9th International Workshop and Summer School on Plasma Physics

at Black Sea

30 November- 3 December 2020

Online

Programme and Abstracts

Ninth International Workshop

& Summer School

on Plasma Physics

organized by:

St. Kliment Ohridski University of Sofia

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BOOK OF ABSTRACTS

9th International Workshop
&
Summer School on Plasma Physics

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TIMETABLE IWSSPP 2020

	Nov. 30	Dec. 1	Dec. 2	Dec. 3	
	Monday	**Tuesday**	**Wednesday**	**Thursday**	
09:30				9:30-10:45	J. Stockel
10:00-**10:20**		I. Ganachev	Blagoev		
10:20-10:40					
10:40-11:00		T. Bogdanov	E. Iordanova	10:45-11:00	break
11:00-11:20		break	break	11:00-11:45	Golem Lecturer
11:20-11:40		T. Bogdanov	G. Yankov		
11:40-12:00		V. Slavov	break	11:45-12:00	break
12:00-12:20		P. Marinova	Krcma	12:00-15:30	GOLEM tokamak remote control
12:20-12:40					
12:40-14:00		lunch	lunch		
14:00-14:20	Opening	M. Dimitrova	D. Truchla		
14:20-14:40	I. Motrescu	M. Dimitrova	K. Trebulova		
14:40-15:00		break	break		
15:00-15:20	E. Calvo	M. Dimitrova	S. Chudjak		
15:20-15:40			J. Cerovsky		Closing
15:40-16:00					

Topic 1 Fusion Plasma and Materials

Topic 2 Plasma Modelling and Fundamentals

Topic 3 Plasma Sources, Diagnostics and Technology

Workshop Remote GOLEM operation

MONDAY, NOVEMBER 30

Chairperson: **Dr. Evgenia Benova**

14:00	**Opening ceremony**	
14:20	UTILIZATION OF A FLEXIBLE ELECTRODE DIELECTRIC BARRIER DISCHARGE FOR AGRICULTURE APPLICATIONS **I. Motrescu,** *Science Department, University of Agriculture and Veterinary Medicine, Iasi, Romania and Research Institute for Agriculture and Environment, Iasi, Romania*	T3
15:00	OPTIMIZING THE PARAMETERS OF AN EHD THRUSTER PLASMA MODEL **E. Calvo**, *Centro de Estudos de Fenómenos de Transporte e Departamento de Engenharia Física, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal and Departamento de Física e Astronomia, Faculdade de Ciências da Universidade do Porto, Porto, Portugal*	T2

TUESDAY, DECEMBER 1

Chairperson: **Dr. Miglena Dimitrova**

10:00	SELF-CONSISTENT MODELING OF CUTOFF-DENSITY RESONANCE IN SURFACE-WAVE PLASMAS **I. Ganachev,** *Shibaura Mechatronics Corporation, Yokohama, Japan and Chubu University, Kasugai, Japan*	T2
10:40	PLASMA JET AS A SOURCE FOR WOUND HEALING **T. Bogdanov,** *Medical University - Sofia, Sofia,Bulgaria*	T3
11:20	TEMPERATURE CONTROL AND MONITORING OF MICROWAVE TORCH FOR BIOMEDICAL APPLICATIONS **T. Bogdanov,** *Medical University - Sofia, Sofia,Bulgaria*	T3
11:40	SURFACE WAVE SUSTAIN DISCHARGE MODELING AT VARIOUS DISCHARGE GEOMETRIES AND WAVE MODES **V. Slavov,** *Faculty of Physics, Sofia University, Sofia, Bulgaria*	T2
12:00	ELEMENTARY PROCESSES IN ARGON SURFACE-WAVE-SUSTAINED PLASMA TORCH AT ATMOSPHERIC PRESSURE **P. Marinova**, *Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria and DLTIS, Sofia University, Sofia, Bulgaria*	T2

Chairperson: **Prof. Ivan Ganachev**

14:00	PROBE MEASUREMENTS DURING EXPERIMENTS WITH LIQUID METAL DIVERTOR TARGETS IN COMPASS **M. Dimitrova,** *Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic and Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T1
14:20	EFFECT OF IMPURITY SEEDING ON THE PLASMA PARAMETERS IN THE COMPASS DIVERTOR REGION **M. Dimitrova,** *Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic and Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T1
15:00	ON DETECTING HOT ELECTRON POPULATION IN THE COMPASS TOKAMAK DIVERTOR **M. Dimitrova,** *Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic and Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T1

WEDNESDAY, DECEMBER 2

Chairperson: **Dr. Evgenia Benova**

10:00	FIRST DEDICATED EXPERIMENTS ON THE AZIMUTHAL FIELD AS A NEW RESEARCH TOOL FOR THE DENSE PLASMA FOCUS **A. Blagoev,** *Faculty of Physics, University of Sofia, Sofia, Bulgaria*	T1
10:40	FABRICATION OF 3D NANOPARTICLE STRUCTURES BY FEMTOSECOND LASER RADIATION **E. Iordanova,** *Institute of Solid State Physics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T3
11:20	INVESTIGATION OF NON-LINEAR EFFECTS IN 3D NANOPARTICLE STRUCTURES IRADIATED BY FEMTOSECOND LASER **G. Yankov,** *Institute of Solid State Physics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T3
12:00	PREPARATION AND SURFACE TREATMENT OF NANOMATERIALS IN PLASMA-LIQUID SYSTEMS **F. Krcma,** *Brno University of Technology, Faculty of Chemistry, Brno, Czech Republic*	T3

Chairperson: **Dr. Miglena Dimitrova**

14:00	CHARACTERIZATION AND APPLICATION OF MICROWAVE PLASMA FOR WOUND HEALING **D. Truchla,** *Brno University of Technology, Faculty of Chemistry, Brno, Czech Republic*	T3
14:20	IMPACT OF MICROWAVE PLASMA TORCH ON THE YEAST CANDIDA GLABRATA **K. Trebulova,** *Brno University of Technology, Faculty of Chemistry, Brno, Czech Republic*	T3
15:00	STUDY OF ELECTRICAL DISCHARGE INITIATED CHEMICAL PROCESSES IN TITAN RELATED ATMOSPHERE AT LABORATORY AND RELEVANT TEMPERATURE AND PRESSURE **S. Chudjak,** *Brno University of Technology, Faculty of Chemistry, Brno, Czech Republic*	T3
15:20	INVESTIGATION OF RUNAWAY ELECTRONS WITH SOLID STATE PELLET INJECTOR: DESIGN AND FIRST EXPERIMENTS **J. Cerovsky,** *Institute of Plasma Physics of the CAS, Prague, Czech Republic*	T1

THURSDAY, DECEMBER 3

Chairperson: **Dr. Miglena Dimitrova**

09:30	INTRODUCTION TO THE GOLEM WORKSHOP: BASICS OF TOKAMAK OPERATION **J. Stockel,** *Institute of Plasma Physics of the CAS, Prague, Czech Republic*	W
11:00	ACCESS TO THE GOLEM EXPERIMENT **Golem Lecturer,** *FNSPE CTU, Prague, Czech Republic*	W
12:00	**WORKSHOP:** GOLEM tokamak remote control	W
15:20	**Closing ceremony**	

UTILIZATION OF A FLEXIBLE ELECTRODE DIELECTRIC BARRIER DISCHARGE FOR AGRICULTURE APPLICATIONS

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[2]*Research Institute for Agriculture and Environment, Iasi, Romania*
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[4]*Research Center on Advanced Materials and Technologies, Science Department, Institute of Interdisciplinary Research, Alexandru Ioan Cuza University of Iasi, Romania*

Atmospheric pressure plasmas are fit for agricultural applications being powerful chemical reactors that operate at room temperature. We have been using a surface dielectric barrier discharge produced with a flexible electrode, similar to one that has been proven useful for microorganism inactivation [1].

Our previous work focused on studying the effects of plasma in different conditions on the changes produced on different sprouting species (e.g. Japanese radish, broccoli, garden cress), in an attempt not only to reveal the optimum conditions for growth stimulation but to elucidate the insights of the plasma modification process. The trend is mostly to report positive effects, omitting the inhibitory possible outcome, which makes it difficult to get close to finding out how and what stimulates the germination and development and why [2].

The discharges are produced using a high voltage source of 10kHz and applying voltages in the range 9 – 14 kV pp values, treatments being performed either directly or when the seeds are placed inside a package; the latter case stops the reactive species to diffuse away from the processing area and intensifies the effects [3]. The net applied power is up to 100 W.

First noticeable modifications are the changes on the surface of the seeds detected using electron microscopy, with morphological changes that depend on the processed species, slight disintegration of the outer epidermis, irregular agglomerations, and strong etching in the case of in-package treatment. The physical changes are reflected on the water contact angle of the seeds measured using the water drop method. For in package treatment with low powers there is an increase of the water contact angle while for high power and long processing time there is a decrease of the water contact angle with about the same amount. The intensified action of the reactive species might trigger some biological response with increased germination potential, longer stems (with about 48%) as compared with the direct plasma treatment, especially for low applied power (~40 W).

Not only the physical properties of the species change after exposure in different conditions, but the biochemical profile of the resulting sprouts as well. The chlorophyll pigments concentrations increase after direct plasma treatment and decrease in the case of in-package exposure. We conclude that the reactive species concentrated action has an important role in the modification of the seeds and further affects the germination and plant growth, probably as physiological responses of the interactions that take place at cell level, which might be biological responses to abiotic stress. The changes are slightly different depending on the species, probably because of the difference in their morphology and biology.

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[1] H. Eto, Y. Ono, A. Ogino, M. Nagatsu, *Appl. Phys. Lett.* **93** (2008) 221502.
[2] T. Tounekti, Z.I. Mujahid, H. khemira, *AIP Conf. Proc.* 1976 (2018) 020029.
[3] I. Motrescu, M. Filip, F.P. Herciu, G. Jitareanu, *Engineering Sustainable Future* **101** (2020) 278.

OPTIMIZING THE PARAMETERS OF AN EHD THRUSTER PLASMA MODEL

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[2]*Departamento de Física e Astronomia, Faculdade de Ciências da Universidade do Porto,*
[3]*Departamento de Física, Instituto Superior Técnico -IST, Universidade de Lisboa,*

In this study we module a corona discharge to describe the behavior of several key parameters in electrohydrodynamic (EHD) propellers for space applications in near space regions. In these environments, the altitudes can reach from 20 to 100km, pressure ranges from roughly 40Torr to 0.25Torr, and the ambient temperature from 190K to 270K. So, the design of the electric propulsion system must be able to operate within these variations. In this work, we used a needle-type anode and a hollow cylindrical cathode with an inner radius of 12mm and a height of 21mm and with 3 – 20kV of a potential difference between the anode and the cathode. The gas pressure and temperature used were 10Torr and 300K, respectively, as in the work developed by Granados [1]. To control the corona discharge, a ballast resistor with 500MΩ and a ballast capacitor of 1pF were implemented to control current peaks.

In a first approach, we investigated the influence of the intrinsic cathode geometry for two noble propellant gases, Argon (Ar) and Xenon (Xe). In terms of geometry, we began by changing the hollow radius of the cathode. Using Argon, we verified that the width was already optimized in 12mm, since any other variation, upper or lower, would decrease the output thrust and the thruster efficiency. On the opposite hand, when using Xenon, we concluded that the optimal hollow radius was 20mm since it was the one who resulted in a better output thrust and thruster efficiency. Still focusing on the geometry, we proceeded to verify the influence of the cylinder height. At 20kV, we discovered that for Ar, the cylinder height should be halved, to around 10.5mm, and that for the Xe, the cylinder height should be reduced by about 30%, i.e. to 14.7mm.

In the second part of our work, we studied the influence of secondary electron emission coefficient, γi, in the cathode. This coefficient depends on the bombardment of ions, neutrals or electrons from the gas in the cathode's surface and of the type of surface and if, as is well known, the surface electrons have an energy above the work function of the material they will be emitted out from the surface. In both propellants, we reported a decrease from the output thrust as γi increases as can be verified in literature [2]. Using the experimental coefficients measured for copper surfaces [3], we reach an output thrust, for single stage EHD thruster, of 2.75μN and efficiency of 259mN/kW for the case of Ar and an output thrust of 3.80μN and efficiency of 434mN/kW for the Xe as the working gas.

Acknowledgments: We would like to thank FuseNet for the financial support in travelling and staying in Kiten. We also thank the support of FEUP's *Centro de Estudos de Fenomenos de Transporte* and the *Department of Engineering Physics* for the computational facilities.

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[1] V. H. Granados, M. J. Pinheiro, and P. A. Sá, "Electrostatic propulsion device for aerodynamics applications," *Phys. Plasmas*, vol. 23, no. 7, p. 73514, 2016.
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SELF-CONSISTENT MODELING OF CUTOFF-DENSITY RESONANCE IN SURFACE-WAVE PLASMAS

Ivan Ganachev

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Surface-wave plasmas are a type of wave-heated low-temperature plasmas sustained by an electromagnetic wave traveling along a plasma-dielectric interface [1]. To support surface wave propagation, the electron density n_e must be above the critical density n_c (7.4×10^{10} cm^{-3} for the 2.45 GHz plasmas widely used in industrial applications).

On the other hand, the electron density at the wall (on the outer side of the plasma sheath) is very low as in any sheath, definitely below n_c. Thus there is always a surface where $n_e = n_c$ somewhere in the bulk plasma or in the sheath. Along this surface the electron plasma frequency $\omega_p \propto n_e^{1/2}$ is equal to the wave frequency, resulting in an electron plasma resonance with strong locally enhanced electric fields. While the resonance has been observed both by measurements and modelling, there is little consensus about its "role". Can we do practical estimates forgetting about it, or do we get the particle and energy balance grossly wrong if we omit it?

The answer of this question is complicated by conflicting simultaneous trends when changing the pressure. For example, the general feeling is that the resonance should be more important at low pressures. The thinking is that at low pressure non-collisional transit-time electron heating at the sharp resonance is needed to compensate for the dearth of electron-neutral collisions. However, this is also when electron density at the sheath-presheath boundary goes up due to increased ion mobility, pushing an eventual resonance into the sheath, maybe too close to the wall for it to play any significant role on the particle and energy balance?

What happens actually depends on quantitative balance and cannot be predicted without self-consistent analysis, taking into account as much phenomena as possible. This requires adequate numerical modelling. Full 3d PIC modelling would be best, but is impractical at this point due to the vastly different time scales for ions and electrons, especially at higher pressures.

This contribution attempts to answer some of the questions above by means of self-consistent modelling using a commercially available finite-element multi-physics simulator, capable of multi-fluid plasma simulations. The local electron resonance occurred naturally in all cases tested (admittedly not many), as shown in the example in Fig. 1. The contribution of the resonance area to the particle and energy balance is analysed, to get insight into how important the resonance is. Admittedly this fluid model is not suitable for low pressures dominated by non-collisional heating, where further research is needed.

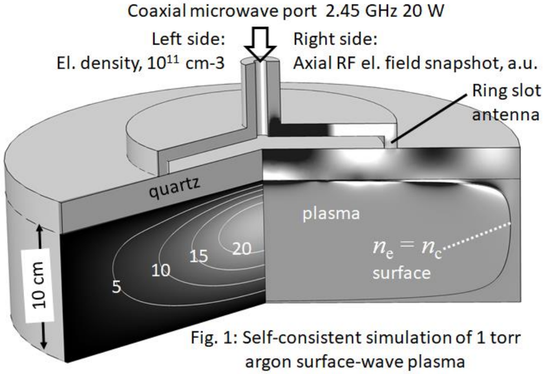

Fig. 1: Self-consistent simulation of 1 torr argon surface-wave plasma

Acknowledgment: Much of the author's experience with such modeling comes from collaboration with Prof. Keiji Nakamura from Chubu University.

Reference:

[1] I. P. Ganachev, H. Sugai: Plasma Sources Sci. Technol. **11** (2002) A178.

PLASMA JET AS A SOURCE FOR WOUND HEALING

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Electromagnetic wave travelling along a dielectric tube can produce plasma inside the gas filled tube which is the typical cylindrical plasma column of surface-wave-sustained discharges (SWD). SWD could be built with single metal antenna emitting the wave into gas media. Both plasma sources produce non-thermal plasma with achievable gas temperature below thermal affection limit of skin. Plasma is radiating significant amount of charged particles and active species, electromagnetic and UV radiation (plasma parameters).

This plasma sources allow variation of discharge conditions as geometric parameters (discharge tube inner diameter and thickness), wave power and gas flow velocity which results in changes of main plasma parameters. Appropriate combination of the parameters leads to low temperature plasma torch obtaining (gas temperature up to 30–38^{o}C) suitable for in vivo treatment of live BALB-C mouse models.

The purpose of this research is to study both devices and the discharge conditions leading to acceleration of wound healing at short treatment times with relatively low gas flow. Comparison between devices effectiveness on wound healing will be presented, too.

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TEMPERATURE CONTROL AND MONITORING OF MICROWAVE TORCH FOR BIOMEDICAL APPLICATIONS

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Biomedical applications' requirements to plasma sources are not so different from requirements for most of applications. More or less, the most important one is temperature control due to higher sensitivity of treated material to the heat. Gas discharge treated samples could be heated via temperature transfer with gas media or direct heating from the interaction with the charged particles. Direct heating from the charged particles is the minor process in comparison with heat transfer from the surrounded gas especially when the gas was ignited at the discharge device and interact with hotter surfaces at its.

That's the case of surface wave sustained plasma with SURFATRON device. While the temperature monitoring of the treated sample could be done with infrared thermography or direct contacted measurement, control of the parameter is no so simple. Multicomponent mixture of geometry-, dynamic- and external- parameters should be taken into a count when temperature control is trying to be done. In some particular cases cooling could be achieved if someone use a gas mixtures or different surrounding/supporting gas is used in parallel with the working one. Vortex or a reversed vortex flow regime of operation could decrease gas discharge temperature, too.

The purpose of this work is to present methodology of plasma temperature monitoring and potential experimental solutions of gas temperature control.

Acknowledgments: This work is supported by the Fund for Scientific Research of Sofia University under Grant No 80-10-56/2020. One of the authors' (TB) work was supported also by the Bulgarian Ministry of Education and Science under the National Program for Research "Young Scientists and Postdoctoral Students".

SURFACE WAVE SUSTAIN DISCHARGE MODELING AT VARIOUS DISCHARGE GEOMETRIES AND WAVE MODES

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Surface electromagnetic wave travelling along dielectric–gas interface can produce plasma in the gas media, so called surface-wave-discharge (SWD). The plasma sustained by the propagation wave becomes in the same time a part of the wave-guide structure for further wave propagation. This wave-guide structure consists of different media one of which is plasma. In cylindrical geometry there are several configurations of SWD: 1) plasma sustained inside cylindrical tube like plasma-dielectric (p-d), plasma-dielectric-vacuum (p-d-v), plasma-dielectric-vacuum-metal (p-d-v-m) and other combinations of the different media; 2) plasma sustained in the outer side of cylindrical dielectric like dielectric-plasma (d-p), vacuum-dielectric-plasma (v-d-p), metal-vacuum-dielectric-plasma (m-v-d-p) which is a type of so called coaxial discharge ets.

The electromagnetic wave propagation along each of these wave-guide structures is described by the corresponding dispersion equation. The electrons in the plasma absorb the electromagnetic wave power and expend it in ionization and excitation collisions with the heavy particles, thus the wave power decreases along the wave-guide. The plasma produced in this way is axially inhomogeneous with almost linear decrease of the electron number density ne from the wave launcher to the end of the plasma column. Because of the plasma axial inhomogeneity, the dispersion equation gives the dependence of the plasma frequency $\omega_p(n_e)$ on the wave number k at a fixed wave frequency ω, the so-called *phase diagrams*. The phase diagrams are usually presented in the form ω/ω_p as a function of dimensionless wave number $x = kR$, where R is the plasma radius. The form of the phase diagram strongly depends on the parameters determined by the discharge conditions. From phase diagrams behaviour it is possible to obtain information whether at the given conditions the plasma can be produced by the propagation electromagnetic wave or not.

The purpose of this work is to investigate theoretically the behaviour of wave phase diagrams at various discharge conditions and to find out values of plasma parameters at which the surface electromagnetic wave can produce plasma.

Acknowledgments: This work is supported by the Fund for Scientific Research of Sofia University under Grant No 80-10-56/2020. One of the authors' (TB) work was supported also by the Bulgarian Ministry of Education and Science under the National Program for Research "Young Scientists and Postdoctoral Students".

ELEMENTARY PROCESSES IN ARGON SURFACE-WAVE-SUSTAINED PLASMA TORCH AT ATMOSPHERIC PRESSURE

Plamena Marinova[1], Evgenia Benova[2]

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The microwave discharges of various types operating at atmospheric pressure usually produce non-equilibrium plasma that can be used for biological systems treatment. In many cases, the treatment should be carried out without thermal damage while providing a high active particles concentration and UV radiation to have for example efficient bactericidal effect. The aim of this work is theoretical investigation of surface-wave-sustained discharge produced in Argon at atmospheric pressure.

The self-consistent model of surface-wave-sustained discharge in argon at atmospheric pressure has been improved by taking into account the variation of electron–neutral collision frequency for momentum transfer with plasma density along the plasma column. The axial profiles of the plasma parameters have been presented in the case of varying electron–neutral collision frequency along the plasma column.

The opportunity to investigate the surface-wave-sustained discharge by self-consistent model allows us to presume the adequate discharge conditions in order to sustain the plasma torch with certain plasma parameters according to the applications. 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, is possible. Thus optimal plasma parameter for given application can be obtained.

The influence of the plasma parameters on the argon ions density, excited argon atoms density has been studied.

In the argon energy levels population the influence of the discharge parameters is observed. However practical applications require detailed knowledge of the discharge characteristics on the discharge conditions, more precisely density profiles of the plasma constituents – electrons, excited species and ions as well as the rate coefficients of the main elementary processes in the gas discharge. Such knowledge can be provided in economical and reliable way by a self-consistent model.

Acknowledgments: This work is supported by the Fund for Scientific Research of Sofia University under Grant No 80-10-56/2020

References:

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[2] Evgenia Benova *et al, J. Phys. D: Appl. Phys.* **51** 474004, 2018
[3] František Krčma *et al, J. Phys. D: Appl. Phys.* 51 414001, *2018*

PROBE MEASUREMENTS DURING EXPERIMENTS WITH LIQUID METAL DIVERTOR TARGETS IN COMPASS

M. Dimitrova[1,2], R. Dejarnac[1], J. Horacek[1], M. Jerab[1], P. Barton[1,3], D. Naydenkova[1], M. Imrisek[1,3], M. Tomes[1,3], J. Varju[1], P. Vondracek[1], Tsv. Popov[2,4], V. Weinzettl[1], M. Hron[1], R. Panek[1] and the COMPASS team

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The paper presents results from swept divertor Langmuir probe measurements of the plasma parameters during the first experiments with liquid Li and LiSn alloy on the COMPASS tokamak [1]. A small sample was placed in the divertor high-field side (HFS) based on a capillary porous system (CPS) technology, whereby the liquid metal is impregnated in a metallic mesh and confined against MHD effects by capillary forces [2].

The radial distribution of the ion saturation current, the plasma potential, and the electron temperature were studied in D-shaped, low- (L-mode) and high-confinement modes (H-mode) deuterium discharges for different exposure of the samples. During the Li experiment, the three ionized states of Li (Li0, Li1+, Li2+) were observed by fast visible color cameras showing that neutral lithium was very well spatially localized in the vicinity of the CPS module. Unfortunately, some droplets were seen to move crosswise on the CPS mesh by $J\times B$ forces towards the edge of the module.

Although the divertor probes were not located at the samples position, some changes in the plasma parameters were observed in the Li experiment when the sample was at more than 5 mm above the divertor surface. Using the vertical probe in the SOL plasma, a slight cooling (around 5 – 10 eV) was found resulting in a decrease in the heat flux.

During the experiment with the LiSn alloy, the plasma parameters measured by the divertor probes did not change even at the maximal insertion of the sample at 2.5 mm; also, no damage to the CPS mesh and no contamination of the main and SOL plasma were observed.

Acknowledgments: This research has been partially supported by the Joint Research project between the Bulgarian and Czech Academies of Sciences, BAS – 20-13, by the European Union project WP DTT1-LMD.P1-T001-D001.

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EFFECT OF IMPURITY SEEDING ON THE PLASMA PARAMETERS IN THE COMPASS DIVERTOR REGION

M. Dimitrova[1,2], P. Ivanova[2], Tsv. K. Popov[2,3], E. Hasan[2], R. Dejarnac[1], J. Gunn[4], J. Stöckel[1], M. Imrisek[1,5], M. Hron[1], R. Panek[1], the COMPASS team and the EUROfusion MST1 Team[6]

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We present results from swept Langmuir probe measurements of the plasma parameters before and during nitrogen, neon and argon impurity seeding in the divertor region of the COMPASS tokamak [1]. The radial distribution of the ion saturation current, the plasma potential, and the electron energy distribution function (EEDF) were studied in D-shaped, low-confinement mode (L-mode) deuterium discharges. The impurity puffing valve was on the low-field side (LFS) close to the outer strike point [3].

The probe measurements showed that prior to impurity seeding the EEDF in the divertor region can be approximated by a bi-Maxwellian distribution with a low-energy electron population (4 – 6 eV) and a group of higher energy electrons (10 – 25 eV) [2]. The impurity seeding led to Maxwellization of the plasma with an electron temperature of 5 – 7 eV, while the peaks on the strike points in the radial profiles of the electron temperature and ion saturation current disappeared during the seeding. The Maxwellization of the plasma in the LFS divertor was slower in comparison with the high-field side for all of the gases and needed higher rates of seeding. However, the discharges with nitrogen were stable and longer in comparison with argon and neon. We discuss a possible mechanism of transition from a bi-Maxwellian to a Maxwellian EEDF.

Seeding neon and argon caused their accumulation in the core plasma thus cooling it, which always resulted in a discharge disruption. This effect was more pronounced with the neon. It was found that the argon was a better cooler than neon – the shots were longer, meaning that the plasma was less disturbed than in the case of neon. Seeding argon succeeded in cooling the plasma in the entire divertor, even in the LFS. A Maxwellian EEDF was established in the divertor region within 50 ms after the seeding with a temperature of 5 – 9 eV, which decreased with time. In the case of neon, in this region the EEDF was still bi-Maxwellian with a maximum electron temperature of 13 eV.

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ON DETECTING HOT ELECTRON POPULATION IN THE COMPASS TOKAMAK DIVERTOR

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In this work we describe an attempt to confirm experimentally the presence of non-Maxwellian electron population in the divertor plasma of the COMPASS tokamak [1]. A recent theoretical study indicated that low-temperature divertor plasmas contain at least two populations of electrons: the first one being thermalized, the second, a hot electron one originating from the upstream SOL [2]. It has also been demonstrated that in the next generation of tokamaks the hot electron population might represent the main power carrier to the divertor plates; therefore, experimental confirmation of the presence of these hot electrons is of utmost importance.

There exist a number of indirect measurements of the hot electron population, but so far no solid confirmation has been achieved [2]. In this study, we applied a fast probe-biasing technique (with switching time < 1 μs). The measurements were performed in COMPASS H-mode discharges with high-density cold inner divertor plasma. In order to explain the experimental results, high-resolution full kinetic modelling was conducted.

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FIRST DEDICATED EXPERIMENTS ON THE AZIMUTHAL FIELD AS A NEW RESEARCH TOOL FOR THE DENSE PLASMA FOCUS

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Recent experiments using 15 frame interferometry on PF-1000 facility in Warsaw confirm axial magnetic field, which can allow magnetic flux lines to densely cover closed surfaces creating "magnetic flux surfaces". Evolution of such 3-dimensional (3-D) magnetic field structures is necessarily accompanied the association between neutron emission and spontaneously self-organized, relatively long lasting, finite plasma structures. A crucial aspect of this association is the simultaneous observation of an induced electric field that can provide a very long (theoretically infinite) acceleration path length along a trajectory enclosed within the magnetic structure leading to high ion kinetic energy, resulting in a high reaction rate. Associated charge and current densities can be related to electric scalar potential and magnetic vector potential measured outside the plasma. We report our first observations of these fields outside the plasma focus and discuss their general features.

The reported technique is capable of unambiguous first-principles interpretation of signals in terms of quantities related to distributions of charge density and rate of change of azimuthal current density ("electromagnetic structure") in the plasma focus. It is non-intrusive and completely insensitive to non-axisymmetric aspects of plasma. Our first results show that axial magnetic field generated by azimuthal current density distribution symmetric about the axis exists before, during and after the pinch phase.

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FABRICATION OF 3D NANOPARTICLE STRUCTURES BY FEMTOSECOND LASER RADIATION

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Glasses composed by noble metal nanoparticles attract significant attention due to the unique optical properties that they express in the near UV and visible spectral range. These are related to the high values of the extinction cross section and nonlinear optical characteristics.

In this work, we present results on the response of noble metal-doped borosilicate glass to laser radiation with femtosecond pulse duration. Furthermore, the ability of laser irradiation to induce modification of the optical properties of borosilicate glasses doped with gold and silver ions is used. The samples are obtained by conventional melt quenching method and noble metal concentration up to 10 wt%. Morphology and optical changes of the glass samples induced by femtosecond laser pulses within a wide range of parameters are investigated. The femtosecond processing is done by regenerative Ti:Sapphire amplified laser system that generates laser pulses with 35 fs duration, at repetition rate of 1 kHz.

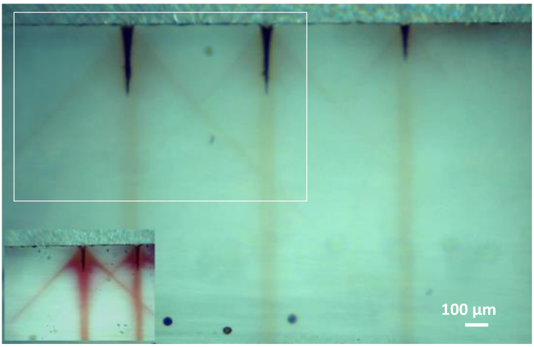

Figure 1. Cross section of ablation lines fabricated in glass with 1wt % Au

Two regimes of laser-matter interactions are considered: i) at laser fluences below the ablation threshold, and ii) above the ablation threshold. Defects associated with formation of color centers in the material, below the permanent modification threshold, are observed (Figure 1). Their properties as a function of the processing conditions are discussed. When permanent morphology modifications are induced, different micro- and nanostructures are observed depending on the laser parameters. The morphology of the ablated area is studied as function of the laser fluence and number of the applied pulses. It is found that the presence of noble metal in the glass at concentrations up to 10 wt% (the maximal used) does not influence the ablation rate.

Novel effects related to laser irradiation refraction by the formed ablated groves are demonstrated. A special attention is dedicated to estimation of the main ablation parameters, the structure and composition modifications in the laser effected zones.

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INVESTIGATION OF NON-LINEAR EFFECTS IN 3D NANOPARTICLE STRUCTURES IRADIATED BY FEMTOSECOND LASER

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The motivation of the research is based on the specific properties of noble metal nanoparticles and their wide applications. The resonance frequency for noble metal nanostructures is in the near UV and visible spectral range, where most of the commercial lasers irradiate. This makes these materials attractive candidates for efficient study and application of their properties. In this study are investigated filament formations in Au ion doped glass materials, transparent in the visible range, during the irradiation by femtosecond laser pulses. Three groups of borosilicate glasses are used - (i) samples doped with Au ions (annealed); (ii) samples with Au ions (not annealed), (ii) sample without Au ions for comparison. The second harmonic generations in the media are observed as well. This proves the formation of poly crystal structures inside the media after femtosecond laser radiation. Self-face modulation and continuum are observed. Thus, the nonlinearity of the media is higher than in the glass without doped noble metal particles. Nonlinear effects of the glass samples are investigated in terms of the laser beam parameters. The laser energy applied is between 10 and 40 μ J. The wavelengths used in the experiments are between 260 to 1200 nm, generated by optical parametric amplifier system (TOPAS). The regenerative Ti:Sapphire amplified laser system emits at 800 nm central wavelength with a pulse duration of 35 fs and 1 kHz repetition rate. Preliminary measurements and calibration of z-scan method are performed. Continuous future study is - measurements of the nonlinear refractive index and multiphoton coefficient; investigation of the relationship between the formation of filaments and local refractive index changes in glasses doped with Au ions.

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PREPARATION AND SURFACE TREATMENT OF NANOMATERIALS IN PLASMA-LIQUID SYSTEMS

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This review lecture deals with various plasmas-liquid methods suitable for preparation and surface treatment of organic as well as inorganic nanomaterials. Nanoparticles can be formed using DC or AC discharges operating directly in the liquid or using discharges in gaseous phase in contact with liquids. A special attention is given also to discharges created in liquid by pulsed laser irradiation. Nanoparticles can be formed from inorganic salt water solution as a precursor or from bulk material which can be dissolved/evaporated directly by plasma. Organic solutions can be used for the carbon based nanostructures creation, too. The surface treatment of already existing nanomaterials by the discharges generated directly in the liquid phase can lead to their anti-agglomeration properties. Nanoparticles prepared/treated under various operational conditions can be commonly characterized by ultraviolet-visible spectroscopy (UV-Vis), scanning (SEM) or transmission (TEM) electron microscopies, dynamic laser light scattering (DLSC), etc. Prepared nanoparticles can be used in various applications like material engineering, biomedicine and other advanced technologies.

CHARACTERIZATION AND APPLICATION OF MICROWAVE PLASMA FOR WOUND HEALING

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Non-thermal plasma has a lot of ways for using in nowadays medicine. It presents many useful actions like charged particles, UV light, electric field, radicals, excited atoms, and molecules. That complicated chemistry directs to uncountable synergistic interaction between cold plasma and biological systems, involve cells and tissues.

The aim of this work is the investigation of the microwave discharge influence for skin wound healing. The potential of using plasma to wound healing firstly comes from the ability of plasma to penetrate by non-homogenous and cracked surfaces as better than liquid medical forms, but there are many more pros of plasma therapy [1].

Active particles generated by plasma, such as hydroxyl radicals, nitric oxide radicals, excited nitrogen molecules, atomic nitrogen, argon and oxygen, are probably responsible for a lot of effects of plasma therapy.

Diagnostics of plasma jet by optical emission spectroscopy has shown the presence of various active particles. Concentrations of active particles generated by plasma are dependent on conditions of plasma generation like applied power and gas flow. These effects were visually recorded using high speed camera.

Two different microwave plasma systems were used for the presented study. The first one was argon microwave plasma torch generated by surface wave using the quartz capillary, the second one was plasma torch with reverse and direct vortex argon flow [2 – 4].

For visual evidence of effects on skin caused by active particles was created simulation of skin tissue, with similar electrical properties as human skin [5]. Interaction between plasma jet and artificial skin tissue shown that UV light and temperature are not responsible for all observed effects which are noticed after plasma treatment [2 – 4].

Some part of experiments was realized in collaboration with Medical University of Sofia in Bulgaria. The theory of positive effect to wound healing was supported by experiments based on treating artificially created wounds on laboratory mice by cold plasma.

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STUDY OF ELECTRICAL DISCHARGE INITIATED CHEMICAL PROCESSES IN TITAN RELATED ATMOSPHERE AT LABORATORY AND RELEVANT TEMPERATURE AND PRESSURE

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The chemical processes initiated by electrical discharges in prebiotic atmospheres became a hot topic during the last decade because of recently extensive discovering of exo-planets. The biggest atmospheric data collection is currently available about atmosphere of Saturn’s moon Titan that is composed mainly from nitrogen and methane at low surface temperature of about 95 K and pressure of about 1.5 atmospheres. The presented work deals with the laboratory simulation of the electrical discharge initiated chemical processes in the Titan related atmosphere nitrogen-methane gaseous mixture. Beside results under laboratory conditions this contribution also gives the first measurement of the main compounds formed at the liquid nitrogen temperature at pressure of 1.5 atmospheres. The ongoing chemical processes, the resulting stable products and their transformation into more complex substances are studied by in situ mass spectrometry with proton ionization (PTR-MS) of the exhausting gas. A total of about 40 aliphatic hydrocarbons, cyano and amino compounds have been successfully identified and some aromatic compounds at higher methane concentrations were synthetized, too. Increasing concentrations of methane have produced more substances with higher molecular weight and less simple substances that were likely to be consumed on more complex substances formation. The pilot experimental data under the liquid nitrogen temperature and pressure 1.5 atm demonstrated the important role of temperature which has a significant impact on creation of heavy molecules as well as for the formation of molecules that can be the life precursors (like formamide). Since the area of the possible creation of the building blocks of life has not yet been thoroughly explored, it carries a wide range of possible experiments and has enormous potential for the discovery of new mechanisms.

Keywords
Titan moon, origin of life, proton transfer time of flight mass spectrometry, exoplanetary atmospheres, electrical discharge.

INVESTIGATION OF RUNAWAY ELECTRONS WITH SOLID STATE PELLET INJECTOR: DESIGN AND FIRST EXPERIMENTS

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The COMPASS tokamak [1] has been used in recent years as a testbed for runaway electron research [2] for its a relatively safe operation even during the presence of fast electrons. In support of runaway electron (RE) investigation at the COMPASS tokamak the first experiments with a room temperature solid state pellet injector (RTSP) [3] were designed and carried out. To investigate the interaction of solid state pellets with runaway electrons a RTSP has been borrowed from IPP Garching and adapted to the COMPASS tokamak experimental conditions. First, the performance of the RTSP was characterised in Garching. The focus of these tests was put on maximising the attainable pellet velocity and determination of the pellet scattering angle. The amount of propellant gas, entering the vacuum vessel with the pellet, was measured as well. Based on the obtained results and results from a simplified numerical model, a new vacuum system for the injector was designed, manufactured and assembled.

It aims at minimising the deleterious influence of the propellant gas on the plasma while still ensuring reliable pellet delivery into the plasma. In this contribution, the vacuum system as finally assembled will be described. Its functionality will be demonstrated on data acquired during initial successful tests and the following experiments. Tests of the RTSP with its new vacuum system were performed at the IPP with graphite pellets (1 x 1. 5 mm), the same pellets as used later for experiments at the COMPASS tokamak. These pellets were launched with velocities about 300 m/s into plasmas at the presence of RE with a current dominantly carried by runaway electrons at the moment of forming of RE beam. Runaway beams have been induced by injecting Argon into a low density plasma with a substantial number of runaway electrons. Besides standard RE diagnostics such as scintillation HXR and neutron detectors, fast cameras were installed to observe the interaction of pellets with fast particles. An impact of pellet injection on the plasma performance was clearly observed. Some illustrative videos will be presented to demonstrate observed plasma/pellet interaction.

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BASICS OF TOKAMAK OPERATION

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This tutorial lecture is devoted to introducing the tokamak principle on a very basic level with the aim to prepare participants for remote operation of the GOLEM tokamak from Kiten. 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.