TIMETABLE IWSSPP'14

	June 29	June 30	July 01	July 02	July 03	July 04		July 05	July 06
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday		Saturday	Sunday
8:00-9:00	arrival	breakfast	breakfast	breakfast	breakfast	breakfast		breakfast	breakfast
8:00-10:00		registration							
9:30-10:15			George Paskalov	Neli Bundaleska	Mario Janda	9:00-9:35	Sander Nijdam	José M. Donoso	departure
10:00-**10:15**		Opening ceremony				9:40-10:15	Jose Palomares		
10:15-11:00		Ivan Ganachev	Benjamin Jones	Luis Conde	J. Mullen	10:20-10:55	Julio Henriques	Tomaz Gyergyek	
11:00-11:30		coffee break							
11:30-12:15		Elena Tatarova	Jan Mlynar	Jan Mlynar	Radomir Panek	11:30-12:05	Zhivko Kiss'ovski	Mariana Atanasova	
12:15-13:00		Francisco Dias	Jan Stockel	Tsviatko Popov	Renaud Dejarnac	12:10-12:45	Dmitry Tsyganov	J. Mullen	
13:00-14:00	lunch	lunch	lunch	lunch	lunch	lunch		lunch	
14:00-16:00	registration	Free discussion forum		excursion	Free discussion forum				
16:00-16:25		M. Bogdanova	WORKSHOP		poster session	15:50-16:25	Eva Kovachevic	J. Mullen	
16:25-16:50		A. Kaziev				16:25-17:00	Johannes Berndth	E. Filippov	
16:50-17:20		coffee break			coffee break				
17:20-17:45		P. Marinova	WORKSHOP		conference photo & poster session	Michal Prochazka		K. Temelkov	
17:45-18:10		T. Bogdanov				Iuliia Onyshchenko		Closing	
18:10-18:35		I. Topala				A. Nastuta			
18:35-19:30		A. Volynets				Irina Filatova			
19:30-21:00	dinner	welcome	dinner	dinner	banquet	dinner		dinner	
		football 19:00 and 23:00				football 19:00 and 23:00			

LEGEND:

(orange)	**Topic1** Fusion Plasma and Materials
(pink)	**Topic 2** Plasma Modelling and Fundamentals
(light blue)	**Topic 3** Plasma Sources, Diagnostics and Technology
(grey)	**Workshop** Remote GOLEM operation
35 min. each	**Workshop** Plasma for Sustainable Environment

MONDAY, JUNE 30

Chairmen: Dr. Evgenia Benova

10:00 Opening ceremony

10:15 SURFACE-WAVE PLASMAS WITH ENHANCED MICROWAVE ABSORPTION
Prof. Ivan Ganachev, *Shibaura Mechatronics Corporation, Yokohama, Japan and Chubu University, Aichi, Japan*

11:30 MICROWAVE PLASMAS APPLIED FOR SYNTHESIS OF FREE STANDING GRAPHENE SHEETS
Prof. Elena Tatarova, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal*

12:15 LARGE-SCALE MICROWAVE PLASMA SOURCE APPLIED FOR GRAPHENE ENGINEERING
Dr. Francisco Dias, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal*

Chairmen: Prof. Jose Manuel Donoso

16:00 ION FLUX AND ENERGY VIRTUAL SENSOR FOR MEASURING ION FLUX AND ENERGY DISTRIBUTION AT A RF BIASED ELECTRODE IN ICP REACTOR (RIE-MODE)
Mrs. Maria Bogdanova, *Skobeltsyn Insitute of Nuclear Physics, Moscow State University, SINP MSU, Russiaand Faculty of Physics, Moscow State University, MSU, Russia*

16:25 FORMATION OF LOW-FREQUENCY PERIODIC STRUCTURES IN PULSED MAGNETRON DISCHARGES
Dr. Andrey Kaziev, *ational Research Nuclear University “MEPhI”, Russia*

Chairmen: Prof. Zhivko Kiss'ovski

17:20 ATMOSPHERIC SURFACE-WAVE-SUSTAINED ARGON PLASMA KINETICS
Mrs. Plamena Marinova, *St. Kliment Ohridski University of Sofia, Bulgaria*

17:45 CONDITIONS FOR SUSTAINING COAXIAL MICROWAVE DISCHARGE BY TRAVELING ELECTROMAGNETIC WAVE
Mr. Todor Bogdanov, *St. Kliment Ohridski University of Sofia, Bulgaria*

18:10 MASS SPECTROMETRY DIAGNOSIS OF ATMOSPHERIC PRESSURE LABORATORY PLASMAS WITH RELEVANCE FOR MOLECULAR ASTROPHYSICS OF HOT CORES
Dr. Ionut Topala, *Iasi Plasma Advanced Research Center (IPARC), Faculty of Physics, Alexandru Ioan Cuza University of Iasi, Romania*

18:35 MECHANISM OF N_2 DISSOCIATION AND KINETICS OF N(4S) ATOMS IN PURE NITROGEN PLASMA
Mr. Andrey Volynets, *Lomonosov Moscow State University, Faculty of Physics and Lomonosov Moscow State University Skobeltsyn Institute of Nuclear Physic, Russia*

TUESDAY, JULY 1

Chairmen: Prof. Ivan Ganachev

09:30 RF PLASMA SOURCES AND APPLICATIONS (from R&D to Commercial)
Dr. George Paskalov, *Plasma Microsystems LLC, Los Angeles, USA*

10:15 STICKING NON-STICK: SURFACE AND STRUCTURE CONTROL OF DIAMOND-LIKE CARBON IN PLASMA ENHANCED CHEMICAL VAPOUR DEPOSITION
Dr. Benjamin Jones, *School of Applied Sciences, University of Huddersfield, UK*

Chairmen: Dr. Radomir Panek

11:30 EQUILIBRIUM OF HIGH-TEMPERATURE PLASMA AND MAGNETIC FIELD IN THE MAGNETIC CONFINEMENT FUSION
Dr. Jan Mlynar, *Institute of Plasma Physics AS CR, v.v.i., Czech Republic*

12:15 BASICS OF REMOTE OPERATION OF A TOKAMAK
Dr. Jan Stockel, *Institute of Plasma Physics, AS CR, Czech Republic*

16:00 **WORKSHOP:** Remote GOLEM operation
Dr. Jan Stockel, *Institute of Plasma Physics, AS CR, Czech Republic*

WEDNESDAY, JULY 2

Chairmen: Dr. Mario Janda

09:30 ALCOHOL REFORMING INTO HYDROGEN-RICH GAS APPLING MICROWAVE “TORNADO”-TYPE PLASMA
Dr. Neli Bundaleska, Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal

10:15 DIAGNOSTICS OF PLASMA STREAMS FROM ION THRUSTERS FOR SPACE PROPULSION
Prof. Luis Conde, *Department of Applied Physics. Technical School of Aeronautical and Space Engineering. Universidad Politécnica de Madrid, Spain*

Chairmen: Dr. Renaud Dejarnac

11:30 SOFT X-RAY TOMOGRAPHY IN SUPPORT OF IMPURITY CONTROL IN TOKAMAKS
Dr. Jan Mlynar, *Institute of Plasma Physics AS CR, v.v.i., Czech Republic*

12:15 LANGMUIR PROBE AND EVALUATING THE ELECTRON ENERGY DISTRIBUTION FUNCTION - CLASSICAL AND ADVANCE TECHNIQUES OF APPLICATION
Prof. Tsviatko Popov, *Faculty of Physics, St. Kliment Ohridski University of Sofia, Bulgaria*

14:00 EXCURSION

THURSDAY, JULY 3

Chairmen: Dr. Francisco Dias

09:30 TIME-RESOLVED OPTICAL DIAGNOSTIC OF SELF-PULSING NANOSECOND DISCHARGES FOR BIOMEDICAL APPLICATIONS
Dr. Mario Janda, *Division of Environmental Physics, Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava, Slovakia*

10:15 CHARACTERISATION OF PLASMAS CREATED BY ARGON DBD-JETS USING CALIBRATED OPTICAL EMISSION SPECTROMETRY; THE RENAISSANCE OF OES
Prof. Joost van der Mullen, *Université Libre de Bruxelles, Belgium*

Chairmen: Dr. Jan Stockel,

11:30 EDGE PLASMA STUDIES IN THE COMPASS TOKAMAK
Dr. Radomir Panek, *Institute of Plasma Physics AS CR, Prague, Czech Republic*

12:15 THE NARROW FEATURE IN POWER FLUX DEPOSITION PROFILES IN COMPASS LIMITER PLASMAS
Dr. Renaud Dejarnac, *Institute of Plasma Physics, ASCR v.v.i., Czech Republic*

16:00 POSTER SESSION

DETERMINATION OF THE PLASMA PARAMETERS IN THE ISTTOK TOKAMAK — P 1.1
Dr. Miglena Dimitrova, *Institute of Plasma Physics, Academy of Sciences of the Czech Republic v.v.i., Czech Republic*
Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Bulgaria

DETERMINATION OF THE EEDF BY DIVERTOR PROBES IN THE COMPASS TOKAMAK — P 1.2
Dr. Miglena Dimitrova, *Institute of Plasma Physics, Academy of Sciences of the Czech Republic v.v.i., Czech Republic*
Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Bulgaria

PLASMA POTENTIAL EVALUATED BY BALL PEN AND LANGMUIR PROBES IN THE COMPASS TOKAMAK — P 1.3
Dr. Miglena Dimitrova, *Institute of Plasma Physics, Academy of Sciences of the Czech Republic v.v.i., Czech Republic*
Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Bulgaria

BI-MAXWELLIAN ELECTRON ENERGY DISTRIBUTION FUNCTION IN THE VICINITY OF THE SEPARATRIX IN TJ-II STELLARATOR PLASMA — P 1.4
Prof. Tsviatko Popov, *Faculty of Physics, St. Kliment Ohridski University of Sofia, Bulgaria*

EMISSION PROPERTIES OF THE PLASMA FACED MODEL-MATERIAL COVERED WITH THIN INSULATOR FILMS **Mrs. Anastasiia Dvornova**, *Plasma Physic Department, National Research Nuclear University MEPhI, Russia*	P 1.5
RFIT-450 ION THRUSTER THERMAL MODEL **Mr. Kirill Kruglov**, *Research Institute of Applied Mechanics and Electrodynamics of Moscow Aviation Institute (National Research University), Russia*	P 2.1
SIMULATION OF PLASMA FILLED HEMISPHERICAL CAVITY AS DIELECTRIC RESONATOR ANTENNA **Mr. Georgi Trenchev**, *Sofia University "St. Kliment Ohridski", Faculty of Physics, Bulgaria*	P 2.2
DEVELOPMENT OF SIMULATION TOOLS FOR NUMERICAL INVESTIGATION AND COMPUTER-AIDED DESIGN (CAD) OF GYROTRONS **Dr. Milena Damyanova**, *Institute of Electronics of the Bulgarian Academy of Sciences, Association EURATOM-INRNE, Bulgaria*	P 2.3
THEORETICAL STUDY OF PLASMA SUSTAINED AROUND DIELECTRIC CYLINDER BY TAVELLING EM WAVE **Mr. Krasimir Ivanov**, *St. Kliment Ohridski University of Sofia, Bulgaria*	P 2.4
SPATIAL AND TEMPORAL PATTERN FORMATION IN PLASMA OF A DC DRIVEN "BARRIER" DISCHARGE: STABILITY ANALYSIS AND NUMERICAL SOLUTIONS **Dr. Ismail Rafatov**, *Middle East Technical University, Turkey*	P 2.5
CORROSION RESISTANT SILICON FILMS DEPOSITED IN MAGNETRON DISCHARGE WITH LIQUID CATHODE **Mr. Alexander Tumarkin**, *National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Russia*	P 3.1
PLASMA REACTOR FOR DEPOSITION OF CARBON NANOWALLS AT ATMOSPHERIC PRESSURE **Mr. Zhivko Dimitrov**, *Faculty of Physics, St. Kliment Ohridski University of Sofia, Bulgaria*	P 3.2
VIRTUAL PANEL CONTROLLED ELECTRONIC PROBE SYSTEM **Mr. Mladen Mitov**, *Technical University of Sofia, Bulgaria*	P 3.3
LANGMUIR PROBE DIAGNOSTICS IN DC GAS DISCHARGE TECHNOLOGICAL REACTOR **Mr. Mladen Mitov**, *Technical University of Sofia, Bulgaria*	P 3.4
LAYER DEPOSITION ON THE WALLS OF THE PORES OF ANODIC OXIDE OF ALUMINUM IN DC GAS DISCHARGE TECHNOLOGICAL REACTOR **Mrs. Ana Bankova**, *Technical University of Sofia, Bulgaria*	P 3.5

INFLUENCE OF THE PLASMA FOCUS X-RAY PULSES ON THE SYNTHESIS OF ENDOGLUCANASE BY MUTANT STRAIN OF TEICHODERMA REESEI-M7 — P 3.6
Mr. Stanislav Zaprynov, *Sofia University "St. Kl. Ohridski", Faculty of Physics, Deptm. of Optics and Spectroscopy, Bulgaria*

INTEGRAL DIAGNOSTICS OF AN ICP DISCHARGE SYSTEM — P 3.7
Pavel Masherov, Andrey Mogulkin, *Research Institute of Applied Mechanics and Elecrodynamics of the Moscow Aviation Institute (National Research University), Russia*

HOT PROBE MEASUREMENTS OF A LASER PRODUCED PLASMA — P 3.8
Dr. Andrei Nastuta, *Iasi Plasma Advanced Research Center (IPARC), Faculty of Physics, Alexandru Ioan Cuza University of Iasi, Romania*

LUNAR REGOLITH COMPOSITION ANALYSIS USING SOLAR WIND — P 3.9
Mr. Dmitry Trufanov, *National Research Nuclear University MEPhI, Russia*

INFLUENCE OF DIAPHRAGM CONFIGURATION ON DC DIAPHRAGM DISCHARGE BREAKDOWN IN ELECTROLYTE SOUTION — P 3.10
Mrs. Lucie Hlavatá, *Brno University of Technology, Faculty of Chemistry, Czech Republic*

WATER VAPOR INFLUENCE ON THE PROTON COMPONENT OF THE HYDROGEN PENNING DISCHARGE — P 3.11
Mr. Dobrynya Kolodko, *Plasma physics department, National Research Nuclear University MEPhI, Russia*

FRIDAY, JULY 4

WORKSHOP: Plasma for Sustainable Environment

Chairmen: Prof. Elena Tatarova

09:00 GUIDING OF STREAMER PATHS BY BACKGROUND IONIZATION
Dr. Sander Nijdam, *Eindhoven University of Technology, The Netherlands*

09:40 ATMOSPHERIC PRESSURE ELECTRICAL DISCHARFES: AN EFFICIENT AND GREEN ALTERNATIVE FOR NANOPARTICLE SYNTHESIS
Dr. Jose Palomares, *Department of Applied Physics, Eindhoven University of Technology, The Netherlands*

10:20 VUV RADIATION OF SURFACE WAVE DRIVEN ARGON PLASMAS
Dr. Julio Henriques, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal*

11:30 SMALL MICROWAVE PLASMA SOURCE AND ITS APPLICATIONS
Prof. Zhivko Kiss'ovski, *Faculty of Physics, Sofia University, Bulgaria*

12:10 ABOUT THE MECHANISM OF CARBON NANOSTRUCTURE FORMATION IN MICROWAVE ARGON PLASMA
Dr. Dmitry Tsyganov, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal*

15:50 LOW TEMPERATURE PLASMAS FOR FUNCTIONALIZATION OF ADVANCED CARBONS
Prof. Eva Kovacevic, *GREMI UMR 7344 CNRS &Université d'Orléans, France*

16:25 LOW TEMPERATURE PLASMAS FOR SURFACE MODIFICATIONS
Dr. Johannes Berndt, *GREMI UMR 7344 CNRS &Université d'Orléans, France*

IWSSPP Session

Chairmen: Prof. Joost van der Mullen

17:20 BARRIER COATINGS FOR ARCHAEOLOGICAL ARTEFACTS PRESERVATION
Mr. Michal Prochazka, *Faculty of chemistry, Brno University of Technology, Czech Republic*

17:45 EFFECTIVE SURFACE MODIFICATION OF POLYETHYLENE BY AN ATMOSPHERIC PRESSURE PLASMA JET
Mrs. Iuliia Onyshchenko, *Research Unit Plasma Technology, Department of Applied Physics, Faculty of Engineering and Architecture, Ghent University, Belgium*

18:10 ON THE PLASMA JETS INTERACTION WITH BIOMEDICAL SURFACES
Dr. Andrei Nastuta, *Iasi Plasma Advanced Research Center (IPARC), Faculty of Physics, Alexandru Ioan Cuza University of Iasi, Romania*

18:35 APPLICATION OF NON-THERMAL PLASMA FOR PRE-SOWING SEEDS DISINFECTION AND EARLY PLANT GROWTH PROMOTION
Dr. Irina Filatova, *Institute of Physics of the National Academy of Sciences of Belarus, Belarus*

SATURDAY, JULY 5

Chairmen: Prof. Tsviatko Popov

09:30 PROPAGATOR METHOD AS A KINETIC OPERATOR TO ANALYZE DISCONTINUITIES IN PLASMAS
Prof. Jose Manuel Donoso, *Department of Applied Physics. Technical School of Aeronautical and Space Engineering. Universidad Politécnica de Madrid*, *Spain*

10:15 SHEATH FORMATION IN AN OBLIQUE MAGNETIC FIELD - SOME COMMENTS ON LENGTH SCALES AND THE ROLE OF SOURCE TERMS
Dr. Tomaz Gyergyek, *University of Ljubljana, Faculty of electrical engineering, Slovenia*
and Jožef Stefan Institute, *Slovenia*

Chairmen: Dr. Jan Mlynar

11:30 ARGON ATMOSPHERIC PRESSURE DISCHARGES FOR BIOMEDICAL APPLICATIONS
Dr. Mariana Atanasova, *St. Kliment Ohridski University of Sofia, Bulgaria*

12:15 PLASMA POWER INTERRUPTION TO INVESTIGATE THE ENERGY COUPLING BETWEEN ELECTRONS AND VIBRATIONAL CO2 STATES
Prof. Joost van der Mullen, *Université Libre de Bruxelles, Belgium*

Chairmen: Dr. Evgenia Benova

16:00 THE ROLE OF SPUTTERED MATERIAL IN THE RACETRACK REGION OF A HiPIMS
Prof. Joost van der Mullen, *Université Libre de Bruxelles, Belgium*

16:25 VISUALISATION OF PLASMAINDUCED PROCESSES IN INTERELECTRODE GAP OF PION INSTALLATION USING LASER ILLUMINATOR ON MOLECULAR NITROGEN
Mr. Evgeny Filippov, *National Research Nuclear University MEPhI, Russia*

17:20 DETERMINATION OF SPATIALLY-RESOLVED AND TIME-RESOLVED ELECTRON TEMPERATURE OF NANOSECOND PULSED LONGITUDINAL DISCHARGE IN VARIOUS GAS MIXTURES
Dr. Krassimir Temelkov, *Metal Vapour Lasers Laboratory, Institute of Solid State Physics, Bulgarian Academy of Sciences, Bulgaria*

17:45 CLOSING

SURFACE-WAVE PLASMAS WITH ENHANCED MICROWAVE ABSORPTION

Ivan Ganachev

Shibaura Mechatronics Corporation, Yokohama, Japan and
Chubu University, Aichi, Japan

The sustaining of microwave plasmas requires efficient energy transfer from the microwave to the plasma. This is not straightforward, since high-density plasmas do not let the microwave enter them, penetrating only a shallow skin layer with a depth ("skin-depth") roughly proportional to the square root of the plasma density. This is consistent with the general plasma behaviour of shielding all electric fields, which itself is caused by the high mobility of free electrons in the plasma: The electrons move in a way to create a field opposing the existence of fields in the plasma. This is described by a large (negative) dielectric constant ε_p. For high plasma densities $1/\varepsilon_p \to 0$, just as in a metal conductors, and as a result the electric fields stay out.

This behaviour can be overcome be either applying very high frequencies, above or at least close to the electron plasma frequency ω_p, or by an external DC magnetic field $\mathbf{B}_{dc}$. The magnetic field dramatically decreases the electron mobility for movements across the magnetic field lines, making possible the existence of electric fields perpendicular to $\mathbf{B}_{dc}$. Both approaches are expensive, requiring either expensive millimetre wave generators or bulky electromagnets.

Here is where surface waves have been providing a practical and cost-efficient solution for plasma processing since the late 1970s [1, 2]. Plasma processing is done not by the microwave itself, but by ions and reactive radicals hitting the processed surface or the neutral gas molecules. At low pressures these high-energetic species and the electrons have long mean freepaths for inelastic collisions, comparable to the process chamber size. Thus it is enough to create high-energy electrons only along the processing chamber boundary. This can be achieved without the microwave penetrating the plasma, it is enough that it travels only along the plasma boundary, and it even need not be the entire boundary. The shallow-depth electron heating provides a way to sustain high-density microwave plasmas, otherwise non-transparent to microwaves. The lack of strong high-frequency fields in the plasma bulk is even an advantage, since one can process sensitive electronic devices, which would otherwise be destroyed by the induced high-frequency surface currents.

However, with this approach the volume for plasma-microwave interaction becomes too small, and power transfer to the plasma becomes an issue [3]. Fortunately, surface waves are heavily absorbed in conditions of surface wave resonance, where the negative plasma permittivity has the same magnitude as the permittivity of the surrounding dielectric medium ($\varepsilon_p \approx -\varepsilon_d$). Thus one way to enhance the absorption it to tune ε_p via the microwave frequency. Another approach is to have artificial dielectrics (i.e. corrugated regions) at the boundary, ensuring effective dielectric constant equal to ($-\varepsilon_p$). Absorption can be increased also by dielectric bodies or hollows locally enhancing the microwave. This has the advantage that one can distribute them in a way to control the plasma density profile, especially at higher pressures. In this presentation we present practical solutions demonstrating these and other approaches to enhance the surface-wave absorption [4].

References:

[1] M. Moisan, P. Baudry and P. Leprince, IEEE Transc. Plasma Sci. **PS-3** (1975) 55.
[2] I. P. Ganachev and H. Sugai: Plasma Sources Sci. Technol. **11** (2002) A178.
[3] M. A. Lieberman and A. J. Lichtenberg, Principles of Plasma Discharges and Material Processing, Willer, New York, 1994, sec. 13.3.
[4] H. Sugai and I.P. Ganachev, J. Plasma Fusion Res. **84** (2008) 187.

MICROWAVE PLASMAS APPLIED FOR SYNTHESIS OF FREE STANDING GRAPHENE SHEETS

E. Tatarova(*)[1], A. Dias[1], J. Henriques[1], A.M. Botelho do Rego[2], A.M. Ferraria[2], M.V. Abrashev[3], C.C. Luhrs[4], J. Phillips[5], F. M. Dias[1] and C.M. Ferreira[1]

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Self standing graphene sheets were synthesized using microwave plasmas driven by surface waves at 2.45 GHz stimulating frequency and atmospheric pressure. The method is based on injecting ethanol molecules through a microwave argon plasma environment, where decomposition of ethanol molecules takes place. The evolution of the ethanol decomposition process was studied in situ by plasma emission spectroscopy and Fourier transform infrared spectroscopy. Free gas-phase carbon atoms created in the plasma diffuse into colder zones and aggregate into solid carbon nuclei. The main part of the solid carbon is gradually withdrawn from the hot region of the plasma in the outlet plasma stream where nanostructures assemble and grow. Externally forced heating in the assembly zone of the plasma reactor has been applied to control the structural quality of the assembled nano-structures. The synthesized graphene sheets have been analyzed by Raman spectroscopy, scanning electron microscopy, high-resolution transmission electron microscopy and X-ray photoelectron spectroscopy. The presence of sp^3 carbons is reduced by increasing the gas temperature in the assembly zone of the plasma reactor. As a general trend, the number of mono-layers decreases when the wall temperature increases from 60º to 100º C. The synthesized graphene sheets are stable and highly ordered.

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LARGE-SCALE MICROWAVE PLASMA SOURCE APPLIED FOR GRAPHENE ENGINEERING

F. M. Dias[1]. E. Tatarova[1], J Henriques[1], N. Todorov[2], N. Bundaleski[3], O. Teodoro[3]

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The development of large-scale, high-density plasma sources based on microwave propagation is interesting for improving the production efficiency of next generation plasma-based technologies. In particular, N_2-Ar large-scale plasma sources driven by microwaves have advantageous properties for plasma processing technologies, such as the nitriding of surfaces. These sources provide high number densities of active species like ground-state $N(^4S)$ atoms as that play a key role in surface treatment processes. Furthermore, one possible way to control the dissociation rate of nitrogen may be the use of mixtures like N_2-Ar [1].

In the present work, the unique environment of large-scale slot-antenna excited N_2-Ar microwave plasmas driven by surface waves at reduced pressure has been applied for graphene sheets engineering. Here we describe a technique that make use of nitrogen-argon plasma for graphene N doping.To this end graphene flakes freely suspended on a quartz substarte (at a distance 4.5 cm from the launcher) has been treated by plasma at different exposure times. The microwave power delivered to the plasma was kept constant at 600 W. The plasma treated samples have been analysed by Raman spectroscopy and X-ray photoelectron spectroscopy was used to provide insight into the chemical bonding of graphene with nitrogen.

References:

[1] E. Tatarova, F. M. Dias, E. Felizardo, M. J. Pinheiro, C. M. Ferreira, B. Gordiets, *J. Appl. Phys.* **108** (2010) 123305

ION FLUX AND ENERGY VIRTUAL SENSOR FOR MEASURING ION FLUX AND ENERGY DISTRIBUTION AT A RF BIASED ELECTRODE IN ICP REACTOR (RIE-MODE)

M.A. Bogdanova[1, 2], D.V. Lopaev[1], S.M. Zyryanov[1, 2]

[1] *Skobeltsyn Insitute of Nuclear Physics, Moscow State University, SINP MSU, Moscow Russia*

[2] *Faculty of Physics, Moscow State University, MSU, Moscow Russia*

The modern technology of micro- and nanoelectronics involves a great number of steps, e.g. pattern transfer, where Reactive Ion Etching (RIE) in rf plasma reactors is widely used. RIE is carried out placing samples on the surface of rf biased electrode, as rule in an asymmetric rf low-pressure discharge. In an effort to control the etching process, ion flux and energy distribution should be controlled precisely as much as possible. However, measurements of them during the process in the real-time operation mode are impossible. Nevertheless, if virtual sensor of ion flux and energy can be developed, such a sensor would allow monitoring ion energy spectrum without direct measurements during plasma processing. This virtual plasma diagnostics should include calculation of ion energy spectrum based on the simple physical model of ion motion in collisionless rf sheath. In addition the modeling has to be fulfilled in the real-time operation mode by using the set of external measurable parameters. This paper is just devoted to creation of such ion energy distribution virtual diagnostics.

The paper contains model calculations of ion energy spectrum on the surface of rf biased electrode in $Ar-$ and H_2- plasma under different conditions. The modeling results were compared with the data, obtained by Retarded Field Energy Analyzer (RFEA). A good agreement between calculated and experimental data lets us make a conclusion that the model of ion motion in collisionless rf sheath can be successfully applied to ion energy virtual sensor creation.

Besides, the paper includes measurements of ion flux on the surface of rf biased electrode, obtained by using the variable self-bias method, which doesn’t require measurements inside the plasma. The results of these measurements have shown a quiet good agreement with the data, obtained by Langmuir probe and RFEA.

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FORMATION OF LOW-FREQUENCY PERIODIC STRUCTURES IN PULSED MAGNETRON DISCHARGES

A. V. Kaziev, G. V. Khodachenko

National Research Nuclear University "MEPhI", Moscow, Russia

Recently, several research groups have reported observation and investigation of various wave-like phenomena in high-power impulse magnetron sputtering (HiPIMS) discharges (e. g. [1–3]). Considerable effort is being made to determine the mechanisms of drifting ionization zones appearing in such plasmas, and to gain control over their formation. Our present contribution deals with the investigations of similar effects taking place in quasi-stationary magnetron discharges: high-current impulse magnetron discharge (HCIMD), and low-pressure high-current impulse diffuse discharge (HCIDD) [4], also known as non-sputtering magnetron discharge (NSMD). HCIMD is a high-voltage (up to 1.5 kV), high-current (up to 20 A/cm^2), long (~ 1–40 ms) impulse sputtering tool [4]. The low-voltage (~ 80 V) NSMD dramatically inhibits the sputtering rate thus limiting the deposition process under certain conditions. The dynamics and transition regimes of these discharge types were investigated in reactive mode. Namely, HCIMD was utilized to sputter the aluminum target in gas mixture of Ar and CO_2.

The pulsed magnetron discharge regimes were investigated using the synchronized fast gated camera (BIFO K011), fiber optic spectrometer (Avantes AvaSpec) and magnetic probes. The experiments were carried out in two discharge chamber configurations: the conventional planar magnetron device and the so-called apparatus with profiled electrodes, where the specially shaped cathode is immersed into the cusped magnetic field [1]. Experimental results demonstrate strong influence of the magnetic field magnitude and geometry on the discharge regime. In a certain range of these parameters, HCIMD transits into a low-voltage regime (either arc or NSMD) after ~ 50–100 μs of the pulse. Rotating periodic structures were observed both in HCIMD and NSMD. Frequency of their rotation falls into kHz-range.

We propose a phenomenological model for the low-frequency (f ~ 2–10 kHz) periodic structures observed both in HCIMD and NSMD. It is based on the ionization instability effect that takes place in glow discharges, often resulting in striations. The equation of ionization balance is analyzed by introducing small harmonic perturbations of electron density n and electron temperature T_e in azimuthal (along $\mathbf{E}\times\mathbf{B}$) direction. Provided the instability increment is positive, the range of possible perturbation wavelengths λ_k can be derived. The lower limit appears to be $\lambda_k^{min} = 2\pi(D_m/\nu_i)^{1/2}$, where D_m is the coefficient of cross-B ambipolar diffusion and ν_i is the frequency of ionization. The upper limit strongly depends on the electron energy loss mechanism: $\lambda_k^{max} = 2\pi[T_e/(eB\varkappa_{eg}\nu_{eg})]^{1/2}$, where $\varkappa_{eg}$ is the fraction of electron energy lost in its collision with gas particle and ν_{eg} is the frequency of these collisions. For our experimental parameters we obtain λ_k^{min} = 0.5–5 cm and λ_k^{max} ~ 100 cm. The calculated wavelengths of the inhomogeneities, as well as their frequencies of rotation, are in good agreement with our experimental results for low-frequency periodic structures in HCIMD and NSMD.

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ATMOSPHERIC SURFACE-WAVE-SUSTAINED ARGON PLASMA KINETICS

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Surface-wave-sustained discharges (SWDs) have been studied both theoretically and experimentally in the past 50 years. The wide interest SWDs own to the increasing number of applications in various fields, including technology and medicine due to their ability to work in wide range of discharge conditions. The new applications demand the plasma sources to be small, inexpensive and to have sufficiently high concentration of charged particles and chemically active species. More over plasmas for medical applications need to be sustained at open air – atmospheric pleasure, and to have considerably low temperature. Adequate solution for the above requirements can be found in various SWDs at atmospheric pressure. Plasma characteristics such as dependence of concentration and distribution of plasma particles on discharge conditions have to be studied.

This model consists of both electrodynamics of the wave propagation and kinetics of the electrons and the heavy particles. Basis of the model are Boltzmann's equation, particles balance equations and Maxwell's equations. The model is applied to the plasma torch (plasma–vacuum configuration at atmospheric pressure). Because of the high pressure it is necessary to account for the effect of electron and heavy particles interactions on the wave propagation. Therefore the electron–neutral collision frequency (obtained from the kinetic part of the model) in the expression for the plasma permittivity is considered. Using the full expression for the plasma permittivity in the Maxwell's equations, a complex dispersion equation is obtained. Its solution gives dependences, usually presented through phase and attenuation diagrams. The wave energy balance equation solved together with the electron energy balance equation provides a link between electrodynamics and kinetics. The self-consistent model of plasma sustained by traveling electromagnetic wave at atmospheric pressure allows us to study the influence of the discharge conditions on the plasma properties.

In this work a theoretical study of Argon plasma column sustained by travelling electromagnetic surface wave is made by means of self-consistent model. The self-consistent model gives the dependence of the electron energy distribution function on the discharge conditions in parallel with the plasma characteristics such as axial distribution of electrons, ions, excited atoms, electron mean energy, and wave characteristics. Influence of the wave frequency on the discharge parameters: plasma density, electron mean energy and electron – neutral collision frequency can be investigated as well.

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CONDITIONS FOR SUSTAINING COAXIAL MICROWAVE DISCHARGE BY TRAVELING ELECTROMAGNETIC WAVE

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The electromagnetic wave travelling along a dielectric tube can produce plasma inside the tube which is the typical cylindrical plasma column of surface-wave-sustained discharges. The cylindrical plasma column is studied in details. If there is a metal cylinder at the tube axis, electromagnetic wave could produce plasma also outside the dielectric tube [1, 2]. We named this configuration coaxial discharge.

The possible configurations depend on the radial distribution of different materials like metal, dielectric (vacuum, Teflon etc.) and plasma. We have studied the metal–dielectric–plasma coaxial configuration. The basic relation in our model is the local dispersion relation and wave energy balance equation, obtained from Maxwell's equations [3]. The plasma is axially inhomogeneous and the dispersion relation gives the so called phase diagrams – dependence between the normalized plasma density and the dimensionless wave number. From the behaviour of the phase diagrams at different wave modes and discharge configurations we can obtain information about the ability of the wave to sustain the plasma and about the wave and plasma characteristics. The axial profiles of normalized plasma density, wave power and wave number are obtained.

It is shown that depending on the values of plasma parameter σ ($\sigma = \omega R/c$, R – plasma radius, ω – electromagnetic wave frequency, c – speed of light) and geometry parameter η ($\eta = R_m/R$, – dimensionless metal road thickness, R_m – metal rod radius) plasma can or cannot be sustained by the wave and plasma characteristics change drastically.

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MASS SPECTROMETRY DIAGNOSIS OF ATMOSPHERIC PRESSURE LABORATORY PLASMAS WITH RELEVANCE FOR MOLECULAR ASTROPHYSICS OF HOT CORES

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Since the first discovery of molecules in space, CH, around 75 years ago, tremendous efforts have been made to identify more and more classes of molecules in interstellar space or at the surface of various astronomical objects. As result we know now over 150 interstellar and circumstellar molecules, with an inevitable increase of the molecular mass and complexity (bond angles, length and atomic partners).

In order to cross check telescope observations (mainly rotational transitions data) with data from laboratory experiments, many approaches to generate exotic molecules have been continuously developed: plasma experiments, crossed molecular beams, selected ion flow tube mass spectrometry, UV processing or atomic/ion bombardment of interstellar ice analogues.

We present here results related to mass spectrometry diagnosis of atmospheric pressure laboratory plasmas with relevance for molecular astrophysics of hot cores. The hot molecular cores define massive regions of dust and gas (containing a large fraction of molecules), representing the birth sites of high mass stars. Most hot molecular cores we know have masses between 10 to 3000 solar masses; they emit electromagnetic radiations largely in far infrared range. The molecular hydrogen density in central region of hot cores reaches to 10^7 cm^{-3} and the average temperature in the range 100-300 K (on small scale, higher temperature values were pointed, up to 1500K).

Our approach to generate complex chemical systems with relevance for the ongoing processes in hot molecular cores, is to use a non equilibrium plasma at atmospheric pressure. The plasma is generated in a dielectric barrier discharge configuration, using high voltage pulses from a high voltage switch system. As results discharge currents of around 2 A are measured trough plasma volume, somehow different from the general acceptance of community working with dielectric barrier discharge, used with current values around several tens of milliampers. The discharge is feed with a complex mixture of gases: noble gas – hydrogen – alcohols (methanol, ethanol, isopropyl alcohol). Electrical and optical monitoring of the discharge is assured by current and voltage probes connected to a digital oscilloscope and by emission spectroscopy.

Molecular beam mass spectrometry is used to detect and identify the chemical population generated in plasma volume. A quadrupole-based system was used for this purpose (HPR-60 MBMS, from Hiden Analytical Ltd), with 2500 amu upper mass range. The sampling system consists of three differentially pumped stages, separated by aligned skimmer cones. Neutral atomic or molecular gas population is detected in real time by the molecular beam mass spectrometer. Low energy electron impact ionization is used in order to differentiate members of the isomeric families.

The results indicate that in plasma environment a non equilibrium chemical population is generated, with a representative fraction of molecular clusters. Relatively high mass molecules are dissociated and recombination phenomena lead to many types of molecular families, some of them being also identified in molecular hot cores.

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MECHANISM OF N_2 DISSOCIATION AND KINETICS OF $N(^4S)$ ATOMS IN PURE NITROGEN PLASMA

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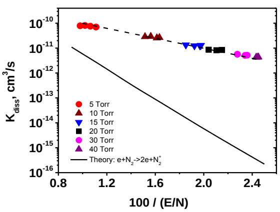
At the increased pressure the associative ionization is the main ionization mechanism in nitrogen plasma. Crucial point is that nitrogen molecules are able to accumulate considerable energy in their vibrations because of (v-v) exchange processes. Through the intermediate agents this energy is spent on excitation of electronic states of atoms and molecules which consequently participate in associative ionization processes. Despite of big interest to nitrogen plasma, mechanism of such energy transmission has not been studied yet in details. Metastable $N_2(A^3\Sigma_u^+)$ molecules and $N(^2P)$ atoms are believed to be most probable intermediate agents [1] that realize energy stored in N_2 vibrations into N_2 ionization. Since direct N_2^+ production in collision of two $N_2(A^3\Sigma_u^+)$ molecules is impossible, the mechanism of associative ionization has to include few steps with using other particles. Such particles can be nitrogen atoms. As a first step, $N(^4S)$ kinetics was studied in N_2 DC glow discharge in quarts tube at pressures 5-40 Torr. $N(^4S)$ absolute concentrations on axis of the reactor was measured with actinometrical technique on Ar as well as evaluated using decay $N_2(C\ ^3\Pi_u)$ radiation dynamics [2]. The obtained data allowed validating accurately calculated actinometrical constants depending on EEDF changes due to N_2 vibrational excitation. It was shown that the main loss mechanism of $N(^4S)$ atoms is their recombination on surface of the reactor's walls. Rate of $N(^4S)$ loss as function of plasma parameters was measured by two methods: 1) as response of actinometric signal at the current modulation and 2) from radial profiles of $N(^4S)/N_2$ dissociation degree obtained by spatially resolved actinometry [3]. Simple phenomenological model of surface processes was developed and showed good agreement with experimental data. Thus the loss rate of $N(^4S)$ as obtained as function of discharge parameters and reduced electric field. The effective constant of $N(^4S)$ production – effective dissociation rate constant - as function of reduced field was calculated from this loss rate data (see pic). Solid line represents calculated rate dissociation constant in electronic collisions with unexcited N_2 molecules of the ground state. It can be seen that nitrogen dissociation in N_2 plasma proceeds with higher rate than it is predicted by theory with the difference being notable (few orders) at low E/N. Transformation of EEDF due to N_2 vibrational excitation does not allow explaining solely this increase. It means that particles having low energy threshold to N_2 dissociation fully controls $N(^4S)$ production. N_2(v) molecules on Treanor plato are most probable candidates for it. This fact is needed in the following research.



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RF PLASMA SOURCES AND APPLICATIONS (from R&D to Commercial)

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Over the past decades RF plasma technology has been used in many areas, such as material science, electronics, basic physics, etc. Typically, the RF plasma system includes power supply (RF generator and matching network), plasma torch and reactor. Depending on the applications two different RF plasma sources are used: inductive and capacitive. Most thermal plasma processes are based on inductively coupled plasma (ICP), which generates equilibrium plasma in the temperature range of 8000 to 12000 K. The advantages of ICP torches are well known and described elsewhere. Non-equilibrium plasma is mostly used in the semiconductor industry and for some special applications, such as plasma synthesis of fine powder and bio-material surface treatment. We will focus on the present situation in this field by discussing the commercial and R&D efforts. In this overview an attempt is made to present existing and future research and development related to RF plasma technology. In particular, the following area will be covered: powder processing (spheroidization, densification and purification); synthesis of ultra-fine and nano-size materials; environmental applications.

A few problems still exist and require future investigation and development, such as ignition of RF plasma discharge at atmospheric pressure, precise control of the plasma parameters and efficiency of RF power supplies. Solid state RF generators, having efficiency of 90% and higher, are successfully used for low pressure and low power plasma torches. High power (>25 kW) solid state RF generators are in the development stage. For the last decade a big progress was made by introducing RF plasma to some of bio-medical, water treatment and waste-to-energy applications. Efficiency of plasma processes is one of the critical factors for existing and new plasma systems.

STICKING NON-STICK: SURFACE AND STRUCTURE CONTROL OF DIAMOND-LIKE CARBON IN PLASMA ENHANCED CHEMICAL VAPOUR DEPOSITION

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A low-friction, hard-wearing, biocompatible thin-film material, diamond-like carbon (DLC) contains both sp^2 (graphitic) and sp^3 (diamond-like) bonded carbon atoms, and often a significant level of hydrogen. Medium-range order, clustering of the sp^2 bonded atoms within a sp^3 matrix, plays a substantial part in the properties of the material. Tuning the balance of the constituents, phases and ordering allows the creation of a material with properties that can be tailored to match requirements resulting in application in many areas including electronics [1], aerospace [2], and medical devices [3].

Plasma enhanced chemical vapour deposition (PECVD) is a widely used laboratory technique for DLC deposition. This presentation reviews research utilising micro and nanoscale characterisation techniques in order to understand the effects of production processes and improve film quality and function for the end user. Application of methods such as electron microscopy, atomic force microscopy, X-ray photoelectron spectroscopy and X-ray diffraction has enabled improved understanding of the changes in film structure, surface and properties with variation of plasma conditions. This includes work to improve film adhesion by three orders of magnitude [4] and enhance the non-stick surface to facilitate production of improved medical tools [3, 5], and create machining tools with both improvement in life and reduction in power consumption [6].

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EQUILIBRIUM OF HIGH-TEMPERATURE PLASMA AND MAGNETIC FIELD IN THE MAGNETIC CONFINEMENT FUSION

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Physical basis of the force equilibrium between high temperature plasma and magnetic field shall be explained in this talk, using both the fluid description in the ideal magneto-hydrodynamic (MHD) and the description of trajectories of plasma particles.

Fundamental facts shall be reviewed first, including the difference between equilibrium and stability and fundamental facts on plasma behaviour in an external magnetic field. Next, the simpler case of plasma equilibrium in a cylindrical field will be studied, in particular with respect to the basic MHD relation among the plasma pressure gradient, the electric current density and the external magnetic field. The major part of the talk shall be then focused on the most widespread magnetic field configuration in the magnetic confinement fusion experiments, the tokamak (notice that the international project ITER is a tokamak). Conditions for equilibrium in tokamaks will be detailed, with a special attention given to the shape of the magnetic field lines. Requirement for a vertical magnetic field will be explained as well as the resulting additional electric current in the plasma known as the Pfirsch-Schlüter current.

Towards the end of the talk, the general MHD equilibrium formula for the tokamaks, i.e. the Grad-Shafranov equation will be mentioned, and its applications to the real tokamak operations discussed. In the concluding remarks, the practical connection between plasma equilibrium and plasma stability will be clarified and the need of a real-time control of plasma position pointed out.

BASICS OF REMOTE OPERATION OF A TOKAMAK

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This tutorial lecture is devoted to introducing the tokamak principle on a very basic level with the aim to prepare participants for remote operation of the GOLEM tokamak from Kiten. The lecture is given before the satellite workshop. Attention will be paid to the formation of toroidal magnetic and electric fields in the tokamak vessel, breakdown of the working gas and ohmic heating.

Next, the GOLEM tokamak, operational at the Faculty of Nuclear Physics and Physical Engineering, will be described with sufficient details. In particular, we will focus on the description of:

- Power supplies
- Vacuum and gas handling systems
- Necessary steps for conditioning of the tokamak vessel (baking and glow discharge cleaning)
- Available diagnostic tools (magnetic and optical diagnostics, probes, HXR spectrometer and fast camera)
- Structure of the GOLEM database.

Participants will be informed how to read experimental data. Simple examples of data processing will be presented (e.g. how to calculate the edge safety factor and to estimate the electron temperature).

ALCOHOL REFORMING INTO HYDROGEN-RICH GAS APPLING MICROWAVE ´TORNADO´-TYPE PLASMA

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Energy independence and security, as well as adverse impact of fossil fuels on the planet´s ecosystem are burning topics of the day. One of the prominent options for sustainable production of carbon-free energy is the use of renewable energy resources. Considerable research efforts are currently being directed into hydrogen production methods, since H_2 meets the basic requirements as a green energy source - it has the highest heating value and it is environmentally friendly. As a rule H_2 is produced from different hydrocarbons by different conversion processes such as steam reforming, partial oxidation, CO_2 reforming, and pyrolysis [1, 2]. In recent years, plasma sources have been investigated for hydrocarbon reforming. Among the various hydrocarbons feed stocks the alcohols are favored owing to environmental concerns.

In this study, application of microwave argon plasma, operating at 2.45 GHz under atmospheric pressure and vortex gas flow has been investigated for reforming of alcohols (methanol and ethanol) into hydrogen-rich gas. The main outlet products hydrogen and carbon monoxide were detected by mass spectrometry (MS) and Fourier transform infrared spectroscopy (FT-IR). The average value of the hydrogen yield achieved is 98.2% for methanol and 98.4% for ethanol.

Theoretical models were developed for elucidating the decomposition of methanol and ethanol in the argon microwave plasma environment. The models are based on a set of non-linearly coupled, spatially dependent differential equations describing plasma thermodynamics, gas heating and flow, as well as chemical kinetics. The theoretical predictions for the H_2 and CO relative densities agree well with experimental findings. Integral reaction schemes considering methanol and ethanol decomposition via two parallel channels were proposed and experimentally validated.

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DIAGNOSTICS OF PLASMA STREAMS FROM ION THRUSTERS FOR SPACE PROPULSION

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The next generation of satellites will make use of the recent developments in space propulsion by accelerated plasma streams. The advantages of electric propulsion (EP) for long-term missions rely in combined reasons of economy and practical interest. These systems produce ion streams up to exhaust velocities of tens of kilometers per second, higher than those of conventional chemical or bipropellant systems. This fact provides higher values of the specific impulse and brings relevant weight savings over traditional propulsion systems. In addition, the EP engines are powered by electric the solar panels and make use of chemically inert gases as propellant (usually xenon) of easy stowage. Therefore, EP offers considerable advantages for in orbit station keeping of geostationary satellites, deep space missions or planetary probes. This field has received a special attention (topic C) within the Horizon 2020 CEE research program for space and will face a strong competition n the following years.

In this communication the characterization of the exhaust plasma streams from the prototype ALPHIE (Adaptable Low Power Hybrid Ion Engine) designed for small and medium satellites is discussed. The classical collecting and emissive Langmuir plasma probes provide local measurements allowing the mapping of the outgoing plasma flow. In particular, the spatial profile of the plasma potential is of paramount relevance to determine the local electric fields governing the dispersion of the plasma stream. The diagnostic using emissive Langmuir probes is reviewed with emphasis in low density plasmas. Relevant details of this technique, such as the strong or weak emission modes, probe length, etc. that are frequently overlooked and might potentially mislead the experimental results are discussed. The measurements could also be dramatically affected by careless signal conditioning and/or defective circuit grounding. As we shall see, our results support the conclusion that potential structures around the probe, as the virtual cathodes, would be responsible for the operation of emissive probes in low density plasmas. The determination of the energy spectrum of outgoing low energy ions is also discussed. This parameter modulates the effective thrust imparted by the ion engine and is critical because unwanted ion flows might affect the operation of nearby payloads by ion bombardment.

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SOFT X-RAY TOMOGRAPHY IN SUPPORT OF IMPURITY CONTROL IN TOKAMAKS

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In this contribution, an example of synergy among plasma diagnostic systems, data analyses and machine control in modern fusion experiments will be given. It is motivated by the challenging task of measuring spatial distribution of plasma impurities and possibly eliminating heavy impurity influx into the high-temperature plasma core. With construction of ITER and designing DEMO, this task becomes essential in particular due to tungsten components in the first wall. In this respect, research at JET, ASDEX-U and the upcoming upgrade of TORE SUPRA to WEST play key roles. Soft X-ray (SXR) diagnostic systems provide fundamental data in these studies and also serve as a good example of development of novel diagnostic systems towards reactor-relevant solutions.

Spatial distribution of SXR radiation (with spectral range typically 1 keV – 15 keV) is presently measured at many tokamaks using pinhole cameras with photosensitive elements shielded by a beryllium foil. In order to reconstruct the spatial distribution of SXR plasma emission from the measured line integrated signals, several tomographic methods have been developed and validated [1]. However, semiconductor photosensitive elements cannot survive in harsh conditions of future fusion reactors due to radiation damage, which calls for development of radiation hard SXR cameras.

In IPP Prague, data from SXR cameras [2] recently contributed to analyses of plasma position and stability. A tomographic code for real-time applications was developed. In CEA Cadarache, absolutely calibrated SXR cameras [3] and off-line tomography [4] are available, and a new tomographic and imaging project based on three novel, radiation hard cameras with Gas Electron Multiplier (GEM) detectors has been proposed. At JET, tomographic reconstruction of SXR emissivity is challenging given the different toroidal positions and spectral sensitivities of the pinhole cameras [5], but at the same time essential for the fusion community due to the all-metal, ITER-like first wall. Collaboration among the three research centres has proven to be beneficial; the link between feasibility study of SXR real-time control on COMPASS, the measurements of impurity distribution at JET and the foreseen real-time impurity monitoring and control in the WEST configuration of TORE SUPRA will be presented.

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LANGMUIR PROBE AND EVALUATING THE ELECTRON ENERGY DISTRIBUTION FUNCTION - CLASSICAL AND ADVANCE TECHNIQUES OF APPLICATION

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The electric probe is a rather simple and attractive scientific instrument; after the seminal works of Langmuir and Druyvesteyn, numerous probe measurements in various type of plasmas have been conducted by many authors. Today, the field of electric probes is enormous, and many works on the subject can be found in the literature. Since the time of Langmuir and Druyvesteyn, probe theory has been extended dramatically, allowing the diagnostics of different types of plasmas. The probe technique is relatively simple, but demands some care and attention in details if meaningful data are to be obtained: the probe technique is relatively simple when all the requirements of the "classical" probe theory are satisfied, and in particular measurements at low pressure plasma without magnetic field.

In this lecture a review of recent advance in applications of the Langmuir probe for evaluating of the electron energy distribution function in plasma at intermediate [1] and high [2] gas pressures, as well as at wide range of magnetic fields applied [3, 4, 5, 6, 7] is presented and discussed.

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THURSDAY, JULY 3

TIME-RESOLVED OPTICAL DIAGNOSTIC OF SELF-PULSING NANOSECOND DISCHARGES FOR BIOMEDICAL APPLICATIONS

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The streamer-to-spark transition leading to the gas breakdown is a crucial issue for the generation of various atmospheric pressure electrical discharges, as well as in the design of high voltage (HV) devices. An influence of 'memory' effect (e.g. pre-heating and pre-ionization) of the gap on the streamer-to-spark transition and streamer breakdown mechanism can be investigated by using the transient spark (TS) discharge studied in our group [1-2].

The TS is a DC-driven self-pulsing streamer-to-spark transition discharge initiated by a streamer, which transforms to a short (~10-100 ns) high current (>1 A) spark pulse due to the discharging of the internal capacity C of the circuit. Charging and discharging of C is repeated with the frequency f in the kHz range. The TS generates highly reactive non-equilibrium plasma suitable for bio-medical applications [3-4].

The increase of f is achieved by increasing the generator voltage, and it is accompanied by changes of the TS characteristics, e. g. the spark current pulses are getting broader and smaller. The increase of f also changes the breakdown mechanism. The breakdown voltage decreases due to the pre-heating of the gas between the electrodes, and significant shortening of the streamer-to-spark transition time (τ) occurs with increasing the TS repetition frequency [2]. Above ~3 kHz, τ decreased from a few μs down to ~100 ns.

In order to explain these changes, we studied TS by several optical diagnostic techniques. We employed an iCCD (ANDOR Istar) camera with 2-ns gate coupled to a spectrometer to obtain time-resolved emission spectra of TS. The spectra of the N_2 2^{nd} positive system were used to estimate time evolution of the gas temperature during the streamer-to-spark transition. Next, the emission of Hα line was used to calculate the electron density (from Stark broadening). The imaging of the TS was used to observe the frequency influence on the propagation of the streamer, and the evolution of the plasma channel diameter. Additionally, the spatiotemporal evolution of the discharges was analyzed by a photomultiplier tube (PMT). A cylindrical lens was used in the optical system to collect all the light in the plane perpendicular to the electrode's axis to avoid missing any discharge channel in case of its branching. The light collection system was set on a micrometric translation stage to enable mapping of the light emission along the electrode's axis.

The estimated average streamer propagation velocity increased with f. At ~4 kHz it was $\sim 5\times 10^7$ cm/s. Interestingly, the secondary streamer was only ~2 times slower than the primary one. The fast propagation of the secondary streamer could explain short streamer-to-spark transition times in TS at repetition frequencies above 3 kHz. We suppose that it is related with a memory effect induced by previous TS pulses.

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CHARACTERISATION OF PLASMAS CREATED BY ARGON DBD-JETS USING CALIBRATED OPTICAL EMISSION SPECTROMETRY; THE RENAISSANCE OF OES

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Cool atmospheric pressure plasmas are very interesting study object that find applications in gas cleaning, soft surface treatments, wound healing and biofilm destruction [1, 2]. These plasmas are far from equilibrium: there is a large inequality between the temperatures of the heavy particles and electrons e.g. Th / Te < 10-2 whereas the electron density ne is much smaller than the value predicted by Saha's law (nes): such as ne/nes < 10-3.

A special class of cool APPs is formed by plasmas created by dielectric barrier discharges (DBD). In these discharges the dielectric prevents the formation of high temperature arcs. They are sustained by AC sinusoidal voltages in the frequency range 10 kHz< f <100 kHz [3].

This contribution deals with the OES characterization of argon plasmas created by a DBD jet using a broadband-survey-approach by which in each measurement-stroke the spectral bandwidth of 280 nm< λ < 900 nm is investigated in a pick-up time of less than 10 ms time. In each stroke we get the spectrum of a continuum on which lines and bands are superimposed. All these constituents are useful and are determined absolutely; meaning that they are calibrated with a standard light source.

From the absolute intensities we can deduce plasma properties but as the plasma is far from equilibrium we can not use classical methods.

The most dominant lines are those created in the 4p -> 4s transitions in Argon; the interpretation of their absolute intensities is done using a collisional radiative model which gives the electron temperature.

The continuum being created by elastic electron-atom interactions is used to determine the electron density.

The molecular bands are investigated to get insight in the Absolute Emission Rates (AERs). This AER method was applied to band radiation of OH and N2 which were found to behave completely differently. Especially the N2 bands show interesting features. It is found that most of the detectable transitions in the afterglow, the region close the plasma application zone, are related to the creation of radical nitrogen species.

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EDGE PLASMA STUDIES IN THE COMPASS TOKAMAK

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The COMPASS tokamak operates in a divertor plasma configuration with ITER-like plasma cross-section. Recently, an H-mode has been achieved in COMPASS. The H-mode is generated by an increase of the plasma current above 240 kA or a pulse of Neutral Beam Injection (NBI) heating system. The L-H transition is characterized by a sudden decrease of Da signal as well as its fluctuations. The H-mode is accompanied by characteristic plasma instabilities (Edge Localized Modes – ELMs) of different types with frequencies in the range of 80 – 2 000 Hz or exhibits so called ELM-free periods.

This contribution will present a characterization of edge plasma during H-mode in COMPASS with a focus on the ELM classification. In addition, the characterization of ELM parameters using different probe techniques will be provided. Examples of edge electron temperature and density profiles measured by High Resolution Thomson scattering diagnostics will be also presented.

Moreover, a new system for generation of magnetic perturbation (MP) has been put into operation recently. The saddle coils on the vacuum vessel are used to introduce n = 2 magnetic perturbation. The first measurement of MP effect on plasma in L- and H-modes will be presented, including the strike-point splitting, response of plasma to perturbation, etc.

THE NARROW FEATURE IN POWER FLUX DEPOSITION PROFILES IN COMPASS LIMITER PLASMAS

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The current ramp-up phase of ITER discharges will be in limiter configuration, with the high field side (HFS) wall as the favored start-up surface. Recent experimental observations on JET using IR thermography show a clear narrow feature in the parallel heat flux density $q_{//}$ near the Last Closed Flux Surface (LCFS) of inner wall limiter (ILW) plasmas [1], which is consistent with earlier work [2-3]. A significant effort has subsequently been made on the COMPASS tokamak to investigate this effect using a specially diagnosed (IR thermography + Langmuir probes), roof-shaped IWL to limit circular Ohmic discharges on the central column [4]. Using detailed analysis of the probe data, in combination with power fluxes derived from IR measurements, this paper discusses the possible physics mechanisms that could give rise to the narrow heat flux channel.

The set of 16 embedded Langmuir probes in the IWL can be used to estimate $q_{//}$ if a theoretical value of the sheath heat transmission coefficient γ_{sh} is assumed. However, at locations where the limiter surface is not at floating potential, V_{fl}, there can be a significant effect on γ_{sh} [5]. The ILW probes are both domed and flush mounted, located on both sides of the limiter apex, covering ~30 mm radial distance from the LCFS, mapped to the outer midplane. Evidence of a narrow heat flux feature with a power decay length of $\lambda_{q,\,omp}$ *~5 mm* is obtained with the probes, consistent with the findings from IR thermography viewing the same limiter [4]. One possible contribution to this narrow feature might be the drift mechanism described in [6]. Another important contributor could be the presence of non-ambipolar current flow. Probe measurements closest to the ILW apex show net electron collection of order *-2Jsat* at $V_{probe} = 0$ and negative floating potential $V_{fl} \sim 1.5T_e/e$. The magnitude of the non-ambipolar contribution to the narrow heat flux component is being investigated, including possible amplification due to secondary electron emission [5]. For some shots, probes on the ion side show more essentially ambipolar conditions. Nevertheless the narrow feature is still present, although somewhat reduced in amplitude, suggesting that the two effects are additive. The different mechanisms at play and their relative contributions will be presented in the paper. Since the IWL probes allowed measurements at only six discrete radial locations, it is not always clear from the data whether the deposited power flux can be adequately described by a profile characterized by a single or double exponential; however, for some shots, and on either the ion and electron sides, the probe data are consistent with a 2-lambda profiles roughly similar to those obtained from thermography.

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POSTER SESSION

DETERMINATION OF THE PLASMA PARAMETERS IN THE ISTTOK TOKAMAK

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The first derivative probe technique was applied to study the ISTTOK tokamak plasma [1]. This technique employs the electron part of the Langmuir probe current-voltage (*IV*) characteristic and yields information on the plasma potential and the electron energy distribution function (EEDF). The *IV* characteristic was measured with new electrical probes mounted on a horizontal manipulator, one oriented in parallel and the other perpendicularly to the magnetic field lines. Using the first-derivative probe technique, the plasma potential and the EEDF at different radial positions were acquired. We show that, in the vicinity of the last close flux surface (LCFS), the EEDF is non-Maxwellian and can be approximated by a bi-Maxwellian one with a dominant cold electron population and a minority group of hot electrons. In the limiter shadow, the EEDF obtained is Maxwellian. A comparison with the results obtained by processing the same data with the classical probe technique [2], which assumes Maxwellian electron energy distribution functions is presented and discussed.

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DETERMINATION OF THE EEDF BY DIVERTOR PROBES IN THE COMPASS TOKAMAK

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This paper reports experimental data obtained on the COMPASS tokamak by Langmuir probes embedded in the divertor tiles [1]. The measured current-voltage (*IV*) probe characteristics were processed by the recently published [2, 3] first derivative probe technique for precise determination of the plasma potential and the electron energy distribution function (EEDF). Measurements were performed during L-mode hydrogen and deuterium plasmas with toroidal magnetic field B_T =1.15 T, plasma current I_p=180 kA and averaged electron density $n_e = 8*10^{19}\,\mathrm{m}^{-3}$.

The spatial profile of the electron temperatures shows that in hydrogen plasmas in the vicinity of the inner and outer strike points the EEDF can be approximated by a bi-Maxwellian distribution, with a dominating low-energy electron population (4 - 7 eV) and a minority of higher energy electrons (12 - 25 eV). In the private flux region between the two strike points the electron energy distribution function is found to be Maxwellian with temperatures in the range of 7 - 10 eV. In the case of deuterium plasmas at similar conditions of the discharge the EEDFs are found to be always bi-Maxwellian.

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PLASMA POTENTIAL EVALUATED BY BALL PEN AND LANGMUIR PROBES IN THE COMPASS TOKAMAK

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The radial distribution of the main plasma parameters in the scrape-off-layer (SOL) of the COMPASS tokamak is measured during L and H-mode regimes by using both Langmuir [1, 2] and Ball-pen probes [3, 4] mounted on a horizontal reciprocating manipulator. Radial profiles of the plasma potential and the electron energy distribution functions (EEDF), i.e. electron temperatures and densities, are derived from measured Langmuir probe current-voltage characteristics by applying the first derivative probe technique (FDPT) [1, 2] and compared with the results from classical probe technique [5].

Ball-pen probe measurements provides direct evaluation of the plasma potential with high temporal resolution. The derived results for plasma potential from Langmuir probe and Ball-pen probe are in a quantitative agreement.

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BI-MAXWELLIAN ELECTRON ENERGY DISTRIBUTION FUNCTION IN THE VICINITY OF THE SEPARATRIX IN TJ-II STELLARATOR PLASMA

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The radial distribution in vertical direction of the plasma parameters in the vicinity of the last closed flux surface (LCFS) in stellarator TJ-II are studied by using a vertical Langmuir probe. The measurements were performed in a series of identical discharges where during the first phase of the discharges the plasma was heated by electron cyclotron resonance (ECRH). During the second phase neutral beam injection (NBI) was applied. The first-derivative probe technique [1, 2] was used to derive data for the plasma potential and electron energy distribution function (EEDF) from the *IV* probe characteristics measured in both cases. During NBI phase the EEDF in the confined plasma is bi-Maxwellian while in the SOL the EEDF is Maxwellian. In contrast, during the ECRH phase of the discharge both in the confined plasma and in the SOL the EEDF is bi-Maxwellian with the low-energy electron fraction predominating over the higher energy one. In addition, measurements with only ECRH of the plasma at higher volume-average electron density and different magnetic configurations, both on a shot-to-shot basis and with single-discharge configuration sweeping [3] were performed.

Results for the electron temperatures and densities obtained by the first-derivative probe technique are used to calculate the radial distribution of the electron pressure and the parallel electron power flux density [4].

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EMISSION PROPERTIES OF THE PLASMA FACED MODEL-MATERIAL COVERED WITH THIN INSULATOR FILMS

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Investigation of the emission properties of the plasma faced materials covered with thin insulator films is actual problem due to beryllium and tungsten, chosen as first wall materials for international thermonuclear reactor ITER, can be easily covered by oxide layer. Aluminum is usually used as model material for imitation experiments because beryllium is toxic. As it was found in the simulation experiments on the linear simulator [1], formation of a thin (~10 nm) oxide layer on the aluminum target had strongly increased electron emission under plasma impact. Such unexpected increase of electron emission changed current-voltage characteristic. As a result, surface-plasma instability generated [2]. However there was no ability in [1] to measure the film thickness without exposure to atmosphere. In this work we present the results of in situ measurements of emission properties of some model material with thin dielectric layer on its surface in correlation with dielectric film thickness.

"Large Mass-Monochromator MEPhI" set up [3] allows to analyze thin surface films in the range of 5 - 60 Å using the energy analyzer and surface element analysis by knock out and scattered positive and negative ions directly during sputtering process at low-angle ion scattering geometry. Bombardment by Ar+ ions provides acceptable sputtering rate under thickness control with light ions scattering. Miniature anode for electric field-current measurement from central zone of the sample was situated opposite the sample, so ions scattered from the surface can go through vacuum gap between cathode and anode.

The model sample was made of Si smooth substrate. On its surface ~150 Å layer of tungsten and then 30 Å layer of aluminum were deposited by electron-beam evaporation. Aluminum layer was completely oxidized after exposure to atmosphere forming thin insulator film on the tungsten layer.

The experimental results have shown that for various values of the insulator film thickness detectable current was measured only after microbreakdown series. Current-voltage characteristic of these samples had strong hysteresis effect and was interpreted by "switch-on" model [4]. Investigations on scanning electron microscope have shown that after microbreakdowns the film was damaged and became discontinuous. The secondary electron emission coefficient from the edges of the film "islands" was five times higher than from the substrate surface. Comparison of the field emission properties with other PFC materials has shown that emission is as high as in the case of tungsten nano "fuzz" sample [5], which is the material with high probability of unipolar arc ignition in thermonuclear devices.

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RFIT-450 ION THRUSTER THERMAL MODEL

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The principle of operation of the ion thruster RFIT-450 developed by the RFIT laboratory of the Moscow Aviation Institute is based on the RF-heating of the working gas plasma. A part of the lead-in power is lost during the thruster operation due to the plasma deposition on the gas-discharge chamber walls that leading to the thruster units heating. The ion extraction system (IES) is the primary unit of the ion thruster. Acceleration of the working gas ions proceeds in this system. IES is a combination of 2 (or 3) densely perforated electrodes with the potential difference of some kV and a gap of 1 – 2 mm between them. Such gap should be minimum, but along with this there should not be a breakdown between the electrodes. Uncontrolled thermal deformation of the IES electrodes causes degradation of the RF IT operational characteristics, first of all reduction of ion current, worsening in the ion beam divergence, reduction of thruster efficiency and its specific impulse, etc.

To define operational conditions for the SC systems, which are related to the thruster, it is important to know thermal flows to them from the thruster. All the mentioned together with the selection of materials to be used for the thruster units production requires preliminary thermal calculation.

The calculated temperature distributions for the surfaces of the ion thruster RFIT-450 units are presented in the paper.

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SIMULATION OF PLASMA FILLED HEMISPHERICAL CAVITY AS DIELECTRIC RESONATOR ANTENNA

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Plasma antennas are becoming an increasingly interesting research topic because of their steerable radiation pattern and uncommon characteristics. They are highly configurable, can be turned on and off rapidly, and exhibit lower thermal noise compared to metal antennas [1]. In recent years, research has been conducted on cylindrical plasma columns sustained by DC, RF or microwave field [2], and their application as leaky wave antennas or regular monopole antennas.

Dielectric resonator antennas (DRA) [3] with high dielectric permittivity are known for their small size and excellent operating characteristics for modern mobile communications (WiMAX, LTE). Hemispherical dielectric resonator antennas are characterized by simple shape, high radiation efficiency and wide bandwidth.

Hemispherical DRA with a low density weakly ionized plasma as dielectric material will combine the positive features of plasma and dielectric antennas, and is particularly interesting, as antennas of this type have not been studied yet. The hemispherical plasma antenna is simulated with Ansoft HFSS in the microwave S-band. The excitation antenna system is comprised of a microstrip ring resonator exciting the antenna through a ring slot. In this configuration, the hemispherical plasma antenna operates like electric dipole with high radiation efficiency. Distribution of electric and magnetic fields in the hemispherical plasma antenna are simulated, and compared with distributions in regular DRA. Obtained radiation pattern and bandwidth show the advantages of hemispherical plasma antennas for future communication technology.

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DEVELOPMENT OF SIMULATION TOOLS FOR NUMERICAL INVESTIGATION AND COMPUTER-AIDED DESIGN (CAD) OF GYROTRONS

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As the most powerful CW sources of coherent radiation in the sub-terahertz to terahertz frequency range the gyrotrons have demonstrated a remarkable potential for numerous novel and prospective applications in the fundamental physical research and the technologies. Among them are powerful gyrotrons for electron cyclotron resonance heating (ECRH) and current drive (ECCD) of magnetically confined plasma in various reactors for controlled thermonuclear fusion (e.g., tokamaks and most notably ITER), high-frequency gyrotrons for sub-terahertz spectroscopy (for example NMR-DNP, XDMR, study of the hyperfine structure of positronium, etc.), gyrotrons for thermal processing and so on. Modelling and simulation are indispensable tools for numerical studies, computer-aided design (CAD) and optimization of such sophisticated vacuum tubes (fast-wave devices) operating on a physical principle known as electron cyclotron resonance maser (ECRM) instability. During the recent years, our research team has been involved in the development of physical models and problem-oriented software packages for numerical analysis and CAD of different gyrotrons in the framework of a broad international collaboration. In this paper, we present the current status of our simulation tools (GYROSIM and GYREOSS packages) and illustrate their functionality by results of numerical experiments carried out recently. Finally, we provide an outlook on the envisaged further development of the computer codes and the computational modules belonging to these packages and specialized to different subsystems of the gyrotrons.

THEORETICAL STUDY OF PLASMA SUSTAINED AROUND DIELECTRIC CYLINDER BY TAVELLING EM WAVE

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Electromagnetic wave travelling along the dielectric-gas interface can produce plasma. These gas discharges called surface-wave-discharges (SWDs) exist in various geometries: planar, spherical, cylindrical, coaxial, and around dielectric cylinder. When at the dielectric tube axis is arranged a metal road, the plasma is produced outside the tube which is the typical coaxial surface-wave-sustained discharge (CSWD). The experimental investigations show that in some conditions the plasma can be produced outside the dielectric cylinder even when there is not any metal antenna at the dielectric axis [1].

In order to find out these conditions theoretically we have built one-dimensional fluid model for vacuum–plasma and dielectric–plasma configurations. The basic relations in our model are the local dispersion relation describing the wave propagation and the wave energy balance equation, both obtained from Maxwell's equations. Analyzing the phase diagrams, the axial profile of dimensionless plasma density and the 3D distribution of electric and magnetic field components, one can obtain information about the ability of the electromagnetic wave to sustain plasma at given discharge conditions.

The purpose of this work is to investigate theoretically the behaviour of wave phase diagrams and axial profiles at various discharge conditions and to find out the values of plasma parameters at which plasma can be sustained.

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SPATIAL AND TEMPORAL PATTERN FORMATION IN PLASMA OF A DC DRIVEN "BARRIER" DISCHARGE: STABILITY ANALYSIS AND NUMERICAL SOLUTIONS

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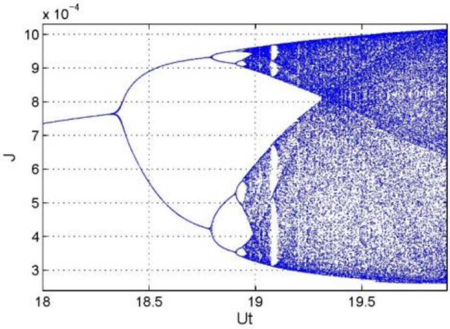
We developed and applied three-dimensional numerical code to study a spatial and temporal pattern formation in the system, consisted of a planar glow discharge layer with short length in the forward direction and wide lateral dimensions, which is coupled to a planar semiconductor layer with low conductivity. The whole structure is sandwiched between two plane electrodes, to which a dc voltage is applied. Experiments show that such a system can create different homogeneous stationary and homogeneous oscillating modes, patterns with spatial and spatiotemporal structures [1, 2].



Bifurcation diagram: current *J* vs. total applied voltage U_t, obtained for 1D system. Conditions are the same as in [3]. Parameters are dimensionless.

The discharge model consists of continuity equations for electrons and positive ions, which are coupled to Poisson's equation for the electric field.

The semiconductor layer is assumed to have a homogeneous and field-independent conductivity and dielectric constant.

Parameter regime corresponds to a transition between Townsend and glow discharge, as in the experiments [1] and in our previous works [3-5]. The discharge is in nitrogen at 40 mbar, in a gap of 1.4 mm. The applied voltages are in the range of 513–570 V. The semiconductor layer consists of 1.5 mm of GaAs with dielectric constant $\varepsilon_s = 13.1$ and conductivity $\sigma_s = (2.6\times10^5\ \Omega\text{cm})^{-1}$.

Numerical solutions of the initial value problem reveal the onset of pattern formation in the considered parameter regime. These solutions agree well with the linear stability analysis predictions [5] within its range of validity.

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CORROSION RESISTANT SILICON FILMS DEPOSITED IN MAGNETRON DISCHARGE WITH LIQUID CATHODE

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Corrosion of metals is a widely spread effect, and corrosion resistance is a hot topic for many applications. It often happens so that replacing the steel details susceptible to chemical corrosion with chemically inert ones is unreasonable or even impossible. Moreover, there is a problem of high-temperature corrosion of refractory metals, which significantly reduces their applicability range.

One of the ways to protect metals from corrosion in aggressive environment is covering them with a protective coating, which must be dense, chemically inert in relation to the aggressive environment and have a good adhesion to a protected material. Coatings made of silicon may meet these requirements due to low chemical activity of silicon at temperatures below 1000°C. This is so due to the fact that the layer of silicon dioxide covering silicon surface makes it passive. Furthermore, silicon has a good adhesion to most of the metals.

In this work silicon coating were deposited in magnetron discharge with liquid target (MDLT) on polished plates made of low-carbon steel, high-carbon steel, and tungsten foils at various substrate biases. The structure of the deposited layers was analyzed using the scanning electron microscopy.

The steel samples (both coated and uncoated with Si films) were subjected to a short-term exposure in concentrated sulphuric, hydrochloric and nitric acids as well as to a long-term exposure in 10% solutions of these acids. To determine the protective properties of resulting coatings on tungsten, the series of experiments has been conducted. It involved endurance check of the samples in vacuum with a pressure of 1 Pa at the temperature of 800°C for 30 minutes. The loss of mass occurring in the duration of the experiments was used to evaluate the tungsten level of corrosion.

The samples deposited at bias voltages of -600 V and +100 V demonstrated the best protective properties. Thus, the steel samples almost did not react with acids and the rate of tungsten erosion decreased by two orders of magnitude. This shows that this way of protecting metals against corrosion is efficient and prospective.

PLASMA REACTOR FOR DEPOSITION OF CARBON NANOWALLS AT ATMOSPHERIC PRESSURE

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Graphene and carbon nanostructures have attracted growing interest because of their applications in microelectronics [1], sensors [2] and supercapacitors [3]. In recent years research has focused on deposition of vertically oriented graphene (carbon nanowalls) due to its specific morphology – intersecting vertical walls with sharp edges and high surface to volume ratio. Plasma-enhanced chemical vapour deposition (PECVD) is a key technology for preparation of carbon nanowalls. DC, RF and microwave gas discharges are used for deposition of nanowalls at low pressure, which leads to long periods of deposition [3].

In this study a novel plasma reactor for deposition of carbon nanowalls at atmospheric pressure is presented. A low power microwave discharge is used as a plasma source. Working gas is a mixture of argon, hydrogen and methane. The substrate is heated by plasma jet. Substrate temperature is measured by thermocouple and it is in the range of 600-700 C. The chemical composition of plasma in gas mixture is investigated by optical emission spectroscopy. The emission spectrum of the plasma torch in Ar/ H_2/CH_4 mixture shows a presence of carbon (Swan band) and intensive CH line (388nm). These species are essential for the process of carbon nanowalls deposition. In order to ensure the vertical growth of graphene walls additional voltage in the range -20 to -100 V is applied. Deposited carbon nanostructures on metal substrate at different experimental conditions are shown.

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VIRTUAL PANEL CONTROLLED ELECTRONIC PROBE SYSTEM

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Nowadays there is a wide range of laboratory equipment. To perform an average experiment it is more and more common to use more than one measuring device. The problem is, that sometimes it is hard or even impossible to perform measurements controlling all the devices manually. That's why modern laboratories combine the measuring equipment into virtual instruments. Some experiments require custom electronic equipment. The problem with this equipment is that in most cases it is not designed to be used in virtual systems. The presented electronic probe system consists of custom designed electronics and stock laboratory equipment combined into virtual instrument. The whole system is controlled by a virtual panel. The system is capable of measuring simple IV's and displaying the result in real time as a graph. It is also able to perform second derivative Langmuir probe measurements.

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LANGMUIR PROBE DIAGNOSTICS IN DC GAS DISCHARGE TECHNOLOGICAL REACTOR

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The progress of modern electronics is bound to optimization of existing and development of new technologies. Latterly a wide range of technological processes, directly related to production of electronic components and devices are performed in plasma. Most of the industrial devices for plasma related processes in electronics, such as layer deposition, plasma polymerization, plasma etching etc. are designed to meet the specific requirements of the customer and are not suitable for experimental purposes. The reactor presented in this work has a very flexible construction, which gives us the ability to work with samples with different sizes and geometry and to change the samples processed in it in minutes. Layer deposition and plasma etching can be performed in this reactor. It is also equipped with automated electronic probe system allowing us to perform measurements with Langmuir probes. The main goal of the work is investigation of the relation of the plasma parameters during layer deposition on different structures and the layer parameters.

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LAYER DEPOSITION ON THE WALLS OF THE PORES OF ANODIC OXIDE OF ALUMINUM IN DC GAS DISCHARGE TECHNOLOGICAL REACTOR

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The anodic aluminum oxide is known for a wide range of applications in classic electronics, nanotechnology, UHF modules and others. One of its applications is its use as a building component in a variety of sensors operating on an optical or absorption principle. The nanomembranes of anodic aluminum oxide became one of the most widely used construction material for ultra sensitive and ultra thin applications in micro electromechanical systems (MEMS) and other sensor structures due to their remarkable mechanical properties. Of great interest is the metallization of the walls of the pores of the anodic aluminum oxide. The metallization of the walls of the pores changes the mechanical and electrical properties of the membrane. By metallizing the walls of the pores, it is also achieved a huge conductive surface, compared to the size of the membrane, which can find a wide range of applications. Due to the size of the pores, to metallize their walls are quite hard. The work presents metal layer deposition on the walls of the pores of anodic oxide of aluminum and the problems related to the process in DC gas discharge..

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INFLUENCE OF THE PLASMA FOCUS X-RAY PULSES ON THE SYNTHESIS OF ENDOGLUCANASE BY MUTANT STRAIN OF TEICHODERMA REESEI-M7

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The 4 kJ Plasma Focus (PF) was used to examine the effect of X-Ray pulses (appearing in the pinch phase of the PF machine) on the fungi spores of the genus Trichoderma. These species are of interest due to their ability to produce enzymes for the degradation of the polysaccharide part of biomass. Bioconversion of cellulose-containing substrate to glucose represents an important area of the modern biotechnology.

The experiments have been carried out with the mutant strain Trichoderma Reesei - M7, a cellulase producer. Spores of the enzyme producer were treated with certain doses of characteristic X-ray radiation from metallic tungsten (mainly the W $K\alpha1$ and $K\alpha2$ lines) with a high dose rate. The last is a specific property of the Dense Plasma Focus device, which has pulsed operation and thus gives short and highly energetic pulses of multiple types of rays and particles. In this case we have focused our study on the influence of the hard X-rays mentioned, selecting them among the other types of radiation.

The doses of X-rays absorbed by the spores vary in the range of approximately 5 to 11000 mSv, measured with Thermo-Luminescent Dosimeters (TLD). The influence of the applied doses in combination with the exceptionally high dose rates (in the order of tens of mSv per microsecond) on the activity of the produced endoglucanase, amount of the biomass and the extra-cellular protein, was studied at the condition of batch cultivation.

In the dose range of 200÷1200 mSv some enhancement was established of endoglucanase activity - around 18÷32%, despite the drop of the biomass amount, compared with the untreated samples.

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INTEGRAL DIAGNOSTICS OF AN ICP DISCHARGE SYSTEM

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An intermediate diagnostics method between two limiting cases, full [1] and simple [2] ones, of integral diagnostics of an ICP gas discharge unit (that can be incorporated in an RF ion engine or a plasma/ion technologic facility) has been proposed. The method includes antenna coil current measurement with and without ICP discharge in case of full load matching with an RF generator (RFG) when reflected RF power is equal to zero and the RFG load is purely active. With these data efficiency of RF power transfer “RFG-discharge” is easily obtained using Ohm law. The said features that constitute the simple method were supplemented with additional calculations of system parameters that were not measured directly in the experiment and with a-priory prepared information on antenna coil electrical parameter measurements including an active resistance of the antenna coil at the system’s driving frequency.

In the course of the analyses a set of three ICP system parameters were singled out as indicators of the system design and circuit engineering, while another set of five parameters were denoted as indicators of discharge plasma property state. The “RFG-discharge” power transfer efficiency was additionally named an indicator of discharge arrangement. Due to the known value of the antenna coil active resistance the last parameter was divided into two components: the “RFG-antenna” and “antenna-discharge” efficiencies that helped to present the detailed RF power balance of an ICP discharge system.

The proposed integral diagnostics method was applied to the serially manufactured German technologic RF xenon/argon ion source RIM-20 [3]. Results of these studies led to RIM-20 characterization from many sides, disclosed the presence of parasitic RF power leak in the process of ICP discharge operation thus pointing out the direction of its further development.

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HOT PROBE MEASUREMENTS OF A LASER PRODUCED PLASMA

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Over the last 50 years it was proved that laser ablation can be used as a method of removing material from different types of targets irradiated it with a laser beam. There have been develop several applications which have as foundation stone the laser ablation process. Applications that could include laser engraving, cleaning contaminated surfaces (removal of paint or coating) [2-5], deposition of thin coatings on different materials[6], production of new Nano-materials such as carbon nanotubes [7]. In order to improve those application one must first study the fundamentals of laser ablation. There have been developed many methods [8-10] (optical or electrical) in order to have a better understanding of the underline phenomena involved in the laser ablation process.

In this paper we present an electrical study of a laser produced plasma on a Nickel target. The experiments have been performed in a stainless steel vacuum chamber pumped down to 10-5 Torr residual pressures. The radiation from a 3rd harmonic of a Nd-YAG nanosecond laser (355 nm, 5ns, variable fluences) was focused by a f = 25 cm lens onto the target placed in the vacuumed chamber. The estimated spot diameter at the impact point was 0.3mm. The Nickel target rotated during the experiments and was grounded from the vacuum chamber.

The total ionic and electronic current extracted from the plasma plume was measured using a heated cylindrical Langmuir probe. To have a more complete view over the plume dynamics the probe was placed at different angles with respect to the expanding plume direction, following a circular curve with a radius of 3cm. The shape and internal structure of the expanding plume were investigated

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LUNAR REGOLITH COMPOSITION ANALYSIS USING SOLAR WIND

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Moon surface composition and structure analysis comprises an essential part of Moon origin and evolution research, which also concerns solar system. Lunar regolith surface layer analysis may be conducted by means of analyzing the atoms dislodged from the surface by solar wind, which primarily consists of H^+ (~96%) и He^{++} (~4%) ions with characteristic energies of 1 keV and 4 keV respectively, and with flow rate of $3*10^8$ ions/sm^{2}sec.

For analyzing the neutral atoms dislodged and reflected from the Moon surface by solar wind it is convenient to use high-aperture electrostatic analyzers. To do so it is necessary to convert the neutral atoms into charged ions beforehand. Currently, solid-state convertors are being used for this purpose due to the ease of operation, small size and weight.

The particles that are being registered pass several stages, each of which influences their final number and energy: scattering of lunar regolith driven by solar wind flow, reflection of scattered atoms from convertor surface and conversion to ions, motion of resulting charged particles in the fields of registering apparatus.

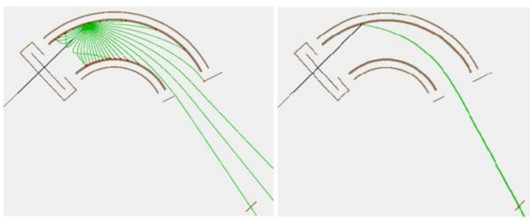
Total motion computation may be conducted with the help of computer modeling using, for instance, the SIMION ion optics modeling program and the SCATTER code for calculation of interaction between atomic particles and condensed medium.

When solar wind interacts with the Moon surface the atoms with characteristic energies up to 100 eV are dislodged from it.

Scattered atoms reflect from the convertor surface and part of them is ejected as ions. At the energies of scattered particles up to 100 eV angular distribution of reflected particles is close to the cosine one (angles of incidence up to ≈60°) and energy loss is dispensable for high atom number convertors.

The obtained results may serve as SIMION code modeling input parameters of charged particles motion in analyzer. Among all the particles reflected in a certain point of a convertor it is necessary to mark those that get to the analyzer entrance slit (pic. 1).

Thus, the number of regolith particles of certain kind getting to the registering apparatus and their energies may be calculated while solar wind serves as a test harness.



a) b)

Pic. 1 *Ion motion trajectories in the fields of the converter: a) particles reflect at all angles b) the particles getting to the analyzer entrance slit are marked*.

INFLUENCE OF DIAPHRAGM CONFIGURATION ON DC DIAPHRAGM DISCHARGE BREAKDOWN IN ELECTROLYTE SOUTION

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Electric discharges in liquids have been studied in detail mainly during the last two decade. The creation of different reactive particles, as for example the reactive hydroxyl or hydrogen radicals and molecules having high oxidative potential (hydrogen peroxide) is studied especially with respect to utilise these species in the process for water treatment, removal of organic substances from water, or water sterilising.[1-4]

This contribution deals with generation of diaphragm discharge in water solutions of sodium chloride with fixed conductivity of 275µS. The non-pulsing DC voltage up to 4 kV was used for the discharge generation. A plasma reactor was divided by a dielectric barrier manufactured of Shapal-M^{TM} ceramics into two reactor spaces connected by a small orifice drilled through the ceramics. The ceramics had variable thickness (0.3–2 mm) and orifice inner diameter was 0.3–1 mm. Time resolved current and voltages characteristics were recorded by a four-channel oscilloscope LeCroy LT374L interconnected with a high speed ICCD camera iStar. The camera was focused to the orifice vicinity and image scanning was synchronized through the current value.

The current-voltage characteristics using mean current and voltage values were constructed for each orifice parameter. Three different phases current-voltage curve were recognized under all conditions. Only electrolysis proceeds during the first phase at the lowest was applied voltage (300–1200 V depending on the orifice dimensions), while bubbles were created thanks to the intense Joule heating inside the orifice during the second phase. Finally, at applied voltages over 1600 V the discharge was ignited. These facts were confirmed by iCCD images taken during all three phases. We were find, by comparing current-voltage characteristics of different orifice diameter sizes, that this parameter had an important influence on the bubbles generation phase. On the contrary, the diaphragm thickness was played an important role at the discharge breakdown.

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WATER VAPOR INFLUENCE ON THE PROTON COMPONENT OF THE HYDROGEN PENNING DISCHARGE

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The high atomic to molecular ion ratio is important for hydrogen ion sources, but in the usual low-temperature hydrogen plasma the molecular ion component is dominating. One can increase proton component by increasing plasma temperature, but in this case energy spectrum will be widened. Injection of water vapor can change hydrogen plasma component ratio as it was shown in [1]. In this work experimental mass-spectroscopy investigation of the water vapor injection into the hydrogen discharge of the Penning ion source has been made.

The experiment was made on the specially designed stand, main parts of which were Penning plasma source, chamber for emittance measurement, water vapor source, separating electromagnet and ion beam detector. Residual gas pressure was 8×10^{-6} Torr. Plasma source consists of the coaxial cathode (permanent magnet with 0, 05 T axial magnetic field strength) and anode. Discharge voltage and current were up to 1 kV and 200 mA respectively. The working gas (hydrogen) was injected using gas flow controller up to working pressure $1–4\times10^{-4}$ Torr. Formation and acceleration of the ion beam was made by supplying positive acceleration potential on whole body of the plasma source. In case of 5 kV accelerating voltage and 200 mA discharge current the ion beam current was 150 μA in 2 mm distance from the source. The intensity of the separated ion beam was measured with Keithley picoammeter and it was about 10^{-12} A.

The mass-spectrum of the ion beam was measured and the intensity of the H^+ portion was in order less than the molecular without water injection. Injection of water vapor was made using thermochemical water source based on $Ca(OH)_2$ thermal destruction with heating [2]. Such injection increases the proton component of the ion beam and changes emittance with the same discharge parameters.

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GUIDING OF STREAMER PATHS BY BACKGROUND IONIZATION

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Introduction

It is well known that streamer discharges are influenced by background ionization and other effects of previous discharges [1]. Also externally applied background ionization can have a great influence on streamer propagation and morphology [2]. We have investigated these two phenomena by two different methods.

Firstly we have applied two consecutive high voltage pulses and then studied how the morphology of the discharge induced by the second pulse is affected by the original discharge.

Secondly, we have used a laser beam to create a path of pre-ionized gas and then studied how streamers follow this path.

Double pulse experiments

We have studied the influence of repeating positive streamer discharges by applying two subsequent high voltage pulses with a variable interval between them [3]. The pulse-to-pulse interval Δt was varied between 200 ns and 40 ms. Experiments have been performed in a 103 mm point-plane gap at 133 mbar for three different gases: artificial air, pure nitrogen and pure argon. The discharges are studied with two ICCD cameras which image the same area by means of a half-mirror.

We observe that for small values of Δt the streamers just continue their old paths. In this situation the highly conductive channels left by the first pulse discharge act as extended electrode tips. At larger values of Δt attachment and recombination decrease the conductivity so that this can no longer be sustained. At larger values of Δt (roughly above 2.5 μs for air and 30 μs for nitrogen, for argon this is less determined) new streamer channels appear. At first they avoid the entire area of the previous discharge; next they follow the edges of the old channels; then they start to follow the old channels exactly and finally (with Δt in the order of (tens of) milliseconds) they become fully independent of the old paths. Altogether, these experiments give insight in the effects of leftover ionization and other species on subsequent discharges.

Laser guiding experiments

In the second experiment we have used an KrF excimer laser to create a trail of increased pre-ionization and studied the effect of this trail on streamer development and morphology, with a focus on streamer guiding. The laser produces pulses at 248 nm of about 1 mJ per 20 ns long pulse at a maximum repetition rate of 10 Hz. Some time (ns – ms) after the laser pulse a single high-voltage pulse was applied to the electrode tip. The background ionization density due the laser pulse was about 10^9 cm^{-3} in 133 mbar pure nitrogen, argon or nitrogen-oxygen mixtures.

It was found that in pure nitrogen and pure argon streamers are almost always guided along the laser-induced path. For oxygen concentrations above about 0.5% no guiding was observed. At such oxygen concentrations the streamer produces so many free electrons through photo-ionization that it is no longer influenced by the laser produced electron trail.

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ATMOSPHERIC PRESSURE ELECTRICAL DISCHARFES: AN EFFICIENT AND GREEN ALTERNATIVE FOR NANOPARTICLE SYNTHESIS

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Electrical discharges at atmospheric pressure have proved to be reliable method for production of metallic nanoparticles [1, 2, 3]. By means of high intensity sparks and dc glows or arcs a relatively large production of nanoparticles can be achieved. The particles are formed out of the electrode material after it is evaporated by the high temperature of the discharge, or extracted by ion sputtering.

Contrary to other categories for nanoparticle synthesis, such as mechanical milling or chemical processing in liquids or gasses, electrical discharges in inert gasses do not require high energy inputs, do not leave chemical waste, can easily control the particle size and can produce high purity products. This process has a relatively low cost and it can be easily upscaled for greater production, making it a good candidate for industrial applications. The process is designed in closed loop system that avoids the use of hazardous precursors, solvents and stabilizers. The main input is electric power for the electric discharges and the pumps for gas recycling. The used of high quality flanges results in an inherently low possibility of workplace exposure to nanoparticles. The process does not call for complicated and expensive safety measures, as quasi-atmospheric inert gas is used as transport medium and hazardous chemicals are avoided. All these factors make this method a green and sustainable synthesis process.

In the present contribution we show results on the spectroscopic, photographic and electrical monitoring of the electrical discharges used for nanoparticle synthesis. The study covers three different regimes for electrical discharges: the spark, glow and arc regimes. The results indicate that the short and intense spark discharges produces fewer nanoparticles with small-medium sizes. On the other side, the arc plasmas show the largest production rates together with the largest particles sizes and agglomeration. The glow discharge serves as a bridge between the two extremes by increasing the discharge current. This regime offers the highest flexibility in terms of nanoparticle size.

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VUV RADIATION OF SURFACE WAVE DRIVEN ARGON PLASMAS

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In this work we present a theoretical and experimental investigation of a microwave (2.45 GHz) argon (Ar) plasma driven by propagating surface waves at low-pressure conditions. The plasma source was studied using visible and VUV spectroscopy. The electron density and the relative emission intensities of the excited Ar atoms and ions were studied as a function of the microwave power, pressure and axial position. The surface wave was launched using a waveguide-surfatron setup. The microwave power delivered to the launcher has been varied between 90 and 300 W. VUV radiation was collected by a Horiba Jobin-Yvon Plane Grating Monochromator (PGM) axially coupled to the discharge tube. The VUV light path is kept at relative low pressure (10^{-5} mbar) using a turbo pump coupled to the spectrometer. A $C_7H_5NaO_3$ scintillator was used to convert the VUV radiation into visible radiation by fluorescence. Finally, this radiation is detected by a R928 Hamamatsu photomultiplier. Visible radiation was collected perpendicularly to the discharge tube by a quartz optical fiber, connected to the entrance slit of a SPEX 1250M spectrometer equipped with a nitrogen cooled charge-coupled device (CCD) camera.

The experimental results were analyzed using a 2D self-consistent theoretical model coupling in a self-consistent way electron and heavy particle kinetics, discharge electrodynamics, and gas thermal balance. The set of coupled equations used includes the electron Boltzmann equation, the rate balance equations for the most important excited species and charged particles, the gas thermal balance equation, and the equations describing wave propagation and power dissipation. The principal collisional and radiative processes that determine the population density of the Ar(4s, 4p, 5p, 5s, 3d, 4d) excited states are accounted for. In particular the model predictions for the emitted lines that fall in the VUV spectral range, i.e., resonance lines at 104.8 and 106.7 nm, have been validated with the experimental measurements. Moreover the model[1] describes in a self-consistently way the spatial structure of the plasma source considered.

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SMALL MICROWAVE PLASMA SOURCE AND ITS APPLICATIONS

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Atmospheric pressure discharges have many industrial and environmental applications [1] as plasma cutting of metals, surface functionalization and modification, deposition of thin layers, plasma sterilisation and detoxification of hazardous gases, which require plasma with certain parameters. This study presents the design of small microwave plasma source [2] which generates dense plasma with stable parameters at low and atmospheric pressure. The discharge is sustained by surface waves which propagate along the surface plasma-dielectric tube. The exciter of the surface waves is an open coaxial line and the initial precise tuning of the source ensures good matching over a wide range of neutral gas pressures and of microwave power levels. Self-consistent model of argon discharge is applied and the EEDF shape and the mean electron energy at different values of the electron density are obtained. Probe and optical diagnostics are used to measure plasma parameters at the conditions of Maxwellian EEDF.

One of the methods for deposition of carbon nanostructures is plasma enhanced chemical vapour deposition (PECVD). System for synthesis of carbon nanostructures at atmospheric pressure by microwave PECVD is constructed using our small plasma source. The process is carried out in a chamber at a controlled gas-mixture of argon, hydrogen and methane. The movable target holder allows adjustment of the distance between the plasma flame and the substrate. Substrate temperature is measured by electronic system and its value (400-700 0C) is controlled by the amplitude, frequency and duration of microwave pulses at a fixed distance to the plasma flame. Biasing of the substrate with DC voltage is applied to support the deposition of vertical nanostructures. SEM and Raman spectroscopy are used for characterization of the resulting carbon nanostructures at certain discharge conditions.

Small plasma source works properly also at low gas pressure. Microwave discharge in a finite length quartz vessel is realized and its properties as plasma antenna are investigated. Radiation pattern and efficiency of the plasma antenna are measured and they are in agreement with results obtained by software simulations.

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ABOUT THE MECHANISM OF CARBON NANOSTRUCTURE FORMATION IN MICROWAVE ARGON PLASMA

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In the present work, a surface-wave driven microwave plasma at atmospheric pressure conditions has been applied for synthesis of carbon nanostructures. Three different types of nanostructures have been selectively synthesized by controlling the temperature in the assembling zone of the plasma reactor. The method is based on introduction of ethanol vapors through a microwave argon plasma environment, where decomposition of ethanol molecules takes place. Gas-phase carbon atoms diffuse into colder zones both in radial and axial directions, nucleate and transform into solid carbon. A part of the solid carbon is deposited on the discharge tube wall while the main part is gradually withdrawn from the hot region of the plasma in the outlet gas stream.

We suggest that the formation of carbon structures can be described by following chain of processes: 1) formation of active nucleus; 2) process of growing and transformation of the active nucleus into spherical clusters; 3) process of growing of spherical clusters up to nanoparticles. An integral reaction scheme of the ethanol decomposition and nanostructures formation is proposed and presented in Fig. 1

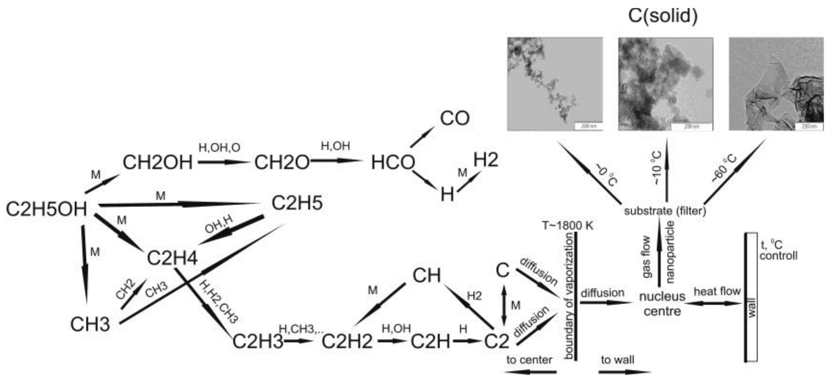

Figure. 1 Integral reaction flow analysis of ethanol decomposition and synthesis of nanostructures.
Q_{Ar} = 250 sccm, Q_{Et}=0.6 sccm

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LOW TEMPERATURE PLASMAS FOR FUNCTIONALIZATION OF ADVANCED CARBONS

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Advanced carbon materials, as for example carbon nanotubes or graphene, are important building blocks for novel applications in science and technology. They can be used for example in the field of biosensors, as electron emitters, or as catalysts.One important requirement for future applications concerns the surface modification or doping of these materials, which can result in controllable changes of their electronic [1] or chemical [2] properties. Specific functional groups of interest are here in particular nitrogen [3] or oxygen [4] containing groups or even complex organic molecules [2] and biomolecules. This contribution will focus on the use of low temperature plasmas which are not only versatile tools for the synthesis of advanced carbon materials [5, 6] but also widely used for the surface modification of different materials. We will report here about experiments dealing with the controlled functionalization of carbon nanotubes and graphenes [6-8]. Different type of deposits and their behavior in contact with nitrogen and ammonia plasma are compared, involving the role of the surface temperature on the functionalization procedure. The effect of the plasma treatment on the different carbon materials is analyzed by means of contact angle measurements, near edge x-ray absorption fine spectroscopy (NEXAFS) and XPS. We will discuss the importance of the plasma characteristics for the formation of amino groups and nitrogen incorporation in the material. Important issue of the plasma functionalization of surfaces concern: the formation of dangling bonds, destructive effects of plasma-surface interactions and recovery of the surfaces.

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LOW TEMPERATURE PLASMAS FOR SURFACE MODIFICATIONS

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Low temperature plasmas operated in reactive gases are a breeding place for a great variety of different species. Depending on the nature of the gas one can find different kind of reactive neutrals (as for example H- or N-atoms [1]), macromolecules which are formed due to chemical reactions inside the discharge, sometimes nano- and even microsized particles and also different kinds of positively and negatively charged ions[2]. Consequently the interaction of low temperature plasmas with surfaces is a rather complex process which is characterized by the great number of different species involved in that process and by the fact that the kinetic energy of those species can vary from a few meV (for thermal species) up to possibly a few 100 eV. Despite this complexity reactive low temperature plasmas can be used to create surfaces with specific tunable characteristics. This contribution will discuss some general strategies to control this complex process of plasma surface interaction and will give some specific examples concerning the plasma based synthesis and functionalization of nanoparticle-deposits.

The examples concern surfaces with switchable wetting properties and the decoration of surfaces with nanoparticles for fuel cell applications [3, 4].

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BARRIER COATINGS FOR ARCHAEOLOGICAL ARTEFACTS PRESERVATION

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Archaeologists find hundreds of historical items every year. These items carry information about procedures of their fabrication, as well as signs of nation's wealth and culture. To preserve these artefacts, several procedures have to be performed. Dirt and corrosion must be removed and then anti-corrosion protection is created. Corrosion removal studies have been published elsewhere [1]. We will focus on anti-corrosion finishing and its characterization.

In standard archaeological procedures, different types of waxes are applied on artefacts. However, this treatment requires enough time and human resources. Our approach (very new to this branch) is to use chemical vapour deposition (CVD) to create thin films directly on the surface of the artefact. These thin films are conformal layers with good barrier properties and chemical resistance. CVD also offers the advantage of deposition of protective coatings on several artefacts at the same time. Standard CVD technique has some disadvantages, as well. To overcome them, we have to use special modifications of CVD.

First option is to implement plasma into the deposition process. Plasma enhanced chemical vapour deposition (PECVD) has been used successfully in many industrial branches, such as automotive, mechanical engineering and microelectronics [2]. Using organosilicones as precursors brought new possibilities to this technique. Organosilicone-based thin films can bind both to organic and inorganic surfaces (even to glass!). Organic groups provide elasticity as well as many options of functional modification. Hexamethyldisiloxane and tetraethoxysilane are the most common precursors. They were used in many applications, including semiconductor and food industry [3]. There are also other interesting compounds with similar properties but with different structure, e.g. trimethylphenylsilane or methyldiphenylsilane.

Second possibility is the deposition of parylene. Parylene (poly-p-xylylene) forms pin-hole free films with excellent barrier properties and chemical resistance. Some types of parylene are biocompatible. Parylene has been used in medicine [4], microelectronics and even in space.

Other types of thin films, such as diamond-like carbon films, may be suitable for this application, as well. However, there are only few studies focussed on their barrier properties.

The scope of this work is to examine different types of thin films for possible application in archaeology. Thin films were prepared on sample substrates in order to allow measurements of their properties. Their composition was analysed by infrared spectrometry. To determine barrier properties, oxygen transmission rate measurements were performed. Chemical resistance and stability were tested using salt fog and higher temperature in corrosion chamber. Most promising results were obtained for parylene C. However, more types of thin films will be tested soon.

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EFFECTIVE SURFACE MODIFICATION OF POLYETHYLENE BY AN ATMOSPHERIC PRESSURE PLASMA JET

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Nowadays, polyethylene is a very important polymer and is used for a wide variety of applications in many technological fields because of its excellent bulk properties, such as a high strength-to-weight ratio, good resistance to corrosion and relatively low production cost [1]. However, for some industrial applications, the poor adhesion of polyethylene is a disadvantage. For most commercial purposes, it is thus important to increase the surface free energy of polyethylene, but at the same time, to keep the excellent bulk properties. Generally, to extend the polyethylene application range, chemical modification processes have been used, but these are not very ecological and the more stringent ecological requirements force the industry to search for alternative environmentally safe methods. One of these benign methods is non-thermal plasma treatment, a modification technique which can improve the surface properties of a polymer while preserving all the bulk characteristics.

Among the different types of atmospheric pressure plasma sources, plasma jets have been established as suitable sources of low-temperature and non-equilibrium atmospheric pressure plasma. Such sources have gained great recognition because of their possibility to selectively treat parts of a substrate and their easy integration into existing production processes. In addition, these plasma sources are not limited to flat and thin samples and can thus be used for various sizes and degrees of curvature of the surface as opposed to plate-to-plate dielectric barrier discharges and corona discharges [2]. Among other applications, the treatment of temperature-sensitive surfaces such as polymers and biomedical tissues is of great interest [3, 4].

In the past, a study by Szili et al. [4] has shown that the plasma jet footprint (or treated area) can be minimized by increasing plasma-surface distance or by decreasing plasma exposure time. This report shows the influence of a broader range of plasma jet process parameters on the spatial distribution of the plasma jet footprint. Results were obtained by iterating through all possible combinations of process parameters, including discharge power, gas flow rate, treatment time and source-sample distance. The size of the plasma jet spot was examined in detail on polyethylene samples using contact angle measurements and X-ray photoelectron spectroscopy (XPS) analysis. It was found that longer exposure times, shorter capillary-sample distance, higher discharge power and gas flow lead to a small contact angle decrease due to the introduction of a small amount of oxygen. In addition the effect of all processing parameters on the width of water contact angle footprints of polyethylene were investigated.

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ON THE PLASMA JETS INTERACTION WITH BIOMEDICAL SURFACES

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After a successful combination of fundamental and applied research work in the past century, plasma technologies evolved and gained their role in many industrial applications, with major benefits for the society.

During the past decade, an increasing interest was devoted towards the atmospheric pressure plasma use for medical applications. From medical instruments, the plasma based sterilization/decontamination methods were developed even further and shifted also to human skin treatment [1]. The list of plasma applications in relation with living organisms can be continued with wound healing [2], blood coagulation, treatment of dental cavities, and induction of apoptosis for cancer cells, trials in cancer therapy. However, no precise limits of the plasma use in direct contact with living organisms are available for the moment, in terms of duration, energy density, absolute emission intensity of photons, and concentration of reactive chemical species. Despite of the obvious commercial interest of plasma use in contact with living tissues, very few data are available on the spatio-temporal plasma dynamics at the interface with biological origin surfaces.

In this study, we report the results obtained from the diagnosis of an atmospheric pressure plasma jet facing the human skin. Using microsecond duration high voltage pulses, the plasma is generated in helium using the principle of a dielectric barrier discharge. After leaving the dielectric tube, in air the plasma has a jet shape, with a length of few centimeters. This jet can be directed to any type of surfaces, in particular the human skin. Electrical currents flowing in the system were monitored and their temporal dynamics is discussed in detail. Moreover photon emission at the interface was monitored by time averaged techniques, such as emission spectroscopy and time resolved techniques, such as photomultiplier traces or ultra fast photography. The combination of the results retrieved from the electrical and optical studies, revealed new insights on the plasma-skin interface: the range of the electrical currents flowing in the tissue and the time span of the plasma on the skin surface.

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APPLICATION OF NON-THERMAL PLASMA FOR PRE-SOWING SEEDS DISINFECTION AND EARLY PLANT GROWTH PROMOTION

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Intensive farming involves constant anthropogenic pressure on the environment through the utilization of chemical fertilizers and stimulants, pesticides, herbicides, and fungicides which are all chemical toxins. The transition to sustainable agriculture requires the development of environmentally non-degrading, technically appropriate and economically viable technologies for plant productivity improvement. In the recent years, low temperature plasma treatment is considered as promising technique for seed disinfection and germination enhancement [1–5].

This paper is devoted to the study of the efficiency of low-pressure RF air plasma treatment of seeds of some important agricultural crops in improvement of the sowing properties and phytosanitary condition of seeds. Tested seed samples (spring wheat, blue lupine and maize) were treated with 5.28 MHz air plasma at a pressure 40 Pa [4]. The optimal conditions of plasma treatment ensuring its maximum biological efficiency are established in laboratory and field tests that realized at a specific power input of ~ 0.35 W/cm^3 and plasma treatment duration of 5 – 7 min. The plasma parameters and the seed coat surface structure modified by plasma irradiation are investigated using the methods of optical emission spectroscopy and scanning electron microscopy to analyze possible mechanisms of biological effect of plasma treatment.

It is shown that the plasma treatment of seeds stimulated their germination (by 5–20 %) and the early stages of seedling development improving their shoot and root growth, providing a good fungicidal and bactericidal effects. It was observed drastic reduction of the total infection level (*Colletotrichum gloeosporiodes* and *Kabatiella caulivora*, *Alternaria spp.*, *Cladosporium spp.*, *Mucor spp.*, *Penicillium spp.* and bacteria) of blue lupine seeds that decreased from 100% in the control up to 23% for the plasma treated seeds during 5 min. Plasma treatment inhibited by 90% *Fusarium* spp. that causes the most harmful root disease of wheat and blue lupine. The plasma seeds treatment increased crop yield of spring wheat by 3.4 centners per hectare (c/h), maize – by 1.6 c/h, blue lupine – by 11.4 c/h as compared with yield produced from untreated seeds.

It is established that the action of plasma-generated reactive species on seed coat resulting in the change of its morphology is one of the most important factors of plasma treatment responsible for the germination enhancement, bactericidal and fungicidal effects.

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PROPAGATOR METHOD AS A KINETIC OPERATOR TO ANALYZE DISCONTINUITIES IN PLASMAS

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We present a path-integral like method to numerically solve drift-diffusion equations for plasma physics [1, 2]. The algorithm uses short-time propagators as approximate Green´s functions that tend to smooth typical discontinuities arising in plasma dynamics as, for instance, the effects of plasma-wall interaction or localized particle flows. The usual numerical schemes based on differences may fail to represent these abrupt conditions by inducing numerical diffusion and instabilities. However, the robust mesh-free computational integral method has been proved to be unconditionally stable if no restrictions are imposed by boundary conditions. The extension of the method to deal with boundary value problems [3] is analysed for plasma kinetic equations. It is found that the advancing scheme is useful not only to deal with imposed abrupt conditions in the plasma bulk, but also to describe the merging of natural discontinuities in the system. Such kind of discontinuities may be induced by the effects of electromagnetic fields generated by charge separation as well as for the existence of two differentiated plasma regimes at a certain interface. In any case, the kinetic equation may have drift and/or diffusion coefficients that are likewise discontinuous [4]. The method works almost being numerically insensitive to these discontinuities leading to feasible physically meaningful solutions. The scheme works as an effective integral kinetic operator. In this sense, we study the possibility of dealing with Fokker-Planck equations connecting two different dynamical statics (Maxwell-Boltzmann and Fermi, for instance) to describe the interaction of two regimes at an interface. The results may be relevant to look into the dynamics of plasma-wall interaction, charge structures in plasma thrusters, plasma layers or in emissive probes [5].

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SHEATH FORMATION IN AN OBLIQUE MAGNETIC FIELD - SOME COMMENTS ON LENGTH SCALES AND THE ROLE OF SOURCE TERMS

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Sheath formation in front of a negative electrode immersed in magnetized plasma with an oblique magnetic field is studied by a one-dimensional fluid model. Three kinds of source term are used in the continuity equation: 1) the so called zero source term, with no production of charged particles, 2) the constant source term, where the ions are produced uniformly with a constant, specified rate and 3) the exponential source term, where the ion production is proportional to the electron density, which is given by the Boltzmann law. Four different length scales are used for the normalization of the space coordinate: the Debye length λ_D, the ion Larmor radius r_{Li} , the ionization length L and the collision length L_c or mean free path. When the problem is analysed on the pre-sheath scale only, where the plasma neutrality is assumed a-priori it turns out that all 4 scalings of the space coordinate are equivalent, only the horizontal axes of the space profiles is expanded or shrunk. It turns out that the length of the pre-sheath is larger for the exponential source term than for the constant source term for the same parameters. For the zero source term the results are qualitatively different. The initial velocity at $x = 0$ must be increased for several orders of magnitude in comparison with the constant and the exponential source term, in order to obtain comparable results with the other two terms.

When the problem is analysed in the full scale (this means the pre-sheath and the sheath region together) the ratio $\varepsilon = \lambda_D / L$ becomes a very important parameter. If it is selected to be very small the transition between the sheath and pre-sheath is rather sharp, but also the computation time needed for numerical solution of the system of equations increases. So some compromise values of ε are selected. Again it turns out that the length of the pre-sheath is larger for the exponential source term than for the constant source term for the same parameters. For the zero source term the initial velocity must be increased for several orders of magnitude. Some issues regarding finite (non-zero) ion temperature are also addressed.

ARGON ATMOSPHERIC PRESSURE DISCHARGES FOR BIOMEDICAL APPLICATIONS

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Plasmas for biomedical applications are one of the newest fields of plasma utilization. Particularly plasma use in health care dates from about the beginning of this century. Especially high is the interest toward plasma usage in medicine. Promising results are achieved in blood coagulation, wound healing and treatment of several forms of cancer [1]. There are indications that plasma medicine could offer solutions for lesions that cannot be treated otherwise, like diabetic complications and other severe ulcers [2].

However, the investigations of the biomedical applications from biological and medical viewpoint are much more advanced than the studies on the dynamics of the plasma – the configuration effect, i.e. the practically appropriate design and its effect on the plasma properties, the chemical composition, the transport of species, etc. In this work we aim to address some specific challenges in the field of plasma modelling, which arise from biomedical applications. Three main problems stand out in this research area: what are the plasma reactive species' and electrical fields' *spatial distributions* and what are the *production mechanisms*; what are the *fluxes and energies* of the various species that the plasma delivers to the treated surfaces (cells, tissues, etc); what is the *gas flow* pattern?

The recent and most widely used, especially for medical applications, devices are the so called *cold atmospheric plasmas* (CAPs). These are discharges characterized by low gas temperature – less than 50°C at the point of application – and non-equilibrium chemistry. Typically they are RF apparatuses [3]. Microwave devices working at higher gas flow (jets) can also be employed [4].

So far, an extensive theoretical and experimental study has been done only on the so called *plasma needle* [5]. Various other RF atmospheric plasma torches with different design are tested for multiple applications but not well studied and characterized (see for instance [6] and the references therein). In this study we focus on two of these devices, namely the *capacitive coupled plasma jet* (CCPJ) [7] and on a plasma device, which has barely been investigated for biomedical applications **–** *the surface wave sustained discharge* [8].

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PLASMA POWER INTERRUPTION TO INVESTIGATE THE ENERGY COUPLING BETWEEN ELECTRONS AND VIBRATIONAL CO_2 STATES

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Carbon dioxide (CO2) is considered the largest contributor to the greenhouse effect. One route to find solutions in this world-wide environmental problem is to convert CO_2 into fuels. In this approach plasmas can play an important role. Since one important plasma-task is to get an energy efficient dissociation of CO_2 into CO whereas further fragmentation should be avoided, the plasma must be far from equilibrium.

One of the experimental methods to get insight in the equilibrium state of a gas discharge is offered by the power interruption (PI) method: a sudden interruption of the driving power forces the plasma to a condition with a different state of equilibrium departure. In the response to PI the various plasma aspects react differently.

Recently the PI method was applied to surfatron plasmas created in argon and argon/mixtures in the intermediate pressure of about 1-50 mbar. The response of free electrons was investigated using Thomson scattering. For *pure* argon plasmas it is found that at PI the electron temperature T_e decays fast with less that 1 μs to the heavy particle temperature, while the electron density decays slower; in the order of tens of microseconds. Argon with small admixtures of O_2 or H_2 exhibits a similar behaviour.

However, strikingly different is the result for Ar with small CO_2 additions. After power switch-off a sudden but small decrease in T_e is seen after which it remains for more than 100 μs constant at values as high as 0.8 eV. This is much higher than the gas temperature and thus points to a mechanism of *post-heating* of the electrons. The same electron-post-heating is found in Ar/N_2 mixtures and the reason can be found in the fact CO_2 and N_2 exhibit relatively large cross sections to excite vibrational states by electron collisions. Knowing that, the observed post-heating can be assigned to super-elastic energy transfer from vibrational excited N_2(X) and CO_2(X) molecules to electrons.

These PI experiments reveal that there is an excellent energy coupling between the electron-translational and CO_2-vibrational degrees of freedom. Thus models that aim to describe plasmas for CO_2 valorisation must include vibrational CO_2 states and describe inelastic and super-elastic e-CO_2(X) collisions properly.

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THE ROLE OF SPUTTERED MATERIAL IN THE RACETRACK REGION OF A HiPIMS

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The magnetic (B-) field in a magnetron sputtering device traps the electrons in a region just above the target. This creates a sort of plasma-reservoir from which ions are launched via a sheath towards the target. Especially the region where the B field lines are parallel to the target forms a high-density plasma. The area on the target just below that region, where sputtering is very intense, is known as the race track.

The basic idea of high power impulse magnetron sputtering (HiPIMS) is to apply high power pulses of short time durations (typically 50 μs). As a result the plasma density is increased from $n_e = 10^{15}$ m^{-3} for conventional DC magnetron sputtering to above 10^{19} m^{-3} for HiPIMS. This leads to a dramatic enhancement of sputtering.

This contribution is devoted to the time-dependent behavior of the cloud of sputtered material in front of the target. The main objective is to find out how this 'cloud' influences the evolution of the plasma and thus the sputtering.

We used the Poisson guided fluid model MD2D in a quasi 2D-approach. The most essential model-input parameter is a time dependent voltage V(t). Output parameters are, among others, the current I(t) and thus P(t). They are found to depend strongly on the sheath parameters like the coefficients of secondary emission of electrons, the sputtering by Ar^+ ions and the self-sputtering by the metal ions M^+.

To study the influence of the ionization processes of the metal M (i.e. the production of M^+) we performed two MD2D models. In model A the excitation and ionization of M is implemented using ("normal") data from literature; in B these processes were artificially lowered by a factor of 100. The electron density $n_e(t)$, in both cases followed as a function of time, is found to behave completely different. In case A the $n_e(t)$ evolves much more explosive. So for instance we found that in case A at t=50μs the electron density is $n_e = 8.2$ 10^{19} m^{-3} being a factor 100 larger than in case B where the M^+ -production was artificially lowered. This proofs the importance of the creation of M^+ and thus the self-sputtering on the evolution of the plasma. The effect of other input parameters, like the gas pressure and the (self-) sputtering coefficient(s) will be reported as well.

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VISUALISATION OF PLASMAINDUCED PROCESSES IN INTERELECTRODE GAP OF PION INSTALLATION USING LASER ILLUMINATOR ON MOLECULAR NITROGEN

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Micropinch mode is the result of sausage-type instabilities because of strong radiative losses on the line radiation of multiply charged ions of heavy elements (model radiative collapse), which gives rise to a plasma object with high values of density and temperature. This phenomenon has general nature and is shown in axial discharges of different types (such as X-pinch plasma focus, Z- pinch, low-inductive vacuum spark (LIV), etc.).

The paper presents results of the research process in the electrode gap of High-current low-inductance vacuum spark (HLIV) on the "PION"[1] system by means of active laser diagnostic with imaging of radiation field.

The influence of the cathode geometry and position of the trigger system on the plasma dynamics of HLIV is considered. The regularities of the discharge for different initial conditions are established. The conditions under which the most stable plasma point is formed in space and time are determined.

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DETERMINATION OF SPATIALLY-RESOLVED AND TIME-RESOLVED ELECTRON TEMPERATURE OF NANOSECOND PULSED LONGITUDINAL DISCHARGE IN VARIOUS GAS MIXTURES

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Electron temperature together with gas temperature and electron density are the most fundamental plasma parameters in gas discharges and play a very important role in understanding and prediction of numerous phenomena in gaseous discharges, laser physics, plasma technologies, gas-discharge mass spectroscopy, absorption and emission spectroscopy, and plasma in general. One of the main problems in plasma physics is the determination of characteristic constants for basic processes in plasma, such as asymmetric charge transfer, Penning ionization, diffusion, heat conduction, and electron-heavy particle collisions, which are fundamentally important and widely used in the abovementioned fields.

Elastic and inelastic electron-heavy particle collisions, such as electron impact excitation, de-excitation, and ionization, as well as three-body recombination, depend on the electron temperature. Measurements of electron temperature by Langmuir probe are not suitable for pressure of helium (He) or neon (Ne) above 10 Torr, especially in high-voltage and high-current nanosecond pulsed longitudinal discharges (NPLDs). Laser Thomson scattering measurements of electron temperature have been proved to be effective but challenging because of the low signal and excessive stray light, as well as the complicated experimental setup. In the literature there are several models of varying degrees of complexity, which predict, among the other parameters, values of electron temperature with considerable variation, and furthermore there is no overlap.

Under conditions of Local Thermodynamic Equilibrium measurement of the relative intensities of some He and Ne spectral lines, originating from different upper levels, enabled us to determine the average electron temperature, as well as the time-resolved electron temperature in the discharge afterglow, in a NPLD in He, Ne, and Ne-He mixtures. This type of discharge is widely used for excitation of high-power metal and metal halide vapour lasers, oscillating in deep ultraviolet, visible, near infrared and middle infrared spectral ranges.

Unfortunately, spectral investigation through devices equipped with photomultiplier are prohibited for the discharge period of a nanosecond pulsed longitudinal discharge, because of the noise from high-power electrical pulses and the steep rise of voltage and current pulses of $TV.s^{-1}$ and $GA.s^{-1}$. That is why, a simple method based on the time-resolved measurement of electrical discharge parameters, such as tube voltage and discharge current, was developed and applied for determination of electron temperature and electron density in the discharge period of a NPLD, exciting DUV Cu^+ Ne-CuBr, He-Hg^+ and He-Sr^+ lasers. The obtained results were in fairly good agreement with the existing self-consistent models or with the theoretical estimations.

Using the results obtained for average electron temperature and analytically solving steady-state heat conduction equation for electrons as well, radial distribution of electron temperature, i.e. spatially-resolved electron temperature, was also obtained.

Preliminary results, concerning determination of spatially- and time-resolved electron temperature through solving of nonstationary heat conduction equation for electron gas are obtained.

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