12th International Workshop and Summer School on Plasma Physics

at Black Sea

8 - 14 June 2026

Kiten, Bulgaria

Programme and Abstracts

Twelfth

International Workshop

& Summer School

on Plasma Physics

organized by:

St. Kliment Ohridski University of Sofia

co-organizers:

PLASMER Foundation

Clean&Circle Center of Competence

Institute of Plasmas and Nuclear Fusion, Lisbon, Portugal

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TIMETABLE IWSSPP'26

	June 8	June 9	June 10	June 11	June 12	June 13	June 14
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
8:00-9:00	arrival	breakfast	breakfast	breakfast	breakfast	breakfast	breakfast
9:30-10:00		registration	Dimitrova	Tatarova	Bundaleska	Blagoev	departure
10:00-10:15		Opening					
10:15-11:00		Pawlat	Paskalov	Kissovsky	Felizardo	Atanasova	
11:00-11:30		coffee break					
11:30-12:15		Dimitrova	Čechová	Abrashev	Dias	Atanasov Closing	
12:15-12:40		Simeonova	Krejsová	Marinov	Marinova		
12:40-14:00		lunch					
14:00-14:25		Ivánek	excursion	Marath Santhosh	Bogdanov	departure	
14:25-14:50		Vasileva					
14:50-15:20		coffee break		coffee break			
15:20-16:00		Free discussion forum		Polanšek	Free discussion forum		
16:00-18:00	registration			discussions Project AEGIS			
18:30-19:30	Round table discussions Project AEGIS						
19:30-21:00	welcome	dinner	dinner	banquet	dinner	dinner	

LEGEND:

Topic1 Fusion Plasma and Materials
Topic 2 Plasma Modelling and Fundamentals
Topic 3 Plasma Sources, Diagnostics and Technology
Workshop AEGIS

BOOK OF ABSTRACTS

12th International Workshop
and
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IWSSPP International Advisory Committee

THURSDAY, JUNE 9

Chairperson: Dr. Evgenia Benova

10:00	**Opening**	
10:15	COLD PLASMA FOR FOOD: PRESERVATION OF NUTRIENTS AND SHELF LIVE EXTENSION **Prof. Joanna Pawlat**, *Dept. Electrical Eng.& Smart Technol., Lublin University of Technology, Poland*	T3
11:30	DETERMINATION OF THE HEAT FLUX IN THE WEST TOKAMAK DIVERTOR **Dr. Miglena Dimitrova**, *Institute of Plasma Physics of the Czech Academy of Sciences, Prague, Czech Republic, Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T1
12:15	ANTIBACTERIAL POTENTIAL OF COLD MICROWAVE ARGON PLASMA IN AN EXPERIMENTAL PERI-IMPLANT ENVIRONMENT **Ms. Maria Simeonova**, *Medical University – Sofia, Sofia,Bulgaria*	T3

Chairperson: Dr. Miglena Dimitrova

14:00	IRRADIATION TESTING OF ANTIMONY-BASED HALL SENSORS IN DEMO-RELEANT CONDITIONS **Mr. Matěj Ivánek**, *Institute of Plasma Physics of the Czech Academy of Sciences, Prague, Czech Republic*	T1
14:25	PLASMA PROPERTIES IN THE VICINITY OF THE LAST CLOSED FLUX SURFACE IN HYDROGEN AND HELIUM DISCHARGES IN THE TJ-II STELLARATOR **Ms. Elmira Vasileva**, *Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T1

WEDNESDAY, JUNE 10

Chairperson: Prof. Joanna Pawlat

9:30	DIAGNOSTICS INTERFACE WITH PLASMA FACING COMPONENTS FOR COMPASS UPGRADE TOKAMAK **Dr. Miglena Dimitrova**, *Institute of Plasma Physics of the Czech Academy of Sciences, Prague, Czech Republic, Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*	T1
10:15	PLASMA TECHNOLOGIES: FROM R&D TO COMMERCIAL **Mr. George Paskalov**, *Plasma Systems,Gardena, USA*	T3
11:30	PLASMA TECHNOLOGIES FOR WATER TREATMENT AND PLANT STRESS MITIGATION **Dr. Ludmila Čechová,** *Central European Institute of Technology, Brno University of Technology, Brno, Czech Republic*	T3
12:15	NON-THERMAL PLASMA AS A TOOL FOR ENHANCING ONION YIELD UNDER FIELD CONDITIONS **Ms. Lenka Krejsová**, *Faculty of Chemistry, Brno University of Technology, Brno, Czech Republic*	T3

THURSDAY, JUNE 11

Workshop Advanced Electromagnetic Graphene-based shields via plasma Induced Synthesis (AEGIS)

Chairperson: Prof. Elena Tatarova

9:30	ADVANCED ELECTROMAGNETIC N-GRAPHENE-BASED SHIELDS VIA PLASMA INDUCED SYNTHESIS **Prof. Elena Tatarova**, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal*	AEGIS
10:15	METHODS FOR EM WAVE CHARACTERISATION OF GRAPHENE-CONTAINING MATERIALS **Prof. Jivko Kissovsky**, *Faculty of Physics, University of Sofia, Sofia, Bulgaria*	AEGIS

Chairperson: Prof. Elena Tatarova

11:30	RAMAN SPECTROSCOPY OF CARBON MATERIALS **Prof. Miroslav Abrashev**, *Faculty of Physics, University of Sofia, Sofia, Bulgaria*	AEGIS
12:15	EM WAVE ABSORPTION BY GRAPHENE ON POROUS SUBSTRATES **Mr. Simeon Marinov**, *Faculty of Physics, University of Sofia, Sofia, Bulgaria*	AEGIS
14:00	PLASMA-ENGINEERED 2D MATERIALS FOR ENERGY STORAGE DEVICES **Dr. Neelakandan Marath Santhosh**, *Department of Gaseous Electronics (F6), Jožef Stefan Institute, Ljubljana, Slovenia*	AEGIS
15:20	IN-LINE AIR PLASMA TREATMENT OF PA6 YARN FOR IMPROVED DYE UPTAKE **Mr. Juš Polanšek**, *Department of Gaseous Electronics (F6), Jožef Stefan Institute, Ljubljana, Slovenia*	AEGIS

FRIDAY, JUNE 12

Chairperson: Dr. Mariana Atanasova

9:30	SECONDARY ELECTRON EMISSION PROPERTIES OF GRAPHENE AND N-GRAPHENE PRODUCED BY PLASMA **Dr. Neli Bundaleska**, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal*	T3
10:15	PLASMA ENABLED GRAPHENE-BASED NANOCOMPOSITES FOR PHOTOCATALYTIC APPLICATIONS **Dr. Edgar Felizardo**, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal*	T3

Chairperson: Dr. Neelakandan Marath Santhosh

11:30	PLASMA-ASSISTED SYNTHESIS OF ADVANCED GRAPHENE-BASED MATERIALS FOR URANIUM AND RARE EARTHS RECOVERY AND H_2 STORAGE APPLICATIONS **Dr. Ana Dias**, *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal*	T3
12:15	NON-THERMAL PLASMA TREATMENT AS A SUSTAINABLE APPROACH FOR WASTEWATER REUSE IN HYDROPONIC FARMING **Dr. Plamena Marinova**, *Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria*	T3
14:00	WORKING-GAS-DEPENDENT OXIDATIVE EFFECTS OF HIGH-FREQUENCY IMMERSED PLASMA IN A DEOXYRIBOSE MODEL **Dr. Todor Bogdanov**, *Department of Medical Physics and Biophysics, Faculty of Medicine, Medical University–Sofia, Sofia, Bulgaria*	T3

SATURDAY, JUNE 13

Chairperson: Dr. Evgenia Benova

9:30	TENTATIVE VALIDATION OF THE HYPOTHESIS OF CONSTRAINED PLASMA DYNAMICS **Prof. Alexander Blagoev,** *Faculty of Physics, University of Sofia, Sofia, Bulgaria*	T1
10:15	SELF-CONSISTENT GAS-TEMPERATURE COUPLING IN A GOLLISIONAL–RADIATIVE MODEL OF ATMOSPHERIC-PRESSURE ARGON PLASMA **Dr. Mariana Atanasova**, *Faculty of Mathematics and Informatics, Sofia University, Sofia, Bulgaria*	T2
11:30	COLLISION-STRENGTH MODELLING OF UPPER-LEVEL 5P–4D–6S KINETICS IN AN ATMOSPHERIC-PRESSURE RF ARGON PLASMA **Dr. Ivailo Atanasov**, *Faculty of Medicine, Medical University – Sofia, Sofia, Bulgaria*	T2
11:30	**Closing**	

COLD PLASMA FOR FOOD: PRESERVATION OF NUTRIENTS AND SHELF LIVE EXTENSION

J. Pawłat[1]*, M. Kwiatkowski[1], P. Terebun[1], D. Zarzeczny[1], A. Starek[2], M. Krajewska[2], A. Sagan[2], I. Niedźwiedź[3], R. Różyło[4], D. Andrejko[2], E. Grządka[5], B. Chudzik[6], B. Budzyńska[7]

[1]Dept. Electrical Eng.& Smart Technol., Lublin University of Technology, PL
[2]Dept. Biol. Bases of Food and Feed Technologies of University of Life Sciences in Lublin, PL
[3]Dept. Microbiol., Biotechnol. and Human Nutrition, University of Life Sciences in Lublin, PL
[4]Dept. Food Engineering and Machines, University of Life Sciences in Lublin, Lublin, PL
[5]Faculty of Chemistry, Institute of Chemical Sciences, UMCS, PL
[6]Dept. Biology and Biotechnology, UMCS, PL
[7]Independent Laboratory of Behavioral Studies, Medical University of Lublin, PL
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This study explores the application of glidearc plasma (GAD) as an innovative method for improving the quality, safety, and shelf life of selected food products and biomaterials. The research targets included a wide range of food matrices, including carrot-banana smoothie, fresh bovine milk, tomato juice, and bakery products such as gluten-free and wheat-rye bread. Plasma treatment was carried out using a two-electrode GAD system operating under atmospheric pressure with air or nitrogen as working gases at 50 Hz, 3.8 kV, and 40 W, ensuring non-thermal conditions, with sample temperatures remaining below 30 °C for liquids and 38 °C for solid products. GAD treatment proved highly effective in reducing microbial contamination across all tested products. In tomato juice, a 300-second exposure significantly improved microbiological quality, reducing total aerobic microorganisms by over 2 log units after storage and extending shelf life to 10 days under refrigeration. A longer treatment of 600 seconds further decreased microbial counts below the quantification limit (<1 log CFU/mL). Importantly, plasma processing preserved key physicochemical parameters, including pH, soluble solids (Brix), lycopene, and vitamin C content, while also stabilizing these properties during storage. In contrast, untreated juice exhibited substantial microbial growth and progressive deterioration. In liquid food systems, CAP showed additional benefits beyond microbial inactivation. Plasma-treated milk retained up to 89% of B-group vitamins, outperforming conventional thermal processing methods. Toxicological evaluation using zebrafish larvae confirmed the safety of plasma-treated milk, as evidenced by improved survival rates. In the case of carrot–banana smoothie, a novel combination of CAP and sumac spice resulted in enhanced nutritional properties, including increased levels of minerals, sugars, vitamin C, and polyphenols. However, toxicity assays revealed that high concentrations of sumac could be harmful due to its low pH, causing complete mortality in diluted samples, highlighting the need for careful formulation.

In conclusion, a GAD plasma treatment represents a versatile and effective non-thermal conditioning technology, it enhances microbiological safety, extends shelf life, and maintains or even improves nutritional quality. Nevertheless, process optimization and further toxicological studies are required, particularly when CAP is combined with bioactive additives, to ensure safety and maximize its potential for industrial applications.

Acknowledgments: We are grateful for the fruitful discussions in the following cooperative initiatives: NAWA Strategic Partnerships Programme agreement no BPI/PST/2024/1/00082/U/00001, COST CA20114 (Therapeutical applications of Cold Plasmas); CA23104 (Mainstreaming water reuse into the circular economy paradigm), and CEEPUS CIII-AT-0063.

DETERMINATION OF THE HEAT FLUX IN THE WEST TOKAMAK DIVERTOR

M. Dimitrova[1,2], J. P. Gunn[3], P. Ivanova[2], E. Vasileva[2], J. Kovačič[4], K. Raykov[2], M. Mitov[5,6], E. Hasan[2], J. Gaspar[3] and the WEST team

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Langmuir probes embedded in plasma-facing components are frequently employed to estimate the heat flux impacting them. Net non-ambipolar current flowing onto a tokamak divertor [1] affects its heat loading; as does the ion temperature, a quantity that is almost never measured.

Concerning non-ambipolar currents, "pop-up" Langmuir probes [2] installed in the WEST divertor provide local estimates of the heat loading using standard sheath theory. As recently observed in the COMPASS tokamak [3], when the floating potential is negative, corresponding to a strongly non-ambipolar case with net electron flow to the divertor surface, the heat transmission coefficient (γ) value can be as much as a factor of two higher than the value of 7 ordinarily assumed [4] under ambipolar conditions.

Concerning the ion temperature, a retarding field analyzer (RFA) has been in operation for more than one year on the WEST tokamak to measure that quantity in the outer divertor. It was found that the ion temperature in attached plasma regimes is not even close to the electron one, but it is rather 4-6 times higher [5].

These effects have a radial distribution in the divertor with a maximum influence around the outer strike point where the electron temperature typically peaks.

Acknowledgments: This research was partially supported by contract No KP-06-N68/2 between the Bulgarian National Science Fund and the Institute of Electronics, Bulgarian Academy of Sciences and by the Joint Research Project between the Bulgarian (IC-CZ/03-04/2025-2026) and Czech Academies of Sciences (BAS – 25-05).

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[3] M. Dimitrova *et al Plasma Phys. Control. Fusion* **66** (2024) 115014
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[5] P. Ivanova *et al Measurement Science and Technology* (2026) (in press)

ANTIBACTERIAL POTENTIAL OF COLD MICROWAVE ARGON PLASMA IN AN EXPERIMENTAL PERI-IMPLANT ENVIRONMENT

M. Simeonova[1], T. Bogdanov[1]

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Peri-implant infections remain a major challenge in contemporary dental implantology due to the persistence of bacterial biofilms on implant surfaces and the limited efficacy of conventional decontamination protocols. This study investigates the antimicrobial potential of low-temperature microwave argon plasma as a physical approach for dental implant surface decontamination under in vitro conditions. A 3D-printed mandibular bone segment with an inserted titanium dental implant was used to simulate a peri-implant environment. The model system was inoculated with bacterial suspensions of Streptococcus mutans NBIMCC 1786, representing an opportunistic oral pathogen, and Chromohalobacter canadensis NBIMCC 9077, used as a comparative extremophilic bacterial strain. Plasma treatment was performed using an atmospheric-pressure non-equilibrium microwave argon plasma source operating at 2.45 GHz, 10 W microwave power, and 5 L/min argon flow, with exposure times of 1, 3, 5, and 7 minutes. The antimicrobial effect was evaluated by optical density measurements and culture-based observations during the post-treatment period.

The results demonstrated a pronounced growth-inhibitory effect after plasma exposure, particularly within the first 24 hours. However, the response was species-specific and not strictly dependent on longer treatment duration. Chromohalobacter canadensis showed rapid inhibition with limited additional benefit from prolonged exposure, while Streptococcus mutans exhibited a non-linear response, with shorter treatments producing a more stable inhibitory effect in some experimental conditions. These findings suggest that low-temperature microwave argon plasma has promising potential as an alternative method for implant surface decontamination, while also emphasizing the need for optimized, microorganism-specific plasma treatment protocols.

IRRADIATION TESTING OF ANTIMONY-BASED HALL SENSORS IN DEMO-RELEANT CONDITIONS

M. Ivanek[1,2], I. Duran[1], S. Entler[1], P. Sladek[1], O. Bares[1], J. Soltes[3], L. Viererbl[3], T. Melichar[3], L. Stepan[4], J. Reboun[5], P. Turjanica[5], R. Bankov[1]

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The measurement of magnetic field in fusion reactors places high demands on sensor technologies operating under extreme conditions. Metallic Hall sensors demonstrated sufficient tolerance to high temperatures and in ionizing radiation and have been chosen for deployment in ITER as Outer-Vessel steady state magnetic field diagnostics [1]. However, the operational environment of the European demonstration fusion power plant (EU-DEMO) is expected to be more severe, with neutron fluences exceeding ITER levels by up to two orders of magnitude [2]. Current research activities aim to address the thermal stability of these sensors at EU-DEMO-relevant temperatures but their performance under the corresponding radiation conditions has not been explored.

To extend the qualification to the more demanding EU-DEMO radiation environment, an instrumented high-fluence neutron irradiation experiment was conducted in which antimony Hall sensors were exposed to neutron and gamma radiation in the core of the LVR-15 research reactor. After 6 irradiation reactor cycles, the sensors were exposed to fast neutron (E >0.1 MeV) fluence of 5×10^{20} cm^{-2}. Despite this exposure, no critical degradation was observed, indicating robustness in their sensing performance. These findings provide important experimental evidence supporting the viability of metallic Hall sensors for magnetic diagnostics in future fusion reactors. This work outlines the experimental approach and discusses the key results obtained.

Acknowledgments: This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No
101052200 — EUROfusion). The work was also supported by MEYS project number 9D22001. The work was supported by the TACR project Magnetic sensors for thermonuclear energy reactors No. TK03030070, and by Strategy AV21 of the Czech Academy of Sciences within the research program "Sustainable Energy". Presented results were obtained with the use of infrastructure Reactors LVR-15 and LR-0, which is financially supported by the Ministry of Education, Youth and Sports - project LM2023041. Views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

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[2] Luis R., et al., Neutronics Simulations for DEMO Diagnostics. Sensors (2023) Sensors, https://doi.org/10.3390/s23115104.

PLASMA PROPERTIES IN THE VICINITY OF THE LAST CLOSED FLUX SURFACE IN HYDROGEN AND HELIUM DISCHARGES IN THE TJ-II STELLARATOR

E. Vasileva[1], M. Dimitrova[1], D. López-Bruna[2], P. Ivanova[1], E. Hasan[1]

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The aim of the work is to confirm the working hypothesis [1] that the ionization of hydrogen and deuterium neutrals by thermal electrons penetrating the scrape-off layer (SOL) from the bulk plasma is the main reason for the appearance of a bi-Maxwellian electron energy distribution function (EEDF) in the SOL of tokamak plasmas. To validate this assumption, radial measurements of the electron temperatures and densities, or the plasma properties, in helium plasmas in the TJ-II stellarator were performed using probes.

The advantage of the first-derivative probe technique [2] is that it provides information about the EEDF; this is why we used it to process these measurements. We thus found that in the vicinity of the last closed flux surface the EEDF is bi-Maxwellian; i.e., together with thermal electrons with energies in the range 10 – 30 eV, there exists a cold electron group with energies of 5 –7 eV.

To verify the above experimental findings, we attempted to confirm that the appearance of the cold-electron group and its density profile are compatible with the radial locations where the ionization source of electrons is significant. The calculations were performed using the EIRENE code [3] in both hydrogen and helium plasmas. Thus, in fact, the differences in the positions of appearance of a bi-Maxwellian EEDF can be explained by differences in the rate coefficients for ionization of hydrogen and helium [4].

In conclusion, the existence of a non-Maxwellian EEDF depends on the type of working gas and the electrons temperature near the SOL. In the case of the presence of a sufficient number of neutrals and electrons with energies exceeding the ionization energy of the neutrals, one should expect to observe a non-Maxwellian EEDF [5].

Acknowledgments: This research was partially supported by contract No KP-06-N68/2 between the Bulgarian National Science Fund and the Institute of Electronics, Bulgarian Academy of Sciences, and by the Joint Research Project between the Bulgarian (IC-CZ/03-04/2025-2026) and Czech Academies of Sciences (BAS – 25-05).

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[5] M. Dimitrova *et al Plasma Phys. Control. Fusion* **66** (2024) 075022

WEDNESDAY, JUNE 10

DIAGNOSTICS INTERFACE WITH PLASMA FACING COMPONENTS FOR COMPASS UPGRADE TOKAMAK

M. Dimitrova[1,2], P. Bilkova[1], I. Duran[1], T. Markovic[1], K. Kovarik[1], M. Varavin[1], J. Caloud[1,3], J. Adamek[1], D. Naydenkova[1], S. Lukes[1,3], M. Komm[1], O. Bogar[1], M. Imrisek[1],. Mikszuta-Michalik[1], J. Svoboda[1,3], P. Böhm[1], J. Cavalier[1], V. Weinzettl[1], R. Dejarnac[1], M. Durovec[1], D. Sestak[1], V. Veselovsky[1], P. Belina[1], P Ivanova[2], P. Vondracek[1], M. Hron[1], R. Panek[1], and the COMPASS Upgrade team

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The COMPASS Upgrade tokamak, currently under construction at IPP Prague [1, 2], is a medium-size, full metal, high magnetic field (up to 5 T), high plasma density (above 10^{20} m^{-3}) device planned to be operated with hot walls (up to 500 °C). Various constraints on and requirements for the design of individual diagnostics have been published in [3], while the status of the progress in the diagnostic plans for the first plasma has been reported in [4].

In this work, the current design of the plasma facing components (PFCs) [5] on COMPASS Upgrade tokamak is shown, together with all the diagnostic systems planned to be implemented on them. The diagnostics are presented in two groups for better visualization – the first one includes those in limiters; the second comprises those in a closed divertor. Our attention is focused on the difficulties related to accommodating various diagnostics, while avoiding possible complications during tokamak operation.

The diagnostics included and the main interface with the PFCs are: magnetic sensors behind the PFCs (and the limited space available); embedded mirror for the sub-millimeter interferometer; openings in the PFCs for soft and hard X-ray diagnostics, slow and fast bolometry, impurity spectroscopy monitors, divertor Thomson scattering, Langmuir probes [6] and reciprocating manipulators for probe diagnostics, divertor manipulator for samples, MANTIS imaging spectroscopy system, grooves in PFCs and integrated holders for fiber Bragg gratings, shunt resistors, thermocouples, etc.

Acknowledgments: This work has been carried out within the framework of the project COMPASS-U: Tokamak for cutting-edge fusion research (No. CZ.02.1.01/0.0/0.0/16_019/0000768), by the Joint Research Project between the Institute of Plasma Physics of the CAS and the Institute of Electronics BAS BG (BAS – 25-05), co-funded by MEYS project No. 9D22001 and LM2023045.

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[3] V. Weinzettl *et al Fusion Eng. Des.* **146** (2019) 1703-1707
[4] V. Weinzettl *et al Fusion Eng. Des.* **191** (2023) 113545
[5] R. Dejarnac *et al Fusion Eng. Des.* **211** (2025) 114815
[6] M. Dimitrova *et al JINST* **17** (2022) P11018

PLASMA TECHNOLOGIES: FROM R&D TO COMMERCIAL

G. Paskalov

In this paper we overview and describe the characteristics of various types of RF plasma system, which are used for different applications such as: powder processing; plasma sintering; plasma sterilization; waste treatment; element separation and nano-powder synthesis.

Over the past decades RF plasma technology has been used in many areas, such as material science, electronics, basic physics, etc. Typically, the RF plasma system includes power supply (RF generator and matching network), plasma torch and reactor. Depending on the applications, two different RF plasma sources are used: inductive and capacitive. Most thermal plasma processes are based on inductively coupled plasma (ICP), which generates equilibrium plasma in the temperature range of 8000 to 12 000 K. The advantages of ICP torches are well known and described elsewhere. Non-equilibrium plasma is mostly used in the semiconductor industry and for some special applications, such as plasma synthesis of fine powder and bio-material surface treatment. We will focus on the present situation in this field by discussing commercial and R&D efforts. In this overview an attempt is made to present existing and future research and development related to RF plasma technology.

Powder processing: This technology refers primarily to the densification, spheroidization and purification of metal, ceramic and inter-metallic powders. The process of powder treatment contains a few stages: in-flight melting of the material, quenching and collection. RF plasma was successfully employed for many materials and a wide range of particle sizes.

1. Environmental applications

Dissociation of the hydrogen chloride in the RF plasma

The dissociation of HCl in the RF plasma discharge with the temperature above 6 000 K has thermodynamic character. The full dissociation of HCl to hydrogen and chlorine is achieved at the following conditions: plasma gas consisting of the mixture of Ar and HCl at ratio 1:1; plasma gas rate = 1 liter per second; discharge power = 10 kW. These results are confirmed by gas analysis of the product before and after the quenching device. The analysis of the gas mixture in the reactor shows that they contain argon, chlorine and hydrogen in molecular form. A similar RF plasma system was developed in cooperation with Kurchatov Science Center for plasma chemical decomposition of hydrogen sulfide. The efficiency of the process was demonstrated by using a 100-kW plasma torch. The pilot unit, having 600 kW power level was designed and tested at a gas refinery plant. An industrial plasma chemical reactor is based on a RF plasma system at a power level of 3 to 5 MW with optimal conversion level of hydrogen sulfide about 50 - 70% at a pressure of 1 – 10 atm, and an energy consumption of ~1.2 - 1.5 kWh/nm3 H2.

RF plasma system for medical waste treatment

This work is focused on the studies of RF plasma discharge with respect to use on bio-hazardous medical waste. The system includes liquid nitrogen crushing unit, plasma reactor, high temperature oxidizer and emission control system. The medical waste is processed in the plasma reactor under nitrogen in the atmosphere and reduces to carbon residue. The off gas is directed to the oxidizer and scrubbed before being discharged. The system works as a continuous batch. Processing rate is 1 ton/day. Total power required = 160 kW.

2. Plasma system for element separation

The separation of metallic elements and isotopes in fully ionized metal plasma has been studied since 1966. In this presentation we describe the characteristics of a system in which metallic elements: copper and gold are separated by using ionized plasma in a strong magnetic field. Copper/gold alloy was sputtered in microwave plasmas, ionized and accelerated by RF antenna in an axial magnetic field. The uniformity of plasma was controlled by optimizing plasma parameters and the axial magnetic field. Control of the plasma profile has been carried out by using microwave ICRH and special RF antenna configuration. The sputter plate (copper Dore bar) was biased by negative DC voltages in the range of -100 to 1000 Volts. The RF antenna was tuned to the ion cyclotron frequency and sharp resonances were observed for collected material. The purity of the product (gold) depends on the configuration of the collector and substrate's material.

3. Plasma sintering

Technology is focused on zirconia nano-crystalline structure modification. It is shown that RF plasma technology can process (sinter) partially and fully stabilizes Zirconia in flight without grain growth and binders. Plasma processed Zirconia has nearly 100% theoretical density. Pre-existing oxidation and contamination are evaporated during plasma process. Atmospheric and low-pressure plasma systems are presented. The process of producing pure zirconia powder from Zircon ($ZrSiO_4$) also is presented.

PLASMA TECHNOLOGIES FOR WATER TREATMENT AND PLANT STRESS MITIGATION

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Plasma activated water (PAW) has attracted increasing interest across the scientific fields, due to its effect on plant growth and bacterial inactivation. In a plasma-liquid system, the reactive oxygen and nitrogen species (RONS) from plasma are transferred into aqueous media. This results in water with changed properties (e.g., lower pH and higher conductivity) and enriched with nitrogen species and hydrogen peroxide. Nitrogen species in water promote plant growth, while hydrogen peroxide and a lower pH contribute to antibacterial properties [1]. The PAW can be prepared from different types of water, based on the intended applications – distilled water, tap water, or even wastewater [2]. In wastewater treatment, plasma treatment leads to degradation of pollutants, including antibiotics or microplastics [3].

In plant systems, PAW has shown potential to enhance stress tolerance and modulate physiological responses, offering a promising approach for mitigating abiotic stress. This work aims to investigate the effects of PAW on plant growth and elemental uptake under abiotic stress conditions, including heavy metal contamination, salinity, drought, and wastewater containing emerging contaminants (e.g. heavy metals or microplastics). Water was treated by the pin-hole discharge generating plasma directly in liquids (Faculty of Chemistry, Brno University of Technology). The water was characterized by the changes of pH, conductivity, and concentrations of H_2O_2, NO_2^-, and NO_3^-. Plants were cultivated under controlled conditions and exposed to abiotic stressors, such as media contaminated with cadmium or lead or saline solutions. Growth parameters and stress-related responses were evaluated, with particular attention to elemental uptake and redistribution. The spatial distribution of Cd, Pb, Na, and various nutrients was determined by the Laser-Induced Breakdown Spectroscopy (LIBS). This technique is based on the detection of optical emission from laser-induced plasma and can detect any element of the periodic table [4].

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NON-THERMAL PLASMA AS A TOOL FOR ENHANCING ONION YIELD UNDER FIELD CONDITIONS

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Conventional agriculture relies on chemical fertilizers and pesticides with negative impacts on the environment and human health [1]. Non-thermal plasma is a promising sustainable alternative, as it generates reactive oxygen and nitrogen species (RONS) with stimulating and antimicrobial effects that can enhance seed germination, promote plant growth, and improve pathogen resistance.[2] Plasma-activated water (PAW) provides a practical approach for field applications, as reactive species are transferred into the liquid phase, resulting in water with altered physicochemical properties (e.g., lower pH and higher conductivity) and enrichment in nitrogen species and hydrogen peroxide. These compounds contribute to plant nutrition and antimicrobial activity, and recent studies have shown that PAW can improve germination, root development, and crop yield.[3]

The aim of this study was to determine whether plasma treatment could enhance onion (*Allium cepa* L., cv. Sturon) growth while maintaining or increasing the concentration of key volatile compounds, especially propanal and dimethyl sulfide. The work also includes the characterization of soil and PAW, as well as analytical methods for determining and characterizing volatile substances, such as UV–VIS spectrometry, atomic absorption spectrometry (AAS), proton transfer reaction time-of-flight mass spectrometry (PTR-TOF-MS) and gas chromatography-mass spectrometry (GC–MS). Planting experiments were conducted at seven locations using five treatment variants: untreated control, corona discharge plasma treatment with two sequential applications (10 s or 40 s), soaking in distilled water for 24 h, and immersion in plasma-activated water (PAW) for 24 h, with PAW generated by dielectric barrier discharge (DBD) for 2 min.[4] After harvest, twenty onions from one site were weighed, processed into liquid samples, and analyzed using PTR-TOF-MS to quantify volatile compounds; selected samples were further examined by GC–MS.

Although statistical significance was not achieved, all plasma treatments showed consistent positive trends compared to the control. The most notable improvement in onion growth and fragrance content was observed after two sequential 10-second corona discharge treatments. Wet treatment variants (distilled water vs. PAW) showed only minimal differences, suggesting that immersion itself may represent the primary biological stimulus independent of plasma activation. Future research should focus on increasing experimental replication across multiple sites while employing more homogeneous plasma sources to improve statistical robustness.

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THURSDAY, JUNE 11

Workshop Advanced Electromagnetic Graphene-based shields via plasma Induced Synthesis (AEGIS)

ADVANCED ELECTROMAGNETIC N-GRAPHENE-BASED SHIELDS VIA PLASMA INDUCED SYNTHESIS

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Materials with tunable electromagnetic properties are in high demand for effective electromagnetic interference (EMI) shielding. However, carbon-based absorbers produced via conventional multistep chemical processes often exhibit limited tunability due to the complex and non-linear interplay of numerous synthesis parameters. Here, we present a plasma-enabled strategy for the controlled fabrication of ultralight nanocomposites exhibiting absorption-dominated EMI shielding. This approach employs a one-step, plasma-assisted assembly of free-standing nitrogen-doped graphene (N-graphene) sheets uniformly decorated with metal oxide nanoparticles, which are subsequently integrated into a polymer matrix. The microwave plasma environment enables multiple processes to occur simultaneously, including the synthesis of free-standing N-graphene nanosheets, in situ formation of nanoparticles from micron-scale precursors, surface functionalization, and the generation of multiple chemical phases (i.e., multiphase hybridization), while also promoting hierarchical structural organization. This integrated process allows precise control over interfacial interactions and electromagnetic loss mechanisms. Overall, the proposed scalable plasma-enabled approach offers a streamlined route to multifunctional, lightweight nanocomposites with tailored electromagnetic properties. It eliminates the need for complex multistep chemical treatments and facilitates systematic investigation of structure–property relationships for next-generation EMI shielding materials.

METHODS FOR EM WAVE CHARACTERISATION OF GRAPHENE-CONTAINING MATERIALS

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Graphene-containing materials have attracted significant attention due to their unique electromagnetic (EM) properties, making them promising candidates for applications in sensing, shielding, and advanced communication systems. This talk presents an overview of some contemporary methods for the characterisation of EM wave interactions with graphene-based composites and structures.

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RAMAN SPECTROSCOPY OF CARBON MATERIALS

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The basics of the theory and experiment of Raman spectroscopy will be briefly presented. The main advantages and disadvantages of this experimental method will be discussed. Information about the structural properties of various carbon materials (diamond, graphite, single-layer, multi-layer and vertical graphene, single nanotubes, nanofibers and amorphous carbon) that can be obtained from Raman spectra will be compared.

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EM WAVE ABSORPTION BY GRAPHENE ON POROUS SUBSTRATES

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Graphene materials have numerous applications electronics and communication technologies including been used for the production of EW absorbers and metamaterials. For the purpose of producing such composite materials with electromagnetic wave absorption properties, graphene nanostructures were deposited on silicon carbide (SiC) foam using a plasma-enhanced chemical vapor deposition method (PECVD). The characteristics of the produced composite material are measured using a vector network analyser, and from the obtained S-parameters, we calculate the dielectric permittivity within the frequency band 8-18 GHz. COMSOL software was also used to model the behaviour of the composite absorber within a waveguide.

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PLASMA-ENGINEERED 2D MATERIALS FOR ENERGY STORAGE DEVICES

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The growing demand for efficient, long-lasting, and sustainable energy storage requires advanced energy materials that offer fast charge/ion transport, high electrical conductivity, minimal internal resistance, and long-term stability. Two-dimensional materials, including graphene, MXene, layered double hydroxides, etc., show great promise owing to their large, open surfaces, short diffusion lengths, and tunable electronic structures, which can benefit electrochemical energy storage devices, including supercapacitors and batteries. However, their large-scale application remains limited due to issues with restacking, poor interfacial charge transfer, and insufficient conductivity. Besides, the material production is heavily dependent on wet-chemical or high-temperature processing routes that are often slow, chemically intensive, and difficult to scale. In this regard, a plasma-enabled soft-chemistry dry approach is considered an alternative, enabling rapid, solvent-free, and highly controllable synthesis and post-treatment of 2D materials, thereby allowing simultaneous control of growth, tailoring surface chemistry, manipulating structural defects, heteroatom incorporation, and interface activation. This paper presents a comprehensive overview of how plasma serves as an all-in-one platform for synthesizing, processing, and tailoring surface properties with desired features. As a synthesis medium, plasma assembles gas molecules into a nanostructure or reforms a material into nanoarchitecture. In addition, the paper discusses the potential of plasma to improve electrochemical properties via interlayer engineering, redox-active centres, and hybrid morphologies for next-generation electrochemical energy storage and conversion devices. Representative examples include plasma-surface-engineered 2D materials and their hybrids, which exhibit improved electrochemical activity and have been explored in multivalent aluminium batteries and supercapacitors [1–3]. These findings reveal that a fast, facile, and cost-effective plasma surface-engineering process establishes a promising pathway for scalable synthesis and processing of advanced nanostructures, which can be used as electrodes, enabling their practical application in high-performance supercapacitors.

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IN-LINE AIR PLASMA TREATMENT OF PA6 YARN FOR IMPROVED DYE UPTAKE

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Atmospheric-pressure plasma treatment is a promising route for modifying polyamide surfaces and improving textile processing performance [1]. In this contribution, we present air-plasma treatment of polyamide 6 (PA6) yarn as a pretreatment for faster and more efficient low-temperature dyeing. The main focus is a surface dielectric barrier discharge operated in air, where the plasma dose was adjusted through treatment time and process conditions in order to maximize acid-dye uptake while avoiding excessive surface degradation. Dyeing experiments with Becamide Blue showed that, within a narrow processing window, plasma pretreatment enabled strongly enhanced dye uptake in a 40 °C dye bath after only 3 min, reaching up to one order of magnitude higher uptake than the untreated reference. These results are consistent with previous reports that atmospheric-pressure plasma can enhance dyeing behaviour and reduce the thermal demand of nylon processing [2,3].

Surface analysis by FTIR and XPS showed that the plasma removed the hydrocarbon finish and introduced a moderate concentration of polar oxygen-containing groups, including OH and COOH species, while partial protonation of amide nitrogens to NH_3^+ created additional ionic sites for the anionic dye. These changes increased wettability and favoured rapid dye adsorption. However, the results also showed that the treatment window is limited: at excessive plasma dose, less favourable nitrogen-oxygen species accumulated at the surface, reducing the beneficial effect on dyeing. The work therefore identifies the balance between activation and over-treatment as the key requirement for practical implementation.

To support industrial translation, we also developed a simpler and more reliable in-line dielectric barrier discharge system for continuous yarn treatment. This second system was tested at line speeds of 40 and 80 m min^{-1} and at powers between 70 and 150 W. Under optimal conditions, it achieved about 70 % higher dye uptake after 3 min at 40 °C than the untreated sample. It also offered easier integration into production lines and greater operational robustness than the first system. Together, these results show that air-plasma treatment is a promising and scalable pretreatment for energy-efficient dyeing of PA6 yarn.

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FRIDAY, JUNE 12

SECONDARY ELECTRON EMISSION PROPERTIES OF GRAPHENE AND N-GRAPHENE PRODUCED BY PLASMA

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Graphene and graphene-based materials have attracted considerable interest in a wide range of applications due to their uniue physical and chemical properties. However, conventional synthesis methods are often time-consuming and involve complex chemical processes that rely on toxic reagents, frequently resulting in materials of limited quality. In contrast, plasma-based synthesis of advanced two-dimensional nanostructures offers an environmentally friendly alternative, eliminating the need for catalysts or hazardous chemicals while enabling precise control over the growth process.

Free-standing graphene structures produced at the Plasma Engineering Laboratory of IPFN, using a microwave plasma method under atmospheric pressure conditions were investigated as potential low secondary electron emission (SEE) materials. The development of materials with low SEE is of critical importance for a wide range of modern technologies, spanning applications from space systems (e.g., telecommunication satellites) to particle accelerators. In parallel, chemically inert graphene coatings were prepared via electrophoretic deposition in collaboration with CEFITEC, Universidade Nova de Lisboa. Furthermore, the tunability of SEE properties through nitrogen doping was demonstrated. The observed reduction in SEE is attributed to a synergistic effect involving modifications of the electronic structure and changes in graphene plasmon behavior induced by the incorporation of nitrogen atoms into the graphene lattice, combined with the material's distinctive crumpled morphology.

Plasma enabled graphene-based nanocomposites for photocatalytic applications

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Photocatalysis finds applications both in the synthesis of valuable materials (such as in the conversion of CO_2 in solar fuels) and in the degradation of undesirable chemical components and inactivation of microbial pathogens (e.g. self-cleaning coatings).
Research conducted on metal oxide photocatalysts, particularly TiO_2, shows that their incorporation into carbon-based structures can enhance the photocatalysis rate and/or lower the activation energy.

The Institute of Plasmas and Nuclear Fusion has developed a disruptive plasma technology and several working prototypes, that allows the fabrication of high-quality graphene and derivatives (N-graphene, Graphene/N-graphene-metal oxides) using cheap and readily available carbon precursors. Using this technology several graphene/N-graphene-TiO2 composites were synthetized and characterized. Structural and optical characterization confirmed that the incorporation of graphene does not compromise the crystallinity of TiO_2 and promotes absorption in the visible range and promotes charge separation. Preliminary photocatalytic degradation tests with methylene blue evidenced the enhanced adsorption capacity of graphene-containing composites, attributed to π–π interactions, although the overall photocatalytic activity was lower than that of commercial P25, highlighting the importance of the TiO_2/graphene ratio. In gas-phase CO_2 photoreduction experiments, the formation of CO and CH_4 was confirmed under batch conditions, validating the photocatalytic activity of the studied materials. CO was identified as the dominant product, in line with its simpler two-electron reduction pathway, whereas CH_4, which requires an eight-electron process, was produced in lower amounts.
The results indicate the potential of graphene derivatives as promoters in heterogeneous photocatalytic systems, while underscoring the need for structural and operational optimization to enable the efficient conversion of CO_2 into solar fuels.

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PLASMA-ASSISTED SYNTHESIS OF ADVANCED GRAPHENE-BASED MATERIALS FOR URANIUM AND RARE EARTHS RECOVERY AND H_2 STORAGE APPLICATIONS

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The growing demand for critical raw materials and clean energy solutions has intensified the need for efficient approaches for resource recovery and energy storage. Graphene-based materials are being developed as advanced adsorbents and membranes for the selective extraction of rare earth elements (REEs) from waste sources. Their high surface area and tunable surface chemistry enable targeted environmentally friendly extraction processes. At the same time, hydrogen is widely regarded as a key energy carrier for a sustainable future. However, its large-scale implementation is hindered by challenges associated with safe and efficient storage. Conventional approaches, including cryogenic storage, high-pressure systems, and metal hydrides, present limitations related to safety, cost and energy efficiency. Solid-state hydrogen storage solutions, especially porous materials and metal alloys/hydrides are being studied as safe and efficient solutions for reversible H2 storage applications. In this work, microwave plasma-based technologies [1, 2] are used for the synthesis and functionalization of advanced graphene-based materials with tailored physicochemical properties. The plasma environment enables precise control over surface chemistry, defect engineering, heteroatom doping, and metal particles anchoring. The synthesized graphene-based materials were systematically characterized using XPS, Raman, XRD, SEM and TEM to evaluate their structural, morphological and surface properties. Their performance was investigated for two key applications, selective recovery of uranium and REEs from aqueous systems; and hydrogen storage. Results demonstrate that plasma functionalization significantly improves adsorption capacity, selectivity, and kinetics for metal ion recovery, attributed to the introduction of active binding sites and increased surface area. In parallel, the engineered materials exhibit promising hydrogen storage capabilities, benefiting from optimized pore structure and surface functionalities that enhance physisorption and potential spillover mechanisms.

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PLASMA WASTEWATER TREATMENT FOR AGRICULTURE REUSE

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The challenge for the developing modern agriculture is to reduce the amount of water used for irrigation of plants or to find alternative sources of water, improve plant development, increase crop yields and last but not least reduce the use of synthetic fertilizers and pesticides. One of the great interests is the possibility that plasma technology may have a stimulating effect on seed germination and bulb growth and positive influence on plant development. Plasma treatment and decontamination of water can reduce the use of fertilizers and pesticides in agriculture ant to lead to cleaner soils and safe food production. The presence of pathogens and bacteria in the water used to irrigate cultivated areas can harm crops and greatly reduce yields. Plasma water treatment is a proven method to reduce these microorganisms and the introducing of nutrients into the water at the same time. Since plants diseases caused by irrigation with wastewater can lead to deficiency in the nutrients in the plants in different stages of development the possibility to monitor them is of great importance. Laser induced breakdown spectroscopy (LIBS) was used for determination of elemental distribution in the plants parts. Municipal drinking water and wastewater after treatment with plasma was used for irrigation of plants were grown in hydroponic system in order to determine the plasma treatment condition that have beneficial effect on the plants. The variations in the content of micro elements and macro elements in plants treated with wastewater, plasma activated wastewater and plasma activated water were determined. This work consists of preliminary investigations into the application of a novel plasma system Beta device resonator a microwave Argon plasma torch at 2.45 GHz developed by the the Clean and Circle centre of competence, University of Sofia as promising and suitable for the treatment of water and wastewater for agricultural reuse.

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WORKING-GAS-DEPENDENT OXIDATIVE EFFECTS OF HIGH-FREQUENCY IMMERSED PLASMA IN A DEOXYRIBOSE MODEL

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High-frequency immersed plasma is an effective tool for generating reactive oxygen and nitrogen species directly in liquid media. In this study, we investigated the working-gas-dependent oxidative effects of high-frequency immersed plasma in a deoxyribose-based model system. Plasma treatment was performed using air and argon as working gases, and oxidative degradation was assessed through the formation of thiobarbituric acid-reactive substances. In parallel, the accumulation of long-lived reactive species, including hydrogen peroxide, nitrites, and nitrates, was evaluated spectrophotometrically.

The results demonstrated a treatment-time-dependent increase in deoxyribose degradation and reactive species formation under both gas conditions. However, argon plasma produced more pronounced oxidative effects, particularly in the presence of Fe(II), where a synergistic enhancement of degradation was observed. In contrast, air plasma induced a biphasic response in iron-containing samples, suggesting plasma-induced modulation of iron availability and redox state. These findings indicate that the oxidative outcome of plasma treatment is governed not only by reactive species generation but also by the interaction between plasma chemistry and transition-metal redox processes.

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SATURDAY, JUNE 13

TENTATIVE VALIDATION OF THE HYPOTHESIS OF CONSTRAINED PLASMA DYNAMICS

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The hypothesis of constrained plasma dynamics deals with a feature of the equation of motion of the single-fluid MHD model of the plasma. This equation contains terms which can be generically described as an acceleration term, a momentum convection term, a magnetic force density term and a pressure gradient term. For the case of a finite plasma created within a neutral medium, the acceleration term, the momentum convection term and the pressure gradient term are significantly constrained by the interaction dynamics of the neutral species which are dominant in the boundary regions. In this situation, the externally controlled magnetic force density term can be made to vary on a timescale much shorter than the timescale dictated by the interactive dynamics of the ions and the neutrals, leading to violation of the equation of motion. The hypothesis of constrained plasma dynamics posits that in such situations, the apparent deficit in the force density drives electron convection currents which create a poloidal magnetic field, which ensures that the net magnetic force density is commensurate with the slower dynamics constrained by the coupling between ions and neutrals. Microscopic mechanisms for generation of such electron currents have already been proposed. This talk reports on recent experiments where the current through a spark channel in a low-pressure spark is made to oscillate over tens-of-microseconds timescale. The magnetic force density is then repeatedly forced to pass through zero. A pair of clockwise and counterclockwise diamagnetic loops, a magnetic probe oriented to detect the azimuthal magnetic field and an electric displacement rate probe are deployed. The results, which include observation of poloidal magnetic flux emission, provide a tentative validation of the hypothesis of constrained dynamics.

SELF-CONSISTENT GAS-TEMPERATURE COUPLING IN A GOLLISIONAL–RADIATIVE MODEL OF ATMOSPHERIC-PRESSURE ARGON PLASMA

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Atmospheric-pressure argon plasmas are commonly modeled under the assumption of fixed gas temperature. In the present work, a self-consistent gas-temperature calculation is introduced into a collisional–radiative model of microwave-sustained argon plasma. The implementation couples the plasma kinetics to a simplified radial heat-conduction balance, allowing the neutral gas temperature to evolve together with the electron kinetics and heavy-particle chemistry.

The influence of the gas-temperature calculation is investigated over a wide range of electron densities. At low and moderate densities, the results remain close to those obtained with fixed gas temperature. At high electron densities, however, strong gas heating develops and substantially modifies the plasma kinetics. The increase of gas temperature reduces the neutral density, leading to lower effective electron-neutral collision frequency, reduced electron temperature, and changes in the balance between excitation, ionization, recombination, and radiative processes.

The calculations indicate a transition from a low-density electron-controlled regime to a high-density thermal-feedback regime characterized by saturation of the total photon emission rate and restructuring of the dominant radiative pathways. In particular, the strong upper-level cascade predicted by the fixed-temperature model is significantly suppressed when gas heating is treated self-consistently.

The results demonstrate that gas heating is not merely a secondary correction to the plasma energetics, but can fundamentally alter the sustaining kinetics and radiative signature of atmospheric-pressure argon discharges.

COLLISION-STRENGTH MODELLING OF UPPER-LEVEL 5P–4D–6S KINETICS IN AN ATMOSPHERIC-PRESSURE RF ARGON PLASMA

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A collisional–radiative model of argon plasma kinetics is extended by introducing an effective collision-strength description for near-degenerate excited-state mixing within the upper 5p–4d–6s blocks. This approach replaces the previously used oscillator-strength-based treatment for small-energy-gap transitions between these upper levels. The formulation is designed to avoid the unrealistically strong enhancement of excited–excited coupling characteristic of Bethe-type scaling at very small transition energies.

The influence of the modified kinetics is investigated over a wide range of electron densities under stationary argon plasma conditions. The calculations show that the new mixing model produces only moderate changes in the global discharge power balance and total ionization power density. However, substantial differences are observed in the steady-state population distribution within the upper excited levels.

The bounded collision-strength formulation suppresses population transfer into the 4d and 6s blocks while increasing the population of the 5p block and its cascade feeding of lower excited states, particularly 5s. As a consequence, significant changes are obtained in the relative contributions of stepwise ionization and radiative decay channels associated with the upper levels.

The strongest sensitivity is found in the radiative redistribution between the 4d–4p, 6s–4p, and 5p–4s transition groups, whose relative intensities exhibit systematic dependence on the effective collision-strength parameter. These results suggest that spectroscopic measurements may provide experimentally accessible constraints on near-degenerate excited-state mixing processes.

The study demonstrates that a bounded collision-strength approach provides a physically transparent alternative for describing near-degenerate coupling in collisional–radiative models, improving the interpretation of upper-level population kinetics and radiation redistribution in argon discharges.