10th International Workshop and Summer School on Plasma Physics

at Black Sea

4 - 10 July 2022

Kiten, Bulgaria

Programme and Abstracts

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Tenth International Workshop

& Summer School

on Plasma Physics

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BOOK OF ABSTRACTS

10th International Workshop
&
Summer School on Plasma Physics

4–10 July 2022
Kiten, Bulgaria

	July 4	July 5	July 6	July 7	July 8	July 9
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
8:00-9:00	arrival	breakfast	breakfast	breakfast	breakfast	breakfast
8:00-10:00		registration	excursion			departure
9:15-9:30		Opening ceremony				
9:30-10:15		Bogdanov		Ganachev	Blagoev	
10:15-10:45		coffee break		coffee break	coffee break	
10:45-11:30		Todorova, Marinova		Gerardin	Smejkalová Čechová	
11:30-11:55		van der Mullen		Ivanova	Closing	
11:55-12:20				Hasan		
12:30-13:30		lunch		lunch	lunch	lunch
14:00-14:25		Atanasova	lunch	Dimitrova	departure	departure
14:25-14:50	registration		Dimitrova			
14:50-15:20		coffee break	coffee break	coffee break		
15:20-16:05		Free discussion forum	Dejarnac	Free discussion forum		
16:05-16:30			Torres			
16:05-17:20						
19:30-21:00	welcome	dinner	banquet	dinner	dinner	dinner

LEGEND:

Topic1 Fusion Plasma and Materials

Topic 2 Plasma Modelling and Fundamentals

Topic 3 Plasma Sources, Diagnostics and Technology

THURSDAY, JULY 5

Chairman: Dr. Evgenia Benova

9:15	**Opening ceremony**		
9:30	MICROWAVE PLASMA WOUNDS TREATMENT OF DIABETIC RATS **Dr. Todor Bogdanov**, *Department of Medical Physics and Biophysics, Faculty of Medicine, Medical University–Sofia, Sofia, Bulgaria*	T3
10:15	TREATMENT OF LANDFILL LEACHATE WITH NON-THERMAL PLASMA FOR DETOXIFICATION OF RECALCITRANT COMPOUNDS **Dr. Yovana Todorova**, *Faculty of Biology, Sofia University "St. Kliment Ohridski", Sofia, Bulgaria*, **Dr. Plamena Marinova**, *Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria*	T3
11:30	THE UNIVERSAL NATURE OF µWAVE-PLASMA RELATIONS; A TRIP FROM THE LAB VIA OUTER SPACE INTO DEEP-SKY, AND BACK **Prof. Joost van der Mullen**, *Department of Applied Sciences, Université Libre de Bruxelles,Brussels, Belgium*	T2
14:00	ROLE OF DIELECTRIC PERMITTIVITY ON PLASMA BEHAVIOUR IN SURFACE-WAVE DISCHARGE **Dr. Mariana Atanasova**, *Faculty of Mathematics and Informatics, Sofia University, Sofia, Bulgaria*	T2

WEDNESDAY, July 6

9:00	EXCURSION	

Chairman: Prof. Joost van der Mullen

14:25	CONCEPTUAL STUDY OF EMBEDDED PROBES IN THE COMPASS-U TOKAMAK FIRST WALL **Dr. Miglena Dimitrova**, *Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic*	T1
15:20	LIQUID METALS AS PLASMA-FACING COMPONENTS IN TOKAMAKS **Dr. Renaud Dejarnac**, *Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic*	T1
16:05	MAGNETIC DIAGNOSTICS FOR COMPASS UPGRADE TOKAMAK **Mr. André Torres**, *Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic*	T1

THURSDAY, July 7

Chairman: Dr. Renaud Dejarnac

9:30	MODE JUMPS IN HIGH-FREQUENCY DISCHARGES **Prof. Ivan Ganachev**, *Shibaura Mechatronics Corporation, Yokohama, Japan*	T3
10:45	3D FIELD LINE TRACING CALCULATIONS IN SUPPORT OF PLASMA-FACING COMPONENTS DESIGN IN A TOKAMAK **Dr. Jonathan Gerardin**, *Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic*	T1
11:30	APPLICATION OF THE TRIPLE-PROBE TECHNIQUE TO MAGNETIZED PLASMAS **Dr. Pavlina Ivanova**, *Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T1
11:55	LANGMUIR PROBE MEASUREMENTS ON THE WEST TOKAMAK DIVERTOR IN DEUTERIUM AND HELIUM PLASMAS **Dr. Embie Hasan**, *Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T1
14:00	GROUNDED CURRENT DETERMINED BY SWEPT LANGMUIR PROBES IN THE COMPASS TOKAMAK DIVERTOR **Dr. Miglena Dimitrova**, *Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic*	T1

FRIDAY, JULY 8

Chairman: Dr. Evgenia Benova

9:30	MEASUREMENTS OF THE ELECTRIC FIELD OUTSIDE THE DENSE PLASMA FOCUS CONNECTED WITH AN AXIAL MAGNETIC FIELD **Prof. Alexander Blagoev**, *University of Sofia, Faculty of Physics, Sofia, Bulgaria*	T1
10:45	CHARACTERIZATION AND APPLICATION OF MICROWAVE PLASMA TORCH ON WOUND HEALING **Mrs. Kateřina Smejkalová**, *Brno University of Technology, Faculty of Chemistry, Brno, Czech Republic*	T3
11:10	EVALUATION OF THE EFFECT OF PLASMA ACTIVATED WATER ON SEED GERMINATION **Mrs. Ludmila Čechová**, *Brno University of Technology, Faculty of Chemistry, Brno, Czech Republic*	T3
11:30	**Closing**	

TUESDAY, JULY 5

MICROWAVE PLASMA WOUNDS TREATMENT OF DIABETIC RATS

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Several decades after development of surface wave sustained plasma (SWP) sources new horizons for their application are revealed. Bio-medical industry is highly interested in the possible uses of plasma sources for assisting or inducing vital biological processes. This low temperature plasma torch contains microwave radiation and UV radiation which can be successfully used for sterilizations and activation of the healing and regenerative proceses in acute wounds, for example. Some other plasma sources have been used on diabetic wounds with relatively high impact on wound regeneration. In combination with Reactive Oxygen Species (ROS) and Reactive Nitrogen Species (RNS), produced by the SWP source they could effect on the existing biological pathways and assist some main agents production leading to “healing” of the diabetic wounds.

Investigation is focused on the effect of a microwave plasma torch sustained by travelling electromagnetic wave with the use of Ar gas on in vivo treated wounds of diabetic rats. Till now this type of plasma source has not been often used for treatment of such wounds. Results about wound healing progress will be presented in dependance of plasma treatment conditions.

TREATMENT OF LANDFILL LEACHATE WITH NON-THERMAL PLASMA FOR DETOXIFICATION OF RECALCITRANT COMPOUNDS

M. Belouhova[1,2], Y. Todorova[1,2], I. Yotinov[1,2], I. Schneider[1,2], Y. Topalova[1,2], T. Bogdanov[2,3], Pl. Marinova[2,4], E. Benova[2]

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The leachate from solid waste landfills contains high concentrations of various organic and inorganic recalcitrant compounds, most of which are highly toxic. The treatment of this complex mixture of contaminants of environmental concern, including per- and poly-fluoroalkyl substances (known as PFAS) is a challenge for waste management and the conventional technologies usually have low efficiency. For this reason, the development of advanced approaches and innovative technologies for the removal of pollutants in leachate and sludges from treatment is an area of growing research interest in the last years. Plasma methods have the potential to successfully contribute to solving existing treatment problems and to be the basis of effective hybrid technologies for the complete removal of hazardous pollutants.

The effect of non-thermal plasma treatment of leachate and sludge on their toxicity is presented. The samples were taken from the Sofia Waste Treatment Plant (Bulgaria). The plasma is produced by a microwave plasma torch sustained by an electromagnetic surface wave at 2.45 GHz in Argon at atmospheric pressure and input wave power 50, 75, and 100 W. The specially designed experimental setup allowed to achieve a continuous flow process of treatment. The toxicity of treated and untreated samples was studied by fluorescence staining with CTC (5-cyano-2,3-ditolyl tetrazolium chloride) and DAPI (4',6-diamidino-2-phenylindole) on a test bacterial culture E. coli NBIMCC 8785 at an incubation time of 1 hour. The method assesses the intensity of metabolic processes in bacterial cells and their inhibition in the presence of toxic agents. The obtained images were processed with a digital analysis program. The changes in the complex toxicity of the samples due to plasma treatment were assessed by comparing the effect of treated and untreated samples on two indicators of the test bacterial culture: (1) the share of living cells; (2) the intensity of bacterial fluorescence.

The fluorescence analysis showed that the plasma treatment led to a reduction in the toxicity of treated samples. The share of living cells increased 13-fold from 0.6% for untreated leachate to 7.7% for leachate treated with plasma (100 W). The clearest increase in the fluorescence intensity, and accordingly in the metabolic activity of the test bacteria, was found for treatment with 75 W power (by 27 %). Repeated treatment of the same sample flow did not show a significant effect on complex toxicity.

The results of the study show that plasma treatment can successfully reduce the toxicity of the leachate and sludge from landfills. The plasma-based technologies have the potential to improve the efficiency of the removal of recalcitrant compounds.

Acknowledgments: This work is supported by the PROMISCES (Preventing Recalcitrant Organic Mobile Industrial chemicalS for Circular Economy in the soil-sediment-water System) project which has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No 101036449. The equipment used in the investigation is from the Clean&Circle Center of Competence, Grant № BG05M2OP001-1.002-0019: "Clean Technologies for Sustainable Environment - Waters, Waste, Energy for a Circular Economy", financed by the Science and Education for Smart Growth Operational Program (2014-2020) and co-financed by the EU through the ESIF.

THE UNIVERSAL NATURE OF μWAVE-PLASMA RELATIONS; A TRIP FROM THE LAB VIA OUTER SPACE INTO DEEP-SKY, AND BACK

Joost van der Mullen[1] and Mariana Atanasova[2]

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Surface wave induced plasmas (SIP) are based on the interplay between μwaves and plasmas; the microwave excites the plasma while the plasma guides the wave. This narrative suggests a well-balanced matrimony. But, are the tasks always harmonically allocated? or are we dealing with master-slave relations? And how is that for other types of μwaves-plasmas interactions?

This study to the various aspects of μwave-plasma relations departs from the (hopefully) well-controlled laboratory and travels via the outer atmosphere into the deep cosmos.

First, we find in the ionosphere (at about 100 km) that turbulence can influence the propagation of radio signals. This can lead to *fading*, slow undulations (typically seconds) of radio signals that can hinder intercontinental radio communication. Beneficial is that the physics behind *fading* provides insight in the electron density distribution in outer atmosphere.

Further away, on large distances we find *pulsars*; rotating *Neutron Stars (NS)*, equipped with very strong magnetic (B-) fields, typically 10^6 stronger than what high-tech on earth can make. Due to their large mass, in the order of that of the sun ($2\ 10^{30}$kg), pulsars are stable rotators that can function as *cosmic clocks*. They have even been employed to validate general relativity. Dependent on the distance, the clock signals can be hundred thousand years old, and the frequency dependent arrival-time gives insight in the distribution of electrons in local and the outer galaxy. This transit-time dispersion is based on the same laws ruling *fading* and can be employed in laboratory for plasma diagnostics: interferometry and reflectometry.

Even further away, in the deep cosmos, lies the origin of Fast Radio Bursts (FRBs). These are irregular radio pulses of about a millisecond. The transit-time dispersion reveals that FRBs are much further away than pulsars. At about 10^9 ly ($\sim10^{22}$ km) such an FRB must be generated in very distant galaxies. This distance leads to estimations of the energy per burst of typically $E= 10^{33}$J. With a burst-duration of $\tau = 3$ms this implies $P \approx 3\ 10^{35}$W, about 10^9 times the power of the sun! It is suggested that FRBs are produced by violent eruptions quaking the surface of *magnetars*; neutron stars with B-fields that are 10^3 times larger than of 'regular' pulsars.

It is obvious that for these high energies the *μwave - plasma* relation will no longer be linear. Non-linearity is already relevant at much lower power levels e.g. for those of waves emitted by strong radio stations that influence the propagation of other weaker ones. This mechanism, the *Luxemburg-Gorky* effect, has led to the construction of so-called *ionospheric heaters;* set-ups that can excite ionosphere regions. Studying the response teaches a lot about the physics of the upper atmosphere, but also on how radio waves can affect plasmas and vice versa.

Back on earth we can use these insights in the lab to re-study the relation between μwaves and plasmas e.g. to understand the role of plasma chemistry. Space and cosmos offer wide varieties but on earth we can easily play with steering conditions, e.g. those offered by plasma chemistry.

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ROLE OF DIELECTRIC PERMITTIVITY ON PLASMA BEHAVIOUR IN SURFACE-WAVE DISCHARGE

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Atmospheric surface-wave discharges (SWDs) have proved as effective instruments for biological and medical treatments [1–3]. However, the in-depth understanding of the interplay between the plasma and the treated surface that is necessary for getting these tools into practise is not yet achieved. One important aspect is how a substrate, generally seen as dielectric, influences the properties of discharge created by an electromagnetic wave.

In order to study the interaction of SWD with a dielectric substance like water, theoretical investigation on plasma–infinite dielectric set-up is caried out. Increasing the dielectric permittivity from 1 (the value of air) to 80 (the permittivity of water at 20 °C) it is observed that above certain value the electromagnetic wave sustaining the plasma, and propagating at the interface between plasma and dielectric, is a backward wave. Can a backward wave sustain a discharge? And is this the reason why this type of discharges is known to not penetrate in water substrates? These are questions of high importance for all but especially the bio-medical applications of SWD.

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WEDNESDAY, JULY 6

CONCEPTUAL STUDY OF EMBEDDED PROBES IN THE COMPASS-U TOKAMAK FIRST WALL

M. Dimitrova, J. Gerardin, A. Podolnik, V. Balner, J. Adamek, V. Weinzettl, I. Duran, K. Kovarik and R. Dejarnac

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The COMPASS Upgrade (COMPASS-U) tokamak is a compact, medium-size, high-magnetic field (5T) and high-density device under construction with a flexible set of poloidal field coils for different configurations (single, double null etc.) [1, 2]. In a recently published article [3], the constraints and requirements were reviewed, namely, high temperature of the vacuum vessel (500 °C), high plasma density (5×10^{20} m^{-3}), high heat-flux density to the metallic plasma facing components, strong auxiliary plasma heating, spatial constraints and liquid metals in the divertor.

One of the most commonly used diagnostics in tokamaks to measure local parameters is based on Langmuir probes. This contribution presents a conceptual study of the Langmuir probe diagnostic for the COMPASS-U tokamak first wall (inner and outer limiters, divertor baffles). Because of the expected high heat fluxes in a metallic environment, the diagnostic is based on flush-mounted probes embedded in limiter tiles. Typical issues related to flush-mounted probes, such as the non-saturation of the ion current because of sheath expansion, precise alignment of the probe with respect to the tile where it is embedded and the dependence on the angle of incidence are discussed. Calculations of the foreseen heat fluxes and angles of incidence at probes location for COMPASS-U typical scenarios were performed using the 3D field line tracing code PFCflux [4, 5] at all poloidal probes positions for optimization. Model current-voltage characteristics for a flush-mounted probe were calculated using the 2D3V particle-in-cell code SPICE2 [6, 7] for different angles of incidence. The results are used to predict the current collected by the probes for different magnetic field values [$2.5 < Bt < 5$ T] and to outline reliability of the proposed diagnostics. Capability of the electronic system to provide reliable measurements is also reviewed.

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LIQUID METALS AS PLASMA-FACING COMPONENTS IN TOKAMAKS

R. Dejarnac [1], J. Horacek[1], M. Hron[1], M. Jerab[1], J. Adamek[1], S. Atikukke[2], P. Barton[1], J. Cavalier[1],J. Cecrdle[3], M. Dimitrova[1], E. Gauthier[4], M. Iafrati[5], M. Imrisek[1], A. Marin Roldan[2], G. Mazzitelli[5], D. Naydenkova[1], A. Prishvitcyn[6], M. Tomes[1], D. Tskhakaya[1], G. Van Oost[6,7,8],J. Varju[1], P. Veis[2], A. Vertkov[9], P. Vondracek[1], V. Weinzettl[1] and R. Panek[1]

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Liquid metals are considered as an alternative to conventional, solid plasma facing components to overcome issues such as melting of leading edges, cracking, heat capacity deterioration subsequent to neutron irradiation or re-crystallization. One candidate technology is the capillary porous system (CPS) where the liquid metal is impregnated in a metallic mesh or felt and confined against MHD effects by capillary forces. However, this potential solution comes with new issues such as resilience to transients (ELMs, disruptions), tritium retention, or evaporation. These issues were investigated experimentally for the first time in ELMy Hmode plasmas in the tokamak COMPASS [1]. Two specially designed CPS modules, one filled with liquid Li and one with a liquid LiSn alloy (~75% of Sn), were installed in the COMPASS divertor and exposed to powerful ($q_{//}$ ~ 25 MW/m^2), short (200 ms flat-top) deuterium plasmas in the presence of ELMs (ε^{ELM} = 15 kJ.m^2).

No liquid metal droplet was directly ejected from the CPS mesh surface (IR + fast visible cameras) and no deterioration of the mesh was observed for perpendicular heat fluxes up to q^{dep} = 12 MW/m^2 for both metals. Visible spectroscopy in direct view of the CPS module shows that the neutral lithium is very well localized in space onto the mesh. A red cloud corresponding to neutral lithium is seen on the fast visible cameras surrounding the wetted area by ~2-3 cm. During ELMs, a green plume corresponding to Li^{1+} ions is seen in both upstream and downstream directions leaving the module on several tens of cm with no perturbation of the plasma discharges, followed by a blue color that could be interpreted as Li^{2+}. For both metals, no vapor shielding was observed as the maximum surface temperature of the modules never reached the evaporation temperatures of Li (~450ºC) and of the LiSn alloy (~1300ºC). The LiSn module maximum surface temperature measured by IR camera reached 950ºC at the end of the discharge with each ELM contributing to ΔT^{ELM} ~ 45ºC. Particle in cell simulations predict that the radiating neutral lithium cloud has a radius of L^{mfp} ~ 6 cm, in agreement with experimental observations, and that the Li ionization front is located well above both the Li^{1+} gyro-radius (~30 μm) and the magnetic presheath (<1 mm), leading to negligibly small prompt Li re-deposition [2]. No clear evidence of Sn is observed by the cameras, nor by visible spectroscopy. No contamination by Sn of core and scrape-off layer plasmas was observed.

References:

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MAGNETIC DIAGNOSTICS FOR COMPASS UPGRADE TOKAMAK

A. Torres[1,2], T. Markovic[1,3], B. B. Carvalho[2], A. Havranek[1], K. Kovarik[1], V. Weinzettl[1], H. Fernandes[2]

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COMPASS Upgrade is a fully metallic, high magnetic field tokamak currently being developed in Prague, Czech Republic. This device will be able to operate with a heated vacuum vessel, with all in-vessel components heated up to 500 °C, which represents a major challenge for the development of the magnetic diagnostics. The signals of the inductive coils and loops will be primarily used for the control of plasma shape and position, and reconstruction of magnetic equilibrium. For these reasons it is an essential diagnostic that must operate reliably across all scenarios and temperatures of operation.

Beyond an overview of these challenges, this talk focuses on the design and engineering of the magnetic sensors and the efforts to ensure accurate and reliable data across all operation stages of the experiment. The development of a bespoke modular data acquisition system with real-time integration will be also presented, from concept to prototype testing.

As consequence of the choice of reliable mineral insulated cables for the key sensors, Mirnov coils have a limited bandwidth of 17 kHz, which is deemed enough for real-time control and equilibrium reconstruction. Likewise, the integrator drift measured in the data acquisition prototypes is compliant with the 5 μV requirement established for COMPASS Upgrade.

THURSDAY, JULY 7

MODE JUMPS IN HIGH-FREQUENCY DISCHARGES

Ivan Ganachev[1,2], Haruka Nakano[1], Keiji Nakamura[2]

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Mode jumps are frequently encountered in high-frequency discharges. Typical examples include the jump between capacitive- and inductively-coupled modes encountered in RF inductively coupled plasmas (ICPs), or the jumps between the various standing-wave resonances in planar surface-wave (SW) discharges. Mode jumps between standing surface wave modes can happen in surface-wave sustained plasma columns, too, if the discharge tube is much shorter than the length necessary to absorb all the microwave power supplied.

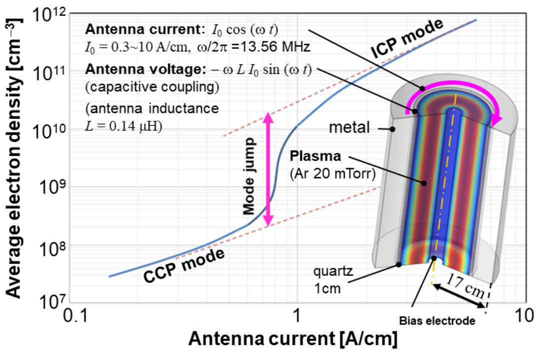
Standing-wave mode jumps are relatively easy to model in surface wave discharges, due to the simple dispersion equations. In the simplest case of a surface wave of frequency $f = \omega/2\pi$ traveling along the interface between a semi-finite plasma of electron density n_e and a semi-infinite dielectric medium with dielectric constant ε_d, the surface-wave dispersion equation is very simple

$$\beta_{sw} \equiv 2\pi/\lambda_{sw} = (\omega/c)\,(1/\,\varepsilon_p + 1/\,\varepsilon_d)^{-1/2} \tag{1}$$

and provides a relation between the SW wavenumber β_{sw} (or SW wavelength λ_{sw}) and the plasma dielectric constant ε_p. The latter can be expressed in terms of the electron density n_e and the critical density $n_c = \varepsilon_0 m_e \omega^2/e^2$, $\varepsilon_p = 1 - n_e / n_c$, so that equation (1) establishes a relation between the surface-wave wavelength λ_{sw} and the electron density n_e (here and in eq. (1) c and ε_0 are the speed of light and absolute permittivity of vacuum, while e and m_e are the electron's charge and mass, respectively). If the plasma is of limited length L, the standing wave resonance condition $L = n\,\lambda_{sw}/2$, $n = 1, 2, \ldots$ gives a discrete spectrum of standing wave resonance densities, between which standing-wave mode jumps occur.

Mode jumps in ICPs have a different mechanism. ICPs are sustained by the secondary RF current induced by a primary current flowing in an antenna wound outside a dielectric window. ICP excitation needs some minimum electron current to compensate for all losses in the plasma. On the other hand, there is a parasitic capacitive coupling proportional to the antenna inductance. Capacitive coupling exists even at low antenna currents, even for currents too low to sustain plasma by inductive coupling. For such low antenna currents there is still a discharge, but the electron density is much lower. When increasing the antenna current, a sudden jump occurs from the low-density capacitively-coupled mode to the high-density inductively-coupled mode, as shown in the figure.

We present multi-species fluid modelling of the afore-mentioned types of mode jumps and discuss the factors which affect the related behaviours.



3D FIELD LINE TRACING CALCULATIONS IN SUPPORT OF PLASMA-FACING COMPONENTS DESIGN IN A TOKAMAK

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Plasma-facing components (PFCs) are key components to be designed inside a tokamak in order to protect the vacuum vessel and all in-vessel components (diagnostics, cables, pumping system, etc.) from high particle and heat fluxes. The charged particles coming from the plasma follow the magnetic field lines and impact the PFCs with a certain angle. The resulting heat flux is very sensitive to the shape of the PFC, which needs to be optimized in order to maximize the area wetted by the plasma, involving grazing incident angles (1-2°) of the field lines at the surface of the PFC. The shape also needs to allow enough margin for the shortwave misalignment (i.e., misalignment of one PFC with respect to its neighboring one), to avoid situation where one side of a misaligned PFC can be exposed to very high heat fluxes due to a normal incidence of the incoming particles.

PFCFlux [1,2] is a 3D field line tracing code with the main assumptions that the particles strictly follow the magnetic field lines (optical approximation) and are coming from the outer mid-plane. It uses a magnetic field equilibrium (which can have some 3D asymmetry like a ripple effect), 3D CAD design of the PFCs and the plasma parameters defining the energy flux density (power inside the scrape-off layer, power exponential decay length λ_q,). This code can estimate the charged particle heat flux taking into account the magnetic shadowing involved by the positioning of the PFCs with respect to each other in a 3D environment.

3D field line tracing is used to design the PFCs by calculating the pattern of deposited heat loads on the front face of PFCs and evaluating the sensitivity of the design to misalignment. This contribution will highlight such process by showing charged particle heat flux calculations performed with PFCFLUX on the PFCs of different tokamaks (COMPASS-U [3], WEST [4], DEMO [5]). In particular, the complexity of the heat flux pattern on the inner wall of COMPASS-U during plasma current Ramp-Up and Ramp-Down phases, the effect of PFCs misalignment in the divertor of WEST and how to protect the first wall with discrete limiters during off-normal events (e.g., Vertical Displacement Events) on DEMO [6] will be presented.

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APPLICATION OF THE TRIPLE-PROBE TECHNIQUE TO MAGNETIZED PLASMAS

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The triple-probe technique [1] is a diagnostic widely used in determining the electron temperature in various devices and plasma conditions. It was developed for measurements in low-pressure gas-discharge plasmas in the absence of a magnetic field. This paper presents a comparison of the experimental results obtained by swept Langmuir probe measurements with those obtained by the triple-probe technique in magnetized plasmas in three experimental machines with different magnetic field magnitudes (0.01-1.15 T). We focus on results for the electron temperature as determined in the linear device with low magnetic fields ($0.01 > B_T > 0.1$ T) in Ljubljana, Slovenia [2, 3], and the TJ-II stellarator, Madrid, Spain [4] and the COMPASS tokamak in Prague, Czech Republic [5], both with higher magnetic fields ($B_T > 1$ T); the results demonstrate that the T_e determined using triple probes is overestimated in comparison with the swept Langmuir probes.

The reliability of the triple-probe results for the electron temperature is discussed in tokamak plasmas at higher magnetic fields. The explanation of the overestimation proposed in this paper is based on a shift of the floating potential towards the plasma potential in the presence of a magnetic field, yielding a more positive voltage measured by the triple-probe technique and therefore higher electron temperatures. Using the extended formula for the electron probe current [6] in the presence of a magnetic field a correction factor is derived so that the triple-probe technique yields similar temperature to swept Langmuir probe techniques. An explanation of this phenomenon is proposed based on the fact that the floating potential is generally shifted closer to the plasma potential in the presence of magnetic field (B_T).

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LANGMUIR PROBE MEASUREMENTS ON THE WEST TOKAMAK DIVERTOR IN DEUTERIUM AND HELIUM PLASMAS

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In this work, results are presented from Langmuir probe measurements in the WEST tokamak. The magnetically-driven "mouse-trap" probe is located in the lower divertor near the outboard strike point. The plasma potential, electron temperatures and densities are determined following the first-derivative probe technique (FDPT) [1] using the current-voltage characteristics measured.

One of the most important results obtained is that in deuterium plasma and close to the wall the electron energy distribution function (EEDF) is bi-Maxwellian. The origin of the cold electron population is discussed in detail in [2], where it is shown that the main reason of this phenomenon is the intensive ionization of the deuterium neutrals by thermal electrons in the vicinity of the LCFS.

The plasma parameters are determined at different working gases in deuterium and different amounts of helium. Analyzing the discharges with different amounts of He, it was found that below 80% the EEDF is always bi-Maxwellian, while for 82% of He, discharge #55825, a Maxwellian distribution appears with $T_e = 13 \div 15$eV. Therefore, in a gas mixture with He deuterium still plays an important role in the ionization process. The corresponding electron density values show that the electron population is dominated by thermal electrons, whose density is almost twice as high as that of the cold electrons in contrast with the case of deuterium plasma.

The comparison between the results acquired by the flush probe on the mousetrap head and the divertor probes shows a good agreement. The temperature of the He plasma is not sufficiently high to observe a bi-Maxwellian distribution – the production of electrons requires that the electron temperature be near the He ionization potential, which exceeds 21 eV.

It should be pointed out that processing the *IV*s by a conventional technique (e.g. a four-parameter fit [3, 4]) provides results for the electron temperature that practically coincide with the temperature of the thermal electron fraction.

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GROUNDED CURRENT DETERMINED BY SWEPT LANGMUIR PROBES IN THE COMPASS TOKAMAK DIVERTOR

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In COMPASS tokamak [1, 2], the divertor is characterized by a floating potential asymmetry – positive values in the inner divertor and negative against ground, in the outer. This is very important in calculating the heat flux [3], because when the floating potential is negative, which corresponds to a non-ambipolar case, the heat transmission coefficient (γ) value is higher by a factor of more than three than the value of 7 – 8 ordinarily assumed.

In this work, our attention was focused on determining the grounded current (the ion-saturation current density when the current-voltage characteristic is at zero potential). This current can also be used and included in calculating γ, as proposed by Brunner [4].

The existence was found of a very close relation between the values of the floating potential and the grounded current. Multiple different discharges were used to find the limits wherein calculating γ using the grounded current may be applied and which divertor' regions play a significant role. It was seen that stronger negative currents at zero voltage are recorded in the outer divertor in L-mode (γ is about 20). In H-mode, the region with the highest values was localized around both the inner (γ~ 15) and the outer strike points (>25). In the case of a reversed magnetic field, when the profile of the floating potential is reversed, the grounded current was higher in the inner divertor and around the strike points. In the inner divertor, γ reaches 30, in the vicinity of the outer strike point, around 15.

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FRIDAY, JULY 8

DETECTION OF POLOIDAL MAGNETIC FLUX EMISSION FROM A PLASMA FOCUS

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A recent comprehensive review of plasma focus research over the last 20 years has highlighted [1] 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 axial magnetic field, both in the radial implosion and pinch phases, 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 by 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.

Because of severe technical difficulties with the conventional methods of magnetic field detection, such as magnetic probes and Faraday Rotation, there is a severe deficiency in the total amount of experimental information available on the evolution of poloidal magnetic flux. A beginning towards mitigation of this deficiency was made in our previous work [2], where we reported direct observations of the azimuthal electric fields arising outside the pinch of the plasma focus discharge and discussed their general features. This paper seeks to demonstrate a modified version of this diagnostic, proposed by S Auluck [3], to remove an undesirable feature of that technique. We demonstrate that poloidal magnetic flux emission from the plasma focus continues well after the pinch phase showing that the post-pinch warm plasma, which is of technological importance, continues to be an MHD-active object worthy of further characterization and study.

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CHARACTERIZATION AND APPLICATION OF MICROWAVE PLASMA TORCH ON WOUND HEALING

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The low temperature plasma application in medicine turned to direct therapeutic purposes during the last decade [1, 2]. Various atmospheric pressure operating systems were successfully tested. Plasma is generated mainly in helium, some systems allow also generation of sufficiently cold plasma in argon. A special plasma conditions, mainly high excitation level of long living metastable particles, can be obtained using microwave discharges [3, 4].
The aim of this presentation is the investigation of the microwave plasmas for skin wound healing. Microwave discharges used for this work were generated in argon; the surface wave sustained and direct vortex torch were compared. The model wounds on laboratory mousses were treated by plasma and wound healing was examined during 3 weeks after the plasma treatment. Both plasma systems showed healing acceleration. Application of torch discharge was proved to be the most effective method in the healing of skin defects. The plasma vortex system was visualized using fast camera at selected powers and gas flows. Additionally, determination of active particles was taken by optical emission spectroscopy. Based on these measurements, plasma parameters were determined: electron temperature, rotational and vibrational temperatures. To determine role of different plasma active species, the treatment of indigo coloured artificial skin model was treated under various conditions by both plasma systems. Results show that the direct interaction between plasma particles is the main effect, role of radiation, only, is more or less negligible.

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EVALUATION OF THE EFFECT OF PLASMA ACTIVATED WATER ON SEED GERMINATION

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One of the biggest concerns of modern agriculture is the contamination of agricultural soil and water by pesticides. These chemicals pose a threat to the environment. The excessive use of pesticides might be affecting non-target organism such as aquatic organisms, birds and animals. They can also have negative impact on human health [1].

Plasma activated water (PAW) is a new type of liquid fertilizer prepared by the interaction of plasma with liquids. The chemistry of plasma activated water is similar to the gas plasma chemistry, with short-lived reactive oxygen and nitrogen species (RONS) such as NO·, ·OH or $\cdot O_2^-$. Subsequently, these short-lived species form long-lived RONS, such as hydrogen peroxide, nitrites and nitrates, which stay present in water for days. Thanks to H_2O_2 and NO_2^-, plasma activated water gains antibacterial properties, while NO_3^- with small amount of H_2O_2 can stimulate germination and growth of plants. These properties can make plasma activated water a new and environmentally friendly tool to increase germination of seeds and subsequently, to increase and sustain agricultural production, while it may also protect the seeds from bacteria [2].

In this work, plasma activated water was prepared by three different plasma-liquid systems and it was characterized by measurements of pH, conductivity and concentration of RONS. The first system was based on the dielectric barrier discharge in air with the liquid electrode (PAW1,2). In the second system, plasma was generated directly in the liquid by high dc voltage, applied on the main pin-hole based electrode (PAW3). In the third system, gaseous products from the ozonizer were bubbled into the liquid (PAW4,5). A mixture of oxygen and nitrogen (1:4) was used for plasma generation. Activation time was 2 minutes in all systems. The effect of plasma activated water on seed germination was tested on seeds of white mustard *Sinapis alba*, winter wheat *Triticum aestivum* and corn *Zea mays*. The results for germination of wheat seeds are compared in Table 1.

Table 1 Comparison of germination in PAW prepared by different plasma systems (LOD = limit of detection).

	Water	H_2O_2 (mg/l)	NO_2^- (mg/l)	NO_3^- (mg/l)	Germination (%)
PAW1	Distilled	0,72±0,01	0,05±0,02	11±6	97,5
PAW2	Tap	0,84±0,02	0,83±0,03	43±3	97,3
PAW3	Tap	23,77±0,02	0,12±0,01	42±8	97,5
PAW4	Distilled	2,93±0,09	0,06±0,03	10±2	98,0
PAW5	Tap	5,18±0,07	0,09±0,01	26±2	97,5
Control	Distilled	Under LOD	Under LOD	Under LOD	95,8
Control	Tap	Under LOD	0,05±0,02	25±2	94,4

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