BOOK OF ABSTRACTS

7th International Workshop
&
Summer School on Plasma Physics

26 June – 2 July 2016
Kiten, Bulgaria

TIMETABLE IWSSPP'16

	June 26 Sunday	June 27 Monday	June 28 Tuesday	June 29 Wednesday	June 30 Thursday	July 1 Friday	July 2 Saturday	July 3 Sunday
8:00-9:00	arrival	breakfast	breakfast	breakfast	breakfast	breakfast	breakfast	breakfast
8:00-10:00		registration						
9:30-10:15			Frantisek Krcma	Yovana Todorova	Joost van der Mullen	9:35-10:05 Uros Cverbal	Ilarion Mihaila	departure
10:00-**10:15**		Opening ceremony		Plamena Marinova		10:05-10:35 Elena Tatarova		
10:15-11:00		Renaud Dejarnac	Vladimir Demidov	Joost van der Mullen	Liubov Kravets	10:35-11:05 Eva Kovacevic	Mariana Atanasova	
11:00-11:30		coffee break					Closing	
11:30-12:15		Tsviatko Popov	George Popa	Tomaž Gyergyek	Neli Bundaleska	11:30-12:00 Julio Henriques 12:00-12:30 Nenad Bundaleski		
12:15-13:00		Jan Stockel	Alexander Blagoev	Todor Bogdanov	Francisco Dias	12:30-13:00 Johannes Berndt		
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		WORKSHOP	Vladimir Solokha		WORKSHOP	Ekaterina Shershunova	excursion (optional)	
16:25-16:50			Miglena Dimitrova		poster session	Ekaterina Meshcheriakova		
16:50-17:20		coffee break			coffee break			
17:20-17:45		WORKSHOP	Abdul Qayyum		conference photo & poster session	Davide Silvagni		
17:45-18:10			Mikhail Yablokov			Ivan Andryushin		
18:10-18:35			Umedjon Khalilov			Georgi Trenchev		
18:35-19:30								
19:30-21:00	dinner	welcome	dinner	dinner	banquet	dinner	dinner	
	football 19:00 and 22:00					football 22:00		

LEGEND:

	Topic 1 Fusion Plasma and Materials
	Topic 2 Plasma Modelling and Fundamentals
	Topic 3 Plasma Sources, Diagnostics and Technology
	Workshop Remote GOLEM operation
25+5 min. each	**Workshop** Plasma Nanoscience
	Workshop "Hunting" for a leak in the vacuum system of a VUV spectrometer

MONDAY, JUNE 27

Chairman: Dr. Evgenia Benova

10:00 **Opening ceremony**

10:15 EXTENSIVE STUDY OF POWER DEPOSITION ON MISALIGNED EDGES AND AROUND GAPS BETWEEN TILES ON COMPASS T1
Dr. Renaud Dejarnac, *Institute of Plasma Physics of the CAS, Tokamak Department, Czech Republic*

11:30 ADVANCES IN LANGMUIR PROBE DIAGNOSTICS OF THE PLASMA POTENTIAL AND ELECTRON-ENERGY DISTRIBUTION FUNCTION IN FUSION PLASMAS T1
Dr. Tsviatko Popov, *Sofia University "St. Kliment Ohridski", Bulgaria*

12:15 BASICS OF REMOTE OPERATION OF A TOKAMAK T1
Dr. Jan Stockel, *Institute of Plasma Physics of the CAS, Tokamak Department, Czech Republic*

Chairman: Dr. Jan Stockel

16:00 **WORKSHOP:** Remote GOLEM operation
Dr. Jan Stockel, *Institute of Plasma Physics of the CAS, Tokamak Department, Czech Republic*

TUESDAY, JUNE 28

Chairman: Prof. Joost van der Mullen

09:30	PHYSICAL AND CHEMICAL ASPECTS OF DISCHARGES IN LIQUIDS **Prof. Frantisek Krcma**, *Brno University of Technology, Faculty of Chemistry, Czech Republic*	T3
10:15	PROBE MEASUREMENTS OF ELECTRON DISTRIBUTION FUNCTIONS IN PLASMA: FROM LOW TO HIGH PRESSURE **Prof. Vladimir Demidov**, *West Virginia University, USA*	T3
11:30	Considerations on new developments achieved in electrical probe technique used for plasma diagnosis **Prof. George Popa**, *Iasi Plasma Advanced Research Center (IPARC), Faculty of Physics, Alexandru Ioan Cuza University of Iasi, Romania*	T3
12:15	PROBE MEASUREMENTS OF ELECTRON DISTRIBUTION FUNCTIONS IN PLASMA: FROM LOW TO HIGH PRESSURE **Prof. Aleksandyr Blagoev**, *Sofia University "St. Kliment Ohridski", Bulgaria*	T1

Chairman: Dr. Renaud Dejarnac

16:00	DIGITAL FILTER POLYCHROMATOR FOR THOMSON SCATTERING APPLICATIONS **Mr. Vladimir Solokha**, *Peter the Great Saint-Petersburg Polytechnic University, Russia*	T1
16:25	PLASMA PARAMETERS IN DIVERTOR REGION OF THE COMPASS TOKAMAK DURING ISOTOPE EFFECT EXPERIMENT **Dr. Miglena Dimitrova**, *Institute of Plasma Physics of the CAS, Tokamak Department, Czech Republic*	T1
17:20	LANGMUIR PROBE MEASUREMENTS IN GLAST SPHERICAL TOKAMAK **Dr. Abdul Qayyum**, *National Tokamak Fusion Program, 3329 Islamabad, Pakistan*	T3

17:45 RELATIONSHIP OF ADHESIVE, CONTACT AND ELECTRET PROPERTIES OF PTFE MODIFIED BY DC DISCHARGE T3
Dr. Mikhail Yablokov, *Institute of Synthetic Polymer Materials Russian Academy of Sciences, Russia*

18:10 UNDERSTANDING THE IMPORTANCE OF HYDROGEN IN CATALYZED CNT GROWTH FROM HYBRID MD/TFMC SIMULATIONS T3
Dr. Umedjon Khalilov, *University of Antwerp, Belgium*

WEDNESDAY, JUNE 29

Chairman: Prof. Frantisek Krcma

09:30	SURFACE-WAVE-SUSTAINED PLASMA TORCH FOR BIOMEDICAL APPLICATIONS **Dr. Yovana Todorova and Ms. Plamena Marinova**, *Sofia University "St. Kliment Ohridski", Bulgaria*	T3
10:15	THE KEY-ROLE OF THOMSON SATTERING IN PLASMA CHARACTERIZATION **Prof. Joost van der Mullen**, *Université Libre de Bruxelles, Belgium*	T3
11:30	Fluid and kinetic modelling of plasma-wall transition **Prof. Tomaž Gyergyek**, *University of Ljubljana, Faculty of electrical engineering, Slovenia*	T2
12:15	COAXIAL MICROWAVE DISCHARGE FOR BIO-MEDICAL APPLICATION **Mr. Todor Bogdanov**, *Department of Medical Physics and Biophysics, Faculty of Medicine, Medical University – Sofia, Bulgaria*	T2
14:00	EXCURSION	

THURSDAY, JUNE 30

Chairman: Prof. Vladimir Demidov

09:30 POWER MANIPULATION AND LASER AGITATION — T3
Prof. Joost van der Mullen, *Université Libre de Bruxelles, Belgium*

10:15 COMPOSITE MEMBRANES WITH THE HYDROPHOBIC AND HYDROPHILIC LAYERS — T3
Dr. Liubov Kravets, *Joint Institute for Nuclear Research, Russia*

11:30 MICROWAVE DRIVEN PLASMAS APPLICATIONS — T3
Dr. Neli Bundaleska, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico,Universidade de Lisboa*, *Portugal*

12:15 "HUNTING" FOR A LEAK IN THE VACUUM SYSTEM OF A VUV SPECTROMETER — T3
Dr. Francisco Dias, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico,Universidade de Lisboa*, *Portugal*

16:00 **WORKSHOP:** "Hunting" for a leak in the vacuum system of a VUV spectrometer
Dr. Francisco Dias, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico,Universidade de Lisboa*, *Portugal*

16:25 **POSTER SESSION**

P1 ELECTRON ENERGY DISTRIBUTION FUNCTION IN DIVERTOR REGION OF THE COMPASS TOKAMAK DURING NEUTRAL BEAM INJECTION HEATING — T1
Ms. Embie Hasan, *Faculty of Physics, Sofia University "St. Kliment Ohridski", Bulgaria*

P2 EFFECT OF THE RESONANT MAGNETIC PERTURBATION ON THE PLASMA PARAMETERS IN DIVERTOR REGION OF THE COMPASS TOKAMAK — T1
Dr. Miglena Dimitrova, *Institute of Plasma Physics of the CAS, Tokamak Department, Czech Republic*

P3 APPLICATION OF MIDDLE ENERGY ION SCATTERING TO ANALYSIS OF PLASMA-FACING MATERIALS T1
Mr. Daniel Bulgadaryan, *National Research Nuclear University 'MEPhI', Russia*

P4 MANUFACTURING PROCESS IMPACT ON THE DIELECTRIC PROPERTIES OF ALUMINA CERAMICS FOR FUSION APPLICATIONS T1
Mr. Dario Andres Cruz Malagon, *CIEMAT - Universidad Politécnica de Madrid, Spain*

P5 EFFECT OF DIELECTRIC TUBE PARAMETERS ON PLASMA SUSTAINED BY DIPOLAR ELECTROMAGNETIC WAVE IN CYLINDRICAL CONFIGURATION T2
Mr. Ivan Tsonev, *Sofia University "St. Kliment Ohridski", Bulgaria*

P6 THEORETICAL STUDY OF THE ROLE OF DIELECTRIC WAVEGIUDE IN PLASMA SUSTAINING BY TRAVELING ELECTROMAGNETIC WAVE T2
Mr. Krasimir Ivanov, *Sofia University "St. Kliment Ohridski", Bulgaria*

P7 PARAMETRIC COMPUTATIONAL STUDY OF SHEATHS IN MULTICOMPONENT Ar/O2 PLASMA T2
Mr. Jakub Hromadka, *Department of Surface and Plasma Science, Charles University in Prague, Czech Republic*

P8 EFFECTS OF RESONANT HELICAL FIELD ON TOROIDAL FIELD RIPPLE IN IR-T1 TOKAMAK T2
Mr. Bahram Mahdavipour, *Plasma physics Research Center, Science and Research Branch, IAU, Tehran, Iran, Iran*

P9 TWO-COLOR LASER-PLASMA GENERATION OF ULTRASHORT FREQUENCY-TUNABLE MID-INFRARED PULSES T2
Dr. Nikolay Vvedenskii, *University of Nizhny Novgorod, Russia*

P10 PLASMA SURFACE MODIFICATION OF POLYPROPYLENE TRACK MEMBRANE TO IMPROVE ITS PERFORMANCE PROPERTIES T3
Dr. Liubov Kravets, *Joint Institute for Nuclear Research, Russia*

P11 INFLUENCE OF AN ANODIC ALUMINUM OXIDE, GROWN ON THE CATHODE, ON THE IGNITION VOLTAGE OF DC GAS DISCHARGE AND EFFECTS CAUSED BY THE PLASMA IN THE BRAKE POINTS T3
Mr. Kiril Raykov, *BAS, Bulgaria*

P12 GROWTH OF NANOSCALE OXIDE FILMS ON ALUMINUM IN DC GAS DISCHARGE REACTOR T3
Mr. Mladen Mitov, *Technical University of Sofia, Bulgaria*

P13 Stationary diagnostics of magnetized plasmas T3
Mr. Ivan Sorokin, *National Research Nuclear University MEPhI, Russia*

P14 PROBE MEASUREMENTS OF ELECTRON ENERGY SPECTRUM AND PLASMA-WALL INTERACTION IN HELIUM/AIR MICRO-PLASMA AT ATMOSPHERIC PRESSURE T3
Prof. Iya Kurlyandskaya, *St. Petersburg University of State Fire Service of EMERCOM RF, Russia*

P15 LASER-INDUCED BREAKDOWN IGNITION OF NATURAL GAS IN A 2-STROKE ENGINE T3
Mr. Nikita Pasechnikov, *Bauman Moscow State Technical University, Russia*

P16 EXPERIMENTAL INVESTIGATION OF SURFACE-WAVE-SUSTAINED PLASMA WITH LIQUIDS T3
Ms. Plamena Marinova and Ms. Maya Zhekova. , *Sofia University "St. Kliment Ohridski", Bulgaria*

FRIDAY, JULY 1

WORKSHOP: Plasma Nanoscience

Chairman: Dr. Johannes Berndt

9:35 PLASMA SYNTHESIS OF NANOWIRES AND THEIR ADVANCED APPLICATIONS
Prof. Uros Cvelbar, *Jožef Stefan Institute, Slovenia*

10:05 MICROWAVE PLASMAS APPLIED FOR SYNTHESIS OF FREE-STANDING CARBON NANOSTRUCTURES
Prof. Elena Tatarova, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico,Universidade de Lisboa*, Portugal

10:35 PLASMA SYNTHESIS AND FUNCTIONALIZATION OF CARBON BASED NANOMATERIALS
Prof. Eva Kovacevic, *GREMI, France*

Chairman: Prof. Uros Cvelbar

11:30 PRODUCTION OF N-GRAPHENE BY MICROWAVE N2-AR PLASMAS
Dr. Julio Henriques, *IPFN - Instituto Superior Tecnico - UL, Portugal*

12:00 XPS CHARACTERIZATION OF CARBON BASED NANOSTRUCTURES
Dr. Nenad Bundaleski, *Institute of Nuclear Sciences 'Vinča', Serbia*

12:30 PLASMA BASES SYNTHESIS OF NANOPARTICLES: DIAGNOSTICS AND APPLICATIONS
Dr. Johannes Berndt, *GREMI, France*

Chairman: Dr. Francisco Dias

16:00	TIME-SPACE DEVELOPMENT OF NANOSECOND DIELECTRIC BARRIER DISCHARGE IN FLAT AIR GAPS UNDER ATMOSPHERIC **Ms. Ekaterina Shershunova**, *Institute for Electrophysics and Electric Power Russian Academy of Sciences, Russia*	T3
16:25	STUDY OF LOW-PRESSURE INDUCTIVELY COUPLED PLASMA BY MEANS OF OPTICAL EMISSION SPECTROSCOPY AND LANGMUIR PROBE DIAGNOSTICS **Ms. Ekaterina Meshcheriakova**, *National Research Nuclear University MEPhI, Russia*	T3
17:20	BISPECTRAL ANALYSIS: COMPARISON OF WINDOWING FUNCTIONS **Mr. Davide Silvagni**, *Université de Lorraine, France*	T2
17:45	NON-LINEAR STATIONARY RECOMBINATION WAVES IN NON-SELF-SUSTAINED DISCHARGE DUSTY PLASMA **Mr. Ivan Andryushin**, *Russian Research Center Leipunskii Institute of Physics and Power Engineering, Russia*	T2
18:10	3D MODEL OF A REVERSE-VORTEX FLOW GLIDINC ARC PLASMATRON **Mr. Georgi Trenchev**, *University of Antwerp, Belgium*	T2

SATURDAY, JULY 2

Chairman: Prof. George Popa

09:30	DIAGNOSIS OF ATMOSPHERIC PRESSURE PLASMA IN HYDROCARBON MIXTURES WITH RELEVANCE FOR ASTROPHYSICS LABORATORY EXPERIMENTS **Dr. Ilarion Mihaila**, *Iasi Plasma Advanced Research Center (IPARC), Faculty of Physics, Alexandru Ioan Cuza University of Iasi, Romania*	T3
10:15	ELECTRON DENSITY AND WAVE POWER AT THE TIP OF AN ATMOSPHERIC SURFACE WAVE DISCHARGE **Dr. Mariana Atanasova**, *Sofia University "St. Kliment Ohridski", Bulgaria*	T2
11:00	**Closing**	

MONDAY, JUNE 27

EXTENSIVE STUDY OF POWER DEPOSITION ON MISALIGNED EDGES AND AROUND GAPS BETWEEN TILES ON COMPASS

R. Dejarnac[1], Y. Corre[2], P. Vondracek[1], J-L. Gardarein[3], J. Gaspar[2], E. Gauthier[2], J. P. Gunn[2], J. Horacek[1], M. Komm[1], R. Panek[1], R. A. Pitts[4] and the COMPASS team

[1]*Institute of Plasma Physics, Czech Academy of Sciences, 182 00 Prague, Czech Republic*
[2]*CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France*
[3]*Université d'Aix-Marseille, CNRS, IUSTI UMR 7343, F-13013 Marseille, France*
[4]*ITER Organisation, CS 90 046, F-13067 St Paul-lez-Durance cedex, France*

A major issue for the ITER full tungsten (W) divertor is the presence of leading edges (LEs) appearing as a result of assembly tolerances between adjacent plasma-facing components. The advantage of glancing magnetic field angles for spreading plasma heat flux on top surfaces is lost at the misaligned edges with an interaction occurring at near normal incidence, which can quickly drive melting of W for the heat fluxes expected in ITER. Geometrical arguments assume that power loads on the top and side of a leading edge may be described by $Q_n = q_{//,0}*\sin(\alpha)$ and $Q_s = q_{//,0}*\cos(\alpha)$, respectively, with $q_{||,0}$ the heat flux density parallel to B and α the field line angle. This optical approximation (OA) assumption has, however, recently been challenged by edge melting experiments on JET [1], which found that the theoretically expected Q_s needed to be reduced by a factor 5 ($f_s = 0.2$) in L-mode plasmas to explain the observed power load, whilst Q_n was as expected, violating the power balance. Such discrepancies are a significant issue for ITER as it still considers the option of shaping divertor monoblocks by the end of year 2016, a choice which adds manufacturing complexity and reduces steady state power handling capability. A dedicated experiment have thus been designed on COMPASS to thoroughly study this phenomenon.

A special graphite tile with four regions presenting gaps and LEs has been installed on the COMPASS inner wall at a location directly viewed by a high resolution IR camera (0.3-0.5 mm/pixel). The misalignment, *h*, is different for each region, *h=0, 0.3, 0.6, 0.9 mm*, covering both the typical maximum misalignments (~0.3 mm) expected on ITER and the values used in the JET experiment (~1.0 mm). The *h = 0 mm* region is also equipped with a toroidal gap (TG). Ohmic, circular inner wall limiter discharges with $B_T = 0.9$ T and $I_P = 130$ kA are used, giving Q_n ~1 MWm^{-2} for shallow, ITER relevant incident angles $\alpha = 2.5^o$ on the test tile. Simulations of this experiment with the 2D particle-in-cell (PIC) code used in [2], show mitigation factors ($0.4 < f_s < 0.7$) on the LE side (due to ion orbit effects) but find that the missing power is re-deposited on the top surface immediately downstream, yielding $f_n > 2$ over ~5-6 mm toroidally, consistent with the power balance. The synthetic surface temperature profiles, from 2D FEM thermal calculations using as input the power deposition profiles from 1) OA and 2) PIC are compared to experimental IR data. A good agreement is found in all OA cases. Importantly, the pure mitigation of the incoming flux as reported in the JET case [1] is not observed in COMPASS. Profiles using PIC do not match experimental observations, proving a weak effect of the Larmor smoothing for such conditions. Additionally, four discharges performed with the combination of four possible orientations of B_T and I_p allow to separate the contribution of the parallel particle flux from the ion gyration flux along the TG. Experimental observations agree well with theoretical expectations.

References

[1] J.W. Coenen et al., *Nucl. Fusion* **55** (2015) 023010.
[2] R. Dejarnac et al., *Nucl. Fusion* **54** *(2014)* 123011.

ADVANCES IN LANGMUIR PROBE DIAGNOSTICS OF THE PLASMA POTENTIAL AND ELECTRON-ENERGY DISTRIBUTION FUNCTION IN FUSION PLASMAS

Tsv. K. Popov[1], M. Dimitrova[2,3], P. Ivanova[3], J. Kovacic[4], T. Gyergyek[4,5], R. Dejarnac[2], J. Stockel[2], M. A. Pedrosa[6], D. Lopez-Bruna[6], C. Hidalgo[6] and R. Panek[2]

[1]*Faculty of Physics, St. Kliment Ohridski University of Sofia, 5, J. Bourchier Blvd., 1164 Sofia, Bulgaria*
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[4]*Jožef Stefan Institute, 39, Jamova, 1000 Ljubljana, Slovenia*
[5]*University of Ljubljana, Faculty of Electrical Engineering, 1000 Ljubljana, Slovenia*
[6]*Laboratorio Nacional de Fusión, CIEMAT, Complutense 40 – 28040 Madrid, Spain*

Advanced Langmuir probe techniques are reviewed for evaluating the plasma potential and electron-energy distribution function in magnetized plasma. The classical, the triple probe and the first derivative probe technique are reviewed and discussed. The first-derivative probe technique was applied to derive data for plasma parameters from the *IV* Langmuir probe characteristics measured in the plasma boundary region in the COMPASS and ISTTOK tokamaks, as well as in the TJ-II stellarator. It is shown that in the COMPASS tokamak in the vicinity of the last closed flux surface (LCFS) the electron energy distribution function (EEDF) is bi-Maxwellian with the low-temperature electron fraction predominating over the higher temperature one, whereas in the far scrape off layer (SOL) the EEDF is Maxwellian. In the TJ-II stellarator during NBI heated plasma, the EEDF in the confined plasma and close to the LCFS is bi-Maxwellian while in the far SOL the EEDF is Maxwellian. In contrast, during the ECR heating phase of the discharge both in the confined plasma and in the SOL the EEDF is bi-Maxwellian. The mechanism for the appearance of a bi-Maxwellian EEDF in the vicinity of the LCFS is discussed. The comparison of the results from probe measurements with the ASTRA package and EIRENE code calculations suggests that the main reason of the appearance of a bi-Maxwellian EEDF in the vicinity of the LCFS is the ionization of the neutral atoms. Results for the electron temperatures and densities obtained by the first-derivative probe technique in the COMPASS tokamak and in the TJ-II stellarator were used to evaluate the radial distribution of the parallel power flux density. It is shown that in the SOL the radial distribution of the parallel power flux density is a double exponential. It is pointed out that in the calculations of the parallel power flux density at the LCFS the energy losses from inelastic processes (excitation and ionization) must be taken into account.

BASICS OF REMOTE OPERATION OF A TOKAMAK

Jan Stockel[1], Renaud Dejarnac[1], Vojtech Svoboda[2], Ondrej Grover[2]

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[2] *Faculty of Nuclear Physics and Physical Engineering, CTU, Prague, Czech Republic*

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. 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, ...).

After the lecture, the GOLEM tokamak will be operated remotely from Kiten during the satellite workshop.

TUESDAY, JUNE 28

PHYSICAL AND CHEMICAL ASPECTS OF DISCHARGES IN LIQUIDS

F. Krcma[1], Z. Kozakova[1], V. Mazankova[1], E. Klimova[1], L. Hlochova[1], L. Hlavata[1], L. Jonisova[1], L. Dostal[2]

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Electrical discharges interacting with liquids are one of the hot topics of current plasma physics and plasma chemistry [1]. A special tension is kept for the discharges generated directly in liquid phase or in bubbles in the liquid phase. Mainly various water solutions are studied but also some first works have been done using organic liquids like ethanol, hexane or liquid polypropylene. The typical studied configuration is point to plane supplied by pulsing high voltage of tens kV [2, 3], some studies were carried out also in coaxial configuration [4]. The presented results are connected mainly to the diaphragm discharge configuration [5, 6] and the newly designed electrode system based on this configuration [7].

The electric discharge in liquid phase generated both physical and chemical effects. The emission of UV (and partially also VUV) radiation and shock waves are the main physical effects. Chemical effects are related mainly to production of OH radicals (fast recombining to stable hydrogen peroxide) and atomic hydrogen and oxygen species in case of water solutions without additional bubbling. The carbon, CH and CH_3 species are important in the case of discharge in organics. If air or nitrogen gaseous bubbles are introduced into the discharge in water solutions, the nitrides and nitrates are together with peroxynitriles the main additional species. Thus the discharges generated in liquids forms very reactive environment with potential in many application fields.

The main studied applications are in waste and drinking water treatment (like decomposition of phenol, dyes, hormones, pharmaceutics, etc.), surface treatment, and nanoparticles synthesis. A special focus is given to biomedical applications like sterilization, wound healing, ablation, etc. The applications in water treatment and surface treatment of ancient glass base on our own research will be presented in details.

Acknowledgments: This work was supported by the Ministry of Education, Youth and Sports of Czech Republic under projects LD14014 and was carried out under the COST Action TD1208.

References:

[1] S. Samukawa, M. Hori, S. Rauf, et al. *J. Phys. D: Appl. Phys.* **45 (**2012) Art. No. 253001.
[2] Ruma, P. Lukes, N. Aoki, E. Spetlikova, S.H.R. Hosseini, T. Sakugawa, H. Akiyama *J. Phys. D: Appl. Phys.* **46 (**2013) Art. No. 125202.
[3] P.H. Ceccato, O. Guaitella, M.R. Le Gloahec, A. Rousseau, *J. Phys. D: Appl. Phys.* **43** (2010) Art. No. 175202.
[4] P. Sunka, V. Babicky, M. Clupek, M. Fuciman, P. Lukes, M. Simek, J. Benes, B.R. Locke, Z. Majcherova, *Acta Phys. Slovaca* **54** (2004) 135-145.
[5] Z. Kozakova, M. Nejezchleb, F. Krcma, I. Halamova, J. Caslavsky, J. Dolinova, *Desalination* B258 **(**2010) 93-98.
[6] P. Lukes, M. Clupek V. Babicky, E. Spetlikova, I. Sisrova, E. Marsalkova, B. Marsalek, *Plasma Chem. Plasma Proces.* **33** (2013) 83-95.
[7] F. Krcma, inventor, Brno University of Technology, assignee. *Jet system for plasma generation in liquids*. Czech Republic patent CZ 305304 B6, 2015 Jun 10.

PROBE MEASUREMENTS OF ELECTRON DISTRIBUTION FUNCTIONS IN PLASMA: FROM LOW TO HIGH PRESSURE

V. I. Demidov[1,2], S. F. Adams[1]

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An electric probe is a small conducting object that is inserted into or faces (wall probe) plasma for the purpose of diagnostics and connected to the outside world through some kind of electrical circuitry [1-3]. The probe allows measurements of a non-Maxwellian electron distribution function (EDF) for non-equilibrium plasma, which is important for experimental study of plasma properties. Electric probe method for diagnostics of plasmas is reviewed with emphasis on the spatial resolution that is required to study inhomogeneous, low-temperature plasmas. The review is based on the low-temperature plasma electron kinetics.

It is stated that EDF can be extracted from probe measurements by applying an appropriate probe theory. The Druyvesteyn formula is most commonly used for this extraction and has been used in numerous works, but the more general theory can be used for a wider range of gas pressures. It is demonstrated that the Druyvesteyn formula can be obtained from the general theory as a limiting case. It is also demonstrated how the application of wall probes can be justified for plasma studies of an energetic part of EDF. Details of ground-state and excited-state neutral atoms and molecules in low pressure short (lacking a positive column) glow discharges and atmospheric-pressure micro-discharge plasma are evidenced by plasma electron spectroscopy (PLES), based on a wall probe. The presence and transport of energetic (suprathermal) electrons, having nonlocal origin, are responsible for electrostatic charging of the plasma boundary surfaces to potentials many times that associated with the ambient electron kinetic energy. The energy-flux distribution function is shown to be controllable for applications involving analysis of composition and processes taking place in a multiphase (plasma-gas-solid), chemically reactive, interaction region.

The methods for studying anisotropic plasmas and their usefulness in plasma research are also discussed. It is shown that to determine anisotropic electron energy distribution functions, a planar, one-sided probe is most convenient.

Acknowledgments: This work was prepared while one of the authors (V.I.D.) held a National Research Council Research Associateship Award at AFRL.

References:

[1] J. D. Swift, M. J. R. Schwar, Electrical Probes for Plasma Diagnostics, Iliffe Books, London (1970).
[2] V. I. Demidov, S. V. Ratynskaia, K. Rypdal, *Rev. Sci. Instrum.* **73** (2002) 3409.
[3] V. A. Godyak, V. I. Demidov, *J. Phys. D: Appl. Phys.* **44** (2011) 233001.

CONSIDERATIONS ON NEW DEVELOPMENTS ACHIEVED IN ELECTRICAL PROBE TECHNIQUE USED FOR PLASMA DIAGNOSIS

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New technical developments and experimental results are presented on plasma diagnosis performed with electrical probes. The technical development refers to a new experimental arrangement of the electrical circuit, which is based on a single measured parameter, either as time-dependence of the probe current I(t) or of the probe potential V(t). Subsequently, using an integral approach in the first case, or a differential one in the later, the time-dependence of complementary probe parameters as V(t) and I(t), respectively, can be obtained. From these temporal functions the current voltage characteristic can be achieved. The new method was used and compared with the standard diagnosis method of stationary argon plasma produced in a multipolar confinement plasma system. The errors of each method are discussed. The technique was used for measuring plasma parameters in a linear magnetized plasma device.

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HYBRID NUCLEAR REACTORS

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The demands for primary energy source with acceptable economic parameters, with huge stocks of raw material, high power density and safe operation, carbon dioxide free, are becoming more and more pressing. Unfortunately the development of fusion energy projects is quite slow so far despite the considerable financial support for the main laboratories and facilities. It is obvious that the society can't wait 70-80 or more years to the commercialization of "clean" thermonuclear energy. Indeed, the research tokamak - ITER, which should demonstrate the net production of fusion energy, will start experiments sometime after 2020. ITER will work probably about 30 years until it exhausts the list of questions that it can answer. Then the project DEMO should be implemented. This is a prototype of industrial power plant that has to begin operation after about 35-40 years according to the original scenarios. DEMO should provide electricity in the industrial grid. But the expenditures for the construction of these reactors are too large. The initial price of the ITER project was claimed to be within the 5 billion Euros. In practice, the actual amount will be, probably about 3 times bigger. It is hardly to expect for DEMO to be less expensive if it is going to be based on the same concept. And with such a magnitude of investment needed, fusion energy has no future. On the other hand the existing nuclear power industry will face a shortage of raw material. It, as is known, is based on the chain fission reaction of the isotope ^{235}U. The uranium ore contains an average of 0.71% of ^{235}U, therefore an expensive enrichment of the initial product is required. The available stocks of the ore deposits will be depleted after 50-100 years. The paradox in this situation is that a large amount of uranium (but the even isotope ^{238}U!) is standing in a warehouse or in costly landfills high-level radioactive nuclear waste. There are also other negative effects of the use of current fission reactor technology for power generation. Not by chance is now the strong resistance against the use of nuclear energy. Probably the answer of all these problems are the hybrid fusion-fission reactors, proposed first in 1951 by A. Sakharov. The idea was later supported by Hans Bethe and many other scientists. In the last two decades starts the experimental study of some systems which can be quite promising in this area. Besides, the development of the fast breeder reactors and so called electrical breeding supports these advances. This report is a short review on the principles, experimental devices and projects of fusion-fission nuclear plants for energy production, transmutation of high radioactive nuclear waste as well as production of fuel for the slow fission reactors.

DIGITAL FILTER POLYCHROMATOR FOR THOMSON SCATTERING APPLICATIONS

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Incoherent Thomson scattering diagnostics (TS) is a proven technique capable of reliable and robust instantaneous measurement of electron temperature (T_e) and density (n_e) local values in wide area of plasma physics experiments: from hall-effect thrusters to tokamaks and stellarators.

The TS cross section is very low (approximately $\sigma_{TS} = 6.7 \circ 10^{-30}$ m^2), and the corresponding TS signals, measured in fusion experiments, are usually of ~10^{-15} of incident power. The polychromators based on interference filters[1] allow to maximize the collected light intensity, that in turn allows to use probing lasers with rather low pulse energy 1-2J making this approach routinely used in fusion devices.

Availability of compact commercially available digitizer based on high speeds wave form sampling (ASIC systems[2]) with sampling rate as high as 5 GS/s (bandwidth ~1 GHz) and 12 bits resolution allows to develop a digital polycromator with fiber input supplying the TS signals for processing and fiber output providing digital information. Such device can be based on 6-7 channel filter polychromator[3] equipped with NIR enhanced avalanche photodiodes, analog-memory acquisition system and computer for data processing in one case.

In the presentation the digital polychromator test-bench at the Globus-M tokamak is discussed. The presentation focus is on the analysis of scattered signal measurement accuracy, calibration technique and estimation of Te, ne with corresponding errors. The measurement results are presented in comparison with the routine Globus-M TS system.

Acknowledgments: No thanks

References:

[1] T.N. Carlstrom, J.C. DeBoo, et al., *Review of Scientific Instruments* **61** (1990), 2858.
[2] S. Ritt, R. Dinapoli, U. Harmann, NIMA, 623 (2010), 486-488
[3] https://spectraltech.ru/product/3/

PLASMA PARAMETERS IN DIVERTOR REGION OF THE COMPASS TOKAMAK DURING ISOTOPE EFFECT EXPERIMENT

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Even though there is a large experimental evidence that isotopic composition has an impact on confinement properties of the tokamak plasma, the main mechanism governing the isotope effect is still unclear. As recent experiments have shown, the L-H power threshold in deuterium or helium can be reduced by a factor of 2 compared to hydrogen plasmas [1,2] and understanding this effect would strongly increase the confidence in scenario development for future fusion devices.

In order to study the effect of isotopes in L-mode, Langmuir probe measurements of the plasma parameters were performed in the divertor region [3] of the COMPASS tokamak. The probe data has been processed using two different methods - the first-derivative probe technique (FDPT) [4,5] for evaluating the real electron energy distribution function (EEDF) and the classical method [6] that assumes Maxwellian EEDF.

The measurements were done in hydrogen and deuterium, their mixtures as well as in hydrogen-helium mixture. The influence of glow discharge cleaning of the tokamak chamber with He, H_2 or D_2 on plasma parameters was also studied.

It was found that the EEDF in the divertor region is bi-Maxwellian with a low-energy electron population with temperatures 4-6 eV and high energy electron group 10-25 eV. However, during some shots the EEDF is bi-Maxwellian only at the beginning and changes to Maxwellian with the time.

After adding heavier gases (D_2 or He) into hydrogen plasmas, either by using the glow discharge cleaning before the shot or by gas puff during the shot, the ion-saturation current and the electron density decreases while the electron temperature remains at the same level.

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References:

[1] F. Ryter et al., *Nucl. Fusion* **53**, (2013) 113003.
[2] P. Gohil et al., in *Proc. 24th Int. Conf. on Fusion Energy* (2012) ITR/P1-36(San Diego, CA, 2012).
[3] M. Dimitrova, R. Dejarnac, Tsv. K. Popov, P. Ivanova, E. Vasileva, J. Kovačič, J. Stöckel, J. Havlicek, F. Janky and R. Panek, *Contrib. Plasma Phys*. **54** No. 3 (2014), 255.
[4] Tsv. K. Popov, P. I. Ivanova, J. Stockel and R. Dejarnac, *Plasma Phys. Control. Fusion* **51** (2009), 065014.
[5] Tsv. K. Popov et al., *Plasma Phys. Control. Fusion* **57** (2015) 115011.
[6] P. C. Stangeby, The Plasma Boundary of Magnetic Fusion Devices (2000) (Plasma Physic Series) (Bristol: IOP Publishing)

LANGMUIR PROBE MEASUREMENTS IN GLAST SPHERICAL TOKAMAK

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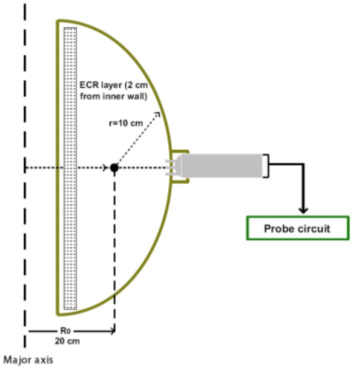
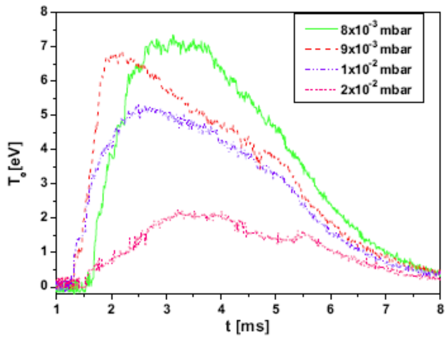
Triple-probe has been developed and operated successfully to characterize ECRH-assisted hydrogen microwave plasmas in GLAST Spherical Tokamak. This technique enables to determine transient plasma parameters such as floating potential, electron temperature and electron number density in rapidly time-varying plasmas. An effective electron heating mechanism is applied to produce microwave plasma by injecting radiofrequency (RF) radiation at a frequency of 2.45 GHz in the presence of resonant toroidal magnetic field. Plasma parameters and corresponding fluctuations are measured as a function of time in different gas fill pressures for various applied magnetic fields. The results demonstrate the dependence of plasma parameters such as V_f, T_e, n_e and their fluctuations on gas fill pressure during the pre-ionization phase of the GLAST operation. Plasma behaviour is observed to be closely depending on the coupling of RF power during microwave discharge. Additionally, the hydrogen plasma shows pronounced fluctuations in comparison with argon plasma with some decrease in electron temperature and densities.





Figures shows the semi poloidal cross-section of the GLAST with probe position and temporal profiles of a electron temperature.

Acknowledgments: The authors express gratitude to thank the staff of the NILOP Mechanical Workshops for providing manufacturing support during fabrication of triple Langmuir probe. Support from IAEA through CRP No 166997 "on utilization of a network of small magnetic confinement fusion devices of main stream fusion research" is also acknowledged.

References:

[1] T.K. Popov, P. Ivanova, M. Dimitrova, J. Kovacic, T. Gyergyek, M. Cercek, Plasma Sources Sci. Technol. 21(2012) 025004.
[2] N. Hershkowitz, Phys. Plasmas 12 (2005)055502.
[3] S.L. Chen, T. Sekiguchi, J. Appl. Phys. 36 (1965) 2363.
[4] C. Riccardi, G. Longoni, G. Chiodini, M. Fontanesi, Rev. Sci. Instrum. 72 (2001)461.
[5] R.L. Merlino, Am. J. Phys. 75 (2007) 1078.

RELATIONSHIP OF ADHESIVE, CONTACT AND ELECTRET PROPERTIES OF PTFE MODIFIED BY DC DISCHARGE

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Improvement of the contact and adhesion properties of polymers by low-temperature plasma treatment is usually associated with chemical transformations on their surface, such as the formation of chemically different (mainly, oxygen-containing) polar groups and structural changes due to plasma-induced partial degradation of the surface layer. However, no direct correlation between the values of the contact angle, adhesion of plasma-modified polymers and the formation of electret charges in the surface layers of the films has been revealed. In this study, we examined the relationship of the change in the adhesive and contact properties of the surface of DC discharge-modified PTFE films with the plasma-induced formation of electret charges in the polymer.

Samples of the PTFE film of 40 μm thickness (Russia, "Plastpolymer", St. Petersburg) were used. The procedure for film modification by DC discharge is detailed in [1]. The surface properties were characterized by values of the contact angle (θ) of deionized water. The electret potential (*U)* was measured by the compensation technique using a dynamic capacitor. From the measured *U* value, the effective surface charge density (σ) was calculated by the equation $\sigma = \varepsilon_0 \varepsilon U/L$. The adhesive properties were investigated according to the procedure described in [2]. The peel strength (*A*) was determined using the T-peel test for the Scotch®810/PTFE film contact. Values of θ, *A*, and *U* were measured immediately after plasma treatment, during the storage of the films in air at room temperature and atmospheric pressure for 14 days, and after heating at 150°C for 30 min in air at atmospheric pressure.

It was shown that the treatment of the films at the anode is more effective than at the cathode, and the values of θ for water measured either immediately after the discharge treatment or after 14 day storage or 30 min heat treatment are lower. The films modified at the anode acquire hydrophilicity and retain this property after storage or heating ($\theta < 60°$). These films also possess better adhesion properties: the values of *A* measured immediately after the DC discharge treatment and after storage or heating were higher. These results indicate the existence of an inverse correlation between the contact angle and the peel strength: the less the value of θ, the greater the value of *A*. This relationship is characteristic of the both types of films modified at the anode or at the cathode. It was established that the initial film had a small negative surface potential and the effective charge density of this film is $\sigma = -15\ \mu C/m^2$. The presence of this potential is apparently due to the sample prehistory. After modifying the film at the anode, the effective density of negative charge increases to $-36\ \mu C/m^2$, whereas the film treated at the cathode acquires a positive surface potential. It was also shown that as the storage time increases the contact angle also increases, the peel strength decreases, and the effective surface charge density is reduced. The data obtained show the existence of correlations between the effective surface charge density and θ, as well as between σ and *A*.

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References:

[1] D. Richkov, M. Yablokov, A. Richkov, *Appl. Phys.A, Mater. Sci. Process.* **A 107** (2012), 589
[2] M. Yablokov, A. Kechek'yan, S. Bazhenov, A. Gilman, M. Piskarev, A. Kuznetsov, *High Energy Chem.* **43** (2009), 512

UNDERSTANDING THE IMPORTANCE OF HYDROGEN IN CATALYZED CNT GROWTH FROM HYBRID MD/TFMC SIMULATIONS

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Atomic scale simulations of the growth of carbon nanotubes (CNTs) provide an essential tool for understanding the nature of the growth process, especially, in the early stages [1,2]. It is known that hydrogen has a dual role, i.e., it either enhances or slows down CNT growth, depending on its concentration [2]. In spite of recent advances, however, understanding the precise role of H in the onset of CNT growth and CNT etching is still elusive.

This issue, however, is difficult to address either experimentally (due to the dynamic evolution of the nanoscale nucleation process) or by quantum-mechanical calculations, which remain currently computationally too expensive to address the inherent time and length scales. On the other hand, hybrid classical molecular dynamics / force bias Monte Carlo (MD/tfMC) technique is a good alternative to follow the system evolution during CNT growth and H-etching for long time scales (e.g., in the order of μs) [3]. During the calculations, all atomic interactions, including bond associations and dissociations, are described by the ReaxFF force field [4].

We thoroughly discuss the role of hydrogen in the appearance of unstable carbon structures during in situ experimental observations and precursor-dependent CNT growth rate as well as the experimentally proposed initial stage of multi-walled CNT growth [2]. Therefore, we introduce the k-coefficient (or dehydrogenation degree) to distinguish various growth (sub)stages and demonstrate that control over the k-coefficient is a highly important factor in controlling CNT nucleation and growth [2,5]. Also, we unravel the H etching mechanism for CNTs, based on our theoretical and existing experimental results. The obtained results demonstrate that the metallicity and γ-angle (i.e., ortho HC-CH bond alignment with the chirality vector) can explain the preferential etching of (semi-) metallic tubes over semiconductor tubes. Specifically, we found that the adsorbed ortho H pairs more perpendicular to the tube axis are responsible for C-C bond breaking for SWNTs, which in turn determines the onset of the CNT etching. Finally, we discuss also the H-role in the plasma pre-treatment of the nanocatalyst before the CNT growth.

In general, the overall results indicate that unravelling the precise role of H is important in order to selectively realize CNT growth or CNT etching.

Reference:

[1] V. Jourdain. & C. Bichara, Carbon 58, 2–39 (2013)
[2] U. Khalilov, A. Bogaerts & E. C. Neyts, Nat. Commun. 6, 10306 (2015)
[3] K. M. Bal & E. C. Neyts, J. Chem. Phys. 141, 204104 (2014)
[4] J. E. Mueller, A.C.T. van Duin, & W.A. Goddard III, J. Phys. Chem. C 114, 4939-4949 (2010)
[5] U. Khalilov, A. Bogaerts & E. C. Neyts, *Nanoscale* **6**, 9206 (2014)

WEDNESDAY, JUNE 29

SURFACE-WAVE-SUSTAINED PLASMA TORCH FOR BIOMEDICAL APPLICATIONS

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The plasma source used in these investigations is surface-wave-sustained discharge operating at 2.45 GHz (plasma torch) and atmospheric pressure produced by an electromagnetic wave launcher surfatron type in Argon.

The surface-wave-sustained plasma torch operating at room temperature can be used for water treatment and activation as well as for direct treatment of cells, bacteria, seeds, living tissues, temperature sensitive materials, ets. In the direct plasma treatment several agents are included in the same time: UV radiation, electric field, charged and excited chemically active particles. We are able to produce surface-wave plasma torch operating at room temperature without heating the treated material.

The plasma antimicrobial effect was studied by direct contact treatment on agar plates and in bacterial suspensions. The direct treatment experiments were conducted with cells from *Pseudomonas sp.* AP-9 at different cell density ($10^7 \div 10^9$ cells/ml), exposure time (3, 5, 10, 15, 20 s) and power (14, 17, 20, 22 W). The results show the clear sterilization area with diameter dependent on exposure time and bacterial density.

The effect of plasma treatment in liquids was assessed on bacterial suspensions of Gram-negative bacteria *Pseudomonas sp*. AP-9 and Gram-positive spore-forming bacteria *Brevibacillus laterosporus* BT-271. The both bacteria are very active biodegraders in the municipal and industrial wastewater treatment processes and were isolated and stored in lyophilized condition in the laboratory of Environmental Biotechnology, Department of General and Applied Hydrobiology, Sofia University. At the treatment both bacterial cultures were with concentration of 10^9 vegetative cells/ml and the exposure time <60 s reduced not completely the bacterial number. But the SEM pictures of treated cells at 60 s time show serious damages on cell surface and suggest that the increase of time will result in complete inactivation. The results are base for the proposal that the tested plasma treatment after scaling up and stage of technologization can be applied for the water treatment in different facilities. The innovation will be especially useful for the treatment of waters and materials for medical application.

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THE KEY-ROLE OF THOMSON SATTERING IN PLASMA CHARACTERIZATION

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The wide variety of the plasma state and the corresponding myriad of applications form an obstruction in the classification and characterization of plasma sources. To tackle this problem, we need a solid basis for the validation of models and the cross-validation of experimental methods. This can be offered by laser Thomson scattering (TS). As TS is the scattering of (laser) light on free electrons it gives direct information of the electron density and temperature. So, in contrast with the often used method of Optical Emission Spectroscopy, we do not need much modelling for the deduction of the main plasma properties out of the signal. On the other hand TS is costly and experimental demanding.

In this contribution we will address the benefits of TS but also the complications that can come into play. A classical problem for TS experiments is the false stray-light that might deteriorate the detection limit. This originates form the fact that TS is not very efficient. Typically only one out of 1015 photons directed to the plasma will be scattered and detected. This low efficiency also implies that TS can, in principle, only be applied to plasmas that are reproducible. This condition, which is needed since the TS photos of several laser shots have to be accumulated, can be released if the electron density is very high. In that case it is possible to perform single (laser) shot TS.

When TS is applied to atmospheric plasmas we get extra problems due the presence of molecules. This implies that the Thomson and Raman spectra will overlap, so that disentangling methods are needed to get the pure TS signal. Another characteristic, especially found in cool atmospheric plasmas (CAPs) is the low ionization degree which can induce deviations in the electron energy distribution function (EEDF). These deviations mainly affect the tail of the EEDF; an energy region that is not easy to measure with TS. Finally, the laser heating of the electron gas is another issue that has to be considered.

Various case-studies will be presented for low and atmospheric pressure plasmas. Moreover we will present a novel method by which the strong condition of plasma reproducibility mentioned above, can be released (partially).

References:

[1] J.M. Palomares et al, Spectrochimica Acta Part B 65 (2010) 225–233
[2] S. Hübner (2013) thesis http://alexandria.tue.nl/extra2/759549.pdf

FLUID AND KINETIC MODELLING OF PLASMA-WALL TRANSITION

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Plasma-wall transition is one of the oldest problems in plasma physics. In the lecture I will describe some fluid and kinetic models, which can help us to understand this problem. We will speak some basic terms, like “sheath”, “pre-sheath”, “Bohm criterion”, “asymptotic two-scale limit” and others. We will also take a look at the effects of the presence of energetic electrons, emitted electrons and magnetic field, using the fluid model and kinetic model of the plasma diode.

COAXIAL MICROWAVE DISCHARGE FOR BIO-MEDICAL APPLICATION

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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 (SWD). One of the main characteristics of surface-wave-sustained cylindrical plasma column is the single wave mode regime of operation. Usually only the azimuthally symmetric wave propagates in this configuration. If there is a metal cylinder at the tube axis, electromagnetic wave can produce plasma outside the dielectric tube in a low pressure chamber. This configuration is called coaxial discharge.

Sustaining the coaxial discharge by various wave modes in various configurations is theoretically studied. It confirms the assumptions based on the experiments that not only the azimuthally symmetric but also higher modes can sustain the discharge.

The purpose of this work is to investigate theoretically the wave and plasma characteristics of coaxial plasma sustained by azimuthally symmetric, dipolar and higher wave modes at low and atmospheric pressure. The basic relation in our model is the local dispersion relation obtained from Maxwell’s equations. Since the plasma is axially inhomogeneous the local dispersion relation gives the dependence between the normalized plasma density and the dimensionless wave number, so called phase diagrams. From the behavior of the phase diagrams at different wave modes and discharge conditions one can obtain information about the ability of the wave to sustain the plasma and about the plasma density. Axial profile of normalized plasma density and 3D distribution of electric and magnetic field are obtained too.

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THURSDAY, JUNE 30

POWER MANIPULATION AND LASER AGITATION

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Power Manipulation and Laser Agitation can be used for in-depth studies on the (non-) equilibrium state of plasmas. In the first case we modulate the plasma driving power and study the reaction of the plasma-as-a-whole. A special method is the power interruption (PI) technique; a sudden power switch-off followed by the subsequent re-ignition generates information on transport mechanisms like diffusion, ionization, recombination and heat transfer [1]. The second method is more refined: we agitate just one specific atomic transition, using laser induced fluorescence (LIF) and study how this disturbance propagates through the system. This provides insight in the importance and strengths of the various transition rates and probabilities [2]. To make the information obtained from these relaxation techniques (LIF and PI) more valuable it is important to know the plasma characteristics. For this we can employ Thomson scattering; the scattering of light on free electrons giving the electron density and temperature.

The first part of this contribution is devoted to time-resolved LIF. By combining high rep-rate YAG-Dye laser systems with well-known and controllable surfatron plasmas it is possible to explore the excitation kinetics in the argon atom system, ArI, and to unravel the excitation transfer between ArI and other atomic and molecular systems. Laser systems that can offer 8 ns pulses of typically 1 mJ of tunable wavelength with a rep-rate of 1 to 5 kHz are nowadays commercially available. They give at least 100 times more relevant LIF photons per unit of time than the conventional 10 Hz systems.

The second part describes the application of the power interruption method to argon surfatrons operated in the intermediate pressure regime. By analyzing the results of Thomson scattering (TS) during PI, insight was among others obtained in the importance and strength of diffusion and recombination processes. The method was applied to plasmas operated in pure argon and in argon mixtures such as Ar/H_2, Ar/O_2, Ar/N_2 and Ar/CO_2. Huge differences were found in the PI responses of different plasmas mixtures. The slow decay of the electron temperature after PI in Ar/CO_2 plasmas points towards a strong coupling between the electrons and the vibrational CO_2 system.

References

[1] Hubner S. et al, Plasma Process. Polym. DOI:10.1002/ppap.201300190 2014.
[2] Palomares J-M et al, Spectrochimica Acta B DOI:10.1016/j.sab2013.

COMPOSITE MEMBRANES WITH THE HYDROPHOBIC AND HYDROPHILIC LAYERS

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The last decade has seen a growth of interest in preparation of two-layer composite membranes that contain hydrophilic and hydrophobic layers. Such membranes are employed in various separation processes, such as desalination of water, pervaporation, reverse osmosis, micro- and nanofiltration. In this work we describe the synthesis and characterization of polymer composite membranes with hydrophilic porous substrate and hydrophobic top layer. To prepare the composite membranes a polytetrafluoroethylene (PTFE) thin film has been applied by the technique of electron-beam sputtering deposition in vacuum on one side of a poly(ethylene terephthalate) track-etched membrane (PET TM) used as a porous substrate.

A PET TM of a 10.0 µm thickness with an effective pore diameter of 250 nm used in the experiments were prepared by bombardment of a PET film (Lavsan, Russia) with krypton ions accelerated in a cyclotron (energy, ~3 MeV/nucleon) followed by physicochemical treatment according to a standard procedure. PTFE layers were applied onto track membrane surface by physical vapor deposition using electron-beam sputtering of the polymer in vacuum. Surface topography of the membranes was studied using atomic force microscopy (AFM), the surface properties were characterized by values of the water contact angle (θ), and the chemical structure was investigated by X-ray photoelectron spectroscopy (XPS) and Raman spectroscopy.

It was found a significant reduction in the effective pore diameter of the membranes produced by this way. At the same time, according to the AFM data, the pore diameter on back side of the membranes with deposited PTFE layer remains unchanged. Thus, the electron-beam sputtering deposition of the PTFE layer in vacuum onto the PET TM surface leads to a change in the pore geometry, and the pores acquire an asymmetric shape. The study of the surface properties of the membrane has shown that the deposition of the PTFE film leads to substantial hydrophobization. The initial membrane has the water contact angle of 65°, whereas the PET TM with a PTFE layer on the surface has $\theta = 120°$. By XPS and Raman spectroscopy it was shown that the PTFE layer deposited on the PET TM surface is mainly made from polymer chains composed of $–CF_2–$ units as the initial polymer. The deposition of the PTFE layer onto the PET TM surface leads to the formation of the composite membrane consisting of two layers, one of which is the initial PET matrix bearing terminal carboxyl groups on the surface and having an average level of hydrophilicity. The other layer deposited by electron-beam sputtering of PTFE does not contain ionizable functional groups.

The results of measurement of current-voltage characteristics for the test membranes show that the conductivity of the initial PET TM is independent of the direction of the current. In contrast, analysis of the current-voltage curves of the composite membranes shows that their conductivity depends upon the current direction. This means that the deposition of a hydrophobic PTFE layer on the surface of PET TM imparts asymmetry of conductivity, the rectifying effect similar to *p-n* junction in a semiconductor. Membranes of this kind can be used for directional ion transport.

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MICROWAVE DRIVEN PLASMAS APPLICATIONS

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Microwave plasmas and in particular surface-wave sustained plasma operating at atmospheric pressure conditions distinguish with their unique properties: high electron temperature; electrodeless; maximum absorption of the microwave energy by the plasma. The latter insures high concentration of energetic electrons and free radicals in the plasma. The plasma parameters can be controlled in the wide range in a reproducible way by the system geometry, microwave power, pressure, gas composition etc. Therefore, this type of plasma has potentially versatile applications. Three examples are given in this study: reforming of hydrocarbons for syngas production, biomass surface processing as a pretreatment process in bioethanol production, and synthesis of advanced carbon nanostructures [1].

Hydrogen is considered to be one of the fuels of the future – clean and sustainable. It is produced from hydrocarbons, including bioethanol, which makes the whole process CO_2 neutral/balanced. Reforming of alcohols by microwave plasma has very high hydrogen yield and conversion rates. Detailed analysis of the process, which include experimental investigation of the plasma and exhaust gas, but also modelling, provides rather clear general inside view of the whole process [2].

One of the important issues in producing bioethanol is sugarcane pretreatment process. It includes destruction of lignin and hemicellulose layers, in order to 'open' the cellulose and facilitate its further processing. The exposure of samples in the afterglow region of the microwave air/water plasma is suitable for this purpose, as confirmed by the structural and spectroscopic analysis of the treated sugarcane [3].

Microwave plasma environment can be used for synthesis of advanced carbon and Si-based nanostructures. It should be stressed that this process, in perspective, provides the possibility of its extension towards large scale, enabling commercial production of novel nanostructured materials [4].

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References:

[1] Tatarova E, Bundaleska N, Sarrette J Ph and Ferreira C M 2014 Plasma Sources Sci. Technol. 23 063002

[2] Bundaleska N, Tsyganov D, Tatarova E, Dias F M and Ferreira C M 2014 Int. J. Hydrogen Energy 395 663–70

[3] Bundaleska N, Tatarova E, Dias F M, Lino da Silva M, Ferreira C M and Amorim J 2014 J. Phys. D: Appl. Phys. 47055201

[4] Tsyganov D, Bundaleska N, Tatarova E, Dias A, Henriques J, Rego A, Ferraria A, Abrashev M V, Dias F M, Luhrs C C, and Phillips J, Plasma Sources Sci. Technol. 25 (2016) 015013

“HUNTING” FOR A LEAK IN THE VACUUM SYSTEM OF A VUV SPECTROMETER

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Many plasma devices work at sub-atmospheric pressure conditions and/or require measuring equipments kept at even lower pressures, e.g. mass and VUV spectrometers, which are expected to operate at pressure values typically below 10-4 mbar. As a result, researchers and other experimental device operators should have, at least, basic knowledge on vacuum technology, namely on what if often the most boring, time-consuming task: leak detection.

Although leak detection tasks are frequently left to technicians, sometimes unusual things happen and problem-solving requires the researcher to recall vacuum technology basics.

In this contribution, we propose some kind of a “virtual” laboratory training lecture. As an introduction, basic physical concepts for vacuum and fluid technologies, as pressure, flow characterization, fluid equations, conductances, and leak detection techniques, as well as good laboratorial practices will be recalled and emphasized. Then, a real situation concerning finding a leak in the vacuum system of a VUV spectrometer [1] will be used as the presentation core, and students will be guided through the leak detection procedure following actual vacuum measurements.

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References:

[1] Espinho S., Felizardo E., Tatarova E., Dias F. M. and Ferreira C. M., Appl. Phys. Lett., 2013, 102, 114101.

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PLASMA SYNTHESIS OF NANOWIRES AND THEIR ADVANCED APPLICATIONS

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Plasma technologies will in near future play important role in advanced applications through synthesis processes of nanomaterials.[1] The biggest advantage of plasma technology is that it provides the competitive method that can synthesise large quantities of nanomaterials like nanowires, nanotubes or nanoparticles which are appropriate for use in advanced devices like PVs (photovoltaic), water splitting cells, gas sensing, catalytic devices for liquid purifications, etc. The tremendous interest and progress in plasma synthesis was done for 0D, 1D and 2D nanostructures including inorganic nanowires (NWs), nanotubes, nanowalls, and quantum dots in recent years. The advantage of plasma growth is not only abundant quantity, but short time-scales of synthesis and many other advanced properties of materials, e.g. single-crystallinity of materials, superstructure of crystal lattices, pureness, etc.[2-4] Moreover, such materials show improved performance to others nanomaterials synthesized by other methods when tested in devices.

For synthesis or modification of nanowires, the key role in near future will be given to methods like plasma flight-thru or direct growth on solid-solid interfaces. In this way, we can produce sufficient amounts like 50 g/min not only of NWs, but also of quantum dots, core-shell quantum dots, etc. or produce NWs in arrays directly on electrodes. [4,5] This is more than 10-times better compared to other plasma methods or thermal processes (thermal, gas decomposition), chemical vapour deposition (CVD) or wet chemical processes (hydrothermal, solvothermal, sol-gel mediated).[2] With these amounts, we overcome large market price of nanomaterials and make them available for general public use, and apply them to numerous devices. However many problems connected with production process and technology implementation still persist. The advantage of plasma synthesized materials is also their structure and good control of their physical properties. With plasma methods we can build so-called superstructure materials which have highly-ordered vacancies planes, are single-crystalline and without any impurities.[3,6] These vacancies act as fast electron transport routes when electrons are released by photon impact. And more we can tailor their band-gap energy. Additionally, the band gap can be also tailored by other methods like atmospheric pressure plasmas created in inert gases as well as electron beams, where we modify materials by electron impact. These surface-matter interactions release atoms from nanomaterial and modify their properties in terms of performance.

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References:

[1] K. Ostrikov, U. Cvelbar, A.B. Murphy, *J. Phys. D: Appl. Phys.* **44**,(2011) 174001.
[2] U. Cvelbar, *J. Phys. D: Appl. Phys.* **44**,(2011) 174014.
[3] Z. Chen, U. Cvelbar, M. Mozetič, J. He, M.K. Sunkara, *Chem. Mater.* **20** (2008) 133505.
[4] U. Cvelbar, U. Chen, M. K. Sunkara, M. Mozetič, *Small.* **4** (2008) 1610.
[5] K. Ostrikov, I. Levchenko, U. Cvelbar, M.K. Sunkara, M. Mozetič, *Nanoscale*. **2** (2010) 2012.
[6] G. Filipič, O. Baranov, M. Mozetič, U. Cvelbar, *J. Appl. Phys.* **117** (2015) 043304.

MICROWAVE PLASMAS APPLIED FOR SYNTHESIS OF FREE-STANDING CARBON NANOSTRUCTURES

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In this lecture, selective synthesis of self-standing carbon nanostructures using microwave driven plasmas at atmospheric pressure conditions is discussed. Gas or liquid carbonaceous precursors are injected into a microwave plasma environment, where decomposition processes takes place. The governable transport of plasma generated gas-phase carbon atoms and molecules into colder zones of plasma reactor results in carbon nuclei formation. The main part of the solid carbon is gradually withdrawn from the “hot” plasma region in the outlet plasma stream where carbon nanostructures assemble and grow. Controllable bottom-up self-organization of free-standing graphene sheets and diamond-like particles is achieved via synergistic tailoring of the "hot" plasma environment and thermodynamic conditions in the outlet plasma steam. The synthesized structures have been analyzed by Raman spectroscopy, scanning electron microscopy, high-resolution transmission electron microscopy and X-ray photoelectron spectroscopy.

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PLASMA SYNTHESIS AND FUNCTIONALIZATION OF CARBON BASED NANOMATERIALS

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The presentation addresses the low temperature plasma deposition of several types of conductive carbon based nanomaterials (CBN) with high surface area. Examples concern carbon nanotubes, nanoparticles, nanowalls, or free standing graphene [1-2]. These materials are interesting for various applications raniging from astrophysics to technology (e.g. fuel cells, bioengineering, supercapacitors). In particular in the field of microtechnology and bioengineering these materials attract a great attention as an excellent base material for different sensors. Their applications are based mostly on their excellent mechanical and electrical characteristics. However such materials are initially chemically inert, thus different functionalization methods are necessary in order to control their surface functionality as well as their band-gap.

Here we present different plasma based synthesis methods, as well as functionalization by means of plasma- from deposition of ultrathin films to grafting of different functional groups. In-situ and ex-situ plasma and material diagnostics (e.g. mass spectroscopy, electron density measurements, FTIR, XPS) are applied in order to understand and control synthesis and functionalization of the materials and the final active surfaces.

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References:
[1] M. Gaillard, Ch. Boulmer-Leborgne, N. Semmar, E. Millon, A. Petit, *Applied Surface Science*, **258** (2012), 9237.
[2] E. Tatarova, J. Henriques, C. C. Luhrs, A. Dias, J. Phillips, M. V. Abrashev and C. M. Ferreira, *Appl. Phys. Lett.* **103** (2013), 134101

PRODUCTION OF N-GRAPHENE BY MICROWAVE N_2-AR PLASMAS

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Nitrogen doped graphene sheets, have attracted much attention due to their exceptional performance as parts of fuel cells, lithium-ion batteries and supercapacitors. Free-standing Nitrogen-doped graphene sheets where produced in a low pressure microwave N2-Ar plasma. Graphene sheets were treated by plasma at different exposure times and doped with nitrogen atoms, which incorporated the hexagonal carbon lattice, mainly, in pyridinic, pyrrolic and quaternary functional groups. Optical emission spectroscopy were applied to monitor the nitrogen atoms, gas temperature and electron density at the substrate position. Raman spectroscopy and X-ray photoelectron spectroscopy (XPS) techniques were applied to characterize the produced N-graphene, along with transmission electron microscopy (TEM) to study the morphology and structure of the samples. Doping levels as high as 5.6 % were achieved and an increase in the sp^2/sp^3 ratio was observed for a relatively short exposure times. This study shows that by incorporating nitrogen atoms into graphene, its physico-chemical properties are considerably altered.

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References:

[1] A. Dias, N. Bundaleski, E. Tatarova, F.M. Dias, M. Abrashev, U. Cvelbar, O.M.N.D. Teodoro, J. Henriques, *J. Phys. D: Appl. Phys.* **49** 2016, 055307.
[2] J. Henriques, E. Tatarova, F.M. Dias and C.M. Ferreira, *J. Appl. Phys.* **90** 2001, 4921.
[3] J. Henriques, E. Tatarova, V. Guerra and C.M. Ferreira, *J. Appl. Phys.* **91** 2002, 5622.
[4] C.M. Ferreira, E. Tatarova, V. Guerra, J. Henriques, B. Gordiets, F.M. Dias and M. Pinheiro, *IEEE Trans. on Plasma Sci.* **31** 2003, 645.

XPS CHARACTERIZATION OF CARBON BASED NANOSTRUCTURES

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X-ray induced photoelectron spectroscopy (XPS) is a powerful surface sensitive analytical technique. Providing quantitative composition analysis with typical sensitivity of 0.1 % and reliable information on chemical bonds of the first 15-30 atomic layers, XPS is highly suitable for characterization of nanostructures. In particular, essential information can be extracted from the XPS analysis of different carbon nanostructures synthesized during last 25 years, such as fullerenes and their derivatives, diamond like carbon, single and multiple wall carbon nanotubes, graphene and its derivatives.

The XPS analysis of carbon based nanostructures will be illustrated on several examples: plasma treated diamond like carbon thin films, amorphous carbon thin films, fullerene C_{60} and fullerenols, graphene and nitrogen doped graphene. Different strategies in the data analysis will be introduced. Additionally, potential experimental and data analysis problems will be stressed and discussed.

The main features in XPS spectrum are photoelectron lines of core levels, X-ray induced Auger lines, and valence band. The first approach in XPS characterization consists of detailed analysis of photoelectron lines of core levels. Unlike most of the analytical techniques analysis of photoelectron lines provides independently two sets of information, the composition and the chemical bonds, which has to be interpreted in the self-consistent way. This constraint appears to be a rigid filter in spectra analysis, preventing misinterpretations. From the line intensities surface composition analysis can be performed in a rather straight forward way, by applying appropriate sensitivity factors. Typically the line consists of several contributions, each attributed to different bonds. The exact position of a contribution carries the information on the chemical bonds, which is interpreted by comparison with the available literature data. One of the most important issues in C 1s line analysis is the proper choice of the line profile. The best approach to the latter is performing XPS analysis of reference samples.

Auger lines and valence band spectra may carry essential information as well. For instance, in the case of the carbon based materials so-called D-parameter is defined, representing the width of the C KLL Auger line. The value of the D-parameter can be correlated with the sp^2/sp^3 ratio in the systems consisting of the mixture of carbon in these two hybridizations. Additionally, when C 1s line of the two samples look practically the same, the shape of the valence band can be used as a reliable fingerprint of a chemical phase.

PLASMA BASES SYNTHESIS OF NANOPARTICLES: DIAGNOSTICS AND APPLICATIONS

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Low temperature plasmas with their unique non-equilibrium properties are frequently used for the deposition of thin films, the activation of surfaces or the synthesis of nanoparticles. These processes and in particular the plasma based formation of nanoparticles are a rather complex procedures, which involves many different plasma species, various timescales and several physical and chemical processes (see e;g. [1]). The first step in the plasma based formation of nanoparticles is the fragmentation of the original parent molecule due to electron impact reactions. These reactions are responsible for the initial formation of radicals, positive and negative ions which can induce subsequent polymerization reactions leading by and by to the formation of larger and larger molecules and eventually to the formation of nanoparticles .The whole process comprises rather different time scales that can reach from some tens of microseconds (electron impact induced formation of ions) and some hundreds of milliseconds (formation of larger anions) to some tens of seconds (formation of nanoparticles)**.** The formation of nanoparticles in low temperature plasmas plasmas is not a phenomenon that is restricted to specific gas mixtures or discharge types. The formation of nanoparticles has been observed for different types of gaseous precursors as for example hydrocarbons (e;g. methane or acetylene), fluorocarbons (e.g. CF_4 or C_2F_6) or silane. An important aspect related to the formation of particles concerns the response of the plasma to the formation of particles [2]. The growth of particles in plasmas significantly changes the properties of the plasma as e.g. electron temperature, electron density, the density of excited states… This contribution will focus on some basic phenomena important for the formation of nanoparticles in reactive low temperature plasmas, the diagnostics of such systems and on some applications of nanoparticles. The latter aspect will comprise the fabrication of superhyrophobic surfaces and the applications in the field of fuel cells.

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References:

[1] J. Berndt, E. Kovacevic, I. Stefanovic, J. Winter and L. Boufendi, Contrib. Plasma Phys. **49**, (2009), 107-133.

[2] H. Tawidian, T. Lecas, M. Mikikian, *Plasma Sources Science and Technology* **23,** (2014), 065009.

TIME-SPACE DEVELOPMENT OF NANOSECOND DIELECTRIC BARRIER DISCHARGE IN FLAT AIR GAPS UNDER ATMOSPHERIC PRESSURE

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Study of nanosecond dielectric barrier discharge (NDBD) dynamics in millimeter air gaps at atmospheric pressure was carried out using an electrode divided into ring segments [1, 2, 3].

Unipolar negative rectangle pulses from the specially developed high voltage semiconductor generator [4, 5] were applied to the electrodes of the discharge gap. The amplitude of the voltage pulses was 0÷20 kV, their duration 600 ns and rise/fall time 40 ns. The pulse repetition rate was set to 30 Hz.

Both electrodes were covered by alumina ceramics plates with $\mathcal{E}$ = 9 and dimensions 50x50x2 mm. The height of the discharge gap ranged from 1 to 3 mm during the experiment. The NDBD was ignited in atmospheric air at natural humidity of 40–60 %.

The time-space development of the NDBD was estimated through the comparison of the current waveforms in different volumes of the gap, obtained using low-inductance resistive current sensors.

The experimental results showed that time-space development of the NDBD depends on the rate of growth of electric field *dE/dt* in the air gap. The breakdown electric field in mm-range was observed to decrease with increasing the height of the air gap.

The uniform NDBD was realized in 1-mm and 2-mm gaps at E = 73 kV/cm and *dE/dt* ≈ 1.7 {kV/(cm·ns)}, and at E = 58 kV/cm and *dE/dt* ≈ 1 {kV/(cm·ns)}, respectively. Such situation corresponded to the quite simultaneous development of the discharge currents in the air gap. The delay between their starts was less than 1ns. It`s worth to note that the order of the discharge currents appearance was random in this case.

Filaments on a diffuse background appeared with increasing the height of the gap. In 3-mm air gap the discharge currents developed in the particular order: firstly– in the central segment, and then spreading radially. They also ignited with bigger delays between each other than in smaller gaps. In our estimates, the value of breakdown electric field in 3-mm air gaps was ~ 54 kV/cm. The NDBD was realized at *dE/dt* ≈ 0.7 {kV/(cm·ns)}, what was lower than *dE/dt*, obtained in the diffuse mode.

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References:

[1] L. Mangolini, K. Orlov, U. Kortshagen, J. Heberlein, U. Kogelschatz, *Applied physics letters*. **80** (2002), 1722.

[2] M.V. Malashin, S.I. Moshkunov, E.A. Shershunova. *Spatially homogeneous plasma of dielectric barrier discharge in planar millimeter air gaps under atmospheric pressure.* Book of abstracts: XLIII International Zvenigorod Conference on Plasma Physics and Controlled Fusion, (8-12 February 2016, Zvenigorod, Russia), p. 211.

[3] M.V. Malashin, S.I. Moshkunov, V.Yu. Khomich, *Plasma Physics Reports*. **42** (2016), 163.

[4] M.V. Malashin, S.I. Moshkunov, I.E. Rebrov, V.Yu. Khomich, E.A. Shershunova, *Instruments and Experimental Techniques*. **57** (2014), 140.

[5] E.A Shershunova., M.V. Malashin, S.I. Moshkunov, V.Yu. Khomich, *Acta Polytechnica*. **55** (2015), 59.

[6] M.V. Malashin, S.I. Moshkunov, V.Yu. Khomich, E.A. Shershunova, *Instruments and Experimental Techniques.* **59** (2016), 226.

STUDY OF LOW-PRESSURE INDUCTIVELY COUPLED PLASMA BY MEANS OF OPTICAL EMISSION SPECTROSCOPY AND LANGMUIR PROBE DIAGNOSTICS

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Inductively coupled plasma (ICP) sources are widely used for various technological applications, including etching of semiconductors, thin film deposition, and surface modification of materials [1-3]. These sources are able to produce highly-uniform low temperature plasmas of high-density (up to 10^{12} cm^{-3}) in large volumes. Due to absence of electrodes in the discharge chamber, it is possible to attain relatively small impurity content in plasma while the energies of ions incident on a substrate and the discharge power can be controlled independently.

Low pressure ICP discharges are attractive for use in plasma modification processes, since high ionization degree (up to several percent) and reduced energy spread of incident ions can be reached under such regimes. It has been reported that an external magnetic field allows ICPs to operate at very low pressures (down to 10^{-4} mbar) and it can also increase plasma density [4-7]. This contribution is devoted to investigation of plasma parameters of an ICP discharge in an axial magnetic field at various pressures and for different working gases.

Parameters of ICP discharge were measured in Ar, N_2, H_2 and their mixtures at working pressures in the range of 5×10^{-4}–1×10^{-2} mbar and magnetic fields in the range of 0–60 G. The input RF power was 1 kW, and the reflected power did not exceed 10%. Spatial distributions of plasma parameters were obtained using an array of cylindrical Langmuir probes. Along with the probe measurements, the elemental composition of the ICP discharge including impurities was analyzed via optical emission spectroscopy. According to the results of our experiments, the ionization degree was enhanced with the decrease in operating pressure and reached the value of about several percent at a pressure of 5×10^{-4} mbar.

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References:

[1] J. Hopwood, Review of inductively coupled plasmas for plasma processing, *Plasma Sources Science and Technology,* **v.1**, № 2 (1992), p. 109.
[2] J. H. Keller, Inductive plasmas for plasma processing, *Plasma Sources Science and Technology,* **v. 5**, № 2 (1996), p. 166.
[3] T. Okumura, Inductively Coupled Plasma Sources and Applications, *Physics Research International,* **v. 2010**, (2010).
[4] J. E. Stevens, M. J. Sowa, J. L. Cecchi, Helicon plasma source excited by a flat spiral coil, *Journal of Vacuum Science & Technology,* **v. 13**, № 5 (1995). pp. 2476-2482
[5] L. Ho-Jun, Y. Il-Dong, W. Ki-Woong**,** The effects of magnetic fields on a planar inductively coupled argon plasma, *Plasma Sources Science and Technology,* **v. 5**, №3, (1996), p. 383.
[6] D. L. Tang, R. K. Y. Fu, X. B. Tian,, Improved planar radio frequency inductively coupled plasma configuration in plasma immersion ion implantation, *Review of Scientific Instruments,* **v. 74**, № 5 (2003), pp. 2704-2708.
[7] E. A. Kral'kina, Low-pressure radio-frequency inductive discharge and possibilities of optimizing inductive plasma sources, *Physics-Uspekhi,* **v. 51**, № 5 (2008), p. 493.

BISPECTRAL ANALYSIS: COMPARISON OF WINDOWING FUNCTIONS

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The Higher-Order Spectral Analysis is shown to be a very useful diagnostic tool in experimental studies of nonlinear wave interactions in plasma. In particular, it is shown that the bicoherence spectrum may be used to discriminate between nonlinearly coupled waves and spontaneously excited waves and to measure the fraction of wave power due to the quadratic wave coupling in a self-excited fluctuation spectrum [1][2]. Therefore, together with the power spectrum, it can be used to analyze turbulences phenomena in plasma.

In the Discrete Fourier Transform calculation the application of a windowing function is needed in order to avoid aliasing phenomena [3]. In this paper, the influence of the windowing function in the bicoherence spectrum is analyzed. Two windowing methods are compared: the multiplication of the initial signal by the Hanning function and the subtraction of the straight line which links the two extremities of the signal.

The influence of these two windowing methods on both the power spectrum and the bicoherence spectrum is showed. Although both methods give precises results, the Hanning function appears to be the most suitable window.

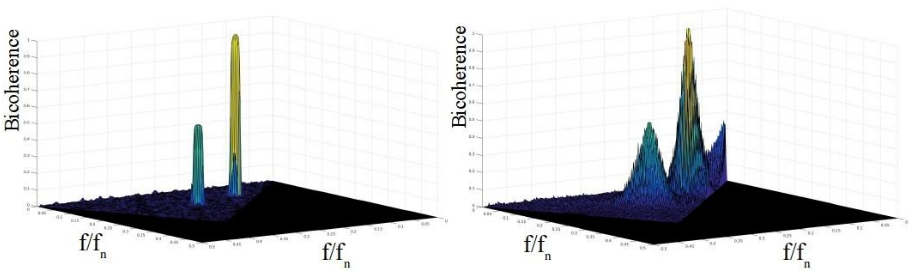

Figure 1. Bicoherence spectrum computed with the Hanning windowing (left) and with the straight line windowing (right). f/f_n represents the frequency normalized by the sampling frequency.

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References:

[1] Y. C. Kim, E. J. Powers, "Digital Bispectral Analysis and Its Application to Nonlinear Wave Interactions", *IEEE Trans. Plasma Sci.*, vol. PS7, p. 120, 1979.
[2] J.W.A. Fackrell, "Bispectral analysis of speech signals", *Edinburgh Research Archive, University of Edinburgh*, 1996.
[3] I. Bilinskis, *Digital Alias-free Signal Processing,* Wiley, 2007.

NON-LINEAR STATIONARY RECOMBINATION WAVES IN NON-SELF-SUSTAINED DISCHARGE DUSTY PLASMA

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The development of perturbation non-linear stage of recombination instability and the stationary states of dusty plasma of non-self-sustained discharge, supported by a beam of ionizing radiation, are studied. The discharge is used for simulation of nuclear-induced plasmas and studying of dust plasma structures, including stratified dust clouds [1,2]. The influence of discharge parameters on the behaviour and spatial distribution of the dusty plasma components is analysed.

It was described in [3,4] that the physical mechanism of recombination instability is as follows. When the generation rates for electrons and ions in the discharge plasma are independent of the time and absorption by dust particles is the main channel of their loses, the perturbation of the density of dust particles leads to an increase and a decrease in the electron and ion densities in the regions with lowered and increased densities of dust particles, respectively. The ion flux from the region with the lowered density of dust particles to the region with the increased density tends to increase perturbation owing to friction on dust particles (the ion drag force). However, the electric field appearing because of the high mobility of electrons (ambipolar electric field) is responsible for the smoothing of the distribution of dust particles. The competition between the ion drag force and electric field action on dust particles primarily determines whether perturbation will increase or decrease. Consequently, it was supposed that the main role in setting of plasma components concentration distributions belongs to ions. This work has shown that situation changes with an increase of instability increment and dust particles become central in the process of stratified dust structures formation. This occurs due to the electric field created by the dust particles, which makes a significant contribution to the effective ambipolar diffusion.

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References:

[1] Fortov V. E., Rykov V. A., et. al. // Phys.- Doklady, 2004, Vol. 49, No 9, pp. 497-500.
[2] Deputatova L. V., Vladimirov V. I., et. al. // Phys. Rep., 2010, Vol. 36, No 13, pp. 1167-1172
[3] Andryushin I. I., Vladimirov V. I., Deputatova L. V., Zherebtsov V. A., Meshakin V. I., Prudnikov P. I., Rykov V. A. // High Temperature, 2013, Vol. 51, No. 6, pp. 733–741
[4] Andryushin I. I., Vladimirov V. I., Deputatova L. V., Zherebtsov V. A., Meshakin V. I., Prudnikov P. I., Rykov V. A. // High Temperature, 2014, Vol. 52, No. 3, pp. 337–343

3D MODEL OF A REVERSE-VORTEX FLOW GLIDINC ARC PLASMATRON

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This study employs a comprehensive computational model for a 3D gliding arc plasma in COMSOL. The plasma arc is stabilized in the reverse-vortex gas flow of a gliding arc plasmatron [1, 2]. The modelling gas is argon, with a reduced reaction set [3]. The gas flow is modeled with a RANS turbulent model. Results for the arc plasma density and gas temperature are presented. The model is based on a gliding arc plasma reactor envisaged for CO_2 conversion.

The reverse-vortex flow is a new method of stabilizing the gliding arc discharge. A vortex flow is produced when the gas enters a cylindrical tube through a tangential inlet. If the outlet is on the opposite side with respect to the inlet, a forward vortex is produced. If it is on the same side, a secondary reverse-vortex will result (fig. 1). The reactor geometry used in our model is illustrated in figure 2.

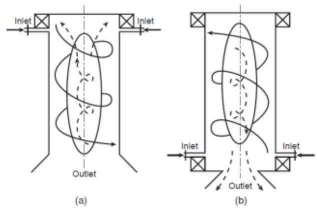

Fig. 1: Schematical comparison between forward (a) and reverse (b) vortex flows. [1]

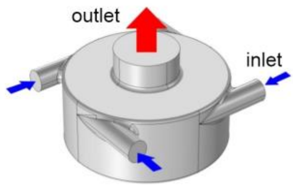

Fig. 2: Geometry used in the model, with a radius of 6.35 mm.

In figures 3 and 4, the resulting arc is represented by semi-transparent isosurfaces. The arc glides in the reactor until it stabilizes in the centre, spinning around its own vertical axis.

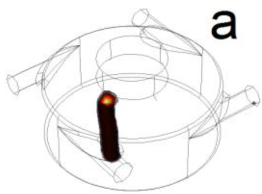

Fig. 3: Plasma arc at initial stage (100 μs).

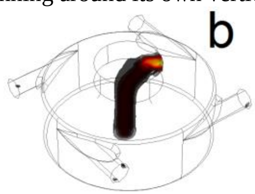

Fig. 4: Plasma arc at a later stage (1.1 ms).

The resulting plasma density is within the typical range for low-temperature gliding arcs at atmospheric pressure [1, 2]. The gas temperature is also typical for a low-temperature plasma source [1].

References:

[1] A. Fridman, *Plasma Chemistry*, p. 187-207, Cambridge University Press, New York, US, 2008
[2] A. El-Zein, G. El-Aragi, M. Talaat, A. El-Amawy, Discharge characteristics of gliding arc plasma reactor with argon/nitrogen, Journal of Advances in Physics, **7**(1), 1316-1323, 2015
[3] St. Kolev, A. Bogaerts, A 2D model for a gliding arc discharge, Plasma Sources Sci. Technol., **24**, 015025, 2015

SATURDAY, JULY 2

DIAGNOSIS OF ATMOSPHERIC PRESSURE PLASMA IN HYDROCARBON MIXTURES WITH RELEVANCE FOR ASTROPHYSICS LABORATORY EXPERIMENTS

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Low temperature atmospheric pressure plasma devices are suitable experimental solutions to generate transitory molecular environments with various applications. In this study we present experimental results regarding the plasma chemistry of dielectric barrier discharges in helium - hydrogen (0.1%) - hydrocarbons (1.2%) mixtures. Four types of hydrocarbon gases were studied: methane (CH_4), ethane (C_2H_6), propane (C_3H8), and butane (C_4H_{10}).

Discharge diagnosis and monitoring was assured by electrical measurements and optical emission spectroscopy. Fourier Transform Infrared (FTIR) spectroscopy was used to study both gas phase and deposits in generated plasmas. The results show a conversion of initial hydrocarbon gases and synthesis of new products, such as CH_4, C2 hydrocarbons and CO. In addition, end products of surface reaction are studied using FTIR and X-ray photoelectron spectroscopy (XPS) of films deposited on various substrates.

Molecular beam mass spectrometry is engaged to sample positive ions populations from plasma source. Dissociation and generation of higher-chain hydrocarbons were discussed as a function of feed gas, showing a strong influence on both molecular mass distribution and recombination processes in the plasma volume. The overall reaction mechanisms, supported by the mass spectrometry results, are proposed as follows:

$$C_nH^+_x + CH \rightarrow C_{n+1}H^+_{x+1} + CH \rightarrow C_{n+2}H^+_{x+2} + CH \rightarrow ... \rightarrow C_{10}H^+_{12}$$

We need to mention that this is not the only reaction that occurs in our plasma sources, the complete reaction scheme being branched into many other possible chemical channels.

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ELECTRON DENSITY AND WAVE POWER AT THE TIP OF AN ATMOSPHERIC SURFACE WAVE DISCHARGE

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Atmospheric surface wave discharges (ASWDs) can find numerous applications being a handy tool, subject of an easy control of the discharge parameters. They can operate in a variety of conditions: excitation frequency from MHz to GHz, gas flow rate from cm^3/min to several L/min, plasma radius from μm to cm, creating plasmas in rare gases, molecular gases and gas mixtures. The plasma is non-thermal – the electron temperature is much higher than the gas temperature. One can produce from room temperature plasma to thousands of Kelvins gas temperature plasma just tuning the externally control parameters.

Several agents play role in the ASWDs treatment: UV radiation, electric field, charged and excited chemically active particles. Hence these plasmas can be used for sterilization, water purification, water activation for medical and agricultural applications, direct treatment of thermally sensitive articles like seeds, food products, living tissues, materials, etc.

For the practical applications it is important to know the electron density n_e and the wave power S at the tip of the plasma torch where the actual treatment happens. In this work we investigate theoretically what are n_e and S at the treating point and how they depend on discharge parameters.

The study is carried by means of 1D model. A steady-state Boltzmann equation in an effective field approximation coupled with a collisional-radiative model for high-pressure argon discharge is numerically solved together with Maxwell's equations for an azimuthally symmetric TM surface wave. By means of the model the axial dependence of the electron density is determined. A weak dependence of n_e at the application point on the discharge parameters and the gas temperature is obtained.

Acknowledgements

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POSTER SESSION

THURSDAY, JUNE 30

ELECTRON ENERGY DISTRIBUTION FUNCTION IN DIVERTOR REGION OF THE COMPASS TOKAMAK DURING NEUTRAL BEAM INJECTION HEATING

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This work presents the results from the swept probe measurements in the divertor region of the COMPASS tokamak [1] in D-shaped, L-mode discharges, with toroidal magnetic field B_T = - 1.15 T, plasma current I_p = 180 kA and varying line-average electron densities from 2 to $8x10^{19}$ m^{-3}. Using the neutral beam injection (NBI) heating, the electron energy distribution function (EEDF) was studied before and during the application of the beam.

The current-voltage characteristics data were processed using the novel first-derivative probe technique (FDPT) [2-4]. This technique allows to evaluate the plasma potential and the EEDF (respectively the electron temperatures and densities).

At low average electron density of $2x10^{19}$ m^{-3} the EEDF is bi-Maxwellian with low-energy electron population with temperatures 4-6 eV and high energy electron group 12-25 eV. With increasing the line-average electron density the electron temperatures decrease. Above $7x10^{19}$ m^{-3} line-average electron density the EEDF is found to be a Maxwellian with temperature 6-8.5 eV.

The dependence of the NBI heating power in divertor region was studied.

Acknowledgments: This research has been partially supported by the Joint Research Project between the Institute of Plasma Physics of the CAS and the Institute of Electronics BAS BG, by the Czech Science Foundation grant GA16-25074S, by MSMT project # LM2011021 and by the Co-fund by MEYS project # 8D15001. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References:

[1] Panek R et al., *Plasma Phys. Control. Fusion* **58** (2015), 014015.
[2] Tsv. K. Popov, P. I. Ivanova, J. Stockel and R. Dejarnac, *Plasma Phys. Control. Fusion* **51** (2009), 065014.
[3] Popov Tsv K et al., *Plasma Phys. Control. Fusion* **57** (2015), 115011.
[4] Popov Tsv K et al., *Plasma Sources Sci. Technol.* **25** (2016), 033001.

EFFECT OF THE RESONANT MAGNETIC PERTURBATION ON THE PLASMA PARAMETERS IN DIVERTOR REGION OF THE COMPASS TOKAMAK

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This work discusses the application of Resonant Magnetic Perturbations (RMPs) in the COMPASS tokamak [1] in Ohmic D-shaped discharges, with toroidal magnetic field B_T = 1.15 T, plasma current I_p = 170 kA and line-average electron density $n_e = 5\times10^{19}$ m^{-3}. In order to study the effect of RMPs on the plasma parameters in the divertor region with high spatial resolution, the strike-points were swept radially across 39 Langmuir divertor probes during a shot. The current-voltage characteristics data were processed using the novel first-derivative probe technique [2,3]. This technique allows one to evaluate the plasma potential and the real electron energy distribution function (EEDF), respectively the electron temperatures and densities. It has been found that in the vicinity of the inner and outer strike points of the divertor, that EEDF is bi-Maxwellian, with a low-energy electron population (4 - 6 eV) and a higher energy one (10 - 30 eV).

When applying RMPs with alternate directions of the current in the external coils, we observed splitting of strike points characterized by change of spatial profiles of the floating potential and the ion saturation current at the outer strike point. In addition, we will present also the poloidal profiles of the parallel power flux density in COMPASS. Using these data, we determine the decay lengths of the parallel power flux density the inner and outer divertor region.

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References:

[1] P. Cahyna, R. Panek, V. Fuchs, L. Krlin, M. Becoulet, G. Huysmans and E. Nardon, *Nucl. Fusion* **49** (2009), 055024.
[2] Tsv. K. Popov, P. I. Ivanova, J. Stockel and R. Dejarnac, *Plasma Phys. Control. Fusion* **51** (2009), 065014.
[3] M. Dimitrova, R. Dejarnac, Tsv. K. Popov, P. Ivanova, E. Vasileva, J. Kovačič, J. Stöckel, J. Havlicek, F. Janky and R. Panek, *Contrib. Plasma Phys*. **54** No. 3 (2014), 255.

APPLICATION OF MIDDLE ENERGY ION SCATTERING TO ANALYSIS OF PLASMA-FACING MATERIALS

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Interaction between plasma and the first wall leads to erosion of plasma-facing materials in fusion devices that can result in deposition of thin layers of sputtered materials. Therefore, determination of presence and thickness of deposited layers is an actual problem. Various means of surface analysis are used for this purpose [1], but SIMS destroys a surface while analyzing, while non-destructive method of surface analysis with RBS has not very high depth resolution for very thin layers and requires using of expensive accelerators. At the same time, it was shown earlier [2] that the thickness of thin layers of light elements on the surfaces of heavy substrates can be analyzed with very high depth resolution (~0.3nm) with scattering of hydrogen ions of keV energies. In this work we describe the application of medium energy ion scattering spectroscopy for analysis of thin layers on plasma-facing materials and experimental setup for executing of this technique.

The photo of experimental setup is shown in fig. 1. A duoplasmatron is used as an ion source. Separating electromagnet allows to separate the ions with mass–charge ratios of up to *M/Z* = 100 at a maximum accelerating voltage of up to 40 kV [3]. Scattered and recoil ions are detected using quarter-spheric deflector as energy analyzer at scattering angle θ=38°, ion current is recorded with secondary electron multiplier.

Fig. 1. Experimental setup: (1) ion source, (2) separating electromagnet, (3) vacuum chamber, (4) electrostatic energy analyzer, (5) secondary electron multiplier

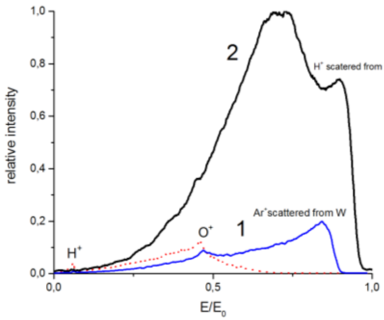

Fig. 2. (1) energy spectra of recoils and Ar^+ scattered from W target before and after irradiation by 17,3 keV Ar^+ beam, (2) spectrum of H^+ scattered from Mo/B_4C target

Energy spectra measured at Ar^+ irradiation of tungsten target are shown in fig. 2, 1. Just after exposure on atmosphere the target was covered by several layers of oxides and adsorbed molecules. After target surface sputtering with Ar ions recoil peaks were reduced and high energy peak of Ar^+ scattered from tungsten appears demonstrating surface composition change. Scattering of H^+ from thin (5 nm) Mo layer deposited on B_4C layer on target is shown in fig. 2, 2. The position of first maximum of spectrum allows determining the thickness of deposited Mo layer before and after sputtering under plasma impact.

References:

[1] C. P. Woodruffe and T. A. Delchar, Modern Techniques of Surface Science, Cambridge University Press, Cambridge, (1986); 564 pp.

[2] Kurnaev V.A., Trifonov N.N., Drozdov M.N., Salashenko N.N. (1999) *Vacuum* 56 (2000), 253

[3] Mamedov N. V., Kurnaev V.A., Ivanov D. (2012). *Bulletin of the Russian Academy of Sciences: Physics,* 76(6), 683–686.

MANUFACTURING PROCESS IMPACT ON THE DIELECTRIC PROPERTIES OF ALUMINA CERAMICS FOR FUSION APPLICATIONS

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Materials for radio frequency (RF) windows and different antenna supports and insulators for the heating systems and for diagnostics are still an unresolved issue in future fusion machines such as DEMO. Alumina ceramic (Al_2O_3) is one of the main candidate materials for these systems. The dielectric properties, such as electrical permittivity (ε) and loss tangent (tan δ), determine its power losses. Therefore, tan δ values need to be low, between 10^{-6} and 10^{-3} depending on the application. However, due to the crucial role of the manufacturing process in determining its final dielectric properties, there is the need to undertake a joint effort with the industry in order to validate a standard manufacturing route that ensures a supply of ceramic material with homogeneous and standardized dielectric properties for the fusion machines.

In this work, the studied alumina samples were provided by Nanoker, a high-performance ceramics manufacturer. Different manufacturing routes were used for each batch of samples to systematically test the effect on the loss tangent. The dielectric properties were measured using two different resonant methods, depending on the frequency range. These combined methods have the advantage of covering the very broad range of frequencies required for alumina applications in fusion (from kHz to GHz) and giving the best accuracy for very low losses.

Results revealed that the samples have the desired dielectric properties but depending on the manufacturing route, they have better performance at different frequency ranges. Besides, the different routes presented quite different deviations in the measured dielectric loss between samples from the same batch. Uniformity in the loss tangent values is also an important parameter when choosing the best manufacturing process in order to obtain a reference material. Therefore, assuring the reproducibility of the samples has become the next goal.

Acknowledgments: "This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission."

References:

[1] R. Vila, M. González, J. Mollá, A. Ibarra, *J. Nucl. Mater.* **253** (1998), 141-148.
[2] J. Mollá, R. Heidinger, A. Ibarra, *J. Nucl. Mater.* **212** (1994), 1029-1034.
[3] A. Kakimoto, A. Etoh, K. Hirano, S. Nonaka, *Rev. Sci. Instr.* **58** (1987), 269.
[4] G.P. Pells, R. Heidinger, A. Ibarra, H. Ohno, R.H. Goulding, *J. Nucl. Mater.* **535** (1992), 191-194.
[5] R. Vila, E.R. Hodgson, *J. Nucl. Mater.* **283-287** (2000), 903-906.

EFFECT OF DIELECTRIC TUBE PARAMETERS ON PLASMA SUSTAINED BY DIPOLAR ELECTROMAGNETIC WAVE IN CYLINDRICAL CONFIGURATION

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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 (SWD). One of the main characteristics of surface-wave-sustained cylindrical plasma column is the single mode regime of operation. Usually only the azimuthally symmetric wave mode propagates in this configuration. In some particular cases dipolar wave mode can produce plasma.

Sustaining the cylindrical discharge by dipolar wave mode in plasma–vacuum and plasma–dielectric configurations is theoretically studied by the authors. It confirms the assumptions based on the experiments that not only the azimuthally symmetric but also higher modes can sustain the discharge. In the real experiment a dielectric tube exists and it can play significant role.

The purpose of this work is to investigate theoretically the effect of the dielectric tube in producing and sustaining plasma by dipolar wave mode and wave propagation characteristics. The basic relation in our model is the local dispersion relation obtained from Maxwell's equations. It gives us the so called phase diagrams – the dependence between the normalized plasma density and the dimensionless wave number at different wave modes with and without dielectric tube. From the phase diagrams and axial profiles of plasma and wave parameters we can obtain information about the ability of the wave to sustain the plasma and plasma density, as well as about the role of the dielectric tube.

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THEORETICAL STUDY OF THE ROLE OF DIELECTRIC WAVEGIUDE IN PLASMA SUSTAINING BY TRAVELING ELECTROMAGNETIC 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, around dielectric cylinder, and others. The experimental investigations show that in some conditions the plasma can be produced outside the dielectric cylinder and that azimuthally symmetric, dipolar and higher wave modes can propagate and sustain plasma in the same time.

In order to find out these conditions theoretically we have built one-dimensional model for describing the electromagnetic wave propagation along cylindrical waveguides including various media: vacuum, dielectrics with different permittivity, and plasma. The vacuum–plasma and dielectric–plasma configurations studied before [1] are included and extendedly studied for comparison with the new results. 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 wave energy flux, as well as 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 waveguide configuration.

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 by azimuthally symmetric, dipolar or quadrupolar wave.

Acknowledgments: This work was supported by the Fund for Scientific Research at the University of Sofia under Grant 109/2016.

References:

[1] Ivanov K., Bogdanov T., Benova E., J. Phys.: Conf. Series **356** 2012, 012045.

PARAMETRIC COMPUTATIONAL STUDY OF SHEATHS IN MULTICOMPONENT Ar/O_2 PLASMA

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Multicomponent plasmas [1] – [3] containing more species of both negative and positive ions are widely used in many industrial applications that are based on plasma-assisted technologies. Usually, multicomponent plasmas are chemically active ensembles of mutually interacting particles that are out of the thermodynamic equilibrium. Hence, it is very demanding to investigate them theoretically and therefore benefits of computer models [4] are often exploited in multicomponent plasma research.

Our contribution presents results obtained by our own 2D Particle-In-Cell plasma model. Particle models are a simulation technique that is well suited for multicomponent plasma since they are able to capture all kinetic effects caused by elastic and also inelastic scattering processes between particle species. Scattering processes in our model were treated by modified null collision method [5]. On the other hand particle models are very demanding on computer resources and their usage is often limited by small computational domain that can be examined or simplified geometries. Our 2D model has already been used to investigate sheaths in simplified electronegative argon plasma that contained Ar^+ ions, electrons and heavy negative O^- ions [6]. It was proven that presence of O^- ions in plasma significantly affects sheath structure especially in cases of high electronegativity as their properties (mass, thermal energy, cross section of elastic scatter) are different of those of electrons and consequently they tend to stay in the bulk of plasma.

Our present contribution extends our previous work [6] and investigates sheath structures in multicomponent Ar/O_2 plasma formed in the surroundings of immersed solid substrates. The results of chemical kinetics model presented in [7] were used to model Ar/O_2 plasma mixture. The kinetic model takes into account more than 100 reactions between charged, neutral and excited species. The reactions are described by rate constants and continuity equations are solved for all considered particle species to evaluate their number densities. Consequently, these results were taken as an input for the particle model of Ar/O_2 plasma and sheath structures near immersed solids were solved for different plasma and substrate parameters (such as pressure, plasma composition, substrate form and its bias). Quantities such as potential distribution, number density of charged particles and their fluxes on the probes were observed in order to identify influence of particular species on sheath formation.

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References:

[1] R. N. Franklin, *J. Phys. D: Appl. Phys.* **34** (2001) 1959.
[2] R. N. Franklin, *J. Phys. D: Appl. Phys.* **35** (2002) 536.
[3] R. N. Franklin, *J. Phys. D: Appl. Phys.* **36** (2003) 34.
[4] C. K. Birdsall, A. B. Langdon, Plasma physics via computer modelling, IOP Publishing, (1991).
[5] S. Roucka, R. Hrach, *IEEE Trans. Plasma Sci.* **39** (2011) 3244.
[6] J. Hromadka, T. Ibehej, R. Hrach, *Phys. Scr.* **90** (2015) 105603.
[7] P. Cerny, S. Novak, R. Hrach, V. Hrachova, *Eur. Phys. J. Appl. Phys.* **56** (2011) 24006.

EFFECTS OF RESONANT HELICAL FIELD ON TOROIDAL FIELD RIPPLE IN IR-T1 TOKAMAK

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The Toroidal magnetic field which is created by Toroidal coils has the ripple in torus space. This magnetic field ripple has an importance in plasma equilibrium and stability studies in Tokamak. In this paper, we present the investigation of the interaction between the toroidal magnetic field ripple and resonant helical field (RHF). We have estimated the amplitude of toroidal field ripples without and with RHF (with different q=m/n) (m=1, n=2, n=3, n=4, n=5, n=2 & 3) using "Comsol Multiphysics" software. The simulations show that RHF has effects on toroidal ripples.

Refrences

[1] Tokamaks, John Wesson, Oxford University Press, Third edition(2004).
[2] Tokamak Coils Materials and Toroidal Field Ripples Calculation Using the Comsol Multiphysics, B. Mahdavipour et al., J. of Inorganic and Organometallic Polymers and Materials(2015), DOI: 0.1007/s10904-015-0325-z.
[3] RHF Effect on Shafranov Parameter and Shafranov Shift in IR-T1 Tokamak, A. Salar Elahi, M. Ghoranneviss, J Fusion Energ (2009) 28:412–415,DOI 10.1007/s10894-009-9214-1.

TWO-COLOR LASER-PLASMA GENERATION OF ULTRASHORT FREQUENCY-TUNABLE MID-INFRARED PULSES

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A new method for generation of coherent ultrashort (few-cycle) mid-infrared pulses is studied analytically and numerically. The method utilizes gas ionization by incommensurate two-color femtosecond laser pulses. These incommensurate two-color pulses contain the fields at two different frequencies. One of the frequencies is detuned from the doubled value of the other one. Such incommensurate pulses can be obtained with the use of the nonlinear crystal (for example, BBO or KDP) or with the use of the optical parametric amplifier. In the latter case, the main (in the respect of intensity) field component has greater central frequency than the weaker field; and the frequency of the weaker field can be reasonably easily tuned around the halved value of central frequency of the main field which stays fixed [1].

We calculate the electron current which is excited by such a two-color pulse in a gas during ionization through the use of the semiclassical approach both analytically and numerically and find out that the low-frequency component of that current can have central frequency in the mid-infrared range, which can be controlled by tuning the frequency of the weaker optical field. The full-dimensional simulations based on the quantum-mechanical approach (the solution of the 3D time-dependent Schrödinger equation) support the results obtained from the semiclassical approach. We estimate energy radiated by that current and discuss the possibilities of employing the phenomenon for creating the tunable source of coherent few-cycle mid-infrared pulses.

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References:

[1] N.V. Vvedenskii, A.I. Korytin, V.A. Kostin, A.A. Murzanev, A.A. Silaev, and A.N. Stepanov, *Phys. Rev. Lett.* **112** (2014), 055004.

PLASMA SURFACE MODIFICATION OF POLYPROPYLENE TRACK MEMBRANE TO IMPROVE ITS PERFORMANCE PROPERTIES

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In the present paper the surface and electrochemical properties of polypropylene track membrane with pore diameter of 250 nm (pore density of 10^8 cm^{-2}) produced to the technique described in [1] and modified by RF-discharge in an atmosphere of non-polymerizing gases (nitrogen, air and oxygen) have been studied. The both sides of the membrane were treated by plasma. The effect of the nature of plasma-forming gases on morphology and chemical composition of membrane surface layer was investigated. Membrane characterization was carried out by atomic force microscopy (AFM) and water contact angle measurements. The chemical structure of membrane surface was investigated by X-ray photoelectron spectroscopy (XPS).

It is established that important changes in the structure and chemical composition of membrane surface layer are encountered under plasma treatment. So, when the membrane is submitted to the plasma of non-polymerizing gases one can observe an etching of the membrane surface layer accompanied by reduce of its thickness and increase of the effective pore diameter. A consequence of the plasma influence is the transformation of the surface relief – the roughness of the membranes surface increases due to discharge etching in air and oxygen especially. Besides, the plasma causes oxidation of the membrane surface layer and of the pore surface, thus leading to the formation of oxygen-containing functional groups, mainly carbonyl and carboxyl. The content of functional groups depends on the type of plasma gases, the most effective treatment being in oxygen. Such effects are related to the processes of destruction of macromolecules on the polymer surface and subsequent oxidation of the produced free radicals. It is shown that due to the formation of polar groups on the surface the wettability of the modified membranes improves. It promotes penetration of water molecules into pores increasing the water permeability. Besides, as our experimental data show the measured electrical current through the modified membranes depends on the pore diameter and the chemical structure of the pore surface – type and concentration of the fixed functional groups. The increase of concentration of the oxygen-containing groups on the surface and the pore diameter of the membranes after plasma treatment leads to the growth of their electrical conductivity. There is a good fit of the observed data if only the concentration of polar groups (a sum of carbonyl and carboxyl groups) is taken into account. The impedance spectroscopy also reveals the essential influence of the surface functional groups on the ion transfer processes in the membranes, since the increase of polar groups concentration on the surface of the modified membranes leads to improved conductivity.

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References:

[1] L.I. Kravets, S.N. Dmitriev, P.Yu. Apel, *Collect. Czech. Commun.* **62** (1997) 752.

INFLUENCE OF AN ANODIC ALUMINUM OXIDE, GROWN ON THE CATHODE, ON THE IGNITION VOLTAGE OF DC GAS DISCHARGE AND EFFECTS CAUSED BY THE PLASMA IN THE BRAKE POINTS

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In this work, results from experimental study of the influence of an oxide coating on the cathode, over the ignition voltage of DC gas discharge are presented. Aluminum cathodes with different surface roughness are used. Solid and nanoporous anodic aluminum oxide (AAO) has been grown on the cathodes. Increasing the potential between the electrodes, results in electrical breakdown in the AAO and ignition of the gas discharge. The break points in the AAO on the surface of the cathodes and the resulting damage caused by the plasma in the oxide layer are presented. Comparison of the gas discharge ignition voltages for different thicknesses and structures of the oxide layer is made. For this investigation, electronic microscopy, EDX analysis, cross sections, optical microscopy and electrical microprobe have been used.

GROWTH OF NANOSCALE OXIDE FILMS ON ALUMINUM IN DC GAS DISCHARGE REACTOR

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During the last decades the DC gas discharges have been used extensively in the fields of industry and research. One of the applications of these discharges is surface modification of materials. In the field of microelectronics, growth of nanoscale, homogeneous, oxide films with predefined thickness is important.

In this work, prototype of cylindrical plasma chemistry reactor with sectional cathode and common anode has been used. Nanoscale oxide film has been grown on an aluminum substrate, in an Ar/O2 mixture gas discharge. With the equipment developed for this experiment we can control oxide-growth rate over time at the same discharge current and gas pressure. The gas discharge parameters are monitored using a Langmuir probe. The oxide layer produced in this process can find various applications in micro and nanoelectronics.

STATIONARY DIAGNOSTICS OF MAGNETIZED PLASMAS

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Stationary plasma diagnostics of the local parameters and ion mass-spectrum are necessary to control discharge regimes and plasma composition during the experiments. Corpuscular diagnostics of plasma ion flux can provide information about plasma-chemical kinetic of the discharge. Usually optical spectroscopy is used for the determination of the plasma composition [1, 2], but often it cannot deliver the reliable information. The residual gas analysis, for example by quadrupole mass-spectrometer, can provide information of the neutral species in vacuum chamber, but not of the ion composition of plasma.

In-situ mass-spectrometry systems based on the mass separation and detection of plasma ions are usually complicate, for example the omegatron mass-spectrometer [3, 4] requires an additional RF source of the electrical field and ultra-high-vacuum differential pumping, the plasma ions mass-spectrometer (PIMS) [5] is based on the cycloidal focusing in the perpendicular electrical and strong magnetic field, which is not always used on linear plasma devices. A simpler ion separation method of magnetized plasmas is using own-magnetic field of the plasma device as a separating factor. The idea of stationary mass-spectrometer using own-magnetic field is widely used [6-8], but usually it is not possible to measure both positive and negative ions in one experiment. Combined diagnostics module (CDM) for in-situ analysis both the local parameters and ion mass spectrum of magnetized plasmas developed for the linear plasma device PR-2 is presented.

Scheme of CDM is shown on Fig. 1. CMD consists of the static mass-spectrometer (MS) and the probe system containing twelve single Langmuir probes. MS is based on classical scheme of static magnetic ion separator with 180° magnetic deflection of the accelerated ions. Symmetrical MS body allows to measure relative fluxes both positive and negative ions from plasma column. Ions reaching the entrance slit are accelerated by the electrical field applied in the accelerating gap of 1 mm width. Then they are deflected by the magnetic field of plasma device and as a result separated by the mass-to-charge ratio. Mass-spectrum of plasma ions is obtained by changing the accelerating voltage, and registered by fore ion collectors placed at different radii of ion trajectories. The collector at the lower radius is used for a rough mass-analysis of typical light working gases. The second collector has a better mass resolution and is used for more accurate measurements in a heavier mass range.

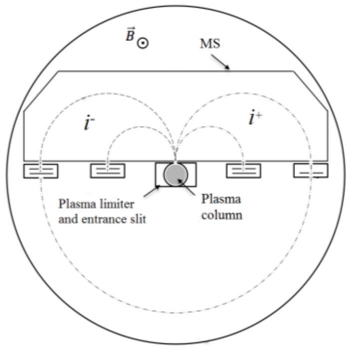

Figure 1. Scheme of the combined diagnostics module on PR-2.

References:

[1] D. Nishijima et al., Phys. Plasmas, 14, 103509 (2007)
[2] A. Kreter et al., J. Nucl. Mater., 417, 651 (2011)
[3] E.M. Hollman et al., Rev. of Sci. Instr., 72/1, 623 – 626 (2001)
[4] M. Ono, A. Tonegawa, et al., J. Plasma Fusion Res, SERIES, 7, 50-53 (2006)
[5] G.F. Matthews, Plasma Phys. Control. Fusion, 31, 841 – 863 (1989)
[6] H. Kojima et al., JNM, 128&129, 965-968 (1984)
[7] I.V. Vizgalov et al., Instrum. Exp. Techniques, 42, 718-721 (1999)
[8] O. Waldmann et al., 34th EPS Conf. On Plasma Phys. Warsaw, 31F, 5.108 (2007)

PROBE MEASUREMENTS OF ELECTRON ENERGY SPECTRUM AND PLASMA-WALL INTERACTION IN HELIUM/AIR MICRO-PLASMA AT ATMOSPHERIC PRESSURE

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It is experimentally demonstrated that a wall probe [1] may be a useful instrument for interpretation of electron energy spectrum, and the plasma-boundary interaction in a micro-plasma with a nonlocal electron distribution function at atmospheric pressure. Two micro-plasma devices were fabricated with three layers of molybdenum metal foils with thickness of 100 µm separated by two sheets of mica insulation with thickness of 110 µm. In one device a hole with the diameter of 200 µm formed a cylindrical discharge cavity that passed through the entire five layers. In the second device the hole has the diameter of 65 µm. in both devices the inner molybdenum layer formed a wall probe, while the outer layers of molybdenum served as the hollow cathode and anode. The discharge was open into air with flow of helium gas. Typical results of measurements of wall probe current and its first derivative with respect to probe potential are shown in Figs 1 and 2 (I_d is the discharge current). It is shown that due to energetic electrons the wall potential can be much higher than that associated with the ambient electron kinetic energy. It is also found that the wall probe I-V trace is sensitive to the presence of helium metastable atoms. The first derivative of the probe current with respect to the probe potential shows peaks revealing fast electrons at specific energies arising due to plasma chemical reactions (see, Fig. 2). The maximums at 15 and 20 eV correspond to binary collision between helium metastable atoms and helium metastable atoms with thermal electrons. Maximum about 3-5 eV corresponds to Penning ionization of Nitrogen molecules by metastable helium atoms. Groups of electrons near energies of 10 eV correspond of Penning ionization of Oxygen by metastable helium atoms. The devices may be applicable for developing analytical sensors for extreme environments, including high radiation and vibration levels and high temperatures.

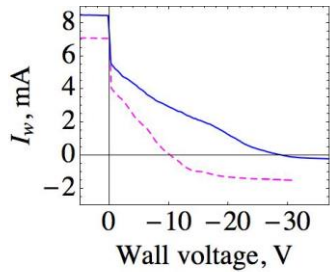

Fig. 1. Wall current I_w with respect to wall potential in a helium dc discharge surrounded by air. Dashed curve (65-µm device, I_d = 6.5 mA) and solid curve (200-µm device, I_d = 8.2 mA).

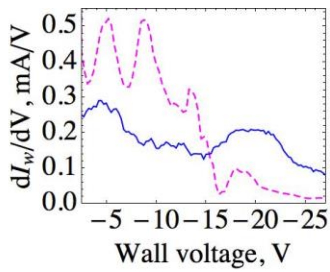

Fig. 2. First derivative, dI_w/dV, with respect to wall potential for Fig. 1.

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References:

[1] V. I. Demidov, A. A. Kudryavtsev, *Phys. Plasmas* **21**, (2014).

LASER-INDUCED BREAKDOWN IGNITION OF NATURAL GAS IN A 2-STROKE ENGINE

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Laser-induced ignition for internal combustion engines is investigated intensively after demonstration of a compact ‘laser plug’ possibility [1]. Laser spark benefits as compared to traditional spark plugs are: higher compression rate, and possibility of almost any fuel ignition, so lean mixtures burning with lower temperatures could reduce harmful exhausts (NO_x, CH, etc.). No need in electrode and possibility for multi-point, linear or circular ignition can make combustion even more effective. Laser induced combustion wave appears faster and is more stable in time, than electric one, so can be used also for ramjets, chemical thrusters, and gas turbines. Laser ignition takes place due to gas breakdown followed by plasma and shock wave formation, those lead to deflagration core onset (detonation and autocatalytic reaction are also possible). Laser breakdown threshold (unlike electric) in gases decreases with pressure increase up to 10s of MPa, so smaller ignition energy is needed at high compression.

The experimental setup consists of GT33 2-stroke engine with a custom-built head that allows attachment of pressure and temperature sensors, optical fiber for flame emission temporal and spectral analysis, laser spark plug or sapphire window for ignition radiation supply, and water cooling. To load engine, automotive generator coupled to an electronic load has been used. Exhaust was supplied to an industrial 5-gases analyzer. Fuels tested were methane and propane-butane mix. Drop castor oiler was connected after carburetor for piston lubrication. DPSS laser pulses (1064 nm, 12 ns, 10 mJ) were synchronized to top dead center for up to 100 Hz; the ignition timing was rather different to the electric one. To the best of our knowledge, we performed the first demonstration of a 2-stroke gas-fueled engine laser spark ignition.

Ignition possibility has been checked in a broad range of air/fuel ratios. Combustion brightness temperature measured was 2600 K, and peak pressure reached 45 bar (at 16 bar compression). Indicated horsepower was ca. 15 % than specified for gasoline, that is slightly higher than known for gas fed 4-stroke engines. NO_x concentration in exhaust 16 ppm was measured, that is significantly lower than automotive engines have. Soot deposits on laser spark plug protective sapphire window were ablated at beam path.

Laser ignition system allows use multiple fuels in lean mixtures at higher compression ratios, so it can be used for high performance engines (e.g. for UAV) and for harmful emissions reduce from industrial power plants.

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References:

[1] N. Pavel, M. Tsunekane, T. Taira, *Opt. Express* **19** (2011) 9378.

EXPERIMENTAL INVESTIGATION OF SURFACE-WAVE-SUSTAINED PLASMA WITH LIQUIDS

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Plasma sustained by electromagnetic wave traveling along a dielectric-plasma interface can operate in broad range of discharge conditions: gas pressure from a few mTorr to several atmospheres; wave frequency from 10 MHz to above 10 GHz; plasma radius from 0.5 mm up to 12.4 cm produced till now; plasma length depends on the wave power and can reach several meters but also microplasma of a few millimeters length is in use. Surface-wave-sustained discharges (SWD) can operate in rare gases, molecular gases and gas mixtures. In most of the cases the plasma is non-thermal one – the electron temperature is much higher than the gas temperature even at atmospheric pressure.

The surface-wave-sustained plasma torch operating at room temperature can be used for water treatment and activation as well as for direct treatment of cells, bacteria, seeds, living tissues, temperature sensitive materials, etc. Therefore investigation of the effects of plasma-liquid interaction as absolutely necessary for understanding the phenomena. Furthermore plasma parameters can be easily optimized by changing the radii, the thickness and the dielectric permittivity of the discharge tube. Also, by means of varying the electromagnetic wave power and the gas flow. Thus optimal plasma parameter for given application can be obtained. One of the main difficulties in diagnostic of small-size plasma is measurements of the axial distribution of plasma parameters and reliable method for such measurement appears to be optical emission spectroscopy. By means of optical emission spectroscopy in UV, visible and NIR spectrum of a plasma torch axial profiles of the electron, gas temperatures and relative concentrations of Ar^+ and Ar_2^+ ions can be estimated even for plasma torch with length of a few mm.

Experiments of surface-wave-sustained plasma at atmospheric pressure (plasma torch) acting on water were performed and also measurements of the plasma parameters were carried out under various discharge conditions, including different tube diameters, input power and gas flow. The discharge radii considered in the study are: 0.05 cm, 0.1 cm and 0.15 cm.

In presence of water the geometrical dimensions of the plasma as well as the plasma column structure have been studied and compared to these without the water at the same discharge conditions (wave power, gas flow and plasma radius).

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