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Max-Planck-Institut für Plasmaphysik
Greifswald, Germany

October 16-19, 2007

Programme and Abstracts

PROGRAMME **Tuesday, October 16, 2007**

Opening			8:30
T. Klinger, *IPP-Greifswald*	Tu1-1	Physics and progress of the Wendelstein 7-X project	8:45
W. Zwingmann, *CEA Cadarache*	Tu1-2	Integrated Tokamak modelling taskforce: validation of equilibrium reconstruction	9:30
E. Belonohy, *KFKI-RMKI Budapest*	Tu1-3	Systematic study of anomalous transport events on the W7-AS stellarator	10:00
Coffee			10:15
M. Otte, *IPP-Greifswald*	Tu2-1	The WEGA stellarator: results and prospects	10:45
J. Badziak, *IPPLM Warsaw*	Tu2-2	Laser driven proton fast ignition of inertial fusion: concepts, issues and prospects	11:30
K. Jungwirth, *ASCR Prague*	Tu2-3	Highlights of the laser plasma research at PALS	12:00
Lunch			12:30
O. Grulke, *IPP + Uni Greifswald*	Tu3-1	Spatio-temporal dynamics of drift wave turbulence in a helicon discharge	14:00
M. Leconte, *Uni Marseille*	Tu3-2	Effects of an external magnetostatic perturbation on the dynamics of edge localized modes	14:45
A.N. Karpushov, *EPFL Lausanne*	Tu3-3	Ion temperature fluctuations in elmy H-mode of the X3 EC-heated plasmas of TCV	15:00
P. Manz, *Uni Stuttgart*	Tu3-4	Influence of ExB shear flows on plasma edge turbulence	15:15
M. Scholz, *IPPLM Warsaw*	Tu3-5	Fast neutron source based on Plasma-Focus device	15:30
A. Malinowska, *Soltan Inst. Otwock-Swierk*	Tu3-6	Experimental studies of fast protons originating from fusion reactions in Plasma-Focus device	15:45
Coffee			16:00
Poster	TuP	1 - 45	16:00
Tour IPP			18:00
Reception			19:00

Tu1-1

Physics and Progress of the Wendelstein 7-X Project

Thomas Klinger, Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

Wendelstein 7-X is the largest stellarator device under construction. Its key element is an optimized magnetic field configuration, generated by 50 non-planar superconducting coils. It is the mission of the project to demonstrate the reactor potential of the optimized stellarator line, the so-called HELIAS concept. In particular, stellarators can operate in steady-state, which is still difficult to achieve in nowadays tokamaks. Wendelstein 7-X aims for steady-state operation of fusion-relevant plasmas for the first time.

This talk gives an overview of the construction status of Wendelstein 7-X and outlines the future research concept. The latter is largely based on experiences obtained with the predecessor device, Wendelstein 7-AS operated until 2002. With the help of codes calculations on transport, MHD equilibrium and stability, and plasma edge different integrated discharge scenarios could be predicted for Wendelstein 7-X. Heating, plasma diagnostics and data analysis methods are designed to provide the best basis for the development of various integrated discharge scenarios. Among those, the most promising ones are selected for the development of high-power steady-state discharges.

Tu1-2

Integrated tokamak modelling taskforce: Validation of the equilibrium reconstruction from experimental data

W. Zwingmann, M. Airaj, L. Appel[1], V. Drozdov[1], L.-G. Eriksson, B. Guillerminet, G.T.A. Huysmans, F. Imbeaux, P.McCarthy[2], D.C. McDonald[1], P. Moreau, M.Romanelli[1], P. Strand[3], and the IMP-1/ISIP teams

Association Euratom-CEA, CEA/DSM/DRFC, Centre de Cadarache
13108 St-Paul-Lez-Durance, FRANCE
[1]UKAEA Euratom Fusion Association, Culham Science Centre, Abingdon, UK
[2]Department of Physics, University College, Cork, Republic of IRELAND
[3]Euratom-VR, Chalmers University of Technology, Göteborg, SWEDEN

The Integrated tokamak modelling (ITM) taskforce aims at providing the European scientific community with simulation tools for preparing and analysing discharges of fusion experiments. The task force consists of the infrastructure and software integration project (ISIP), and five integrated modelling projects IMP-1 to -5. We will report on advances made in the project IMP-1 on equilibrium and linear stability.

Equilibrium reconstruction is the essential tool for determining the field configuration and current density in a fusion discharge. We compare the direct technique, solving the magnetostatic force balance for each set of measurements, with alternative methods. The direct technique for axisymmetric fusion machines, such as tokamaks, relies on the solution of the Grad-Shafranov equation, and is used successfully for most existing tokamaks. However, the main assumptions for using the Grad-Shafranov equation are often too restrictive. We provide therefore extensions suitable for fusion devices with a dominant magnetic field. These are the anisotropic pressure model covering also toroidal rotation, and an algorithm for the calculation of the three-dimensional field due to external perturbations such as field ripple. These extensions are implemented in the equilibrium reconstruction code EFIT, originally written by L.L.Lao. To comply with the guidelines of the ITM taskforce, the code has been completely rewritten and given the name EFIT_ITM. The code is further optimised to increase execution speed and lower memory demands.

An important objective for the ITM taskforce is the definition of a generic data structure suitable for all existing and future fusion devices. This data structure contains geometric description and data, including a formal description of all magnetic field sources, in particular the coil system, vessel structure, and models of a ferromagnetic transformer. Formal descriptions of diagnostics used for the equilibrium reconstruction is provided. The codes provided by IMP-1 are coupled together, comprising data input from experimental data, equilibrium reconstruction made with EFIT_ITM, high-precision equilibrium with the fixed boundary code HELENA, and finally linear stability analysis with MISHKA and CASTOR. All these codes have standardised interfaces and are driven from the interactive simulation tool Kepler. The data structure is meant for extension once further simulation tools are available to the ITM guidelines. It is demonstrated that the complete chain delivers results from experimental data from various tokamaks, including JET, ASDEX, Tore Supra, and with simulated data for the ITER device. We present results of the validation of the chain with data from JET and Tore Supra, in particular for investigating stability limits in plasma with an internal transport barrier.

Tu1-3

Systematic Study of Anomalous Transport Events on the W7-AS Stellarator

E. Belonohy[1], A. Bencze[1], G. Papp[2], G. Pokol[2], G. Por[2], K. McCormick[3], S. Zoletnik[1]
and the W7-AS Team
[1]*KFKI-RMKI, Euratom Association, Budapest, Hungary*
[2]*Budapest University of Technology and Economics, Euratom Association, Budapest, Hungary*
[3]*MPI für Plasmaphysik, Euratom Association, Garching, Germany*

Understanding the behaviour of edge localised modes (ELMs) and other cross-field transport events is a key issue in our way toward the next-step magnetic fusion devices. On Wendelstein 7-AS (W7-AS) ELM-like transients were observed in various plasma parameters in L-mode as well as H-mode discharges and they have already been shown to contribute to the anomalous heat and particle transport in discharges where the rotational transform was close to 1/2 or 1/3 [1]. Given the strong sensitivity of these transients and the anomalous transport on the magnetic configuration [2], an attribute that can be excellently studied on W7-AS due to its flat and externally controllable iota profiles, an extensive study involving a series of 147 low density discharges ranging over a wide iota range ($\iota = 0.3 - 0.6$) including additional density scans at particular iota values was conducted to systematically study the appearance and interrelation of these phenomena in the electron density profiles (by Li-BES), electron temperature profiles (by ECE) and the edge poloidal magnetic field (Mirnov coils). The analysis is performed using a newly developed algorithm based on correlation techniques that can separate and characterize different phenomena present in fluctuations. The magnetic configuration dependencies and relation among the transients, changes in confinement and the H-mode will be discussed.

Furthermore, various W7-AS H-mode operational regimes are studied using time frequency analysis and correlation techniques. A dedicated study is under way to compare the highly promising High-Density H-mode (HDH) [3], an ELM-free mode exhibiting no impurity accumulation to the quiescent H-mode (showing extensive impurity accumulation) and the standard ELMy H-modes. ELMs, known to be an important component in influencing edge transport in the H-mode, seem to be present in all H-modes to a given degree at specific iota values. Initial investigations of Mirnov signals have identified modes appearing in the HDH phase showing similarities with Alcator C-Mod's Quasi-Coherent mode [4]. As this mode is not universal for all HDH phases on W7-AS, its characteristics and similarity to the Alcator C-Mod's QC mode is explored.

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Tu2-1

The WEGA Stellarator: Results and Prospects

M. Otte, D. Andruczyk, R. König, H.P. Laqua, O. Lischtschenko, S. Marsen, Y.Y. Podoba, J. Schacht, F. Wagner, G.B. Warr and A. Werner

Max-Planck-Institut für Plasmaphysik, Euratom Association, Wendelsteinstr. 1, 17491 Greifswald, Germany

WEGA is a medium size classical stellarator with a major radius of $R = 72$ cm and a plasma radius of $a = 11$ cm operated since 2001. The main objectives are the training of students, the test of diagnostics and infrastructure for Wendelstein 7-X and basic plasma research.

The magnetic field coil system consists of 40 toroidal field coils, 4 helical field coils ($l = 2$ and $m = 5$) and 2 pairs of vertical field coils and error correction field coils, which allows very flexible magnetic configurations. The machine can be operated steady state up to a field strength of $B_0 = 0.4$ T and up to $B_0 = 0.9$ T in pulsed operation. The plasmas are generated and heated using two magnetrons at a frequency of 2.45 GHz and a newly installed gyrotron at a frequency of 28 GHz with a maximum microwave power of 26 kW and 10 kW, respectively. Typical plasma parameters are in the order of $n_e = 10^{17}$-10^{18} m^{-3} and $T_e = 5$-10 eV for the 2.45 GHz and $n_e <= 5 \times 10^{18}$ m^{-3} and $T_e > 20$ eV for the 28 GHz heating scenarios, respectively.

The research program covers the determination of the magnetic flux surfaces utilizing the field flexibility of the device, the characterization of the basic plasma parameters, investigations on the heating mechanism of microwaves, current drive experiments, fluctuation measurements, and biasing experiments. As diagnostic tools various probes are used as well as a single-channel microwave interferometer,

In preparation of the 0.5 T operation , a heavy ion beam probe was installed in spring of this year that allows radially resolved measurements of the plasma potential.

Furthermore, WEGA is also used for testing of new diagnostic hardware and software foreseen for W7-X. As an example the prototype of the component based and steady state control system for W7-X will be tested starting at the end of 2007.

Tu2-2

LASER-DRIVEN PROTON FAST IGNITION OF INERTIAL FUSION: CONCEPTS, ISSUES AND PROSPECTS

J. Badziak [1], J. Honrubia [2], S. Jabłoński [1], J. Wołowski [1]

[1] Institute of Plasma Physics and Laser Microfusion, Hery 23, 01-497 Warsaw, Poland
[2] GIFI, Universidad Politecnica de Madrid, Madrid, Spain

Fast ignition (FI) is a novel approach to inertial confinement fusion (ICF), which differs from the conventional central-hot-spot ignition ICF in using separate drivers for compression and ignition of the hydrogen fuel [1]. In this approach, the fuel precompressed by a long-pulse (ns) driver (laser beams, X-rays) is ignited by a short-pulse (ps) ultra-intense (~ 10^{20}W/cm^2) particle beam. FI has some significant potential advantages over conventional ICF: higher gain, lower overall driver energy, the reduction in symmetry requirements, and flexibility in compression drivers. The price to be paid is the need for efficient production and coupling to the fuel of a particle beam of extreme parameters.

In the original, most studied FI concept, the ignition hot spot is created by a beam of relativistic electrons generated in short-pulse laser-plasma interaction [1, 2]. More recently proposed approach to FI employs laser-generated proton beams [3-5]. The proton fast ignition (PFI) promises high efficiency of the beam-fuel coupling and avoidance of the complexities plaguing electron transport, but it has other physical constrains.

In this talk, basic PFI concepts, underlying physics and issues to address for the future development of PFI are reviewed. The requirements for the fuel and the igniting (proton) beam as well as the ways to meet these requirements are discussed. Recent achievements in laser-driven generation of high-current collimated proton beams are briefly presented and the possibility of attaining the proton beam parameters required for PFI with the method currently known is considered. The requirements for the compressing laser and the laser driving proton beam are discussed and prospects for PFI experiments using just designed and planned to be built laser facilities are outlined.

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Tu2-3

Highlights of the Laser Plasma Research at PALS

K. Jungwirth

Institute of Physics AS CR, v. v. i., Na Slovance 2, 182 21 Prague, Czech Republic

At the time, when the Research Centre PALS (Prague Asterix Laser System) with its TW iodine and worldwide most intense plasma soft x-ray lasers enters the second decade of its existence, an unprecedented growth of pulsed laser beams irradiation intensities is occurring, triggered by dramatic increase of interest in the physics of laser-produced plasmas. Very strong motivations are coming e.g. from the fast ignition laser fusion approach or from the new emerging applications of intense laser plasma-based sources of both coherent and incoherent radiations and high-energy particles.

The increase of irradiation intensities at the target by several orders of magnitude up to 10^{20} W/cm^2 has been achieved within the last few years mainly by shortening the pulse duration and by improving the pulse shape. Moreover, following the officially accepted ESFRI Roadmap for Pan-European infrastructures, the laser facilities HiPER and ELI, entering already the preparatory project stage, will represent qualitatively new powerful tools in hot dense matter physics in general, including relativistic or even ultra-relativistic plasma physics.

Depending on the laser pulse intensity and wavelength, duration and contrast, irradiation geometry, target material and structure, plasmas created at interaction of focused pulsed high-power laser beams differ widely and so do also various phases of interaction of a laser beam with the targets. It can result in crater creation and generation of shock waves in the target material, foil acceleration and/or surface ablation. Short-pulse and short-wavelength (x-ray) lasers interact predominantly directly with the target material, being capable of producing even solid-density plasmas. The longer the laser pulse and its operating wavelength, the more important is creation of an expanding plasma plume that can interact with the main part of the laser beam and become itself the desired source of plasma radiations or plasma jets.

The staff and collaborators of the PALS Research Centre in Prague have achieved in all those research fields remarkable results, some of which will be highlighted in this paper. The PALS high-quality infrared laser beam (wavelength 1315 nm, pulse duration 0.4 ns) is exploited for target experiments at focused laser beam intensities of up to 10^{16} W/cm^2 and for pumping plasma-based high-intensity soft x-ray lasers. First, the results of HEDP-relevant target experiments by using intense soft x-ray laser beams, with their numerous perspective applications in fusion research, material science, and astrophysics, will be mentioned. The next parts of the invited lecture will present new experimental and simulation results achieved at investigation of laser ablation and of various non-linear processes in the plasma plume including acceleration of ions to high energies and creation of surprisingly stable high-current plasma jets. Particular attention will be paid to the recent unique PALS investigations of supersonic interaction of plasma jets with ambient media, which supplied rich material for comparing the experiment with theoretical models applying both to astrophysical and ICF conditions.

Tu3-1

Spatiotemporal dynamics of drift wave turbulence in a helicon discharge

O. Grulke

MPI for Plasma Physics, EURATOM Association, and Ernst-Moritz-Arndt University, Greifswald, Germany

It is a common feature of turbulent transport that it is characterized by large transport events, which appear intermittently in time and space. The events are ascribed to spatiotemporal fluctuation structures with relatively large spatial size and long lifetime. Those structures are observed in the scrape-off layer of tokamaks, which emerge close to the separatrix and propagate radially outwards due to the self-consistent poloidal electric field pattern associated with the fluctuation structures. It is believed that the poloidal electric field is predominantly a result of the magnetic field curvature, which leads to a polarization of spatiotemporal fluctuations of the plasma density. This paper presents investigations of the spatiotemporal dynamics of turbulent fluctuations structures in the linear helicon laboratory experiment VINETA, in which magnetic field curvature is absent. The governing instability is the drift wave instability. The change of single operational parameters allows for a controlled transition of the dynamical state from coherent drift modes (with modenumbers $m \leq 9$) to weakly developed turbulence. The linear modes are in excellent agreement with the linear dispersion relation, if details of the radial evolution of the plasma collisionality are included. In the weakly developed turbulent state two radial regimes must be distinguished. In the strong radial pressure gradient region the drift wave fluctuations develop as quasi-coherent modes, which propagate purely poloidally, but with a significantly increased phase shift between plasma density and plasma potential fluctuations, which results in a strong radial transport associated with the quasi-coherent mode. In result of this transport, plasma peels off the gradient region and develops independently of the quasi-coherent mode. Poloidally its propagation is determined by the background $E\times B$ drift due to the radial plasma potential profile. However, also a significant radial component of propagation is observed, which is caused by its self-consistent potential fluctuation pattern, leading to a radial $E\times B$ drift. In contrast to the situation in the tokamak scrape-off layer the potential is found to be a result of the associated parallel electron current. These findings are in good agreement with global numerical simulations, which identify a correlation between radial fluctuation propagation and parallel electron flux.

Tu3-2

Effects of an external magnetostatic perturbation on the dynamics of Edge Localized Modes

M. Leconte[1], P. Beyer[1], S. Benkadda[1], X. Garbet[2]

[1] *Equipe Dynamique des Systemes Complexes, LPIIM, CNRS-Universite de Provence, Centre de St Jerome, Case 321, 13397 Marseille Cedex 20, France*

[2] *Association Euratom-CEA, CEA-Cadarache, 13108 St Paul-lez-Durance, France*

In divertor tokamak plasmas, an Edge Transport Barrier forms during the L-H transition. A poloidal shear flow has been shown to play a crucial role in the barrier sustainement.

In the first part of this work, we show that the statistics of the shear flow determine its stabilizing effects, particularly in the strong shear limit. In this limit, we present a simple model of passive-scalar advection [1] which shows that the correlation time τ_c of a mean shear flow, and the correlation time τ_{ZF} of zonal flows are parameters governing the ability of the shear flow to reduce the turbulence. We show also that the cross-phase $\cos(\delta)$ between pressure $\tilde{p}$ and velocity fluctuations $\tilde{v}_x$ is less reduced by the shear than the amplitude of turbulence $\langle\tilde{p}^2\rangle$. The H regime is promising for the next generation of tokamak experiments such as ITER. However, an instability known as Edge Localized Mode (ELM) develops as the power is increased further. ELMs are characterized by intermittent bursts in the radial heat flux, therefore causing the transport barrier to relax quasi-periodically. Over the last decade, the possibility of controlling ELMs has become more and more plausible, as recent experiments were carried out on DIII-D using I-coils and on TEXTOR using an ergodic divertor [2]. These experimental studies demonstrate a qualitative control over the ELMs by imposing a magnetostatic perturbation at the plasma edge. However, in order to get any quantitative result, much work has to be done in the understanding of ELM dynamics. In the second part of this work, we present results from numerical simulations of Resistive Ballooning Mode (RBM) turbulence reproducing the stabilization of barrier relaxations by a static magnetic perturbation. We focus our study on the edge region around the resonant surface $q = 3$. We use the *TEXTOR* tokamak geometry, and plasma parameters close to those used in typical experiments on this machine.

References

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Tu3-3

Ion Temperature Fluctuations in ELMy H-mode of the X3 EC-heated Plasmas on TCV

A.N.Karpushov, B.P.Duval, Ch.Shlatter

Ecole Polytechnique Fédérale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas, Association Euratom-Confédération Suisse, CH-1015 Lausanne, Switzerland

This paper presents experimental observations of variations in the NPA measured energy distribution of neutral fluxes from the ELMy H-mode TCV plasma during strong third harmonic EC-heating. In X3-heated plasmas edge localised modes (ELMs) are characterised by larger amplitudes and lower frequencies than are typical in ohmic H-modes [1]. The strong sawteeth in such regime are synchronised with ELM cycle.

On TCV, a "Five-Channel Energy Analyser of Atomic Particles" (5-ch.NPA) [2], operated in double electrical analysis mode, detects particles without atomic mass discrimination in the energy range 0.6-6.5 keV, with a time resolution up to 0.1 ms. A 28-channel "Compact Neutral Particle Analyser" (CNPA) [2] with mass and energy separation in E||B field simultaneously detects two mass species (11 channels for hydrogen and 17 for deuterium) in the 0.5-50 keV energy range with a time resolution in the 0.5-4.0 ms range.

These experiments featured 700-800 kW of delivered X-mode X3 EC with ~220 kW of Ohmic heating, into single null down diverted plasma magnetic configuration. The central electron density was $5\text{-}7\times10^{19}$ m^{-3}, plasma current 300-350 kA and the electron temperature 1.9-2.1 keV before an ELM (or sawtooth crash) to 1.2-1.6 afterwards. The EC power deposition and current drive profiles are calculated by the TORAY ray-tracing code with magnetic equilibrium reconstruction from the LIUQE code and Thomson scattering electron temperature and density profiles. The DOUBLE-TCV numerical code was used to model the energy spectra of neutrals leaving plasma for analysis of the NPA data.

The NPA measured central ion temperature of ~ 800 eV and are consistent with carbon (C^{VI}) temperature profile measurements from the charge exchange recombination spectroscopy (CXRS) [3]. The NPA measurement indicates the drop in the “effective temperature” of the CX NPA energy spectrum of ~15 % following an ELM (or sawtooth crash) that cannot be explained with classical theory of two-body Coulomb electron-ion collisions alone. Additional effects (such as a modification of the ion temperature radial profile) must be considered to interpret this phenomenon.

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Tu3-4

Influence of ExB shear flows on plasma edge turbulence

P. Manz[a], M. Ramisch[a], F.Greiner[b], N. Mahdizadeh[a] and U.Stroth[a]

[a]*Institut für Plasmaforschung, Universität Stuttgart, Pfaffenwaldring 31, 70569 Stuttgart, Germany*
[b]*Institut für Experimentelle und Angewandte Physik, Universität Kiel, Olshausenstr. 40, 24098 Kiel, Germany*

Abstract. Poloidal ExB shear flows are widely accepted as a trigger mechanism of transport barriers in the edge of fusion plasmas. Strong ExB flows can act on turbulent transport through the shear decorrelation mechanism, which can reduce the radial size of turbulent structures or change the phase relation between density and potential fluctuations. ExB flows are externally generated to investigate their influence on turbulent fluctuations and the corresponding response of the Reynolds Stress as supposed drive of natural ExB flows.
The experiments have been carried out on the toroidally confined low-temperature plasma of the torsatron TJ-K. The plasma is dimensionally similar to fusion edge plasmas and throughout accessible for Langmuir probes. Multi-probe arrays are used to resolve the turbulent dynamics perpendicular to the confining magnetic field in high detail. In previous investigations, it has been shown that the dominant instability driving turbulence in TJ-K is the drift-wave. Typical characteristics of drift-waves as a cross-phase close to zero and a finite parallel wavenumber have been verified. Furthermore, strong ExB flows are externally generated by core plasma biasing. It is shown that the fluctuations are dominated by large-scale coherent structures even though strong flow shear is present and the particle confinement is improved. These structures reveal increased correlation and poloidal wave lengths. The confinement improvement is understood as a consequence of cross-phase modifications relating the large-scale structure to inward transport. The reaction of the biasing generated shear flow to the Reynolds Stress is investigated.

Tu3-5

Fast-neutron source based on Plasma-Focus device.

M. Scholz , B. Bienkowska, M. Chernyshova, V.A. Gribkov, S. Jednorog, Z. Kalinowska, L. Karpinski, M. Paduch, R. Prokopowicz, A Szydlowski,

Institute of Plasma Physics and Laser Microfusion (IPPLM)
23 Hery Str., 01-497 Warsaw, Poland

The ability to accurately and precisely monitor the fusion power is essential for the mission of large Magnetic Confinement Fusion (MCF) machines. This can be achieved by using the neutron diagnostic systems. Mentioned systems should apply the technique that demonstrates the highest accuracy of neutron measurements, especially the total neutron yield. Thus, the absolute calibrations should be performed for a range of neutron intensities usual for large MCF devices.

One of the calibration methods for such systems includes putting a (point) neutron source into the vacuum vessel and moving it through a large number of positions so as to map out the response expected from extended plasma. Ideally, a 2.5 MeV neutron source should be used to simulate the response from deuterium plasma as well as 14 MeV source would be useful for diagnostic of tritium plasma respectively.

In the present paper, we describe 2.5 MeV neutron source based on small Plasma Focus device, assembled in IPPLM and designed to work in a repetition mode of operation (up to 10 Hz). The above mentioned source has been equipped with a 28-μF condenser bank, containing 4 low inductance capacitors with 4 pseudo-sparks (the switching time and jitter are less than 4 ns), a charger, and a triggering system. Maximum charging voltage is up to 25 kV. An important part of the device is chamber of a special geometry designed to be an efficient source of pulse neutrons.

The neutron chamber has been tested with regard to its neutron generation parameters. Initial investigations have been carried out for several activation materials including Hf, In, Cd, Al and Au. Qualitative as well as quantitative analyses have been performed based on semiconductor detector system equipped with coaxial precalibrated detector. More than 15 nuclear reactions with different energy threshold have finally been found out among the detector material. A considerable effort has been devoted to perform Monte Carlo calculations of the neutron transport with MCNP version 5 code and MCNP5DATA cross section library. Then, main parameters of 2.5 MeV neutron radiation (absolute yields) have been investigated by both the numerical and activation method.

Tu3-6

EXPERIMENTAL STUDIES OF FAST PROTONS ORIGINATED FROM FUSION REACTIONS IN PLASMA-FOCUS DISCHARGES

A. Malinowska, K. Malinowski, M.J. Sadowski, J. Zebrowski, A. Szydlowski

The Andrzej Soltan Institute for Nuclear Studies (IPJ), 05-400 Otwock-Swierk, Poland
a.malinowska@ipj.gov.pl

The paper describes results of the recent measurements of fusion-reaction protons, which were performed within the PF-360 facility [1] operated at the IPJ in Swierk, Poland. The main aim of those studies was to perform time-integrated measurements of fast protons (of energy of about 3 MeV) by means of ion-pinhole cameras, which were equipped with nuclear track detectors of the PM-355 type and absorption filters made of thin metal foils. In order to determine the spatial distribution of fusion-produced protons the use was made of several miniature pinhole cameras placed at different angles to the PF-360 axis. The irradiated and etched detectors were analyzed with an optical microscope coupled with a CCD camera and a PC unit.

To gain more information about fusion processes occurring inside the high-temperature deuterium plasma, the results were compared with those provided by other diagnostic techniques. The most important result has been a comparison of the fusion-reaction protons characteristics with the results of neutron measurements. Fusion-reaction neutron measurements, which were performed by means of a few scintillation-probes placed at different distances from the PF-360 electrode outlet.

Among various studies, which are routinely carried out within high-temperature plasma experiments, measurements of the fusion-generated products are of particular importance. The energetic fusion-reaction products can escape from the plasma region and deliver important information about plasma parameters and its behaviour. The fast fusion-reaction protons, which are deflected by local magnetic fields, can also inform about the spatial distribution of currents flowing through a plasma column, and in particular about so-called current filaments [2]. The presented results, and in particular pinhole images of fast protons recorded at different angles to the z-axis and around this axis, as well as corresponding histograms and estimated energy spectra have shed a new light on mechanisms of the fusion reactions occurring within dense magnetized plasma produced by high-current pulse discharges.

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POSTERS TuP

TuP1

First HIBP results on the WEGA Stellarator

I. Bondarenko, A. Chmyga, G. Deshko, A. Komarov, A. Kozachok, L. Krupnik, S. Khrebtov, A Zhezhera.
IPP NSC KIPT, Kharkov, Ukraine.

A. Melnikov, S. Perfilov.
INF RRC "Kurchatov Institute", Moscow, Russia.

M. Otte, Y. Podoba, F. Wagner.
Max-Planck-Institut für Plasmaphysik, Greifswald branch, Germany.

M. Schubert.
L.P.M.I.A. Boulevard des Aiguillettes B.P. 239 54506, Vandoeuvre-Les-Nancy cedex, France.

The heavy ion beam probe (HIBP) is an established non perturbing diagnostic for determining spatial distributions of plasma potential, density, temperature and poloidal magnetic field (axial current) of magnetically confined fusion plasma. These are determined from the change in the primary ion beam parameters (charge, intensity and trajectory) passing through a plasma volume due to collisions with electrons and interactions with the confining magnetic field. A heavy ion beam probe plasma diagnostic system has been installed and evaluated on the WEGA stellarator in Greifswald, Germany in 2006-2007.

The WEGA HIBP operates with a beam of singly charged sodium ion with an energy of up to 50 keV, ion current up to 100 μA, and beam diameter of 5-6 mm in the confined plasma region. Plasma experiments with the HIBP diagnostic system were carried out at a magnetic field strength of B_0=0.45 T. In the experiments, helium plasma was heated non-resonantly with microwaves at 2.45 GHz. The first single point plasma potential measurement V_{pl}=42 V (±20 V) obtained with the HIBP is consistent with Langmuir probe potential measurements.

Further improvements of the beam line and control system are planned over the coming months to enable precise profile measurements

This work was supported by STCU P-202 project.

TuP2

Double-Slit Ion Energy Analyzer for Heavy Ion Beam Probing Diagnostics

I. Bondarenko, A. Chmyga, G. Deshko, A. Komarov, A. Kozachok, L. Krupnik, S. Khrebtov, A Zhezhera.
IPP NSC KIPT, Kharkov, Ukraine.
L. Eliseev, A. Melnikov, S. Perfilov.
Institute of Nuclear Fusion, RRC Kurchatov, Institute, Moscow, Russia.

Heavy Ion Beam Probing diagnostic can measure simultaneously a number of plasma parameters as well as their fluctuations with a high temporal and spatial resolution. These are the electric potential φ_{pl}, the electron density n_e, the electron temperature T_e, and the poloidal magnetic field B_θ (equivalently the plasma current density). The measurements of φ_{pl}, n_e and their fluctuations, which are important ingredient in the radial particle flux Γ_r have been successfully performed in many HIBP experiments.

Measurements of plasma density and potential fluctuation wavelength are possible by simultaneous registration of secondary ion flux from different plasma points. This is possible with the help of multi-cell array detectors and multi-slits energy analyzers. These devices permit directly measurements of plasma electric field too.

This work dedicated to double-slit ion energy analyzer investigations as a first step to multi-slit analyzer.

Double-slit ion energy analyzers installed now at HIBP diagnostic system on TJ-II stellarator in CIEMAT, Madrid and on HIBP stand device in IPP NSC KIPT, Kharkov, Ukraine. Similar device will be installed on T-10 tokamak in RSC "Kurchatov Institute", Moscow, Russia.

The main tasks of double-slit energy analyzer calibration are obtaining and optimizing analyzer gain function (G) and energy transmitting function (F) values for both entrance and detector slits. It is necessary for accurate measurements of absolute values of plasma potential and electric field. These functions values depending on analyzer geometry parameters, such as entrance-slit width (W), entrance slits and detector plates space positions. G value has also strong dependence on ion beam entrance angle.

In order to optimize G function angle dependence it is necessary to change entrance and detector slits position with accuracy near 0.1 mm during calibration process. In order to obtain mostly equal G an F values for bought slits it is necessary to move entrance slit position with the same or larger accuracy.

Double-slit analyzer supplied by remote movement system, based on several stepping motors in order to make sure these movements without analyzer letting-to-air. During Kharkov experiments, obtained G accuracy for both analyzer slits 10^{-3} and F – $3*10^{-3}$ with entrance slits moving accuracy 0,1 mm. Further accuracy increasing is connected with entrance slit motors step decreasing.

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TuP3

"Development of the HIBP diagnostic for Uragan 2M stellarator"

I.Bondarenko, A. Chmyga, G. Deshko, A. Komarov, A. Kozachok, L. Krupnik, S. Khrebtov, A. Zhezhera.

Institute of Plasma Physics, NSC KIPT, Kharkov, Ukraine.

The project of HIBP plasma diagnostic system for stellarator Uragan-2M is present in this work. The device Uragan-2M was constructed near 1991. It is the flexible torsatron with small helical ripples and considerably high parameters (R0 = 170 cm, ape = 22 cm, B0 = 0,8 - 2.4 T, l = 2, m = 4). It was put to operation at the end of 2006.

Heavy ion beam probe (HIBP) diagnostic is most attractive of non-contacting methods not influencing on plasma parameters. It allows obtaining information about space distribution of the electric potential, density, electronic temperature and poloidal magnetic field (axial current) of plasma. This method based on the changing of a primary ion beam parameters (charge, intensity and pathway) at transit through a plasma volume because of collisions with electrons and interaction with a confining magnetic field.

Calculations by computer code was made in order to optimize HIBP diagnostic set for stellerator Uragan-2M. HIBP system consists of two main parts.

The first of them is the injector of the accelerated probing beam, consists of:

-Tl+ ion source with ion current up to 500 mA;

-accelerator tube up to 1 MeV with extractor and focusing systems;

-primary beam-line.

The second part of the HIBP system is detection hardware for secondary ions registration. It includes:

-tradition energy parallel plate analyzer up to 200keV;

-multi cell array detector;

-secondary beam-line.

All parts of diagnostic set up should be tested on separate device and installed on stellarator. The first stage of HIBP operations at Uragan-2M stellarator will be with 400 keV energy beams, the second one – up to 800 keV.

TuP4

Study of relative line strengths within the OI infrared transition $3p^5P – 3d^5D^o$

A. Baclawski and J. Musielok
Institute of Physics, Opole University, ul. Oleska 48, 45-052 Opole, Poland
e-mail: abac@uni.opole.pl

Experimental data concerning a number of OI infrared transitions, among them the results for the OI transition $3p^5P – 3d^5D^o$, have been recently reported by Golly et al. [1]. The authors have applied a wall-stabilized high-current arc at atmospheric pressure. Argon was applied as working gas and some amount of CO_2 was added in order to excite the oxygen spectrum. At the plasma conditions (N_e and T) and spectral resolution of this experiment, in order to determine intensities of individual fine structure components, it was necessary to decompose the measured spectral feature by applying a special fitting procedure.

In this contribution we report new measurements of relative line strengths within a selected OI multiplet from the infrared part of the spectrum. We make advantage of the properties of the wall-stabilized operated in helium, outlined in detail e.g. in [2]. Applying helium as the working medium, at nearly the same arc current, significantly higher temperatures and lower electron densities are achieved, compared to the corresponding parameters of the argon plasma. Consequently one obtains a much better line to continuum ratio facilitating line intensity measurements. Moreover, we used a spectral instrumentation with a resolution exceeding those of Ref. [1] nearly by a factor of 10.

We compare our measured results with the data of the above mentioned experiment, with LS- coupling results and also with recent theoretical calculations [3-6].

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TuP5

Time-resolved intensity of ArXXVII resonance line for plasma diagnostics during high pressure gas injection

E.O.Baronova, V.V.Vikhrev, D.Kh.Morozov.
RRC Kurchatov Institute, Moscow, Russia

High pressure gas (Ar,Ne,Xe,etc) injection is widely used to mitigate consequences, caused by disruption or sudden shutdown of tokamak machines. The goal of injection is fast dissipation of plasma energy before unstable plasma touches the chamber wall. What is happening within injection process, how gas penetrates into plasma and how plasma loses the energy-are the subjects of study of various groups of scientists.

Given paper describes time-resolved intensity of X-Ray line during high pressure gas injection in tokamak in order to develop plasma diagnostics during gas injection. At the first stage we constructed a quasi-stationary collisional-radiative model to describe behavior of ArXVII lines.

Model consists of two parts: MHD part and Collisional Radiative part. Zero-dimentional MHD part is based on energy balance equation for plasma dynamics during high pressure gas injection. Model includes energy exchange between electrons and ions, Joule heating, radiation losses, generation of high energy electron beam (run away 'seed' and avalanche effect are taken into account). Special attention is given to the calculation of radiation losses in unstable plasma. Time-dependent collisional-radiative part calculates the distribution of Ar0-ArXIX and population of the levels. Density effect, opacity effect and the presence of diagnostic admixture before injection are taken into account.

The results of calculations of plasma parameters (electron density, electron and ion temperatures, radiation peak) are in good agreement with experimental results on DIII-D machine. Calculated time-resolved intensity of resonance ***w***-line of ArXVII shows the increase in intensity during gas injection, comparing with intensity before injection. Time-dependent line shape might be compared with experimental one to study the injection process as well as to develop the model itself. Such self-consistent approach might become an efficient way to understand physics of gas penetration and dissipation of plasma energy within gas injection. Experiment might be carried out using spectrometer for T_i measurements from Doppler broadening.

TuP6

The influence of gas pressure on the H_α line shape in the gap of dielectric barrier discharges generated in helium – hydrogen gas mixtures

H. W Janus, J. Musielok

Institute of Physics, Opole University, ul. Oleska 48, 45-052 Opole, Poland
E-mail: janus@uni.opole.pl

In a gas mixture consisting of 99.5% of helium and 0.5% of molecular hydrogen, dielectric barrier discharges were generated by applying an AC voltage (f = 1 kHz) to two electrodes, deposited on the outward surfaces of the ceramic plates. The two ceramic plates form a slit-like discharge gap of 0.5 mm (distance between the inward ceramic surfaces). The radiation of the hydrogen H_α spectral line emitted from this gas gap was studied, applying gas pressures from 4 kPa to 60 kPa.

The spectral instrumentation allowing phase and polarization sensitive measurements to be performed, is described in detail e.g. in [1,2].

In this contribution we present results of spatial and spectral resolved H_α line radiation determined at various gas pressures, different light polarization and different phases of the discharge.

A large broadening of the H_α profile was observed. We attribute this large broadening mainly to the linear Stark effect. On the basis of detailed analysis of the line shape, the electric field strengths in the gas gap at different pressures were determined.

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TuP7

Changes of H_α line shapes and distributions of electric field strengths of barrier discharges generated in Ar/H_2 gas mixtures caused by changes of the gas pressure

H. Janus, J. Kusz and T. Wujec

Institute of Physics, Opole University, ul. Oleska 48, 45-052 Opole, Poland
E-mail: janus@uni.opole.pl

Barrier discharges were generated in a gas gap between two plane-parallel $BaTiO_3$ ceramic plates in a gas mixture consisting of argon and 0.5% of molecular hydrogen. On the outward surfaces of the ceramic plates electrodes were deposited and supplied with AC voltage of a frequency of 1 kHz. The thickness of the gas gap was 0.5 mm. The pressure was varied in the range between 1.7 and 10 kPa.

The light emitted from this discharge was registered applying a spectral instrumentation with a spectral resolution of 0.015 nm. The optical imaging system allows measuring (selecting) the radiation emitted from plasma layers of a thickness of 0.06 mm oriented parallel to the ceramic surfaces.

The experimental setup was equipped with a chopper synchronized with the generator feeding the electrodes. In this way the light emission at given polarization of the electrodes could be studied. An analyzer placed into the optical imaging system allows light polarization sensitive measurements to be performed.

Results of changes of H_α line profiles and changes of the electric field strength distributions are reported as a function of the gas pressure in the discharge gap. Significant broadening of the H_α caused by the linear Stark effect is observed. Detailed analysis of the H_α line shapes allows determining the distributions of electric field strengths within the gas gap as a function of the gas pressure.

TuP8

EUV AND X-RAY SPECTROSCOPY OF HIGHLY CHARGED IRON- AND TUNGSTEN-IONS PRODUCED IN PLASMA FOCUS DEVICE

K. Nowakowska-Langier[1], L. Jakubowski[1], M.J. Sadowski[1], E.O. Baronova[2].

[1] The Andrzej Soltan Institute for Nuclear Studies (IPJ), 05-400 Otwock-Swierk, n. Warsaw,Poland
[2] Nuclear Fusion Institute , NRC Kurchatov Institute, 123182 Moscow, Russia
k.nowakowska-langier@ipj.gov.pl

This paper reports on results of the recent experimental studies concerning extreme-ultra-violet (EUV) and X-ray measurements within the MAJA -PF plasma focus device [1]. The main aim of these studies was investigate an influence of the material of the central-electrode ending on the formation of dense magnetized plasma and the emission of EUV and X-rays. The MAJA -PF facility was equipped with Mather-type electrodes made of copper, and it was operated with two different materials of the central electrode end-plate. The first end–plate was equipped with cylindrical insert which had a sharpened conical top made of pure iron and the second was made of tungsten.

Experiments were carried out with the pure deuterium with a 10% admixture of argon filling. The investigated PF shots were supplied from a 35kJ condenser bank. The routine diagnostics included time-resolved measurements of dI/dt waveforms, hard- and soft- X-ray signals and neutron pulses. In addition there were recorded time –integrated X-ray pinhole images. Spectroscopic studies were carried out by means of two spectrometers: 1st – an X-ray Johann-type spectrometer with a quartz crystal (2d = 0,668 nm) –designed for measurements in the wavelength range from 0,36 nm to 0,42 nm, and 2nd – an EUV spectrometer with a rectangular grating (4200 lines/mm) designed for measurements in range from 10 nm to 100 nm.

The recorded X-ray spectra demonstrated different lines corresponding to highly-ionized species, and in particular to Ar XVII and XVI lines (originating from the argon admixture)as well as Fe-K_{α} and Fe XIX lines (originating from the material released from the electrode ending). The recorded EUV spectra contained lines originating from argon- iron- and tungsten-ions. Some quantitative estimates have been performed and the obtained results have been compared with those of the previous spectroscopic studies [2]. The described results have also delivered information about behavior of tungsten under plasma loads, which is of particular interest for future fusion reactors.

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TuP9

EMISSIVE PROBE DIAGNOSTIC IN LOW TEMPERATURE PLASMA – EFFECT OF THE SPACE CHARGE AND VARIATIONS OF THE ELECTRON SATURATION CURRENT

A. Marek, M. Jílek, I. Picková, P. Kudrna, J. Klusoň, M. Tichý

Charles University in Prague, V Holešovičkách 2, 18000 Prague, Czech Republic

key words: *emissive probe, probe contamination, space charge effect*

Emissive probes are used as suitable experimental tools for determining the plasma potential in many types of plasmas ranging from hot isothermal plasma [1] through low-temperature and low-pressure applications [2] to dense plasma [3]. They can be used also in presence of electron drifts or high energy tails and even in non-neutral plasmas of cathode sheaths [4]. Several techniques of the plasma potential determination were established. Their basic overview is given e.g. in [5]. Two techniques for plasma potential determination by emissive probes are frequently used – the strongly emitting probe technique and the inflection point in the limit of zero emission technique.

In present work we report on study of the electron saturation current variations at varying probe heating that was found to be closely related to the probe wire contamination. The study was performed in two types of low temeprature argon plasma – weakly magnetized plasma of the cylindrical magnetron device [6] and non-magnetized plasma of the Double Plasma Machine [7]. Effect of overestimation of the plasma potential by the strongly emitting probe technique in the low temperature plasma is discussed in present work and experimental data are compared with theoretical model [8].

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Corresponding author address
Pavel Kudrna
Charles University in Prague
V Holešovičkách 2
180 00 Prague
Czech Republic
e-mail: pavel.kudrna@mff.cuni.cz
phone: +420 221 912 225

TuP10

Interaction Between Nitrogen And Hydrocarbons In Magnetized Plasmas

Adam Cwiklinski*, Werner Bohmeyer†, Mandy Baudach** and Andrey Markin‡

*Department of Physics, Freie Universität Berlin, Arnimallee 14, 14195 Berlin
†Max-Planck-Institut für Physik, EURATOM Association, Wendelsteinstr. 1, 17491 Greifswald
**Department of Physics, Humboldt Universität zu Berlin, Newtonstr. 15, 12489 Berlin
‡Institute of Physical Chemistry and Electrochemistry, Russian Academy of Sciences, Leninsky pr. 31, 119991 Moscow, Russ. Fed.

In the ITER fusion device the tritium inventory will be a crucial constraint for long term operation. For safety reasons, too high an inventory requires a major cleaning procedure which is to be postponed as long as possible or - ideally - to be avoided completely. Since CFC materials will be used in the high heat flux divertor region, tritium enriched amorphous hydrocarbon (a-C:H) films will be formed resulting from plasma wall interaction and the interaction between plasma and eroded divertor material. Nitrogen is suspected to be a possible measure for reducing the amount of a-C:H films in the (sub) divertor region or in the pumping duct.

In the linear plasma device PSI-2 ($T_e = 1 \ldots 10 eV, n_e = 10^{17} \ldots 10^{18} m^{-3}$) hydrocarbon layer formation can be investigated on large time scales. Parameters which can be varied include the substrate temperature, hydrocarbon and nitrogen fluxes, as well as electron temperature and density. Results will be presented from in-situ film thickness measurements, quadrupole mass spectroscopy (QMS) and spectroscopic data which aim to distinguish between surface effects due to ionic species and radicals and volume processes (so called scavenger effect). Preliminary results indicate the existence of the scavenger effect. Moreover, it is found that the film erosion rate depends also on the history of the specimen.

TuP11

PLASMA HEATING AND WAVE RADIATION IN THE MAIN IONOSPHERIC TROUGH IN THE REGION OF THE TERMINATOR FROM THE APEX SATELLITE DATA

N.I.Izhovkina[1], I.S.Prutensky[1], S.A.Pulinets[1],

A.Kiraga[2], Z.Klos[2], H.Rothkael[2]

[1]*Institute of Terrestrial Magnetism, Ionosphere and Radio Waves Propagation, Troitsk, Moscow Region, 142190 Russia*

[2]*Space Research Center, CBK PAN, Bartycka, 18a, 00-716, Warsaw, Poland*

e-mail: izhovn@izmiran.ru, pruten@izmiran.ru

The data of the measurements of the broadband wave radiation in the main ionospheric trough in the subauroral zone of the topside ionosphere in the region of the day – night terminator (APEX satellite experiment) are presented. It is shown that the observed attenuation of the electrostatic radiation in a broad frequency band and fluctuations (variations) in the cutoff frequency of the electrostatic mode spectrum at the level of the local plasma or upper hybrid frequency are related to plasma heating by damping electro-static oscillations in the ionosphere trough. Waveguide channels for propagation of electromagnetic whistler mode waves observed on the satellite can be generated during the propagation of the gravity – thermal disturbance from the day – night terminator. It was revealed that electrostatic wave spectra in ionospheric plasma depend on geophysical and solar wind parameters/

TuP12

Shear Flow Driven Instabilities and Collisionless Heating of Particles in Ionosphere

Mikhailenko V.S., Mikhailenko V.V., Azarenkov M.O., Chibisov D.V., Stepanov K.N.

Kharkov National University, 61108 Kharkov, Ukraine

An important often observed feature of the ionospheric plasma environment is magnetic field-aligned shear flows, existed over a wide range of scale sizes. These flows correlated with broad band low-frequency electrostatic oscillations and with heating of ions predominantly across the magnetic field. In situ measurements have established that the observed oscillations have frequencies in the range 10Hz to several time of hydrogen ion gyrofrequency (~600Hz for H+). Oscillations were detected [1] under conditions in which the parallel current density is subcritical even to the current-driven electrostatic ion cyclotron (CDEIC) instability. That instability has the lowest threshold in the ionospheric plasma environment [2] and was considered as a most likely source for plasma oscillations and anisotropic ion heating observed in the ionosphere. Recently we have found [3] that in plasma with currents along the magnetic field which are below the threshold for CDEIC instability, as well as in currentless plasma, flow-shear driven kinetic and hydrodynamic ion cyclotron and ion sound-drift instabilities exist. These instabilities may be responsible for the observed ion cyclotron turbulence and anomalous heating of ions in the ionosphere.

Motivated by these suggestions, the analytical theory of the shear-flow-driven ion cyclotron and combined ion sound-drift turbulence of inhomogeneous plasma with magnetic field-aligned flow is developed. The focus of these investigations is on 1) the analytical determining the mechanisms and levels of the saturation of the shear-flow driven ion cyclotron, ion sound-drift instabilities on the ground of the weak turbulence theory and on the ground of the renormalized theory of strong turbulence, which accounted for the enhanced scattering of ions in shear flow by ion cyclotron and ion sound waves; 2) determining the ion and electron heating rates of the resultant turbulent heating of plasma due to the interaction of plasma particles with ion sound and ion cyclotron turbulence in plasma with sheared flow.

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TuP13

Waves and stability of flowing solar wind structures in the framework of the Hall magnetohydrodynamics

Ivan Zhelyazkov

Faculty of Physics, Sofia University, BG-1164 Sofia, Bulgaria

Abstract

Now it is well established that the solar atmosphere, from photosphere to the corona and the solar wind is a highly structured medium. Satellite observations have confirmed the presence of steady flows. Bulk motions are registered along the magnetic field lines which outline the magnetic structures. Recent observations made by two *HELIOS* spacecrafts have revealed fine structures in high-speed solar wind flows. These structures are in the form of thin flow layers (or tubes) that are adjacent to each other with differences in their plasma parameters (density, magnetic field, steady flow speed). These structures can be separated by tangential discontinuities in the magnetic filed, across which the total (kinetic plus magnetic) pressure is continuous. Here, we investigate the parallel propagation of magnetohydrodynamic (MHD) surface waves traveling along an ideal flowing plasma slab surrounded by flowing plasma environment in the framework of the Hall magnetohydrodynamics. The magnetohydrodynamics with Hall effect (Hall MHD) gives a fluid description of magnetized plasmas taking into account scales of the order of the ion inertial length, $l_{\mathrm{Hall}} = c/\omega_{\mathrm{pi}}$, at which the dynamics of ions and electrons separates and the medium becomes dispersive. The magnitudes of the plasma densities and flow velocities inside and outside the slab are different. Two possible directions of the relative velocity (in a frame of reference co-moving with the ambient flow) have been studied. From the two kind of surface wave modes that can propagate, notably sausage and kink ones, the dispersion behavior of the kink mode turns out to be more complicated than that of the sausage mode. In general, the flow increases the waves' phase velocities compared to their magnitudes in a static Hall-MHD plasma slab. Moreover, the plasma flows at some values of the magnetic Mach numbers (the ratio of flow speeds to the Alfvén speeds in the corresponding medium), may cause the triggering of the Kelvin–Helmholtz instability. The applicability of the results to real solar wind flow-structures interacting with the Earth magnetosheath is also discussed. We note that the Hall MHD is applicable (with appropriate plasma and magnetic field characteristics) to fusion plasmas, too.

TuP14

Collective phenomena of dust particle motion in Yukawa Balls

Y. Ivanov, S. Käding, A. Melzer

Institut für Physik
Ernst-Moritz-Arndt-Universität Greifswald, Germany

Dusty plasmas are ideal systems for the investigation of the dynamics of finite systems on the kinetic level. Since recently, spherical dust crystals, so-called Yukawa Balls, have been generated in a plasma bulk under laboratory conditions. A heated lower electrode produces an upward termophoretic force which compensates the influence of gravity in these experiments. These systems have been intensively investigated with respect to the structure.

Here, investigations of the dynamics of Yukawa Balls are presented. 3 high-speed CMOS cameras were positioned under right angle to each other to simultaneously record the 3D particle coordinates. The particle trajectories were extracted with sub-pixel resolution.

A typical problem connected with stereoscopic imaging is that particle images recorded by single cameras can overlap. This complicates the identification of particle positions in volumetric systems compared to 2D clusters. We have developed an algorithm to reconstruct 3D particle trajectories with even overlapping particle images.

The dynamical properties of Yukawa Balls were derived using the Normal Mode Analysis (NMA) from the analysis of the particle Brownian motion around their equilibrium positions. This method allows to assess the crucial physical parameters of the system like the particle charge or the screening strength.

The experimental normal modes show a good agreement with the molecular dynamics simulation results.

TuP15

Stereoscopic Investigations of Order Phenomena of 3D Yukawa Balls

S. Käding[1], D. Block[2], Y. Ivanov[1] and A. Melzer[1]

[1]*Institut für Physik*
Ernst-Moritz-Arndt-Universität Greifswald, Germany
[2]*Institut für Experimentelle und Angewandte Physik*
Christian-Albrechts-Universität Kiel, Germany

Particles immersed in a plasma collect a high negative charge that allows the trapping of the particles in the sheath were the electric field forces can balance gravity. Typically the particles are arranged in a flat cloud near the electrode. But recently it has become possible to trap ball-shaped three-dimensional dust clusters called Yukawa balls. They usually consist of a small number of microspheres ($N = 1 \ldots 100$) that are trapped between dielectric walls in a rf discharge at low gas pressure. The Yukawa balls that usually consist of several concentric shells allow a detailed insight into their structure and dynamic properties. Therefore they are ideal systems to study condensed matter on the kinetic level.

Such investigations require the knowledge of the simultaneous 3D particle positions. For the reconstruction of the particle coordinates with high spatial and temporal resolution we have developed a stereoscopic system of three high-speed video cameras that are arranged perpendicular to each other.

The experiments presented here deal with the order phenomena in 3D Yukawa balls. The clusters are investigated with respect to the occupation number of the shells as well as particle movement on the shells and transitions between shells. Occupation number and particle motions reflect the physical properties of the dust particles in view of particle charge and screening strength.

TuP16

Study of effect of grain size on dust charging in an RF plasma using three-dimensional PIC-MCC simulations

V. R. Ikkurthi[1], K. Matyash[2], R. Schneider[2], A. Melzer[1]

[1]*Institut für Physik, Ernst-Moritz-Arndt-Universität Greifswald, 17487 Greifswald, Germany*

[2]*Max-Planck Institut für Plasmaphysik, EURATOM Association, 17491 Greifswald, Germany*

The charge on the particles in a dusty plasma is a crucial parameter for the formation of Coulomb crystals, their structure and their dynamics.

Here, a newly developed 3-dimensional Particle-Particle Particle-Mesh (P^3M) code is applied to study the charging process of micrometer size dust grains confined in a capacitive RF discharge.

In our plasma model, particles (electrons and ions) are treated kinetically (Particle-in-Cell with Monte Carlo Collisions (PIC-MCC)), which allows to self-consistently resolve the electrostatic sheath in front of the material wall. In order to accurately resolve the plasma particles' motion close to the dust grain, the PIC technique is supplemented with Molecular Dynamics (MD), employing an analytic electrostatic potential for the interaction with the dust grain.

This approach allows to follow the plasma particle trajectories in the close vicinity of the dust grain and by this to include finite-size effects for dust grains. This allows to self-consistently resolve the dust grain charging due to absorption of plasma electrons and ions.

The charging of dust grains confined above lower electrode in a capacitive RF discharge and its dependence on the size and position of the dust is investigated. The results are compared with laboratory measurements.

TuP17

TRANSVERSAL DISPLACEMENT OF THE PLASMA FLUX DURING ITS MOTION IN A CURVILINEAR MAGNETIC FIELD

A. Timoshenko, V. Taran, V. Tereshin

Institute of Plasma Physics, KIPT, 61108 Kharkov, Ukraine
timoshen@yandex.ru

The motion of central part of the vacuum arc plasma beam, propagated along the toroidal magnetic field, is analyzed in a frame of drift approximation. The main aim is to eliminate the contradiction between drift theories [1, 2], which predict the transversal motion of plasma beam in direction coincided with centrifugal drift of ions, and experimental data [3-5], which show that plasma shifts to the direction of centrifugal drift of electrons. This contradiction is removed if one takes into consideration that:

a) ions cannot admit to be magnetized during its motion along the curvilinear trajectory even in a case of relatively strong magnetic fields;
b) the hypothesis on the shorting currents in plasma [2, 3] is no valid.

In contrast to [1, 2], where the electric field of polarization arises owing to appearance of the non-compensated charges on the opposite parts of plasmoid or plasma balk, in present paper this electric field appears as a result of displacement of ion density profile relatively to electron one which both are assumed be Gaussian [6]. The components of polarization field and displacements are interdependent in self-consistent integral equations. The solutions of equations allow obtaining the polarization fields and calculating the self-consistent plasma displacement in transversal directions. It is shown that during plasma beam motion along the curvilinear trajectory the center of electron density profile rotates around the center of ion density profile (and electric polarization field does too) with a frequency that is mach more of ion cyclotron frequency. At that, the ion component performs the radial oscillations near a curvilinear magnetic line of force. Obtained results are in good agreement with an experimental data.

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TuP18

Investigation of numerical thermalization in particle-in-cell simulations

V. Tarjáni, J. D. Skalný
Department of Experimental Physics
Faculty of Mathematics, Physics and Informatics, Comenius University
Mlynská dolina, 842 48 Bratislava, Slovak republic
e-mail: tarjani@neon.dpp.fmph.uniba.sk

Abstract

Particle-in-cell (PIC) is widely used method for plasma modelling. Like any other method it represents only an aproximation to real plasma. This fact implies possibility for development of some parasitic effects in simulation. It is very important to know the nature of this effects and how they affect the simulation. In this article we investigate one of them known as numerical thermalization (maxwellization) which means the artificial increased rate in which velocity distribution function of particles relaxes toward Maxwellian. We used 1d model of homogenous plasma to measure how the thermalization time is affected by fundamental simulation parameters such as cell size Δx and number of particles per Debye length N_D. Recently some works shows that explicit introduction of collisions to PIC method may have negative side effects to simulation, so we also studied this phenomena.

TuP19

High-Informative Correlation Analysis for Studies of Plasma Physical Evolution.

V.I. Erofeev

Studies of Langmuir turbulence have shown that traditional plasma theory cannot provide appropriate level of reliability of its predictions [1-5]. On the one side, some recognized theoretical concepts (e.g. the Langmuir wave collapse) do not comply with experimental plasn observations [1,2]. On the other, approaches of the theory permit to justify incompatible versic of the same physical phenomena with equal rigor (as is the case with ideas of Langmuir wave quanta conservation and of their quick energetic decay [1--3]). We discovered two intertwined reasons of the noninformativeness of plasma theoretical deductions. On the one side, asymptot convergence of intermediate iterative calculations, due to which variations in the leading orde of the perturbation theory yield diversity of scenarios of the plasma physical evolution. On th other, traditional substitution of real plasmas by plasma ensembles: Ensemble statistics evolve following specific laws dictated by the ensemble content [1--5]. These reasons motivated us to create technique of reducing full plasma description to more simplified kinetic ones, with account for the asymptotic character of its possible convergence and with refrain from ensemble substitutions [6--8].

The above reflected ***irrationality of the ensemble method*** puts forth the wide-scale revision modern theoretical physics. It visualizes the scientific inconsistency of the ***nonequilibrium statistical mechanics***: the recipes of the latter are useless for studies of physical phenomena in nature [3]. It comprises reconsideration of attitude to the ***equilibrium*** statistical mechanics: thi science ***emulates*** only and not ***substantiates*** the laws of thermodynamics. It necessitates the critical analysis of physical kinetics (which general science utilizes principles of the nonequilibrium statistical mechanics). This is far not the full list of reorganizations in theoretic physics to be initiated.

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TuP20

THERMOPHYSICAL DEDUCTIONS FROM THE ELASTIC COLLISION OF ALKALI-METAL MONATOMS WITH HYDROGEN

L. Reggami*, M.T. Bouazza*, and M. Bouledroua†

*Department of Physics, Badji Mokhtar University, 23000 Annaba, Algeria
†Faculté de Médecine and Laboratoire de Physique des Rayonnements, Badji Mokhtar University, 23000 Annaba, Algeria

The last few years have witnessed a growing interest in the cold and ultracold collisions of the alkali metals (Li, Na, K, Rb, and Cs) with hydrogen. The determination of the needed physical parameters, such as the scattering lengths and the effective ranges, required calculation of accurate interatomic potentials. This has been already done very recently by Geum and his collaborators [1]. We propose in this work to use these authors' singlet and triplet potential-energy curves to investigate the elastic collision of the type Ak + H($1s$), where Ak is one of the above alkali monatoms in its ground state. The work will focus on the determination of the thermophysical properties and their behavior with temperature. Particularly, by adopting the Chapman-Enskog model, we will determine the collision integrals $\Omega^{(p,q)}$, deduce the transport coefficients, and examin their variation law with temperature. More attention will especially be given to the quantum-mechanical determination of the diffusion of the alkalis in a hydrogen gas.

The work will further characterize the ultracold collisions by including the quantal and semiclassical calculations of the scattering length a and the effective range r_e. The effect of the long-range forces is demonstrated and, for this purpose, we will make use of the most accurate dispersion coefficients from C_6 to C_{16} given in Refs. [2, 3, 4].

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TuP21

Modeling and measurements of the demixing effect in an arc plasmas containing hydrogen

Pawelec E.
Uniwersytet Opolski, Instytut Fizyki, ul. Opolska 48, Opole, Poland
ewap@uni.opole.pl,

The wall-stabilized arc is a widely used source of the atomic and ionic radiation. This type of plasma is very popular in the spectroscopic research, e. g. for measurements of atomic and ionic structure data, such as spectral line strengths or Stark shifts and widths. The arc plasma sources used also for many other industrial and scientific applications – especially as the plasma generators for various plasmatrons and jets.

Hydrogen is a very popular tool for plasma diagnostics – very small admixtures of this element exist in most gases and the lines of the Balmer series, exhibiting strong Stark broadening, are widely used for determining the electron density.

Problems with behavior of admixtures in an arc plasma, exhibiting strong gradients of plasma parameters, is rather complex. In the case of hydrogen, especially longitudinal demixing can be very important for plasma diagnostics.

In this work we present the comparison of the results of the measurements of the plasma parameters in the wall-stabilized arc working in the mixture of argon, hydrogen and helium, with the theoretical calculations of the plasma temperatures and molar ratios for Ar-H_2. The gas mixture is introduced uniformly along the arc column between each of the stabilizing plates. From measured lateral distribution of radiation (HeI, HI, ArI line intensity and width measurements), after Abel inversion the radial temperature and species distributions were obtained at various positions of the arc column, in both radial and axial directions.

The model consisted of one-dimensional calculations of all plasma parameters (both temperature and demixing), based on the theory developed by Murphy. The results show that even the relatively simple model can predict the molecular ratio distributions in the gas mixtures and its dependence on the initial gas flow ratios.

TuP22

COMPRESSION DYNAMICS OF PLASMA IN Z-PINCH FROM DEUTERATED POLYETHYLENE

A.A.Akunets*, S.Ananev, J.L.Bakshaev, P.I.Blinov, V.V.Vihrev, S.A.Danko, E.D. Kazakov. V.S.Konyahin, В.Д. Korolev, B.R.Meshcherov, S.L.Nedoseev, V.G.Pimenov **, E.A.Smirnova, G.I.Ustroev, A.S.Chernenko.

Institute of Nuclear Synthesis, Russian Research Center «Kurchatov Institute», Moscow, Russia, korolev@dap.kiae.ru

**Physical institute. P.N.Lebedeva of the Russian Academy of Science, Moscow, Russia ** Institute of organic chemistry. N.D.Zelinsky of the Russian Academy of Science, Russia*

Investigation of dynamics compression fast Z-pinch was carried out on S-300 machine at current up to 1.7 MA with front of increase of 100 nanoseconds. Loadings represented profiled cylinders in diameter 3-5 mm and height 10 mm made on the base of agar-agar with density of 30 mg/sm^3. For energy concentration in central part of load was made neck with diameter 1-2 mm. As a material for neck was used deuterated polyethylene with density 50 mg/sm^3 or 75 mg/sm^3. Plasma compression in the field of neck was investigated with help of a high speed optical streak camera, X-ray framing image tube and five laser probing channels. The structure of hot dense plasma was determined by using of integrated photographing in the field of energies E> 0.2 keV by a pinhole camera. The X-ray radiation in the range of (0.4-120) keV was registered by semiconductor detectors. Measuring of neutron radiation was carried out in two radial and in two axial directions. From results of pulsing X-ray photographing follows, that in the field of neck during the moment of time corresponding a maximum of a current, the hot plasma, was formed by a radiant of X-ray and neutron radiation.

Laser photography and X-ray framing image indicate the protracted generation of the high-temperature plasma. Some part of substance remains up to the end of compression of hot plasma in initial volume of neck. In separate experiments on integrated streak cameras have been gained from one up to three hot points which occurrence was accompanied by occurrence of short neutron and X-ray peaks by duration of 3-10 nanoseconds. The energy of neutrons measured by a method of time of width in 4 directions concerning an axis of a loading 0^0, 90^0, 180^0 and 270^0 was 2-3 MeV. At using of the neck from deuterated polyethylene the stable and reproduced neutron output was observed.

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TuP23

Dynamics of Xenon Plasma Streams Generated by Magnetoplasma Compressor

I.E.Garkusha[1], V.V. Chebotarev[1], A. Hassanein[2], M.S. Ladygina[1], A.K. Marchenko[1], Yu.V. Petrov[1], D.G. Solyakov[1], V.I. Tereshin[1], S.A. Trubchaninov[1], O.V. Byrka[1]

[1] - *Institute of Plasma Physics, NSC KIPT, 61108, Kharkov, Ukraine*
[2] - *Argonne National Laboratory, USA*

Dense plasma streams of heavy noble gases are widely used in different technological applications: EUV lithography, plasma thrusters, surface processing etc.

The paper presents the investigations of xenon plasma streams generated by magnetoplasma compressor (MPC) of compact geometry with conical-shaped electrodes and pulsed gas supply. The stored energy in the discharge is 28 kJ for applied voltage of 25 kV.

Spectroscopy measurements of plasma density and electron temperature in compression region of MPC have been performed on the base of Stark broadening of spectral lines and intensities ratio in visible wave-range. The influence of self absorption of XeII and XeIII spectral lines on results of plasma density measurements was analyzed. Abel inversion procedure was applied for estimations of radial distributions of the plasma density. It was found that maximum value of plasma density in compression region achieved 10^{18} cm^{-3}. Plasma focus diameter in this case was about 0.6-0.8 cm

The high-speed imaging of the plasma discharge and compression dynamics was carried out in frame-by-frame regime with temporal resolution of 3 μs. Calorimetric measurements of the energy density distribution in the plasma stream have been performed also. It is shown that operation mode of the plasma source is determined by effective mass flow rate. It can be varied by changing both the integral flow rate and time delay between start of working gas injection and the discharge ignition.

Movable piezoelectric detectors were designed and manufactured for plasma pressure measurements. All the detectors were calibrated for absolute measurements. Maximum value of plasma stream pressure was measured at the distance of 10 cm from the electrode outlets. It achieved 22-23 bar and decreased to 12 bar at the distance of 20 cm.

Source efficiency was analyzed from electrotechnical discharge characteristics, namely discharge current, total resistance and inductance in the case of pure xenon discharge and the mixtures of xenon and helium in different proportions. The discharge efficiency achieved 28% and this value is in good agreement with calorimetry. The MPC discharge efficiency strongly depends on time delay between gas supply start and discharge ignition and practically does not depend on kind of working gas in present experimental conditions.

AXUV photodiodes were applied for the measurements of high-ionized Xe radiation in EUV wave-range. First results on analysis of EUV radiation from the compression region are presented.

TuP24

On the origin of low frequency oscillations in Hall thrusters

S. Barral
Institute of Fundamental Technological Research - PAN, Warsaw, 00049, Poland
E. Ahedo
E.T.S.I. Aeronáuticos, Universidad Politécnica, Madrid, 28040, Spain

Hall thrusters are plasma accelerators primarily dedicated to satellite and deep space probe propulsion. By applying a nearly radial magnetic field inside an annular ceramic channel, the electrons emitted from an external cathode are strongly confined along azimuthal cycloidal trajectories before they reach an anode located inside the channel. The resulting low electron axial mobility allows the propellant — usually Xenon — to be efficiently ionized, while inducing at the same time a large axial electric field that accelerates ions. The operation of Hall thrusters is accompanied by a wide spectrum of oscillations from which the most notable are the so-called breathing oscillations, associated with a longitudinal low frequency instability within the $10 - 30$kHz frequency range. Its origin has been investigated in several works [1, 2, 3] which all have emphasized the role of played by ionization. The conclusions of these studies differ, however, on the scaling of the frequency and on the exact mechanism involved. Recently, a new formalism has been proposed for the study of low frequency oscillations where charged species are considered to be at any moment in quasi-equilibrium with the flow of neutral particles [4]. Taking advantage of this new framework, the present study aims at answering two outstanding and crucial questions, namely:

1. *why are breathing oscillations self-sustained?*
   The predator-prey mechanism proposed by Fife and Martinez-Sanchez [1] involves an interaction between the density of ions and the density of neutrals. Observing that these species are convected in the same direction, however, it could be argued that any perturbation will be eventually convected away since no information can propagate back to the point of the initial perturbation and lead to self-excitation. This issue cannot be resolved within the frame of the 0-dimensional predator-prey model which does not include notions related to space and propagation directions.

2. *is the frequency of the mode related to the time of replenishment of the channel by neutrals?*
   A common opinion is that the breathing cycle period is directly related to the time needed for the channel to be replenished by neutrals after a phase of rapid ionization [2]. This is in contradiction to the prediction of the predator-prey model [1], where the cycle period is proportional to the square root of the replenishment time. A definite answer to this question is also out of reach for the predator-prey model, since it does not integrate transport-related time lags.

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TuP25

THE TEMPERATURE EVOLUTION IN LASER HEATED PLASMA

N. Mirnes and A. H. Belbachir
Laboratory of Analysis and Application of Radiation (LAAR)
Physics Department, University of Sciences and Technology of Oran M. B. (USTO)
P. O. Box: 1505, El-M'Nouar, Oran, Algeria
e-mail: nawel002002@yahoo.fr

Abstract:

On the basis of the collisional Boltzmann equation for an unmagnetized plasma, the interaction of a laser pulse with a cylindrical plasma has been studied using the P_1 approximation of Spherical Harmonics Expansion.

Our model leads to two coupled and nonlinear differential equations for the electrons temperature θ_e and electrons density n_e. Two approximations are introduced to solve these equations which are the adiabatic plasma heating and the isobar heating.

The obtained results show that the electronic temperature profile in inhomogeneous plasma has a weak variation in the laser axis directions (z axis), and the temporal variation of the temperature electrons has similar pattern to the laser temporal profil.

We are now working to find the numerical solution for the coupled equations in the general case.

Keywords : Laser pulse interaction, Boltzmann equation, plasma temperature, plasma density, coupled and nonlinear differential equations

TuP26

EXPERIMENTAL RESEARCH OF MAGNETICALLY SELF-INSULATED TRANSMISSION LINE WITH LINEAR CURRENT DENSITY UP TO 7 MA/cm

A.Chernenko, S.Anan'ev, Yu.Bakshaev, A.Bartov, P.Blinov, S.Dan'ko, Yu.Kalinin, E.Kazakov, A.Kingsep, V.Korolev, V.Mizhiritsky, O.Myagkov, A.Shashkov, V.Smirnov, G.Ustroev

Russian Research Center "Kurchatov Institute", 1 Kurchatov Sq., 123182, Moscow, Russia

chernenko@dap.kiae.ru

On the S-300 pulsed power machine at the Kurchatov Institute, some experimental activity is devoted to the prospects of Inertial Fusion Energy (IFE) program.

The results of experiments on the S-300 are presented, devoted to the study of operation of magnetically insulated transmission line (MITL), by the linear current flow density on the inner electrode surface up to $j \approx 7$ MA/cm. The specific parameters of this current-carrying line correspond to those of the conceptual project of IFE reactor based on the fast Z-pinch [1]. The duration of efficient functioning for such a line has been measured and possible reasons for broken isolation have been studied. Instability of expanding plasma sheath inside this line has been recorded, probably of EMHD origin [2]. A series of SXR and HSR measurements have been carried out clarifying the dynamics of rare plasmas inside the MITL gap and both temporal behavior and upper level of leaks.

For examination of influence of a cathode material on plasma dynamics, an inner electrode (cathode) of a line was made from a nickel tubule with diameter of 0.75 mm with wall thickness of 100 μm, and from tubes made from lead or gold foil. Input and output currents were measured by the magnetic loops and shunts correspondingly. The information on dynamics of near-electrode plasmas has been gained by means of multi-frame shadow or Schlieren-photographs of plasma on second harmonic YAG:Nd of the laser and by means of a 4-frame IC images with nanosecond resolution in visible and in the soft X-rays ranges.

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TuP27

Different Methods for measuring Plasma displacement in Tokamaks and construction and Compensation of Continuous Coils in IR-T1 Tokamak

R.Tarkeshian,[1)]
Dr. M. Ghoranneviss,[1)]
Dr. K. Salem,[1)]
A. Talebi Taher,[1)]
Dr. P. Khorshid[2)]

1)Plasma Physics Research Center islamic Azad University - P.O. Box 14665–678 - Tehran_iran

2) Dept. of Physics : Mashhad Islamic Azad University ,P.O. Box 91685-164 91865 Mashhad, Khorasan

The measurement of displacement of a current-carrying plasma column in a torus is important information for plasma position control. Two methods for measurement of plasma displacement are introduced; Comparison between Discrete and continuous coils are described. This paper describes how multiple moments of current- carrying plasma are calculated and used to construct sensing coils and derive the plasma displacement. Also the Fourier integration of the poloidal field by using continuous coils is calculated. For experimental stage, we designed and constructed two Rogowski coil & saddle coils around minor radius of IR-T1 Tokamak and contribution of each coil in horizontal direction is measured; finally the unwanted pickups from the time varying fields (Vertical, Ohmic and Toroidal) are compensated for accuracy in the final position output by modified coils. Detailed information will be send via a full paper,

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TuP28

DAMAGES OF CARBON-TUNGSTEN SAMPLES UNDER INFLUENCE OF DEUTERIUM IONS AND DENSE PLASMA STREAMS WITHIN PLASMA-FOCUS FACILITY

V.A. Gribkov[1-2)], Ye.S. Grebenschikova[1)], Ye.V. Demina[3)], A.V. Dubrovskij[1)], A.V. Kovtun[3)], O.N. Makeev[1)], K. Malinowski[4)], S.A. Maslayev[3)], V.N. Pimenov[3)], M. Paduch[1)], S.V. Rogozhkin[3)], M.J. Sadowski[2,4)], E. Skladnik-Sadowska[4)], M. Scholz[2)], A.G. Zaluzhnij[1)]

[1)] *A. I. Alikhanov Institute of Theoretical and Experimental Physics, 117218 Moscow, Russia.*
[2)] *Institute of Plasma Physics and Microfusion, 01-497 Warsaw, Poland.*
[3)] *A.A. Baykov Institute of Metallurgy and Material Science, 119991 Moscow, Russia.*
[4)] *A. Soltan Institute for Nuclear Studies, 05-400 Otwock-Swierk n. Warsaw, Poland.*

The paper reports on experimental studies of processes and results of the interaction of pulsed streams of fast deuterium ions (E_i ~100 keV) and dense deuterium plasma ($v_{pl} > 10^7$ cm/s) with samples made of carbon and tungsten. Power flux density of plasma/ions streams amounted to $q = 10^7 – 10^{10}$ W/cm^2 whereas and the duration of their pulses was within a range from 10^{-7} s to 10^{-6} s whereas a duration of heat pulses (due to a secondary plasma creation at the target's surface) was up to 10^{-4} s. The experiments were performed within the large PF-1000 plasma-focus facility operated at 700 kJ and with the pure deuterium filling. The carbon-tungsten samples were placed in the zone of their strong melting and evaporation (at a distance of 15 cm from the electrode outlet, where $q \sim 10^{10}$ W/cm^2) or in the zone without their considerable melting (at a distance of 65 cm from the electrode ends where $q \sim 10^7$ W/cm^2). Some measurements were performed also within the intermediate zone (at a distance of 35 cm). Each sample was exposed to 1 through 10 discharges.

The irradiated samples were investigated with optical-, electron- and atomic-force-microscopes. It was found that the interaction of intense plasma-ion pulses with the carbon-tungsten samples caused the formation of a wave-like relief upon the sample surfaces, the evident erosion of the sample material, as well as the creation of numerous micro-cracks (fractures) in the surface layer. The strongest damage of the investigated samples was observed at a small distance from the electrode outlet (where $q \sim 10^{10}$ W/cm^2). It was probably caused by intense pulses of fast ions (mostly deuterons of energies $E_i > 100$ keV) combined with intense plasma streams (carrying about 10^9 W/cm^2). The role of the fast ion streams was also important at larger distances, where the total power flux of both streams was $q \sim 10^9$ W/cm^2. In the considered cases the micro-cracks penetrating the material were in the range 10-30 μm in depth. At the largest distances the sample was bombarded both by streams of the fast ions and dense plasma carrying almost equal power fluxes ($q \sim 10^8$ - 10^9 W/cm^2). In that case one could also observe the partial melting of the surface layer, but the formed micro-fractures were not so deep.

Estimates of the erosion of the irradiated tungsten samples, evidenced by mass losses and a decrease in the sample thickness, have shown that one pulse of the fast deuterons and dense deuterium plasma with $q \sim 10^{10}$ W/cm^2 can induce the evaporation of the surface layer of about 2 μm in thickness. It was also found that the thin surface layer (of about 200 nm in thickness) of the irradiated tungsten sample contains many melted fragments of nanometer dimensions.

The presented results of research on pulsed interactions of the fast ions and plasma streams with the tungsten samples might be useful for preliminary estimations of the tungsten behavior in extreme situations, and particularly at operational conditions of fusion reactors based on the inertial or magnetic plasma confinement.

TuP29

Measurement of neutron yield from deuterium plasmas at JET by activation techniques

R.Prokopowicz*[1,3], M.Scholz[1], A.Szydłowski[2], S.Popovichev[4] and JET EFDA contributors**

[1] *Institute of Plasma Physics and Laser Microfusion, P.O. Box 49, 00-908 Warsaw, Poland;*
[2] *The Andrzej Soltan Institute for Nuclear Studies, 05-400 Otwock-Świerk, Poland;*
[3] *Institute of Atomic Energy, 05-400 Otwock-Świerk, Poland;*
[4] *EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon OX14 3DB, UK;*
** See the Appendix of M.L.Watkins et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA, (2006).*

Abstract

The neutron activation technique has been used at JET for a long time mainly to determine local neutron fluence at measuring points. These measurements were supported by neutron transport calculations in order to relate the neutron fluence to the total yield of neutrons from the plasma. Also the calibration of the time-resolved detectors was achieved in this way. However, this method could be more effectively used provided that many different elemental foils (activators) were exposed simultaneously. It is important then to find nuclear reactions with suitable cross section threshold values of the activation reactions to cover interesting energy interval 0.5 – 16 MeV, and especially close to 2.5 MeV. There exist a few nuclear reactions which have reaction threshold energy E_p in the range 0.5 – 3 MeV and relatively large and well-known cross-section, e.g.: ^{89}Y(n,n')^{89}Y, E_p~1 MeV, $T_{1/2}$=15.66 sec, ^{204}Pb(n,n')^{204}Pb, E_p~1 MeV, $T_{1/2}$=67.2 min., ^{167}Er(n,n')^{167}Er, E_p~0.8 MeV, $T_{1/2}$=2.27 sec. These reactions have not been used so far in JET experiment supposedly because most of their daughter nuclides decay with a half-life time $T_{1/2}$ of only a few seconds or minutes.

The paper reports on measurements made at JET to test usability of some of the aforementioned reactions in experiments planned on large plasma devices like JET or ITER to perform multi-foil neutron activation measurements. The paper demonstrates interesting results obtained also with other nuclear reactions (except of those listed above), such as ^{180}Hf(n,n')^{181}Hf, $T_{1/2}$=5.5 h, ^{111}Cd(n,n')^{111}Cd, E_p~0.2 MeV, $T_{1/2}$=48.54 min., ^{27}Al(n,p)^{27}Mg, E_p~2.5 MeV, $T_{1/2}$=9.46 min. Hafnium and yttrium have never been used in JET and in other high temperature plasma experiments.

Using more reactions allows to obtain more certain results. In order to apply at JET reactions producing short living daughters we propose in the paper some modification of the JET activation system, particularly to shorten a time of delivering sample to the HPGe detector.

* Corresponding author:
prokopowicz@ifpilm.waw.pl , tel. +48 226381460, fax. +48 226668372

TuP30

Cluster analysis of the International Stellarator Confinement Database

A. Kus 1), E. Ascasibar 2), A. Dinklage 1), J. H. Harris 3,4), S. Okamura 5), R. Preuss 1), F. Sano 6), U. Stroth 7), J. Talmadge 8), H. Yamada 2),

1) Max-Planck-Institut für Plasmaphysik, EURATOM-Association, Greifswald, Germany
2) Laboratorio Nacional de Fusión, EURATOM-CIEMAT, 28040 Madrid, Spain
3) Oak Ridge National Laboratory, Oak Ridge, USA
4) Australian National University, Canberra, Australia
5) National Institute for Fusion Science, Toki, Gifu 509-5292, Japan
6) Kyoto University, Kyoto, Japan
7) University of Stuttgart, Stuttgart, Germany
8) University of Wisconsin, Madison, USA

Scaling laws for stellarators are affected by clustering of data in control parameter space. Furthermore, several studies show that the existence of different physical regimes in the same data set deteriorates the statistical significance of regression analyses as well as Bayesian model comparison techniques. This contribution compiles the International Stellarator Confinement Database by physically motivated and statistical cluster analyses aiming at an identification of sparsely covered data regions. The result may guide experiment planning aiming at an increased significance of predictive scaling studies.

TuP31

Experimental study and simulation of W7-AS transient MHD modes

G. Pokol[1,2], G. Papp[1], G. Por[1], S. Zoletnik[3], W7-AS team[4]

[1] Department of Nuclear Techniques, BME, Association EURATOM, Budapest, Hungary
[2] Department of Radio and Space Science, Chalmers University of Technology, Göteborg, Sweden
[3] KFKI-RMKI, Association EURATOM, Budapest, Hungary
[4] Max-Planck-Institut für Plasmaphysik, Association EURATOM, Garching, Germany

It has been documented previously that transient MHD modes were present in pure ECRH W7-AS plasmas. The appearance of these modes has been shown to be in correlation with transient transport events (ELM-like modes). Here the spatial structure of the individual transients is analyzed using short-time Fourier transform and continuous analytical wavelet transform based techniques. Processing of Mirnov coil data largely confirms the properties derived from earlier, simpler analyses. In order to give a theoretical explanation to the properties of these modes (spatial structure resonant to magnetic structure and rapid damping) a simple diffusion based model is constructed, and calculations regarding shear Alfven waves are also presented.

TuP32

ECRH of over-dense plasmas in TJ-K

A. Köhn, H. Höhnle, E. Holzhauer, W. Kasparek, M. Ramisch, U. Stroth

Institut für Plasmaforschung, Universität Stuttgart, Pfaffenwaldring 31, Stuttgart

In the torsatron TJ-K, low-temperature plasmas are created by means of microwaves at 2.45 GHz and 8.25 GHz. The plasmas are characterized as over-dense which means that the cut-off is located at the plasma boundary. Studies in a wide parameter space show that power deposition happens dominantly at the upper-hybrid resonance. This can be seen in the electron-energy distribution function and the measured wave electric field.

Different antenna geometries were tested in order to influence the power deposition profile of the microwave at 2.45 GHz as well as at 8.25 GHz. For the investigation of the OXB mode conversion process, an array antenna has been developed where the direction of the incident wave beam can be modified by tuning the heating frequency from 8.0 to 8.4 GHz. First results from experiments with this antenna will be presented and compared with simulations from a full-wave code.

TuP33

Simultaneous excitation and analysis of three instabilities in magnetized plasma

D. G. Dimitriu[1,2], C. Ionita[2], R. W. Schrittwieser[2]

[1]*Faculty of Physics, Alexandru Ioan Cuza University, 11 Carol I Blvd., RO-700506 Iasi, Romania*

[2]*Institute for Ion Physics and Applied Physics, Leopold-Franzens University, Technikerstr. 25, A-6020 Innsbruck, Austria*

Experimental results are reported on the simultaneous excitation of three low-frequency instabilities in the magnetized plasma column of a Q-machine: the potential relaxation instability, the electrostatic ion-cyclotron instability and the Kelvin-Helmholtz instability. The potential relaxation instability and the electrostatic ion-cyclotron instability are excited by drawing an electron current parallel to the magnetic field to a circular collector. For exciting the potential relaxation instability, the radius of the collector has to be sufficiently larger than the ion gyroradius, so that the ion trajectories can be considered as one-dimensional. For exciting the electrostatic ion-cyclotron instability, the radius of the collector must be considerably smaller than that of the plasma column, but still in the range of a few ion gyroradii. A certain range of collector radii where both instabilities could be excited simultaneously was found. The Kelvin-Helmholtz instability appears in the edge region of a rotating plasma column, where a shear of the azimuthal flow exists. To obtain all three instabilities simultaneously, a circular collector with a certain diameter was placed in the edge region of a Q-machine plasma column and positively biased with respect to the plasma potential. The instabilities are identified in the power spectrum of the oscillations of the current to the collector. The static current-voltage characteristic of the collector reveals the existence of certain current jumps associated with the appearance of the instabilities. For low values of the magnetic field and high values of the potential applied to the electrode, the development of the Kelvin-Helmholtz instability leads to the suppression of the potential relaxation instability and a strong decrease in the coherence of the electrostatic ion-cyclotron instability. By increasing the magnetic field, first the coherence degree of the electrostatic ion-cyclotron instability increases, while the Kelvin-Helmholtz instability is suppressed and the potential relaxation instability re-appears. At high values of the magnetic field the coherence of the electrostatic ion-cyclotron instability decreases again, with the peak of the potential relaxation instability remaining dominant in the power spectrum of the current oscillations.

TuP34

Transition to chaos by type I intermittency in plasma

D. G. Dimitriu, S. A. Chiriac

Faculty of Physics, Alexandru Ioan Cuza University, 11 Carol I Blvd., RO-700506 Iasi, Romania

Double layers are nonlinear potential structures in plasma consisting of two adjacent space charge layers with opposite charges (electron and positive ions, respectively). A common way to obtain such a structure is to positively bias an electrode immersed into a steady-state plasma. In this case, up to a threshold value of the potential applied to the electrode, an intense luminous, almost spherical complex structure appears in front of the electrode, known as fireball or ball o fire. Experimental investigations have shown that such structure consists of a positive core (an ion-enriched plasma) confined by an electrical double layer. By further increasing the potential applied on the electrode, the structure passes into a dynamic state, in which the double layer periodically disrupts and de-aggregates. This dynamics determines the appearance of oscillations of some plasma parameters like the plasma density, the plasma potential or the current collected by the electrode. Up to a threshold value of the electrode potential, the double layer dynamics triggers an ion-acoustic instability in the unperturbed plasma column.

Here we report on experimental results that emphasize the development of a scenario of transition to chaos in plasma by type I intermittency, in connection with the nonlinear dynamics of a complex space charge structure as described above and with an ion-acoustic instability. The transition to chaos evolves by increasing the potential applied on the electrode. Regular ion-acoustic oscillations interrupted by random bursts were observed in the time series of the current collected by the electrode. At higher values of the potential applied on the electrode, the random bursts appear more frequently, the final state of the plasma system dynamics being a chaotic one. The phenomenon has been investigated by plotting the FFT's of the current oscillations and the reconstructed 3D states space of the plasma system dynamics.

TuP35

Cascade of spatio-temporal period-doubling bifurcations in connection with the appearance and dynamics of non-concentric multiple double layers in plasma

D. G. Dimitriu, L. M. Ivan

Faculty of Physics, Alexandru Ioan Cuza University, 11 Carol I Blvd., RO-700506 Iasi, Romania

Multiple double layers are complex space charge structures in plasma consisting of many double layers disposed into a concentric or non-concentric geometry, depending on the exciting electrode size and shape, as well as on the experimental conditions. The concentric multiple double layers appear as several bright and concentric plasma shells, attached to the electrode. The successive double layers are located at the abrupt changes of the luminosity between two adjacent plasma shells. The non-concentric multiple double layers appear as a network of intense luminous plasma spots, located near each other, almost equally distributed on the electrode surface.

Here, experimental results are presented that emphasize a complex route to chaos in plasma, in which a Feigenbaum scenario (cascade of temporal period-doubling bifurcation) develops simultaneously with a cascade of spatial period-doubling bifurcations, in connection with the appearance and dynamics of a non-concentric multiple double layers structure. By gradually increasing the voltage applied on a rectangular electrode immersed in plasma, new plasma spots appear on the electrode surface (spatial period-doubling bifurcations) simultaneously with the appearance of sub-harmonics in the power spectrum of the oscillations of the current collected by the electrode (temporal period-doubling bifurcations). In this case, we can speak about spatio-temporal period-doubling bifurcations in plasma. We mention that a similar phenomenon was also experimentally observed in connection with the concentric multiple double layers. So, our results confirm the assumption that a common physical model stays at the origin of the appearance and dynamics of both types of multiple double layers structures.

TuP36

A 3D computer simulation of negative ion extraction influenced by electron diffusion and weak magnetic field

M. Turek[a] and J.Sielanko[b]
[a)] *Institute of Physics, Maria Curie-Skłodowska University, Lublin, Poland*
[b)] *Institute of Computer Sciences, Maria Curie-Sklodowska University, Lublin, Poland*

Neutral beam injection is considered as the most promising candidate for plasma heating technique in future fusion devices. The development of NBI systems based on negative ion beam (more efficient neutralization for higher beam energy compared to positive ion beams) requires detailed knowledge about negative ion production and transport phenomena, as well as beam extraction and formation. The computer simulations help to understand mentioned above processes and support design and optimization of powerful plasma ion sources

It was experimentally shown that weak transversal magnetic field improves negative ion extraction [1] by stopping electrons and increasing negative ion flow into extraction area. Such effect was also confirmed by two- [2] and three-dimensional [3] particle-in-cell (PIC) simulations. We used PIC based, 3D code [4] which follows trajectories of charged particles in self-consistently determined electric field and static magnetic field in order to investigate extraction of H^- ions by two types of multi-aperture grid systems similar to those tested at IPP Garching. Transversal (with respect to extraction direction) magnetic field was applied in the extarction region, as in our previous work. Additionaly, the random-walk electron diffusion model [5] has been implemented. The electron diffusion enables electrons to travel across magnetic field and suppress tendency to create unphysical aggregations in the magnetic field area. Influence of magnetic field strenght on negative ion extraction current is investigated for different extraction grid systems. Results are compared for cases with and without electron diffusion taken into account.

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TuP37

NUMERICAL TESTS SHOWING THE INFLUENCE OF (∇ B) AND TEMPERATURE FLUCTUATION ON PLASMA CONFINEMENT IN TOKAMAK

M.Ghabbouri, D.saifaoui, A.Boulezhar, M. El mouden

Laboratory of Theoretical Physics, Faculty of Sciences, Ain Chock, Casablanca, Morocco.

Abstract:

The most important improvement that can be obtained for confinement is the great reduction of particles transport caused by barriers transport occurring at plasma core, these barriers prevent the radial diffusion of particles, for this purpose we have exhausted a set of simulations by solving the mapping equations with introducing the term **∇ B**, and studying the sensitivity of reversed shear (responsible to the creation of transport barriers) against the variation of different parameters like as q security factor profiles and the potential applied Φ_0. different numerical results will be present to show how to improve the confinement if we taking into account the plasma temperature, magnetic field gradient and the variation of q and Φ_0, these studies tell us what to be done for improving the confinement.

Key words: plasma confinement, tokamak, anomalous transport, magnetic shear, transport barrier, particle diffusion, radial electric field, enhanced confinement

TuP38

Influence of the instability regime on the cross-field transport

S.Oldenbürger, N.Lemoine, F.Brochard, G.Bonhomme
Laboratoire de Physique des Milieux Ionisés, Université Henri Poincaré, BP 239, F-54506 Vandoeuvre-lès-Nancy Cedex, France

Radial transport is characterized in a magnetized low-beta cylindrical plasma. Several instability regimes, i.e. drift waves and flute modes, are selected by varying the radial electric field and consequently the rotation of the plasma column [1]. The fluctuation induced transport is measured for both kinds of instabilities in the case of regular modes and turbulent states as well. Control and synchronization techniques, involving the use of an electric octagonal exciter, are applied to the weakly turbulent states [2]. The influence of the control on the convective transport is discussed.

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TuP39

Wave propagation and diffusive transport of oscillations in pair plasmas

[1] ***Andrzej J. Turski IFTR PAS*** aturski@ippt.gov.pl
[2] ***Barbara Atamaniuk IFTR PAS*** batama@ippt.gov.pl

In view of applications to electron-positron and fullerene *pair plasmas,* a thorough discussion is given of the two-component plasmas. Space-time responses of many-component linearized Vlasov plasmas on the basis of multiple integral equations are considered. An initial-value problem for Vlasov-Poisson/Ampère equations is reduced to the one multiple integral equation and the solution is expressed in terms of forcing function and its space-time convolution with the resolvent kernel. The forcing function is responsible for the initial disturbance and the resolvent is responsible for the equilibrium velocity distribution. By use of resolvent equations, time-reversibility, space-reflexivity and other symmetries are revealed. The symmetries carry on physical properties of Vlasov pair plasmas, e.g., conservation laws. Properly choosing an equilibrium distribution for pair plasma, we can reduce the resolvent equation to

- An undamped dispersive wave equation
- Or diffusive transport equations of oscillations.

We have to do with anomalous diffusion employing fractional derivatives in time and space. Linkage between the space-time variables leads to new type of fractional derivative operators. Fractional diffusion equations account for typical *"anomalous"* features, which are observed in many systems, e.g. in the case of dispersive transport in amorphous semiconductors, liquid crystals, polymers, proteins and biosystems. In contrast to the Gaussian diffusion, fractional diffusion is related to LÈVY STABLE NON-GAUSSIAN PROCESSES. The typical features of the processes are heavy tails of probability density distributions. Conservation laws in relation to the fractional diffusion are discussed.

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TuP40

Characterization of a Filtered Pulsed Cathodic Vacuum Arc Plasma Source: Plasma Transport Analysis.

R. Sangines[1], R.N. Tarrant[1], M.M.M. Bilek[1], D.R. McKenzie[1], and D. Andruczyk[1,2].

[1] *School of Physics, The University of Sydney, NSW 2006, Australia*

[2] *Max-Planck Institute for Plasma Physics, Greifswald, 17491, Germany*

Abstract. Studies of plasma behaviour produced by a filtered high current pulsed cathodic vacuum arc system are reported. A titanium plasma is ablated from the cathode by surface flash over triggering at the centre of the cathode disk. The multiple spots move outwards due to their mutual repulsion and the arc current pulse is terminated when they reach the edge of the cathode disk. The plasma moves into a positively biased quarter-torus magnetic filter and is guided towards the substrate position located at its exit. Electron density and plasma current measurements have been employed to analyse the transport of the plasma produced by different cathode currents, and its dependence on confining magnetic field and bias conditions. The optimum transport to the substrate requires the right combination of the strength of the confining magnetic field and the magnetic filter bias. The optimum values of these two parameters were found to increase with increasing cathode current. Initially the optimum through put of plasma increases more strongly than the arc current (roughly 1.5 times the increase in the current); however, at high cathode current regimes (2.4 kA) a significant change of the plasma behaviour is seen and transport efficiency is reduced.

TuP41

Reduced nonlinear description of Farley-Buneman instability.

[1] *Barbara Atamaniuk IFTR PAS* batama@ippt.gov.pl
[2] *Alexander A. Volokitin ITMIRP,SRI RAN,* volokitin@space.ru
[3] *Andrzej J. Turski IFTR PAS* kzucho@ippt.gov.pl

The study on nonlinear wave-wave interaction is an essential part of researches of wave processes in an ionosphere and a magnetosphere. Usually the main attention is paid to investigation of plasma turbulence at well developed stage, when the wide spectrum of plasma wave is present. On the other side, it is well known that even system with finite number of interacting waves can realize a turbulent state in active media. In such cases, when the number of cooperating waves remains small due to a competition of processes of their instability and attenuation, the turbulence appears in the result of their stochastic behavior. The perturbed ionospheric plasma is one of important example of such active media. The regimes of nonlinear stabilization of instability of low frequency waves in magnetized, weakly ionized and inhomogeneous ionospheric plasma are considered. The wave are excited due to Farley-Buneman instability in the presence of electric current perpendicular to ambient magnetic field, or due to one of the drift instabilities appearing in strongly inhomogeneous plasma or due to the both factors. At conditions when electrons are magnetized and characteristic time of density oscillations exceed the rate of electron ion collisions the drift of electrons perpendicular to magnetic field is the main motion. Consequently, the main nonlinearity appears in result of convection of a density perturbation in one wave by another wave in the perpendicular to magnetic field and mathematically is expressed in a specific vector form. Thus the problem is essentially three dimensional and difficult for full numerical simulation. The strong collisional damping of waves allow to assume that in the considering case a typical perturbed state of plasma can be described as finite set of interacting waves, some of which are unstable and other strongly damping. The dynamic of this set of waves now can be described by mathematical system of ordinary differential equations of kind, which describe auto oscillations. This allow to avoid difficulties of 3D simulations and to make full study of nonlinear stabilization, conditions of stochasticity and to consider the different regimes and properties of few plasma turbulence in the conditions when the number of interacting waves keeps small by the strong competition of processes wave damping and instabilities.

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TuP42

The role of the electron energy balance in Hall thruster plasma instabilities

Z. Peradzyński[1,2], K. Makowski[1], ,S. Barral[1], J. Kurzyna[1], Dudeck[4]

[1]Institute of Fundamental Technological Research, Polish Academy of Sciences,
[2]Institute of Applied Mathematics & Mechanics, Warsaw University,
[4]Laboratoire d'Aérothermique du CNRS Orleans, France

The simple fluid description of the hall thruster plasma uses a hyperbolic system of four equations

$$\frac{\partial N_a}{\partial t} + V_a \frac{\partial N_a}{\partial x} = -\beta N_a n_e \qquad (1)$$

$$\frac{\partial n_i}{\partial t} + \frac{\partial (n_i V_i)}{\partial x} = \beta N_a n_e \qquad (2)$$

$$\frac{\partial V_i}{\partial t} + V_i \frac{\partial V_i}{\partial x} + \frac{1}{n_e}\frac{\partial}{\partial x}\left(\frac{kT_e}{m_i} n_e\right) = -\nu_{eff}\left(\frac{I}{n_i e} - V_i\right) + \beta N_a (V_a - V_i) \qquad (3)$$

$$\frac{\partial}{\partial t}(kT^{3/2}) + \frac{\partial}{\partial x}(V_e kT_e^{3/2}) = Q\,, \qquad (4)$$

for N_a- the density of neutrals, n_i- ion density (=electron density), V_i – axial ion velocity and T_e – electron temperature. The Ohm law (i.e. the reduced electron momentum balance) is used to determine the Electric field. $\beta = \beta$ is the ionization rate and V_e is the electron axial velocity field, which can be expressed in terms of ion velocity and the total current density *eI*: $V_e = V_i - \frac{I}{n_i}$. The total current density $I = I(t)$ can be determined from the boundary condition $\int_0^L E dx = V_0$ to obtain

$$I(t) = \left(\int_0^L \frac{\nu_{eff}}{e n_i} dx\right)^{-1} \cdot \left[\frac{e}{m_i} U_0 + \int_0^L \left(\nu_{eff} V_i + \frac{1}{n_i}\frac{\partial}{\partial x}\left(\frac{kT_e}{m_i} n_i\right)\right) dx\right]$$

The source term

$$Q = [2 V_e E_{kd} - \beta N_a (\gamma E_i + \frac{3}{2} k T_e)] \sqrt{kT_e} \qquad (5)$$

is the a difference of two relatively large terms, gains and losses. E_{kd} denotes here, the energy of the axial (V_e) and the azimuthal (V_θ) motion of the electron fluid; it can be expressed by V_e in terms of cyclotron frequency, and electron collision frequency:

$$E_{kd} = \frac{m}{2}(V_e^2 + V_{e\theta}^2) = \frac{m}{2}\left(1 + \frac{\omega_B^2}{\nu_e^2}\right) V_e^2$$

The system (1)-(4) has four real characteristic velocities, which are responsible for the propagation velocities of short wave disturbances of neutrals, of ion sound and electron temperature respectively. They are:

$$V_a \quad , \quad V_i - \sqrt{(\frac{5}{3}\frac{k}{m_i}T_e)} \quad , \quad V_i + \sqrt{(\frac{5}{3}\frac{k}{m_i}T_e)} \quad , \quad V_e \, .$$

If the frequency (hence the wave number) is high enough RHS of these equations are not influencing the propagation velocity. For lower frequency however its influence can manifest very drastically. Especially, the electron energy equation plays an important role in such a case, since its source term (5) is composed of two large terms of opposite signs. This source term introduces a relaxation time τ, and characteristic frequency $\omega_c = \tau^{-1}$, which is equal to $\omega_c = \frac{\partial}{\partial T_e^{3/2}} Q$. Thus for $\omega < \omega_c$, the left hand side of Eq.(4) can be neglected and the electron temperature can be determined from "zero order equation" $Q(T_e, V_i, n_i, N_a, x)=0$. In this way one arrives at the new ion momentum equation

$$\frac{\partial V_i}{\partial t} + V_i \frac{\partial V_i}{\partial x} + \frac{k}{m_i}\left\{\left(T_e + T_{e,V_e}\frac{I}{n_i}\right)\right\}\frac{\partial}{\partial x}\ln n_i + \frac{\partial T_e}{\partial N_a}\frac{\partial N_a}{\partial x} = f \qquad (6)$$

instead of Eq.(3), where $T_{e,V_e} = \frac{\partial}{\partial V_e} T_e$. The so obtained system (1), (2), (6) has new characteristic velocities: $\lambda_0 = V_a$, $\lambda_{1,2} = V_i + \frac{k}{2m_i}T_{e,V_e} \pm \sqrt{\theta + (\frac{k}{2m_i}T_{e,V_e})^2}$

where $\theta = \left(T_e + T_{e,V_e}\frac{I}{n}\right)$

We have however: $T_{,V_e} = -\frac{Q_{,E\,kd}}{Q_{,T\,e}}E_{V_e} =< 0$, which shows that for some values of discharge parameters the characteristics of the new system of equations may become complex valued. This however implies immediately instability of propagating disturbances. The typical value for the critical frequency in case of SPT-100 is $\omega_c = 10^7$. This suggests that the energy equation may significantly contribute to the generation of instabilities in the range of low and medium frequency instabilities.In [1] the so called transite time instability was studied on the basis of isothermal model of plasma discharge. We will show however that the presence of the electron energy balance change considerably results.

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TuP43

SOLITARY WAKE – HUMP OF ELECTRICAL POTENTIAL

V.I.Maslov, A.M.Egorov, I.N.Onishchenko, E.Svistun*
NSC Kharkov Institute of Physics & Technology, 61108 Kharkov, Ukraine
*Karazin Kharkov National University, Kharkov, 61108, Ukraine
e-mail: vmaslov@kipt.kharkov.ua

One method of wake – field excitation is by single electron bunch or laser pulse. If perturbation's group velocity is close to driver's velocity or if a driver is impulse, then it is short. Really in [1] together with packet the wake – soliton has been excited. In [2] the properties of envelope soliton for vector potential and solitary hump of electrical potential have been investigated. At formation of wake – electron – hole [3-6] the electrical potential distribution is hump. However without trapped electrons the analytical solution is derived as dip but hump, induced by driver, is nonstationary. In this paper the properties of solitary hump is described with taking into account trapped electrons. It is shown that they stabilize hump. The hump's properties are investigated in adiabatic electron dynamics as well as in nonadiabatic trapped electron dynamics for small and large amplitudes.

One perspective method of electron acceleration by wake – field is the acceleration of monoenergetical electron beam by bubble, excited by electron bunch or laser pulse [5-8]. It has been observed that nonstationary vortical electron dynamics is realized in the wake - field of electron bubble. In this paper by analogy with [9-11] the exact nonlinear vector equation is derived without any approximations. This equation describes vortical electron motion of Rossby type in the wake – field of electron bubble. This equation connects the electron vorticity and perturbations of electron density and wake magnetic field. Also the connection of the electron vorticity and wake magnetic field is estimated.

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TuP44

CONTROL OF PARTICLE DYNAMICS IN PLASMA DISCHARGE OF SOURCE OF EXTREME ULTRAVIOLET RADIATION

V.I.Maslov, N.A.Azarenkov*, V.T.Lazurik*, A.Svistun*, A.F.Tselujko*
NSC Kharkov Institute of Physics and Technology, Kharkov 61108, Ukraine
*Karazin Kharkov National University, Kharkov, 61108, Ukraine
E-mail: vmaslov@kipt.kharkov.ua

The particle dynamics in a plasma discharge source of the extreme ultra-violet (EUV) is considered. The problem of the EUV generation in economic compact systems is important and EUV is widely applied. In particular, this radiation is very important for lithography. At first, we consider Z-pinch evolution in this discharge. Namely, radial and longitudinal dynamics of the cylindrical plasma column in the discharge with the large voltage, applied to it, is considered. One can increase the energy of the EUV radiation due to improvement of plasma confinement. Here we show that the use of the external magnetic field H_0 can reduce the energy losses and improve the plasma uniformity in cylindrical plasma discharge. Such H_0 does not prevent to recreation of the breaken plasma column along the direction of H_0. However it prevents to the column expansion up to its recreation and restoration of a longitudinal current. Thus, the time, necessary for the following pinch formation, is smaller. Also the energy expenses also is smaller. At presence of H_0 of the certain value the velocity of the expansion of the broken of plasma column in the radial direction approximately on two order is smaller than the velocity of the recreation the broken off plasma column.

On some time interval the electric double layer (DL) appears in EUV source, which helps plasma heating and plasma density increase. After strong plasma density and temperature increase DL disappears. The short magnetic coil is used for spatial stabilization of DL. The electron beam, formed by this DL, is used for intermediate plasma heating and ionization. Approximately all potential drop applied to the discharge is concentrated in DL. The potential difference in DL is 500V. When the plasma with the density higher than the critical one is formed in the system, the magnetic field inhomogeneity is self-consistently suppressed; DL is destroyed.

We consider the behavior of the plasma flow, propagating into the cylindrically symmetrical magnetic field of the short coil along its axis in the EUV source. We consider values of the external magnetic field in a range in which its effect on electrons is essential, and on positive ions its effect can be not taken into account. As a result of interaction of the plasma flow with coil the plasma flow radius decreases. We derive parameters at which widening of the plasma flow under the effect of the pressure is minimum.

It is shown that for fixed plasma flow velocity and radius and also for fixed ratio of length and diameter of the magnetic coil there is the optimum value of the magnetic field for the best control of the plasma flow and for small widening of this flow. For the smaller and larger magnetic field values, the control of the plasma flow is essentially worse. The connection of the optimum magnetic field value, velocity and radius of the plasma flow and ratio of length and diameter of the magnetic coil, are derived.

Electron vortices can be excited in cylindrical plasma of finite length in EUV source with crossed radial electric and longitudinal magnetic fields. We consider the possibility of ionization of multi – charged ions by these vortices. It is shown that the energy of electron rotation in the excited vortices is large and sufficient for multi – charged ion generation.

TuP45

MHD Modelling of Flow Phenomena during the Impulse Plasma Deposition Process

M. Rabiński[1)], K. Zdunek[2)]

[1)] The Andrzej Soltan Institute for Nuclear Studies (IPJ), 05-400 Otwock-Swierk, Poland, rabinski@ipj.gov.pl

[2)] Warsaw University of Technology, Woloska 141, 02-507 Warsaw, Poland

The paper presents recent computational studies of plasma dynamics in a coaxial accelerator used in surface engineering for Impulse Plasma Deposition (IPD). In our earlier studies we proposed a schematic pattern of a discharge region and a physical model of dynamic phenomena in the IPD accelerator with a tubular external electrode. The simplified snow plow code of our previous studies assumes that all the swept up mass is compressed into an infinitely thin layer immediately behind the shock. In the presented work the complete two-dimensional two-fluid magnetohydrodynamic model has been applied to investigate the sweeping of the working gas by the moving layer as well as the details of phenomena that take place behind a current sheet.

The modified and extended version of code [1] originally evaluated by D.E. Potter [2] for the modelling of Plasma-Focus devices has been applied to investigate formation and evolution of the discharge region. A strict correlation of the calculated flow phenomena obtained during the numerical simulation and an observed erosion pattern has been found. Results of the modelling allowed interpretation of some previous experimental observations [3].

It has been found previously that the conditions behind the front face of the electrodes favour initiation of the Rayleigh-Taylor instability on the current sheet surface [4]. Later the toroidal region of dense plasma is continuously supplied with the gas swept away by the current layer, which enhances the instability. Within the plasmoid volume nitrogen plasma is enriched with the erosion products, eg. titanium for TiN coatings. Thus the plasmoid structure plays crucial role for the phase composition of material that is synthesized during the IPD process. Presented computational model allows to investigate the process in question and to indicate the direction of the accelerator design modifications.

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PROGRAMME Wednesday, October 17, 2007

A.E. Costley, *ITER Cadarache*	We1-1	ITER diagnostics	8:30
V.S. Voitsenya, *NSC KIPT Kharkov*	We1-2	Material dependence of the contamination film growth on in-vessel mirrors for plasma diagnostics	9:15
V.I. Tereshin, *NSC KIPT Kharkov*	We1-3	Surface modifications and treatments under influence of plasma streams in wide range of heat loads	9:30
Y.A. Kravtsov, *Space Moscow, Uni Szczecin*	We1-4	Quasi-isotropic approximation and Stokes vector formalism: interrelation between two approaches in plasma polarimetry	10:00
Coffee			10:30
R. König, *IPP-Greifswald*	We2-1	Diagnostic developments for quasi-continuous operation of the Wendelstein 7-X stellarator	10:50
H. Thomson, *IPP-Greifswald*	We2-2	The steady state challenge for the X-ray tomography system on Wendelstein 7-X stellarator	11:20
J. Sarközy, *KFKI-RMKI Budapest*	We2-3	Video diagnostics for W7-X stellarator	11:35
L. Krupnik, *NSC KIPT Kharkov*	We2-4	Recent results and short review on electric potential measurements by HIBP diagnostic	11:50
S. Bondarenko, *NSC KIPT Kharkov*	We2-5	Test bench calibration of the double-slit ion energy analyzer for HIBP diagnostics	12:05
Lunch			12:20
O. Schmitz, *FZ Jülich*	We3-1	Application of advanced edge diagnostics for transport studies on the stochastic boundary of TEXTOR-DED	14:00
M. Krychowiak, *IPP Greifswald*	We3-2	LIF measurements on an atomic helium beam in the edge of a fusion plasma	14:30
E.O. Baronova, *Kurchatov Moscow*	We3-3	The influence of Stark-effect on the shape of He-like lines in dense plasma	14:45
S Ksiasek, *Uni Opole*	We3-4	Study of longitudinal distribution NeI line radiation in plasma produced in wall-stabilized d.c. arcs applying Ar and He as working gases	15:00
G. Popa, *Uni Iasi, Romania*	We3-5	On the diagnostics methods of the rather dense and magnetized plasma	15:15
S. Noack, *Uni Leipzig*		Spectroscopic analysis of long living plasmoids at atmospheric pressure	15:45
Coffee			16:00
Poster	WeP	1 - 45	16:00
G. Fußmann, *HU Berlin*		Ball lightning - an old puzzle revisited	18:00

We1-1

ITER Diagnostics

A E Costley

ITER Organisation, Cadarache, France

The implementation of diagnostics on ITER will be a major challenge, arguably the most difficult ever undertaken in plasma diagnostics. The number and type of plasma and first wall parameters that will have to be measured will be very similar to those measured on today's large devices, but the specification of some of the measurements, such as relative spatial resolution and accuracy, will be more demanding. More measurements will be used in active feedback control, and since the tokamak will be operating close to operational limits with very high levels of stored energy, high reliability in the diagnostic systems will be essential. On the other hand, the environment of ITER will be very harsh compared to those experienced on today's machines. In-vessel components will be exposed to high levels of neutron and gamma radiation, neutron heating and particle bombardment. The flux levels will be typically 10 times higher than the maximum reached on present machines; the neutron heating will be typically 1 MW/m^3 compared to essentially zero on existing machines, but the most significant extrapolation is in the pulse length: this will be up to several thousand seconds, that is 100 times longer than that typical on present-day machines and, combined with the higher flux levels and planned high number of plasma pulses (30,000), means that the end-of-life fluence levels experienced by in-vessel diagnostic components will be more than 10^5 times higher. As a consequence, many phenomena that relate to the physical properties of materials, and how they are changed by irradiation, have to be taken into account in diagnostic design for the first time. Phenomena such as radiation induced conductivity and radiation induced EMF that can occur in cables, radiation induced absorption and radio luminescence in optical materials, erosion and deposition on mirrors, all have to be considered. This is new territory for diagnostic design and requires dedicated R&D to generate the necessary knowledge base. In parallel, the identification and development of diagnostic techniques that are better suited to the ITER environment is also needed. Since the early days of ITER, these issues have been tackled in a co-ordinated programme involving all ITER partners and a comprehensive diagnostic system is being prepared.

In the paper an overview of the diagnostic system will be given and the special measures being taken to cope with the ITER environment will be described. Areas where further development are needed will be highlighted.

e-mail of corresponding author: Alan.Costley@iter.org

We1-2

MATERIAL DEPENDENCE OF THE CONTAMINATING FILM GROWTH ON IN-VESSEL MIRRORS FOR PLASMA DIAGNOSTICS

V.S.Voitsenya[a], G.De Temmerman[b], M.Lipa[c], R.A. Pitts[d], B. Schunke[e]

[a]*Institute of Plasma Physics, NSC KIPT, Akademichna St. 1, 61108 Kharkov, Ukraine;*
[b]*Center for Energy Research, University of California at San Diego, La Jolla USA;*
[c]*CEA/Cadarache- DRFC, F-13108 Saint Paul lez Durance, France;*
[d]*EPFL, Centre de Recherche en Physique des Plasmas, Assoc. EURATOM, Lausanne, Switzerland;*
[e]*ITER, Cadarache,F-13108 Saint Paul lez Durance, France*

voitseny@ipp.kharkov.ua

All optical diagnostics systems in ITER have to be based on mirrors [1]. The probable deterioration of their reflectivity due to erosion by charge exchange neutrals and/or re-deposition of material eroded from plasma facing components [2] represents a serious concern for the reliability of the spectroscopic and laser measurements. Until recently, these damaging effects (erosion and deposition) were considered independently, neglecting the role the mirror material may play. To assess this from two different situations, both simulation mirror exposures in Tore Supra (TS) and TCV tokamaks, and in laboratory experiments were made.
Two sets of mirror samples (single crystal Mo and polycrystalline SS, Cu) were installed on the high field side of the TS torus and exposed for the one-year-experimental campaign without protection from plasma impact including long lasting glow discharges and cleaning procedures [3]. After exposure all samples were found to be eroded, though the measured eroded depths did not correspond to the sputtering yields published. Namely, the difference between erosion of SS and Cu exceeded 15 and the difference between SS and Mo erosion was less than factor 2 in comparison with corresponding values ~2.5 and ~10 known from [4].

In TCV, the mirrors (Mo, W, Si) were installed in the divertor region, recessed behind the front surface of the graphite divertor tiles to avoid direct plasma impact. They were exposed for campaign periods of 2-3 weeks, including conditioning with regular helium glow discharges. Under identical exposure conditions the mirror substrate was found to strongly influence the deposit thickness found on the sample: the carbon layer thickness on a Si sample was found to be about five times higher than on a Mo substrate.

To explain these results we took into account that the sputtering of the mirror and the re-deposition of contaminants take place simultaneously: if the flux of contaminants is small the sputtering of mirror material begins to be significant. In the opposite case the erosion of material can become small due to gradual deposit growing and protecting the mirror surface. The criterion for the contaminants flux to be ‘small’ depends not only on the experimental conditions but also on the mirror material. For example, the case of a mirror of carbide forming metal has to be distinguished from the case when stable carbides of the mirror material do not exist. In other words, the difference in ‘stickiness’ of carbon to the mirror material is the key issue for the evolution of optical properties of in-vessel mirrors in fusion devices with carbon-based protection of vessel walls, like the TS or TCV tokamaks with graphite limiters. In the TS mirror experiment such strong differences are observed for stainless steel and copper, and in TCV – for Mo and Si. These results were qualitatively supported by laboratory experiments in Basel University [5] and in Kharkov (Cu and SS mirrors).

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We1-3

SURFACE MODIFICATIONS AND TREATMENTS UNDER INFLUENCE OF PLASMA STREAMS IN WIDE RANGE OF HEAT LOADS
(Invited Lecture)

V.I.Tereshin, V.V.Chebotarev, I.E.Garkusha, V.S.Taran

Institute of Plasma Physics, NSC KIPT, 61108 Kharkov, Ukraine
tereshin@ipp.kharkov.ua

The paper presents results of recent experimental studies on the plasma-surface interaction in the wide range of plasma streams heat loads 0.15-40 MJ/m^2 and time duration 3-300 μs. In the case of large heat loads > $1MJ/m^2$ and long pulses plasma parameters were adequate to ones of plasma flow to the diverter plates in tokamak-reactor ITER under off normal events. Such plasma parameters were achieved in quasi-steady-state plasma accelerators (QSPA) [1]. The QSPA device became especially attractive facilities for investigations of plasma-surface interaction in conditions of high heat loads simulating the ITER disruptions and ELMs.

The plasma streams of different working gases (hydrogen, nitrogen, helium and their mixtures) with low heat loads (0.1-0.5 MJ/m^2) were generated with pulsed plasma gun in Prosvet device [2]. Under such heat loads a surface modification is provided resulting to essential increasing the tribological characteristics of the metal surface layers, their corrosion characteristics and so on. The surface treatment with pulsed plasma streams was carried out also for metal samples coated preliminary in Bulat device [3] with using both arc discharge and combined arc and high frequency one. Such combined treatment provided obtaining the mixed surface layers (consisting of film and substrate materials) of new quality.

The surface morphology, material structure and element content, erosion characteristics and other properties of different materials (tungsten, graphite, combined tungsten-graphite target, and other materials) were analyzed under surfaces irradiation with plasma heat loads typical for disruptions and repetitive ELMs in ITER. Variation of the heat load value provided carrying out the irradiated surface analysis in conditions of its before melting point, melting and evaporation. Experiments with preliminary heated targets (up to the temperature 650 ^{0}C) were done also. Formation of the submicron cell structures as well as nanostructures at the tungsten surface layer under plasma irradiation was found and investigated. Blister formation at the tungsten surface (heated above the DBTT temperature) was observed under surface irradiation with hydrogen plasma.

Under the plasma irradiation by pulsed nitrogen plasma streams with energy density (10-15) Дж/см^2 the essential increase of surface wear resistance of structural steels was measured both for non quenched (by 10-15 times) and preliminary quenched (by 6-8 times). Simultaneously, improvement of corrosion properties of structural steels (and also permanent magnets) surfaces was obtained. The exposed metal surface (40H) is characterised by higher broadening of diffractional reflections. This can be interpret as amorphisation of a surface layer. On the base of X-ray analysis the period of γ-Fe crystal lattice for 12HN3A samples was measured. For plasma treated samples it was equal a=3.6256 A, i.e. considerably exceeds one of non treated samples (a=3.5264 A).

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We1-4

Quasi-isotropic approximation and Stokes vector formalism: interrelation between two approaches in plasma polarimetry

Yu.A. Kravtsov[1,2)], B. Bieg[2)], K.Yu.Bliokh[3)], M.Hirsch[4)]

[1)]Space Research Institute, Profsoyuznaya St. 82/34, Moscow 117997, Russia
[2)]Institute of Physics, Maritime University of Szczecin, 1-2 Waly Chrobrego St., Szczecin 70500, Poland
[3)]Institute of Radio Astronomy, 4 Krasnoznamyonnaya St., Kharkov 61002, Ukraine
[4)]Max Planck Institute for Plasma Physics, Greifswald, Wendelsteinstrasse D-17491, Germany

Abstract

Quasi-isotropic approximation (QIA) of geometrical optics method is presented, which describes evolution of electromagnetic waves in weakly anisotropic media on the basis of coupled differential equations. Being applied to inhomogeneous magnetized plasma, QIA embraces both Faraday effect and Cotton-Mouton phenomenon. It is shown that equation for Stokes vector evolution, which is widely used in plasma polarimetry, can be derived directly from QIA, what evidences deep unity of two approaches under consideration. In the same time QIA equations suggest noticeably more information than Stokes vector approach. In particular, in distinction to equation for Stokes vector they describe the phase, common for both components of the electromagnetic field, take into account curvature and torsion of the ray, and allow specifying area of applicability of the method. Besides, coupled QIA equations can be reduced to a single equation for complex polarization angle, which allows computing traditional parameters of polarization ellipse without solving the equation for Stokes vector. The results under consideration might be applied for solution of the inverse problems of plasma diagnostics.

We2-1

Diagnostic Developments for Quasi-Continuous Operation of the Wendelstein 7-X Stellarator

R. König[a], J. Cantarini[a], K. Grosser[a], D. Hildebrandt[a], M. Hirsch[a], G. Kocsis[b], P. Kornejew[a], M. Laux[a], E. Pasch[a], S. Recsei[b], V. Szabó[c], H. Thomsen[a], A. Weller[a], A. Werner[a], R. Wolf[a], M. Ye[a], S. Zoletnik[b]

[a]Max-Planck-Institut für Plasmaphysik, Euratom Association, Wendelsteinstr. 1, 17491 Greifswald, Germany
[b]KFKI-Research Institute for Particle and Nuclear Physics, Euratom Association, H-1121 Budapest, Konkoly Thege 29-33, Hungary
[c]Budapest University of Technology and Economics – Department of Applied Mechanics, Euratom Association, P.O. Box 91, H-1521, Budapest, Hungary

The stellarator W7-X will be equipped with quasi-continuous ECRH heating power of 10 MW at 140 GHz, the pulse length at full power only being limited to 30 minutes by the size of the cooling water reservoir. Monte Carlo simulations show that diagnostic components in direct view of the plasma will be exposed to heat loads of 50–100 kW/m^2 by plasma radiation alone. At some locations additional convective losses can result in even higher total heat loads of up to 500 kW/m^2.
We will report about our efforts to find, for various types of diagnostics, ways to cope with high heat loads during long pulse discharges. Without any cooling, components exposed to heat loads of 50 kW/m^2 can easily reach their radiation equilibrium temperature of the order of 700 °C within 5-10 min. To avoid such temperature excursions we are for example developing actively water cooled windows, which are particularly needed for high optical throughput diagnostic observation systems. Where light levels permit, observation through a pinhole is usually the method of choice. An ITER-like IR/visible endoscope design study for divertor control and observation as well as the design of a toroidal view video diagnostic will be presented. For the interfero-polarimeter as well as for the multichannel interferometer high heat load compatible retroreflectors, which will be integrated into the carbon tiled heat shield at the inner wall, are presently being designed. The thermal analysis of the divertor integrated pop-up Langmuir probe arrays showed that the probe tip temperature can be limited to an acceptable equilibrium value of less than 300°C. Diagnostics like the soft x-ray multi camera tomography system (XMCTS) and the diamagnetic loops, which might be exposed to significant convective loads, require a baffle like cooling structure made of clamped carbon tiles. In particular for the XMCTS a detailed thermal analysis of the entire system was necessary to design the independent cameras cooling system. In addition a small vacuum compatible shutter is being developed to be able to close the camera observation pinhole for calibration purposes during long pulse discharges.
In high density discharges a further problem arises from high ECRH stray radiation levels toroidally varying from 50–200 kW/m^2, requiring appropriate shielding measures to be taken to avoid serious damage to diagnostic components made of absorbing materials.
For the magnetic diagnostics a special digital integrator has been developed which in the lab already demonstrated its suitability for one hour discharges and which has already successfully demonstrated its suitability on the small classical stellarator WEGA.

We2-2

"The steady-state challenge for the X-Ray Tomography System on Wendelstein 7-X stellarator"

H. Thomsen[1], P. Carvalho[2], U. v. Toussaint[3], S. Gori[3], S. Mohr[1], A. Weller[1]
1 Max-Planck-Institut für Plasma Physik, EURATOM Ass., 17491 Greifswald, Germany
2 Associação Euratom/IST Centro de Fusão Nuclear, Instituto Superior Técnico 1049-001 Lisboa, Portugal
3 Max-Planck-Institut für Plasma Physik, EURATOM Ass., 85748 Garching, Germany

The steady state operation of Wendelstein 7-X stellerator presently under construction in Greifswald poses special challenges to the diagnostics development [1]. A critical issue is the heat load on plasma facing components (~ 500 kW/m²) over a long discharge time (up to 30 min), which leads to the necessity of active cooling. As result, the design of the 400 channel Soft-X Multi Camera Tomography System (XMCTS) [2] has to cope with drifts and dark currents due to the heating of active components like photo diodes and in-vessel preamplifiers. In order to allow for a quantitative measurement of dynamic drifts and offsets, a shutter system and blind diodes are considered in order to compensate these effects. Another important issue is the large amount of data gathered by the XMCTS during long pulse discharges. The strategy is twofold: a fast but less precise online reconstruction is planned, which will give information on the plasma shape and position on human time scale. The two options under investigation are a FPGA-based Cormack-Inversion method and an approach based on neural networks [3, 4].
Dependent on the available hardware, as much information as possible should be stored for more accurate offline-analysis. An intelligent way of marking interesting data is required. Pattern recognition methods and application of Neural Networks are considered for this automated data analysis. In case that the steady-state storage of all measured data is not feasible, at least this marked data will be stored in high time resolution.
The status and first solutions are presented.

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[3] *U. v. Toussaint, S. Gori and V. Dose,* Invariance Priors for Bayesian feed-forward neural networks, *Neural Networks* **19** *(2006) 1550-1557*

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We2-3

Video Diagnostic for W7-X Stellarator

J. Sárközi[a], G. Kocsis[a], R. König[b], U. Neuner[b], Á. Molnár[a], G. Petravich[a], G. Por[c], G. Porempovics[d], S. Récsei[a], V. Szabó[d], A. Szappanos[a] and S. Zoletnik[a]

[a]KFKI-Research Institute for Particle and Nuclear Physics, EURATOM Association, H-1121 Budapest, Konkoly Thege 29-33, Hungary

[b]Max-Planck-Institut für Plasmaphysik, Teilinstitut Greifswald, Wendelsteinstr. 1, D-17491 Greifswald, Germany

[c]Budapest University of Technology and Economics – Institute of Nuclear Techniques, P.O. Box 91, H-1521 Budapest, Hungary

[d]Budapest University of Technology and Economics - Department of Applied Mechanics, P.O. Box 91, H-1521 Budapest, Hungary

The video diagnostics for W7-X - which is under development - is devoted to observe plasma and first wall elements during operation, to warn in case of hot spots and dangerous heat load and to give information about the plasma size, position, edge structure, the geometry and location of magnetic islands and distribution of impurities. The video diagnostics will be mounted on the tangential Q-ports of the torus that are not straight and have about 2m length and a typical diameter of 0.12m which makes its realisation more difficult. The geometry of the 10 tangential views of the Q-ports allows giving a complete overview of the vessel interior making this diagnostic indispensable for the machine operation.

Different concepts of the diagnostics were investigated and finally the following design was selected. According to the large heat load expected on the optical window located at the plasma facing end of the Q-port, the port window is protected by a cooled pinhole and a shutter located behind the pinhole.

The imaging optics and the detection sensor is located behind the port window in the port tube which will be under atmospheric pressure. To detect the visible radiation distribution a new camera system called Event Detection Intelligent Camera (EDICAM) is under development. The system is divided into three major separated components. The Sensor Module contains only the selected CMOS sensor (LUPA-1300 1.3 Mega pixel high speed CMOS image sensor), the analog digital converters and the minimal electronics necessary for the communication with the subsequent camera system module called Image Processing and Control Unit (IPCU). Its simple structure makes the Sensor Module suitable to operate in a harsh environment that is expected behind the port window. The IPCU which can be located far from the Sensor Module and therefore far from the plasma is designed to perform real time evaluation of the images detecting predefined events (hot spots, flying objects, structures with sharp edges, etc.) managing the sensor read out and the input triggers and producing the output triggers generated by the detected events. The IPCU can also be used to reduce the amount of the stored data. A Standard 10 Gigabit Ethernet fiber optics connection connects the IPCU module to the PC with GigEVision communication protocol.

We2-4

Recent results and short review on electric potential measurements by Heavy Ion Beam Probe diagnostic.

L.Krupnik[1], A.Melnikov[2], G.Van Oost[3]

[1]Institute of Plasma Physics, NSC KIPT, Kharkov, Ukraine;
[2]Institute of Nuclear Fusion, RRC Kurchatov, Institute, Moscow, Russia;
[3]Ghent University, Ghent, Belgium

The discovery of the high confinement modes (H-mode) in ASDEX[1] renewed the interest in understanding the important role of the electric fields in confinement of toroidal plasmas[2].

Heavy Ion Beam Probe (HIBP) diagnostics provide a unique possibility for direct measurements of electric fields in toroidal plasma, albeit that some information concerning the electric fields in plasmas can be obtained by some indirect techniques. Therefore, HIBP diagnostic is very important for the study of the particle and energy transport and confinement in toroidal devices.

First measurements of the plasma potential φ, were done with a Tl^+ beam in the ST tokamak. During the 1980's and early 90's, HIBP diagnostics were implemented on many magnetic confinement devices. The special issue of the journal IEEE Transactions on Plasma Science[3] gives a complete and detailed overview the early work on HIBP experiments in tokamaks TM-4, ISX-B, TEXT, T-10, ISTTOK, stellarator ATF and the mirror devices EBT, NBT, TMX and GAMMA-10. In more recent review on radial electric field measurements [4] a section is devoted to the HIBP diagnostics and its applications.

In this review, we will mainly focus on a number of relatively recent results demonstrating new development of diagnostic and more specific features of the HIBP implementation on TJ-II, T-10, CHS, JFT-2M, and other machines. The most relevant earlier works are also included.

This work has been supported by INTAS, Grant No 05-1000008-8046

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We2-5

Test bench calibration of the Double-Slit Ion Energy Analyzer for Heavy Ion Beam Probing Diagnostics

I. Bondarenko, A. Chmyga, G. Deshko, S. Khrebtov, A. Komarov, A. Kozachok, L. Krupnik, A. Zhezhera.
IPP NSC KIPT, Kharkov, Ukraine.
L. Eliseev, A. Melnikov, S. Perfilov and S. Lysenko.
INF RRC "Kurchatov Institute", Moscow, Russia.

Heavy Ion Beam Probing diagnostic can measure simultaneously a number of plasma parameters as well as their fluctuations with a high temporal and spatial resolution. These are the electric potential φ_{pl}, the electron density n_e, the electron temperature T_e, and the poloidal magnetic field B_θ (plasma current density). The measurements of φ_{pl}, n_e and their fluctuations have been successfully performed in many HIBP experiments with parallel plate ion energy analyzer. The correlation measurements of plasma density and potential fluctuation in the plasma core are possible by simultaneous registration of secondary ions, coming from different plasma points. Such simultaneous measurements of plasma potential make possible the direct calculation of the electric field E, its mean and oscillation components. In its turn, poloidal electric field oscillations correlated with density ones open the way to direct study of the convective turbulent particle flux Γ_r.

To perform the E measurements one needs to create double-slit energy analyzer and to calibrate it in order to unify the analyzer gains G and dynamic factors F for both entrance slits.

This work presents the results of the design study, investigations of the features and a calibration of double-slit ion energy analyzer prototype at the test bench in IPP NSC KIPT, Kharkov, Ukraine, with beam energy up to 10 keV. Double-slit ion energy analyzer is installed now at HIBP diagnostic on TJ-II stellarator in CIEMAT, Madrid. Similar device is planned to be installed on T-10 tokamak in INF RRC "Kurchatov Institute", Moscow, Russia.

The main tasks of the calibration are:

1) experimental measurements and shape optimization of the analyzer gains G as a function of the entrance angle α
2) unification of the gains in shape and absolute values for two slits
3) unification of the dynamic factors in shape and absolute values for two slits.

Such calibration gives one the limits of the experimental errors for measurements of absolute values of plasma potential and electric field.

Optimizing function $G(\alpha)$ and $F(\alpha)$ depend on analyzer geometry parameters, such as entrance-slit width, entrance slits and detector plates space positions with respect to the ground plate. Performed computational and experimental studies result in the 0.1 mm tolerances in the entrance and detector slits positions. In order to unify the absolute values of G and F for both slits it is necessary to adjust entrance-slit position with the same or higher accuracy.

An efficient and convenient solution for the unification of the absolute values of **G** and **F** is to move one entrance slit with respect to another one fixed. This technique was used with remote control moving system, based on several step motors. With this, we avoid the disturbance of the calibration procedure due to necessity to open it into air, so increase the reliability and the accuracy of the calibration.

Hitherto obtained accuracy for both analyzer slits is ΔG - 10^{-3} and ΔF – 3×10^{-3}, which is limited by the existing step motor accuracy 0.1 mm for entrance slits moving. Further experiment is planned with the use of the higher accuracy step motors.

The presented study considered is a first step to multi-slit analyzer elaboration.

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We3-1

Application of advanced edge diagnostics for transport studies in the stochastic boundary of TEXTOR-DED

O. Schmitz[1], S. Brezinsek[1], I. Classen[2], M. Clever[1], J.W. Coenen[1], K. H. Finken[1], M. W. Jakubowski[1], M. Kantor[1], U. Kruezi[1], M. Lehnen[1], Y. Liang[1], U. Samm[1], B. Schweer[1], G. W. Spakmann[2], H. Stoschus[1], G. Telesca[1], B. Unterberg[1], E. Uzgel[1], D. Reiter[1], Y. Xu[3] and the TEXTOR Team

[1] Institut für Energieforschung-Plasmaphysik, Forschungszentrum Jülich GmbH, Trilateral Euregio Cluster, Association Euratom-FZJ, D-52425 Jülich, Germany

[2] FOM-Institute for Plasma Physics Rijnhuizen, Trilateral Euregio Cluster, Association EURATOM-FOM, PO-Box 1207, 3430 BE Nieuwegein, The Netherlands

[3] Laboratoire de Physique des Plasmas - Laboratorium foor Plasmajysica, Ecole Royale Militaire - Koninklije Militaire School, Trilateral Euregio Cluster, Association EURATOM - Belgian state, B-1000, Brussels, Belgium

The experimental detection of three dimensional plasma structures and the analysis of correlated transport characteristics require advanced edge diagnostic equipment. This is relevant especially for the understanding of edge transport in three dimensional magnetic field topologies existing in stellarators as well as in tokamak plasmas with non axissymetric, resonant magnetic perturbations (RMP). In this contribution the importance of edge diagnostic systems with both, high spatial and high time resolution, for investigation of transport processes in such three dimensional magnetic topologies will be discussed based on experimental results from the TEXTOR tokamak. Here a well defined RMP field is applied with the Dynamic Ergodic Divertor (DED).

The DED induces a resonant magnetic perturbation with variable poloidal/toroidal base mode numbers of $m/n = 3/1, 6/2, 12/4$. In this topology field lines with short and long connection lengths L_c to the DED target can be distinguished. Referring to the transport characteristics field lines with short L_c act as a multipolar helical scrape off layer (SOL), dominated by parallel transport along the field lines to the wall elements. In contrast, the field lines with long L_c have the ability to diffuse and therefore to generate an stochastic domain with enhanced radial transport. Both domains are poloidally interwoven and their radial and poloidal extensions can be varied from a few millimeters to up to several centimeters by changing the base mode configuration.

The successful identification and analysis of these transport domains will be demonstrated here based on experimental results from various diagnostic techniques applied at different toroidal and poloidal locations. The suite of diagnostics feasible for radially high resolving measurements of electron density n_e and temperature T_e consists of *beam emission spectroscopy* on thermal helium, a new, high resolution *edge Thomson scattering* system and a *fast reciprocating probe* system. In addition a new *supersonic helium beam* system allows to measure n_e and T_e profiles with up to $100\,kHz$ time resolution. To investigate the plasma ion component a *diagnostic hydrogen beam* was applied measuring the ion temperature profile $T_i(r)$ as well as simultaneously the poloidal $v_\vartheta(r)$ and toroidal $v_\varphi(r)$ rotation profile in the plasma edge by *charge exchange spectroscopy*. To resolve the poloidal asymmetry of the stochastic edge layer two dimensional measurements of the T_e distribution were obtained with the unique *electron cyclotron emission imaging* system at TEXTOR accompanied by observations with spectroscopically filtered *CCD cameras*. The plasma parameters on the DED target were measured by a set of 16 *Langmuir probes* at equatorial midplane and by an fast *infrared camera* system.

Based on the in detail identification of the topological transport domains a successful control of the particle confinement was shown. In adapting the edge safety factor as well as the plasma position two contrary confinement regimes were obtained. An improved particle confinement with resonant increase in the plasma density was observed for plasmas located close to the DED. Here a large fraction of field lines connect the DED surface with resonant island chains deep inside the plasma. In contrast a *particle pump out* regime with a reduction in the central plasma density was seen for plasmas retracted from the DED. This pump out is evoked by enhanced radial particle transport presumably caused by a dominating stochastic character of the perturbed edge layer.

We3-2

LIF measurements on an atomic helium beam in the edge of a fusion plasma

Maciej Krychowiak[1)], Ph. Mertens[2)], B. Schweer[2)], S. Brezinsek[2)], R. König[1)], O. Schmitz[2)], M. Brix[3)], T. Klinger[1)] und U. Samm[2)]

1) *Max-Planck-Institut für Plasmaphysik, EURATOM-Association, 17491 Greifswald, Germany, e-mail: maciej.krychowiak@ipp.mpg.de*

2) *Institut für Plasmaphysik, FZ Jülich, EURATOM-Association, TEC, 52425 Jülich, Germany*

3) *UKEA, JET- Experimental Department, EURATOM-Association, Culham Science Centre, ABINGDON, Oxfordshire, OX14 3DB, U.K.*

Thermal helium beams are well-established fusion plasma diagnostics for measuring of radial profiles of electron density and temperature in the plasma edge. The method is based on measurements of three spectral lines of atomic helium. Electron density and temperature are obtained by comparing two line intensity ratios, with main dependence on either n_e or T_e, with those calculated using a collisional-radiative (cr) model for helium. Most of the rate coefficients needed for the data evaluation are known only from calculations. Deviations between calculated and measured line intensities and penetration depth of the thermal helium beam are observed. Therefore, the LIF spectroscopy on a thermal helium beam on the tokamak TEXTOR in Jülich is to further improve the cr model.

For this purpose, several laser pumping schemes starting from the $n = 2$ levels of atomic helium have been tried, since these are the states from which the population distribution is determined by plasma excitation in the course of beam penetration. This is being done using a high-power, pulsed laser system consisting of two stages: a pulsed excimer laser (λ = 308 nm) which pumps a dye laser. The dye laser emits at all wavelengths in the near UV and in the visible spectral range with peak powers of up to 4 MW and a resolving power of $\lambda/\Delta\lambda = 10^5$. The laser light is transported by use of folding mirrors to the tokamak and adjusted onto the gas nozzle. The fluorescence signals are measured perpendicularly at three radial positions simultaneously. This provides measurements for different pairs of electron density and temperature. Results of population densities measurements as well as of some rate coefficients between excited levels derived from collisional-induced fluorescence signals are presented.

We3-3

The influence of Stark effect on the shape of He-like lines in dense plasma

***Baronova E.O.**, Sholin G.V., Vikhrev V.V.,Jakubowski L*[1]

RRC Kurchatov Institute, Moscow, Russia
[1)]*A. Soltan Institute for Nuclear Studies, Swierk n. Warsaw, Poland*

We explain relative intensities and width of *He*-like lines, emitted from hot dense plasma as a result of Stark effect. For the elements within $10<z<50$ there is a forbidden line $2\ ^1S_0 - 1^1S_0$ in the close vicinity of intercombination line $2^3P_1 - 1^1S_0$. In the presence of strong electric fields the intensity of forbidden line is relatively high and thus might give the yield to intercombination line.

The intensity of resonance, intercombination, forbidden lines is calculated versus the strength of electric field. We also calculate the shift of $n=2$ levels versus electric field strenght. Collisonal-radiative model is constructed for *He*-like Argon lines in dense plasma with electric field. It is shown, that strong electric field $E \approx 10^9$-10^{10} *V/cm* produces the same affect on a line shape as plasma opacity. Good agreement is obtained with spectra of ArXVII lines, emitted from Z-pinch with current 500 *kA*.

Intensities of intercombination and resonance line are widely used to determine plasma parameters. Presented study might limit the applicability range of existing methods and show the way to measure strong electric fields. We also discuss the reasons for presence of strong electric fields in plasma.

Study of longitudinal distribution of NeI line radiation in plasmas produced in wall-stabilized d.c. arcs applying argon and helium as working gases

Ireneusz Książek

Institute of Physics, Opole University, ul. Oleska 48, 45-052 Opole, Poland, iksiaz@uni.opole.pl

The wall-stabilized arc is a convenient laboratory source for excitation of atoms and ions. It is commonly used in experiments aimed to determine atomic transition probabilities e.g. [1, 2]. This source reveals some very advantageous properties as: very good temporal and spatial stability, well-defined cylindrical geometry, and conditions at least close to partial Local Thermal Equilibrium (pLTE) [3]. The cylindrical shape of the plasma column simplifies the interpretation of the registered spectra. In the case of side-on observation (perpendicular to the arc axis), one can apply the Abel inversion procedure in order to obtain the radial distribution of the plasma emissivity. In the case of end-on observation, one can assume that the plasma is uniform along the line of sight, if the contribution to the plasma radiation, originating from near-electrode regions can be neglected.

Usually the discharge is conducted in some inert gases with only small admixture of the element under study. As the main plasma component, the so-called "working gas", helium and argon are commonly used. The application of helium enables obtaining higher temperatures at lower electron densities but the discharge is less stable than in argon and departures from LTE conditions are usually cannot be neglected.

Results of our previous works revealed that in some cases, especially in plasmas containing mainly helium, the assumption of uniformity along the plasma column is not justified [4,5]. This departure from uniformity is caused by the demixing effect – phenomenon of separation of plasma components in presence of gradients of plasma parameters. The longitudinal demixing associated with the electric field, is caused mainly by differences in the degree of ionization of the elements present in plasma.

In this contribution we present results of measurements performed with helium as well as with argon as working gases. In both cases the longitudinal distribution of intensities of neon lines is not uniform though the gas mixture were introduced uniformly along the arc column. Furthermore, the observed distributions depend strongly on the amount of neon introduced into the gas mixture.

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We3-5

On the diagnostics methods of the rather dense and magnetized plasma

G.Popa
Faculty of Physics, "Al.I.Cuza" University, 700506 Iasi, Romania

Electrical and spectral methods used for diagnostic of rather dense (10^{10} - 10^{14} cm^{-3}) and magnetized plasma are presented. The magnetized plasmas of three different devices were investigated: magnetron discharge, Castor Tokamak and Pilot-Psi machine.

The both d.c. and pulsed magnetron discharges with metallic targets of plasma physics laboratory in "Al.I.Cuza" University were studied either in non-reactive or in reactive mode of operation. The emission and absorption spectral methods were used in combination with mass spectrometry and electrical probes. The CCD image of the plasma race track related to the time evolution of the plasma parameters and the discharge voltage at constant discharge current were correlated in order to separate contribution of surface processes and those within the plasma volume in the mechanism of the reactive mode of the magnetron discharge.

The experimental results are presented on measuring the plasma parameters by Katsumata and ball pen probes in Castor Tokamak (IPP of Prague). The diffusion coefficient in perpendicular direction has been obtained from analysis of the spectra of the floating potential or of the ion saturation current of the Katsumata probe collector. The ion temperature was also measured using Kasumata probe as an electrostatic analyzer and compared with data obtained by ball pen probe method.

The electrical probes and multi-channel analyzer with multi-collectors were also used for measuring the plasma parameters in magnetized plasma column of the Pilot-Psi machine (FOM Institute of Ruijnhusen). The radial electric field and density gradients are the main reason for plasma drift in azimuthally direction. Data are compared with those obtained by spectral method.

POSTERS WeP

WeP1

Assessment of a 1-D, multi-colour x-ray imaging system for the MAST ST

S. Jabłoński[1)], A. Czarnecka[1)], J. Kaczmarczyk[1)], A. Patel[2)], L. Ryć[1)],
J. Rzadkiewicz[3)], A. Zabolotsky [2)]

[1)] Institute of Plasma Physics and Microfusion, Association EURATOM/IPPLM,
Hery 23, 01-497 Warsaw, Poland
[2)] UKAEA Fusion, (EURATOM/UKAEA Fusion Association), Culham science centre,
Abingdon, Oxon., OX14 3DB, UK
[3)] A. Soltan Institute for Nuclear Studies, 05-400 Otwock-Swierk near Warsaw, Poland

The conceptual design and results from simulations of a multi-colour 1D soft x-ray imaging diagnostic for the Mega-Ampère Spherical Tokamak (MAST) is presented. Experimentally determined plasma density, temperature and plant geometry are used in this simulation. The diagnostic consists of pinholes, filters and array detectors with readout/digitisation electronics. The design also allows for fast operation (<20μs) required for e.g. tearing modes.

Work here compares results from semiconductor and scintillator/multi-channel photomultiplier sensors. The diagnostic design is targeted for the x-ray energy range ~1.5-10 keV - primarily for resolving the core radial temperature profile (0.5-3keV) with spatial and temporal resolution needed for interpretive codes such as TRANSP and consistency with existing temperature diagnostics. Additional chords are off the equator and are important for constraining core elongation in routine magnetics reconstruction of the equilibrium (EFIT). We start with data that folds-in known errors and distributions from likely hardware and digital resolution. The sensitivity of unfolded temperature profiles/errors to the background impurity concentration is also tested.

WeP2

Application of solid state nuclear track detectors in TEXTOR experiment for measurement of fusion-reaction protons

A. Szydlowski[1)*], A. Malinowska[1)],
G. Van Wassenhove[2)], B. Schweer[3)], A. Gałkowski[4)]
[1)] *The Andrzej Soltan Institute for Nuclear Studies (IPJ), 05-400 Otwock-Swierk, Poland*
[2)] *Ecole Royale Militaire, Association EURATOM – Belgian State, B-1000, Brussels, Belgium,*
[3)] *IPP, Association EURATOM – Forschungszentrum Juelich, D-52425 Juelich, Germany,*
[4)] *IPPLM, Association EURATOM - IPPLM, Hery 23, 01-497.Warsaw, Poland*

The paper reports measurements of the space distribution of the d(d, p)t fusion reaction reactivity using escaping 3-MeV protons. The measurements were carried out by means of a small ion pinhole camera which was equipped with a pinhole (0.3 mm diameter) and a solid-state nuclear track detector of the PM-355 type was located 4 cm behind this pinhole. The camera was attached to a special manipulator, which enabled to locate it in a chosen position within the plasma boundary. The manipulator was provided with a water cooled cold nose, which ensured that the detector was kept at relatively low temperature. The first measurement was performed with the pinhole camera located at a distance of 49 cm from the plasma center, i.e. the pinhole was located 4.4 cm from the LCFS. The paper compares the results obtained in two different series of successive discharges. The first series of discharges (Nos 99818 – 99830) was executed with an additional heating of TEXTOR plasma by means of a 1.5 MW neutral beam of fast deuterons. In this measurement the camera was aligned in this way that its input pinhole was oriented along the mayor radius, oppositely to the torus center, i.e. at $\gamma = 0^0$. The average emission of neutrons in those discharges amounted to $1.4 \cdot 10^{13}$ neutrons/sec. The second series was accomplished with an additional heating of TEXTOR plasma by means of fast hydrogen neutrals and ICRF microwaves. In those discharges the camera was oriented at $\gamma = 90^0$. The detectors irradiated with fusion-reaction protons, which were emitted from the aforementioned discharges, were subjected to the typical etching procedure. Then, the proton flux distribution upon the detector surface was measured.

The described proton measurements were supplemented by computations of the magnetic field configuration and proton trajectories in the TEXTOR facility. The computer simulations of different trajectories of charged particles have been performed using the Gourdon Code. Detection efficiency, defined as the ratio of the number of detected particles to that of particles emitted from the plasma has been also calculated. The main aim of these calculations was to properly explain the obtained results and to draw conclusions about the space distribution of the fusion reaction reactivity.

The reported studies have been carried out as the P5 task of the research program supported by the EURATOM Community under the Contract with the Association EURATOM-IPPLM, Poland. This research was also supported by the Ministry of Education and Science, Poland, under contract No. 47/EUROATOM/2005/7.

[*]Corresponding author: Tel.: +48 22 7180536, Fax: +48 227793481
E-mail address: szydlowski@ipj.gov.pl

WeP3

DIAGNOSTICS OF FAST ELECTRONS WITHIN CASTOR TOKAMAK BY MEANS OF A MODIFIED CHERENKOV-TYPE PROBE

J. Zebrowski[1)], L. Jakubowski[1)], M.J. Sadowski[1)], K. Malinowski[1)], M. Jakubowski[1)], V. Weinzettl[2)], J. Stockel[2)], M. Vacha[3)], M. Peterka[4)]

[1)] The Andrzej Soltan Institute for Nuclear Studies (IPJ), 05-400 Otwock-Swierk, Poland
[2)] Institute of Plasma Physics AS CR, v.v.i., Association Euratom/IPP.CR, Czech Republic
[3)] Faculty of Mathematics and Physics, Charles University, Czech Republic
[4)] Gymnasium nad Aleji, Prague, Czech Republic
zebrowski@ipj.gov.pl

The paper reports on experimental studies performed within the CASTOR tokamak, which was operated at IPP in Prague, Czech Republic, during the last experimental campaign carried out in autumn 2006. The main aim was to implement a new diagnostic technique for measurements of energetic (> 50 keV) electrons within the tokamak edge plasma region. That technique was based on the use of a Cherenkov-type probe similar to the first prototype detector [1], which was tested during the previous experiments with the CASTOR device.

During the reported experimental campaign the use was made of an improved version of the Cherenkov detection system, which contained of the measuring head equipped with an aluminium nitrade (AlN) radiator protected by a thin titanium (Ti) layer. That radiator was coupled through a long optical cable with a fast photomultiplier placed in a shielding box. The application of long optical cable and improvements of the shielding efficiency enabled electromagnetic noise signals to be reduced considerably.

The described experimental campaign was the last one before the CASTOR shut-down. The reported measurements were carried out during series of plasma discharges performed with the ohmic heating and currents amounting to 5-15 kA, at a magnetic toroidal field equal to 0.8-1.4 T, and the electron density reaching 0.5-1.5 x 10^{19} m^{-3}. In the described studies particular attention was paid to a dependence of the integrated Cherenkov signals (i.e. the fast electron flux) on values of the discharge current and toroidal magnetic field. The detailed analysis of a dependence of the fast electron flux on the detector radial position and plasma density was reported elsewhere [2].

Other measurements concerned the integrated hard X-ray signals at a close vicinity of the Cherenkov detection head. Their dependence on the radial position of the Cherenkov probe was investigated. A statistical approach, which was based on a single-count analysis of the time-resolved Cherenkov signals, has also been applied. Some estimates of a correlation of the mentioned X-ray signals and the studied Cherenkov radiation have been presented. Possible sources of the noise observed upon the measured signals have been discussed. The conclusions concern the reduction of an electromagnetic interference upon the recorded electron signals and the dependence of these signals on the Cherenkov-detector position and the main parameters characterizing the CASTOR discharges.

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WeP4

Thermal-mechanical analysis for in-vessel diagnostic components in W7-X

M.Y.Ye, A. Werner, M. Hirsch, A. Weller and R. Koenig
Max-Planck-Institut fuer Plasmaphyisk, EURATOM Association, Teilinstitut Greifswald,
Wendelsteinstr. 1, D-17491 Greifswald, Germany

Abstract

The superconducting stellarator W7-X now under construction in Greifswald is designed for stationary operation (30 minutes) with cw heating by up to about 10MW ECRH, and additional heating up to 24 MW for 10s by NBI and ICRH. For long pulse plasma operation, the most serious challenge for the design of in-vessel diagnostic systems is the thermal-mechanical problem. Although the heat shield with active cooling is designed to protect all in-vessel diagnostic systems from high thermal load, some diagnostic components like detectors, lenses and mirrors inside the vacuum vessel still directly suffer from radiative thermal load. 3-D Monte-carlo simulation indicates that the typical thermal load from plasma radiation to individual in vessel components ranges from several 10 to 100 kW/m^2. In addition, some diagnostic parts located behind the heat shield receive the radiation from the heat shield which may be higher temperature of up to ~400°C. Therefore, some diagnostic components demand not only active cooling designed to remove the power loading for long pulse plasma operation, but also an optimized design to minimize thermal deformation of optical components. A finite element analysis (FEA) is conducted for a better understanding of thermal-mechanical effects on in-vessel diagnostic components and to guide the design of the diagnostic system. In this conference, we will present the results of the thermal-mechanical analysis of the retro-reflectors for the CO2-laser interferometer, of the diamagnetic loops and of soft X-ray camera arrays.

WeP5

Optimisation of the line of sight configuration of the multi-channel interferometer at Wendelstein 7-X

H. Dreier[1], A. Dinklage[1], R. Fischer[2], M. Hirsch[1], P. Kornejew[1]

Max–Planck–Institut für Plasmaphysik, EURATOM Association,

[1]Teilinstitut Greifswald, D–17491 Greifswald / [2]D–85748 Garching

The multi-channel interferometer at the Wendelstein 7-X stellarator is proposed for density control and the measurement of plasma density profiles and will be part of the start-up diagnostics. For the optimisation of the beamline configuration the probabilistic approach of Bayesian experimental design is applied. As a benefit of this method, parameters of physical interest, e.g. the peaking or the steepness of the electron density distribution, can be directly implemented as design criteria. The quality of the design is analysed according to its expected information gain (*expected utility*) about the parameters of interest, which enables one to compare different diagnostic configurations quantitatively.

The focus of this work lies on the comparison of different technical approaches for the interferometer diagnostic. Different physical problems (high confinement regimes, neoclassical predictions, pellet injection) and their effect on the density distribution are applied as optimisation goals. The influence of the port system and the in-vessel components (retro-reflectors) is discussed. For this, the design was done with and without technical restrictions, the resulting expected utilities are compared and analysed. Furthermore, the impact of an additional beamline at a different toroidal position (congruent to the Thomson scattering diagnostic) is examined.

WeP6

Admissible cross-talk limits in a two colour interferometers for plasma density diagnostics. A reduction algorithm.

Miguel Sánchez[1], Luis Esteban[1], Petra Kornejew[2], Matthias Hirsch[2]

[1] *Laboratorio Nacional de Fusión, Asociación EURATOM-CIEMAT,*

E-28040 Madrid, Spain

[2] *Max-Planck-Institut für Plasmaphysik, TB Physik, Wendelsteinstr. 1,*
G-17491 Greifswald, Germany

Mid Infrared (10,6 μm CO_2 laser lines) interferometers as a plasma density diagnostic must use two-colour systems with superposed interferometers beams at different wavelengths in order to cope with mechanical vibrations and drifts. They require a highly precise phase difference measurement where all sources of error must be reduced. One of these is the cross-talk between the signals which creates nonlinear spurious periodic mixing products. The reason may be either optical or electrical crosstalk both resulting in similar perturbations of the measurement. In the TJII interferometer a post-processing algorithm is used to reduce the crosstalk in the data. This post-processing procedure is not appropriate for very long pulses, as it is the case for in new tokamak (ITER) or stellarator (W7-X) projects. In both cases an on-line reduction process is required or - even better - the unwanted signal components must be reduced in the system itself.

CO_2 laser interferometers which as the second wavelength use the CO laser line (5,3 μm), may apply a single common detector sensitive to both wavelengths and separate the corresponding IF signals by appropriate bandpass filters. This reduces complexity of the optical arrangement and avoids a possible source of vibration induced phase noise as both signals share the same beam path. To avoid cross talk in this arrangement filtering must be appropriate.

In this paper we present calculations to define the limits of crosstalk for a desired plasma density precision. A crosstalk reduction algorithm has been developed and is applied to experimental results from TJ-II pulses. Results from a single detector arrangement as under investigation for the CO_2 / CO laser interferometer developed for W7-X are presented.

WeP7

Design and calibration of Thomson-scattering polychromator for Wendelstein 7-X

S. Schmuck[1], A. Dinklage[1], R. Fischer[2], J.P. Knauer[1], B. Kurzan[2], H.-D. Murmann[2], E. Pasch[1]

Max - Planck – Institut für Plasmaphysik EURATOM Association,

[1]Wendelsteinstr.1, 17491 Greifswald, [2]Boltzmannstr. 2, 85748 Garching

One of the basic diagnostics planned for initial operation of W7-X is the Thomson scattering system, using Nd:YAG lasers and interference filter polychromators. For this purpose, a new polychromator arrangement was designed. For calibration of the polychromators two different techniques are tested. One technique is based on a tunable OPO laser system and the second possibility is based on a super continuum fiber laser together with a monochromator system. The experimental arrangement of the prototype polychromator will be presented.

WeP8

Design study of the observation optics for the Thomson scattering system planned at Wendelstein 7-X

J. Cantarini, J.P. Knauer and E. Pasch
Max-Planck-Institut für Plasmaphysik EURATOM Association,
Wendelsteinstr.1, 17491 Greifswald, Germany

The main aim of the Thomson scattering system is the measurement of electron temperature and density profiles with high time and spatial resolution. To cover the whole laser beam line (1.6 m) through the plasma cross section, two ports are provided for the observation optics, which images the scattering volumes (each with 28 mm length and 9 mm diameter) onto fiber bundles. The observation optics are important components of the diagnostic set-up, because their imaging properties determine the spectral and spatial resolution of the whole system. Therefore the design of the optics must be optimised according to the geometrical constrains of the observation ports in terms of position and dimensions. To optimise this optical engineering, the commercial ZEMAX program is used. The composition of the optical system is elaborated to minimise losses of collected light with wavelength from 700 nm up to 1064 nm. Environmental criteria (e.g. neutrons, ECR plasma heating, temperature) will be considered choosing optical materials. The first results of calculations will be presented.

WeP9

Comparison of fast tomographic methods for application on the Soft X-Ray Tomography System on Wendelstein 7-X stellarator

P. J. Carvalho[1], H. Thomsen[2], U. v. Toussaint[3], S. Gori[3], A. Weller[2], R. Coelho[1], H. Fernandes[1]

1 Associação Euratom/IST Centro de Fusão Nuclear, Instituto Superior Técnico 1049-001 Lisboa, Portugal
2 Max-Planck-Institut für Plasma Physik, EURATOM Ass., 17491 Greifswald, Germany
3 Max-Planck-Institut für Plasma Physik, EURATOM Ass., 85748 Garching, Germany

The Wendelstein 7-X stellarator presently under construction in Greifswald is projected to be operated on a steady state regime. One requirement for this regime is the constant monitoring of the plasma conditions. Using the X-Ray Tomography System a poloidal cross-section of the plasma's X-Ray emissivity can be reconstructed and the plasma's position and MHD activity can be observed.
Fast tomographic algorithms such as the Cormack inversion [1-2] or neural networks (NN) can be applied to obtain reconstructions at a human time scale (10~100 reconstructions per second). This paper discusses the potential application of these algorithms on the Wendelstein 7-X stellarator, comparing performance (Cormack inversion is faster) and reliability of the results (NN reconstruction has less artifacts).

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WeP10

Investigation of the Neutral Gas Pressure Effect on the Metal Resistive Bolometer

D. Zhang, L. Giannone, O. Grulke*, M. Piechotka, T. Windisch, A. Stark, T. Klinger

Max-Planck-Institut für Plasmaphysik, EURATOM Association, Wendelsteinstr. 1, 17491 Greifswald, Germany

**Ernst-Moritz-Arndt Universität, 17491 Greifswald, Germany*

The bolometer system planned for W7-X [1] consists mainly of metal (Au) resistive detector [2] arrays. All the detectors are exposed to neutral gas environment. The thin bolometer foil used for detecting the radiated power loss may be sensitive to the neutral gas pressure due to the strain gauge effect [3]. Recently, a prototype of this kind of bolometer camera consisting of 12 channels has been installed on the cylindrical plasma device VINETA [4] in order to investigate the influences of the neutral gas pressure on the bolometer signals. Experiments were carried out for a large number of Ar-discharges under different gas pressure conditions. It is found that the pressure effect of the neutral gas can make considerable contributions, thus inducing non-negligible errors of the results in most of the investigated cases. Using the VINETA plasmas (Ar, T_e<10 eV, n_e<10^{-19} m^{-3}) [4] as examples, the paper demonstrates and discusses how to minimize the neutral gas effects, especially in the dada analysis process. The radiated power and the radiation intensity profile obtained in different helicon discharges are presented.

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WeP11

STRUCTURE OF NB FILMS DEPOSITED BY MEANS OF ULTRA-HIGH VACUUM CATHODIC ARC

R. Nietubyc[1)], M.J. Sadowski[1)], P. Strzyzewski[1)], J. Pelka[2)]

[1)] The Andrzej Soltan Institute for Nuclear Studies (IPJ), 05-400 Otwock-Swierk, Poland
[2)] Institute of Physics, PAS, Aleja Lotników 32/46, 02-668 Warsaw, Poland
R.Nietubyc@ipj.gov.pl

The niobium (Nb) coating became recently a promising technology for the preparation of superconducting RF cavities designed for particles accelerators. Replacing a bulk Nb structure by a thin Nb film, which is have the thickness of a few micrometers and the desired superconductive properties, needs an extended diagnostics of the film structure. This paper reports on the x-ray diffraction studies, which have been performed in order to establish and optimize the technology of ultra-high vacuum cathodic arc (UHVCA) deposition process.

Within the frame of this work different Nb films, which were deposited on polycrystalline copper and single-crystal sapphire (001) substrates at various experimental conditions, have been investigated. Measurements have been performed at the W1 beam-line of the DORIS-III synchrotron operated at the Hasylab in Hamburg. (θ-2θ) and grazing geometries have been applied in order to study the lattice deformation in the plane and out-of-plane directions.

The collected results showed different film growth mechanisms occurring upon the copper and sapphire substrates. The films having the structures different than that of bulk Nb were formed in both cases. The film grown upon single crystal substrates appeared to be stressed, and the lattice constant in both directions changed as a function of depth. It was observed that a quasi-epitaxial layer has been found in the vicinity of interface.

The films deposited on the copper substrate have been found to be less stressed, but they have had higher defects concentrations than those grown upon the sapphire substrates. It was shown that a heat treatment, as applied to both films, can remove partially the lattice deformations and defects. An influence of energy of the deposited ions on lattice stresses and crystallites sizes has been found for Nb/sapphire deposition processes only.

The performed investigation demonstrated that the structure of Nb films obtained by the UHVCA deposition can be controlled by the appropriate process technology.

WeP12

HOLLOW CATHODE PLASMA JET SYSTEM FOR TiO_x THIN FILM DEPOSITION

P. Virostko[1,2], Z. Hubička[1], P. Adámek[1,3], M. Čada[1], J. Olejníček[1], P. Kudrna[2], S. Leshkov[2], M. Tichý[2]

[1]Department of Low-Temperature Plasma, Institute of Physics, Academy of Sciences of the Czech Republic, v. v. i., Na Slovance 2, 182 21 Prague 8, Czech Republic
[2] Charles University in Prague, Faculty of Mathematics and Physics, Department of Surface and Plasma Science, V Holešovičkách 2, 180 00 Prague 8, Czech Republic
[3] University of South Bohemia, Pedagogical Faculty, Department of Physics, Jeronýmova 10, 371 15 České Budějovice, Czech Republic

key words: *hollow cathode plasma jet, probe diagnostic, deposition of thin films*

We shall present a novel construction of the low-temperature hollow cathode plasma jet system for deposition of thin films based on UHV vacuum technology. The system is similar to that presented in [1]. The hollow cathode made of Ti is water-cooled and acts simultaneously as a nozzle for the working gas flow. Discharge in the hollow cathode is ignited by RF (13.56 MHz) or DC power; the impulse working regime is also supported. When depositing the TiO_x layers the mixture of Ar and O_2 is used. The Ti particles reactively sputtered from the inner surface of the nozzle react with oxygen and a layer of TiO_x is created downstream on the Si or glass substrate. The system works in the pressure range from several tenths of Pa to several hundred Pa.

This work is also intended to present measurements of plasma parameters during the deposition process. Determination of plasma parameters contributes to better understanding of the processes during the deposition as well as to the reproducibility of the deposition process. As diagnostic methods we applied Langmuir probe together with measurement of the positive ion current flowing to the substrate.

Especially the measurement of the ion current to the substrate attracts attention since it has been shown that the intensity of the ion current to the substrate represents a significant characteristic of the deposition process and that it may therefore affect properties of the deposited films [2]. However, we present also data from time-resolved Langmuir probe measurements, i.e. the time dependences of the electron density, mean electron energy and of the electron energy distribution function (EEDF).

We intend also to compare the positive ion current flowing to the substrate measured at three different frequencies. The measurement method consists in biasing the substrate by applying the AC voltage at different frequencies (pulsed DC at frequency 30kHz, RF at 13.56 MHz and "medium wave" frequency 500kHz) to the same negative potential and letting the substrate to discharge by impinging positive ion current (modification of the RF probe [3]).

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Corresponding author address
Petr Virostko
Institute of Physics, Academy of Sciences of the Czech Republic
Na Slovance 2
182 21 Prague
Czech Republic
e-mail: virostko@fzu.cz
phone: +420 266 052 127

WeP13

ECR plasma assisted α-Fe thin film PVD deposition on melt-spun Nd,Fe,B, alloys

V.D.Fedorchenko[1)], A.M. Bovda[1)],V.A.Bovda[1)],Christina H.Chen[2)], V.V.Chebotarev[1)], I.E.Garkusha[1)], A.V.Medvedev[1)], V.I.Tereshin[1)]

[1)]*Institute of Plasma Physics, NSC Kharkov Institute of Physics and Technology, Akademicheskaya St. 1, 61108 Kharkov, Ukraine*
[2)] *University of Dayton, Magnetics Laboratory, 300 College Park, Dayton, OH 45469, USA*
chebotarev@ipp.kharkov.ua

In this paper the plasma assisted PVD of α-Fe thin film on the melt-spun Nd-Fe-B alloys was investigted. Plasma was created by planar rectangular ECR plasma source with multipolar magnetic field and double-slotted antenna generating microwave radiation (frequency of 2.45 GHz and magnetron power up to 300 W) in magnetic structure. The sputtered target consisting of three iron plates 120mm in length and height of 12mm was placed at the distance of 2.5 cm from the magnet position plane and was oriented along antenna slot. Magnetic melt-spun ribbons were placed on the specially treated rough surface of the iron disc of 70 mm in diameter with ferrite magnet behind it. The magnetic field lines were directed transversely to the disk surface and magnetic ribbons were drawn up along the magnetic field. The disc-substrate was placed at the distance of 4.5 cm from the target plates.

The initial pressure in the vacuum chamber was $2\cdot10^{-5}$ torr. The working pressure (2×10^{-3} torr) was attained by variation of gas (Ar) flow and pumping speed. At the gas flow of 1 sccm and the microwave power up to 300 W in the range of target plates the measured plasma parameters were as follows: electron density $\leq 1\times10^{10}$ cm^{-3}, electron temperature equaled 22 eV. The current density of ion flow to grounded disk-substrate was ~ 0.5 mA/cm^2.

After careful degreasing and ultrasonic washing ion etching of the flakes was carried out under the voltage bias of -300 V, the current density ~1 mA/cm^2 during 10 min and then deposition process was realized at the pulsed voltage bias to the target plates of -1000 V with frequency 100 Hz, total current on the target 240 mA, current density 2.9 mA/cm^2. The substrate was under ground potential. The deposition rate of 0.0083 microns/minutes was achieved. The processing duration was a half an hour.

It was revealed that magnetic melt-spun ribbons were homogeneously coated with α-Fe film with typical thickness of 1μm.

Key words: PVD coating, Nd-Fe-B ribbons, ECR plasma, voltage bias, α-Fe film

WeP14

MOLYBDENUM COATINGS WITH FILTRATION OF PLASMA FLOW

V.V. Gasilin, Yu.N. Nezovibat'ko, O.M. Shvets, V.S. Taran, V.I. Tereshin, V.A. Zavaleev

Institute of Plasma Physics, KIPT, 61-108 Kharkov, Ukraine
vtaran@ipp.kharkov.ua

Deposition of molybdenum coatings in arc discharge with assistance of HF one is analyzed in this paper. To avoid substrate heating to high temperature and micro-arc formation during cleaning process, the surface cleaning was carried out with HF plasma only. For reduction of droplet fraction in plasma the "freestanding" filter was utilized [1]. As a filter a solenoid was used, which generated a curvilinear (with the angle of 90°) transportation magnetic field. The effective cross-sectional area of the plasma flow at which was observed the uniform distribution of the thickness of the applied coating, was equal to 113 sm^2. The coating on the base of arc discharge, filter and HF-biasing of substrate were deposited on different substrates, including glass and stainless steel.

The physical (durability and adhesion) and optical (refractive index) properties of molybdenum films are presented. The reflective characteristics of the obtained molybdenum films in the range of wavelengths from 200 to 700 nm were measured.

Molybdenum films were also investigated under the effect of the plasma emission, using an ECR discharge in a simple double-mirror magnetic trap [2].

The time varying negative potential was supplied to sample holder what provided a wide energy distribution of ions bombarded the sample surface in range 30…..1500V.

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WeP15

Plasma Spraying of Powdered Materials by Laminar Flow

M. Kutsishvili, L. Kikvadse
Georgian Technical University, Plasma Spray Laboratory
M.Kostava Street 77, 0175 Tbilisi, Georgia
email: m_khutsishvili@inbox.ru

Abstract.

The work is devoted to the investigation of a new technique for plasma spraying of powdered materials.

The offered plasma spray process using laminar jet is certainly one of the most promising methods of producing high-quality coatings. Improvement of coatings fabricated by offered method results from a number of advantages.

- The powder particles are fed into the plasma flow which is characterized by low angle of divergence. These particles are then molten and accelerated mainly in axial direction. The molten particles are propelled onto a surface inside laminar plasma flow with acceleration on the whole transportation length in plasma forming gas atmosphere. It causes the following: the particles velocity increasing, oxidation rate decreasing, deposition efficiency risen, increasing of density, adhesive strength between a sprayed coating and substrate, plasma coating homogeneity.
- The energy content of laminar plasma flow is comparatively higher than that for turbulent flow. Increased interaction time of powder particles and laminar jet due to large spread of last one results in total melting of particles and subsequent improvement of coating properties.
- The distinguishing feature of the offered method and plasma torch design is the diffusive attachment of arc to the nozzle-anode (it has supposedly been spread on the large surface of anode), and low current density on the anode. It permits to improve the arc stability on the nozzle-anode, decrease the variations and fluctuations of major process parameters (arc current and voltage, plasma jet temperature and velocity), and reduce the anode erosion.
- The laminar plasma flow is characterized by low noise level.

The given investigation contributes to the technology implementation in order to obtain high performance plasma sprayed coatings.

WeP16

Sublimation TiN Coating of RF Power Components

J. Lorkiewicz[1)], A. Bilinski[2)], J. Kula[1)], S. Pszona[1)], J. Sobczak[2)]
1) The Andrzej Soltan Institute for Nuclear Studies (IPJ), Otwock-Swierk, Poland
2) Institute of Physical Chemistry, Warsaw, Poland

Abstract

Field emission or multipactor effects often limit the performance of elements of RF couplers and transmission lines. The multipactor is initiated when certain resonance conditions are reached for trajectories of electrons, which strike surfaces with secondary electron yield (SEY) significantly bigger than 1. Multipacting electron currents may, apart from absorbing a considerable part of RF power, lead to inhomogeneous heating, thermal stresses and, especially in ceramic windows, to fractures.

As a particular plasma application method, titanium evaporation in reactive atmosphere of ammonia has been chosen to deposit thin (up to a thickness of 10 nm) protective surface layers containing titanium nitride and titanium oxinitrides, which suppress secondary electron emission. The coating procedure, first applied by the author in DESY (Hamburg) for TESLA couplers anti-multipactor protection, has been recently implemented in The Andrzej Soltan Institute for Nuclear Studies (IPJ) where a new coating device is used, equipped with a special titanium sublimation setup, an oil-free turbo-pumping system and a 100 l vacuum chamber. Several series of cylindrical and coaxial RF coupler windows have been coated so far after optimizing the processing parameters.

A check of the obtained surface layers' ability to attenuate secondary electron emission has been performed: measurements of the secondary electron yield from TiN layers deposited on alumina samples were done in IPJ both, on the as-delivered coated samples and after a preliminary electron bombardment of their surfaces. Also the chemical composition of the surface layers has been studied using XPS method.

Corresponding author: Jerzy Lorkiewicz, present address INFN – Roma Tor Vergata, Rome, Italy, e-mail: lorkiewicz@ipj.gov.pl

WeP17

ANALISYS OF DISCHARGE CHANNEL STRUCTURE ACORDING TO DIFFERENT SCENARIOS OF SECOND BREAKDOWN AND MHD-INSTABLITY DEVELOPMENT UPON ELECTRICAL EXPLOSION OF WIRES

S.I. Tkachenko[1], D.V. Barishpoltsev[2], G.V. Ivanenkov[2], V.M. Romanova[2], A.E. Ter-Oganesyan[2], A.R. Mingaleev[2], T.A. Shelkovenko[2] and S.A. Pikuz[2]

[1]*Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, Russia*

[2]*P.N.Lebedev Physical Institute, Moscow, Russia*

Experimental data on the electrical explosion of micron-scale diameter wires with a 10 kA current pulse having a rise rate of up to 50 A/ns are presented. Numerous experiments have made it possible to systemize data on the explosion of copper and tungsten wires in open air. A series of optical images of discharge channels enabled us to form a picture of the motion of explosion-generated shock wave (SW) fronts and the boundaries of dense vapor from the electrical explosion of the wires (EEW).

It can be stated that when wires are electrically exploded in air, a breakdown of the inter-electrode gap is possible in two scenarios, depending to a large extent on the thermophysical properties of the exploding wires. In the first case, the breakdown occurs in the air at the boundary of dense explosion products, e.g., tungsten vapor. The shunting of current hinders further heating of the wire material. In the second scenario, development of breakdown occurs in the wire material vapor rather than in the surrounding medium. An example of the development of such a process can be observed when low-melting-point copper wire is exploded. The energy continues to be deposited in the wire explosion products, which supports their further explosive expansion. This can explain the noticeable difference in optical shadowgraphs of the discharge channel structure between electrically exploding copper and tungsten wires in air.

At EEW made from tungsten, molybdenum and titanium the second breakdown has shunting nature. The difference of the discharge channel structure in these cases can be explained by difference of typical time of MHD-instability development.

The same scenarios of the second breakdown and MHD-instability development and consequent difference in optical shadowgraphs of the discharge channel structure we can see upon EEW in vacuum.

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WeP18

APPLICATIONS OF LASER PLASMA EUV SOURCE BASED ON A GAS PUFF TARGET

A. Bartnik, H. Fiedorowicz, R. Jarocki, J. Kostecki, R. Rakowski, A. Szczurek, M. Szczurek

Institute of Optoelectronics, Military University of Technology, Kaliskiego 2, 00-908 Warsaw, Poland

Laser plasma with temperature of the order of tens eV can be an efficient source of extreme ultraviolet (EUV). The radiation can be focused using different kind of optics giving sufficient fluence for some applications. In this work we present results of investigations concerning applications of a laser plasma EUV source based on a double stream gas puff target. The target was irradiated with 4 ns Nd:YAG laser pulses with energy 0.8 J and 10 Hz repetition rate. The source was equipped with two collectors. One of them was a grazing incidence multifoil mirror, the second one was an ellipsoidal multilayer mirror. For both collectors sizes of focal spots and spectra of focused radiation were measured. The multifoil mirror enables to collect radiation in a wide spectral range while the multilayer mirror was designed to reflect radiation in relatively narrow wavelength range centered at 13.5 nm. Both collectors enable to obtain comparable fluence of the focused radiation with xenon plasma.

The multifoil mirror was used in experiments concerning micromachining of organic polymers by direct photo-etching and also for investigations of surface modification of inorganic materials. The micromachining experiments were performed for different polymers that were irradiated through a fine metal grid as a contact mask. The smallest element of a pattern structure obtained this way was 5μm while the structure height was 50μm giving an aspect ratio about 10. The photo-etching speed was maximal for polytetrafluoroethylene (PTFE) reaching 30nm per shot. In experiments with inorganic materials the EUV radiation was used both for surface modification and detection of the surface changes. The changes were measured utilising scattered or luminescent radiation emitted from samples irradiated with EUV pulses. Intensity distribution of the radiation in different spectral ranges selected with absorption filters before and after intense EUV irradiation for different inorganic samples was measured. For some samples significant differences in intensity or intensity distribution was revealed being an evidence of the surface changes.

The ellipsoidal multilayer mirror is going to be used as a condenser in EUV microscope with a zone plate as an imaging optic. The mirror enables to reflect radiation in relatively narrow wavelength band $\lambda = 13.5\pm0.5$ nm for an angle of incidence 45^0. Different parameters of the gas puff target in EUV source were applied to obtain quasi-monochromatic radiation. The collected radiation fluences and intensity distributions for different gases in a focal spot of the mirror were measured.

WeP19

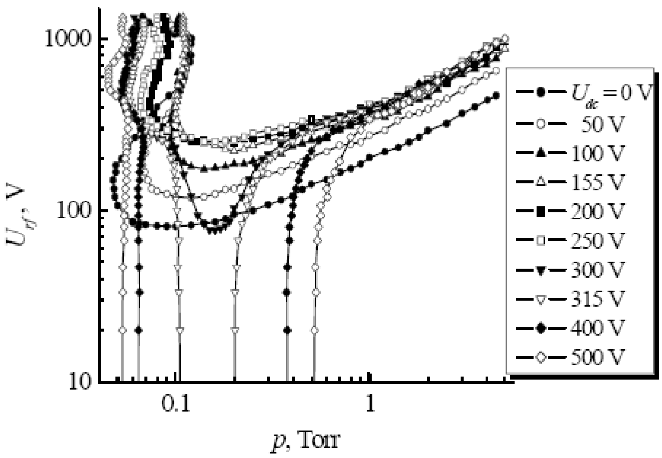
LONGITUDINAL COMBINED DISCHARGE IGNITION IN LOW PRESSURE NITROGEN

V. Lisovskiy[1], *N. Kharchenko*[2], *V. Yegorenkov*[1]

[1] *Kharkov National University, 4 Svobody sq., Kharkov, 61077, Ukraine*
[2] *Scientifical Center of Physics and Technology, 6 Svobody sq., Kharkov, 61077, Ukraine*

Gas discharges in the combined (RF+DC electric field) is applied in a number of technological devices for spectral-chemical analysis, plasma oxidation of silicon, plasmatrons, gas discharge lasers. The aim of our paper is to study the longitudinal combined discharge ignition in low pressure nitrogen. Experiments were performed at the nitrogen pressure in the range $p = 0.01 - 5$ Torr with the amplitude values of the RF voltage $U_{rf} \leq 2000$ V, $U_{dc} \leq 600$ V and the RF field frequency $f = 13.56$ MHz. The distance between stainless steel electrodes was $L = 30$ mm. The RF voltage was applied to one of the electrodes whereas another one was grounded. The RF electrode also served as a "cathode", because a negative DC potential was applied to it.

The figure depicts the breakdown curves $U_{rf}(p)$ we registered for different values of the DC voltage U_{dc} applied. In the absence of the DC voltage we have the conventional RF breakdown curve with the multi-valued region at low nitrogen pressure [1,2]. Application of U_{dc} first leads to the increase of the ignition RF voltage due to the enhanced flow of electrons to the electrodes. However at sufficiently high U_{dc} the DC voltage contributes to the ionization of gas molecules. At U_{dc}, close to U_{dc} at the minimum of the ignition curve of the DC discharge (at $p \approx 0.15$ Torr), a sharply expressed minimum appears at the ignition curve $U_{rf}(p)$. At higher U_{dc} within the nitrogen pressure range where the applied U_{dc} causes the DC discharge ignition, there is no need to apply the additional RF voltage for the combined discharge ignition, here $U_{rf} = 0$. Outside this range the application of the DC voltage U_{dc} makes the ignition of the combined discharge considerably easier.



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WeP20

Physics of the plasma-cathode interface of glow discharges in oxygen with aluminium cathode.

Z. Wroński*
Institute of Physics, M. Curie-Sklodowska University
20-031 Lublin, Poland
E-mail: wrona@tytan.umcs.lublin.pl

Glow discharges in oxygen with aluminium cathode work usually at product *pd* of gas pressure and cathode space length lower than that of other cases, e. g. Ne/Ti discharge. This feature is due to a low cross section of electron ionisation of O_2 molecule and high coefficient of secondary electron emission from the oxidised cathode surface. Because of the above, the O_2 plasma – Al cathode interface has the peculiar character: we observe there the lot of energetic ions bombarding the cathode surface and very strong optical emission from both Al and O atoms.

We will present results of the experimental studies of plasma-cathode interface by optical emission spectrometry. The complex numerical modelling of electrodynamics structure of this interface and excitation processes allows to explain:

- strong line emission of aluminium atoms, very high when compared with that of oxygen species,
- parabolic dependence of Al line intensities on discharge current density,
- hyperbolic decrease of Al line intensities with increasing gas pressure,
- spatial distribution of these line intensities.

Interaction of fast heavy species with cathode surface is concluded to be the main process affecting the presence of both Al and O atoms in the plasma phase and their line emission.

*) corresponding author

WeP21

Supersonic argon plasma generated by an arc-jet

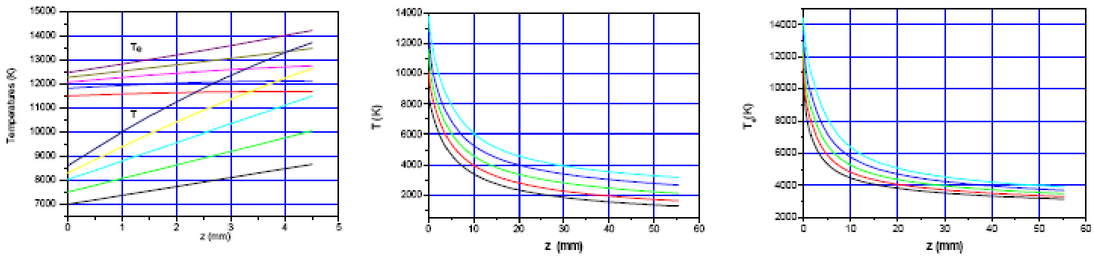
Aniela Kaminska*, Michel Dudeck**

* IEPE Poznan University of Technology, Poznan, Poland
** ICARE laboratory, Orléans cedex, France

Arc-jet plasma sources are very performing tools to generate supersonic, high enthalpy and low pressure plasma flow. The generated plasma flow can be used for many current technological applications such as cleaning, deposition of surface coating and also for space interests for spacecraft environment simulation and space propulsion.

The plasma flow generated by D.C. arc-jet sources presents a strong local non-equilibrium state, not only for chemical processes involving neutral and ionised species but also for the kinetic processes and for the different internal modes.

The plasma flow properties of a D.C. arc-jet running with argon are presented. They are numerically determine by a 2D code named PAPYRUS developed at IEPE Poznan University of Technology and described the plasma properties considering local thermal and ionisation non-equilibrium processes. The used description takes into account two temperatures, a Joule heating, cathode and anode effects, ionisation process, dissipation effects such as viscosity and ambipolar diffusion, wall conditions and radiation processes.



1.a 1.b 1.c

Fig. 1 Heavy particles T and electron T_e temperatures inside the throat (1.a) and inside the divergent part of the nozzle (1.b, 1.c) for an arc current varying from 60 to 140A

Axisymmetric and supersonic properties have been evaluated in the throat and in the divergent part of the nozzle. Exemplary results are presented in Fig.1. The different physical processes are commented such as rarefaction, dissipation, convection and reactive effects.

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WeP22

Where is the breathing mode ? High voltage Hall effect thruster studies

J. Kurzyna,[1)] ***K. Makowski,***[1)] ***A. Lazurenko*** [2)]***, S. Mazouffre*** [2),] ***and Z. Peradzyński*** [1,3)]

[1)] *Institute of Fundamental Technological Research, Polish Academy of Sciences*
Świętokrzyska 21, 00-149 Warsaw, Poland,
e-mail: jkurzyna@ippt.gov.pl
[2)]*ICARE – CNRS, 1C Avenue de la Recherche Scientifique, 45071 Orléans Cedex 2, France*
[3)]*Department. of Mathematics, Computer Sciences and Mechanics, Warsaw University,*
Banacha 2, 02097 Warsaw, Poland

PPS®-X000-ML closed electron drift thruster [1] is a high voltage, new generation plasma propulsion engine being currently under examinations at ICARE – CNRS. With discharge voltage up to 1 kV and power of 6 kW it results in maximum thrust of 330 mN and specific impulse of 3200 s. To study the stability of electric discharge in the thruster plasma, current and voltage oscillations were examined. A set of electric probes was used to capture plama oscillations locally in the vicinity of the thruster exhaust *i.e.* in the region where the magnitude of magnetic induction decreases. Current and voltage oscillations were measured directly on elements of the electric power circuit that supplied the thruster. Because in the time-scale of acquistion recorded signals are nonstationary and hence, Fourier analysis is of limited use the self-adaptive method known as Empirical Mode Decomposition (EMD) was apllied [2]. With the use of EMD recorded time series are being expanded onto a sequence of mono-component signals – intrinsic mode functions (*imf*). Some of these *imf*s may solely represent physical modes that are present in the studied process. Applying Hilbert-Huang transform to intrinsic mode functions one can find their instantaneous frequencies and amplitude (power) resulting in time-frequency spectra of the primary signal. Similarly to our previous studies [3] and known numerical modeling also here three main plasma oscillation frequency bands may be distinguished: low range of ~30 kHz (breathing mode), medium range of 0.1÷1 MHz (transit time) and high frequency range ≥10 MHz (electrostatic azimuthal wave).

It appears that running the thruster at high voltage leads to significant changes of plasma oscillation waveforms. One can observe that magnitude of LF oscillations seem to decay with the applied voltage whereas MF oscillations seem to gain in intensity to finally dominate the overall waveform of the signals at the highest voltage (900 V). To the best knowledge of the authors, such a behavior was never observed before. If the triggering of HF emission is considered the role of LF main current oscillations seems to be overtaken by intense MF oscillations. It looks like to each MF cycle does correspond one HF burst. One can stress here that EMD method suits well to resolve the oscillations in all three bands mention above. It is also useful for indicating the appropriate correlations.

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WeP23

Waves and stability of flowing solar wind structures in the framework of the Hall magnetohydrodynamics

Ivan Zhelyazkov

Faculty of Physics, Sofia University, BG-1164 Sofia, Bulgaria

Abstract

Now it is well established that the solar atmosphere, from photosphere to the corona and the solar wind is a highly structured medium. Satellite observations have confirmed the presence of steady flows. Bulk motions are registered along the magnetic field lines which outline the magnetic structures. Recent observations made by two *HELIOS* spacecrafts have revealed fine structures in high-speed solar wind flows. These structures are in the form of thin flow layers (or tubes) that are adjacent to each other with differences in their plasma parameters (density, magnetic field, steady flow speed). These structures can be separated by tangential discontinuities in the magnetic filed, across which the total (kinetic plus magnetic) pressure is continuous. Here, we investigate the parallel propagation of magnetohydrodynamic (MHD) surface waves traveling along an ideal flowing plasma slab surrounded by flowing plasma environment in the framework of the Hall magnetohydrodynamics. The magnetohydrodynamics with Hall effect (Hall MHD) gives a fluid description of magnetized plasmas taking into account scales of the order of the ion inertial length, $l_{\rm Hall} = c/\omega_{\rm pi}$, at which the dynamics of ions and electrons separates and the medium becomes dispersive. The magnitudes of the plasma densities and flow velocities inside and outside the slab are different. Two possible directions of the relative velocity (in a frame of reference co-moving with the ambient flow) have been studied. From the two kind of surface wave modes that can propagate, notably sausage and kink ones, the dispersion behavior of the kink mode turns out to be more complicated than that of the sausage mode. In general, the flow increases the waves' phase velocities compared to their magnitudes in a static Hall-MHD plasma slab. Moreover, the plasma flows at some values of the magnetic Mach numbers (the ratio of flow speeds to the Alfvén speeds in the corresponding medium), may cause the triggering of the Kelvin–Helmholtz instability. The applicability of the results to real solar wind flow-structures interacting with the Earth magnetosheath is also discussed. We note that the Hall MHD is applicable (with appropriate plasma and magnetic field characteristics) to fusion plasmas, too.

WeP26

Microwave Plasma Treatment of Volatile Organic Compounds

J. Mizeraczyk, M. Jasinski, M. Dors, Z. Zakrzewski

Centre for Plasma and Laser Engineering, The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-952 Gdansk, imp@imp.gda.pl

Recently, microwave plasma generators (MPGs) operated at atmospheric pressure have been developed (e.g. [1, 2]). They found applications in the treatment of various gases.

In this paper, a new MPG for treatment of volatile organic compounds (VOCs) (destruction of refrigerants, reforming of methane to produce hydrogen) is presented. The MPG (Fig. 1) can be operated at atmospheric pressure in various gases (including air, nitrogen, methane, etc.) at high gas flow rates.

The main parts of the experimental setup used in this investigation were a microwave generator (2.45 GHz magnetron), MPG, microwave supplying and measuring system, and gas supplying system. The microwave (2.45 GHz) power was supplied from the magnetron to the MPG via a rectangular waveguide (WR-284) having a reduced-height section (Fig. 1). Differently than in our previous designs of MPGs [1], there is not any nozzle in our new MPG. Instead, the plasma is generated straightforward inside a quartz cylinder.

Photos of the atmospheric pressure microwave discharges in nitrogen and methane, generated by the waveguide-based (nozzleless) MPG are shown in Fig. 2, respectively.

In our investigations of hydrogen production via methane reforming, the microwave power and methane flow rate was 2.5-6.0 kW and 27–152 l/min, respectively. The investigations show that the energetic parameters of the hydrogen production by the new MPG are attractive. The energy efficiency of hydrogen production (77 g [H_2] / kWh) in our system is 3 times higher than that in conventional methods. The absence of oxygen compounds (usually harmful) as by-products is highly beneficial in our method.

Fig. 1. Waveguide-based (nozzleless) MPG operated at atmospheric pressure at high gas flow rates. The inner diameter of the quartz cylinder is 26 mm.

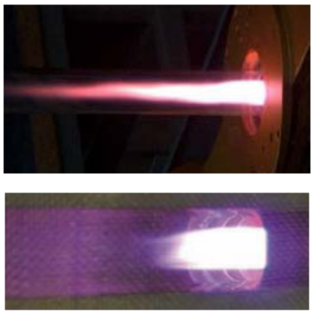

Fig. 2. Microwave discharges in nitrogen (200 l/min) – upper photo, and in methane (152 l/min).

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WeP27

STERILIZATION OF MICROORGANISMS BY OZONE AND ULTRASOUND

V.V. Krasnyj, A.V. Klosovski, O.M. Shvets, V.S. Taran, V.I. Tereshin

Institute of Plasma Physics, KIPT, 61-108 Kharkov, Ukraine
vtaran@ipp.kharkov.ua

The paper presents the results of recent experimental methods of sterilization of different types of microorganisms with the use of ozone and ultrasound [1]. The main aim was optimize the process of sterilization in water solution taking into account the following factors: necessary ozone concentration, power of ultrasonic emitter and water temperature.

Presently the basic methods of low temperature sterilization are: a gas method on the basis of ethylene oxide and plasma method on the basis of hydrogen peroxide
However, the duration process of these methods and the cost of equipment initiated search of new more simple methods. The ozone technologies with the use barrier glow discharge are one of the promising methods and good alternative for the above mentioned methods. For the aims of cleaning and disinfection the ultrasonic washings are used also with addition of chemical ingredients.

In the present work ultrasonic cavitations was used with the simultaneous ozone generation. The high concentration of ozone in water solution was achieved by a two-barrier glow discharge at atmospheric pressure and cool thermo-electric module.
Such a sterilizer consist of ozone generator based on a barrier glow discharge with the flat electrodes covered with dielectric with a high-voltage pulsed power supply of up to 250 W [2]. The sterilization camera is equipped with ultrasonic source with the power of 100 W. The experiments on the inactivation of bacteria of the Bacillus Cereus type, E-coli, yeasts et.al., were carried out in the distilled water saturated by ozone. Ozone concentration in the aqueous solution was to 20 mg/liter with ozone concentration at the output of ozone generator 30 mg/liter. The complete inactivation of spores took 15 min.
Selection of temperature of water, the concentrations of ozone and ultrasonic power allowed defining time necessary for destroying the row of microorganisms.
On the basis of researches, comparing of the offered method of sterilization is executed to other methods of low temperature sterilization.

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WeP28

Wood surface modification in Diffuse Coplanar Surface Barrier Discharge for creating water repellent films from N_2/HMDSO mixtures

M. Odrášková[1], Z. Szalay[1], J. Ráheľ[1,2], A. Zahoranová[1], M. Černák[1,2]

[1] *Comenius University, Mlynská dolina F2, 842 48 Bratislava, Slovakia*

[2] *Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic*

Plasma assisted organosilicon film deposition from HMDSO compound is already well established technique. In addition, plasma mediated deposition of HMDSO is a dry method, which allows to completely skip the technological step of material drying common for standard water-repellent preservatives.

Radial cuts of spruce (*Picea abies*, Karst.) were tested for creating the water-repellent surface from HMDSO compound by Diffuse Coplanar Barrier Discharge at atmospheric pressure. The best results were achieved when the treated sample was in a continuous motion during the course of film deposition. The composition of N_2/HMDSO mixture exhibited an apparent maximum for 30% of total gas flow flowing through the HMDSO liquid, where best hydrophobic coating was achieved. The chemical composition of deposited layer was analyzed by ATR-FTIR. The presence of Si-O-Si and $Si(CH_3)$ functional groups was confirmed.

WeP29

Research on Energy Efficient Metal-Halide Plasma Lamps

S. Peters , S. Franke, R. Methling, M. Wendt, M. Kettlitz H. Schneidenbach, and H. Schöpp
INP Greifswald, Felix-Hausdorff-Str. 2, D-17489 Greifswald, Germany
(peters@inp-greifswald.de)

Nearly 20 % of the world-wide energy consumption is spent on lighting. The use of more efficient light sources like plasma lamps or light emitting diodes (LED) therefore offers a huge possibility to save energy and natural resources. Since many years metal-halide plasma lamps have been established as high performance light sources for general lighting or for illumination in automotive headlights. Increasingly they substitute the less bright and inefficient incandescent lamps. Therefore, plasma lamps have been a subject of modern research. A special task in this field is the development of high efficient enviroment-friendly lamps. The replacement of toxic materials such as mercury has become a challenge and motivation for the development of new high efficient lamps in recent years. Relating to the reduction of energy consumption and the idea of dynamic lighting for home as well as public facilities, a reliable dimming control of plasma lamps is another attractive feature extending their useful properties and acceptance. For these purposes experiments and theoretical investigations were performed to understand the physical mechanism inside the lamps and to find optimized operating conditions for high radiation output and performance.

In the research field of mercury-free lamps for general lighting high-pressure discharges have been investigated, searching for a proper substitution of mercury. Combining Xe and AlI_3, replacing mercury, plasma parameters were established allowing efficient emission of rare-earth atoms and molecules. Lamps filled with Xe, AlI_3, TlI, and TmI_3 were characterized and their operating conditions were optimized. Luminous efficacies of more than 90 lm/W and colour rendering index higher than 75 were achieved, which are competitive to commercial mercury-containing lamps [1].
For automotive lighting a new design of a mercury-free lamp, consisting of a sapphire capillary combined with ceramic parts, was investigated by optical diagnostics. Comparing the measured spectra with calculated intensities allowed optimizing the lamp performance [2] and gave excellent results in practical test on the road.

Recently, several approaches have been made to dim plasma lamps, e.g. [3]. Generally, reduction of the input power means leaving the technical and physical lamp optimum. That causes considerable changes of the lamp behaviour, it influences the electrode performance as well as the plasma properties and thus finally lamp lifetime. Using simplified model lamps with an Hg/NaI filling the plasma parameters and the photometric properties were determined by varying input power down to 30% of the main value. The energy balance of the lamps was calculated and compared to the experimental data. The observed arc constriction with decreasing input power was attributed to an increasing cooling effect by molecular radiation in the peripheral plasma region [4]. The sodium content in the arc core decreased and the plasma properties as well as the radiation from this region became mercury dominated.

Fruitful cooperation with OSRAM/Germany in several projects as well as funding by the German Federal Ministry of Education and Research (BMBF) has been kindly acknowledged.

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WeP30

The Influence of Uncertainties of Atomic Data to the Reconstruction of an EEDF

D. Dodt[1],A. Dinklage[1], R. Fischer[2], R. Preuss[2]
(1, 2) Max-Planck-Institut für Plasmaphysik, EURATOM Association,
(1) Wendelsteinstr.1, 17491 Greifswald, Germany
(2) Boltzmannstrasse 2, 85748 Garching, Germany

Abstract

The plasma of a noble gas discharge is described using a collisional radiative model. The dominant elementary processes in the parameter range considered are electron impact excitation, radiative decay, and recombination at the walls for ions and metastable atomic states. The model aims at the reconstruction of the energy distribution of the electrons (EEDF) from the measured line emission of the plasma. The resulting systematic uncertainties in the forward model are studied in a Bayesian framework.

The uncertainties of the underlying atomic data are quantified and their effect onto modelled state densities and reconstruction parameters is investigated. Particularly the possibilities for the validation of Einstein coefficients for the spontaneous emission of optically allowed Ne **I** transitions are assessed.

WeP31

MECHANISM OF OBSERVED TRANSPORT BARRIER FORMATION IN KIND OF ELECTRICAL DOUBLE LAYER

V.I. Maslov, F. Porcelli*, E.Svistun**
NSC Kharkov Institute of Physics & Technology, 61108 Kharkov, Ukraine
*Politecnico di Torino, Turin, Italy
**Karazin Kharkov National University, Kharkov, 61108, Ukraine
e-mail: vmaslov@kipt.kharkov.ua

Now internal transport barrier formation is widely investigated problem [1, 2]. For internal transport barrier formation in nuclear fusion devices is important that the electrical field should be distributed on radius in kind of shear type. The strong shear is formed when the electrical field is distributed in narrow soliton – type and electrical potential in double - layer – type. The quasi – hump radial distribution of the electrical field has been observed (see [1]).

The reasons that the electrical field approximately equals zero near axis of the system and in peripheral region are considered in this paper. Also reason of the hump radial distribution of the electrical field is considered. The electrical double layer can be formed in dense plasma with strong anomalous transport in peripheral region of the nuclear fusion devices. The perturbations are not excited near axis of the dense plasma due to strong collisions. Also electrons easily follow for ions due to strong collisions. This leads that the electrical field approximately equals zero near axis of the system. Owing decrease of the plasma density on the large radius the electrons worse follow for ions. This leads to electrical field formation in this region. In peripheral region the perturbations are excited. Due to this anomalous transport the electrons easily follow for ions and the electrical field could be small in peripheral region. The radial place of electrical double layer and strong shear localization is determined. The width of the double layer is also determined.

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WeP32

THEORY OF TRANSPORT BARRIER FORMATION BY POLOIDAL CHAIN OF MAGNETIC ISLANDS

V.I. Maslov, F. Porcelli*, E.Svistun**
NSC Kharkov Institute of Physics & Technology, 61108 Kharkov, Ukraine
*Politecnico di Torino, Turin, Italy
**Karazin Kharkov National University, Kharkov, 61108, Ukraine
e-mail: vmaslov@kipt.kharkov.ua

Now internal transport barrier (ITB) formation is widely investigated problem [1, 2]. Role [3, 4] and formation [5] of magnetic islands in nuclear fusion plasma are also investigated now intensively. In particular their effect on ITB formation is very important. The role and conditions of electric field shear formation is considered. The reason of the shear formation at sufficient plasma heating near the chain of magnetic islands [3] is demonstrated. We estimate the electric field shear and shear $\partial_r\omega_{\theta o}$ which can be formed near islands. We consider in consent with [3] the value of $\partial_r\omega_{\theta o}$, formed due to plasma heating near the low order rational surface with poloidal chain of narrow magnetic islands. This shear could be large if electrons propagate without collisions around torus. Because distance between electron trajectories grows with time on non-rational surfaces this leads that instability growth rate is maximum on rational surface. This can lead that plasma is overheated near rational surface. The focusing antenna also can lead to plasma overheating near rational surface. This overheating can provide ITB. The plasma electrons start to miss the region of magnetic islands during their radial shift. This provides ion volume charge in the region of magnetic islands. Small part of electrons leaves the island and the essential shear is formed. This overheating can be small, of order of 1% for ITB formation.

The characteristic time of ITB formation has been derived and shown to be small.

The conditions on magnetic island width are derived, at which it leads to essential shear formation and does not lead to anomalous transport on trapped particles. Even narrow island can lead to ITB. Several poloidal chain of islands are better for ITB as in experiment [3].

Shear can damp instabilities with growth rate smaller than ion cyclotron frequency $\gamma < \omega_{ci}$.

Overheating due to focusing antenna can provide internal transport barrier formation. We consider general case, when the radial width of this over – heated region near magnetic islands is wider than the radial width of the magnetic island. The plasma pressure of this over - heated near island region is the barrier for electrons. This leads to strengthening of the electric field and its shear in this region. Due to formation of the abrupt density profile the anomalous transport can be enhanced on large radius after transport barrier formation. Due to this anomalous transport enhancement the electrical field could be approximately zero after shear region.

We derive inverse dependences of radial width of some vortices on the shear of the electron angle velocity $\partial_r\omega_{\theta o}$ and on degree of steepness of the plasma density profile $\partial_r n_{0e}$. These dependences promote ITB formation. Dimensions of the coherent ordered motions decrease with $\partial_r\omega_{\theta o}$ and $\partial_r n_{0e}$. Amplitude of the electron radial oscillations is smaller for larger $\partial_r\omega_{\theta o}$ and $\partial_r n_{0e}$. It results in mincing of excited nonlinear vortexes, to termination of their interaction, to decrease of their correlation, observed in [3]. It promotes abrupt plasma density profile and ITB especially in the case of small magnetic shear.

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WeP33

Theoretical study of plasma parameters dependence on gas temperature in atmospheric pressure argon microwave discharge

M. Pencheva[1], E. Benova[1] and I. Zhelyazkov[2]

[1]*Department for Language Teaching and International Students, Sofia University, BG-1111 Sofia*
[2]*Faculty of Physics, Sofia University, BG-1164 Sofia, Bulgaria*

Abstract

The gas temperature is an important parameter in many applications of atmospheric pressure microwave discharges. That is why it is necessary to study the influence of that temperature on the plasma characteristics. Our investigation is based on a self-consistent model including the wave electrodynamics and gas-discharge kinetics. We adopt a blocks' energy structure of the argon excited atom. More specifically, we consider 7 different blocks of states, namely 4s, 4p, 3d, 5s, 5p, 4d, and 6s. Each block k is characterized by its effective energy u_k (derived as an average energy of all levels in the block), as well as its effective g-factor and population. The argon dimmer, atomic and molecular ions also are taken into account in the model. We solve the Boltzmann equation in order to get the electron energy distribution function and the necessary rate constants of the elementary processes. The collisional-radiative part of the model is based on 87 processes. As a result we obtain the electron and ions' number densities, mean electron energy, mean power for sustaining an electron–ion pair, electron–neutral collision frequency, population of the excited blocks of states of the argon atom as functions of the gas temperature.

WeP34

Collisional-radiative model of stationary microwave argon discharge at atmospheric pressure

I. Zhelyazkov[1], M. Pencheva[2] and E. Benova[2]

[1]*Faculty of Physics, Sofia University, BG-1164 Sofia, Bulgaria*
[2]*Department for Language Teaching and International Students, Sofia University, BG-1111 Sofia, Bulgaria*

Abstract

In contrast to microwave discharges at low gas pressures, where many elementary processes might be ignored because of their negligible contribution to the electron and heavy particles' balance equations, for such discharges at atmospheric pressure the consideration of a large number of collisional processes is mandatory. Because of the many applications of microwave gas discharges at atmospheric pressure in various ranges of science, technology and medicine, it is necessary to build up an adequate model of those discharges. Here, we offer a collisional-radiative model of argon stationary microwave discharge at high pressures. Our configuration is a thin plasma column of radius $R = 0.5$ mm surrounded (for simplicity) by vacuum and sustained by an electromagnetic wave of frequency $\omega/2\pi =$ 2.45 GHz and power in the range of 60–100 W. There are three key parameters, notably the mean power θ for sustaining an electron–ion pair, effective electron–neutral collision frequency ν_{en}, and gas temperature T_g. We note that the plasma column radius R, gas pressure p and temperature T_g are fixed external parameters determined by the experimental conditions while the mean power θ and collision frequency ν_{en} should be derived from the kinetic model of the discharge. The implemented collisional-radiative model, based on 87 elementary processes in argon plasma with solving the Boltzmann equation, however yields much more information concerning the plasma properties such as the electron and ion number densities, electron energy distribution function, mean electron energy, and populations of excited argon's states. Coupled with the electrodynamics of the traveling electromagnetic wave sustaining the discharge, our model becomes self-consistent one from which one can determine the axial distributions of all wave and plasma characteristics.

WeP35

Microwave produced plasma study in a cylindrical system

Vipin K. Yadav[1]

Institute for Plasma Research, Bhat, Gandhinagar 382428, Gujarat, India
and
Centre for Space Physics, Chalantika, Garia Stn Road, Kolkata 700084, West Bengal, India

Abstract

Hydrogen plasma using electron cyclotron resonance (ECR) technique is produced and is studied in a small linear system for breakdown parameters. Microwave power in the experimental system is delivered by a magnetron at 2.45 GHz for 30 ms during which the breakdown of neutral fill gas occurs. The axial magnetic field required for ECR in the system is such that the fundamental ECR surface (B = 875 G) resides at the geometrical centre of the plasma system. ECR breakdown parameters such as plasma delay and plasma decay time are observed from plasma density measurements, carried out at the centre of plasma system using a specially designed Langmuir probe. The operating parameters such as working gas pressure (10^{-5}-10^{-2} mbar) and input microwave power (160-800 W) are varied and the corresponding effect on the breakdown parameters is observed and the parameter space for operating the pulsed experimental system has been identified. All the relevant experimental results obtained are presented.

WeP36

A Unique Microwave Plasma Generator at Atmospheric Pressure with Pre-ionized Jet

Liu Liang, Zhang Guixin, Luo Chengmu and Feng Jian

Department of Electrical Engineering, Tsinghua University, Beijing, 100084 , PRC

Abstract. Until now, many scientists have already developed some high-power and high-efficiency microwave systems to excite masses of plasma, especially the SLAN series from Germany. Most of them are used with regular slots around the cavity to generate surface waves to maintain plasma. This kind of plasma is very steady and voluminous but not homogenous. Recently, our research group designed a similar system with a unique slot to make the distribution of electric field and plasma more homogenous. Moreover, we have already obtained the microwave plasma at atmospheric pressure in air-open circumstance with a special pre-ionized jet, which can effectively save energy and obtain plasma more easily. This paper will present the details about the design and the pre-ionized method.

Keywords: Microwave Plasma, Slot, Pre-ionized, Electric Field.
PACS: 52.50.Sw

WeP37

PULSED –PERIODIC PLASMATRON FOR APPLICATIONS

Yu. Chivel

Institute of Molecular and Atomic Physics, Minsk, Belarus, e-mail: yuri-chivel@mail.ru

Abstract: High power plasma source - pulsed – periodic plasmatron has been designed. As compared with plasmatrons it have higher flow parameters, comparable with ones, typical for High Current Plasma Accelerators, while in comparison with last, it operates at standard atmospheric pressure.

High Current Plasma Accelerators (HCPA) [1] are one of the most perspective system for a number of applications: surface hardening, thermal spraying, surface modifications. This systems provide on the surface such action parameters – intensity,
exposure time, as technological lasers, but it have advantages - largeness action spot, up to tens square centimeters and efficiency [2] . But HCPA normally operates only under low pressure of ambient gas (1- 10 Torr.), that present problems in manufactoring applications.

In paper a principles of operation of high current pulsed-periodic plasmatron [3], which operates at atmospheric pressure and it,s design are discussed. Also, results of investigations of pulsed –periodic plasmatron operations are presented. The pulsed –periodic flows with diameter ~2cm and lenght ~6cm, temperature 15-20 kK and velocity 106 cm/s at air under atmospheric pressure were obtained. Frequencies up to 1Hz are realized at energy of pulsed flow 3kJ.

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WeP38

Influence of the particle formation and behaviour on the electrical parameters in low pressure radio-frequency CH_4-N_2 discharges.

Jérémy Pereira, Véronique Massereau-Guilbaud, Isabelle Géraud-Grenier and André Plain

LASEP, Faculté des Sciences, Université d'Orléans, Site de Bourges, rue G.Berger, BP 4043, 18028 BOURGES CEDEX, France.

The amorphous hydrogenated carbon nitride a-CN_x:H particles are generated in a classical planar radio-frequency (rf) (13.56 MHz) reactor [1] in different CH_4/N_2 mixing ratios. The particle formation and behaviour are studied in function of the nitrogen percentage in the CH_4+N_2 mixture for the following experimental parameters: total pressure P(120 Pa), total gas flow rate Q (5.6 sccm) and incident rf power (80 W) .

An Ar+ laser (λ=514.5 nm) is used to localize the particles in the plasma bulk, to determine the particle appearance time and to measure the laser beam extinction through the discharge. Particles are mainly observed at the sheath boundaries and in the centre of the discharge where they are trapped in clouds resulting from the action of different forces [1].

The particle formation is very sensitive to the experimental conditions:

- the higher the N_2 percentage in the mixture, the shorter the particle appearance time,
- the particle size decreases as the N_2 percentage is increasing to 30 % and after it increases with the N_2 percentage.

The particle behaviour depends on the N_2 percentage:

- until 70% of nitrogen, particles are trapped in clouds located at the sheath boundaries,
- for higher nitrogen percentages, all the plasma bulk is filled with particles .

The time evolution of the laser beam extinction through the particle clouds is correlated:

- the particle behaviour in the discharge,
- the dc self bias voltage variations [2],
- the intensity and voltage delivered by the radio-frequency generator.

The correlation allows to explain the cloud instabilities observed in the plasma.

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WeP39

Electron Density in Atmospheric Pressure Microwave Surface Wave Discharges

M. Jasinski, Z. Zakrzewski, and J. Mizeraczyk

Centre for Plasma and Laser Engineering, The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-952 Gdansk, imp@imp.gda.pl

Microwave surface wave sustained discharge finds practical applications in elemental analysis, gas purification, environmental protection, diamond deposition, surface treatment, sterilization. All these applications require plasma sources capable of working efficiently under various operating conditions. In the last decades, field applicators for such sources were developed, investigated and implemented in practice. In the present investigations we used 2.45 GHz surfaguide-type plasma source, based on WR 430 standard waveguide.

In this paper we present results of the spectroscopic measurements of the electron density in a microwave surface wave sustained discharges in Ar and Ne at atmospheric pressure. The discharge in the form of a plasma column was generated inside a quartz tube (inner diameter – 1 mm) cooled with a dielectric liquid. The microwave power delivered to the discharge was applied in the range of 200-1500 W. In all investigations presented in this paper the gas flow rate was relatively low (0.5 l/min), so the plasma column was generated in the form of a single filament, and the lengths of the upstream and downstream plasma columns were almost the same. The electron density in the plasma columns was determined using the method based on the Stark broadening of H_β spectral line spontaneously emitted by the plasma. Both theories, i.e. GKS (Griem, Kolb, Shen) and Gig-Card (Gigosos, Cardenoso), were used to work out the experimental results.

The measured electron densities ranged around 10^{15} cm^{-3}, depending on the discharge conditions and the location along the plasma column. Except for a region close to the waveguide, the behavior of the electron density (Fig. 1) along the plasma columns at different microwave powers was in agreement with the theory of surface wave sustained discharges.

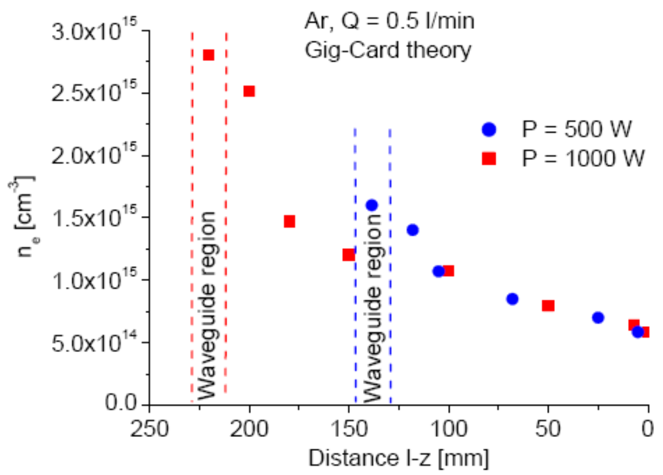

Fig. 1. Electron density along Ar plasma columns at two values of microwave powers.

WeP40

Some Methods to Determine the Parameters of the Ions Emitted by Thermonuclear Targets and to Focus the Ions on the Targets

L.E.Shchebelina

Ioffe Physical Technical Institute, 194021 St. Petersburg, Russia
e-mail: o.konst@mail.ioffe.ru

In this work, for the first time the analytical equations describing the electric fields of the grids of the different configurations and time of flight of the charged particles through sets of such grid electrodes are derived. These grids can consist of the parallel rods, square cells, and belts inclined with the different angles. Such systems are being used to focus, reflect and analyze particle fluxes, for example, in time-of-flight spectrometry (see also Refs. [1,2] and a bibliography therein).

The plasmas created by thermonuclear microexplosions or heating the targets without ignition of microexplosions will emit the atomic and cluster ions damaging the optical elements and other vulnerable equipment (see, e. g., Refs. [3,4]). To determine the parameters of these ions and, thereby, to predict their influence on the equipment and to develop the measures to minimize this influence, the time-of-flight spectrometry can be used.

The effects related to focusing of the particles on thermonuclear targets by grid electrodes for some of the ignition scenarios and to operation of some of the installations with confinement of plasma by the electric fields (see, e g., Ref. [5]) will also be considered.

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WeP41

Use of activation technique and MCNP calculations for fast neutron spatial distribution investigation at the PF-1000 Plasma Focus device.

B. Bienkowska[1)], M. Scholz[1)], K. Wincel[2)],B. Zaręba[2)]
[1)] *Institute of Plasma Physics and Laser Microfusion (IPPLM), P.O. Box 49, 00-908 Warsaw, Poland*
[2)] *Soltan Institute for Nuclear Studies, 05-400 Otwock – Świerk, Poland*

Neutron yield investigations on Plasma Focus (PF) devices have played important role for providing information on plasma parameters and dynamic properties. Moreover, the fame of the PF has been based on the fact that it is the very intense neutron-producing device. The scaling laws for the neutron yields formulated at the beginning of the plasma focus investigations were very promising for these devices. Later investigations, however, carried out on bigger devices suggested that there is a certain condenser energy limit above which the scaling laws are not valid. Hence the essential problem to be resolved in PF research has always been to discover the physics which dominates the configuration, a question closely related to the neutron production mechanism.

Measurements and calculations of energy and spatial distributions of neutrons generated by plasma focus PF-1000 device operated at IPPLM are described in this paper. They have been studied using calibrated activation detectors and the MCNP version 5 Monte Carlo transport code [1] with MCNP5DATA cross section library [2]. The neutron intensity distribution has been obtained at several detectors positioned on different angels in relation to the axis of the device. The measured angular distribution of neutron intensity has been compared with MCNP calculation results. They have shown the dependence of the detector response on the energy spectrum of different neutron sources and on local geometrical/structural characteristics of the PF-1000 device.

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WeP42

INVESTIGATION OF PLASMA DISCHARGES WITHIN MAJA-PF DEVICE OPERATED WITH TUNGSTEN INSERTS IN THE CENTRAL ELECTRODE

K. Malinowski[1)], E. Skladnik-Sadowska[1)], M. Ladygina[2)], L. Jakubowski[1)], M.J. Sadowski[1)]

[1)] The Andrzej Soltan Institute for Nuclear Studies, 05-400 Otwock-Swierk near Warsaw, Poland
[2)] Institute of Plasma Physics, KIPT, 61-108 Kharkov, Ukraine
k.malinowski@ipj.gov.pl

The paper presents results of recent experimental studies at the MAJA-PF plasma-focus facility [1], which were carried out for two different configurations of the end-plate of the central electrode. The main aim was to investigate an influence of the shape and material of the electrode end-plate on the formation and structure of the plasma pinch column. Another aim was to record and identify spectral lines originated from tungsten, which is of particular interest for fusion reactors. The first version of the copper end-plate contained an insert made of a copper-tungsten alloy with a small conical recess in its center. The second version of that plate contained a cylindrical rod made of pure tungsten with the conical ending oriented along the z-axis.

The MAJA-PF device was operated at the 35 kJ and the pure deuterium filling. Some discharges were performed with a small admixture of argon. Routine measurements (of dI/dt and dU/dt traces, as well as X-ray and neutron signals) were performed, and particular attention was paid to X-ray pinhole pictures and time-resolved spectroscopy of plasma in the visible radiation (VR) range. All spectroscopic observations were performed at a distance of 1 cm from the central electrode end. Optical spectra were recorded by means of a Mechelle®900 spectrometer [2], operated with a chosen delay in relation to a so-called current peculiarity (dip) and with exposition times varied from 200 ns to 10 μs.

In discharges performed with the first version of the inner electrode, it was possible to record numerous spectral lines of deuterium-, copper- and carbon-ions, but tungsten lines were probably coated by the other ones and not identified. For shots with the pure deuterium filling the electron concentration, as estimated on the basis of the D_α broadening, decreased from about (8-10) $\times 10^{17}$ cm^{-3} to about 2.0 $\times 10^{17}$ cm^{-3} in 5 μs after the current peculiarity. For shot with a 10% admixture of argon the electron concentration decreased form about 6 $\times 10^{17}$ cm^{-3} to about 2.0 $\times 10^{17}$ cm^{-3} in 3 μs.

In experiments performed with the second version of the inner electrode, distinct and intense hot-spots were recorded in the X-ray pinhole pictures. Among numerous spectral lines there were recorded and identified distinct WI and WII lines. The electron concentration, estimated also from the D_α broadening, decreased from about 6 $\times 10^{17}$ cm^{-3} to about 2.0 $\times 10^{17}$ cm^{-3} in about 10 μs, i.e. during a relatively longer period. Estimates of the concentration of the tungsten component were impossible because of close positions of the other lines. Nevertheless, the recorded optical spectra and diagrams of temporal changes of the plasma density are of importance for basic studies of PF discharges and for applications of the generated plasma-ion streams.

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WeP43

ABRUPT CHANGE IN X-RAY AND ION EMISSION OF THE PALS LASER PLASMA AT LASER INTENSITY OF ~10^{15} W/cm^2

L. Ryć[1], J. Krása[2], L. Láska[2], P. Parys[1], K. Rohlena[2], J. Wołowski[1]

[1] Institute of Plasma Physics and Laser Microfusion, Association EURATOM/IPPLM, Hery 23, 01-497 Warsaw, Poland
[2] Institute of Physics, A.S.C.R., Na Slovance 2, 182 21 Prague 8, Czech Republic

The parameters of both x-ray and ion emissions from laser plasma change clearly depending on the lens-target separation (focusing conditions) and these changes are correlated with each other. The most radical changes in the emissions measured in the PALS laser experiments are observed when the target is shifted into a close vicinity of the focal plane, which causes the exceeding of a threshold level of about 6×10^{14} Wcm^{-2} of the laser intensity. The changes are manifested by an abrupt rise of hard x-ray emission, lowering the amount of ions and narrowing the angle distribution of ions. At sharp focusing, instabilities in x-ray emission are observed. All those changes mean that above the threshold a different physical mechanism plays the decisive role in generation of ions and x-rays.

In the paper we summarise and compare the data concerning x-ray and ion emission obtained in some laser experiments on PALS, which were carried out using different targets, laser energy and wavelength (at the fundamental frequency and the third harmonics). Typical patterns of changing the x-ray and ion emission in dependence on the lens-target distance are presented and discussed. Some practical conclusions concerning the use of x-ray and ion diagnostics in the experiments at high laser energy and the condition of high laser beam focusing are drawn out.

WeP44

Laser-driven radiative jets for astrophysical and ICF applications

T. Pisarczyk[1], A. Kasperczuk[1], S. Borodziuk[1], Ph. Nicolai[2], X. Ribeyre[2], C. Stenz[2], V. T. Tikhonchuk[2], E. Krousky[3], K. Masek[3], M. Pfeifer[3], K. Rohlena[3], J. Skala[3], L Juha[3], J. Ullschmied[4], M. Kalal[5], D. Klir[5], J. Kravarik[5], P. Kubes[5], P. Pisarczyk[6]

[1]*Institute of Plasma Physics and Laser Microfusion, 23 Hery St., 00-908 Warsaw, Poland*
[2]*Centre Lasers Intenses et Applications, University Bordeaux 1-CNRS-CEA, Talence, France*
[3]*Institute of Physics AS CR, Na Slovance 2, 182 21 Prague 8, Czech Republic*
[4]*Institute of Plasma Physics AS CR, Za Slovankou 3, 182 00 Prague 8, Czech Republic*
[5]*Czech Technical University, FNSPE, Brehova 7, 115 19 Prague 1, Czech Republic*
[6]*Warsaw University of Technology, ICS, 15/19 Nowowiejska St., 00-665 Warsaw, Poland*

High speed, well-collimated plasma jets were generated in the interaction of a defocused single laser beam with planar, massive metallic targets [1]. The experiment was carried out at the iodine laser facility (Prague Asterix Laser System - PALS) using the first and third harmonics of laser radiation (1.315 and 0.438 μm) with pulse duration of 250 ps. The targets made of materials with different mass densities (Al, Cu, Ag, Ta, and Pb) have been used. In order to optimize the plasma jet parameters, the laser beam energy and the focal spot radius were varied in the ranges of 13 - 160 J and of 35 - 600 μm, respectively. The influence of a focal lens position on the plasma jet characteristics was studied too.

The information about geometry of plasma expansion, plasma dynamics and electron density, velocity and temperature distributions were obtained by means of a 3-frames laser interferometric system, 4-frames X-ray imager, X-ray streak camera, and ion collectors. An additional information about processes of target heating and shock wave propagation was obtained from the *ab-initio* analysis of the craters produced by the laser beam action. To reconstruct quantitatively the crater shape, the crater replica technique was employed.

The experimental data and the subsequent theoretical analysis have shown that the plasma jet formation is a fundamental process, which accompanies the expansion of the laser produced plasma if two specific conditions are met: (i) the laser pulse duration is shorter than the time of radiative cooling and the time of hydrodynamic expansion; (ii) the radiation cooling length is shorter than the target heating depth. Massive targets made of material of a relatively high atomic number are well suited for that. Plasma jets can be created with an appropriate laser pulse of the energy as small as 10 J.

Numerical simulations of jet formation were performed by using the radiation hydrodynamic code laser-plasma interaction code CHIC. The simulations are in a good agreement with the experimental data. They show that the fast radiative cooling of plasma, which starts before the expansion process, plays a crucial role at launching the jet and at its collimation.

The main plasma jets characteristics are the velocity around 500 km/s, the Mach number greater than 10 and the density above 10^{19}cm^{-3} and the total jet energy of a few J. The jet characteristics are appropriate for the astrophysical [3] and ICF applications. The results of first experiments dedicated to studies of a collision of such a jet with a gas cloud will be also presented. They clearly show the effect of shocks formation of the jet propagation.

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WeP45

STUDIES OF PULSED PLASMA-ION STREAMS DURING THEIR FREE PROPAGATION AND INTERACTION WITH CARBON-TUNGSTEN TARGETS IN PF-1000 FACILITY

E. Skladnik-Sadowska[1)], K. Malinowski[1)], A. Marchenko[3)], M.J. Sadowski[1-2)], M. Scholz[2)], L. Karpinski[2)], M. Paduch[2)], B. Zielinska[2)], V.A. Gribkov[2,4)]

[1)] The Andrzej Soltan Institute for Nuclear Studies, 05-400 Otwock-Swierk, Poland
[2)] Institute of Plasma Physics and Microfusion, Hery 23, 01-497 Warsaw, Poland
[3)] Institute of Plasma Physics, KIPT, 61-108 Kharkov, Ukraine
[4)] A.I. Alikhanov Institute of Theoretical and Experimental Physics, 117218 Moscow, Russia
eskladnik@ipj.gov.pl

The paper presents results of recent experimental studies carried out within the PF-1000 plasma-focus facility [1], which were performed at the free propagation of pulsed plasma-ion streams inside the vacuum chamber and at their interaction with different solid targets. The PF-1000 machine was operated at the 700 kJ level and the pure deuterium filling. In addition to the routine diagnostic measurements (dI/dt, dU/dt, X-rays, neutron yields, etc.) particular efforts were concentrated on time-resolved optical spectroscopy of plasma in the visible radiation (VR) range. Optical spectra were recorder by means of a Mechelle®900 spectrometer [2], operated with a chosen delay in relation to a so-called current peculiarity (dip) and with exposition times varied from 100 ns to 100 μs. The recorded spectral lines were used to estimate concentrations of the free-propagating plasma-ion streams. For a comparison similar measurements were carried out during successive experiments with the use of the targets made of carbon and sintered tungsten. Those targets were placed at different distances from the electrode outlet, i.e. within a region of the high-power flux (at z = 15 cm, where $q = 10^{10}$ W/cm^2), an intermediate region (at z = 35 cm) and a region of the relatively low-power flux (at z = 65 cm, where $q = 10^7$ W/cm^2). In the described experiments particular attention was paid to investigation of a plasma layer formed in the front of the target surface.

At the free propagation of plasma-ion streams - the electron concentration, as estimated on the basis of the Stark broadening of the D_β line recorded at a distance of z = 30 cm from the electrode ends, changed from about 4×10^{17} cm^{-3} to 2×10^{16} cm^{-3} in 30 μs after the current dip. In experiments with targets the electron density of a plasma layer in front of the target surface, as estimated on the basis of carbon- and deuterium-ion lines, changed from about 3×10^{18} cm^{-3} to 3×10^{16} cm^{-3} in 30 μs. After that period an increase in the electron density (up to 10^{18} cm^{-3}) was again observed, due to a delayed arrival of copper-ions emitted from the electrodes. The highest values of the averaged electron temperature were 5.7-6.3 eV. For the target made of the sintered tungsten, which was placed at z = 30 cm, the recorded optical spectra showed intense D_α and D_β lines as well as CII-CIV lines, which covered tungsten (WI and WII) lines. In that case estimates of tungsten component parameters were impossible. Nevertheless, the recorded optical spectra and diagrams of temporal changes of the plasma density are of importance for the optimization studies of PF discharges and for possible technological applications of the generated plasma-ion streams.

1. M. Borowiecki, B. Bienkowska, S. Jednorog, et al., *Czech. J. Phys.* Vol. **56**, Supl. B (2006) B184-B191.
2. E. Skladnik-Sadowska, M.J. Sadowski, K. Malinowski, et al., *Czech. J. Phys.* **54**, Suppl.C (2004) C250-C255.

EVENING LECTURE

Ball lightning – an old puzzle revisited

G. Fussmann[1], B. Juettner[1], S. Noack[2], A. Versteegh[3]

[1]*Humboldt-University Berlin,* [2]*University Leipzig, Germany*
[3]*Eindhoven University of Technology, The Netherlands*

Abstract.
Scientists and laymen have been struggling for centuries to document and explain the phenomenon of ball lightning. Despite of thousands of eye witness reports there is up to present no consensus on their real existence nor how they may be generated in the course of a natural event. In the present contribution we report on two recent experiments allowing to produce luminous balls under plain air conditions. In the first case balls of a few centimetres in diameters and life times of up to 8 seconds are produced by applying a short electrical stroke to pure silicon wafers[a)]. In the second case larger luminous clouds can be generated from water discharges[b)]. Using this second mechanism we were able to produce ball-like plasmoids by discharging a capacitor bank via a water surface. In the autonomous stage after current zero they have diameters up to 0.2 m and lifetimes of some hundreds milliseconds, thus resembling ball lightning in some way. They were studied by applying high speed cameras, probes, calorimetric measurements, and spectroscopy. The plasmoids are found to consist of a true plasma confined by a cold envelope. Inside, there occur rapid changes due to the formation of more dense structures having diameters of 2-3 cm. The electron densities are in the range of 10^{20}-10^{22} m^{-3}, the temperature of the neutral particles can exceed 1300 K while the electron temperature is estimated to be 3000-6000 K. The energy sources for the luminescence seem to be provided by chemical reactions.

a) G.S. Pavia, A.C. Pavao et al, Phys. Rev. Lett. 98, 048501 (2007)
b) A.E. Egerov, S.I. Stepanov, G.D. Shabanov, Phys.-Uspekhi 47, 99-101 (2004)

PROGRAMME **Thursday, October 18, 2007**

A. Melzer, *Uni Greifswald*	Th1-1	Strongly coupled dusty plasmas: finite and extended systems	8:30
H.G. Purwins, *Uni Münster*	Th1-2	Self organized patterns in gas-discharge: dissipative solitons and particle-like behavior	9:15
Y. Peng, *Uni Nancy*	Th1-3	Carbon dust growth in a rf-discharge	10:00
Coffee			10:15
V.T. Tikhonhuk, *Uni Bordeaux*	Th2-1	Laser-plasma interactions in the context of inertial fusion research	10:35
V.I. Krauz, *Kurchatov Moscow*	Th2-2	Z-pich studies in Russia: present status	11:05
J.D. Skalny, *Uni Bratislava*	Th2-3	Mass spectrometry of ions extracted from air corona discharges	11:35
K. Czaus, *Soltan Inst. Otwock-Swierk*	Th2-4	Modified miniature Thomson-type analyzer for measurements of mass- and energy spectra of ions within plasma facilities	12:05
Lunch			12:20
Greifswald City Tour			13:30
Dinner			19:30

Th1-1

Strongly coupled dusty plasmas: finite and extended systems

André Melzer

Institute of Physics, University Greifswald, Felix-Hausdorff-Str. 6, 17487 Greifswald, Germany

Particle-containing (dusty) plasmas are ideal systems to study effects of strong coupling where the electrostatic interaction between neighboring particles by far exceeds their thermal energy. In dusty plasmas, microspheres are trapped in a gaseous plasma. There the particles attain a high negative charge due to the continuous inflow of plasma electrons and ions. Due to this high charge the particles can crystallize into ordered structures. The size and time scales of these systems allow a detailed observation by video microscopy.

Recently, dust systems with a small, finite, number of particles have attracted growing interest because of their interesting properties. For dust clusters the boundary imposed by the confinement plays a crucial role. As a consequence, the structure of dust clusters drastically depends on the exact particle number N. Simultaneously, the dynamic properties of dust clusters show a strong dependence with particle number.

In this talk, the fundamental properties of finite and extended dusty plasmas are presented. Recent progresses in diagnostic techniques are described which allow to reveal fundamental properties of dust clusters. The structure and the fascinating interplay of structure and dynamical properties will be demonstrated for dust clusters in 1D, 2D and 3D confinement potentials.

Th1-2

Self-Organized Patterns in Gas-Discharge: Dissipative Solitons and Particle-Like Behavior

by

Hans-Georg Purwins

Institut für Angewandte Physik, Universität Münster, Germany

http://physik.uni-muenster.de/AP/Purwins/

The understanding of self-organise patterns in spatially extended dissipative systems is one of the biggest challenges in modern natural sciences. In the last 20 years it turned out that investigations in the field of low temperature gas-discharge may help to obtain important insight into the formation and behaviour of these structures. In addition, due to the practical relevance of plasma systems one might expect important applications. In the present talk we will concentrate on well localised solitary patterns with particle-like behaviour that are rather robust with respect to interaction and that are referred to as dissipative solitons (DSs).

We first focus on experimental results obtained from planar low temperature dc and ac gas-discharge systems with high ohmic and dielectric barrier, respectively. In the discharge plane of these systems DSs show up as current and related luminescence radiation density spots on an otherwise homogeneous background. Among other things, DSs may exist as stationary or travelling objects, they may be reflected at each other or at the boundary, they undergo scattering at each other, they form bound states ("molecules") and they can be generated or annihilated as a whole. Also large ensembles of DSs are observed that present interesting many-body systems.

The experimental observations are first discussed in the framework of the drift-diffusion approximation. In favourable conditions rather quantitative agreement between experiment and theory can be obtained. However, with respect to pattern formation so far, on the basis of the drift-diffusion approach little general insight has been obtained into the overall behaviour of the investigated systems. This is the reason for which a largely simplified model has been developed that is based on an electrical equivalent circuit and that leads to a set of nonlinear reaction diffusion equation with rather simple structure. It turns out that this model presents a key for a qualitative understanding of many of the experimentally observed phenomena. At the same time, it allows for an embedment of pattern formation in planar low temperature gas-discharge systems into the much larger world of pattern formation in reaction-diffusion systems, thereby allowing for an understanding of the experimentally observed universal behaviour.

Th1-3

Carbon dust growth in a radiofrequency discharge

Y. Peng[1], R. Hugon[1], F. Brochard[1], J-L. Vasseur[1], D. Lacroix[2], C. Brosset[3], J. Bougdira[1]
[1] *Laboratoire de Physique des Milieux Ionisés et Applications, Université Henri Poincaré, BP 239, F-54506 Vandoeuvre-lès-Nancy Cedex, France*
[2] *Laboratoire d'Energétique et de Mécanique Théorique et Appliquée, Institut National Polytechnique de Lorraine, BP 160, F-54504 Vandoeuvre-lès-Nancy Cedex, France*
[3] *CEA Cadarache, SIPP-Bât.508, F-13108 Saint Paul lez Durance Cedex, France*

Plasma wall interactions studies are of primary importance for increasing the life time of the first wall in fusion devices. In ITER, the divertor target plates will receive on a small surface a significant part of the power during operation, and carbon materials will be used. Although carbon has several advantages than the materials used at other places of the plasma chamber (W and Be), the undergo chemical reactions with hydrogen and its isotopes used as fuel for the fusion reaction. Under ITER operating conditions, the high temperature of the wall will promote diffusion and recombination of atomic hydrogen, withholding the fuel. Moreover, carbon atoms produced by erosion may be deposited at other locations, causing further increase of the hydrogen inventory in the vessel, and encountering several subsequent major safety issues.
In our experiment, carbon dust formation and growth are studied in a radiofrequency discharge. Dust particles sediment into the cathode sheath using carbon originating either from a graphite cathode in pure argon plasmas or from C_2H_2 mixed with argon gas in case where a stainless steel cathode is used. In this contribution, we present an *in-situ* and an *ex-situ* characterization of the carbon dust particles under various plasma conditions (pressure, RF power, C_2H_2 percentage). More precisely, dust nucleation, growth and transport are studied *in situ* using complementary analyses (FTIR, OES, laser scattering and fast imaging), whereas the structural properties of the dust particles are studied *ex situ* using TEM and Auger Spectroscopy. A special attention will be paid to the role played by the cathode sheath in the aggregation and coagulation dynamics. Laser scattering measurements at different wavelengths will be used to detect nanometric particles at different stages. Experimental results will be compared to simulations performed with a Monte Carlo model, in order to retrieve the particles diameter and concentration when the particle size is of the order of the laser wavelength (Mie theory). The spatial distribution of macrometric dust particles and their transport will be investigated using a fast camera of high sensibility.

Th2-1

Laser-plasma interactions in the context of inertial fusion research

V.T. Tikhonchuk[1,2)] and C. Labaune[1,3)]
1) Institut Lasers & Plasmas – Université Bordeaux 1, Talence cedex, France
2) CELIA, Université Bordeaux 1-CNRS-CEA, 33405 Talence cedex, France
3) LULI, Ecole Polytechnique-CNRS, 91128 Palaiseau cedex, France

Two ignition scale facilities for inertial confinement fusion are now under construction in France (Laser MegaJoule) and in the United States (National Ignition Facility). They are based on the idea of an isobaric compression of a spherically-symmetric target and require a laser energy larger than 1 MJ. An isochoric heating of a compressed core, known as the fast ignition (FI), offers a possibility to reduce the ignition energy several times and significantly increases the gain, but it requires a PW-power driver, which now becomes available. The FI projects for the inertial fusion energy are under discussion now in Europe, United States and Japan.

In this talk will be presented the main features of the European project HiPER (High Power laser Energy Research) and its first step PETAL (a PetaWatt laser coupled with the LIL beams) aiming at the demonstration of the laser-driven inertial FI fusion before 2020. According to the present design, HiPER will have a multi-beam multi-ns-pulse of about 250 kJ for the target compression and an ignition beam delivering 70 kJ in about 15 ps. The key issues for the laser and target specification will be addressed in this talk in terms of the basic theory, numerical simulations and experiments on currently available large-scale laser facilities, including the 15 kJ LIL laser at CEA/CESTA.

We present the basic features of laser-driven FI targets, using a simple model, which includes the ablative drive, compression, ignition and burn. The physical processes defining the relation between the laser parameters and target performances will be discussed. The main bottlenecks at the compression phase are related to the homogeneity of the laser energy deposition, high level of absorption and an efficient electron energy transport. They were addressed recently in experimental campaigns on the LIL. In the first campaign, we measured the velocity of heat wave propagation into a solid target, showing the importance of the nonlocal effects and self-generated magnetic fields. The experimental data served for the validation of numerical tools, which we are using for the target design. In the second experiment, we studied the efficiency of smoothing the laser beam inhomogeneities in low-density foams covering the target surface. It is shown that an underdense foam can be ionized in the supersonic regime and it enables an efficient smoothing of large- and small-scale inhomogeneities in the very beginning of the laser pulse.

The ignition phase supposes a deep understanding of interaction of relativistically intense laser pulses with overdense plasmas. It requires en efficient transformation of the laser pulse energy in a beam of relativistic electrons or high-energy ions, which will transport the energy to a compressed core. The physical issues related to the laser energy conversion and electron transport will be discussed based on the experimental results obtained on the 100 TW scale laser facilities and on the numerical simulations. We will consider the energy spectrum of fast electrons and the effects of self-generated magnetic fields and anisotropic instabilities defining their angular divergence. The electron beam divergence and an efficient energy deposition are the most complicated points of the FI design. The cone-guided implosion, will be presented as a valuable option to accommodate the electron beam transport problem. Another option related to the ion acceleration will be also addressed. Although the ion acceleration is much less efficient, it offers other benefits on the level of beam transport and energy deposition. Recent experiments and simulations demonstrate our capacities to control the ion energy spectrum and their divergence.

Th2-2

Z-PINCH STUDIES IN RUSSIA: PRESENT STATUS

V.I.Krauz[1], E.V.Grabovski[2], A.S.Kingsep[1], V.P.Smirnov[1]

[1]*RRC "Kurchatov Institute", Moscow, Russia*
[2]*TRINITI, Moscow region, Russia*

The outstanding experimental results in the recent years on the production of a soft X-ray radiation for the indirect way of irradiating a fusion target allow one to consider the Z-pinch systems as the most probable candidate to the role of a driver in the circuit - diagrams of the pulsed fusion. Therefore significant attention is paid to Z-pinch studies in Russia. More than ten scientific centers in Russia are engaged in this activity. In the presentation the brief review of a present status of Z-pinch studies is given. We should accord special priority to results obtained in RRC "Kurchatov institute" and TRINITI who are the leaders in these studies. The parameters of the largest Z-pinch facilities Angara - 5-1, S – 300 and PF-3 are presented.

We can emphasize two main directions in Z-pinch studies:

- Studies of physics of liner compression;
- Development of "Baikal" facility - powerful generator of x-ray radiation for the purposes of inertial nuclear fusion.

The essential progress has been achieved in understanding of physics of compression of wire arrays. It is shown, that the behavior of plasma differs essentially from classical "snow plough" model. The new model based on the effect of "prolonged" plasma production is developed.

The experiments on S - 300 facility devoted to the studies of the coaxial transmission lines with magnetic self-isolation are presented. The experiments were done with current linear density on the surface of the internal electrode up to ~ 7 MA/cm that corresponds to the parameters of the conceptual project of the pulse thermonuclear reactor, designed in Sandia Laboratory. The results of these experiments allow us make a positive conclusion concerning prospects of use recyclable MILT for energy transportation to the target.

The main goal and parameters of the developed "Baikal" facility are formulated. 15 MJ in x-ray radiation in a pulse of 10 ns duration is expected to achieve at the current of 50 MA. The block diagram of "Baikal" facility is given. The development of the units of this facility is realized on the various stands now. The main one is the "MOL"-facility, which is under construction in TRINITI now. Brief description of its main units - the inductive store, magnetic compressor, voltage transformer, plasma open switch etc is given.

Some new ways of plasma-focus facilities development are discussed. In particular, the compression of the foam liners and wire arrays with linear mass up to 1 mg/cm is achieved on PF-3 facility. However velocity of the compression (~ $5\cdot10^6$ cm/s) does not correspond to the velocity which is expected at the discharge current of ~ 3 MA. One of the probable reasons is the bad current concentration at the radial compression of the current sheath. The magnetic probe measurements in the pinch area showed that the significant part of the current may flow on the pinch periphery. This effect may be also responsible for the neutron yield "saturation" observed in experiments on MJ-level facilities.

At the same time the use of highly-radiated gases in PF-experiments opens prospects for preliminary heating of the liner, in particular foam liner that can promote overcoming of the "cold start" problem. This approach was successfully used in the experiments with a new type of a load – fine-disperse dust. The effects of the dust plasma compression and improvement of the pinch MHD-stability at presence the dust components are shown.

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Th2-3

Mass Spectrometry of Ions Extracted from Air Corona Discharges

J. D. Skalny

Department of Experimental Physics, FMPI Comenius University, Mlynska dolina F 2, 842 48 Bratislava, Slovakia, E-mail: skalny@fmph.uniba.sk

The corona discharge, both positive and negative polarities, is known as an efficient source of unipolar ions. However, the information about the spectra of produced ions is scared. The knowledge of the composition of ions produced by corona discharge can contribute towards an understanding of the role of negative and positive ions in devices using corona discharges for example; electrostatic precipitators, air cleaners, ionisers, copy machines and the devices used for corona treatment of polymer surfaces. Moreover there is a considerable interest to use the corona discharge as a source of ions in IMS (Ion Mobility Spectrometer) instead of currently used radioactive sources of ions. Most of listed applications employ the corona discharges in ambient air. Therefore there is need more about the ion spectra and factors, which affect this. The mass spectrometric identification of ions extracted from the drift region of the corona discharges seems to be an efficient method for the analysis of processes affecting the mentioned effect of the current decrease.

The mass spectrometric analysis of ions formed in a corona discharge running at atmospheric pressure is a complicated diagnostic technique due to problem with the large pressure difference between the corona source and the mass spectrometer as well as problem of mass discrimination appeared in small orifice used for extraction of ions. This is the reason that the number of studies trying to analyse the ions extracted from negative corona discharge in air by mass spectrometry, which were appeared in journals, is low. In the case of positive corona the number is even smaller [. It must be noted that the most the results are contradictory each other.

The aim of presented paper is to discuss some parameters, especially, air pressure, humidity of air, the concentration of various impurities introduced into discharge gap of formed in the discharge itself, like ozone, which most likely are the source of mentioned differences between the results of individual authors. Both the positive and negative corona discharges in ambient air will be analysed. The own earlier and new results will be discussed and compared especially with recently published results achieved by other research groups [1-2].

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Th2-4

MODIFIED MINIATURE THOMSON-TYPE ANALYZER FOR MEASUREMENTS OF MASS- AND ENERGY-SPECTRA OF IONS WITHIN PLASMA FACILITIES

K. Czaus, K. Malinowski, M.J. Sadowski, E. Skladnik-Sadowska

The Andrzej Soltan Institute for Nuclear Studies, 05-400 Otwock-Swierk near Warsaw, Poland
p5office@ipj.gov.pl

The paper describes important improvements in the construction and operation of a miniature mass- and energy-analyzer of the Thomson type, which was developed especially for measurements of ions inside vacuum experimental chambers. The described analyzer constitutes a modified and improved version of the prototype miniature mass-spectrometer, which was designed several years ago [1]. In a comparison with that prototype the modified analyzer has an improved input diaphragm set-up, a more effective pumping system and a movable shaft enabling an exchange of nuclear-track detectors under vacuum conditions.

Due to these improvements the modified analyzer makes possible ion measurements not only under high-vacuum inside various experimental facilities (e.g. devices with plasma injectors and plasma magnetic traps), but also under increased operational pressure (e.g. within pulsed experiments of the Z-pinch or Plasma-Focus type). The described analyzer enables different nuclear-track detector (e.g. those of CR-39 or PM-355 type) to be applied. The movable detector support and a separate vacuum valve facilitate the fast exchange of the exposed detectors after a single discharge or after a series of shots without disturbing the gas conditions inside the experimental chamber.

An analysis of the irradiated detectors can be performed outside the main experimental chamber, and after their appropriate etching the recorded Thomson parabolas can be analyzed quantitatively by means of an optical microscope, which is equipped with a CCD camera coupled with a computer.

The paper describes also experimental tests of the modified analyzer, which were carried out within a so-called IBIS facility equipped with a plasma injector of the RPI type [2]. The plasma discharges were supplied form a 50-kJ condenser bank after the pulsed injection of working gas (pure hydrogen or deuterium). There are presented examples of the recorded Thomson parabolas and the obtained energy spectra of protons and deuterons with energies ranging from about 30 keV to about 300 keV. The mass- and energy-ranges of the ion analysis can be changed by an appropriate exchange of the deflecting permanent magnets and the applied analyzing voltage.

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PROGRAMME Friday, October 19, 2007

J.P. Boeuf, *Uni Toulouse*	Fr1-1	Electron and ion transport in Hall-effect thrusters	8:30
S. Mazouffre, *CNRS Orleans*	Fr1-2	A laser spectroscopic study on Xe^{+} ion transport phenomena in the ExB discharge of a Hall-effect thruster	9:15
J. Wolowski, *IPPLM Warsaw*	Fr1-3	Modification of semiconductor materials with the use of plasma produced by low intensity repetitive laser pulses	9:45
A. Rousseau, *CNRS Palaiseaux*	Fe1-4	Micro-jet used as micro-reactor for depollution	10:00
Coffee			10:30
J. Miseraczyk, *Szewalski Inst. Gdansk*	Fr2-1	Microwave plasma sources	10:50
R. Schrittwieser, *Uni Innsbruck*	Fr2-2	Plasma source with cavity-hollow cathode	11:20
P. Franzen, *IPP-Garching*	Fr2-3	The IPP rf-source: a high power, low pressure negative ion source for the NBI system of ITER	11:50
G.J.M. Hagelaar, *Uni Toulouse*	Fr2-4	Modeling of an inductive negative ion source	12:05
Closing			12:35
Lunch			12:45

Fr1-1

Electron and Ion Transport in Hall Effect Thrusters

J.P. Boeuf, J. Garrigues, G. Hagelaar, J. Perez Luna, N. Dubuit

Laboratoire Plasma et Conversion d'Energie (LAPLACE), Université de Toulouse, France

Electric propulsion is currently considered a key technology for the new generations of commercial and scientific satellites. Electric thrusters use electric power to accelerate a propellant by means of electrothermal, electrostatic, or electromagnetic processes. Because the propellant can be accelerated to high velocity this class of space propulsion devices requires very little mass (compared to chemical thrusters) to achieve a given velocity increment of the spacecraft. Electric thrusters are limited by the available electric power on the spacecraft, and the thrust is generally low (typically less than a few 100s mN), which is suitable for satellite station keeping or long duration applications (interplanetary missions) but not for fast orbit transfer.
Hall Effect Thrusters (HETs) are a class of thrusters where ions are accelerated outside the engine without accelerating grids. Contrary to gridded ion thrusters, the ion beam current is not space charge limited. Positive ions are accelerated by the electric field generated in the plasma by a local drop of electron conductivity induced by the presence of an external magnetic field perpendicular to the electron path from cathode to anode. In this EXB configuration, electrons undergo an azimuthal motion, the Hall current, that is made possible by the cylindrical, annular geometry of the thruster.
The gas density is very low at the exhaust of a HET (most neutral atoms are ionised) and collisions between electrons and neutral atoms are not sufficient to allow significant electron transport across the magnetic field. Classical, collisional electron conductivity cannot explain the experimental observations.
The aim of this lecture is to describe recent progresses in the understanding of the physics of these devices and of the anomalous electron transport, and to discuss remaining questions. New concepts and new configurations of Hall Effect Thrusters will also be presented.

Acknowledgments
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Fr1-2

A laser spectroscopic study on Xe^+ ion transport phenomena in the E×B discharge of a Hall effect thruster

S. Mazouffre[1], D. Gawron[1], V. Kulaev[1], N. Sadeghi[2]

1) ICARE, CNRS, 1c Avenue de la Recherche Scientifique, 45071 Orléans, France.
2) LSP, Université Joseph Fourier-Grenoble I & CNRS, 140 rue de la Physique, 38400 St Martin d'Herès, France.

Hall Effect Thrusters (HETs) are advanced electric propulsion devices for spacecrafts of which the underlying principle is the electrostatic acceleration of positively charged ion species [1]. Among others, recognized advantages of HET are: a low propellant consumption thanks to a large ionization rate and a high ejection speed of ions, a long operation time (several hundreds of days continuous run), a high degree of flexibility as a HET can be switched on and off on demand and the possibility to operate either in a high thrust mode or in a high specific impulse mode. At present, the main drawbacks are the low thrust level in comparison with the one achieved by their chemical counterparts and wear of the discharge chamber that limits the overall lifetime. Contrary to gridded ion engines, plasma production and acceleration are not physically separated in a HET. Moreover, the strong electric field necessary to accelerate ions is generated by an efficient trapping of electrons within a magnetic barrier to avoid insertion of any grids in the plasma medium. Despite several decades of studies that led to the use of HET onboard hundreds of communication satellites and space probes, the physics of HET is still ill understood. Thus it prevents scientists and engineers to develop efficiency and robust very high power thusters for interplanetary journeys and very low power thusters for accurate trajectory control of small-satellites [2]. To only name a few, problems to be solved are: anomalous electron transport, scaling laws and plasma-wall interactions.

One way to gain information about the physical processes at work in a HET is to investigate ion transport phenomena within the **E**×**B** discharge of this specific plasma source. In this contribution we present spatially-resolved as well as time-resolved measurements of the Xe^+ ion Velocity Distribution Function (VDF) in the discharge chamber and in the plasma plume of HETs by means of Laser Induced Fluorescence (LIF) spectroscopy [3]. A tunable single-mode diode laser provides a narrow linewidth laser beam used to excite the $5d\,^2F_{7/2} \rightarrow 6p\,^2D^o_{5/2}$ transition at $\lambda = 834.7233$ nm. The fluorescence radiation is monitored at 541.915 nm. Time-resolved measurements of the Xe^+ VDF were performed with a 100 ns time resolution by means of a lock-in photon counting technique [4].

Xe^+ VDFs were measured parallel to the thruster axis, i.e. in the ion flow direction, for two types of thrusters − the 1.5 kW class PPS100 and the 5 kW class PPSX000 − and for a broad range of discharge voltage, gas flow rate and magnetic field strength. The evolution in time of the VDF was measured for one operating conditions (500 V, 6 mg/s) at various locations during the transient regime that follows an ultra fast anode discharge current ignition [5] in order to investigate the ion dynamics during forced and free low frequency current oscillations [6]. All experimental results are presented and discuss in this contribution. First, a critical analysis of the shape of the VDF is proposed. The broadening of the VDF observed for all operating conditions along the channel axis reveals the overlap between the ionization and the acceleration zones. The way the potential profile, and subsequently the electric field development, can be extracted from the velocity profile is also questioned as measurements indicate the existence of fast ions with kinetic energy higher than the applied potential. Second, the influence of applied voltage, gas flow and magnetic field upon the potential curve is studied. Experimental data are compared with numerical outcomes of a hybrid model and PIC simulations to gain knowledge about ion and electron transport properties. In particular, this approach should allow to obtain electron transport coefficients through the magnetic barrier and to better understand scaling effects. Finally, we show the first measurement ever of the behavior in time of the Xe^+ ion VDF and we comment on new insights into the physics of a HET brought to light by way of time-resolved LIF spectroscopy.

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Fr1-3

Modification of semiconductor materials with the use of plasma produced by low intensity repetitive laser pulses

J. Wolowski[1], J. Badziak[1], A. Czarnecka[1], P. Parys[1], M. Rosinski[1], R. Turan[2], S. Yerci[2]

[1]*Institute of Plasma Physics and Laser Microfusion,*
Association EURATOM – IPPLM, 23 Hery St. 01-497 Warsaw, Poland,
e-mail: wolowski@ifpilm.waw.pl
[2]*Middle East Technical University, Ankara, Turkey*

Studies of characteristics of plasmas generated with laser beams of low and medium intensity are directed towards determination of physical processes in a laser-produced plasma as well as towards important application, among others: use of laser ion sources for technological applications, surface modification by laser ablation and laser-induced material deposition.

This work reports experiments concerning specific application of laser-produced plasma at IPPLM in Warsaw. A repetitive pulse laser system of parameters: energy up to 0.8 J in a 3.5 ns-pulse, wavelength of 1.06 μm, repetition rate of up to 10 Hz, has been employed in these investigations. The characterisation of laser-produced plasma was performed with the use of "time-of-flight" ion diagnostics simultaneously with other diagnostic methods. The results of laser-matter interaction were obtained in dependence on laser pulse parameters, illumination geometry and target material.

The application of laser-induced ion implantation is a novel method for production of semiconductor nanocrystals, competitive to conventional ion implantation techniques. This paper describes application of laser ion source for fabrication of semiconductor nanostructures in the IPPLM within the EC STREP "SEMINANO" project. A repetitive pulse laser system has been employed to produce Ge ions for ion implantation into SiO_2 substrates of different thickness. The parameters of the Ge ion streams were measured with the use of ion diagnostics. The modified SiO_2 layers and sample surface properties were characterised with the use of different methods at the Middle-East Technological University in Ankara and at the Warsaw University of technology. The production of the Ge nanocrystallites has been demonstrated for annealed samples prepared in different experimental conditions.

Micro-jet used as micro-reactor for depollution

X. Aubert[1], A. Pipa[2], Y. Röpcke[2], D. Marinov[3], A. Rousseau[1]

[1]*LPTP, Ecole Polytechnique, CNRS, 91 128 Palaiseau, France*
[2]*INP, Greifswald, 17489 Greifswald, Germany*
[3]*Department of Physics, State University of Saint-Petersburg, Saint-Petersburg, Russia*
Antoine.rousseau@lptp.polytechnique.fr

Microplasmas are now widely investigated, one of their advantages being to generate a plasma at relatively high pressure close to the Paschen minimum [1]. Here, the microplasma is generated in a microhollow cathode type configuration made of a hole drilled through a metal/dielectric/metal sandwich [1]. One of the electrodes acts as the cathode (K) and the other as the anode (A1). The hole diameter ranges from 100 to 400 μm and the pressure ranges from 50 to 500 Torr. When a second electrode (A2) is added, a large volume of plasma plume may be generated between A1 and A2, at a low electric field (1-20Td depending upon the gas) [2]. A microhollow cathode type discharge operates in three different regimes depending on the plasma current: abnormal, self-pulsing and normal regime. The self-pulsing regime is achieved in the range of 1-100 kHz, in argon, helium, nitrogen and oxygen. The self-pulsing frequency is controlled by the microplasma device capacitance, the gas breakdown voltage, and the average discharge current [3,4].

In the present study, a flowing micro-jet is generated: the reactor used is separated in 2 rooms by the MHC as shown on the figure 1. Thus, the gas is constrained to flow only through the microhole and the quantity of treated gas is well known.

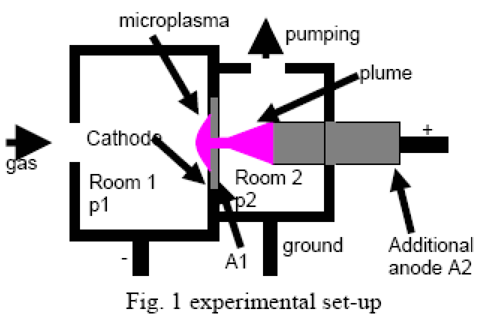

Fig. 1 experimental set-up

First, numerical computations of the hydrodynamic properties are presented: i) the gas flow is supersonic in most operating conditions at the exit of the microhole; ii) Despite a very large injected power density (typically 10^4 W cm^{-3}, the gas heating does not exceed few hundreds of degrees, so that the plasma is non equilibrium. Different measurements are realized on the plume in pure O_2 and in Air. O_3 concentration has been measured by UV absorption spectroscopy; NO and NO_2 have been measured by tuneable diode laser absorption spectroscopy (TDLAS) in the infrared region [5].

Figure 2 shows the O_3 concentration measured downstream the micro-hole as a function of the time averaged cathode current for the 2 electrode configuration and the 3 electrodes configuration in the same gas flow conditions. In the 2 electrode configuration a bell curve shape is observed for different gas flows and pressures. The current corresponding to the O_3 maximum concentration increases with the gas flow. When a 3 electrode is added, $[O_3]$ is strongly reduced probably due to reactions with metastables states of O_2 produced in the plume [6]. This result is independent of the distance between A1 and A2.

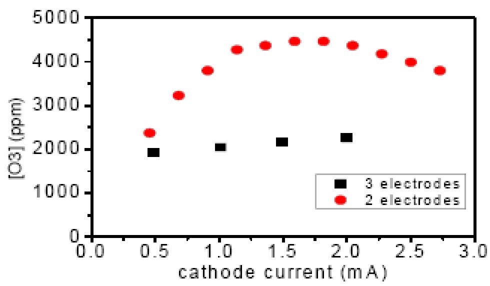

Fig. 2 Variation of the O3 concentration as a function of the cathode current in the 2 electrode configuration and in the 3 electrodes configuration 40sccm, p1= 120Torr and p2= 20Torr

The production of NO and NO_2 in air mixture scales as universal function of the injected power, independently of the working regime (continuous or self-pulsing).

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Fr2-1

Microwave Plasma Sources

J. Mizeraczyk, M. Jasiński, Z. Zakrzewski

Centre for Plasma and Laser Engineering, The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-952 Gdansk, jmiz@imp.gda.pl

In this paper, atmospheric pressure microwave plasma sources (MPSs) for producing the non-thermal plasmas are presented. The MPSs can be operated in various gases (air, nitrogen, rare gases, methane, gaseous kerosene, etc.) at atmospheric pressure and high gas flow rates (up to several m^3/min). A few types of the MPSs, i.e. waveguide-based surface wave sustained MPS, coaxial-line-based and waveguide-based nozzle-type MPSs, waveguide-based cylinder-type MPS, and microdischarge-type MPS are presented.

As an example, results of the use of MPSs for the plasma processing of several volatile organic compounds (VOCs) are presented. The examples are: the abatement of high-concentrated Freon-type refrigerants and the reforming of methane to produce hydrogen.

The processing of the Freons was carried out at atmospheric pressure in a moderate power (200-400 W, 2.45 GHz) waveguide-based nozzle-type MPS. The results showed that the microwave plasma fully decomposed the Freons to at least less-harmful compounds at a relatively low energy cost (1 kg [Freon]/kWh).

For the reforming of methane, a waveguide-based cylinder-type MPS, in which the plasma was generated straightforward (without nozzle) inside a quartz cylinder, was used (Fig. 1). Photos of the atmospheric pressure microwave plasmas in nitrogen and methane-nitrogen mixture, generated by the waveguide-based cylinder-type (nozzleless) MPS, are shown in Fig. 2. At the methane reforming, the microwave power and methane flow rate were 2.5-6.0 kW and 27–152 l/min, respectively. The investigations showed that the performance parameters of the hydrogen production by the cylinder-type MPS are attractive. The energy efficiency of hydrogen production (80 g [H_2] / kWh) by this MPS is 3 times higher than that in the conventional methods.

The above examples show that the MPSs can be a useful tool for the plasma processing of various gases at atmospheric pressure and high gas flow rates.

Fig. 1. Waveguide-based cylinder-type (nozzleless) MPS operated at atmospheric pressure and high gas flow rates. The inner diameter of the quartz cylinder is 26 mm.

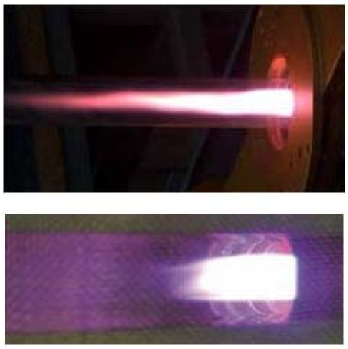

Fig. 2. Microwave discharges in nitrogen (200 l/min) – upper photo, and in methane (152 l/min)-nitrogen (100 l/min) mixture – lower photo.

Fr2-2

Plasma source with cavity-hollow cathode

R. Schrittwieser[1],
C. Ionita[1], D. Luca[2], D. Alexandroaei[2], R. Apetrei[2], G. Popa[2], P.C. Balan[1], S.B. Olenici[2],
A. Murawski[1], I. Vojvodic[3], S. Jaksch[1], P. Scheier[1]

[1]*Institute for Ion Physics and Applied Physics, Leopold-Franzens University of Innsbruck, Austria*
[2]*Faculty of Physics, Alexandru-Ioan-Cuza University of Iasi, Iasi, Romania*
[3]*Faculty of Natural Sciences and Mathematics, University of Montenegro, Podgorica, Montenegro*
e-mail: roman.schrittwieser@uibk.ac.at

A hollow-cathode discharge is characterized by high electron density due to the pendulum effect of electrons between the ion-rich sheaths on the cathode walls. This effect leads to high ionisation efficiency and thus high plasma density with strong light emission. In addition, the high discharge voltage of up to 600 V leads to intensive sputtering of the cathode material due to bombardment by energetic plasma ions. Thus a hollow cathode can be used as a source of intensive light, as cluster source and as sputtering source for various substances depending on the material the cathode is made of. By use of various gases also reactive sputtering can be performed. In contrast to magnetrons a hollow cathode does not need a magnetic field and is therefore suitable also for sputtering of ferromagnetic materials.

Here we present experimental results on the characterisation of a cavity-hollow cathode post-discharge as a sputtering source by various diagnostic means. In this case, the pendulum effect was enhanced by an additional cavity of 5 mm diameter and 5 mm depth, drilled into the lower cylindrical part of the cathode, with a diameter of 20 mm and a height of 10 mm. The upper part consists of a ring with 20 mm diameter with a conical borehole with an inner diameter of 5 mm, which widens upwards. A glass spacer of 18 mm outer diameter a 6 mm height is inserted between the two cathode disks through which emission spectroscopy can be performed. The current-voltage characteristic of the discharge shows two distinct regimes: one normal glow discharge regime with voltages up to 1000 V but low currents of a few mA, and the actual hollow-cathode discharge regime with a current of about 25 mA for a voltage of 600 V. The optical appearance of the discharge is clearly different in both cases, with a conical plasma beam leaving the upper cathode ring in the latter case. This beam carries with it the sputtered particles. Up to now we have used graphite, Ti, Ni and Fe cathodes.

In the sputtering regimes of magnetic (Ni) and non-magnetic cathodes (Cu, Ti) the discharge parameters were: Ar-pressure $6\times10^{-2} \div 1\times10^{-1}$ mbar and discharge current $5 \div 60$ mA. The spatial distribution of the relative electron density in front of the nozzle was measured by emission spectroscopy in order to correlate optical and electrical diagnostic data, obtained by probes and a four-gridded ion energy analyzers. The radial and axial distributions of the emission spectra were mapped in the 340 to 650 nm wavelength range. By applying an Abel transformation to the radial distribution of the light intensity, the proportionality factor to the electron plasma density was calculated. Also the spectra of the discharge for using Ni, Cu and Ti as sputtering materials were measured. The operation of the source was tested in both stationary and pulsed regimes. In the latter case, experimental conditions were sought to operate in self-oscillating and pulsed regimes. The results are useful to find the operating conditions for implementing a highly versatile sputtering source.

In the case of a Ti cathode, we have found evidence that immediately after their production the sputtered Ti-atoms form clusters which become negatively charged. This enhances the deposition rate of the Ti-clusters on substrates of highly oriented pyrolytic graphite (HOPG) which are on the anode potential. For various sputter durations Ti-films were produced on the HOPG and their morphology was investigated by scanning tunneling microscopy (STM).

Fr2-3

The IPP RF source: a high power, low pressure negative ion source for the neutral beam injection system of ITER

P. Franzen, U. Fantz, W. Kraus, M. Berger, S. Christ-Koch, M. Fröschle,
B. Heinemann, C. Martens, P. McNeely, R. Riedl, E. Speth, D. Wünderlich,
Max-Planck-Institut für Plasmaphysik, EURATOM Association, PO Box 1533,
D-85740 Garching, Germany.

IPP Garching has successfully developed a RF driven negative ion source for the ITER neutral beam injection system. The RF source is now an interesting alternative to the reference design with filamented sources due to its in principle maintenance-free operation. Current densities of 330 A/m^2 and 230 A/m^2 have been achieved for hydrogen and deuterium, respectively, at a pressure of 0.3 Pa and an electron/ion ratio of less than 1 for a small extraction area (7.0x10^{-3} m^2) and short pulses (< 4 s). The results have been obtained by utilizing the surface effect, i.e. the conversion of ions or neutrals to negative ions at a surface with a sufficient low work function, achieved by cesium seeding of the source.

The development concentrates now on extending the pulse length and extending the size of the source on two dedicated test facilities. The pulse length can be extended up to one hour at the long pulse test facility having an extraction area of 0.02 m^2. The large source test facility is equipped with the so-called half-size source — a large RF source with the width and half the height of the ITER NNBI source. This source is dedicated to demonstrate the homogeneity of a large RF plasma and to test the modular concept of the IPP RF source.

The development program is accompanied by extensive modeling activities and is strongly supported by diagnostics of the source plasma and the beam. The basic plasma parameters of the source are measured by optical emission spectroscopy (OES) and Langmuir probes; the negative ion density is measured by Cavity Ring Down Spectroscopy, Laser Detachment and the novel technique via the H_α/H_β ratio. With several line-of-sights, the spatial distribution of the plasma parameters is obtained by OES. The long pulse test facility is equipped with a spatially resolved H_α-Dopplershift spectroscopy system for measuring the beam homogeneity; this system gives the unique possibility of relating this to the plasma homogeneity in the source.

The paper will give an overview on the results achieved at the three test facilities of IPP together with a discussion of the underlying physical mechanisms.

Fr2-4

Modeling of an inductive negative ion source

G. J. M. Hagelaar[1], J.-.P Boeuf[1], and A. Simonin[2]

[1]*Laboratoire Plasma et Conversion d'Energie (LAPLACE), Université de Toulouse, France*
[2]*Commisariat à l'Energie Atomique (CEA), Centre de Cadarache, France*

Future fusion reactors may use fast neutral injection to heat the plasma and to drive plasma current. The fast neutrals are generated by neutralization of a beam of negative hydrogen and deuterium ions accelerated to high energies >1MeV, which requires reliable negative ion sources providing high current densities >200 A/m^2 at low source pressure <0.3 Pa. [1] One of the source designs considered for the ITER fusion project is the radio-frequency inductively-coupled-plasma (ICP) source developed at the IPP Garching [1]. The present paper presents a numerical model of the driver region of this ICP source, describing the main physical aspects in a self-consistent way: plasma chemistry and transport, rf-field, stochastic electron heating, etc.

The model is two-dimensional axisymmetric. The plasma is described by a quasineutral fluid model. For each ion or neutral species we solve a separate continuity equation and a full momentum equation including inertia and viscosity terms. The electron density is deduced from charge neutrality. The ambipolar electric field acting on the ions is deduced from electron Boltzmann equilibrium. The electron temperature is calculated from the global energy balance equation, where the total power absorbed from the rf field (50-200 kW) is fixed and is one of the main control parameters in the model. The rf electromagnetic field (1-50 MHz) is solved from Maxwell's equations coupled with the electron momentum equation. Non-local effects (anomalous skin effect, stochastic heating) are described using an effective electron viscosity, estimated from analytical theory. From the rf-field and current we calculate the spatial profile of the average Lorentz force on the electrons (ponderomotive force). This force tends to push the electrons away from the rf coils, which has a significant effect on the ambipolar field and the plasma density profile, especially at lower driving frequencies <10 MHz.

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