OVERVIEW OF EDGE AND DIVERTOR STUDIES AT THE COMPASS TOKAMAK

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In the recent years, the research on the COMPASS tokamak was focused on challenges linked to edge and divertor plasmas, in particular on the problem of power exhaust in both steady-state and intermittent plasma conditions. This activity was supported by improvements of the relevant diagnostics, such as the new divertor probe array, which allows to measure impacting heat fluxes with sub-microsecond resolution, and the High Resolution Thomson scattering, where upgraded optics allows reliable measurement of pedestal profiles.
Strong emphasis was placed on development of relevant scenarios: discharges with impurity seeding at different locations in the divertor were focused on accessing partially detached plasmas. It was demonstrated that such regime can be achieved, when nitrogen is injected at the outer target, although drop of upstream pressure was also observed.
Measurements of peak ELM energy densities in the divertor complemented the existing scaling by Eich et al. and confirmed the validity of proposed model. Measurements performed by the horizontal reciprocating manipulator yielded upstream measurements of power decay length during ELMs. It was observed, that the power decay length exhibits a significant broadening (factor of 4) compared to the inter-ELM value.
Systematic characterization of divertor heat flux profiles in attached L-mode plasmas allowed to challenge existing scalings of the power decay length in such regimes and in conjunction with available data from larger tokamaks to derive an improved semi-empirical scaling formula. It was generally observed, that the s-factor deduced from such heat flux profiles is rather small, at the limit of the instrumental resolution of the divertor diagnostics. This is most probably a consequence of relatively short connection length and the open divertor geometry.

RELEVANCE OF LIQUID METAL WALLS IN NUCLEAR FUSION REACTORS

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Withstanding the high power loads impinging on the divertor region of fusion reactors, and generally on the first wall, remains unsolved and is considered one of the challenges on which the success of fusion energy depends.
One alternative to the conventional use of solid plasma facing materials (PFM) is the use of liquid metals due to the properties of the liquid surface. This alternative comes with its own set of challenges which must be addressed: Which materials are potential candidates? Can these candidates perform as PFM? Are these materials compatible with hydrogen plasmas? Moreover, are hydrogen plasmas consistent with them? How can we use the properties of liquid metals on a power exhaust solution?
Both elemental metals and alloys, have been proposed as candidates for liquid metal plasma facing materials such as lithium, tin, gallium, lithium-tin alloys. This oral contribution will focus on contextualizing this technology as well as summarizing its state of the art.

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PREPARING FOR THE SCIENTIFIC AND TECHNOLOGICAL EXPLOITATION OF JET NEXT TRITIUM CAMPAIGNS.

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JET is uniquely placed to address crucial physical and technological aspects essential for the development of a commercial reactor based on the Tokamak configuration. In this perspective JET most important assets are the use of the reactor fuel D-T, the plasma facing components of ITER (W divertor and Be main chamber first wall) and the plasma parameters to confine the alpha particles. The preparation and realization of the next JET T-T and D-T experimental campaigns, now scheduled for the period 2019-2020, are expected to provide an important contribution to fill major physics and technological gaps for the development of fusion energy. Indeed the experience of operating metallic machines in conditions relevant to next step devices and in D-T is quite limited. The main scientific objectives of these campaigns include the assessment of the isotopic effects on various plasma aspects: on core and pedestal confinement, on the threshold to access the H mode, on ELM behaviour and on plasma-surface interactions. From a technical point of view, the total yield of the entire D-T phase is expected to be 10^{13} n/s cm^2, about a factor of six higher than the previous main D-T campaign on JET, DTE$_1$. Therefore the radiation field will be quite relevant for next step devices, since the neutron flux at the first wall (10^{16} n/cm^2), for example, will be similar to the one in ITER behind the blanket. With respect to the enhancements, for many years JET systems have been upgraded in order to provide adequate support for the scientific exploitation of a full D-T campaign. The main efforts have concentrated on improving three main aspects of JET capability: 1) the heating and ancillary systems to develop scenarios and improve performance 2) the quality of the measurements to maximize the scientific exploitation and investigate the fusion products 3) the testing of specific technologies relevant for ITER and DEMO. With regard to the scenario developments and the increase in performance, a systematic scan of the isotopic composition has already started with a series of dedicated hydrogen and deuterium campaigns. The performance of JET with a carbon wall have been reproduced up to a plasma current of 3 MA, which supports the ambition of achieving 15 MW of fusion power in full DT operation. Such performance is reasonable considering that JET will have an unprecedented level of neutral beam power (up to 35 MW) and higher RF heating. Moreover the developed plasma configurations are compatible with the wall properties, from melting to retention (less than 0.5 %) and dust production (less than 2 g in the last set of campaigns), although tolerable divertor power handling at full power (40 MW) needs to be demonstrated. Two new DT compatible fast valves for massive gas injections, together with a new shatter pellet injector, will allow new studies of disruptions and their consequences, including the investigation of runaway electrons. In terms of general diagnostic capability, compared to the previous DTE1, JET diagnostics have a much better spatial resolution , temporal resolution and accuracy. With regard to the fusion products, JET now can deploy a consistent set of techniques to measure the neutron yield and neutron spectra and to diagnose the fast particles, from their redistribution to their losses. A full calibration of the neutron diagnostics has been completed successfully (for both 2.45 and 14 MeV neutrons). New diagnostic concepts, to test potential solutions for ITER, have been implemented and have even provided the first encouraging results; they range from the measurement of the plasma current with the Faraday Effect to the detection of the fast particle losses and to the total yield assessment with the activation of the cooling water. From a technological perspective, the D-T and T-T campaigns will provide a unique opportunity to test ITER and DEMO relevant technologies. Specific programmes are being put in place to investigate the following aspects: the radiation field, the induced activity and dose rates, the radiation damage in materials and components, waste production and occupational dose. The effects of neutrons and gamma on ancillary technologies and systems, such as fibre optics and electronics circuits, are also expected to be sufficiently high to derive useful information about the competitive advantage of various alternatives. Dedicated studies for DEMO, including the tests of a new tritium pumping cycle and a tritium breeding blanket mock-up, are also foreseen.

X-RAY PHASE-CONTRAST IMAGING FOR LASER-INDUCED SHOCK-WAVE STUDIES

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X-ray phase contrast imaging (XPCI) is an imaging technique based on the phase-shift of an X-ray photon induced by the refractive index. In particular, the phase-shift is related to the real part of the refractive index, while the imaginary part is related to the absorption. A coherent X-ray source such as a synchrotron or X-ray free electron laser are the best choice for XPCI, however, it is possible to use broadband incoherent X-ray sources by limiting the source size and careful positioning of the experiment and detector. The interaction of high power laser with matter produces X-rays according to the intensity, energy and pulse duration. These sources can be used for XPCI. In this work we present the characterization and the application of XPCI using a laser-produced bremsstrahlung source to a shock. The X-ray source was created by irradiating a 5 µm diameter tungsten wire with a Nd:Glass laser pulse 0.5 ps long and energy of 25 J in first harmonic. This produces a strong bremsstrahlung radiation. We applied this source to XPCI static objects and a laser-driven shockwave in a plastic target. In both cases the XPCI clearly indicates the presence of density interfaces with 5 µm spatial resolution. This proof-of-principle experiment shows how this technique can be a powerful tool for the study of warm and hot dense matter on large scale high-energy-density facilities.

SUSTAINMENT OF PLASMA WITH $\beta \sim 1$ USING NEUTRAL BEAMS

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The paper summarizes the results on high-β plasma build-up and sustainment in Gas-Dynamic linear device (GDT) in Novosibirsk. The GDT device (A. A. Ivanov, V. V. Prikhodko, Plasma Phys. Control. Fusion 55 063001 (2013), A. A. Ivanov, et al, Phys. Rev. Lett. 90, 105002 (2003)) is axially symmetric. The 15 keV, 4 MW neutral beams are injected at the center of the device at 45 degrees to the axis during 5 mc. The initial cold plasma for trapping of the beams is produced either by plasma gun installed at the end walls or alternatively by gas ionization with gyrotrons inside the confinement region between the end magnetic mirrors. Sheared plasma rotation is produced by applying voltages to a system of the nested circular electrodes placed at the end walls and by radial limiters inside the central cell. The sheared plasma rotation suppresses radial plasma transport caused by flute instability. The neutral beam injection results in accumulation of fast ions and heating of bulk electrons. The plasma pressure profile, which determined by fast ions with mean energy 10 - 12 keV, is strongly inhomogeneous with strong peaks near the fast ion turning points near the end magnetic mirrors, where the magnetic field is about 0.6 T. Following the achievements of $\beta \sim 1$ in quadruple magnetic mirror experiment (F. Coensgen et al., Phys. Rev. Lett. 44, 1132 (1980)), it has been demonstrated that in axially symmetric GDT experiment plasma beta exceeded 0.6 (A. A. Ivanov, et al, Phys. Rev. Lett. 90, 105002 (2003), A. A. Lizunov, et al, Rev. Sci. Instr. 82, 086105 (2011)) at the fast ion turning points.
At the same time, the electron temperature reaches 0.25 keV with the neutral beams solely and ~ 1 keV with an auxiliary ECR heating. The plasma parameters in the experiment are relevant to those in the neutron source for materials testing, which is based on the gas-dynamic trap (GDTNS (A. Molvik, A. Ivanov, G. L. Kulcinski, et

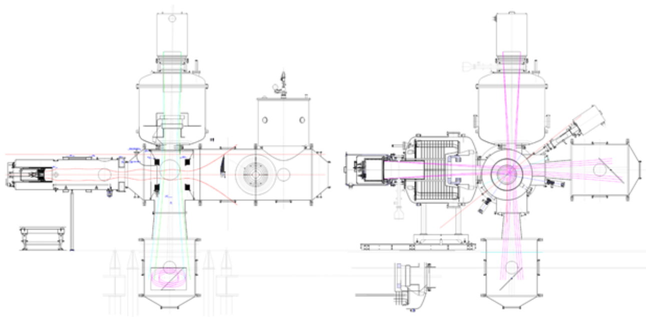

Figure 1. Experiment on field reversal in magnetic mirror

al, Fusion Sci. Technol., 57(4), 369 (2010) , A. Anikeev, P. Bagryansky, A. Ivanov, et al, Nucl. Fusion 40, 753 (2000)). The neutron production of DTNS depends mainly on the electron temperature. With the achieved GDT electron temperature of 0.8 keV, the expected neutron flux would be $2 MW/m^2$. The test area is $1\,m^2$ and the spatial uniformity is well within the requirements of materials scientists. The conceptual design shows that up to 8 000 small material samples could be irradiated with a temperature controlled environment . Alternately, one of the ends could be employed to test a few larger sub-components and blanket modules. In this way tritium breeding studies could be carried out.

To study more in detail production and sustainment of high-β plasmas, now the CAT (Compact Axisymmetric Trap) experimental device is under construction at the Budker Institute, in which fast ions are produced by injection of 3.5 MW, 15 keV, 5mc neutral beams into a compact axisymmetric mirror trap. The neutral power density exceeds the previous records (F. Coensgen et al., Phys. Rev. Lett. 44, 1132 (1980)) attained in the mirror machines by 2 - 3 times. The simulations shows that accumulation of fast ions would provide the initial 0.3 T field reversal within first 0.3 - 0.5 mc of injection. An increase of plasma pressure with higher neutral beam injection power may significantly improve the plasma confinement by increasing the effective mirror ratio or even form a reversed field configuration with transition to plasma confinement at the closed field lines, as in (M. Tuszewski, A. Smirnov, et al, Physics of Plasmas, 19, 056108 (2012)). The experimental layout is shown in 1. The vacuum chamber consists of a cylindrical central cell 3.5 m long and 1 m in diameter and an expander tank attached to the central cell at the end. A set of coils mounted inside and on the vacuum chambers produce an axisymmetric magnetic field with a mirror ratio of 1.5 when the central magnetic field is set to 0.3 T. The initial plasma is produced by a washer stack hydrogen-fed plasma gun. The gun is located in one of the end tanks beyond the mirror throat. The two neutral beams are injected perpendicularly to the plasma axis. Neutral beam currents in excess of 250 equivalent atomic amperes will be injected with an accelerating voltage 15 keV. Partial line tying on to the gun would provide stability to plasma column during accumulation of the fast ions. In between the plasma gun muzzle and the entrance mirror coil the magnetic field has a special profile with local minimum near the mirror coil, which produces the effect of thermal barrier (D. E. Baldwin, B. G. Logan, Phys. Rev. Lett. 43,1318 (1979)). This effect was previously observed in the AMBAL experiment and was attributed to development of Kelvin-Helmholtz instability, which made the ion distribution to be strongly anisotropic in the region right at the entrance mirror coil. In the opposite end tank the magnetic field gradually decreases beyond the exit mirror thereby forming potential barrier to prevent most of electrons to arrive to the end wall thus providing the hot plasma thermal insulation from the end wall. The effect of suppression of electron thermal conduction was studies in the GDT experiments. We expect that this lead to decrease of the electron heat conduction to the both ends thus providing the conditions to self consistent increase of the electron temperature during the neutral beam injection. So, it is expected that the electron temperature of the gun-produced plasma should considerably increase from the initial value of 3 - 10 eV.

According to the results of the numerical simulations, the field reversal would become possible on an early stage of the beam injection. However, there are several open questions. The first one is a behavior of the electrons during the field reversal, which cannot be the fully modeled by the existing code. To control the electron collisionality, which would be playing the critical role during the reversal, the electron gun would be installed on-axis in the tank opposite to the plasma gun. Another problem would be development of the plasma instabilities during the reversal, which would deteriorate plasma confinement. To stabilize the unstable tilts it is foreseen to vary the plasma axial extent by slight changing of injection angle or by changing the axial positions of the internal mirrors coils. The remaining unstable azimuthal mode $n = 1, 2$ would be stabilized by the line tying to the gun (M. Tuszewski, A. Smirnov, et al, Physics of Plasmas, 19, 056108 (2012)). To ensure this stability, a sufficiently high density plasma is to be maintained in between the central cell and the gun.

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LASER-DRIVEN ION ACCELERATION WITH ULTRA-SHORT ULTRAHIGH-CONTRAST PETAWATT LASER

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Ion acceleration driven by ultra-intense lasers has become one of the most attractive topics in relativistic laser-plasma interaction research due to unique properties of laser-driven ion sources. Laser-driven ion acceleration can occur through such mechanism as target normal sheath acceleration, radiation pressure acceleration, Column explosion, etc. Since multi-PW Ti:sapphire lasers were constructed at CoReLS, we have devoted our efforts to generate protons and carbon ions with energy over 100 MeV/nucleon, along with the investigation of ion energy scaling to laser intensity. Ion acceleration experiments have been performed by irradiating ultra-short ultrahigh-contrast PW laser pulses onto ultra-thin foil targets. We demonstrated the generation of 93 MeV proton beam by applying circularly polarized PW laser pulses. Here we present the recent progress and future plan on laser-driven ion acceleration using the multi-PW laser at CoReLS for obtaining ion energy over 100 MeV/nucleon.

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EFFECT OF A SHALLOW PELLET INJECTION ON ITBS PLASMA IN TOKAMAK

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JET H-mode plasma discharge 53212 during the pellet fueling operation in the presence of ITBs are carried out using the 1.5D BALDUR integrated predictive modelling code. The plasma instability during ITB formation with pellet injection in tokamak is investigated. In these simulations, a combination of a neoclassical transport model and an anomalous transport model is used. The boundary condition is calculated theoretically based on a combination of magnetic and flow shear stabilization pedestal width scaling and an infinite-n ballooning pressure gradient model. The toroidal flow calculation is based on NTV toroidal velocity model. It was found that the shallower pellet does not destroy the ITB, which locating mostly between $r/a = 0.8$ and 0.9. Moreover in the plasma center region ($0.4 < r/a < 0.6$) the effective electron thermal diffusivities during the ablation time not change and decreased after pellet ablation it mean a shallow pellet can improve the ITB.

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SYNCHROTRON RADIATION INTENSITY AND ENERGY OF RUNAWAY ELECTRONS IN EAST TOKAMAK

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A detailed analysis of the synchrotron radiation intensity and energy of runaway electrons are presented for EAST. In order to make the energy of the calculated runaway electrons more accurate, we take the shafranov shift into account. The results of the analysis show that the synchrotron radiation intensity and energy of runaway electrons did not reach the maximum at the same time. The energy of runaway electrons reached the maximum value first, and then the synchrotron radiation intensity of the runaway electrons reached the maximum. We also analyze the runaway electrons density, and it shows the density of runaway electrons continuously increased. For this reason, although the energy of the runaway electrons drops but the synchrotron radiation intensity of the runaway electrons will continue to rise for a while.

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RECENT RUNAWAY ELECTRON INVESTIGATIONS IN EAST TOKAMAK

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The runaway electrons produced during spontaneous disruptions were studied when lower hybrid wave heating was used in the EAST tokamak. Up to 60 % of the pre-disruptive plasma current can be transferred to runaway current in the disruptions when seed fast electrons exist in the plasma. The evolutions of the radial profile of the electric field and the runaway electron density are obtained with the aid of an one-dimensional self-consistent simulation model. The results clearly show the competition between the radial diffusion of the induced electric field and growth of the runaway current. Also, the full expression of runaway electron radiation in a tokamak is calculated accurately without any additional simplifications. It is analyzed how radiation spectra and total radiation power of runaway electrons in Tokamak can be analyzed correctly and efficiently.

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TRANSPORT BARRIER RELATION WITH POLOIDAL MAGNETIC FIELD IN DAMAVAND TOKAMAK

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Experimental measurements of poloidal magnetic field Bp, with elliptical cross section of Damavand Tokamak were carried out. This cross section is divided in to four regions labeled 1 to 4. Our results showed that the values of Bpin region 3 are greater than other regions. Overlapping of magnetic Islands in region 3 is pronounced and the width of magnetic islands in this region is smaller than other regions. The thickness of transport barrier is not uniform around all circumference of the barrier transport layer. The turbulence effects can modify the transport barrier.

DESIGN OF LIQUID METAL TEST DIVERTOR IN TOKAMAK COMPASS

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Soid metal plasma-facing components in divertors of thermonuclear reactors will marginally survive in ITER, whilst new approaches are required for the more powerful DEMOnstration power plant. We therefore install in tokamak COMPASS divertor a test target based on liquid lithium/tin. We will exposed it to ITER-relevant surface heat flux (20 MW/m^2). Based on precisely measured heat fluxes, our simulations predict its easy survival, the surface temperature rises up to 800 °C within 120 ms of the standard ELMy H-mode heat flux with ELM filaments reaching hundreds MW/m^2. Consequent strong lithium vaporization will be the major operational limit, observed by spectroscopy, fast visible and infrared cameras. The scientific program will focus on operational issues (redeposition of the evaporated metal, ejection of droplets, fast enough liquid refill) as well as on the effect on the plasma physics (improvement of plasma confinement, L-H power threshold).

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EXPLOSIVE CURRENT SOURCE FOR POWER SUPPLY OF PULSED PLASMA INJECTORS

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In the report the results of calculations and laboratory experiments of explosive current sources (ECS) working on the plasma load are presented. The plasma injectors are characterized by the presence of a nonlinear dependence of their impedance on the current in them. The keeping a large amplitude current in a regime with continually increasing load inductance requires a current source with growing power. In this paper, ECS with special devices of current pulse formation was proposed to be used as such a source. The obtained design of the ECS allowed to regulate the shape of the final current pulse in the load and to provide the matching of the current source with a specific non-linear load. The source has been successfully tested in experiments with pulsed plasma injectors of two types: with one plasma injector and with two connected in parallel. The energy supplied to the load in one pulse was reached 0.5 MJ, the current was up to 3.5 MA.

ON THE POSSIBILITY OF MODIFYING THE PLASMA DENSITY PROFILE IN THE PF DEVICE DURING RADIAL COMPRESSION USING LASER ABLATION

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There are two aspects on initial working gas pressure in the PF. The first is related to the formation of plasma sheath, which usually occurs for low gas pressures in the PF chamber. Next, for higher initial pressures, is associated with the discharge dynamics and good pinching at the final stage of PF. In practice, the effect of pressure increase on the PF dynamics is limited. After exceeding a certain pressure value a noticeable deterioration in operating conditions of the PF occurs.One of the ways to improve the operating conditions of the PF is the axial injection of the gas stream into the focus area while maintaining the low initial gas pressure in the vacuum chamber. Commonly, a gas is injected, through the electrodynamic valve.
In this work, instead of gas injection, we present the possibility of modifying the plasma density profile in the PF by means laser ablation. The purpose of this work is to estimate the density compression ratio versus laser energy used to ablation.

INITIAL STAGE OF THE DISCHARGE INITIATED BY RUNAWAY ELECTRONS IN DENSE GASES UNDER HIGH OVERVOLTAGES

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Results of investigation on the initial stage of the runaway electron preionized gas discharge allowing creation of non-equilibrium low temperature plasma in the gaps under high pressure are presented. The studies were carried out with the optical and high-speed photo shooting techniques in a wide range of conditions: design and material of electrodes, kind and pressure of gases, gap widths, and voltage pulse characteristics. It has been shown that breakdown of strongly overvoltaged gaps at voltage growth rate of 10^{12} to 10^{14} V/s occurs in the form of an ionization wave starting from the potential electrode. Its speed is ranged from 10^{8} to 10^{10} cm/s and depends on the shape of electrodes and gas pressures. It was established that in a in a "tip-plane" gap a ball-shaped streamer is formed during the prebreakdown stage. A mechanism of development of such streamer is proposed. Results of simulations of the breakdown phase for a number of conditions are demonstrated.

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OSCILLATING IONS AND PULSATING DD NEUTRON YIELD UNDER INERTIAL ELECTROSTATIC CONFINEMENT AT MINIATURE VACUUM DISCHARGE

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Earlier, the yield of DD neutrons in a compact scheme of inertial electrostatic confinement (IEC) (Miley G and Murali S K 2014 Inertial Electrostatic Confinement (IEC) Fusion (Springer, New York)) based on nanosecond vacuum discharge (NVD) of low energy with deuterated Pd anode have been observed (Yu.K. Kurilenkov, V.P. Tarakanov, M. Skowronek et al. 2009 J. Phys. A: Math.Theor. 42 214041). The goal of this work is to present and discuss in detail the available experimental results on deuteron oscillations in the field of virtual cathode in NVD followed by pulsating DD neutron yield. PIC simulations for some experimental regimes of pulsating neutron yield are shown, and comparison with available scheme of periodical oscillating plasmas spheres (POPS) suggested earlier in Los Alamos for fusion at ICF scheme in Yu. K. Kurilenkov, V.P. Tarakanov, M. Skowronek et al. 2009 J. Phys. A: Math.Theor. 42 214041 is given. The requirements needed to achieve a positive energy output for IEC scheme with oscillating ions (analogue of Lawson criterion for breakeven) are discussed also.

This research has been supported by the grant No. 14-50-00124 of the Russian Science Foundation.

ANISOTROPY OF NEUTRON EMISSION IN DEUTERIUM Z-PINCH EXPERIMENTS ON GIT-12 GENERATOR AT CURRENT OF 3 MA

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The terawatt-class GIT-12 generator is used to drive a deuterium gas-puff z-pinch with outer plasma shell in order to study the mechanisms of deuteron acceleration and neutron production. In these experiments, a stagnation of z-pinch implosion occurs at a time of about 700 ns, when the generator current achieves approximately 3 MA. After disruption of the z-pinch by instabilities, the hydrogen ions are accelerated up to energies of 40 MeV. By collisions of the accelerated deuterons, a pulse of more than 10^{12} neutrons is generated. Duration of the pulse is of about 20 ns and neutron energies achieve up to 20 MeV in the radial direction. Due to the high deuteron energies, 20 % of the total neutron yield could be produced by non-DD reactions of deuterons with materials inside the vacuum chamber, especially stainless steel and aluminum alloy. The high deuteron energies and non-DD reactions cause a relatively anisotropic neutron emission which is measured using indium activation samples.

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PRODUCTION OF MEV IONS ON HIGH-INDUCTANCE PULSED POWER GENERATOR WITH DRIVER VOLTAGE OF 600 KV

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The Hawk pulsed power generator (NRL, Washington DC) was used to study of charged particle acceleration in z-pinch experiments. The Hawk high-inductance (607 nH) device based on Marx generator with an output voltage of 600 kV and electrical stored energy of 220 kJ can initiate a z-pinch discharge with a peak current of 0.6 MA after an implosion time of 1.2 µs. Radial deuterium plasma injection by 3 Marshall guns and an axial deuterium gas-puff injection were chosen as a load. The consequence of a final stage of z-pinch implosion was a production of intense pulses of hard X-rays, fast ions, and fast neutrons. The energy of observed hydrogen ions reached several MeV, which was proven by in-chamber ion diagnostics (GAFCHROMIC HD-V2 films and CR-39 track detectors) and by neutron time-of-flight detectors in axial and radial directions. These results are in good correlation with results from different experiments (e.g., on GIT-12 in Tomsk).

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STUDY OF MAGNETIC FIELDS AND MEV HYDROGEN IONS IN Z-PINCH PLASMAS VIA ION DEFLECTOMETRY

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Our research is focused on deuterium gas-puff Z-pinch experiments on 3 MA pulsed power generator. In these experiments, > 30 MeV hydrogen ions were detected. Using pin-hole detectors, coaxial rings were observed. In order to elucidate origin of the observed rings, the ion deflectometry was used. The ion deflectometry allows mapping magnetic fields in high density and high temperature plasmas. To evaluate trajectories of deflected ions, a simple numerical code was developed. By comparing the experimental results with simulations, an influence of effects of magnetic field and ion beam divergence on formation of rings was investigated. In addition, the spatial distribution of ion source, ion beam divergence and the value of $B_{\eta Z}$ parameter were estimated.

This research has been supported by the Grant Agency of the Czech Republic (Grant No. 16-07036S), the Czech Ministry of Education (Grant Nos. LTT17015 and LTAUSA17084) and the CTU in Prague (Grant No. SGS 16/223/OHK3/3T/13).

LOW TEMPERATURE PLASMAS INDUCED IN ATOMIC AND MOLECULAR GASES USING INTENSE EUV PULSES

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In this work investigations of EUV induced low temperature plasmas were performed. The sources were based on two different laser systems with pulse energies ranging from 0.8 J to 10 J and pulse duration 4 ns to 10 ns. Experimental arrangements were equipped with EUV collectors for focusing of the radiation onto the gas to be ionized. Ellipsoidal or paraboloidal collectors were also used in EUV detection systems. An auxilary gas puff valve was used for pulse injection of a gas to be ionized, into the focus region. The plasma was investigated mainly by spectral measurements in EUV, UV and VIS ranges. The spectra contained emission lines corresponding to transitions in atoms, molecules and ions. For analysis of the EUV spectra numerical simulations were performed, using a collisional-radiative PrismSPECT code. For computer simulations of the molecular spectra a LIFBASE and Specair codes were employed. The electron density was estimated based on Stark broadening.

This research has been supported by the National Science Centre, Poland, grant agreement no. UMO-2016/21/B/ST7/02225.

NANOSECOND PULSE DBD WITH ELECTROLYTE ELECTRODE IN AIR

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Nanosecond pulse DBD was produced in a plane-parallel electrode asymmetrical arrangement in atmospheric air when applying positive rectangular voltage pulses with $\mathrm{d}V/\mathrm{d}t \approx 1\,\mathrm{kV/ns}$ from a home-made generator (Shershunova E., Malashin M., Moshkunov S., Khomich V., Acta Polytechnica 55 (2015) 59-63) to the discharge gap. The discharge was initiated between a high-voltage metal electrode covered by a textolite and an electrolyte electrode of 0.9 % NaCl isotonic solution. The Q-V curves and brightness distributions (Malashin M.V., Moshkunov S.I., Khomich V.Y., Shershunova E.A., Technical Physics Letters 41 (2015) 436-438) of the discharge were obtained at frequencies up to 1 kHz. According to the analysis of the data it was found that the glow was rather uniform at these pulse repetition rates. There was no significant heating of the liquid, either. So, we can suppose that the plasma source can be successfully used in biological and medical purposes.

This research has been supported by the Russian foundation for basic research (N. 16-08-01037).

OPTICAL EMISSION DIAGNOSTICS OF A GLOW DISCHARGE PLASMA: TRANSITION RATE DIAGRAMS AND SELECTIVE EXCITATION PROCESSES

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A recently introduced formalism of transition rate (TR) diagrams, Ref. (Z. Weiss et al., Spectrochim. Acta B 110 (2015) 79-90), evaluates relative radiative population- and depopulation rates of individual states of an atom or ion as a function of their energy, based on emission spectrum of the plasma under study. TR diagrams provide information about cascade excitation and resonant collisional processes, such as asymmetric charge transfer between ions of the discharge gas and atoms of other elements present. They are well suited for a description of non-equilibrium plasmas with low electron number densities, in which relative level populations established by Boltzmann plots cannot be interpreted in terms of an excitation energy. TR diagrams of some elements in a Grimm-type analytical glow discharge will be presented and discussed, as well as relevant excitation processes taking place.

2D HIGH-RESOLUTION MEASUREMENT OF E/N TEMPORAL EVOLUTION OF COPLANAR HELIUM DBD

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The precise 2D resolved data on spatio-temporal evolution of electric field are essential for understanding the uncharted dynamics of electron driven processes, such as during the formation of surface barrier discharge with coplanar electrodes configuration. The method of local E/N evaluation from the ratio of helium atomic lines intensities (S. S. Ivkovic et al, J. Phys. D: Appl. Phys. 47, 055204 (2014)) was adopted into the novel spectroscopic technique enabling fast, highly spatially resolved 2D imaging of the electric field temporal evolution. The technique was based on the employing of the ICCD camera to monitor simultaneously the discharge space via a pair of interference filters. This resulted in a synchronized, phase resolved 2D imaging of He atomic line intensities development. Achieved spatio-temporal resolution was 50 ns, resp. $25 \times 25\ \mu m^2$. Measurements revealed the anode/cathode directed wave fronts of high electric field peaking approx. 40 kV/cm.

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NON-EQUILIBRIUM, LOW-TEMPERATURE, LOW-PRESSURE RF PLASMA INTERACTION WITH THE SURFACE OF SOLIDS

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The surface roughness has a huge effect on the mechanical, optical and electronic properties of materials. In modern optical systems, the specifications for the surface accuracy and smoothness of substrates are becoming even more stringent. Commercially available pre-polished glass-ceramic substrates were treated with the radio frequency (RF) (13.56 MHz) low-pressure plasma to clean the surface of the samples and decrease the roughness. Optical emission spectroscopy was used to investigate the plasma stream parameters and phase-shifted interferometry to investigate the surface of the specimen. In this work, the dependence of RF Inductively coupled plasma (ICP) on macroscopic parameters were investigated with the focus on improving the surfaces. Ion energy, sputtering rate and homogeneity were investigated. The improvements of the glass-ceramic surfaces from 2.6 to 2.2 Å root mean square by removing the "waste" after the previous operations had been achieved.

ELECTRON DENSITY STUDY IN A LOW TEMPERATURE ATMOSPHERIC PRESSURE RADIO-FREQUENCY HELIUM PLASMA

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Electron density in an atmospheric pressure 3 cm wide plasma source sustained by radio frequency in planar geometry is investigated using Stark broadening of H_β spectral line. Line profile analysis is used to estimate a key parameter of the discharge-electron density. Different line profile broadenings are taken into account, including Doppler broadening, Van der Waals and Stark broadening in the profile fitting procedure. A fitting method for electron density determination is applied that considers the fine structure components. Electron density obtained by the fitting procedure is around $8.3 \times 10^{19}\,\mathrm{m}^{-3}$.

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PROBING OF QUANTUM STATES OF OH RADICAL IN SURFACE STREAMER DISCHARGES GENERATED FROM ARGON/WATER/DIELECTRICS INTERFACE

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Despite popular belief that rotational and vibrational temperatures directly describe real properties of plasma, it is not always the case. To understand the non-equilibrium of rotational-vibrational state distribution from spectra without limiting presumptions, a state-by-state temperature-independent fitting procedure is necessary. This way, challenging case of OH spectra in surface streamer discharges generated from argon/water/dielectrics interface was studied. Analysis shows that excited OH(A) rotational states not only follow two-Boltzmann distribution but are locally overpopulated due to the V-R isoenergetic transfer.
To test the equilibrium in the ground state OH(X), its rotational levels were probed by laser-induced fluorescence. This yielded unrealistically high rotational temperature above 600 K in the post-discharge phase. Both results challenge the usual approach in kinetic models, where boltzmannian rotational distribution is assumed with the temperature of the gas.

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FLOATING HARMONIC PROBE DIAGNOSTICS IN DC CONTINUOUS AND PULSED REGIMES

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Floating harmonic probe (FHP)represents a relatively novel probe method for measurement of the electron temperature and positive ion density in processing plasmas, where the probe tip gets coated by an insulating layer and conventional Langmuir probe method in many cases fails. In the FHP method an ac harmonic voltage in the kHz range is applied to the probe constructed in standard manner and hence microwave instrumentation is not needed. Recently, this concept has been applied to pulsed discharges and utilized also in double probe method. We have tested the FHP method in both continuous and pulsed dc discharges in a low-pressure hollow cathode plasma jet and planar magnetron systems during both reactive and non-reactive sputtering and compared it, when possible, with conventional IV characteristics measurements. We got a good agreement of both the electron temperature and ion density data and FHP measured reliable data even when conventional Langmuir probe could not be used.

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TOMOGRAPHIC INVESTIGATION OF MICROWAVE INDUCED COMPACT MULTICUSP PLASMA

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A microwave induced compact plasma has wide variety of applications such as material processing and generation of high current ion beams. The main requirement of non-invasive plasma diagnostics is to understand the physical processes involved in wave absorption through plasmas and real time control of plasma parameters. An optical emission tomography set-up for compact plasma system has been developed. The experimentally obtained 2D plasma emission profiles show that the plasma emissions are generated in circular ring shapes. There are usually two bright rings, one at the core and another near the boundary of plasma cross section. In addition, a numerical code has been developed that solves Maxwell equations inside a waveguide. 2D electric field profiles reproduces the dark and bright circular rings as seen in the experiments. These patterns inside the plasma are combination of different Bessel modes (TE11and TE21modes) of the wave electric field.

STUDY OF THE TURBULENCE IN MAGNETISED PLASMAS USING PHOTOMULTIPLUIER TUBES

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We discuss an application of the use of photomultiplier tubes to study turbulence in magnetised plasmas. We present experimental results obtained in the simply magnetised toroidal device Thorello. The method was applied to measure characteristics of the turbulent state in the device. In particular the frequency distribution function of fluctuations in the emission light intensity of a hydrogen magnetised plasma was measured and the time series were analysed in order to extract the Hurst exponent. A comparison with traditional electrostatic diagnostics was performed too.

CALCULATION OF OPTICAL DEPTH BASED ON ELECTRON CYCLOTRON EMISSION IN IR-T1 TOKAMAK PLASMAS

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The electron cyclotron emission (ECE) was investigated in IR-T1 tokomak. According to the electron temperature plasma and its direct relationship with the absorption coefficient, the absorption conditions were discussed for both first and second harmonic ordinary and extraordinary modes and electron cyclotron radiation was calculated. The theory of electron cyclotron emission and absorption coefficient were considered as non-relativistic effects in low plasma temperature. By examining the area of absorption in condition $w_p > w_c$, the profile of optical depth in perpendicular emission$q = p/2$ and the equatorial plane torus were calculated and the maximum value of optical depth $t = 1.38$ was obtained for IR-T1 tokamak. These results show that the values of optical depth have a direct relationship with electron density and electron temperature plasma mostly in second harmonic extraordinary mode.

SPECTROMETRIC PROPERTIES OF DIAMOND DETECTORS FOR THE RADIAL NEUTRON CAMERA OF ITER

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Fusion facilities like the ITER tokamak require new diagnostic techniques for measurements of the 2.5 MeV and 14 MeV neutron energy spectra. The Radial Neutron Camera (RNC) diagnostics will measure the time-resolved neutron emission profile for the DT and DD plasmas, providing the evaluation of the fusion power density, neutron emissivity profile, fusion power and total neutron flux, and many others. Diamond detectors planned for the RNC diagnostics will be installed in the In-Port RNC system. The subsystem shall withstand the Vacuum Vessel baking temperature of 240 °C and will operate at the ambient temperature of 100 °C. Recent effects of the experimental work on a spectrometric response of diamond detectors according to the In-Port conditions show excellent results. After four months long experimental session, the CVD diamond detectors passed the exam showing outstanding spectrometric properties important for plasma diagnostic systems.

This research has been supported by the F4E, FPA-327- SG05 activity dedicated to estimate thermal resistance of diamond detectors assumed to work in the In-Port of ITER Radial Neutron Camera (RNC).

POWER NEUTRAL BEAM INJECTOR WITH TUNABLE PARTICLES ENERGY - FIRST TESTS

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High-power neutral beams are widely used for plasma heating in fusion research (E. Hintz and B. Schweer, Plasma Phys. Controlled Fusion 37, A87, 1995). A high captured beam current can provide a stable plasma configuration in systems with a reversed field (M. W. Binderbauer et. al. Physics of Plasmas 22, 056110, 2015; P. Deichuli et. al. Rev. of Sci. Instrum. 86, 113509, 2015). The ion source with tunable voltage is not so difficult if the current changes synchronously to preserve the perveance. The beam power can reduces by tens of times, which is not always acceptable in experiments.
This report describes the ion source with a tunable voltage at a constant current of the IOS. This requires the complication of the IOS and changing the scenario of the power supply system. The beam energy changes from 15 to 40 keV at current 140 A during the pulse. Several ion sources tested.

RADIAL ELECTRIC FIELD AND REYNOLDS STRESS PROFILES MEASURED WITH LANGMUIR AND BALL-PEN PROBES ON COMPASS

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The recent observation of stationary zonal-flow-like structures on JET has motivated the search for similar structures in the radial electric field E_r profiles on COMPASS. The diagnostic used on COMPASS is a complex probe head mounted on a horizontal reciprocating manipulator which allows measurements deep in the edge plasma. This enables a direct measurement of E_r as well as the radial-poloidal component of the Reynolds stress tensor R_{rp} which can drive zonal flows. The probe head features both Langmuir and ball-pen probes which enables a correction for the effect of the electron temperature T_e on measurements of E_r and R_{rp}. The R_{rp} calculated from Langmuir probes is found to be lower than from ball-pen probes due to high-frequency T_e fluctuations. No stationary zonal-flow-like structures have been observed when the E_r well is so narrow that its radial scale is comparable to the expected radial scale of the structures.

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ROLE OF MAGNETIC PERTURBATIONS IN THE RUNAWAY ELECTRON EXPERIMENTS AT COMPASS TOKAMAK

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Feasibility of mitigation of runaway electron (RE), still presenting a serious threat to the operation of tokamak fusion reactors, has been explored on different facilities. We present a study of the effect of resonant magnetic perturbation (RMP) coils on the RE beam decay obtained during RE campaigns at COMPASS. Radial error fields were applied on the pre-disruption phases of the discharges (before the Ar or Ne impurity injection) as well as during the RE beam decay with a suppressed thermal part of plasma. The phase with the strongest impact was identified during the scan of phase shift ($n = 1$) between resulting field direction in top and bottom coil rows by both experimental data and MARS-F simulations. This phase was closely explored by testing different amplitudes of the radial error field. The influence of the error field was significantly stronger in the case of the Ne injection. This conclusion can help to understand and improve the development of RE suppression scenarios.

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DETERMINATION OF THE OPTIMAL CONFIGURATION OF A TOKAMAK-TYPE NEUTRON SOURCE FOR A TRANSMUTATION SYSTEM

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Effects of plasma physics and engineering constraints on the optimal configuration of a fusion-driven system that uses a Tokamak-type neutron source are investigated. For self-consistent determination of the configuration of the system components, a tokamak systems analysis coupled with a radiation transport calculation is used. The inboard radial build of the reactor components is obtained from plasma physics, engineering constraints and radiation shielding requirement, while outboard radial builds are mainly determined by the requirements on neutron multiplication, the tritium-breeding ratio, and the power density. The effects of a tritium-breeding blanket model and an equilibrium fuel cycle on the radial build as well as the transmutation characteristics are also investigated. It is shown that the radial build of the transmutation reactor components and the equilibrium fuel cycle play major roles in determining the transmutation characteristics.

EQUILIBRIUM DESIGN FOR THE COMPASS UPGRADE TOKAMAK

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COMPASS Upgrade (Panek et al. Fus. Eng. Des. 2017), a B = 5 T, R = 0.84 m tokamak with closed divertor, metallic plasma facing components, and up to 8 MW of total heating power and current drive, is to be constructed at the Institute of Plasma Physics of the CAS. Equilibria with various plasma shapes, created using the poloidal field (PF) coils, are calculated using free-boundary equilibrium codes, respecting the operational limits throughout a full tokamak discharge. We show that COMPASS-U will be able to operate at 5 T, 2 MA plasma current with elongation up to 1.8 and triangularity in the range of 0.4 to 0.6. The careful design of both the closed divertor and the plasma shape is essential for the plasma exhaust physics, which presents a key objective of the COMPASS Upgrade project, delivering up to the DEMO-relevant 400 MW m^{-2} of parallel heat flux density onto the divertor target plates.

A NEW MULTI LINE CUSP MAGNETIC FIELD PLASMA DEVICE (MPD) WITH VARIABLE MAGNETIC FIELD

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A new multi-line cusp configured plasma device (MPD) consisting of electromagnets with core material has been constructed with a capability to experimentally control the relative volume fractions of magnetized to unmagnetized plasma volume as well as accurate control on the gradient length scales of mean density and temperature profiles. Argon plasma has been produced using hot tungsten cathode . The radial profiles measured along the non-cusp region (in between two consecutive magnets) show a finite region with uniform and quiescent plasma, where the magnetic field is very low such that the ions are unmagnetized. Beyond that region, both plasma species are magnetized and the profiles show gradients both in temperature and density. The plasma thus produced will be used to study new and hitherto unexplored physics parameter space relevant to both laboratory multi scale plasmas as well as astrophysical plasmas.

CHARACTERIZATION OF HELIUM PLASMAS IN THE GOLEM TOKAMAK

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Investigation of Helium discharges in tokamaks is of increasing importance, because the future ITER tokamak will operate with Helium during its initial operational phase. The GOLEM tokamak can routinely achieve Helium discharges and the contribution demonstrates some it's interesting features:

* The electron temperature determined from the ratio of He spectral lines agrees reasonably with that derived from plasma conductivity.

* Turbulent fluctuations of the floating potential measured by an array of Langmuir probes propagate in the radial direction with phase velocity in the range of 1 km m^{-1}, and their correlation length is significantly higher than 10 mm.

* A strong decorrelation of turbulent fluctuations is observed in the range of radii where the radial electric field changes its orientation.

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TRANSPORT OF NITROGEN IN THE IMPURITY SEEDING EXPERIMENTS AT COMPASS

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Detachment regime is a topic of high interest in the fusion community due to its importance for safety operation of ITER. Major curiosity in detachment divertor physics is in comprehension of transport of seeded impurity and heat fluxes in SOL.

The work reported in this contribution was performed in COMPASS tokamak. Experiments with N_2 seeding in the divertor region have been accomplished with shot-to-shot variation of the amount of injected gas. Three different seeding locations were studied: at the inner target, at the outer target and in the private flux region with the objective of characterization of conditions needed for access to partially detached regime.

Conditions for power balance between radiated power in the divertor region and power of the applied auxiliary heating were discovered such that the drop of temperature and pressure at divertor were observed, while upstream profile wasn't perturbed.

This research has been supported by the the Czech Science Foundation project GA16-14228S and co-funded by MEYS, projects number 8D15001 and LM2015070. This work has also been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom under grant agreement No 633053.

MICROWAVE INTERFEROMETER ON TOKAMAK COMPASS

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The COMPASS tokamak operated at IPP Prague uses the two frequency microwave interferometer for the electron density integrated along the central vertical chord . The main feature of presented interferometer is that the plasma is probed by two waves at close frequencies (139.6 GHz and 138.9 GHz) propagating in mutually opposite directions, and the "unambiguous" interferometer measures the phase difference between these two channels. Therefore, the phase response does not suffer from fringes for the full range of COMPASS electron densities up to $15 \times 10^{19}\,\mathrm{m}^{-3}$. For the line-average electron density real-time calculation the set of coefficients was created. These coefficients correspond to possible vertical and radial plasma positions, different plasma shapes and non-linearity effects connected with refractive index of the plasma.The interferometer provides information on the line-average electron density in real-time and is used in the plasma discharge control system

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INTENSE RELATIVISTIC ELECTRON BEAM PROPAGATION THROUGH PLASMA

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In the framework of X-Ray Flash Radiography, we investigate theoretically the propagation of an intense (2 kA), pulsed (60 ns) relativistic (4 MeV) electron beam (REB) through a cold plasma. The REB electrons interact with the plasma through binary collisions and collective response, whose importance depends on the ratio of plasma over beam density. Under some conditions, the collective response induces partial or total charge and/or current neutralization of the beam, breaking the near-perfect cancellation of self-forces and leading to a noticeable modification of its propagation. We present a simple model of this phenomenon based on an axisymmetric envelope equation, as well as its application to our physical situation where the REB lasts several tens of nanoseconds. According to these calculations, a significant gain in the focusing of the REB can be achieved in a broad range of plasma density 10^{10} to $10^{13}\,\mathrm{cm}^{-3}$.

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

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The NPINCH code was used for modeling of pinching plasma driven by combination of three independent electric current circuits. The first forming line circuit is used for generation of pre-ionization current. The second slow exponentially damped sinus with I_{peak} between 20 kA and 30 kA serve as a pedestal which detach plasma from capillary wall. The third circuit creates a fast triangular pulse with a rise time about 38 ns and I_{peak} between 60 kA and 80 kA which eventually compress plasma. The purpose of this work is to find optimal electric current circuit parameters for pre-ionization and pedestal pulse to obtain the maximum possible gain at wavelength l = 13.4 nm for a wide alumina capillary 4.6 mm in radius. The pedestal circuit parameters according to simulation were chosen $I_0 = 24$ kA, $t_1 = 380$ ns, $t_2 = 10$ µs. The parameters for pulse forming line were chosen to generate 500 A plateau in 12 µs duration.

EFFICIENT GENERATION OF NE K-SHELL RADIATION IN THE MICROSECOND IMPLOSION REGIME

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Experiments with a Ne K-shell plasma radiation source have been carried out on the GIT-12 generator (4.7 MA, 1.7 µs) in the microsecond implosion regime. A novel Z-pinch load consisted of a double gas puff surrounded by a plasma shell was investigated. Two load configurations with the diameters of the plasma shell, the annular gas shell, and the central gas jet of 350/80/20 mm and 350/100/20 mm were used in the experiments. Experimental data on the Ne K-shell radiation power and yield, and the plasma implosion dynamics were obtained for the loads with different initial parameters. The new load configuration demonstrated higher efficiency of the K-shell radiation generation in the microsecond implosion regime in comparison with a triple gas puff. At the peak implosion current of 3.5 MA, the Ne K-shell yield was increased by 20-25 % and reached 14 kJ cm^{-1}. The radiation power increased more than twice, reaching 1 TW cm^{-1} in some shots.

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GENERATION AND CHARACTERIZATION OF A LOW PRESSURE DC GLOW DISCHARGE FOR BEAM PROPAGATION EXPERIMENTS

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In the context of a multi-pulse linear induction accelerator for X-Ray Flash Radiography, we are designing an experiment to investigate the propagation of a high-current relativistic pulsed electron beam (4 MeV, 2 kA, 60 ns) in plasmas. The accelerator providing the electron beam is already in service and we are working on the design of a plasma cell. We generate a DC glow discharge in a prototype (5 cm diameter glass tube, a few tens of cm long). The electron density is estimated from electrostatic probes measurements in the largest part of the discharge (i.e. the positive column), in different gases (Ar, He orN_2) and range of pressure (0.1 - 10 mBar). Although a usual theory for the interpretation of the data gives the expected order of magnitude for the electron density $\approx 10^{10}\,cm^{-3}$ the corresponding temperature is surprisingly high (up to 20 eV). We discuss this result and present alternative measurements lying on the plasma electromagnetic response in the HF band.

NEUTRON YIELD SCALING LAWS FOR PLASMA FOCUS CHAMBERS WITH DEUTERIUM AND DEUTERIUM-TRITIUM FILLINGS

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This paper describes the comparison of experimental results of mean neutron yield measurements for plasma focus devices with deuterium and deuterium-tritium fillings of plasma focus (PF) chambers. Comparison was carried in a range of discharge current amplitudes from 200 to 1000 kA. The dependence $\xi_{exp} =< Y_{DT} > / < Y_{DD} >$ for D+T and D+D reactions was obtained. With the discharge current increasing thru the PF chamber the ratio ξ_{exp} decreases from 150 to 110. Based on the beam-target neutron generation mechanism in PF, the ratio ξ_{exp} matched with the cross-section ratio of corresponding nuclear reactions σDT/σDD at different energies of accelerated ions. Experimental results of definition accelerated ions mean energy shows the value 50 - 70 keV. The hypothesis was stated that while current thru PF chamber increases there is an increase of accelerated ions mean energy in plasma beam that forms into the pinch. That causes a decrease of ratio ξ_{exp}.

INVESTIGATION OF HIGH-SPEED DENSE PLASMA BUNCHES IN A PLASMA-FOCUS DISCHARGE

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Using laser sounding, high-density fast-moving plasma bunches were registered in the 4 kJ Mather type plasma focus (PF). Experiments were performed at the TYULPAN PF- 4 facility (Lebedev Physical Institute, Moscow, Russia)(S.N. Polukhin, A.M. Dzhamankulov, A.E. Gurei, V.Ya. Nikulin, E.N. Peregudova and P.V. Silin Plasma Physics Reports, 2016, 42, 12, 1127). Parameters of the bunches: diameter about 1 mm and length of about 3 mm. The bunches are formed both in the first half-cycle of the discharge and the second after the plasma column break and propagate from the anode along the PF axis with an initial velocity of $2 \times 10\,\mathrm{cm}^7\,\mathrm{s}^{-1}$. The propagation of a bunch is accompanied by a shock wave. The two mechanisms of the plasma bunches formation are considered: axial plasma ejection during the development of Rayleigh-Taylor instability (constriction) on pinch and cumulative plasma ejection when the current-plasma envelope is compressed on the axis of the PF unit.

This research has been supported by the Russian Science Foundation (project No. 16-12-10351).

OPTIMIZATION OF THE EXCITATION CURRENT PULSE OF CAPILLARY Z-PINCH PLASMA WAVEGUIDE BY USING DIFFERENT GASES

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The ability of the capillary discharge plasma column to waveguide high intensity laser pulses is widely used in laser driven plasma wakefield accelerators. In the absence of such single mode guiding channel, the interaction length is basically limited by diffraction to distance of order of the Rayleigh-range. According to one-dimensional MHD model simulations of the capillary Z-pinch plasma, under appropriate initial parameters a transient pure plasma waveguide channel can be evolved.
Our study is aimed to find the optimal excitation current pulse for generating a single mode Z-pinch guiding channel by using different gases. For that, the waveguide properties of the Z-pinch plasma were theoretically investigated inside a 3 mm inner diameter and 200 mm long hydrogen, neon and krypton-gas filled capillary channel. For irradiation a $\mathrm{TEM}_0 0$ mode CO_2 laser pulses was used with FWHM of 1 ps. Intensity of the laser was set to value to reach the high enough contrast compared to plasma radiation.

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FILAMENTATION OF CURRENT SHEATH OF PLASMA FOCUS

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The results of current filaments investigations (analytical and numerical) in the plasma model with London current are presented (Nikulin V.Ya., Startsev S.A., and Tsybenko S.P., Bulletin of the Lebedev Physics Institute, 2015, 42, 133; Nikulin V.Ya., Startsev S.A., and Tsybenko S.P., Bulletin of the Lebedev Physics Institute, 2016, 43, 345; Nikulin V.Ya., Startsev S.A., and Tsybenko S.P., IOP Conf. Series: Journal of Physics: Conf. Series 907 (2017) 012024.).Within the framework of this model, the mechanism of filament generation associated with the corrugation instability of rarefaction shock waves is considered. In addition, the criterion of optimal filamentation of the current sheath is proposed in the work, the fulfillment of which will, in our opinion, improve the reproducibility of the radiative characteristics of the plasma focus, and also increase their intensity.

IMPULSE TRANSFORMER FOR LOW-CURRENT CAPILLARY Z-PINCH AR^{+8} LASERS AND WAVEGUIDES

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It is known that capillary discharge X-ray lasers and waveguides do require fast (100 - 200 ns period) pumping pulses with high (5-50 kA) current amplitude. These pulses are usually produced by Marx-generators in a C-C charge-transfer scheme. Pulses with such parameters have been produced by using an impulse transformer in Ar^{+8} ($\lambda = 46.9$ nm) capillary lasers (Y. Hayashi et al. Plasma Sources Sci. Technol.15:675, 2004). These systems are hybrid ones because they utilize impulse transformer. Our aim is to develop a compact, low current pumping system based on an impulse transformer without using Marx-generator. The system was designed to produce pulses with 9 kA amplitude and 100 ns half period. This study describes results of the development and experimental investigation of the pumping scheme based on 1:4 autostep-up impulse transformer. With this system we achieved 7 kA current amplitude with half period 100 ns.

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COLLECTIVE ACCELERATION OF LASER PLASMA IN A NONSTATIONARY AND NONUNIFORM MAGNETIC FIELD

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This paper presents the new experimental results concerning acceleration of deuterium ions extracted from laser plasma in the rapid-growing nonuniform magnetic field in order to initiate the nuclear reactions $D(d,n)^3$ He and $T(d,n)^4$ He. In order to obtain plasma a laser that generates in Q-switched mode the pulses of infrared radiation ($\lambda = 1.06$ µm) with the energy $W < 0.85$ J and duration of ≈ 10 ns. In the present study, the velocity of a bunch of a laser plasma at a magnetic field induction rate of 3×10^8 T s^{-1} was experimentally measured, and angular distributions of accelerated particle fluxes were measured in the range from 0 to 30 degrees. The proposed system allows the generation of neutrons, including possibly thermonuclear ones, on counterflows using two similar magnetic accelerators located coaxially, facing each other. In this case the problem related to degradation of solid neutron-generating targets is resolved.

PLASMA CHARACTERIZATION AND ELEMENTAL COMPOSITION OF DIFFERENT PARTS OF RICE PLANT USING CALIBRATION FREE LASER INDUCED BREAKDOWN SPECTROSCOPY

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Food is the main source for human diet and health which provides very essential and necessary elements. These elements may be toxic or beneficent depends upon their concentration level and type. So measurement and detection of their level in food is very crucial for health and safety. In the present study we have applied Laser Induce Breakdown Spectroscopy to determine the elemental composition of different parts (Root, Stem and Seed) of rice plant and determined their weighted concentration using CF-LIBS technique. TheCa, Fe, and K are identified as major elements while Ti, Mg, Si, Li, Ba, Sr , Cr, Na and Al as minor elements. H-alpha line of hydrogen has also identified.The electron number density has determined using Stark broadened line profiles of H_α and Ca line respectively and investigated the behavior of electron density as function of laser energy, laser wavelength and the detector position.

SPECTRAL STRUCTURE OF RELATIVISTIC HIGH-ORDER HARMONICS DRIVEN BY OSCILLATORY FLYING MIRROR

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Relativistic high-order harmonic generation from solid targets is one of the most promising candidates for producing a bright attosecond light source in the keV regime. Here we present the spectral structure of relativistic high-order harmonics (RHOH) driven by multiple oscillatory flying mirrors (OFM) in a long underdense plasma. The laser field reflected by oscillatory flying electron nano-sheets produces half-integer harmonics as well as integer harmonics. As the harmonic order goes to higher, due to the doppler effect, the spectral shift is observed for both harmonics. The strong harmonic signal is transferred from integer to half-integer harmonics and repeated at higher-order harmonics. Finally, this transition forms the spectral modulation of RHOH spectrum due to the multiple OFM.

INVESTIGATION OF THE GENERATION AND ATTENUATION OF SHOCK WAVES GENERATED BY PICOSECOND LASER PULSE IN METALS

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The results of experimental and theoretical studies of the shock wave propagation characteristics generated by a 70 ps laser pulse in metals (Al, Pd, Pb, W, Ta, Mo) are presented. Numerical simulation performed using the generated code for schema Courant-Isakson Rice on the basis of equations of hydrodynamics, complemented by wide-range semi-empirical equations of state of investigated materials. A simple analytical model is proposed, which allows to obtain approximation formulas for approximate calculation of the shock wave characteristics in a solid substance in the pressure range up to 20 TPA. Calculations show that, starting from a distance of 2 μm, a shock wave is formed. After that, the attenuation of the shock wave amplitude for all metals is of the power character described by the formula $P(x)/P_0 = x_b$. The mean value of the coefficient b for all metals is -0.735 ± 0.05.The experiments were performed on a picosecond laser installation "Kamerton-T" (GPI RAS).

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EFFECT OF RIPPLE ON SELF-FOCUSING AND EXCITATION OF PLASMA WAVE OF HOLLOW GAUSSIAN BEAM

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An investigation on the propagation of hollow Gaussian beam (HGB) in the presence of ripples superimposing over the beam in collisionless plasma considering the relativistic nonlinearity is presented. The sets of equations governing self-focusing of beam and plasma wave excitation having ripples are derived using Wentzel Kramers Brillouin (WKB) paraxial ray approximation and eikonal method. It is found that the presence of ripple over the beam affects the propagation of HGB when the critical power for self-focusing of HGB is smaller than the initial power of ripple. The excitation of electron plasma wave (EPW) in the presence of rippled HGB has also been studied, and the effect of ripple on the power of excited plasma wave has been calculated analytically and numerically. The derivation of critical power for self-focusing has solved and the ratio of critical power for self-focusing in absence and presence of ripple is calculated.

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CONTROLLED GENERATION OF XUV PULSES VIA RELATIVISTIC FLYING MIRRORS

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Compact sources of coherent radiation in the XUV range of photon energies are of great demand for various applications. A method for controlled generation of XUV pulses with tunable parameters based on the reflection from thin dense electron layers traveling with velocities close to the speed of light (relativistic flying mirrors) is proposed. Due to the double Doppler effect, the reflected wave is compressed, amplified and its frequency is up-shifted. Various schemes described in theoretical and experimental studies have proven the feasibility of the concept.
In our case, relativistic flying mirrors of sufficiently high quality are realized using non-linear Langmuir waves which are generated by short intense laser pulses in underdense plasmas. Adjusting the properties of the target and the counter-propagating laser beam allows one to control the output parameters of the reflected light. The generation of a train of few-cycle XUV pulses is demonstrated using PIC simulations.

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CHARACTERISTIC OF HOLLOW CATHODE DISCHARGE PECVD AND ITS UTILITY FOR BARRIER COATING ON POLYMER FOIL

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This work addresses on the novel design and control of plasma processes using multi hole hollow cathode discharge (MHHCD) for synthesis of SiN_x barrier films on polymer substrate. For the continuous operation of the device dedicated flexible thin film encapsulations are required, which is a foremost challenge. Many efforts have been done for the plasma assisted deposition process control for the optimization of barrier film properties. A large part of our efforts is devoted to the detailed study of the process parameters controlling the plasma treatment. Detailed characterization of the deposition process is systematically performed using numerous plasma diagnostic tools to know the qualitative information of plasma chemistry. High transparent ($\sim 90\%$) SiN_x barrier thin films with WVTR $10^{-2} \approx 10^{-4}\,\mathrm{g\,cm^{-2}\,day^{-1}}$ have been deposited by low-temperature PECVD using plasma and stress control by advanced MHHCD.

MECHANISM OF THE THERMAL CONDUCTIVITY EFFECT ON AN INSTABILITY ARC PHENOMENA IN LOW CURRENT VACUUM ARC

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To analyze the thermal conductivity effect on the stability arc, the cathode spot model is used. Analysis of stable arc current is performed by changing thermal conductivity of Silver by the compound material. It was found that the minimum stability arc is inversely proportioning to the thermal conductivity. The low thermal conductivity has an important role in a more stable arc than high thermal conductivity cathode material. These phenomena are related significantly to the T-F emission and the thermionic emission process. It can be concluded that the electron in the arc is reduced by lower cathode temperature. These results were similar to obtained data, indicating that this analysis by the cathode spot model of the present analysis which is used to investigate the thermal conductivity effect in low-current vacuum arc may be valid for volatile materials.

SILICON IN SPECTROSCOPIC DATA OF WORLD DATABASES

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This article deals with comparison of three world spectroscopic databases: NIST, Kurucz and Atomic Line List. Our target was to calculate the differences in input data and the ratio of Stark broadening and function F which depends on electron density, temperature and pressure. Stark broadening is one of pressure broadenings of spectral lines which arise from the collisions of the emitters with neighboring particles. Stark broadening is due to charged perturbers. We developed the program NKrov to be able to compare data in databases. There were some differences in the database format and content. Our results could be used in science and technology.

ELECTRON DENSITY MEASUREMENT IN SPACE PLASMAS BY RELAXATION SOUNDING TECHNIQUE ON BOARD THE FOUR CLUSTER2 SATELLITES: WHISPER INSTRUMENT

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The Wave of High frequency and Sounder for Probing of Electron density by Relaxation (WHISPER) performs the measurement of the electron density on the four satellites of the CLUSTER2 mission. The two main purposes of the WHISPER experiment are to record the natural waves and to make a diagnostic of the electron density using the sounding technique, the various working modes and the fourier transforms calculated on board provide a good frequency resolution obtained in the bandwidth 2 - 80 kHz. We focus our attention to the active mode when WHISPER is working as sounder. Cluster2 orbits cross various plasmas with a weak or a strong magnetic field like solar wind and plasmasphere. Spectra exhibit numerous resonances where it is difficult to recognize the plasma frequency .We shall show the features in each region and we shall describe the methods to identify observed resonances as electron gyro frequency and harmonics, plasma frequency, upper-hybrid frequency and Bernstein modes.

CRYO-SA-CRDS: A NOVEL INSTRUMENT FOR STUDYING ELECTRON-ION RECOMBINATION IN TEMPERATURE RANGE OF 30 - 300 K

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A Cryogenic Stationary Afterglow apparatus with Cavity Ring-Down Spectrometer (Cryo SA-CRDS) has been designed and tested. Experimental setup covers temperature range from 30 K up to 300 K for precise study of electron-ion recombination, i.e. at conditions relevant for astrochemistry. The discharge tube made of monocrystalline sapphire passes through the microwave resonator which is attached to the second stage of the cold head. To lower the heat transfer the resonator and discharge tube are situated inside of vacuum chamber. The first tests in He/Ar/H_2 and He/H_2 gas mixtures show that the kinetic temperature of $H_3{}^+$ + ions is equal to gas temperature and can be changed from 300 K down to 30 K. Further details will be presented at the conference.

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EFFECT OF MULTI-LINE CUSP GEOMETRY ON CONFINED PLASMA PARAMETERS

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External magnetic field (MF) has been used for the plasma confinement since several decades. It has been observed experimentally that the magnetic field geometry affects the plasma parameters. Cusp magnetic field geometry has been invented for the plasma confinement as many other magnetic field configurations. It has been reported in several workd that the multi-cusp magnetic field configuration confines the primary electron, hence increases the plasma density by 2 - 3 orders of magnitude. The plasma confined in multi-cusp geometry has less than $< 1\%$ fluctuations (quite quiescent).

Multi-cusp geometry has several kinds of magnetic field profiles depending on the alignment of magnets. In this paper, the effect of different multi-cusp geometries on plasma parameters and their fluctuation properties will be reported.

ELECTRON TEMPERATURE GRADIENT (ETG) TURBULENCE INDUCED PARTICLE FLUX DUE TO FINITE ELECTROMAGNETIC FLUCTUATIONS

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In this present work electromagnetic fluctuations induced plarticle flux in finite beta ($\beta \approx 0.01$ to 0.4) plasma of Large Volume Plasma Device (LVPD), in ETG background is investigated. The e. m. particle flux (Γ_{em}) results from the correlated fluctuations between parallel currents ($\delta_{J||}$) and radial magnetic field component (δ_{Rr}). In ETG background, the electromagnetic flux is predicted to be zero but in slab plasma of LVPD, we observed a finite magnitude of it which is comparatively smaller than its electrostatic counterpart (Γ_{es}). A theoretical model is thus proposed for e. m. fluctuation induced plasma transport for slab geometry of LVPD in ETG background. We measured e. m. flux due to parallel ion and electron currents and found a close agreement between the predicted ion current induced e. m. flux with experimentally obtained values.

This research has been supported by the Homi Bhabha National Institute, Mumbai, India.

HYDROGEN FUSION WITH BORON-11 USING LASERS AT EXTREME NON-LTE IGNITION

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Laser boron fusion is based on the use of extreme deviations from local thermal equilibrium LTE by using just available high repetition ps laser pulses of more than PW power (Hora H., Eliezer S. Kirchhoff G.J, et al. 2017 Laser & Part. Beams 35, 730). This is the way to overcome the difficulties of boron fusion at thermal equilibrium that is many orders of magnitudes worse than DT fusion. Measurements of laser fusion gains above the values of DT (Picciotto A., Margarone D. et al. 2014 Phys. Rev. X4, 031030)(Hora H., Korn G., Giuffrida, L. Margarone, L. et al. 2015 Laser & Part. Beams 33, 607) could be explained by using non-LTE plus the advantages of the three- alpha avalanche multiplication (Eliezer S., Hora H., Korn G. et al. 2016 Phys. Plasmas 23, 050704) such that the design of a fusion reactor without problems of radioactive radiation for low cost electricity should be possible using achieved laser technology.

JET MILESTONE TOWARDS FUSION ENERGY

P. H. Rebut

This paper addresses the history of JET, the Tokamak that reached the highest performances with the experiment that, so far, came closest to the goal of a fusion reactor. The reader must be warned, however, that this document is not a comprehensive study of controlled thermonuclear fusion or even of JET. The fusion history is far from been finalised. The next step on the fusion road, the ITER project, is an experimental reactor. But several prototypes will still be required before a commercial reactor could be built. The problems linked to the ELM's, the divertor and the plasma purity have to be solved even for ITER. These problems will be simplified in the case of a hybrid reactor fusion-fission. JET is still in operation some 32 years after the first plasma and still has to provide answers to many questions before ITER takes the lead on fusion research. Some physics interpretations of the observed phenomena, as the magnetic topology changes, are still under discussion in order to understand the confinement. This fascinating story, comprising successes and failures, is imbedded in the complexities of twentieth and the early twenty-first centuries at a time when world globalization is increasing.
The views expressed here on plasma confinement are mainly those of the author, this is especially the case for the magnetic turbulence.

MODELING OF ITER-PROTOTYPE NEGATIVE ION SOURCE

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Neutral beam injection (NBI) system based on neutralization of negative ions is essential for sustaining plasma in controlled thermonuclear fusion reactors. Negative hydrogen and deuterium ions are often generated in a RF-inductively coupled plasma (RF-ICP) discharge. A key role in such a discharge is played by the so called magnetic filter: a magnetic field perpendicular to the plasma flow reduces the electron temperature and density towards the multi-aperture extraction system.
Results from numerical model show the non-ambipolar character of the transport in the expansion region driven by electron magnetic drifts. It induces a top-bottom asymmetry detected up to the extraction grid. As a consequence, the plasma structure is not uniform around the single aperture. Therefore, the surface-produced contribution to the negative ion extraction is not equally distributed between both the sides around the aperture but it come mainly from the lower side of the grid.

This research has been supported by the F4E under the project NBTF.

THE CHALLENGES OF TRANSFERRING PLASMA PRODUCED CHEMICAL REACTIVITY TO SOLIDS AND LIQUIDS

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Plasma chemistry may generate or convert gas species, modify solids or activate liquids. In most cases, activation energy or chemical reactivity is delivered from the plasma to a surface. This is a direct process in etching or functionalization of surfaces. This is indirect in gas phase chemical conversion where plasma-surface interactions may be important. At low pressures, delivery of reactivity is highly sophisticated, enabling monolayer control of etching and deposition, and etching of high-aspect-ratio features. At high pressure, control of chemical reactivity to surfaces is less refined due to non-linear dependencies of excitation rates and energy delivery, and the short time-scales available to control these processes. In this talk, techniques, challenges and successes in transferring plasma produced reactivity to surfaces will be discussed, with examples taken from microelectronics fabrication, plasma catalysis and plasma activation of liquids.

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PLASMA POTENTIAL FROM POSITIVE TO NEGATIVE

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Plasma potential profiles are very important in space plasmas, industrial plasmas, fusion and in all kind of plasmas. Plasma potentials structures and characteristics of plasmas were investigated in an unmagnetized DC hot filament argon discharge. Negative and positive plasma potentials were obtained in multi-dipole argon plasma. Plasma potential profiles, densities, temperatures and parameters were measured by Emissive, probe, Langmuir probe, ion acoustic wave and laser induced fluorescence. Plasma potential changed it's structure from positive to negative and dips, wells were found depending on the primary electron energies emitted from hot filaments. Experimental results and theory will be discussed.

This research has been supported by the NSF grant Collaborative Research: Understanding Sheaths and Pre-Sheaths in Magnetized and Unmagnetized Plasmas Award Number:1464741.

FROM INERTIAL FUSION ENERGY TO ACCELERATOR DRIVEN HIGH ENERGY DENSITY PHYSICS

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After a short introduction of Inertial Fusion and Inertial Fusion Energy we will discuss the development of High Energy Density Physics (HEDP) with intense heavy ion beams as a tool to induce extreme states of matter. The development of this field connects intimately to the advances in accelerator physics and technology. We will cover the generation of intense heavy ion beams starting from the ion source and follow the acceleration process and transport to the target. Intensity limitations and potential solutions to overcome these limitations are discussed. This is exemplified by discussing examples from existing machines at the Gesellschaft fÃijr Schwerionenforschung (GSI-Darmstadt), the Institute of Theoretical and Experimental Physics in Moscow (ITEP-Moscow), and the Institute of Modern Physics (IMP-Lanzhou). Facilities under construction like the FAIR facility in Darmstadt and the High Intensity Accelerator Facility (HIAF), proposed for China will be included. Developments elsewhere are covered where it seems appropriate along with a report of recent results and achievements.
High intensity particle accelerators like FAIR at GSI Darmstadt and the proposed HIAF facility in China are a new tools to induce High Energy Density states in matter. We will address a topic that has until now not been investigated in detail but is paramount to the operation of high intensity accelerators as drivers for inertial fusion or high energy density physics experiments. This is the investigation of activation processes of structural components of heavy ion accelerators due to beam loss during operation. This is a crucial issue to optimize the choice of construction materials and maintenance procedures. Significant optimization of the operation schedule can be achieved if the accumulated residual activity is properly controlled and predicted. Radiation may cause changes of the functional properties of the construction materials, which possibly leads to shortening of their lifetime. Replacing of the activated accelerator components is affected by dose-rate restrictions for the "hands-on" maintenance.

STUDY OF THE KINETIC EFFECTS IN INDIRECT-DRIVE INERTIAL CONFINEMENT FUSION HOHLRAUMS

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We present the study of kinetic effects launched in the high-Z hohlraum wall blowoff/ablator interface on SG-IIIP laser facility. In our design, solid plastic capsules were coated with carbon-deuterium layers; as the implosion neutron yield is quenched, DD fusion yield from the corona plasma provides a direct measure of the kinetic effects inside the hohlraum. Anomalous large energy spread of DD neutron signal (282 keV) and anomalous scaling of the neutron yield with the thickness of carbon-deuterium layers cannot be explained by the hydrodynamic mechanisms. Instead, these results can be attributed to kinetic shocks arisen in the hohlraum wall/ablator interpenetration region, which result in efficient acceleration of the deuterons (28.8 J, 0.45 % of the total input laser energy). The experimental results are consistent with the simulation results. These studies provide novel insight into the interactions and dynamics of vacuum hohlraum and near-vacuum hohlraum.

EXPERIMENTAL OBSERVATION OF WEAKLY TURBULENT COLLISIONLESS SHOCK CAUSED BY ION-ION ACOUSTIC INSTABILITY IN LASER-PLASMAS INTERACTION

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Studies of collisionless shock are beneficial for understanding some important astrophysics phenomena. Collisionless shocks can be classified as laminar and turbulent shocks. The laminar shocks become unstable at high Mach numbers and turn to turbulent when the instability excited by shock reflection ions is fully development. However, so far, which instability causes collisionless shock turbulence is remain unclear. Here we report experimental observation of weakly turbulent collisionless electrostatic shock in laboratory laser-plasmas by proton radiography. Collisionless shock is driven by hot laser-produced plasma expansion into pre-plasma. A 2D particle-in-cell simulation under experimental conditions is performed. Numerical results agree well with the experimental data and both of indicate that the collisionless shock decay is caused by ion-ion acoustic instability which is excited when reflection ions of collisionless shock penetrate through upstream.

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BUBBLE DYNAMICS DURING THE TRANSVERSE OPTICAL INJECTION OF ELECTRONS IN LASER WAKEFIELD ACCELERATORS

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The temporal evolution of the bubble in the nonlinear regime of laser wakefield acceleration is studied by means of numerical Particle-in-cell simulations for standard parameters feasible with current sub-100 TW laser systems. In studied case, the bubble is disturbed by another perpendicularly propagating laser pulse responsible for the injection of plasma electrons into its accelerating phase. The simulations show that longitudinal and transverse radii of the bubble evolve differently in time. In order to examine the influence of these changes on properties of accelerated electrons, the analytical model of the electric and magnetic fields inside the ellipsoidal bubble evolving in time is proposed. The equations of motion of a single electron within the bubble are integrated employing this model. It is found that the wavelength of transverse betatron oscillations of electrons dynamically changes according to changes in the size of the bubble and its ellipticity.

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ENHANCED BRILLOUIN SCATTERING IN INHOMOGENEOUS FLOWING PLASMAS

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The influence of the nonlinear kinetic frequency shift (NKFS) of ion acoustic wave on stimulated Brillouin scattering (SBS) in inhomogeneous flowing plasma is discussed by coupled-mode equations and V-M simulations. The net NKFS can become positive at a large electron-ion temperature ration ZTe/Ti, and negative at a low ZTe/Ti. So in homogeneous plasma, NKFS can greatly reduce the SBS reflectivity at low or large ZTe/Ti. In inhomogeneous plasma, the nonlinear enhancement of SBS takes places at appropriate pump intensity due to the compensation of detuning from NKFS and the flow velocity gradient. Such that in the net negative frequency shift case, the SBS system is auto-resonant if the gradient of the flowing velocity is negative and becomes anti-auto-resonant if the gradient of the flowing velocity is positive. The simulation results have been compared with the recent experiment data on SBS reflectivity obtained at the S-G III laser facility.

This research has been supported by the The National Natural Science Foundation of China Grant No. 11575035.

BEAT WAVE-PARTICLE ACCELERATION BY CROSS-FOCUSING OF TWO INTENSE ELLIPTICAL LASER BEAMS IN COLLISIONLESS PLASMA

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Plasma beat-wave accelerator scheme is one of the most mature methods for acceleration of electrons in laser-plasma interaction. In the present work, cross focusing of two intense elliptical laser beams in collisionless plasma at the difference frequency and its effect on the generation of electron plasma wave (EPW) and particle acceleration has been studied along with the combined effect of relativistic and ponderomotive nonlinearities in paraxial-ray approximation. Nonlinear differential equations have been set up for the beam width of laser beams, the power of generated EPW, and energy gain by electrons. Numerical simulations have been carried out to investigate the effect of typical laser-plasma parameters on the focusing of laser beams in plasmas and further its effect on the power of excited EPW and acceleration of electrons.

IMPACT OF COLLECTIVE EFFECTS ON PLASMA IONIZATION

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Plasma can be produced using different schemes based on ionization processes of a neutral gas. Recently, it was demonstrated that due to collective effects the ionization potential of chemical elements can be changed particularly for a dense plasmas. We investigated this characteristic for monoatom gases and found that the critical density for which these effects are significant is no 10^{13} cm^{-3}. The latter depends on atom's ionization energy. It is also found that this effect can only be observed for a certain range of density and temperature related to the first ionization potential of the chemical element.

SIMULATIONS OF SUB-CHANNEL FORMATION IN LASER-ASSISTED CAPILLARY DISCHARGES

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Capillary discharges are widely used in many experiments devoted to laser-plasma interaction as a simple tool to obtain suitable plasma. For example, state-of-the-art laser-plasma accelerators (LPA) make use of laser guiding by capillary discharge channels (W.Leemans et al. Phys. Rev. Lett. 113, 245002 (2014)). In the recent LPA experiments a relatively narrow sub-channel is formed near the capillary axis by additional laser heating. The aim is to mitigate the unwanted interaction of main laser pulse with the capillary walls and improve its guiding(N.Bobrova et al. Phys. Plasmas 20, 020703 (2013)).
Consistent numerical simulation of both discharge plasma and laser pulse dynamics is required to maintenance such experiments. The MHD code MARPLE (G.Bagdasarov et al. Phys. Plasmas 24, 053111 (2017)) was improved by taken into account additional heating due to laser radiation for this purpose. Simulation results of the laser-assisted capillary discharge will be presented.

STUDY ON THE BEHAVIOR OF THE SELF-BIASED VOLTAGE GENERATED BY THE ELECTRICAL ASYMMETRY EFFECT IN DF-CCP DISCHARGES

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Dual Frequency Capacitively Coupled Plasmas (DF-CCP) are widely used in many industrial surface processing applications. The proposal to submit plasma to a dual frequency has generated an electrical asymmetric effect, and the variation of the phase angle (θ) gave a means of control over the flux and the bombardment energy. In this work, we propose to study the behavior of the self-biased voltage due to the electrical asymmetry effect.
The input voltage is $V_{RF} = V_L \cos(2\pi f_L t + \theta) + V_H \cos(2\pi f_H t)$, where f_L= 13.56 MHz and f_H= 27.12 MHz and we propose to vary V_L and V_H, while keeping the voltage total: $V_0 = V_L + V_H = 500\,\mathrm{V}$.
Our results show that V_L and V_H voltages can play a role in the control of self-biased voltage and that it is also possible, by varying the input RF signal, i.e V_L, V_H and θ, to independently control the ion bombardment energies on each electrode.

TRANSIENT GROWTH AND ABSOLUTE INSTABILITY NEAR THE BAND EDGES IN BEAM-CIRCUIT INTERACTION

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The collective interaction of an electron beam with a periodic structure is central to the generation or amplification of coherent radiation, such as traveling wave tube. When the beam mode intersects with the forward circuit mode in the dispersion diagram, an absolute instability can exist at both lower and upper band edges where the group velocity of the structure mode approaches zero. We find that the upper band edge is more susceptible to absolute instability than the lower band edge, according to the Briggs-Bers criterion. The threshold condition for the onset of absolute instability at both band edges is derived. The Green's function shows transient temporal growths with exponentiation rate proportional to $t^{1/3}$ initially (at a fixed position), whether or not the band edge is subjected to an absolute instability. Such a transient growth rate, at a fractional power of time, is typical of the cumulative beam breakup instabilities in RF linac and induction accelerators.

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

THE INFN NUMERICAL SIMULATION TOOLS FOR MAGNETICALLY CONFINED PLASMAS

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The INFN ion source group has been undertaking an intense activity on numerical modelling, presently carried out in the framework of the PANDORA project. The aim is a self-consistent description of magnetically confined plasmas typical of Electron Cyclotron Resonance (ECR) ion sources and charge breeders, to determine spatial density and energy distributions for both electrons and ions. Calculations focus on two aspects: the interaction of an ion beam with a magnetize plasma and the microwave-plasma interaction, including electrons' dynamics inside the magnetic trap. Equations describing the particular physics cases are implemented in an ad-hoc developed 3D numerical code, including external fields and intra-particles collisions. This contribution describes the state-of-the-art of the work: it will show an overview of the beam-plasma interaction, showing the latest results about the ECR-plasma density fine structure, as well as electron spatial temperature distribution.

POTENTIAL OF FFT BASED ABEL TRANSFORMATION AND INVERSION

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Brief review of FFT based Abel Inversion is provided and its potential demonstrated on illustrative sets of data in order to prove its potential - in particular from the point of view of details which can be secured. Moreover, for the first time ever also FFT based Abel Transformation will be presented. Similar to FFT based Abel inversion a set of novel special functions was developed. This makes very easy to go the opposite way, e.g., to get back the phase shift from density. Thus having the chance to check reliability of the density obtained by the Abel Inversion from the original phase shift by performing a direct comparison of the both phase shift data sets. This feature is rather useful as quite often, in order to get decently looking densities, some artistic approach or overfiltering has been used by the researchers. And unless there is a chance to perform the above check, it is difficult to judge, how correctly that density really represents the original phase shift.

CHARACTERIZATION OF A SINGLE MICRODISCHARGE IN ATMOSPHERIC-PRESSURE AIR DIELECTRIC-BARRIER DISCHARGES

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Atmospheric-pressure air dielectric-barrier discharges (APADBDs) have been identified as one of the important plasma sources since they are employed in applications such as plasma-assisted combustion, pollution control, and flow control. It is reported the filamentary APADBDs contain many tiny microdischarges (MDs). Therefore, it is essential to understand the fundamentals of a single MD for evaluating the overall reactor performance. In this study, the ICCD is employed to unveil the structure of a single MD. The sizes of discharge column and surface ionic wave are detected, and the amount of charge transfer by a single MD is analyzed using the monitor capacitor. A plasma fluid model with air chemistry is developed to study the dynamics of a single MD. The effective width of discharge column and the effective size of surface ionic wave are evaluated and validated with ICCD measurements. Details of the characterization will be discussed in this presentation.

This research has been supported by the Ministry of Science and Technology (MOST) in Taiwan through grant 106-2221-E-194-039- and Advanced Institute of Manufacturing with High-tech Innovations (AIM-HI) in National Chung Cheng University.

EFFECT OF IMPURITY RADIATION ON THE PEDESTAL WIDTH IN ETB FORMATION BASED ON TWO-FIELD BIFURCATION CONCEPT

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The L-H transition in tokamak plasma is investigated by coupled two field transport equations based on bifurcation concept. The thermal and particle transport equations are solved simultaneously by partial differential equation solver based on finite difference method. The transport equations include both neoclassical and turbulent effects. The velocity shear which is calculated from the force balance equation is used as transport suppression mechanism and assumed to affect only on the turbulent channel in thermal and particle transport equations. The impurity radiation is applied in source term in thermal equation. The effect of impurity radiation on pedestal width and edge transport barrier (ETB) criteria can be observed from the profiles of pressure gradient and density gradient versus normalize plasma radius.

This research has been supported by the government budget of Prince of Songkla University, project ID SCI610152S.

FLUID MODELING OF FIRST PRODUCTS SPECIES BY ELECTRONIC IMPACT WITH METHANE IN CAPACITIVELY COUPLED PLASMA

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Fluid modelisation of capacitively coupled radio-frequency (RF) discharges were carried out for low pressure CH4 plasmas. The present computational includes the motions and collisions of both neutral and charged particles, and we consider 23 species in this study (i.e.23 in total; neutrals, radicals, ions, and electrons) and more than 42 reactions (electronic impact with CH4, neutral-neutral, neutral-ions and surface reactions). This model considers the motions of primaries product of electronic impact with CH4.

This research has been supported by the Laboratoire Genie Electrique et Energie Renouvelables, University of Chlef.

THE RESEARCH OF TECHNOLOGICAL PARAMETERS INFLUENCE ON THE IONS' REDISTRIBUTION IN ION-MAGNETRON SETUP

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The research deals with ions redistribution in a cylindrical chamber of ion-magneton setup. The hydrodynamic model of multicomponent partially ionized plasma was taken as the basis of model construction. The assumed simplifications allowed ignoring impact of magnetic field to the model under consideration. Therefore distributions of electrical potentials and electric field intensity in the chamber were calculated. For industrial application it is interesting to know distribution of the fields of the velocity components, pressure and concentration which were found numerically. It was shown that technological parameters lead to the quantitative and qualitative changes in the process characteristics. It should be noted that all needed process variables for numerical simulation such us angular velocity of manipulator, pressure, temperature, volume of the camera and etc. taken considering with industrial coating application units.

HYBRID SIMULATION OF THE INTENSIVE FAST ELECTRONS DOWNSTREAM IN GAS DIODE WITH PLANE-GRID CATHODE SYSTEM

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We theoretically investigate the conditions under which a runaway electron beam moves not only toward the anode, but also in the backward direction (towards to the cathode foil). The research is initiated by earlier experimental work (doi:10.1109/ceidp.2013.6748106). To compute the runaway electron beam characteristics, we apply previously proposed hybrid theoretical approach (doi: 10.1209/0295-5075/114/45001) considering the discharge in 2D-periodic configuration representing plane-grid diode in terms of two-moment "liquid" model. Then, we use obtained electric field and electron number of density distributions to solve Boltzmann equation for runaway (fast) electron component. The derived characteristics of fast electrons behind the anode/cathode foils indicate that fast electrons are generated near the wire surfaces where the electric field reaches its maximum. Hybrid modeling also predicts the possibility of runaway beam generation in backward direction.

This research has been supported by the RFBR 17-08-00932.

NUMERICAL STUDY ON CF4 DESTRUCTION VIA NITROGEN PLASMA TORCH WITH DIFFERENT INCLINATION ANGLES OF GAS INLET DESIGN

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This paper studies the destruction and removal efficiency (DRE) of CF4 with water within a direct-current, non-transferred thermal plasma torch operating with nitrogen. The gas inlet is c cterized by an inclination angle to describe the swirler geometry. The thermal plasma modeling is predicted by an in-house flow solver, where the plasma flow is assumed in a locally thermal equilibrium. The parallelized in-house code base on a finite volume discretization solves the axis-symmetric form of continuity, momentum, energy, current continuity and turbulence transport equations in a Cartesian grid arrangement. For the plasma chemistry, 29 species and 75 chemical reaction equations are considered for the reactions between CF4 and H_2O. The numerical simulation is first validated by an experiment, followed by the case studies of four different inclination angles. The plasma flow characteristics as well as the corresponding DRE is discussed for its dependence on the inclination angle.

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WATER-STEAM PLASMA TORCH WITH REGENERATIVE COOLING

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We reported on SPPT27 a water-steam transferred-arc plasma torch with an efficiency of more than 97 % without an anode. Here we report a non-transferred arc water-steam plasma torch with the same efficiency. This is achieved through the regenerative cooling of the anode by the exclusively plasma-forming water flow, similar to the combustion chambers of rocket engines, which are cooled only by the flow of liquid propellant entering the combustion chamber through the cooling jacket.

This research has been supported by the A.V.Luikov Heat and Mass Transfer Institute.

FABRICATION, CHARACTERIZATION AND IN VITRO PROPERTIES OF SILVER-DOPED BIOCERAMIC COATINGS FORMED ON TITANIUM

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An Ag thin film layer was deposited on cp-Ti by physical vapor deposition (PVD). Then, Ag-based titanium surface was coated by plasma electrolytic oxidation (PEO). The phase structure, surface morphology, elemental composition, wettability and surface topography of both coatings were characterized by XRD, SEM, EDS-mapping, contact angle goniometer and surface profilometer, respectively. XRD results indicated that anatase and rutile were detected on the surface after PEO and PVD+PEO. Both coatings' surfaces were rough and porous. Ag-based PEO coating exhibited much more hydrophilic character than PEO coating. Ag was homogeneously distributed through whole surface. The apatite-forming abilities of both coatings were evaluated after immersion in simulated body fluid (SBF) up to 28 days. The bioactivity of Ag-based PEO surface was considerably improved compared to the PEO surface. The bacterial adhesion of Ag-based PEO coatings was significantly reduced compared to plain PEO surface.

DEVELOPMENT OF NON-EQUILIBRIUM ATMOSPHERIC PRESSURE PLASMA SOURCE FOR MEDICAL APPLICATIONS

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Atmospheric pressure plasma jet (APPJ) source with helium (He) as an active gas is developed. $4.2\,\mathrm{kV_{p-p}}$, 33 kHz sinusoidal voltage is used to produce plasma jet. Helium gas with flow rates of up to 11 liters per minute is used to produce plasma plume of around 6 cm in length into the ambient air. Thorough characterization of the plume has been carried out using optical diagnostics such as emission spectra measurements, ICCD imaging and electrical discharge using voltage and current probes. Plasma discharge parameters such as electron excitation temperature and gas temperature are estimated using emission spectra and are 800 K and 305 K respectively. By estimating velocity and plume current values, the density along the length of the plasma plume has been assessed and the values are in the range of $0.05 - 3.2 \times 10^{12}\mathrm{cm^{-3}}$ at various positions of the plume length. Furthermore, the discharge ignition and plasma plume dynamics with flow rate will be presented.

PLASMA-ASSISTED DEPOSITION OF THIN ITO FILM FOR OPTICAL-FIBRE-BASED BIOSENSORS

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A seek for diagnostics of biomolecules results in the development of new strategies for highly sensitive and efficient sensors. A research of novel nanostructures for sensor design based on an optical fibre covered by a thin indium tin oxide (ITO) film is presented in this contribution. An aim was to tune the plasma discharge towards optimised electrical conductivity, optical transparency in the visible range and refractive index of ITO film - properties necessary for obtaining efficient functional material. Our effort is oriented towards tuneable ITO deposition process, which enables to achieve simultaneous electrochemical and optical (lossy-mode resonance) detection. The ITO films on the silica core of multimode optical fibres were prepared by plasma-assisted deposition employing high power impulse magnetron sputtering of ITO target. The special care was paid to optimization of the film crystallography with respect to electrical resistivity and optical transparency.

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ANTIMICROBIAL MODIFICATION OF POLYETHYLENE USING PLASMA ASSISTED GRAFTING

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Polymeric materials are often used in packaging applications providing transparency, low weight, chemical inertness and flexibility. Low-density polyethylene (LDPE) represents the most often used polymer in food packaging because of its good mechanical properties. However, its low wettability associated with hydrophobic surface is responsible for an attachment of microorganisms which can be responsible for the food contamination leading to the food spoilage. This lack can be solved by suitable surface grafting modification. In this work, the surface of LDPE was grafted by antimicrobial agent, namely ascorbic acid and fumaric acid using radio-frequency (RF) plasma. The LDPE foils were first activated by RF plasma ensuring homogeneous surface treatment and the creation of radicals. The created radials were subsequently used for the grafting of ascorbic acid and fumaric acid onto the LDPE surface. Such modified samples proved antimicrobial effect, especially against Staphylococcus aureus.

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OUTPUT CURRENT CONTROL SYSTEM OF A HIGH VOLTAGE ELECTRIC PULSE GENERATOR FOR PLASMA EXCITATION

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A control and pulse discharge current limiting system integrated into an AC/DC converter and pulse modulator of a high voltage pulse generator have been developed. The peculiarity of such system's operation is the stabilization of the power supplied to the discharge and the correction of the width of output electric pulses towards decrease upon reaching the specified pulsed current amplitude value. The system enables the pulse generator to work in the modes close to the “short circuited load” mode. In this case the driving module of a composite IGBT key performs the correction of the working pulse width and blocks the pulse generator operation if needed. The suggested circuit design solutions allow using the generator in a wide range of electric plasma-forming parameters' modes and working with various types of vacuum gas discharge systems.

PLASMA CHEMICAL REACTOR FOR LIQUID WASTE TREATMENT

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The plasma-chemical reactor with conventional air/oxygen as well as water vapor plasma torches for the treatment of liquid waste with elevated content of organic matter will be presented. The oxidation potential of a submerged plasma jet is combined with DBD discharge. The principal advantages of the reactor are: high local temperature of plasma jet and low temperature of treated liquid, which diminishes corrosion of the reactor wall; elevated quenching rate ($10^6 - 10^7$ K/s) preserves high concentration of radicals produced in discharge (O, OH, H, O_3, H_2O_2, O_3) to promote advanced oxidation processes for decontamination of aqueous effluents and suppress its recombination; high turbulence, induced by plasma jet, contribute to mass transfer from plasma to liquid; UV radiation; embedded off-gas treatment system (cooling, filtration, and neutralization). The principal working characteristics of the reactor and numerical simulation of the process will be presented.

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SIH_4 GAS FLOW RATE DEPENDENCE OF SI-H_2 BONDS DENSITY AT P/I INTERFACE OF A-SI:H LAYERED FILMS DEPOSITED BY PLASMA CVD

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One of the key issues for a-Si:H solar cells is suppression of light-induced degradation. To realize highly-stable a-Si:H solar cells against light exposure, suppressing Si-H2bond formation in films is needed. We have measured the hydrogen content ratio ISiH2/ISiH to evaluate the film quality and developed a method for suppressing Si-H2 bond formation. We found that the Si-H2 bond formation at P/I interface is suppressed at a high gas flow rate above 126 sccm and the spatial variation of film quality is smaller for the higher flow rate.

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