IR temperature profiles are directly compared with the experimental results.

This research has been supported by the MEYS project 8D15001 and LM2015045.

ELECTROMAGNETIC CHARACTERISTICS OF GEODESIC ACOUSTIC MODE ON THE COMPASS TOKAMAK IN HYDROGEN AND DEUTERIUM PLASMAS

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Geodesic acoustic mode (GAM) is turbulence-driven oscillating branch of zonal flows, which can play a role in self-regulation of turbulent transport. This contribution describes electromagnetic characteristics of GAM detected on COMPASS in Ohmic and NBI heated X-point plasmas with varying isotopic composition.

Frequency of the GAM is found in the range $25 - 45\,\mathrm{kHz}$, increasing with plasma heating and decreasing with ion mass. The mode frequency is constant over $1 - 2\,\mathrm{cm}$ radial layer inside separatrix inspected by reciprocating probes, indicating presence of a non-local GAM eigenmode. Magnetic component of the mode is axisymmetric with standing-wave poloidal structure, plasma potential exhibits long range correlations and the mode non-linearly interacts with broad spectrum of turbulent fluctuations. Amplitude of the GAM decreases with reduction of ion mass during transition from deuterium to hydrogen and also with injection of co-current (but not counter-current) NBI.

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EFFECTS OF SECONDARY RADIATION EVOLVED DURING PLASMA INSTABILITIES IN ITER-LIKE DIVERTOR AND NEARBY COMPONENTS

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During abnormal and disruptive operations in tokamaks, radiation transport processes play a critical role in the divertor-generated plasma as a result of instabilities. The secondary plasma developed as a result of disruptions/ELMs is composed mainly from component materials that greatly increase the contribution of radiation flux to nearby components in comparison to radiation from clean DT plasma. This secondary radiation flux to nearby components and resulting damage could be greater than the effect of the direct impact of disrupted plasma on the divertor plate. We have developed and implemented comprehensive enhanced physical and numerical models in our upgraded HEIGHTS package for simulating detailed photon and particle transport in the evolved secondary plasma during various instabilities. Response of ITER divertor's nearby surfaces due to this secondary radiation was simulated using actual full 3D reactor design and magnetic configurations.

This research has been supported by the National Science Foundation, PIRE project.

STUDIES OF RESONANT MAGNETIC PERTURBATIONS ON THE COMPASS TOKAMAK

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When the auxiliary heating power injected into a hot tokamak plasma exceeds a certain threshold, the plasma enters the regime of improved confinement (H-mode), characterized by the formation of steep pressure gradients in the plasma edge regions and improvement of the bulk plasma pressure. However, the resulting pressure gradients typically undergo periodic relaxations (ELMs), which cause deterioration of the confinement and excessive heat loads onto the plasma divertor. These effects can be mitigated (or entirely avoided) by stochastization of edge plasma regions via Resonant Magnetic Perturbation (RMP) field.

In this contribution we provide summary of RMP field experiments on the COMPASS tokamak. We show the effect of RMP on the plasma separatrix and profile of plasma strike-point divertor footprints. We also compare measurements of RMP shielding by the plasma to the results from a MHD model and discuss mode locking. Lastly, we demonstrate the effect of RMP field on ELMs.

This research has been supported by the MEYS grant No. 8D15001 and the MEYS grant No. LM2015045, by the Grant Agency of the Czech Republic grant number GA14-35260S, and by Czech Science Foundation grant 16-24724S.

BERYLLIUM SURROGATES SURFACE MORPHOLOGY INVESTIGATION UNDER ITER-LIKE HELIUM EXPOSURE

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All samples with purity 99.99% wt. were irradiated with He ion beam under ITER-like conditions using FALCON ion source. Aluminum has been used as the surrogate for plasma-material interaction studies. Typical parameters during steady-state expose were the following: He ion flux was $2-4\times10^{22}\,\mathrm{m^{-2}s^{-1}}$, heat flux was above $1\,\mathrm{MWm^{-2}}$, average ion energy of 2 keV and fluence was well above $10^{26}\,\mathrm{m^{-2}}$. It has been observed that at lower fluence cone-like structures are arranged separately from each other. At higher fluence their number is increased and they tend to form mountain-like clusters, column-like structures g rowth and become higher, grass-type structures and flakes could be found anywhere. Increasing the fluence one can also observe formation of the crack network and its propagation. The observed structures may cause exfoliation and local melting of the material with consequent excessive erosion of the first wall and contamination of the edge plasma.

LOW FREQUENCY INSTABILITIES BASED ON ELECTRON AND ION TEMPERATURE ANISOTROPIES IN NON-MAXWELLIAN PLASMAS

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In this study we observe Alfven waves in the solar wind using CLUSTER data for observed ion distributions. We then fit the observed ion distributions using the generalized (r,q) distribution function which is the generalized

form of kappa and Maxwellian distribution functions and apply this distribution to study the Alfven cyclotron instability using both the ion and electron temperature anisotropies for the first time. We studied the role of electron to ion temperature ratios and found that by increasing the perpendicular electron to parallel ion temperature ratio growth rate of Alfven cyclotron instability decreases whereas by increasing the parallel electron to parallel ion temperature ratio growth rate increases. We also found that wave becomes unstable when perpendicular ion temperature is larger than the parallel ion temperature or vice-versa.

WHISTLER WAVES IN MULTICOMPONENT SPACE PLASMAS WITH OBSERVED NON-MAXWELLIAN DISTRIBUTION FUNCTION

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Whistler waves are right handed circularly polarized waves and are frequently observed in space plasmas. The Low frequency branch of the Whistler waves having frequencies nearly around 100 Hz, known as Lion roars, are frequently observed in magnetosheath. Another feature of the magnetosheath is the observations of flat top electron distributions with single as well as two electron populations. In the past, lion roars were studied by employing kinetic theory using classical bi-Maxwellian distribution function, however, could not be justified both on quantitatively as well as qualitatively grounds. We studied Whistler waves by using the non-Maxwellian distribution function such as the generalized (r, q) distribution function which is the generalized form of kappa and Maxwellian distribution functions by employing kinetic theory with single or two electron populations. We compare our results with the Cluster observations and found good quantitative and qualitative agreement between them.

TERRESTRIAL LION ROARS AND NON-MAXWELLIAN DISTRIBUTION

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observed in the Earth's magnetosheath. By analyzing both wave and electron data from the Cluster spacecraft, and comparing with linear Vlasov kinetic theory, Masood et al. (2006) investigated the underlying cause of the lion roar generation. However, the analysis based upon the bi-Maxwellian distribution function did not adequately explain the observations qualitatively as well as quantitatively. This outstanding problem is revisited in the present paper, and a resolution is put forth in which, the flat-top non-Maxwellian distribution function with a velocity power law energetic tail, known as the (r, q) distribution, or the generalized kappa distribution is employed. Upon carrying out the linear stability analysis of the (r, q) distribution against the whistler wave perturbation, good qualitative and quantitative agreements are found between theory and data.

FIRST RESULTS ON SCALING AND MODELLING OF PEDESTAL PARAMETERS IN THE COMPASS TOKAMAK

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The COMPASS tokamak has been recently equipped with a set of high resolution diagnostics for studies of pedestal parameters, which are related with the properties of Edge Localised Modes (ELMs) and with particle and energy confinement. Given the ITER-like plasma cross-section of COMPASS, the obtained results can be

used to improve the existing empirical scalings as well as numerical models predicting the pedestal parameters for ITER and next-step devices.

The pedestal parameters were measured in a single null plasma configurations with plasma current range $160 - 330$ kA, line averaged density $4 - 15 \times 10^{19}\,\mathrm{m}^{-3}$, $B_T = 0.9 - 1.15$ T. Measurements from last 20% of ELM cycle in H-modes with Type-I ELMs (power through separatrix $> 40\,\mathrm{kW/m}^2$) were selected. The profiles were fitted using a modified hyperbolic tangent function. The resulting pedestal widths and heights are compared to the EPED pedestal structure model, finding reasonable agreement.

This research has been supported by the Euratom grant No 633053, MEYS project 8D15001 and LM2015045, GA14-35260S.

PLASMA DENSITY PROFILE MEASURED WITH FAST FREQUENCY SWEPT REFLECTOMETRY IN THE COMPASS TOKAMAK

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In this work the microwave reflectometry system is described and recent illustrative results are presented. The fast microwave reflectometry system in the COMPASS tokamak consists of two O-mode K and Ka bands. It serves preferentially as the frequency modulated continuous wave reflectometer for the density profile reconstruction. Detection method is based on the spectrogram of the reflected signals and uses complete information of the beat frequency spectrum. Density profile is calculated from correct beating frequency curve. System has the capability to measure low field side electron density profile in the density range $4.1018 - 2.1019\,\mathrm{m}^{-3}$ with time resolution up to $36\,\mu$s. The resulting profiles in different plasma regimes are compared with density profile measured by the Thomson scattering system and the Lithium beam diagnostic in COMPASS. The density profiles measured in ELMy regimes illustrate the capabilities of the diagnostic to detect fast profile changes.

FAST VISIBLE CAMERAS AS A DIAGNOSTIC OF THE COMPASS TOKAMAK

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Recently, observations with fast visible cameras have been performed on the COMPASS tokamak. Here, we report on selected results obtained with two Photron cameras (APX-type, up to 250 kfps and SA5-type, up to 1 Mfps). Mainly, we will show that fast acquisition of visible light is a suitable tool to study magnetohydrodynamic (MHD) modes which appear in tokamak plasmas. The modulation of the light intensity by sawteeth, tearing modes and geodesic acoustic modes (GAMs) can be correlated to signals from magnetic field coils, and spatial structure of the modes can be observed.

In addition, fast visible light measurements allow to follow turbulent structures such as filaments in edge localized modes (ELMs) on a frame-by-frame basis and enable to get information about their lifetime, localization and velocities. To this purpose, first results of magnetic field line mapping on camera pictures will be shown.

FEASIBILITY STUDY OF FAST SWEPT DIVERTOR STRIKE POINTS SUPPRESSING ELM HEAT FLUX IN BIG TOKAMAKS

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In order to avoid both surface melting and cracking of divertor targets of big tokamaks by localized ELM heat loads, we study a novel technique of spreading the heat flux in space by fast divertor strike point sweeping with a dedicated copper in-vessel twin-coil. We assume ELM decay length 14 mm at the target and time of 2 ms, which determines the optimal sweeping frequency, as we demonstrate with our material heat conduction simulation. We ran dedicated dynamic Fiesta simulations for strike point sweep amplitude $l_{sweep} = 7$ cm (thus suppressing the heat flux by factor of 5). For an example of the scale of DEMO tokamak ($I_p = 21$ MA, $B_0 = 6$ T, $R_0 = 9$ m), we consider the coil geometry located at the outer surface of the divertor module, thus ~ 1 meter off the strike point, inversely proportional to l_{sweep}. Fiesta then requires $I_0 = 400$ kA turns for 1 ms supplied from 3 kV capacitor for each of the 18 divertor modules, triggered by the ELM-induced voltage.

FILAMENTARY PROBE ON COMPASS TOKAMAK

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Plasma structures elongated with magnetic field lines are called plasma filaments, due to their characteristic shape. The filaments have increased plasma density and temperature and conduct electric current along them, and therefore, they carry out energy from plasma. Large groups of filaments represent severe danger for the first wall.

Filamentary probe recently introduced on the COMPASS tokamak measures electromagnetic properties of the filaments and their change in dependence on distance from separatrix. The probe head is mounted on manipulator moving the probe radially on shot-to-shot basis. This configuration is suitable for long term statistical measurement of the plasma filaments and their evolution during their propagation from the separatrix to the wall.

The basics of the filamentary probe construction, the evolution of the basic parameters of the plasma filaments and their conditional averages in scrape-off layer of the COMPASS tokamak during L-mode regime will be presented.

This research has been supported by the Euratom grant No. 633053, Co-fund by MEYS project number 8D15001, MEYS project LM2015045.

PRELIMINARY FREE-BOUNDARY EQUILIBRIUM SIMULATION RESULTSS OF THE COMPASS-U TOKAMAK

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COMPASS is a moderate size tokamak which features ITER relevant design and extended experimental variability. In order to keep up with the development of fusion research, an upgrade, COMPASS-U, is foreseen to increase the magnetic field and the heating power. In pursuance of minimal risks for the operation of COMPASS-U, significant simulation effort is necessary during its design. Among the most important simulations stands free-boundary equilibrium (FBE) solver FREEBIE with results of plasma configuration consistent with hardware limits and vice versa.

We present FREEBIE contribution to plasma shapes prediction according to poloidal field (PF) coil systems limits and in inverse calculation we set up hardware limits for the PF circuits when the plasma shape is given. Furthermore, beforehand of mentioned simulations, FREEBIE extension by an arbitrary PF coil circuits solver was realized and tested.

MEASUREMENTS OF CHARACTERISTIC TIMES FOR NBI HEATING ON THE COMPASS TOKAMAK

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Fast neutral atoms generated in the whole volume of plasma through charge exchange collisions are in thermal equilibrium with the bulk ions. Escaping plasma column, such neutrals can be detected by Neutral Particle Analyzer.

NPA installed on the COMPASS tokamak is equipped with 12 energy channels for detection of deuterium atoms in the energy range of $0.3 - 80$ keV. This energy range allows observation of fast neutrals generated in interaction between plasma ions and atoms of heating neutral beam (NBI) with energies up to 40 keV.

At the beginning of NBI injection neutral fluxes detected by NPA increase with a characteristic time constant τ_i. Consequently the fluxes decay with a characteristic time constant τ_d after the end of an injection. The characteristic times τ_i and τ_d are measured at different discharge conditions and compared with the energy confinement time and the temporal evolution of the total plasma energy during the NBI heated discharges.

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EFFECT OF NEUTRAL BEAM PLASMA HEATING ON THE COMPASS TOKAMAK

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This contribution is devoted to analysis of the global energy balance of plasma on the COMPASS tokamak (toroidal magnetic field 1.15 T, plasma current 180 kA) heated by using the Neutral Beam Injection (NBI). The deuterium beam with the energy $E_b = 40$ keV and the total power up to 350 kW, which is injected into the plasma in the same direction as the plasma current. It is found that a strong ion heating occurs at relatively low densities ($2 - 3 \times 10^{19}\,\mathrm{m}^{-3}$). The stored plasma energy increases by 40%, mainly due to ion heating, because the electron temperature remain unchanged at NBI. At higher densities ($8 - 9 \times 10^{19}\,\mathrm{m}^{-3}$), the NBI heating appears to be less efficient, which is caused by deposition of t he beam power closer to the plasma edge. The stored energy increases only by 20% in this case. From a simple global energy balance, the NBI power absorbed in the plasma is derived, and some other phenomena occurring during the NBI heating, such as the saw tooth instability are discussed.

This research has been supported by the The work was supported by the MEYS projects number 8D15001 and LM2015045, and the Czech Science Foundation project GA15-10723.

RECENT PROGRESS IN PLASMA TOMOGRAPHY AT JET

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[j] *see Appendix of F. Romanelli, Overview of the JET results, Nucl. Fusion 55 (2015) 104001*

The contribution presents development and current use of plasma tomography at JET tokamak, including soft X-ray (SXR), bolometric, neutron and hard X-ray (HXR) tomography. Algorithms based on Tikhonov regularisation have been fostered, in particular, implementation of the smoothness constraint has been further optimised. The SXR tomography contributed to systematic studies of tungsten transport both in transient and stationary conditions, with special attention to effects of plasma heating, and proved relevant for studies of the post-disruption Runaway Electron (RE) beam due to its potential to clarify the role of MHD activities on RE mitigation. Neutron and HXR tomography proved useful in analyses of distribution of fusion reactions. With the upcoming DT campaign the interest in the neutron tomography reappears, thus the algorithms deserve revamping and further testing. In this respect, the comparison of performance of different implementations of tomography will be detailed.

This research has been supported by the MSMT grant LG14002.

NUMERICAL STUDIES OF X-RAY PROPAGATION ON ICF TARGETS IN POWERFUL LASER FACILITY EXPERIMENTS

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The results of numerically studying of the X-ray in-target field generation with effective temperature near 300 eV (which is a typical temperature of the X-ray field in targets tested on powerful laser facility) are presented in the paper. The research of a thermonuclear target pressure with different characteristics of a laser pulse, ablator and time dependence radiation temperature at the border capsule is performed with the criteria of a powerful laser facility.

DETERMINATION OF ION TEMPERATURE FROM ENERGY SPECTRA OF FAST NEUTRALS AT THE COMPASS TOKAMAK

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Determining temperature of bulk ions (i.e. deuterium) in hot fusion plasmas poses a difficult task.Onemethod is estimation of ion temperature from energy spectra of fast neutrals measured by Neutral Particle Analyzer (NPA). The task is an ill posed problem due to the mechanism of generation of fast neutrals and bad spatial localization of NPA measurements. In order to get an estimate of the ion temperature from the energy spectrum, computer codes simulating neutral transport in a plasma and energy spectra of fast neutrals need to be utilized. Recentlya code DOUBLE was obtained by the Institute of Plasma Physics in Prague to provide the needed simulations. The procedure of estimation is an iterative process consisting of evaluation of a match between simulated and measured energy spectraof fast neutrals. In this contribution the first results of the ion temperature estimations and methods dealing with the ill posed nature of the problem are presented.

IMPACT OF THE PRESENCE OF DOUBLY IONIZED SPECIES IN THE LASER INDUCED PLASMA ON THE ABLATION PROCESSES OF A METAL BY A UV LASER PULSE.

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The particularity of this study is that it involves a 1D hydrodyamical model to describe the behavior of the laser induced plume containing doubly charged ions where the thermal non-equilibrium between electrons and heavy particles is taken into account. By presenting this study, we aim at evaluating the effect of the presence of doubly ionized species on the macroscopic characteristics of the plume, namely the temperature, pressure and expansion velocity but also on the material itself by evaluating the ablation depth and the plasma shielding effect. This study aims at understanding the governing processes of the interaction of ultraviolet nanosecond laser pulses with metals and the optimization of its parameters depending on the intended application.

BEAT EXCITATION OF UPPER HYBRID WAVE IN PREFORMED PARABOLICPLASMA CHANNEL BY RELATIVISTIC CROSS-FOCUSING OF ULTRAINTENSEQ-GAUSSIAN LASER BEAMS

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This paper presents a scheme for beat excitation of an upper hybrid wave (UHW) in a preformed parabolic plasma channel embedded in an external static magnetic field. The UHW is generated on account of beating of two q-Gaussian laser beams of frequencies ω_1 and ω_2 under the effect of relativistic nonlinearity of electron mass. A set of coupled differential equations governing the propagation dynamics of laser beams, has been obtained with the help of moment theory approach. Due to relativistic nonlinearity, propagation characteristics of one

laser beam affect that of other and hence cross-focusing of the two laser beams takes place. Due to nonuniform intensity distribution along the wavefronts of laser beams, background electron concentration gets modified. The amplitude of UHW, that depends on the background electron concentration, thus gets nonlinearly coupled with the laser beams and thus gets excited.

ION ACCELERATION DRIVEN BY 10 PW LASER

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Ultrashort laser facilities currently built will be able to deliver up to 10 PW peak power, e.g., L4 beamline in the frame of ELI-Beamlines project. The interaction of such ultrahigh intensity laser beam with ionized solid targets includes many new phenomena such as relativistic transparency, hole boring of laser beam through the target, substantial losses of electrons oscillating in the laser wave by radiation reaction force. In this contribution, we will study the interaction with the help of numerical 2D3V particle-in-cell simulations including QED module calculating radiation reaction of electrons by MC approach. Namely, laser-driven ion acceleration is investigated for laser parameters relevant for L4 ELI beamline and for newly developed hydrogen solid target and polyethylene foil. It is shown that the radiation reaction force strongly influences ion acceleration driven by 10 PW laser e.g. alters the proton energy spectra and hence cannot be neglected in this type of simulations.

This research has been supported by the Czech Science Foundation (Project No. 15-02964S).

GENERATION OF ELECTRON PLASMA WAVE AND PARTICLE ACCELERATION BY THE BEATING OF TWO CROSS FOCUSED COSH-GAUSSIAN LASER BEAMS IN PLASMA

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This work presents an investigation of the propagation of two intense cosh-Gaussian laser beams (CGLBs) in collisionless plasma with dominant relativistic-ponderomotive nonlinearity and its effect on the generation of electron plasma wave (EPW) and particle acceleration. Due to mutual interaction of two CGLBs, the self focusing of one beam is affected by the presence of another beam in plasma, and cross focusing takes place. The EPW is generated on account of beating of two cross focused cosh Gaussian laser beams of frequencies ω_1 and ω_2. An analytical expression for the nonlinear dielectric constant of plasma, beamwidth of laser beams and the electric field associated with EPW has been evaluated using WKB and paraxial approximations. Numerical simulations have been carried out to investigate the effect of typical laser plasma parameters on cross focusing of laser beams and further its effect on power of excited EPW and acceleration of electrons.

SELF-FOCUSING AND SELF-PHASE MODULATION OF Q-GAUSSIAN LASER BEAM IN COLLISIONLESS THERMAL QUANTUM PLASMA

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Propagation characteristics of q-Gaussian laser beam in collisionless thermal quantum plasma have been investigated. The field distribution in the medium is expressed in terms of beam width parameter 'f' and the parameter 'q' describing the deviation of intensity distribution of the laser beam from Gaussian distribution. An appropriate nonlinear Schrodinger wave equation has been solved analytically with the help of moment theory in W.K.B approximation. The behavior of beam width parameter 'f' with distance of propagation has been examined for different laser-plasma parameters. Self-phase modulation and self-trapping of the laser beam are Goli also examined for different q values.

THE CALCULATION ANALYSIS OF LASER FACILITY STRUCTURAL MATERIALS ACTIVATION AT INERTIAL CONFINEMENT FUSION

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The report presents the results of the calculation analysis to estimation radiation induced activity and its decline over time, decline radiation equivalent dose capacity , the energy spectra of neutrons for the laser facility interaction chamber. The 3D-calculations were performed by Monte Carlo method.

THE RESEARCH OF THE VACUUM BREAKDOWN INITIATED BY LASER PULSES OF NANOSECOND DURATION RANGE

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In this work it is shown results of researches of process of switching a vacuum gap under the action of pulse laser radiation of nanosecond duration range. For different materials of the electrode-target were obtained dependence between times of switching vacuum gap from the energy of laser radiation. On the basis of the experimental data was assumed that a glow discharde, which transforms to the arc as result of ionization-overheating instability, precedes the contracting of the current channel. With increasing energy of laser radiation accelerates the process of instability development and transition to glow discharge arc.

PHOTODISSOCIATION OF DIATOMIC MOLECULES

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Radiation processes play important role in energy balance of thermal plasma in electric arc. Intensive radiation is irradiated from the hot central part of the arc and reabsorbed in cold edge of the plasma. Therefore, besides of continuous and discrete radiation of atoms and atomic ions the influence of molecular species on the absorption properties of the plasma has to be taken into account.

In this paper, the continuous absorption molecular spectra are studied. Simple approximate formulas for photodissociation cross sections of diatomic molecules are presented. Results for selected diatomic molecules are compared with available experimental and theoretical data from literature.

This research has been supported by the Ministry of Education, Youth and Sports under project No. LO1210 and by the Czech Science Foundation under project No. 15-14829S.

THE CALCULATIONS OF THERMOPHYSICAL PROPERTIES OF Mo PLASMA

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The thermophysical properties (equation of states, internal energy, conductivity etc) have been investigated for more than a century for various substances under various conditions. The plasma state of metals is located

at relatively high temperatures. So there is less experimental information about this state than for the low temperature part of phase diagram. Thus, the considered properties can be studied mainly theoretically. However, several years ago some new measurement data have appeared for a number of metals, including Molybdenum. Earlier we have developed calculation model of the thermophysical properties under study in plasma state. It is constructed on the basis of the generalized chemical model to describe the thermodynamic (including ionic composition) and the relaxation time approximation for the electronic transport coefficients. In present research this model has been applied to Molybdenum plasma. Our data have been compared with results of other researchers.

INVESTIGATION OF DEPOSITION EFFICIENCY INCREASE MECHANISMS USING PULSED MAGNETRON SPUTTERING SYSTEMS WITH HOT TARGET

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Pulsed Magnetron Sputtering Systems (PMSS) have profound interest because of the possibility to deposit high-quality coating on the complex shape surface. However, these systems have a low deposition rate. If some structural changes in the PMSS cooling system will be introduced, the evaporation of the material can be obtained in addition to sputtering. The main task of structural changes is heat transfer reducing from the target (hot-target MSS). Not many materials allow carrying out this process due to their thermophysical characteristics. The simulative description of thermal processes occurring on the target is presented in this work; the dependence of the evaporation on the target surface temperature is provided. The most suitable metals were selected to reach a high-intensity emission of atoms. For these materials the dependences of the emission rate and target surface temperature on the magnetron discharge power are presented. The simulation results were confirmed by experiments.

This research has been supported by the Russian Science Foundation through project No. 15-19-00026.

TWO-DIMENTIONAL INTEGRATED HOHLRAUM RADIATION HYDRODYNAMIC SIMULATION OF "COAST LOW-FOOT" NATIONAL IGNITION FACILITY IMPLOSION

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In 2009 – 2012 at the Lawrence Livermore National Laboratory was performed the National Ignition Campaign (NIC) aimed to a full-scale thermonuclear DT fuel ignition by indirectly driven (X-ray) implosion of a spherical capsule filled with a cryogenic DT mixture applying the National Ignition Facility (NIF) laser system. NIF has 192 beams with total laser energy up to 1.9 MJ at the third harmonic of the neodymium laser (laser wavelength 0.351 μm). The authors consider that analysis and interpretation of NIC results is one of the most interesting problems in the physics of controlled thermonuclear fusion.

The report presents the results of a numerical simulation of the performance of cryogenic fusion target under experimental conditions on the NIF. The simulations were done using a two-dimensional code with complete problem setting. The initial data used in the simulation were borrowed from open publications for NIC “coast low-foot” experiment N111215.

MODELING OF TRANSITION OF ATMOSPHERIC PRESSURE GLOW DISCHARGE TO ARC

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In the study of atmospheric pressure discharge should be borne in mind that the heating of the gas occurs at a small discharge currents, in the absence cooling of the electrodes leads to significant their heating. Thus transition of normal glow discharge (GD) to the arc is interesting. In this paper, the simulation of this process, based on a hybrid approach for describing the plasma area. At the same time self-consistently solved the heat balance equation for plasma area and a metal cathode. It was assumed that the heating of the cathode due to: the transfer of energy from the hot gas from plasma area, and the bombardment of the cathode and ions occurring plasma-chemical reactions on it. As a result of the simulation was obtained the VAC discharge with two specific areas. First, almost horizontal portion is typical for glow discharge and the second incident is typical for the transition to the arc.

This research has been supported by the Russian Science Foundation through project No. 15-19-00026.

PARTICLE TRACING IN MAGNETIZED PLASMA-WALL TRANSITION

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The transition from plasma to the wall becomes increasingly complicated when an oblique magnetic field is present. This situation, however, is very important for understanding the particle and momentum transport in magnetic fusion devices. The presence of the magnetic field was found to form a new region between the bulk plasma and the Debye sheath, namely the magnetic presheath. The magnetic presheath scales with the ion cyclotron radius and a boundary condition at its entrance has been established in the form of the Bohm-Chodura criterion. This transition region is thought to be involved in the process of ion orbit deflection due to the strong electric field being present near the wall. However, the scaling with the Larmor radius implies intersection between the ion orbits and the wall, which cannot be modelled with the commonly used fluid approximation. We have applied a particle-in-cell code along with the tracing of the particles to investigate this subject.

This research has been supported by the Slovenian research agency grant No. P2-007 and bilateral project BI-AT/16-17-022.

EFFICIENT MODELLING OF EXTREME FIELD DISCHARGE ON OVERLAPPING GRIDS

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We develop a self-contained software framework for the simulation of a wide class of cold electrical discharges at atmospheric pressure, including positive streamers. A fluid model accounting for photoionization and electron energy equation is solved efficiently on overlapping, structured grids. The governing equations are discretized with finite-difference and finite-volume operators and transformed into parametric space to ease the implementation of high-resolution conservative schemes on curvilinear grids. Collocated grid arrangement further increases efficiency of the implementation. Operator splitting is used to include additional source terms, including those due to chemical reactions and/or the axi-symmetry of the domain. The results elucidate the discharge dynamics and streamer parameters in various gases, geometrical setups and reaction chemistry sets.

ACTIVATION DIAGNOSTIC AND ITS CONTRIBUTION TO TRITIUM CAMPAIGN FOR FUSION DEVICE

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An assessment of the neutron yield for the fusion devices is one of the most important challenge. It is due to requirements regarding knowledge of power output, prediction of neutron budget and safety measures. The fusion neutron detection system to optimal working requires calibration. During deuterium tritium refilling of the tokomak the huge fluxes of 14 MeV neutrons are expected. Thus both the fusion chambers and activation diagnostic must be absolutely calibrated with neutron source that have spectrum similar to $(d,\ t)$ reaction. The 14 MeV neutron generator is considered as the appropriate neutron source which can fulfill mentioned requirements. But the nuclear reactions chosen as the neutron monitors should be tested in real tokamak environment however it operates only with deuterium. The phenomenon of triton burn up allows using this same activation materials for d, d, d, t, and t, t campaign as well as neutron generator characterization. We develop a self-contained software framework for the simulation of a wide class of cold electrical discharges at atmospheric pressure, including positive streamers. A fluid model accounting for photoionization and electron energy equation is solved efficiently on overlapping, structured grids. The governing equations are discretized with finite-difference and finite-volume operators and transformed into parametric space to ease the implementation of high-resolution conservative schemes on curvilinear grids. Collocated grid arrangement further increases efficiency of the implementation. Operator splitting is used to include additional source terms, including those due to chemical reactions and/or the axi-symmetry of the domain. The results elucidate the discharge dynamics and streamer parameters in various gases, geometrical setups and reaction chemistry sets.

HYBRID MODEL FOR PLASMA ACCELERATOR WITH GAS WALLS AND CLOSED ELECTRON DRIFT

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It is proposed the one-dimensional hybrid and hydrodynamic models for description of plasma accelerator with closed electron drift and open walls that produced ion plasma flow converging towards the axis system. Based on the idea of continuity of current transferring in the system are found exact analytical solutions describing electric potential distribution along acceleration gap. It was shown that potential distribution is parabolic for different operation modes as in low-current mode well as in high current quasi-neutral plasma mode and weakly depend on electron temperature. The generalization condition of self-sustained discharge in crossed $\boldsymbol{E} \times \boldsymbol{H}$ fields with taking into consideration both electron and ion dynamic peculiarity is obtained. For more clearance influence of ions dynamics on system process, will used 1-dimentional hybrid model for calculation span mode with neutrals particles ionization.

This research has been supported by the grant of NAS of Ukraine No. 34-08-15 and No PL-15-32.

EVALUATING GYRO-VISCOSITY IN THE KELVIN-HELMHOLTZ INSTABILITY BY KINETIC SIMULATIONS

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The Finite-Larmor-radius (gyro-viscous) term [Roberts and Taylor, 1962] is evaluated by using a full kinetic Vlasov simulation result of the Kelvin-Helmholtz instability (KHI). The velocity field and the pressure tensor are calculated from a high-resolution data of the velocity distribution functions obtained by the Vlasov simulation, which used to approximate the FLR term according to Roberts and Taylor (1962). The direct comparison between the pressure tensor and the FLR term shows an agreement. It is also shown that the off-diagonal pressure gradient enhanced the linear growth of the KHI when the inner product between the vorticity of the primary velocity shear layer and the magnetic field is negative, which is consistent with the previous FLRMHD simulation result. This result suggests that it is not enough for reproducing the kinetic simulation result by fluid simulations to include the FLR term (or the pressure tensor) only in the equation of motion for fluid.

RELIABILITY ANALYSIS OF BREAKER ARRANGEMENTS IN DISTRIBUTION SUBSTATIONS

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Substations are the weakest link between the source of supply and the customer load points in a power system, because they comprise switching arrangements that would lead to loss of load. Determining the reliability expression of different substation configurations can help design a system with the best overall reliability. This paper presents a computerized and implemented method based on disjoint path-set method and its direct application on the evaluation of the reliability expression, reliability indices and costs of different switching arrangements.

EFFECT OF SECOND HARMONIC RADIATION ON THE GROWTH RATE OF BRILLOUIN SCATTERING IN MAGNETIZED PLASMA

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Second harmonic Brillouin (SHB) scattering of laser propagating in plasma is studied in the presence of a static external magnetic field. SHB scattering arises due to the coupling between the longitudinal oscillatory velocity of plasma electrons and the excited ion acoustic upper-hybrid wave (IUH). Using the wave equation as well as the equation of motion at the second harmonic frequency, current density of electrons is obtained to find the growth rate of SHB instability. It is found that the growth rate increases on increasing the plasma density, and it falls to zero after reaching a maximum. It is also deduced that the growth rate increases by enhancing the magnetic field.

PRODUCTION OF HIGH QUALITY ELECTRON BEAMS FROM LASER-PLASMA ACCELERATORS

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Laser-wakefield accelerators (LWFA) can generate electron beams with hundreds of MeV over only a few millimeters. They have been considered for many applications, including compact colliders (by staging several LWFA), as well as compact synchrotron sources and free-electron lasers Many of these applications require low energy spread, low divergence and high charge electron beams with good stability and reproducibility. These parameters are directly dependent on the electron injection process into the accelerating structure. We will present several injection techniques, including ionization injection and density transition icnjection and we will discuss their pros and cons.

LASER-PLASMA ACCELERATION OF ELECTRONS IN DIFFERENT INTERACTION REGIMES

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Experimental studies of laser-accelerated electron beams in two different interaction regimes are presented. The first interaction regime is characterized by a high electron density ($> 10^{19}\,\mathrm{cm}^{-3}$). In this regime the electron beam is characterized by a large divergence, high charge and relatively low energy ($\sim 15\,\mathrm{MeV}$). In the second regime, at low electron density, a collimated electron beam ($\sim 10\,\mathrm{mrad}$) with higher energy is obtained.

The experiments were performed at the ILIL laboratory by focusing the 10 TW laser in a gas-jet target. The set of diagnostics includes the characterization of the spatial profile and the energy distribution of the accelerated electron beam. Shadowgraphy of the interaction region and imaging and spectroscopy of the light scattered at 90° with respect to the laser propagation direction and the polarization direction of the driving laser beam are also performed. Experimental results are presented with a particular focus on the side-scatter diagnostic.

CURRENT STATUS OF THE COMPASS TOKAMAK AND RECENT RESULTS IN THE EDGE AND SOL PLASMA STUDIES

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The COMPASS tokamak is one of few devices operating with an ITER-like plasma shape. Its flexibility, extensive set of edge diagnostics, and NBI heating allow to address key issues in the fusion research such as edge and SOL physics, the L-H transition, MHD, runaway electrons and disruption studies, plasma-wall interaction. Recent results related to the control and characterization of the L-H transition, H-mode, and the edge and SOL plasma studies will be presented in this talk.

Recycling and actuators such as the X-point height play a significant role in accessing the H-mode. Oscillating turbulence-driven plasma flows (GAMs) have been observed in COMPASS L-mode discharges, increasing with the ion mass and decreasing amplitude from D to H plasmas. ELM physics is investigated with two fast visible cameras capable to track ELM filaments. Moreover, COMPASS also contributes to multi-machine databases with pedestal and SOL width scaling studies.

This research has been supported by the Czech Science Foundation grants GA16-25074S, GA16-14228S, GA16-24724S, GA15-10723S, GA14-35260S and co-funded by Ministry of Education, Youth and Sports CR project numbers 8D15001 and LM2015045.

DEVELOPMENT OF A 10PW LASER FACILLITY AND MULTI-GEV ELECTRON ACCELERATION IN LASER WAKE FIELDS

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We will first report the latest progress of implementing a 10PW laser facility at Shanghai, including the demonstration of a 5PW CPA (chirped pulse amplification) laser amplifier based on a 150 mm size Ti:sapphire crystal. We will then introduce the acceleration of electron beams up to multi-GeV level in laser wake-fields and the generation of compact x-ray sources based on the laser wake-field electron accelerators. We have demonstrated a MeV gamma-ray source of high brightness based on the Compton scattering of laser accelerated electron beams with laser pulses.

This research has been supported by the Chinese Academy of Sciences and National Natural Science Foundation of China.

THE PHYSICS OF ULTRA INTENSE VORTEX LASER

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Relativistic laser pulse has been used as an important research tool in well known high energy density physics. But orbital angular momentum effect was ignored. When a relativistic laser pulse interacts with a tailored thin foil target, a strong torque is exerted on the resulting spiral-shaped foil plasma, or “light fan”. We propose a simple and effective scheme to generate ultra intense high-order optical vortices that carry large orbital angular momentum in the extreme ultraviolet region by relativistic harmonics from surface of solid target. We propose to intense LG pulse to drive an intense walk field for proton acceleration. The interaction of such intense LG laser with solid density foil is also discussed. (Y Shi, PRL112 (2014) 235001, X Zhang, PRL114 (2015)173901 (2015), X Zhang, NJP16 (2014) 123051, W Wang, SP 5 (2015) 8274).

PLASMA CLOUD GENERATED BY HYPERVELOCITY DUST IMPACT ON SPACECRAFT AND ITS DETECTION

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The hypervelocity impacts of micrometeoroids or cosmic dust particles on the spacecraft generates a plasma cloud by impact ionization. Plasma cloud particles can be recollected by the charged spacecraft body or by the electric antennas. The recollected charge influence the potential of the spacecraft and of the antennasand these changes generate pulses in the measured electric field. The characteristics of these signals depend not only on the impact speed and mass of the particle, but also on the antenna/spacecraft geometry, the parameters of the ambient plasma and the floating potential of spacecraft surfaces.

We describe the mechanism of plasma cloud generation by dust impact and its detection with electric field instruments and compare theoretical models with data obtained by several spacecraft.

This research has been supported by the Swedish National Space Board (SNSB).

CONTROLLING OF ROTATING PLASMA STRUCTURES IN E CROSS B DISCHARGES

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The rotating spoke is azimuthal plasma non-uniformity which has been observed in a variety of low pressure cross-field discharges of cylindrical geometry. The spoke can appear in different modes ranging from $m = 1$ to higher order modes which propagate in the direction perpendicular to electric and magnetic fields with velocities of much lower than $\mathbf{E} \times \mathbf{B}$ velocity. Recent studies of Hall thrusters and Penning-type discharges demonstrated that the spoke is directly responsible for the enhancement of the electron cross-field transport in these devices. A combination of time-resolving plasma measurements, including high speed imaging and probes suggest that the spoke instability may be triggered by the ionization mechanism. These experimental results are supported by recent particle-in-cell simulations. The advancement in understanding of the spoke mechanism enabled us to develop effective methods of spoke control, including velocity and direction of the spoke, and the spoke suppression.

This research has been supported by the This work was supported by the US DOE under Contract Number DE-AC02-09CH11466.

COMPARATIVE ASSESSMENT OF PLASMA TORCH TECHNOLOGIES FOR AN INCINERATION REACTOR THROUGH NUMERICAL MODELING

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In this work, a three dimensional numerical model of an organic waste incinerator equipped with plasma torch is presented. The model takes into account the different physical phenomenologies occurring in the reaction chamber: pyrolysis of the organic waste, combus-tion of the pyrolysis gas as well as plasma gas injection in the reactor. in this study special attention is paid to the modelisation of the plasma jet and its interaction with the surrounding fluid zone. So as to determine the most suitable plasma torch technology for the process, the study also focuses on a comparative analysis of the use of induction and arc torch technologies. In the plasma model, different injection conditions are used and analysis of the influence on the reactor behavior is discussed through a detailed comparison of flow pattern and temperature field. This work reveals strong impact of the plasma torch technology and provides better understanding of the influence of the plasma injection conditions.

NUMERICAL SIMULATION OF LASER ABSORPTION IN A FOAM PLASMA

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The simulations of laser absorption in porous media of light elements have been so far affected by the not accurate modeling of the internal structure of the targets, which indeed determines unique characteristics for laser absorption, relaxation and transport processes. The internal structure also affects the hydrodynamic properties of these materials: the pressure can exceed the one produced by direct irradiation.

We show recent results about the inclusion of a viscous homogenization model for porous media in the 1D hydrodynamic code MULTI. The expression for the laser radiation absorption coefficient is derived from the model of a partly homogenized plasma and implemented in the hydrocode. The different hydrodynamic quantities are computed in a peculiar way, in order to take into account the behavior of the plasma produced during laser irradiation. Results from simulations performed by this modified version of the code will be presented and future development will be discussed.

PARTICLE-IN-CELL SIMULATION CONCERNING HEAT-FLUX MITIGATION USING ELECTROMAGNETIC FIELDS

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The Particle-in-Cell (PIC) method was used to study heat flux mitigation experiments with argon. In the experiment it was shown that a magnetic field allows to reduce the heat flux towards a target. PIC is well-suited for plasma simulation, giving the chance to get a better basic understanding of the underlying physics. The simulation demonstrates the importance of a self-consistent neutral-plasma description to understand the effect of heat flux reduction.

This work was supported by the German Space Agency 255 DLR through Project 50RS1508.

USE OF COMPUTER EXPERIMENTS TO STUDY THE CURRENT COLLECTED BY CYLINDRICAL LANGMUIR PROBES

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A particle-in-cell simulation has been developed to study the behaviour of ions in the surroundings of a negatively biased cylindrical Langmuir probe. Here, we report our findings on the transition between radial and orbital behaviour observed by means of the aforementioned code. The influence of the ion to electron temperature ratio on the transition for different dimensionless probe radius is discussed. Two different behaviours have been found for small and large probe radii.

The authors greatly acknowledge the support of the FPU Program of the Spanish Ministry of Education (ref. AP2010/0639) and the Spanish Ministry of Science and Innovation (ref. No FIS2010-19951) which is partially financed with FEDER funds.

PLASMA PHYSICS FOR MATERIAL SCIENCE: POLYMER MATERIALS UNDER ACTION OF INTENSIVE FLOWS OF ENERGY

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We use numerical simulation of polymers destruction for comprehensive study of their behavior during energy impact, for verification of volume fracture models, and for validation of wide-range equations of state.

Experiments on the impact of electron beams on Plexiglas and polystyrene samples are considered. Hydrodynamic modeling of heating and destruction of the material was carried out with the help of program package MARPLE3D (KIAM RAS). The velocity of plasma expansion, the evaporated mass, and the mechanical pressure impulse in the sample were estimated. Modeling of the brittle fracture in the sample was carried out using the greatest principal stress criterion and Maynchen-Sack model. Destroyed areas were reproduced in fine agreement with the experiment. The strength characteristics of the poly-mers were obtained by solving the inverse problem.

After verification of the model on the experimental data it can be used to analyze the strength of various structural units.

MHD SIMULATION OF CAPILLARY DISCHARGES WITH VARIOUS CROSS-SECTION SHAPE OF THE CHANNEL

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Many experiments devoted to interaction of laser beams with plasma make use of capillary discharge as a simple tool to create suitable plasma. We may mention here laser plasma accelerators, X-ray lasers etc. However only the capillaries with circular cross-section are usually considered. This reduces the dimension of the problem and allows using 1D codes for numerical simulation of the electron distribution.

We use 3D RMHD code MARPLE for discharge simulation in the capillaries with different section shapes. One may suppose that other than circular cross sections are possibly more convenient for fabrication of thin very long capillaries made of hard enough materials.

Our main results — electron density distribution in the capillaries with different cross-section shapes — will be presented at the conference.

MODELLING OF LOW TRIANGULARITY JET-ILW POWER SCAN USING THE CRONOS CODE

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A deviation from the IPB98$(y, 2)$ scaling (McDonald et al., Plasma Phys Control Fusion 46 (2014) A215) was found in dedicated power scans in the JET-ILW tokamak (Challis et al., Nucl. Fusion 55 (2015) 053031) leading to a lower thermal energy degradation, $\tau \sim P^{-0.3}$, compared to the one expected from the IPB98$(y, 2)$ scaling $\tau \sim P^{-0.69}$. In order to understand the origin of this behavior and its possible extrapolability, essential for predicting ITERâĂŹs performance, simula-tions of electron and ion temperatures and electron density have been performed using the CRONOS suite of codes (Artaud et al., Nucl. Fusion 50 (2010) 043001) with two transport models, Bohm-GyroBohm and GLF23, conducting a power scan with the range used in those experiments. Since the pressure at the pedestal top is essential in this power scan, as it increases with power in a positive feed-back loop between core and edge regions (Garcia et al., Nucl. Fusion 55 (2015) 053007), the energy content of the pedestal is simulated by assuming a scaling previously verified with JET and JT-60U discharges (Garcia et al., Nucl. Fusion 54 (2014) 093010). It is found that the exponent for the scaling for energy confinement time with power by Bohm-GyroBohm is equal to -0.40 while in GLF23 is equal to -0.48, therefore also deviating from the IPB98$(y, 2)$ scaling. Moreover, the effect of $\mathbf{E} \times \mathbf{B}$ flow shear and its impact both in ion temperature and density peaking, which has been analyzed using GLF23 model, will be discussed.

This research has been supported by the Development and Promotion of Science and Technology Talents Project.

EFFECT OF CHARGED PARTICLE BEAMS ON ELECTRON-ION PLASMA DYNAMICS

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The quasi-neutral expansion of an electron-ion plasma is investigated in the presence of a charged particles beams (electrons/ions). For that purpose a multi-fluid model is used, where the particle beam is considered as a fluid apart. Based on Self-similar approach, plasma expansion is studied in both non- relativistic ans fully relativistic regimes. The latter is based on a covariant transformation where relativistic effects concern velocity ans density. It is found that ion can be accelerated showing an expanding front with accumulated ion density associated with ion electron separation. Clues on parameter enhancing such separation are given. The present investigation applies to laser produced plasmas.

STUDY OF SOFT X-RAYS EMISSION FROM PF-1000U DISCHARGES PERFORMED DURING THE RECENT EXPERIMENTAL CAMPAIGN

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The paper reports on measurements of soft x-rays emitted from hot plasmas produced in a modernised PF-1000U facility. The discharges were performed at the D_2-filling with or without a Ne-admixture, under the initial pressure 0.9 or 1.5 torr and at the initial charging voltage 16 or 18 kV. Time-integrated x-ray images were recorded with a pinhole camera situated side-on at an angle of 75° to the z-axis. Differences in the pinch column structure were observed. Time-resolved measurements were performed with four PIN diodes located behind filtered pinholes. Two couples of PIN diodes (with Be-filters of 7 and 10 mm in thickness) observed 30 mm-dia. regions which had a centre at a distance of 30 and 60 mm form the electrode outlets. From the time-resolved signals electron temperatures (T_e) were estimated. For the pure D_2-discharges the estimated Tevalues ranged from 75 to 250 eV depending on the discharge conditions. For discharges with a Ne-admixture T_e values amounted to above 1 keV.

PERFORMANCE OF A LOW-IMPURITY MEGA-AMPERE DENSE PLASMA FOCUS

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Impurities have long been thought to be a contributor to the plateauing of fusion yield in high-current dense plasma focus (DPF) devices. In an effort to greatly reduce impurity levels, we have used monolithic tungsten electrodes which have no connections with the vacuum chamber, thus eliminating arcing. In addition, we have added a pre-ionization pulse, using a 50 mega-ohm shunt resistor to reduce, during breakdown, runaway electrons that vaporize anode material. Experiments in 2015 with these electrodes in the FF-1 device demonstrated that easily-vaporized tungsten oxides are present on the electrodes, preventing a reduction of the impurities. In a new set of experiments, we have used standard high-vacuum techniques, including a TiN coating on the SS304 vacuum chamber and a multi-day bake-out at 120 °C, to limit the oxides present and thus the impurities in the plasma. We report here on the performance of FF-1 with these reduced impurities at peak-current levels above 1 MA.

DEPENDENCE OF PLASMA PARAMETERS ON DEUTERIUM PRESSURE IN THE PF-24 DEVICE

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The PF-24 plasma focus is a 100 kJ Mather type device. The condenser bank of PF-24 consists of 24 pulse condensers connected parallel. The total capacitance of the condenser bank is 116 μF, and it can be charged up to 40 kV. A standard diagnostics of PF-24 include the system of measurements of: current, current derivatives and voltage. The total neutron emission is measured with a beryllium activation counter. The PF-24 device emits neutrons with typical yield of $10^8 - 10^{10}$ n/dis and current rise time below 2 μF. In order to study the dynamic of plasma compression, a dependence of plasma parameters on working gas pressure has been

investigated. To observe the neutron emission dependence on D_2 pressure measurements with pressure between 1 and 3 mbar and 16 kV charging voltage were performed. The highest neutron yields were found in the region $1.5 - 2$ mbar of D_2 pressure. However, there has not been a clear relationship between D_2 pressure and the measured maximum of discharge current.

This research has been supported by the Marian Smoluchowski Krakow Research Consortium "Matter-Energy-Future" from the grant KNOW.

ON THE POSSIBILITY OF A CHAIN NUCLEAR FUSION REACTION BASED ON THE REACTION $p+^{11}B$

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The theoretical and experimental scheme for the realization of the fusion reactor based on the reaction $p +^{11} B$, such as beam colliding, synthesis in the degenerate plasma, ignition when plasma is accelerated by nonlinear ponderomotive forces, the bombardment of ^{11}B solid target by protons at the Coulomb explosion of hydrogen micro-drops are considered. The possibility of using ultrashort high-intensity laser pulses to initiate the reaction $p +^{11} B$ in conditions far from thermodynamic equilibrium is discussed. The prospect of this and other low-radiation fusion reactions is caused by their environmentally pure character — practical absence of neutrons among the products of synthesis. Reaction $p +^{11} B$ has the advantage that further nuclear reactions can generate high-energy protons, maintaining a chain reaction.

This research has been supported by the Russian Foundation for 247 Basic Research (projects Nos. 14-29-06045, 16-02-00350).

NEUTRON PRODUCTION FROM DEUTERIUM GAS-PUFF Z-PINCH ON GIT-12 GENERATOR AT CURRENT OF 3 MA

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Recent experiments on the GIT-12 generator demonstrated that a deuterium gas-puff could generate a pulse of more than 10^{12} neutrons with duration of 20 ns at a current level of 3 MA. Using a set of time-of-flight and threshold activation neutron detectors, the absolute neutron spectra were evaluated. The neutron spectra showed that the number of neutrons with energy above 12 MeV was of the order of 10^9, therefore the 3-MA gas-puff behaves as a very efficient pulsed source of high-energy neutrons. Such neutrons were produced by multi-MeV deuterons that were detected in the experiments by different diagnostic methods. Deuterons with energies up to 40 MeV were observed with the help of a stack of CR-39 track detectors, radiochromic films, and aluminum ion absorbers. The multi-MeV deuterons produced neutrons by nuclear reactions with materials in the experimental chamber such as ^{56}Fe and ^{27}Al. The number of non $D - D$ neutrons could exceed 20% of the total neutron yield.

This research has been supported by the Grant Agency of the Czech Republic (Grant No. 16-07036S), the Czech Ministry of Education (Grant Nos. LD14089, LG13029 and LH13283), the Ministry of Education and Science of Russian Federation (Grant No. RFMEFI59114X0001), the IAEA (Grant No. RC17088), the CTU (Grant No. SGS 10/266/OHK3/3T/13).

GENERATION OF Ne-LIKE Ar SOFT X-RAY LASER PUMPED BY CAPILLARY DISCHARGE AT MULTI-WAVELENGTH OF 46.9 nm, 69.8 nm AND 72.6 nm

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Capillary discharge is demonstrated to be the exciting schemes to develop the small-scale, high-efficiency and low-cost soft X-ray laser sources. In this report, at a low current of 12 kA, a saturated laser on $3\mathrm{p}^1\mathrm{S}_0$ and $3\mathrm{s}_1\mathrm{P}^1$ $(J = 0 - 1)$ transition at 46.9 nm (A line) and a near-saturated laser on $3\mathrm{p}_3\mathrm{P}^2 - 3\mathrm{s}_1\mathrm{P}^1$ $(J = 2 - 1)$ transition at 69.8 nm and a weak laser on $3\mathrm{p}_3\mathrm{D}^2 - 3\mathrm{s}_3\mathrm{P}^1$ $(J = 2 - 1)$ transition at 72.6 nm (E line) were achieved in a Ne-like Ar capillary discharge plasma. A gain coefficient of $0.58\,\mathrm{cm}^{-1}$ was obtained for A line laser and the gain saturation was observed at a gain-length product of about 13.3. To our best knowledge, we have realized the saturated 46.9 nm laser at the lowest current. Meanwhile, a gain coefficient of $0.41\,\mathrm{cm}^{-1}$ and gain-length product of 13.5 were obtained for the C line laser. The above results are expected to lead to the development of very compact and multi-wavelength laser that can be widely utilized in applications.

This research has been supported by the National Natural Science Foundation of China (NSFC) (Grant No. 61275139)

DEUTERIUM GAS-PUFF Z-PINCH AS AN INTENSIVE SOURCE OF MULTI-MEV IONS

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Z-pinch as a result of implosion of a deuterium gas-puff with outer plasma shell has been examined on GIT-12 generator in IHCE in Tomsk since 2013. Such a configuration caused more stable implosion at final stage of z-pinch. The consequence of this was a production of intensive pulses of fast ions. We applied several in-chamber diagnostics such as: stack detector (ion energy), pinhole camera (location of ion source), multi-pinhole camera (asymmetry and anisotropy of ion emission and location of ion source), and ion beam detector (dynamics of ion pulses). A CR-39 track detectors and also GAFCHROMIC HD-V2 films from these diagnostics will be presented. The ion energy spectrum with energies more than 20 MeV was unfolded from the stacks of many HD-V2 films. These results are in good correlation with previous results obtained by neutron time-of-flight diagnostics.

This research has been supported by the GACR No. 16-07036S, the Czech MEYS No. LD13029, LG15013 and LH13283, the MES of Russian Federation No. RFMEFI59114X0001, the IAEA No. RC17088, the CTU No. SGS16/223/OHK3/3T/13.

DIAGNOSTICS OF PLASMA STREAMS AND PLASMA-SURFACE INTERACTION OF ESSENTIALLY DIFFERENT DURATION OF PLASMA PULSES

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Spectroscopic studies of the plasma streams generated by magneto-plasma compressor (MPC) and quasi-stationary plasma accelerator QSPA Kh-50 have been performed. Features of plasma interaction with surfaces have been also carried out in dependence on plasma heat loads, plasma density and pulses duration. Long pulse plasma streams energy density up to 2.4 MJ/m^2, pulse length of 0.25 ms created by QSPA Kh-50. MPC generates short (10 μs) compressed plasma streams with Ne up to 10^{18} cm^{-3}, and plasma energy density varied in the range of $0.05 - 0.5$ MJ/m^2. Temporal and spatial dependencies of Ne and Te have been found. Special attention was paid to the dynamics of spectral lines near surfaces of exposed targets. Performed studies of plasma-surface interaction also include measurements of plasma energy deposited to the material surface as a function of the impacting energy and kind of targets. The resulting microstructure of the treated surfaces after plasma impacts is also discussed.

INVESTIGATION OF THE SPARK CHANNEL OF ELECTRICAL DISCHARGES NEAR THE MINIMUM IGNITION ENERGY

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In this work, we investigate the expansion of the hot gas kernel and pressure wave induced by electrical discharges near the minimum ignition energy experimentally by means of a schlieren setup and numerically through one-dimensional simulations. The effects of discharge energy and energy density on the expansion are discussed. Via comparison of experimental values with numerical simulations, an estimate of the overall losses of the discharge is presented.

This work was supported by the Deutsche Forschungsge- 268 meinschaft (DFG) under grant FOR 1447.

FLOW CHARACTERISTICS PREDICTION OF WELL-TYPE-CATHODE TORCH OPERATING WITH STEAM

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This paper discusses the prediction of the arc and flow characteristics of a non-transferred dc torch with a well-type cathode, where steam is used as the working gas. A turbulent MHD model is adopted to calculate the thermal plasma flow for the experimental cases with an electrode voltage drop ranging from 400 V to 550 V. The arc length is predicted between 230 mm and 330 mm, whereas the arc length increases with the mass flow rate but decreases with the current. The average temperature at the torch exit giving a positive dependence on the mass flow rate, as well as a negative dependence on the current, is estimated between 7600 K and 9800 K. The numerical prediction suggests that the average axial velocity at the torch exit, ranging from 700 m/s to 1900 m/s, grows with the mass flow rate and current. The computation depicts that the average azimuthal velocity at the torch exit is positively dependent on the mass flow rate and current, where it varies between 160 m/s and 340 m/s.

PLASMA MODIFICATION: ITS EFFECT ON POLYETHYLENE NATURAL FIBRE COMPOSITES

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We have employed plasma modification on polyethylene (PE) for preparing natural fibre thermoplastic composites, since they have found many applications in recent years. Natural fibres are less compatible with thermoplastic polymer like PE. In this study a new method to improve the compatibility between coir fibre and PE matrix has been introduced by modifying the surface of PE using plasma. Different methods were adopted for preparing the composites, hot press method was found to be the appropriate one. This work was also focused on the effect of different level of plasma modification on the properties of biocomposite. The porosity of the biocomposites was calculated from the density measurements. The composite based on plasma modified polyethylene showed better mechanical properties and lower water uptake due to better interaction. Thus plasma modification of polymer was found to be an effective technique to improve the compatibility between polyethylene and natural fibre.

This research has been supported by the MSMT of the Czech Republic, project No. LO1207.

EFFECTIVE GENERATOR OF WATER PLASMA

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We present a new concept of the water plasma generator consisting of plasma torch and throttled steam generator, which ensured by common control system and regenerative evaporative cooling. Herewith we use a huge heat of vaporization of water — 2.3 MJ/kg. Plasma generator fulfills precise control of the process of evaporation of water, depending on the cooling needs of the installation. Therefore, we don't use any cooling agent other than flow of steam, and thermal efficiency of setup is about 1.

SYNERGISTIC EFFECTS OF ESSENTIAL OREGANO OIL AND POSITIVE STREAMER DISCHARGE ON BACTERIA AND YEASTS

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Non-thermal atmospheric pressure plasma (NTP) activated liquids has been known for their antibacterial effects on G+ and G- bacteria. NTP was generated by a positive transient spark discharge in capillary-to-hollow electrode configuration. 6 μl of Oregano essential oil (OEO) suspended in 200 μl 5% Polysorbate 80 was electro-sprayed onto a treated surface with 50 μl/min flow rate.

Results show that an *E. coli, S. aureus* and *D. radiodurans* growth was completely inhibited after OEO plasma spraying, the maximal measured reduction was 6, 7 and 8 orders of magnitude after 2, 3 and 4 minutes of treatment respectively.

The FTIR spectra of the OEO and a Polysorbate 80 solution treated and untreated by transient spark discharge were measured, but no change in spectra after plasma treatment were found.

This research has been supported by the Student Grant Agency CTU under grant No. SGS16/223/OHK3/3T/13.

DESIGN AND CONSTRUCTION OF THE 0.5 TPD PLASMA GASIFICATION REACTORS FOR MEDICAL WASTE DISPOSAL

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The thermal plasma technology is the most important technology for the safe disposal of medical waste. In this method with the aid of the thermal plasma the organic waste converts to useful byproducts. The plasma torches are used to waste disposal. We designed the 40 KW air plasma torch for generation of the thermal plasma. On the other hand we designed and constructed the 0.5 TPD plasma gasification reactors which consists of three layer refractory material.

PLASMA-SOLUTION SYSTEM AS A NOVEL METHOD FOR CHITOSAN IMMOBILIZATION ON POLYMERS

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Chitosan is a well-known polysaccharide of natural origin with good biocompatibility and antibacterial features. Use of chitosan in certain applications is hindered because of its poor mechanical strength. A perspective task is seen in attachment of layers of chitosan onto materials (such as polymers) with required mechanical performance. Studies were already presented on using plasma pre-treatment of polymers for subsequent chitosan immobilization from water solutions. Although effective, these methods suffer from disadvantage of being multistage processes. In this work, a plasma solution system was used for simultaneous plasma activation of polypropylene (PP) and in situ anchoring of chitosan. The foils were submerged into a 1% acetic solution of chitosan which served as a liquid cathode in a dc glow discharge in air. A decrease of the chitosan molecular weight upon the action of plasma was detected by GPC. Immobilization of chitosan on PP was confirmed by XPS, FTIR, AFM and SEM.

This research has been supported by the Charles University in Prague grant SVV-2016-260215.

CHARACTERIZATION AND APPLICATIONS OF THE ENEA EUV SOURCE BY DISCHARGE PRODUCED PLASMA

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An Extreme Ultraviolet (EUV) radiation source generated by a Discharge Produced Plasma (DPP) is operating at the ENEA Frascati Research Centre. The Xe-based DPP source has been extensively characterised and the main results will be shown, in terms of both electrical and optical measurements.

Notwithstanding the fact that DPPs typically emit less debris than the laser produced plasmas, the ENEA source can be equipped with a debris mitigation system for both ions and particu-late, which is effective in protecting the exposed samples from debris bombardment in the case when the debris emission could be critical for the ongoing application.

Since the EUV radiation can be used to modify both the chemical structure of many photo-resists and the optical properties of various photonic materials, the ENEA source has been successfully utilized for exposing innovative photoresists and for sub-micrometer patterning by means of contact lithography on lithium fluoride crystals.

This research has been supported by the Italian Ministry of Research and CARIPLO Foundation.

THE SPECTRAL DEPENDENCE OF ABSORPTION COEFFICIENT Al-FOIL IRRADIATED BY A POWERFUL SOURCE OF SOFT X-RAYS

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The results of an experimental study of the transmission spectra of Al-foil irradiated by soft X-ray flux at the Angara-5-1 are presented. Flux of the radiation energy had reached 10^4 J/cm^2 at a pulse duration of 9 ns in the experiments. It has been observed experimentally an anomalously large increase in the Al-plasma transmission in the range of $70 - 130$ eV. In the experimental spectrum were identified absorption lines of ions $Al^{4+} \ldots {}^{7+}$. For a description of the line part of the absorption spectrum of additional simulations using FLEXIBLE ATOMIC CODE, FLYCHK and INDAHAUS were held. The line spectrum Researches are supplemented by radiation 3D-RMHD simulations of heating and expansion of the foil considering radiative transfer processes.

This work was supported in part by the Rosatom State Corporation (contract No. H.4X.44.90.13.1108) and the Russian Foundation for Basic Research (project Nos. 14-02-00438, 16-02-00084, 16-02-00112 and 16-02-00491).

CLOSED CURRENTS AS THE POSSIBLE EXPLANATION OF THE BALL-LIKE STRUCTURES IN THE PLASMA FOCUS DISCHARGE

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The experiments were carried out on the PF-1000 plasma focus device driven by $160 - 350$ kJ capacitor bank. There were used the deuterium filling in the chamber and deuterium or hydrogen filling in the gas-puff nozzle placed in the axis of the anode face. The diagnostics included interferometric measurements and a time resolved XUV pinhole camera. The ball-like structures and the filament structures were clearly visible in the XUV pinhole camera images. The ball-like structures were also visible in the interferometric images. The life-time of the ball-like structures with a diameter of several mm was usually longer than several tens of nanoseconds and they do not change their initial locations. Later, they were absorbed inside the expanded column and/or they expired in surrounding plasma. The closed currents of about tens kiloampers are considered as the main cause of the existence of the ball-like structures.

OPTIMAL SETTING OF DOUBLE PULSE CAPILLARY DISCHARGE FOR NITROGEN X-RAY LASER

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The NPINCHand RMHD Z* codes were used for modeling of pinching plasma driven by combination of two electric current pulses (slow exponentially damped sinus $t_{1/4} > 200$ ns, peak current $I_{peak} < 50$ kA and fast triangular pulse with a rise time about 38 ns, $I_{peak} < 60$ kA). The purpose of this work is to find optimal parameters ($t_{1/4}$ and I_{peak}) of the first slow sinus current pulse for two different capillary radii 0.5 cm and 1 cm according with obtaining the maximum possible gain at wavelength $l = 13.4$ nm (hydrogen-like nitrogen and recombination scheme).

The best gain (calculated by FLY code) is obtained then time of reaching I_{peak} is similar to the pinch timeand electron temperature is around 160 eV. The optimal initial density ρ_0 (or pressure) and start time t_{start} of

second triangular pulse (second pulse start at peak current I_{peak} of the first pulse) were determined for two capillary radii (0.5 and 1 cm) and four current peaks of the first pulse (20, 30, 40 and 50 kA).

INFLUENCE OF KIND OF WORKING GAS ON PLASMA STREAM PARAMETERS, GENERATED BY MAGNETOPLASMA COMPRESSOR MPC

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The present paper devoted to researches of features of discharge evolution and current-voltage characteristics of magneto-plasma compressor (MPC). The working regimes could be varied by choosing the quantity and kind of gas, supplying the MPC. Helium, nitrogen, argon were used as working gases. Both temporal and spatial distributions of plasma density and currents in plasma as well as radial distributions of energy density in plasma streams generated by MPC have been measured.

Position of compression zone, it effective diameter, compression ratio and spatial profiles of energy density are analyzed. The comparative analysis of plasma streams parameters for the three working gases was carried out. Significant reduction of the initial concentration (for example, due to the transition from helium to argon) leads to significant change of current distribution in plasma stream. The generation of toroidal current vortex, and displacement of the current from the axial area are observed.

STUDY OF COMPRESSION OF MIXED COMPOSITION NESTED ARRAYS

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New experimental data obtained at the compression of plasma of two-cascade wire and fiber arrays at a current up to 4 MA at Angara-5-1 facility. Experimental realization of various modes of plasma compression in two-cascade arrays (subalfvenic $V_r < V_a$, superalfvenic $V_r > V_a$ and a mode with formation shock between cascades) is carried out. Stable compression of the internal cascade was observed at compression of the nested arrays in which the outer cascade — a fiber array, the internal cascade — tungsten array. X-ray pulses by amplitude 4 TW and FWHM-duration of ~ 5 ns are obtained. Comparison of experimental data and simulation with a MHD-code has allowed to define the physical conditions at which one or another mode of plasma compression is realized.

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STUDY OF HIGH CURRENT ELECTRON BEAMS INTERACTION WITH ANODE TARGETS

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High current electron beams are used for fundamental researches (diode plasma research, shockwaves generation) and also for different applications (x-ray generation, materials sciences). In this work we present experiment results from high current generators “Calamary” ($U \leq 350$ kV, $I \leq 30$ kA) and RS-20 ($U \leq 1500$ kV, $I \leq 25$ kA). Experiments on diode plasma dynamics investigation, critical energy measurement for different materials, high power x-ray pulses generation and specific shockwave parameters for different materials and beam regimes are presented. Obtained results demonstrated that shockwave specifics hardly depend on beam parameters (focusing, electron range) and target material (even for materials with approximative chemical and physical properties).

Also there were found diode regime for polymeric targets providing very specific plasma dynamics and very fast diode gap bridging over.

This research has been supported by the Grants of Russian Foundation for Basic Researches No. 15-32-20308_mol_a_ved and No. 15-02-03544_a.

STUDY OF IMPLOSION OF A CONDENSED Z-PINCH ON THE ANGARA-5-1-1 FACILITY

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Implosion dynamics and stagnation state of condensed Z-pinch were studiedon the Angara-5-1. The central part of load has been did from deuterated polyethylene with density of $0.06 - 0.5\,\mathrm{gcm}^{-3}$. Parameters of Z-pinch plasma were determined by a diagnostic complex of the Angara-5-1. Usually two phases of implosion were observed which accompanied by the appearance of the hot spots with characteristic size of $100 - 300\,\mu\mathrm{m}$ with the photon energy range of $E > 2.5\,\mathrm{keV}$, pulses of soft X-rays with photon energies $E > 0.8\,\mathrm{keV}$ keV and neutron emission was observed. The temperature of the plasma near the hot spots was $200 - 400\,\mathrm{eV}$. An average energy of neutrons along a load axis in a direction to the anode was equal $2.1 \pm 0.2\,\mathrm{MeV}$ and in a direction perpendicular to an axis $2.4 \pm 0.2\,\mathrm{MeV}$.

The maximum neutron yield $10^{10} - 3 \times 10^{10}$ weakly depended on the initial density of the load.

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THE DYNAMICS OF PLASMA MOTION OF THE EXPLOSION-EMISSION CATHODE OF A RELATIVISTIC MAGNETRON

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The results of investigations of the dynamics of cathode plasma motion in a relativistic magnetron are presented. The light emission from the plasma was observed using a fast frame camera with an exposure time of a few nanoseconds. The magnetron was driven by the linear induction accelerator providing the voltage of $250 - 400\,\mathrm{kV}$ and electron current of $2 - 4\,\mathrm{kA}$. To localize explosive emission centers, the cylindrical cathode surface was made ribbed. The profile of ribs had a rectangular or sharp-edge form. Observations of light emission from the plasma showed that the plasma drifts in time in the azimuthal direction following the cathode profile. The plasma fills the space between ribs moving away from the anode. The experiments showed that within the duration of the current pulse, $\sim 150\,\mathrm{ns}$, the cathode plasma did not expand and could not be the cause for the

FORMATION OF A COMPRESSION EROSION PLASMA FLOW IN A COMPACT END-FACE ACCELERATOR

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Results of studies on a compact end-face plasma accelerator are presented. The device, although small in size and of low energy stored, is capable of generating compression erosion plasma flows (CEPFs) with parameters comparable to those of the larger-dimensioned systems. The main plasma flow measured $\sim 7.5 \times 10^{-2}$ m in length and $\sim 1.9 \times 10^{-2}$m in diameter. The CEPF originates on the central electrode, while on each bar of the outer electrode a much weaker separate plasma jet is formed. The flow elemental composition is mainly governed by the material of the internal electrode. Velocity of the plasma particles was measured to amount to$\sim 1.8 \times 10^{4}$ m/s.

By exposing a single-crystal silicon sample to the compression flows generated by the compact plasma accelerator, a nanostructured copper coating was produced at the Si surface, the former being composed of spherical particles $(50 \div 300) \times 10^{-9}$ m in diameter.

SOFT X-RAY SPECTRA FROM HIGH CURRENT NITROGEN Z-PINCH DISCHARGE

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High current capillary pinching discharge was studied as a method for recombination pumping of Balmer Îś radiation. The critical parameter for 3-body collisional pumping process, in non-stationary under-colled plasma, is quick electron cooling during the pinch expansion phase. The ablation of capillary wall material strongly influences pinch dynamics. So, we have performed computer modelling of ablation based on MHD NPINCH and FLYCHK codes. The results of modelling, namely time evolution of spectra emission in the wavelength range $8 - 14$ nm, were compared with gated spectra measured by CTU capillary device. The used alumina capillary with inner diam. 5 mm and length 22 cm was filled by nitrogen gas with density 5.8×10^{-6} gcm^{-3}. Current passing through the capillary has the peak value 70 kA and FWHM ~ 60 ns. Plasma created from the ablated material leads to the reduction of nitrogen plasma heating and decreases the rate of pinch expansion.

PROBE MEASUREMENT OF ELECTRON ENERGY SPECTRUM AT ATMOSPHERIC PRESSURE

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It is demonstrated that a wall probe is a useful tool for interpretation of plasma properties, including electron energy spectrum, and the plasma-boundary interaction in a microplasma with a nonlocal electron distribution at atmospheric pressure. The microplasma device was fabricated with 3 layers of molybdenum metal foils separated by two thin sheets of mica insulation. A hole with the diameter of 0.2 mm formed a cylindrical discharge cavity that passed through the entire five layers. The inner molybdenum layer formed a wall probe, while the outer layers of molybdenum served as the hollow cathode and anode. The discharge was open into air with flow of He. It was found that the wall probe I-V trace is very sensitive to the presence of He metastable atoms. The first

derivative of the probe current with respect to the probe potential shows peaks revealing fast electrons at specific energies arising due to plasma chemical reactions with He metastable atoms.

This research has been supported by the Air Force Office of Scientific Research.

EXPERIMENTAL STUDY ON THE INFLUENCE OF DBD REACTOR STRUCTURES ON THE GENERATIONS OF O_3, NO, AND NO_2 AT ATMOSPHERIC PRESSURE

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The generation characteristics of O_3, NO, and NO_2 of non-thermal plasmas produced at atmospheric pressure in air were studied. Investigations were carried out on two different dielectric barrier discharge reactors. One is a plane-to-plane electrode structure and has two symmetrical circular electrode parts, which were faced each other. The electrode part is consists of SUS electrode ($40\,\phi$, 1.5 T) and Al_2O_3 dielectric layer ($45\,\phi$, 1 T). The other is a surface electrode structure, which has strip-type top electrode, dielectric layer and plane type bottom electrode. The top SUS electrode is shaped as strip line and its thickness, width and pitch were 1 T, 1 mm and 5 mm, respectively. Al_2O_3 dielectric layer and the bottom SUS electrode have same area and thickness as $3500\,\mathrm{mm}^2$ and 1 T. The generation characteristics of O_3, NO and NO_2 depending on different DBD reactor structures are evaluated by using each components' analyzers.

This research has been supported by the This work was supported by R&D Program of "Plasma Advanced Technology for Agriculture and Food (Plasma Farming)" through the National Fusion Research Institute of Korea (NFRI) funded by the Government funds.

LASER SCHLIEREN DEFLECTROMETRY FOR TEMPERATURE ANALYSIS OF RF-EXCITED NON-THERMAL ATMOSPHERIC PRESSURE PLASMA IN ARGON

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Non-thermal atmospheric pressure plasma jets enable the production of reactive species while the gas temperature is low. Hence, they are commonly used for surface modification and considered for use in bio-medicine. The knowledge of the temperatures of plasma effluent and device components is essential. Additionally, rates of processes and thus the chemistry of the discharge strongly depend on the gas temperature. However, heating in such discharges is still poorly understood. To assess this problem, we investigated the COST Reference Microplasma Jet proposed by the European COST group MP1101 (Golda et al., J. Phys. D: Appl. Phys. 49 (2016) 084003). Laser Schlieren Deflectrometry (Schäfer et al., Rev. Sci. Instrum. 83 (2012) 103506) is applied to determine the gas temperature of the device. In an argon effluent, typical temperatures of $360 \pm 10\,\mathrm{K}$ were found. The results are compared to thermocouple measurements.

This research has been supported by the DFG within the framework of the Research Unit FOR 1123, Transregio 24, and Package Project PAK 816.

DEPENDENCE OF NEGATIVE CORONA CURRENT ON GAS PRESSURE

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The dependence of negative corona current on gas pressure was studied in view of designing a gas-pressure sensors in range of $1 \times 10^{-2} - 7.4 \times 10^{2}$ Torr.

The dependence of current on pressure is characterized by strong heterogeneity. This allowed the implementation of high-speed sensor for a wide range of pressure within a time interval not exceeding $0.1 - 0.2$ s. Choosing negative corona is related to its current pulsations and to the strong dependence of its parameters on the concentration of electronegative gases. In particular, the corona pulses charge and current significantly decrease as the oxygen concentration in argon and nitrogen is increased. The mathematical model of corona current behavior was developed by taking into account the ionization of gas molecules, the attachment and detachment of electrons, the charge drift and the surface ion-electron emission. The results of numerical simulations describe satisfactorily the experimental dependences.

INFLUENCE OF TEMPERATURE AND PRESSURE ON A SINGLE-STAGE EHD THRUSTER PERFORMANCE ON NITROGEN GAS

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In the near-space region (altitudes of $20 - 100$ km), pressure ranges from roughly 40 Torr to 0.25 Torr and temperature between 190 K and 270 K, respectively. Due to that variation, propulsion systems must be designed to operate under these environments.

We developed a numerical model to study the performance (thrust, fluid velocity and thrust-to-power ratio) of a single-stage EHD thruster with a rod anode and funnel-like cathode geometry. We considered the following neutral and ionized nitrogen species: N, N^{+}, N^{2}, N^{2+}, and N^{4+}.

Simulations swept over pressures of $0.5 - 100$ Torr and temperatures in the range $190 - 400$ K, showing that the higher pressures increase the net thrust, thrust efficiency and the peak gas velocity. Simulations showed a variation of thrust of several orders of magnitude for higher pressures and a slightly improvement of the thrust efficiency for lower tempera-tures. A clear over-all influence on the performance parameters is shown on the present study.

USING OF HIGH-CURRENT LIMITED PLASMA DIODE FOR HIGH-GRADIENT INFLUENCE ON SOLIDS

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The high-gradient influence on the different nature solids opens new possibilities of structural-phase state modification at various scale levels. The high-gradient influence method using a high-current pulse plasma diode with the limited working surface of a high-voltage electrode has been proposed in this work. This construction allows forming the density of power flux up to 1 GW/cm^2 into working area plasma at stored energy of capacitor bank to 200 J.

The dynamics of active power input into the discharge for different initial conditions has been investigated. It has been shown that up to 80% of the stored energy is released in the 1st half-period of the discharge current oscillations. It has been noted that the main plasma heating mechanism is a beam mechanism which appears due to the formation of double electric layer of space charge in the current-carrying plasma. The energy released areas have been indicated for the different initial conditions and current flow directions.

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THE STUDY ON THE WATER CHARACTERISTICS OF WATER SURFACE PLASMA ACCORDING TO THE ELECTRODE STRUCTURES

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Water surface plasma is one of the common methods of atmospheric plasma. Plasma can change the species of air by ionization, dissociation and recombination. From theoretical reaction mechanisms, it is expected that the initial produced materials would be O_3, HNO_2, and HNO_3, and that the finally produced materials would be ozone, nitrite, nitrate, hydrogen peroxide, hydrogen ion and various radicals. Particularly, HNO_2 has powerful oxidation potential and keep it for long time. These plasma water can be applied for a sterilizer. The purpose of this study is to analyze the properties of the water surface plasma according to the plasma electrode structure. Three types of electrodes were analyzed, one is traditional dielectric barrier, the other is metal pin ground electrode, and another is pinhole type electrode. Electrical currents and voltages, gas species and ion concentration in discharged water were analyzed for checking water characteristics.

This research has been supported by the R&D Program of 'Plasma Advanced Technology for Agriculture and Food (Plasma Farming)' through the National Fusion Research Institute of Korea (NFRI) funded by the Government funds.

INVESTIGATION OF MICROWAVE ENERGY DISTRIBUTION CHARACTER IN A RESONATOR TYPE PLASMATRON

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An investigation of microwave energy distribution character in a plasma of microwave discharge inside a plasmatron based on a rectangular resonator has been carried out. The experiments were done applying the "active probe" method. Microwave discharge was excited in the air and oxygen. It has been found out that the readings of the "active probe" along the discharge chamber are of periodic character. The readings of the "active probe" and data on the local electric conductivity of plasma obtained using electrical probes have been compared

This research has been supported by the State Program of Scientific Research "Physical materials science, new 220 materials and technologies".

COMBUSTION ENHANCEMENT OF A LEAN-BURN INTERNAL COMBUSTION ENGINE BY APPLICATION OF PLASMA IGNITION SYSTEM

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A high energy ignition system is essential for lean-burn or high-EGR(Exhaust gas recirculation) combustion in a gasoline internal combustion engine, which is getting more and more interest to improve fuel economy. The high energy ignition systems under consideration are plasma jet, laser beam, corona discharge and so on. In this study, a high energy ignition system using corona discharge is developed and tested in a constant volume combustion chamber. The test condition is 350 K and 7 bar and this is simulated similarly to the initial condition of a normal gasoline engine. The developed system shows extension of lean limit of fuel-air mixture by 20% comparing to the normal spark plug ignition system. Combustible EGR rate is also increased from 30% to 35% in a stoichiometric condition. Various shape of corona discharge plugs are also tested and compared in this study.

This research has been supported by the R&D Program of 'Plasma Advanced Technology for Agriculture and Food (Plasma Farming)' through the National Fusion Research Institute of Korea (NFRI) funded by the Government funds.

STUDY OF ETCHING MODE IN GALLIUM ARSENIDE IN THE COMBINED CAPACITIVE AND INDUCTIVE PLASMA DISCHARGE

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In this paper, the method of plasma chemical etching combined chlorine plasma capacitive and inductive discharge, because it allows you to combine two modes of plasma chemical etching: reactive ion etching and etching in inductively coupled plasma.

The first samples were treated: a power capacitive plasma W_{RIT}– 35W, the flow rates of the process gases Ar 100 cm^3/min, and BCl_3 10 cm^3/min, the power source is inductively coupled plasma W_{ICP}– 200, 400 and 600 Watts. GaAs etching rate was 28.2 nm/min 24.9 nm/min 27.8 nm/min, the values of the power source were inductively coupled plasma 200 W, 400 W and 600 W respectively. The second batch of samples was etched: a power of inductively coupled plasma W_{ICP}– 300 W, flow rates of process gases Ar- 100 cm^3/min, and BCl_{3-} 15 cm^3/min, the plasma source power is capacitively W_{RIT} was 10, 35 and 70 Watts. GaAs etching rate was: 516.7 nm/min, 559.5 nm/min, 603.3 nm/min, the values of the source power 10 W capacitive plasma, 35 W and 70 W respectively.

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STUDY OF ARGON AFTERGLOW WITH THE AIR ADDITION

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The reaction kinetics in argon flowing afterglow (post-discharge) with the air addition was studied by optical emission spectroscopy. The optical emission spectra were measured along the post-discharge flow tube. A zero-dimensional kinetic model for the reactions in the afterglow was developed. This model allows to calculate the time dependencies of particle concentrations.

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THE PENNING DISCHARGE EXPERIMENTAL STUDY AND IT'S SIMULATION

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The influence of the demountable Penning ion source electrodes geometry on the discharge characteristics and extracted ion current is investigated. The extracted currents, ignition potentials and the operational pressure ranges are compared at different anode heights and its arrangement relative to the discharge cell. The use of ring and mesh anodes has allowed to visualize the discharge burning areas and their structure versus the pressure, anode potential and cell geometry. Some PIC simulations of Penning discharge are made in the Vorpal code. The good correspondence between the simulated electron density and plasma glow areas on the photos is shown. The other one-particle simulation has shown that the magnetic field nonuniformity significantly affects the ignition and combustion discharge potentials

DENSITY OF NEUTRAL ATOMS IN REACTIVE GASEOUS PLASMAS

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A device for real-time measurements of the density of neutral atoms in plasmas of molecular gases such as oxygen, hydrogen, nitrogen, carbon dioxide, ammonia and alike is presented. The device takes advantage of heat dissipation upon heterogeneous surface recombination of atoms to parent molecules on a catalytic tip. The tip is placed into a differentially pumped housing to assure for surface neutralization of charged particles and relaxation of metastables so that the surface recombination is the only mechanism for heating of the catalyst. The probe allows for measuring atom densities in a broad range of several orders of magnitude. It is particularly suitable for detection of atom gradients next to surfaces of materials that are treated by gaseous plasma as well as for detection of temporal dependence of atom density due to evolution of the surface properties upon etching, cleaning oxidation/reduction and nanostructuring. Examples on application in plasma reactors will be presented.

This research has been supported by the Slovenian Research Agency.

AVERAGE ENERGY OF ELECTRONS IN PLASMA PRODUCED BY ROTATING GLIDING DISCHARGE WITH LIQUID ELECTRODE

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The plasma-liquid system with liquid electrode was developed as a plasma injector for the plasma-catalysis of chemical reactions. Discharge system was based on the rotating gliding discharge with the reverse vortex airflow and the liquid electrode. Discharge plasma composition was determined via the emission spectra of plasma and contained O, H, OH species. The current-voltage characteristics of the discharge were used for the calcuation of reduced electric field in the discharge gap. The average energy of plasma electrons for the different compositions of plasma-generating gas was calculated based on the reduced electric field value of the discharge and on the temperature of the plasma. The system produced non-equilibrium non-thermal plasma torch at the atmospheric pressure with the plasma temperature of 4000 K and with the average energy of plasma electrons of 4.5 eV. The content of water in plasma-generating gas has shown to greatly influence the average energy of plasma electrons.

TEMPERATURE AND TECHNOLOGY VULNERABILITY EFFECTS OF SURFACE DIELECTRIC BARRIER DISCHARGES

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Particles triggering plasmachemical processes e.g. for ozone generation are the electrons. As far as the electron density is controlled by the discharge current then in order to increase electron density it is necessary to increase the discharge current, which leads to the heating of a gas. Gas heating is a destabilizing factor. As the pressure levels off quickly in a gas, a local increase in gas temperature is accompanied with a drop in density. This effect does not influence the field strength, but reduced electric field E/N, so that the electron temperature that depends on E/N also increases. The result is enhanced ionization, locally increased conductivity, current density and Joule's heat release. The gas is therefore heated even more, which can cause various unpleasant effects. Apart of it discharge functioning could be affected by vulnerability of electrode system design, insufficient grounding or not matching of the discharge chamber and the power source.

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EFFECT OF AXIAL NEGATIVE HYDROGEN IONS OUTPUT FROM PENNING DISCHARGE WITH METAL-HYDRIDE CATHODE

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The authors suggest the way of increasing the intensity of a hydrogen negative ion source with volume ionization by using metal-hydride hydrogen activation, when hydrogen is injected into the ionization region in vibrationaly excited state. On the other hand, ejecting electrons in the axial direction is the feature of Penning discharge with metal-hydride cathode founded by authors makes it possible to greatly simplify the design of typical sources construction and extract H^- ions along the magnetic field. For this purpose, a magnetic filter for efficient separation of electrons from the negative ions has been designed. The trajectories of the particles in the magnetic filter have been determined. The experimental studies of extracted axial negative current depending on the magnetic field in the filter were carried out. Comparison of numerical and experimental data has shown the ability to work of H^- ion source based on the Penning discharge with longitudinal extraction.

OPTICAL AND ELECTRIC INVESTIGATIONS OF A COMPLEX SPACE CHARGE STRUCTURE EXCITED BY A SPHERICAL GRID CATHODE WITH A HOLE

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Experiments are carried out in a grounded metallic stainless steel chamber (90 cm length, 44 cm diameter) in argon at $p = 2 \times 10^{-2}$ mbar. A hollow spherical stainless streel grid with a diameter of 6.8 cm is inserted and negatively biased. The grid has a hole of 5 mm diameter. For $V_g < -300$ V complex space charge structures form inside and around the grid. A strong electron beam is ejected of the hole. For $V_g < -400$ V, the beam transits from a collimated to a divergent shape. Space-resolved optical and electrical diagnoses were carried out with a spectrometer and a cylindrical tungsten plasma probe. Plasma potential, electron temperature and density, plasma emission spectrum and spectral lines of exited atoms and ions were measured from the centre of the sphere outward. Preliminary measurements highlight complex processes of excitation and ionization especially in the vicinity of the grid due the accelerated beam collisions with different electron populations.

STUDY OF TEMPERATURE FIELD IN THE NON-THERMAL PLASMA JET BY MEANS OF LASER SCHLIEREN DEFLECTOMETRY AND OPTICAL EMISSION SPECTROSCOPY

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The gas temperature generated in the active discharge zone of atmospheric plasma jets plays a crucial role for PECVD applications. However, the often complex structured discharges with a multitude of thin hot non-stationary filaments produces complex temperature fields inside the plasma source and in the effluent which render most diagnostic techniques inadequate. Here laser schlieren deflectometry (LSD) (Schäfer et al., Eur. Phys. J. Appl. Phys. 71, 2 (2015) 20804) combined with optical emission spectroscopy have been used for the spatially and temporally resolved diagnostic of the temperature in the RF plasma jet. The jet has been operated in argon with a systematically varied admixture of nitrogen. The rotational and vibrational temperatures of N_2 and ${N_2}^+$ are obtained with high resolution and discussed with results of LSD. It is found that three hot channels with a core temperature of 450 K are rotating in radial direction at 30 cm/s for an applied power of 7 W.

This research has been supported by the DFG Transregio 24 "Fundamentals of Complex Plasmas"; 7th European Framework Programme, project No. 316216, "PlasmaShape" and by the grant No. 16-09721Y of the Czech Science Foundation.

OPTICAL PROPERTIES OF ELECTRICAL DISCHARGE IN VAPORS OF ADENINE MOLECULES

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This work is dedicated to the experimental study of the luminescence spectra of molecules adenine vapors in their excitation under the conditions of electrical discharge. The technique of the experiment is study optical spectra of electric discharge which light up the tube, filled with vapors of adenine molecules. Experimental conditions were as follows: pressure of molecules vapors $\sim 10^{-2}$ Pa, the current intensity of discharge $I = 10$ mA, voltage in the dis-charge gap -540 V.

During the research we have obtained luminescence spectra of discharge in the wavelengths region from 200 nm to 500 nm. Spectral bands with maxima at wavelengths of 284, 299, 312 – 315, 329, 337, 352 – 357, 373 – 395, 380 – 387, 400, 407, 417 – 424, 430, 436, 452 and 474 nm were detected in analyzing of these spectra.

ATMOSPHERIC PRESSURE MICROPLASMA JET

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The atmospheric pressure microplasma jet systems are sources of low temperature non-equilibrium plasmas. Numerous plasma components such as activated components of oxygen or nitrogen, charged particles, electric fields and even UV radiation leads to different reactions in the treated tissues, allowing to use of microdischarge systems for various applications. The main advantages of these systems are their compactness, and the fact that the plasma is not limited by the sizes of electrodes. The ability to adjust the size of the jet allows locate the area of influence (case of working with living tissues: blood coagulation, dentistry, the plasma sterilization of living tissues etc). Also it is possible to increase area of plasma in cases where it is necessary. Low voltage atmospheric pressure DC microplasma jet systems with vortex gas flow represented in this work. It was diagnosed using current-voltage characteristics, video/photo registration and emission spectroscopy method.

This research has been supported by the Ministry of Education and Science of Ukraine, National Academy of Sciences of Ukraine, and Taras Shevchenko National University of Kyiv.

EXPERIMENTAL STUDY OF THE LIQUID CATHODE COMPONENTS TRANSFER TO THE DC DISCHARGE PLASMA AT ATMOSPHERIC PRESSURE

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The transfer processes of solvent and dissolved substances in gas phase from aqueous solutions used as cathodes under the action of atmospheric pressure DC discharge were investigated.The electric field strength in plasma

(E), cathode voltage drop (U_c) and rates of solution evaporation were measured. The transfer coefficients were calculated. The effect of transfer processes on plasma physical properties was experimentally studied. The threshold characteristics of cations transfer process were determined.

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FORMATION OF DIELECTRIC-BARRIER DISCHARGE PLASMA JET IN A HELIUM FLOW: EFFECT OF GAS OUTLET VELOCITY AND CONTENT OF AIR ADMIXTURE

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The results of investigations into the influence of helium outlet velocity and content of air admixture (up to 20%) on the formation of plasma jet with the DBD-generator (up to 5 kV, 21 kHz) have been presented. Helium was passing through a quartz tube with a coaxial system of electrodes. Varying of gas outlet velocity was provided by using discharge tubes with different inner diameters (5.58; 7.49 mm) and by changing gas flow rate ($1-40$ l/min). Plasma jet was photographed for upstream and downstream directions of gas flow. Analysis on a dependence of the plasma jet length on gas outlet velocity revealed the transition mode “laminarity-turbulence”. It is accompanied by the decreasing the plasma jet length and blurring of the plasma jet shape. Addition of air admixture significantly influences on both the ignition of the discharge and the formation of the plasma jet.

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THE INFLUENCE OF CO_2 ADMIXTURES ON PROCESS IN TITAN’S ATMOSPHERIC CHEMISTRY

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The exploration of planetary atmosphere is being advanced by the exciting results of the Cassin-Huygens mission to Titan. The complex chemistry revealed in such atmospheres leading to the synthesis of bigger molecules is providing new insights into our understanding of how life on Earth developed. In our experiments Titan’s atmosphere is simulated in a glow-discharge formed from a mixture of $N_2 : CH_4 : CO_2$ gas. Samples of the discharge gas were analysed by GC-MS and FTIR. The major products identified in spectra were: hydrogen cyanide, acetylene and acetonitrile. The same compounds were detected in the FTIR: hydrogen cyanide, acetylene and ammonia. Whilst many of these compounds have been predicted and/or observed in the Titan atmosphere, the present plasma experiments provide evidence of both the chemical complexity of Titan atmospheric processes and the mechanisms by which larger species grow prior to form the dust that should cover much of the Titan’s surface.

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