COMPASS UPGRADE TOKAMAK: STATUS AND PLANS

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Abstract. The COMPASS Upgrade is a medium-sized, high-magnetic-field tokamak ($R = 0.9\,\mathrm{m}$, $B_t = 5\,\mathrm{T}$, $I_p = 2\,\mathrm{MA}$) currently under construction in Prague, Czech Republic. It will provide unique capabilities for addressing some of the key challenges in plasma exhaust physics, advanced confinement modes and advanced plasma configurations, as well as testing new plasma-facing materials and liquid metal divertor concepts. Overview of the engineering design of the main systems, including the vacuum vessel, central solenoid and poloidal field coils, toroidal field coils, support structure, cryostat, cryogenic system, power supply system and machine monitoring and protection system will be given. Next, description of foreseen auxiliary plasma heating systems and plasma diagnostics will be provided as well as a summary of the expected plasma performance and available plasma configurations.

Finally, summary of the priority topics for the future experimental programme will be presented, including a) alternative confinement modes, b) power exhaust incl. liquid metals, c) operation with a hot first wall and d) influence of plasma shape on pedestal stability and confinement.

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ADDRESSING NEW CHALLENGES IN MAGNETIC DIAGNOSTIC DEVELOPMENT ON COMPASS-U IN VIEW OF DEMO

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Abstract. Tokamak operation relies on the magnetic diagnostic for determination and control of the plasma configurations in real-time, through the measurement of the magnetic field generated by the plasma current distribution. As a new metallic first-wall tokamak aiming at addressing DEMO-relevant

challenges, the magnetic diagnostic in COMPASS-U must, likewise, address from the design stage technological challenges that were not present in previous devices and are foreseen to be commonplace in future reactors. The key challenges faced on the development of the magnetic diagnostic is presented, as well as innovative solutions regarding inductive sensors - digital signal integration; design of fully metallic inductive sensors and fast inductive sensors for oscillation detection; and effect of major conductive structures on the detection of plasma equilibrium. In addition, non-inductive Hall effect sensors will provide steady state magnetic field measurements on COMPASS-U, with advancements in these sensors being showcased. A key difference from COMPASS-U to DEMO is the presence of high neutron fluxes, the ongoing research and development of radiation-hard sensors is also presented.

FUSION PLASMA EDGE - THEORY AND MODELLING

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Abstract. Magnetic confinement fusion (MCF) reactors are considered as one of the safest, environmentally clean and practically endless energy sources in future. At present, different MCF test facilities are under operation (ASDEX-U, WEST, TCV, MAST, etc), some under construction (ITER, COMPASS-U, DTT, etc.) and design (DEMO, STEP, etc). A common feature of these devices is an extremely hot plasma in the center (100 million °C) and relatively cold (104-106 °C) plasma edge, where the latter serves as an insulator between the hot plasma core and device chamber elements, as well as a screening of impurity particles coming from these elements. Therefore, understanding of complex processes in the plasma edge and finding different ways of their control represent one of the hottest topics in MCF research. In the given presentation we describe the main features of the fusion plasma edge and the corresponding numerical tools for its study. We consider classical as well as intermittent transport in the plasma edge, plasma-wall interactions and the related atomic processes. For the numerical tools we describe full kinetic (PIC and Monte Carlo), gyrokinetic and fluid models of the fusion plasma edge, and as an example, present number of newest findings.

PERFORMANCE OF ITER TOKAMAK REACTOR DURING PLASMA TRANSIENT EVENTS – SERIOUS DESIGN CONCERNS!

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Abstract. A key obstacle to a successful magnetic fusion energy production is reactor performance during abnormal events. Abnormal events include plasma disruptions, edge-localized modes (ELMs), vertical displacement events (VDEs), and runaway electrons. While tremendous efforts are being pursued to find ways to mitigate such events, a credible reactor design must be able to tolerate few of these transient events without significant mitigation techniques. Accurate and detail prediction of plasma-facing and nearby components response to instabilities are essential for safe and reliable operation of future fusion devices. We have developed a comprehensive simulation package, HEIGHTS (High Energy Interaction with General Heterogeneous Target Systems), to enable detail 3-D investigation of the overall aspects of plasma-material interaction (PMI) phenomena during plasma transient events. Advanced numerical tools and solution methods in an integrated parallel environment were used to efficiently couple major key processes during the transient events, and in particular disruptions and giant ELMs. These include dynamic interaction of the escaping core plasma particles with the evolving and propagating secondary divertor vapor/plasma. The collisions, heating, and scattering of the disrupting energetic plasma particles with the propagating secondary "mini" plasma in tokamak magnetic field structure in realistic rector configuration are critical in assessing the damage to all interior components including hidden structure and the first wall which were not directly exposed to these transient events.

Despite developing numerous efficient numerical techniques and solution methods such calculations take several months on supercomputers to complete. Our preliminary results show, for the first time, that unmitigated transient events could cause significant damage to most interior and hidden components including the first walls that were not directly exposed to these events. The current ITER divertor design may need to be modified to mitigate these events. We investigated in detail the effects of plasma instabilities including disruptions, ELMs, VDEs, and runaway electrons on plasma facing components (PFC) and proposed/studied ways for mitigating such effects. Plasma instabilities cause both surface and bulk damage to plasma-facing and structural materials. The simulation showed that disruptions and high power ELMs cause excessive target erosion of candidate materials such as Be, C, and W and possible plasma contamination. Recent simulation, for example, predicted serious damage from plasma disruptions to nearby and hidden locations due to the secondary radiation resulting from the evolving vapor cloud on original disruption area. The simulation also showed that, in addition to the severe surface erosion, a single event such as VDE or runaway electrons could severely damage the reactor structural materials and disrupt operation for a significant time. We studied the overall effects of disruptions and giant ELMs on PFC. Self-consistent modeling included plasma particles deposition, divertor coating material melting, vaporization, ionization, and as result plasma plume formation and hydrodynamic expansion with shielding effect on the following core plasma deposition on divertor and with radiation fluxes to the nearby components. We also studied the effects of runaway electrons on PFC. The calculations were carried assuming a total energy density of 50 MJ/m^2, 50 MeV incident electrons energy, magnetic field angle of 5 deg, in a magnetic field value 8 T (inboard wall), and an impact duration 0.01 s. It is shown that for a standard geometry of first wall with beryllium armor on Cu substrate, Be can melt at the interface with the structural Cu material. To prevent melting of the heat sink and possible mitigation of the effect of runaway electrons, two solutions were proposed: increasing the beryllium thickness, or use of an additional "slowing down" insert layer above the heat sink structure. Because beryllium is harder to use (being toxic, etc.) the second option was proposed for the first wall heat protection. Similar analysis of structural components response was done for VDE relevant energy load. The high heat flux intensity during VDEs and their duration as well as the area involved in the interaction can significantly influence not only surface of PFC but also structural components and even coolant channels. Therefore, various possible scenarios of plasma impact during VDEs should be carefully predicted and accurately evaluated. Melting of metallic PFC such as tungsten divertor, macroscopic melt motion, and melt splashing are another important issues in fusion devices such as ITER. A viscous stability flow model is developed and applied to investigate the behavior of W-melt in a melt pool under the impact of viscous plasma. The onset conditions of viscous instability, most dangerous wavelengths, and growth rates are predicted for ITER-like conditions.

MICRO HOLLOW CATHODE DISCHARGES IN AR/N2 USED FOR BORON NITRIDE PECVD

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Abstract. A PECVD process based on Micro Hollow Cathode Discharges (MHCDs) in Ar/N2 mixture has been developed to deposit hexagonal boron nitride (h-BN), a material of choice for electronic and optoelectronic applications. We have shown the feasibility of h-BN deposition on large area substrates (2 inches) at relatively low temperature (800 °C). To optimize and better understand the deposition process, the discharge is characterized experimentally and through modelisations. In particular, we use Two-photon Absorption Laser Induced Fluorescence (TALIF) to measure the nitrogen atom density, a key parameter in the process. TALIF measurements show that the atomic nitrogen is produced inside the MHCD hole and can be transported over long distances using a pressure differential between the two sides of the MHCD. To achieve the h-BN deposition, the substrate holder must be polarized which involves an homogenization of the density profile along the substrate's surface.

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A FIRST PRESENTATION OF PLASMA SIMULATION EFFORTS AT MAGDRIVE

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Abstract. AGE is a new plasma simulation code under development at Magdrive and used to model the plasma within the thruster, enabling us to rapidly improve performance. Magdrive is developing the next generation of space plasma propulsion for more agile and efficient spacecraft, enabling high cadence avoidance maneuvers as space traffic increases, and new missions in in-orbit servicing and manufacturing. AGE is designed to advance plasma evolution through the use of a piecewise Gaussian approximation; this allows for tracking of plasma characteristics, including density, flow dynamics, temperature, and ionization states. AGE is written in C++ using an object-oriented paradigm, ensuring flexibility and scalability. The code is parallelized using MPI and can handle multiple fluids, elements and ionisation states. This underscores AGE's potential to contribute to product development, providing a robust tool for simulating the behaviour of plasma in diverse conditions.

RADIATION SHIELDING AND SHUTDOWN DOSE RATE ANALYSIS FOR THE ITER HIGH-RESOLUTION NEUTRON SPECTROMETER (HRNS)

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Abstract. HRNS is an ITER-dedicated system that will provide crucial information about plasma parameters such as DT ion fuel ratio and ion temperature. Like in the case of many other systems of future fusion reactors, the design of the HRNS requires radiation transport simulations, allowing for the prediction of radiation doses during the tokamak operation (beam on simulations) and also in the shutdown period, where the dose rate originates from neutron activated materials (beam off computations). Such diagnostic system needs human-accessible maintenance, requiring compliance with radiation safety regulations. The primary aim of this work was to determine the appropriate thickness of the radiation shielding for the HRNS system. Beam-on simulations were performed with the MCNP code and beam-off part with the R2Smesh code. This work can serve as an example, showing how the MCNP and FISPACT codes can be applied for the needs of radiation safety assessment in the case of future fusion reactors.

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X-RAY AND NEUTRON ENERGY-RESOLVED DIAGNOSTICS OF TOKAMAK PLASMAS

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Abstract. In fusion plasmas, X-ray and neutron energy-resolved measurements can provide key information about essential plasma parameters. While the fuel ion ratio and ion temperature can be inferred from the analysis of emitted neutron spectra, the local X-ray plasma emissivity depends on electron temperature, density and impurity concentration that can be estimated with the help of dedicated synthetic diagnostics and tomographic tools. In this talk, in the first part we will introduce a methodology to determine the core impurity concentration and electron temperature from multiple line-integrated X-ray measurements in different energy bands. The method is tested on synthetic and experimental tokamak data. In the second part, we will present the concept, principle of operation and first results of an innovative neutron spectrometer based on thin-foil proton recoil and a Gas Electron Multiplier detector, intended for future applications of fusion plasma spectrometry.

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THE THALES TH1507U 140 GHZ 1.5 MW CW INDUSTRIAL GYROTRON FOR W7-X ECRH UPGRADE

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Abstract. The TH1507U gyrotron is a new 140 GHz 1.5 MW continuous wave tube manufactured for the ECRH system upgrade of the Wendelstein 7-X Stellarator at IPP Greifswald, Germany The TH1507U is an evolution of the existing TH1507 1 MW unit, whose excellent robustness has been demonstrated by dismantling the 2nd prototype after 10 years operation. The new gyrotron relies on the TE28,10 cavity mode with an axial magnetic field of 5.55 T and it integrates several improvements on cathode structure, beam tunnel, cavity design, voltage depression and cooling configurations. The

prototype, after having successfully accomplished the factory test, has demonstrated power levels between 1.1 MW and 1.6 MW in short-pulse operation (up to 5 ms). The performance at multiple frequencies is being investigated and the qualification of the prototype in long pulse operation (1800 s) is progressing. The results will be presented during the SPPT 2024.

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INTEGRATION OF QUIZZES ON PLASMA PHYSICS REMOTE CONTROLLED EXPERIMENTS INTO THE FREE PLATFORM

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Abstract. The Framework for Remote Experiments in Education (FREE) was created based on new web technologies for remote controlled experiments operation. In particular, the FREE framework allows for the implementation of quizzes based on the data sets produced by each user, leading to specific personalized assessment structures.

Two of the available quizzes are based on plasma physics experiments belonging to the “advanced level experiments” freely accessible on elab, namely the Langmuir Probe and the Electromagnetic Cavity. These experiments allow the download of the data produced and a multitude of parametrization. The respective data sets produced by each user are intended for a variety of analysis and furthermore determine the corresponding fundamental plasma density and temperature. In this communication we will introduce how FREE was used in the implementation of both experiments and give an insight about the quiz’s didactic approach.

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EXCITATION OF LOWER HYBRID WAVE INSTABILITY WITH THE HELP OF MAGNETIC SHEAR IN A TOKAMAK PLASMA

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Abstract. This work investigates the impact of dust grains on the excitation of lower hybrid instability in a tokamak with magnetic shear, which is generated by the injection of oblique neutral beam. In the intermediate zone, the lower hybrid mode propagates, while it is fleeting in the outer and inner regions. Once fully ionized in the plasma, the neutral beam resonantly connects with the lower hybrid wave in the intermediate zone, causing instability in the mode. In a tokamak, the ions may be seen to accelerate through the magnetic field during the big disruption. If an ion-cyclotron instability arises

during disturbances, then an acceleration of electrons may occur. Furthermore, the study hypothetically observes and presents the impact of dust grains type, density, and size on the instability growth.

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EFFECT OF FRESH BUNCHED RELATIVISTIC ELECTRON BEAMS ON THE OUT-PUT POWER IN FREE ELECTRON LASER WITH AN OPTICAL UNDULATOR

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Abstract. Free electron lasers (FELs) are the fourth generation of radiation sources. Because of their tunability, these types of lasers are the best candidates to produce highly brilliant X-ray to gamma-ray beams with laser-like properties. By installing the beam-buncher before the main wiggler one can achieve higher efficiency. Saldin and his coworkers have shown that the using of the pre-buncher increases the efficiency of the common FEL radiation by a factor of 2. Emma et al. have verified high-efficiency tapered FELs with a pre-bunched electron beam. Using 1D simulation they have derived the scaling laws. In the framework of nonlocal theory, Bhasin and Sharma have investigated the effect of the beam pre-bunching on the gain and efficiency. In this contribution, by Smilei (a particle in-cell code), effect of the fresh-bunched relativistic electron beams on the output power of free electron laser with an optical undulator has been investigated.

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EXPERIMENTAL STUDY OF DD FUSION PROTONS AND ACCELERATED DEUTERONS AT PF-1000 PLASMA FOCUS DEVICE

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Abstract. Z-pinch devices create a column of hot, dense plasma, which is however quickly disrupted due to kink and sausage instabilities. The decaying plasma column gives rise to an electric field which consequently accelerates a beam of particles, resulting in nuclear reactions caused by beam-target mechanism.

We conduct experiments on PF-1000 plasma focus device in Warsaw. A megaampere discharge in deuterium gas drives nuclear DD reactions, leading to strong proton and neutron emission. Measuring spectra and anizotropy of the proton radiation utilizing CR-39 track detectors gives us information about the properties of accelerated deuteron beam and by observing the proton deflection in magnetic field surrounding the plasma column, we can measure the magnitude of aforementioned magnetic field. In our presentation, we cover experimental setup, our method of measurement as well as the results of several experimental campaigns.

SELF-DRIVEN ION DEFLECTOMETRY MEASUREMENTS USING ACCELERATED MEV DEUTERON BEAMS AND FUSION-DRIVEN PROTONS IN THE HYBRID X-PINCHES AND PLASMA FOCUSES

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Abstract. We report on the results of self-driven point-projection ion deflectometry measurements from a 1-MA 8-kJ LTD generator at the University of Michigan (called MAIZE) driving a hybrid x-pinch (HXP) with a deuterated polyethylene fiber load to produce a point-like source of MeV ions for backlighting. In these experiments, 2.7-MeV protons were generated by DD beam-target fusion reactions. Due to the kinematics of beam-target fusion, the proton energies were downshifted from the more standard 3 MeV, released in the center-of-mass rest frame. In addition to the 2.7-MeV protons, strongly anisotropic beams of 3-MeV accelerated deuterons were detected by ion diagnostics. Numerical reconstruction of experimental data generated by deflected hydrogen ion trajectories evaluated the total current in the vacuum load region. Deflections of DD-fusion protons and accelerated deuterons were studied for measurements of the pinch currents and hydrogen ion sources also in the MA plasma focus PF-1000.

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PLASMA FOCUS AS A SOURCE OF ELECTROMAGNETIC PULSES COMPARED TO PETAWATT-CLASS LASER FACILITY

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Abstract. Pulse-power devices like plasma foci are known as efficient sources of soft x-rays and neutrons via high-current discharge with hundreds or thousands of kA called z-pinch. Such devices generate also strong electromagnetic pulses (EMPs) during pinch disruptions. These remarkable EMPs hold significance not only for various applications but also for understanding their underlying physical mechanisms. Our study employs biconical antennas and magnetic field probes to analyze EMP emissions up to 1 GHz. The comparative analysis is conducted between mega ampere PF-1000 device, a smaller

plasma focus PFZ-200 with current maximum above 200 kA, and the petawatt-class laser facility PHELIX, featuring a pulse duration of 650 fs and 70 J maximum energy.

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GASIFICATION OF BIOMASS WASTE INTO SYNGAS WITH AN ATMOSPHERIC-PRESSURE NITROGEN MICROWAVE PLASMA TORCH

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Abstract. The microwave plasma is applied in gasification process due to its advantages in terms of the simple and compact setup, ability to operate at atmospheric pressure, and instant response to power. This work is concentrated on microwave plasma gasification of bamboo powder as a typical biomass, specifically on affecting parameters and their performance. First, experimental setup for gasification is introduced, then measurement of various operating parameters on resulting output is carried out, and discussion of its effect is delivered. Operating variables including injection method, microwave power, plasma working gas flow rate, and mixture ratio of argon or oxygen in carrier gas as addition components are investigated with respect to produced syngas composition, efficiency, conversion, and hydrogen production rate. It is experimentally found that the active zone where powder is injected and retention time are the important factors for achieving gasification performance.

INVESTIGATING THE INFLUENCE OF THERMAL PLASMA ON BIOMASS PARTICLES

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Abstract. The utilization of thermal plasma for entrained flow gasification processes is said to produce high-quality syngas with low tars and a high content of hydrogen. The gas is ideal for the usage in further processes such as Methanol or Fischer-Tropsch synthesis. This study examines the influence of thermal plasma on biomass particles, focusing on pyrolysis and gasification processes. Optical as well as solid analysis methods were used to delve into the field of plasma treatment of biomass. For optical analysis, a high-speed camera was employed to capture the interactions in the environment of thermal plasma. The plasma treated particles, e.g. plasma char, were collected and analyzed by proximate and ultimate analysis. Furthermore, EDX analysis was performed to determine the composition of the plasma char surface. In addition, the influence on the gasification kinetics was analyzed using thermogravimetric analysis combined with surface area determination.

STUDY OF ELECTRIC FIELD DISTRIBUTION ON PLASMA AND PLASMA CATALYSIS REACTOR FOR DIFFERENT ELECTRODE CONFIGURATIONS AND PELLET SIZES

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Abstract. In various non thermal plasma-based applications, the dynamics of electric fields and charged particle interactions are crucial. In order to find the efficient plasma reactor, the effect of different electrode configuration for plasma approach and effect of pellet packaging & optimal sizing for plasma catalysis approach was studied for 6 different types of volume discharge and surface discharge reactors using COMSOL Multiphysics 6.0. The different electrode configurations viz. concentric cylindrical, square, helical as volume discharged reactor and floating & 2 types of non-floating electrode as surface discharge rectors are considered. The effect of different size (dia. 1/3/5/10 mm) of spherical pellets was studied for helical and cylindrical plasma reactors for plasma catalysis. The simulated results were then experimentally verified and validated for production of O_3 and conversion/reduction of NO_x from diesel engine exhaust.

PLASMA ACTIVATED MEDIA FOR THE AGRIFOOD INDUSTRY

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Abstract. Low-temperature plasma (LTP) emerged as a novel tool in pre/post-harvest agricultural applications. Direct plasma treatments are effective but limited. Plasma-Activated media like Water (PAW) and Fog (PAF) offer alternatives, delivering plasma reactive species to targets. PAW produced by SDBD discharge achieved almost complete decontamination against fungal (*B. cinerea*) and bacterial (*B. subtilis* and *X. campestris*) microorganisms, with reactive oxygen and nitrogen species (RONS) playing a key role. PAF was produced by using the plasma effluent gas from a VDBD reactor to nebulize water (droplet size $<5\mu$m). Our observation show that it effectively eliminates pathogens and contaminants on agricultural produce without compromising food integrity or nutritional value. Preliminary findings include an extension of shelf life, inhibition of various fungal pathogens, reduction of chemical pesticides and insecticides, as well as effects on the insect ovodeposition cycle.

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ENHANCING SURFACE PROPERTIES OF ADDITIVELY MANUFACTURED METALLIC MATERIALS THROUGH PLASMA NITRIDING

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Abstract. Additive manufacturing (AM) is an innovative technology that has revolutionised the manufacturing industry. It has opened up new possibilities for producing parts with unique customisation, complex designs, and advanced functionalities. One of the most prominent techniques in AM is Laser Powder Bed Fusion (LPBF), which can manufacture metallic parts with complex geometries and refined microstructures. Applying surface plasma nitriding can markedly enhance the wear and corrosion resistance of AM-produced parts, in some cases making them superior to conventionally manufactured equivalents. This presentation will explore the corrosion characteristics and other mechanical and tribological properties of various metallic materials produced through AM, such as stainless steel, maraging steel, tool steel, nickel alloy, and titanium alloy.

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TRANSIENT SPARK WITH ELECTROSPRAY FOR BETTER UNDERSTANDING OF PLASMA ACTIVATED WATER FORMATION

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Abstract. Plasma activated water (PAW) containing mixture of reactive species has vast applications in health and the food sector. For some applications, PAW with specific composition is needed. We therefore studied PAW generation by transient spark (TS) in different gases (N_2, O_2, and air) with direct or indirect contact of TS with water electrospray (ES) microdroplets. With direct contact, ES microdroplets were generated inside TS zone. With indirect treatment, the gas was firstly treated by TS and sprayed by ES water microdroplets downstream. Using direct or indirect treatment and different gases, we ca tune PAW composition thanks to better understanding of PAW formation processes. H_2O_2(aq) is mainly formed due to short-lived species, such as OH radicals, and not by dissolution of H_2O_2. NO_2^- ions are predominantly formed by the dissolution of gaseous HNO_2.

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PLASMA-BASED SYNTHESIS OF SURFACTANT-FREE NI, FE, FEN MAGNETIC NANOFLUIDS

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Abstract. Ferrofluids, comprising magnetic particles suspended in a non-magnetic liquid, can be useful for diverse applications - electronics, mechanical engineering, and bio-medicine. In this work, Ni, Fe, and FexNy nanoparticles (NPs), which were formed in a gas aggregation cluster source, were deposited into bio- and vacuum-compatible polyethylene glycol.

The advantages of our method are a simple control over the NPs size and the possibility to investigate the oxidation using XPS analysis without breaking the vacuum. Preliminary tests confirmed magnetic properties in all nanofluids. The Magnetic Property Measurement System characterization showed that the obtained magnetic behavior was typical for the studied magnetic NPs (Ni-FexNy-Fe). The shape of field-cooled loops at low temperatures suggested a formation of the surface oxides. Plasma-based synthesis of Ni, Fe, and FeN NPs demonstrates great potential for the controllable production of surfactant-free magnetic nanofluids.

Acknowledgement: *This research has been supported by the Charles University Grant Agency under Contract 298722, via grant GACR 23-06925S from the Czech Science Foundation, and Czech-German Mobility grant 8J23DE016 from the Ministry of Education, Youth, and Sports of the Czech Republic.*

LASER-INDUCED PLASMA: FROM ULTRAPURE NANOPARTICLE FORMATION TO NANOPARTICLE-ENHANCED PLASMA EMISSION SPECTROSCOPY

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Abstract. In the last decades, Laser-Induced Plasma (LIP) has gained growing interest because it can be used with wide experimental flexibility. The ignition of the plasma with the laser pulse is obtained simply by steering and focusing the laser pulse on the target/sample with adequate laser irradiance (>GW/cm-2) and this simple operation opens the possibility of applying LIP in several applications. As an example, LIP can be employed in analytical chemistry for elemental analysis, as well as in materials science for the production of thin films, material modification and nanomaterial production. Beyond the practical applications, the LIP represents an extremely interesting system from the fundamental point of view, because during the expansion the characteristics and properties of the plasma change dramatically. When a short or an ultrashort laser pulse is focused on a sample with appropriate irradiance exceeding the breakdown threshold of the sample a plasma with temperature greater than 10000 K and high electronic densities (around 1cm-3) is induced. The plasma lifetime depends on the experimental parameters of the laser (wavelength, pulse duration, energy), the typologies of the sample on which the laser has been focused and the environment against which the plasma expands (e.g. tens of microseconds for a plasma expanding in air at atmospheric pressure or few microseconds for a plasma expanding in water). The induction of the laser plasma starts with the excitation of the electrons in the irradiated material and with the generation of free electrons by multi-photon ionization. After a few tens of femtoseconds, the ejection of electrons and ions occurs massively. The ablated matter is then heated by the rest of the laser pulse, increasing the kinetic energy of the electrons by inverse bremsstrahlung and promoting further ionization by electron collision and photoionization. Although the control of the ablation process for a given laser pulse is limited, the evolution of the plasma is strictly dependent on the dynamics of the LIP. As mentioned above, this implies that it is possible to operate on the plasma characteristics by controlling the expansion features with different background environments. Since the LIP consists of highly excited species, by acquiring the plasma emission with spectrometers with high spectral resolution and high temporal resolution, it is possible to characterize on one hand the plasma species and on the other its expansion dynamics by measuring its parameters such as temperature and electron density. When the experimental conditions allow a stoichiometric ablation of the irradiated portion of the sample and the local thermodynamic equilibrium (LTE) of the plasma can be assumed, it is possible to use the LIP emission to qualitatively and quantitatively characterize the sample on which the laser has been focused. The technique is called Laser Induced

Breakdown Spectroscopy (LIBS). This is a technique that allows the elemental analysis of almost any kind of sample, it is micro-destructive, simultaneously reveals multi-elements with a limit of detection competitive with the one obtained with the conventional analytical techniques and in particular it can identify and quantify the light elements of the periodic table. The instrumentation can be easily compacted to operate in the field as in hostile environments. Instead, when the plasma is induced on a sample immersed in liquid, it is possible to generate nanoparticles (NPs) suspended in the liquid with the same composition as the irradiated sample. This method of nanoparticle synthesis is called Pulsed Laser Ablation in Liquid (PLAL). This technique is a "Green" synthesis method for nanoparticle formation because it does not require chemical precursors for the formation of nanoparticles and does not require final purification, producing therefore nanoparticles free of contaminants, stable in solution without the need for stabilizers, negatively charged and with an excellent size distribution. Regarding the NPs mechanisms formation, what is clearly established is that, initially the laser-matter interaction produces a plasma with high temperature and high electron number density that is the source of material and that this plasma is extremely confined since it expands against an uncompressible liquid. The main elementary processes that sustain the plasma are essentially the same as those of an expanding plasma in background gas, although the different competition between the elementary processes and the different exchange of energy between the plasma border and the liquid environment leads to the nucleation and growth of particle instead of atoms expansion. Since the plasma is subjected to a strong confinement the rate of the recombination phenomena increases dramatically. Part of the energy of the plasma is then transferred to the surrounding liquid inducing a cavitation bubble that is characterized by a typical dynamic of expansion and collapse; finally, NPs are released into the liquid. This way of producing ultrapure NPs opens an important scenario because these nanoparticles can be used to study the interactions between their naked surface with biomolecules, without the mediation of other molecules absorbed on their surface or they can be used to increase the signals of analytical elemental spectroscopic techniques (such as LIBS, LA-ICP-MS) without introducing contamination into the resulting signal. In our research group, for the first time nanoparticles were used to increase the LIBS signal by orders of magnitude, with the so-called Nanoparticle Enhanced LIBS. Furthermore, the use of ultrapure nanoparticles produced with PLAL allowed the analysis of the various substrates without interfering elements except the metal of which the nanoparticle was made. NP-enhanced laser ablation is based on the interaction of the plasmonic system of metallic NPs with the ablated matter during the laser pulse irradiation with ns-laser pulse. When a laser is focused on a sample covered with a layer of NPs a matching between the electromagnetic field of the laser and the one generated on the NPs system occurs. This led to a field enhancement and consequentially to a better atomization of the ablated matter and in turn, an enhancement of the emission intensity in the plasma emission spectrum, allowing the decrease of the detection limit. The main characteristics that have been observed are the following: the same amount of removed matter per laser shot as with traditional ablation, higher atomization yield of the ablated matter, better laser pulse energy distribution on the sample, multiple ignition points for the plasma induction, and enhancement of the plasma emission signal up to two orders of magnitude with respect to the one of conventional LIBS. The enhancement of the NELIBS plasma emission spectra, defined as the ratio between the emission line intensity of an element acquired with NELIBS and LIBS, is strongly related to the efficiency of the plasmonic coupling between the NPs. This means that 2D deposition with a suitable inter-particle distance is required since the NPs are deposited and then dried on the sample. NELIBS has been employed in several applications as the trace element at the sub-ppm level in conductive and isolator solid targets (e.g. meteorites, gemstones, metals etc.) and in the liquid sample analysis (only a few microliters are needed). One of the most interesting uses of such a technique is the elemental analysis of biological samples. As a matter of fact, traditional LIBS has low sensitivity with biological samples because of the high ionization energy of the matrix elements (C, N, H) that tends to quench the plasma and in turn, it requires several signal accumulations to reach a high SNR (Signal to Noise Ratio). The latter requires amounts of samples that are not always available in real applications. NELIBS allows bypassing these inconveniences with a single-shot analysis, because of the more effective conversion of the laser energy into sample atomization and further excitation. NELIBS has been successfully employed for elemental analysis on biological samples, including liquids, proteins and tissues as well as for retrieving information on the structure of NP-protein complex structures.

PROGRESS ON ITER DIAGNOSTICS

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Abstract. Approximately 50 diagnostics will be installed on ITER, distributed in 20 ports, on the vacuum vessel surface, and in the divertor. These diagnostics will measure more than 100 parameters necessary for control of the plasma and first wall processes in order to achieve the required goals, and to gain the knowledge needed for future reactor designs. Many diagnostic projects are now moving forward thanks to support of teams working cooperatively around the world, with several components being already manufactured and delivered to ITER site. The diagnostics on ITER will be subject to new challenges unprecedented in today's tokamaks. The diagnostics will operate in a nuclear environment which requires the design to mitigate the transmutation, radiation damage, and thermo-electric effects, as well as to cope with nuclear heating. The diagnostics will be subject to very limited or no maintenance, and they need to be designed with very high reliability and/or redundancy. The diagnostic components installed inside the vacuum vessel require rugged design to withstand e.g. baking conditions and exposure to steam. Since ITER is a nuclear facility, the design, manufacture and installation of the diagnostic components is subject to safety and quality requirements, in particular for installation on the nuclear confinement barriers such as the vacuum vessel, and vacuum vessel feedthroughs and windows. This contribution will describe how these challenges and requirements are successfully met in the diagnostic designs through standardization, quality requirements, dedicated R&D, and design for protection and replacement of critical items. The contribution will also outline the design of the diagnostic ports, engineered to accommodate several diagnostic systems and their services, whilst maximizing the nuclear shielding performance and respecting the weight limit. The recent progress on the prototypes, manufacture, and installation of the ITER diagnostics will be presented. Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

LASER PLASMA ACCELERATORS: MANIPULATING RELATIVISTIC ELECTRONS WITH INTENSE LASERS

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Abstract. Laser-plasma-based wakefield accelerators are changing the scientific landscape bringing on new hopes for the future of high energy physics of compact light sources. Many of these applications critically require the precise characterization of the accelerated electron bunch as well as the plasma wakefield that largely affects the bunch's quality. Advanced diagnostics of such highly transient, microscopic bunch and field structures, however, remains very challenging. After introducing the context and the physical processes involved in plasma accelerators, I will report on recent major results that demonstrate for the first time the real-time visualization of laser-driven nonlinear relativistic plasma wave, its transition to electron-driven wakefield and the femtosecond microscopy of relativistic electron bunch. It will be followed by a short review of their applications including the status of our EIC project ebeam4therapy.

WIRE-SHORTED RPD AS A VERSATILE SOURCE OF HARD X-RAY

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Abstract. The wire-shorted rod-pinch diode (RPD) is one of the low-impedance (below 1 Ω) variants of the traditional RPD featuring a vacuum AK-gap. Compared with the plasma-filled RPD that requires a plasma gun for initial plasma injection, it is relatively easier to adjust parametrically and does not need extra timing system. The wire-shorted RPD has been tested on several pulsed power drivers at Xi'an Jiaotong University, in order to clarify the plasma dynamics and impedance characteristics. By now, experiments were carried out mainly based on a linear transformer driver HAN-1 (positive-negative 50 kV per stage, 500 kA, 150 ns), concerning plasma diagnostics, characterization of the X-ray spot and radiography properties. It was shown that the wire-shorted RPD is capable of generating quasi-spherical hard X-ray spot with typical dose ~0.6 rad 1m (above 20 keV), diameter ~0.6 mm (AWE standard), and pulse width ~30 ns (FWHM), demonstrating its promising potential in X-ray flash radiography of transient hydrodynamic and ballistic processes. A Mont-Carlo simulation has been setup for the modelling of the X-ray spectrum and is validated experimentally by transmission-absorption measurement; the spectrum is proven to be adjustable in certain range by different anode material substitutions. Also, a description of the load physics and equivalent circuit model was proposed based on optical diagnostics, spectrum estimations and electrical measurements. For the applicational aspect, a compact pulsed power device WRPD-1 (positive-negative 70 kV, 250 kA, 120 ns) has been constructed, which generates quasi-spherical with typical dose ~0.1 rad 1m (above 10 keV), diameter ~0.6 mm (AWE standard), and pulse width ~25 ns (FWHM), and the resolution exceeds 10 line-pairs/mm with a 1.5 magnification. It has provided valuable radiography diagnostics in various experiments in our laboratory including electromagnetic launching, electrical wire explosion, detonation of energetic materials, etc., and is planned for dynamic X-ray diffraction experiments in the near future.

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ADVANCED DIAGNOSTICS FOR PLASMA-BASED ELECTRIC PROPULSION

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Abstract. With electric propulsion (EP) becoming a standard technology for satellites and space-craft, it is important to understand its back-reaction onto the spacecraft. EP offers much higher exhaust velocities than chemical engines by ionizing and, e.g., electrostatically accelerating the propellant. Incomplete ionization and leaking of gas from the thruster or its plume results in a non-negligible amount of neutral gas in the vicinity of the thruster. The ions of the thruster plume inter-act with this neutral background gas by collisions, in particular by charge-exchange collisions. This generates a secondary ion population with low thermal velocities (Caruth, M.R., Gabriel,S.R., Kitamura, S., "Ion thruster charge-exchange plasma flow", AIAA paper 82-0403, 1982; Trottenberg, T., Bansemer, F., Böttcher, S., Feili, D., Henkel, H., Hesse, M., Kers-ten, H., Krüger, T., Laube, J., Lazurenko, A., Sailer, D., Schuster, B., Seimetz, L., Spethmann, A., Weis, S., Wimmer-Schweingruber, R., „An in-flight plasma diagnostic package for spacecraft with electric propulsion", Eur. Phys. J. TI Vol. 8, 16, 2021). In the absence of active spacecraft potential control, the plasma surrounding the spacecraft attains a positive potential with respect to the spacecraft. Therefore, the initially cold, i.e. gas temperature, secondary ions are accelerated back onto the spacecraft and interact with its surface layers. These

can be sensitive instruments, solar panels, or other subsystems that can be disturbed or degraded by the unintended backflow from the EP thruster. Understanding and quantifying this backflow onto the spacecraft is an important issue for spacecraft and EP design, but is severely hampered by the difficulties in providing a realistic test environment for such backreactions in laboratories and plasma chambers on earth. While the latter are readily available, it is often unclear how results obtained in them can be applied to the space environment with its much lower ion and neutral densities and absence of walls. In this talk, we will discuss the diagnostics of electrons and ions as well as the fluxes of charged and neutral species toward plasmafacing surfaces by non-optical methods. We will focus on ion beam diagnostics by Langmuir probes (LPs), Faraday cups (FCs) and retarding field analyzers (RFA), as well as by calorimetric and force probes (CPs, FPs) (Trottenberg, T., Bansemer, F., Böttcher, S., Feili, D., Henkel, H., Hesse, M., Kers-ten, H., Krüger, T., Laube, J., Lazurenko, A., Sailer, D., Schuster, B., Seimetz, L., Spethmann, A., Weis, S., Wimmer-Schweingruber, R., „An in-flight plasma diagnostic package for spacecraft with electric propulsion“, Eur. Phys. J. TI Vol. 8, 16, 2021; J. Benedikt, H. Kersten, A. Piel, “Foun-dations of measurement of electrons, ions and species fluxes toward surfaces in low-temperature plasmas”, Plasma Sources Sci. Technol., Vol. 30, 033001, 2021; Spethmann, A., Trottenberg, T., Kersten, H., Hey, F.G., Grimaud, L., Mazouf-fre,S., Bock, D., Tajmar, M., „Force probes for development and testing of different electric propulsion systems”, Eur. Phys. J. TI Vol. 9, 4, 2022.) in the test environment HIBEx. We will also present initial resulrs obtained by on-board measurements on the satellite “Heinrich Hertz” which are performed by a designated diagnostic package including a retarding potential analyzer, a plane Langmuir probe, and an erosion sensor (Trottenberg, T., Bansemer, F., Böttcher, S., Feili, D., Henkel, H., Hesse, M., Kers-ten, H., Krüger, T., Laube, J., Lazurenko, A., Sailer, D., Schuster, B., Seimetz, L., Spethmann, A., Weis, S., Wimmer-Schweingruber, R., „An in-flight plasma diagnostic package for spacecraft with electric propulsion“, Eur. Phys. J. TI Vol. 8, 16, 2021.).

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CAVIPLASMA: ENERGY-EFFICIENT LARGE-SCALE LIQUID TREATMENT VIA DISCHARGE EXCITED IN HYDRODYNAMIC CAVITATION

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Abstract. In recent years, there has been a surge of interest in the plasma treatment of liquids, notably water, within the field of plasma physics. This treatment yields reactive oxidizing species, both with and without nitrogen (ROS, RONS). The discharge-liquid technologies have found diverse applications across various disciplines, including pollution remediation, biomedical research, and the food industry. Despite dedicated research spanning two decades, a significant challenge remains: the development of an efficient approach for treating large volumes of liquid. In our contribution, we introduce an innovative solution known as CaviPlasma. This novel method capitalizes on the synergistic combination of hydrodynamic cavitation and plasma generation within the cavitation vapor cloud. Our approach shows promising potential for overcoming the technological barriers associated with the large-scale treatment of liquids.

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DEGRADATION OF HIGH SALINITY ORGANIC WASTEWATER BY PLASMA SYNERGETIC CATALYSIS

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Abstract. The phenolic pollutants contained in wastewater pose a serious threat to environment ecological environment, depending on its persistence, toxicity, and low biodegradability. Gas-liquid discharge has a high efficiency for degrading phenolic compounds in low conductivity water. However, it is difficult to generate gas-liquid discharge in high conductivity water. As a result, the degradation of high-salt phenol-containing wastewater has become a worldwide problem. In this study, the stability and characteristics of gas-liquid discharge plasma under high conductivity solution are studied by changing discharge parameters, matching resistance and capacitance, and optimizing electrode structure. Gas -liquid discharge plasma assisted loading of iron ZIF catalyst are employed to treat high salt and phenolic wastewater, and the degradation efficiency is more than 90% by plasma synergetic catalyst.

Acknowledgement: *This research has been supported by the the National Natural Science Foundations of China (Grant No. 52077026).*

BREAKDOWN PATH STUDY IN REPETITIVELY PULSE NANOSECOND DISCHARGE FOR VARIOUS PULSE REPETITION FREQUENCIES BY MODEL AND EXPERIMENT

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Abstract. The breakdown path for repetitively pulsed ns discharges was studied across a pin-to-pin gap with initially quiescent air. Specifically, the breakdown paths from a burst of two consecutive pulses were imaged for various pulse repetition frequencies representing delay times between pulses of 10-50 μs. For delays of 10-17 μs, the 2nd discharge followed a direct path between the pins, whereas from 19-40 μs, the 2nd discharge took a longer oblate spheroid path, returning to a direct path for delay times >40 μs. A model including spatial profiles of gas density following the initial discharge pulse and E field profiles is presented with predictions of the optimum breakdown path of a 2nd pulse between 10-50 μs. Comparison of the model and experiment support the theory that, following an initial pulsed discharge, air recirculation produces a frequency dependent energy coupling of subsequent discharges, as has been seen in repetitively pulsed ignition data.

MAGNETIC FIELD EFFECT ON REVERSE DISCHARGE IGNITION IN BIPOLAR HIPIMS

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Abstract. The reverse discharge (RD) phenomenon in bipolar HiPIMS arises when a sufficiently long positive pulse is applied. It originates from forming a double layer between the positive target and the plasma behind the magnetic trap due to the magnetic field preventing the electrons from reaching the positive target. Eventually, this leads to plasma (and floating) potential reduction behind the magnetic trap, followed by electron acceleration within this structure and RD ignition. This study reveals the significant impact of the magnetic field configuration on RD ignition by analyzing floating potentials and OES imaging. Experiments are performed using a Ti target involving magnetic field adjustments, wire probe measurements, and Ar atoms' light emission capture. It was found that adjusting the magnetic field to a more balanced configuration led to earlier RD ignition, while an unbalanced one delayed or prevented it.

SURFACE PLASMA CATALYZED COMPOSITE INDUSTRIAL WASTE FOR NOX ABATEMENT IN DIESEL EXHAUST

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Abstract. A new approach has been proposed by catalyzing composite industry wastes with pulse discharge plasma for reducing oxides of nitrogen (NOx) in diesel exhaust. Solid wastes such as foundry sand and iron tailings were blended to form a new composite waste which is then introduced into a plasma reactor to extract the benefits of catalytic properties. The obtained NOx removal efficiency is 90% at 140 J/L in plasma catalysis as against 36% obtained with plasma alone.

STUDY ON THE EFFECT OF HYDROGEN IN THERMAL PLASMA JETS AT LOW PRESSURE: POSSIBILITIES AND LIMITATIONS OF OPTICAL EMISSION SPECTROSCOPY

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Abstract. In plasma spraying, hydrogen is often used as a secondary plasma gas in addition to argon. Particularly at low pressure, even small amounts of hydrogen have a strong effect on the plasma jet characteristics. Under such conditions, fundamental mechanisms such as diffusion and recombination are affected, whereas under atmospheric conditions this is less relevant. In this work, low-pressure thermal plasma jets have been studied using optical emission spectroscopy. The results confirm the effect of hydrogen on plasma properties. Problems with emission line broadening analysis have been encountered in the evaluation of these data. It was found that shape deviations, asymmetries, and fine structure components affect the accuracy of the Gauss-Lorentz deconvolution. Since electron densities were low under the low-pressure conditions studied, possible deviations from local thermal equilibrium are discussed in detail.

MODELLING OF GASIFICATION OF CRUSHED WOOD IN THERMAL-PLASMA CHEMICAL REACTOR

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Abstract. The paper presents numerical simulation of gasification of crushed wood using a unique plasma torch stabilized by argon and water vortex in a plasma chemical reactor. The water-argon DC-plasma torch offers the advantage of low plasma mass flow rate, high enthalpy and temperature allowing achievement of an optimal conversion ratio with respect to syngas production compared to other types of plasma torches. Numerical model was created in the ANSYS FLUENT software package. Results of gasification and syngas production from crushed wood show that gasification efficiency and syngas production decrease slightly with increasing particle diameter, while thermal inhomogeneity in the reactor volume is strongest for the largest particle diameter and decreases with decreasing wood particle size. High syngas content (~90%) was achieved for all studied currents (400-600 A) and wood particle diameters (0.2 – 20 mm).

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APPLICATION OF MICROWAVE PLASMA TORCH FOR WASTE PROCESSING

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Abstract. The plasma torch operated with a 950 MHz microwave generator and an input power of 100 kW, utilizing air as the working gas, was employed for treating simulated hospital waste and solid recovered fuel. The flow rates of the materials were 4-25 kg/h. During experiments, the temperatures of the walls of a 200L reactor ranged from 1000 °C to 1200 °C. Analysis of the produced gas revealed a high concentration of N_2 (58-83 vol. %) due to the use of air as the working gas.

Increasing the mass rates of the input materials led to higher concentrations of CO and H_2. Maximum CO_2 concentrations were observed at medium input flow rates (13 kg/h), when sufficient O_2 was provided in the reactor, in accordance with theoretical expectations. Lower concentrations of C_2H_2 and NOx were also detected. It is suggested that the use of different working gases, such as H_2O vapor, O_2, CO_2, or their mixtures, would improve the composition of the synthetic gas.

Acknowledgement: *This research has been supported by the Technology Agency of the Czech Republic [Projects TN02000069] and support of the Academy of Sciences of the Czech Republic [Strategy AV 21 – research program Sustainable Energy].*

CORROSION PERFORMANCE OF MAGNETRON-SPUTTERED MG ALLOYS

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Abstract. Mg alloys are not corrosion resistant. Traditional processes have been used to improve their corrosion-resistance, but without a satisfactory outcome. This talk presents the possibility of forming a "stainless" Mg-Ti alloy by magnetron-sputtering technique. Results indicated the alloy could become passive if the Ti level (atom %) was higher than the Mg in the alloy. Mg alloys may even act as an intelligent anode to protect reinforced concrete structures. To optimize the protection intelligence, a series of Mg-Al alloys were fabricated by magnetron-sputtering. It was confirmed that the protection intelligence could be enhanced after Mg was properly alloyed with Al. The magnetron-sputtering method can also be employed to fabricate Layered Double Hydroxides (LDHs). With a co-sputtered Zn-Al alloy introduced in the process as a sacrificial transition layer, diverse LDH films could be tailored to have significantly increased thickness and much better mechanical robustness.

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ELECTRIFICATION OF HIGH-TEMPERATURE PROCESSES – CFD MODELING AND EXPERIMENTAL VALIDATION OF A MICROWAVE PLASMA TORCH

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Abstract. In the present work, an atmospheric microwave air plasma was investigated experimentally and by use of Computational Fluid Dynamics (CFD). The aim was to develop a simple, robust, and reliable CFD model that can be utilized for the development and optimization of production processes in the foundry, glass and chemical industries. In order to verify the quality of the model, the temperature in the free jet of a 6 kW plasma torch was measured at different positions with thermocouples. The experiments were carried out for different flow rates and power inputs. The comparison with the CFD results shows that the modeling approach can reproduce the temperature profile qualitatively for all cases. Based on this, parameter studies were performed to analyze the interaction of thermo-chemistry and fluid dynamics. The results show that the fluid dynamics, especially the swirl, have a significant influence on the temperature profile in the plasma jet.

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DECREASING DIMENSIONALITY OF MODELS FOR PLASMA-LIQUID INTERACTIONS

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Abstract. Experimental systems utilizing external plasma source of radicals for delivery to water solutions has been used in attempts to kill drug-resistant bacteria and cancer cells or the development of a new kind of drug called plasma-treated medium (PTM). In this contribution, experimental results on the plasma radical treatment of concentrated solutions are compared with modeling. Generally, the spatio-temporal modeling of fast radical chemistry is a challenging task. A decrease of the model dimensionality brings the compromise between the predicting capabilities and computational efficiency. The present model benefits from the de-coupling of liquid flow and reaction-diffusion equations in 2-D, axially symmetrical geometry. Further, more simplified model separates the fast reaction source terms occuring tens of nm below the liquid surface from slower reactions in the liquid bulk, greatly enhancing the solution efficiency.

DIAGNOSING EDGE PLASMA FLUCTUATIONS WITH SYNTHETIC REFLECTOMETRY

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Abstract. Reflectometry diagnostics are employed today and foreseen in future fusion devices (e.g. ITER, DEMO) to measure electron density profiles and inform about fluctuations in fusion plasmas. However, investigating and explaining plasma fluctuations from reflectometry data typically requires support from modeling.

In this talk, a framework for synthetic reflectometry is reviewed. The framework integrates the 2D finite-difference time-domain full-wave REFMUL code with realistic plasma descriptions incorporating either turbulence or magneto-hydrodynamic (MHD) physics. Plasma edge turbulence and MHD is considered here, either captured by the electromagnetic gyro-fluid GEMR code or the non-linear JOREK code, respectively. The framework capabilities are demonstrated employing a normal incidence set-up. Results showcase the capability for tracking the self-consistent evolution of turbulence and cycles of edge localized modes. Advantages and limitations of the technique are discussed.

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THE RADIATION CONDITION EXPECTED IN THE AREA OF THE RADIAL GAMMA RAY SPECTROMETER FOR ITER BY MEANS OF MCNP CALCULATIONS

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Abstract. The Radial Gamma Ray Spectrometer (RGRS) is an ITER-dedicated system for the measurements of runaway electrons and fusion product profiles. RGRS will be positioned in the ITER Equatorial Port No01 behind the ITER Radial Neutron Camera and in front of the High-Resolution Neutron Spectrometer. The system comprises several gamma-ray detectors optimized for high-resolution spectroscopy up to the energy of 18 MeV, the magnetic shielding of such detectors, their shielding against radiation (neutrons and gamma background), and the neutron attenuators to stop neutrons and allow gamma-ray to reach the RGRS detectors.

Knowing the radiation conditions inside and around RGRS during the tokamak operation is essential to optimize its design. This work presents examples to show how the MCNP code can be applied for the needs of design optimization in the case of future thermonuclear reactors. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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QUANTUM EFFECTS IN PIEZOELECTRIC SEMICONDUCTOR PLASMAS: SOLITONS, NONLINEARITIES, AND TRANSMISSION FEASIBILITY

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Abstract. The miniaturization of electronic components using semiconductors relies on precise adjustments of charge carriers' de Broglie wavelengths to match doping profile variations, leading to significant quantum mechanical effects. This study investigates the coupling of lattice ion vibrations with electron waves in piezoelectric semiconductor quantum plasmas, analyzing nonlinearities and spiky solitons. Utilizing a quantum hydrodynamic model incorporating Fermi pressure, the quantum Bohm potential, and exchange correlation potential, we establish dispersion relations and nonlinear evolution equations. Through two-time scale theory, we obtain soliton solutions using modified quantum Zakharov equations. Our findings reveal a gradual decline in transmission feasibility in quantum plasmas and an increase in electric field amplitude of cusp solitons due to quantum corrections, sensitive to particle density and coupling strength. These insights advance energy harvesting and conversion technologies, with implications for piezoelectronics by elucidating the coupling of lattice ion vibrations and electron waves.

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CARRIER-ENVELOPE-PHASE-CONTROLLED ACCELERATION IN WAKEFIELDS DRIVEN BY A FEW-CYCLE LASER PULSE

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Abstract. With the development of laser technology and supersonic gas nozzle, the laser wakefield acceleration driven by few-cycle laser has attracted increasing interest. In this unique parameter interval, the carrier-envelope phase (CEP) becomes particularly important. The effect of the carrier wave effects on the evolution of bubble structure and electron injection are investigated, and a scheme called CEP-controlled ionization injection is proposed. It is found that, as the optical cycles decreases, the dominant effect gradually transitions from the ponderomotive force to carrier wave. Meanwhile, the rapid CEP shift of the laser pulse in plasma enables the electrons of high-Z ions to be ionized periodically. These electrons are then subsequently injected into the wakefield, leading to the generation of a multicolor energy spectrum and a subfemtosecond duration. The results are beneficial for manipulating electron acceleration and betatron radiation generation.

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COMPREHENSIVE CHARACTERIZATION OF ELECTROMAGNETIC PULSES DRIVEN BY SUB-NANOSECOND TERAWATT-CLASS LASER

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Abstract. During an interaction of a high-power laser beam with a target, extremely intense electromagnetic pulses (EMP) are emitted in the MHz-THz band reaching up to hundreds of kV/m. Such extreme EMPs are interesting not only for numerous applications, but also for their physical mechanisms. This contribution presents a comprehensive characterization of the EMP emission produced by irradiating the massive and foil Cu targets with the single beam of PALS laser system (0.3 ns, 700 J). In the presented experiments, an extensive set of diagnostics have been used. Thanks to the ultra-fast magnetic and electric field detectors and horn antennas, broadband EMP emission with frequencies up to 10 GHz was observed. By varying the energy of the interaction laser, we observed a dependence of

the EMP spectrum shape on the laser beam energy. This indicates that the EMP spectrum shape is related to the processes in the laser plasma rather than to eigenfrequencies of experimental hardware.

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ROLE OF NONLOCAL TRANSPORT OF HOT ELECTRONS ON THE LASER-TARGET ABLATION

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Abstract. The non-local heat transport of hot electrons during high-intensity laser interaction with plasmas can preheat the fuel and limit the heat flow in inertial confinement fusion. The laser ablative RT instability in planar foils is studied self-consistently for the first time by using radiation hydrodynamic simulations including the nonlocal transport of hot electrons. It is found that the nonlocal heat flux generated by the hot electron transport attenuates the growth of instability, especially for the short wavelength perturbations. A linear theory of the ablative RT instability coupled with the nonlocal heat flux is developed. It can accurately reproduce the simulation results and show a prominent stabilization of the ablation front considering the nonlocal heat flux. The suppression becomes important as the laser intensity increases, where the nonlocal intensity of the hot electrons enhances. The results can have good references for the laser-driven inertial fusion.

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PLASMA POLYMERIZED HEXANE NANOPARTICLES AS TARGETS FOR LASER DRIVEN PROTON BORON FUSION

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Abstract. Laser pulses of high intensity can be used to irradiate hydrogen- and boron-rich materials and trigger the proton boron pB fusion with the generation of three energetic alpha particles. To enhance the alpha particle yield, thin films of hydrocarbon plasma polymers were used earlier as sources of hydrogen when they conveniently matched the laser parameters (Tosca et al. 10.3389/fphy.2023.1227140). At the present status, we have prepared plasma polymerized hexane nanoparticles (ppC:H NPs) in a GAS. The mean size of NPs can be tuned between 600 nm and 120 nm. We investigated the porosity by measuring BET isotherms, while ERDA measurements for the elemental content. These targets have successfully triggered the pB fusion using a short pulse high energy laser TARANIS (8J in 900fs) and the results showed that ppC:H NPs combined with B-rich materials enhance the laser-driven pB fusion.

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NON-PARAXIAL EFFECTS IN LASER ENERGY DEPOSITION

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Abstract. The propagation of short-pulsed lasers in different media has attracted significant scientific interest with applications in remote atmospheric diagnostics, laser breakdown spectroscopy, and laser energy deposition. In this study we provide analysis of non-paraxial effects on the propagation of the laser beam based on the solution of the wave propagation equation with a non-linear term, which includes a gradient of dielectric constant. The system of equations for complex components of the electric field amplitude was formulated for arbitrary ellipticity and shape of the laser pulse. We consider laser beam propagation through the plasma plume created by the ionizing pulse for the case of linear and circular polarization using a combination of femtosecond and nanosecond pulses. Results provide guidance for future experiments on controllable laser energy deposition.

DYNAMICS OF LASER-PRODUCED PLASMAS CREATED IN AMBIENT, LOW DENSITY GASES

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Abstract. In this work investigations of various processes, accompanying a laser induced breakdown in a gas stream, injected into a chamber, filled with a gas under a low pressure, were performed. The high temperature laser produced plasma (LPP) emitted soft X-ray (SXR) radiation and streams of charged particles. Apart from that the plasma was expanding into the surrounding gas. All these factors induced a low temperature plasma in a vicinity of the LPP. Dynamics of the plasma formation was investigated using two streak cameras operating in SXR and optical ranges respectively. Time integrated spectral measurements in the SXR range, with support of a numerical code PrismSPECT, dedicated for spectral analysis, allowed for estimation of the electron temperature of the LPP. Apart from that time-resolved spectral investigations of low temperature plasmas induced in the ambient gas were performed.

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ANGULAR VARIATION OF ACCELERATED IONS SPECTRA IN HIGH REPETITION RATE LASER-MATTER INTERACTION EXPERIMENTS

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Abstract. In laser-matter interaction experiments, high repetition rate lasers are gaining more and more interest due to the possibility of achieving a good statistics, also linked to the significative ongoing improvements of the laser technology. One of the main purposes is their use in laser-driven beam acceleration schemes, as for example in Extreme Light Infrastructure facilities. An open issue of great interest is the level of reproducibility that can be obtained in nominally identical shots and, how the stochastic variations of the interaction can affect the spectra of the accelerated ions at different angles. We present the results of ion spectra achieved with both TOF and Thomson spectrometry at different angles, in an experimental campaign, at the VEGA III laser at CLPU (Salamanca), with laser intensities up to 10E20 W/cm2 and about 25 J energy on solid targets. We show results obtained considering a statistical analysis of a significant number of similar shots.

OPTIMIZING PERFORMANCE OF ARTIFICIAL NEURAL NETWORK-BASED TOMOGRAPHY MODEL AT GOLEM TOKAMAK: IMPACT OF TRAINING DATA QUANTITY AND QUALITY

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Abstract. The paper presents an Artificial Neural Network (ANN)-based model for the tomography reconstruction of visible plasma radiation distribution at the GOLEM tokamak. To train the model, the training dataset is constructed using emissivity phantoms with associated synthetic measurements from one poloidal cross-section of the GOLEM tokamak. The trained model is validated by the test dataset. The performance optimization of the ANN-based model is investigated by considering the effect of the quantity and quality of the training data.

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NEUTRAL BEAM CONTRIBUTION TO FUSION AND SUPPORT OF STEADY-STATE OPERATION IN FNS TOKAMAK

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Abstract. Steady-state operation in the compact fusion neutron source (FNS) design is to be provided by the non-inductive current drive (CD) in tokamak plasma. Neutral beam injection (NBI) will be used to control the current profile and to create up to 90% neutrons. NBI performance is limited by the injector beamline geometrical transmission and by ions neutralization efficiency; it is next reduced by the beam direct and orbital losses in plasma. Finally, the beam output in the tokamak is defined by fast ion distributions in phase space. We present an extended approach of NBI performance evaluation based on the NBI full life-cycle simulation – from the beam production in the injector device - and until its full thermalization in plasma volume. The beam particles statistics is reproduced by BTR code, since 2005 it has been used for ITER NBI design. The fast ion deceleration in tokamak is implemented by BTOR software package created in 2018-2022.

DISRUPTIVE LOCKED MODE INSTABILITY AFTER THE L-H TRANSITION IN THE COMPASS TOKAMAK

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Abstract. Much effort has already been devoted to predicting the sensitivity of tokamaks to small asymmetric error fields (EFs), which are unavoidable in tokamak design and can drive dangerous locked-mode (LM) instabilities even at 0.1% amplitude. However, our experiments on COMPASS were the first to show that the threshold for triggering a LM during a transient phase of a tokamak discharge is much lower than in a steady state. This was observed for n=1 EF activated before the L-H transition at the ITER baseline plasma edge helicity. A threshold for EF penetration subsequent to the L-H transition is robustly obtained, showing no significant trend with density or applied external torque, and is explained by the reduced intrinsic rotation of the 2/1 mode during the transient. This finding cautions against using any parametric EF penetration scaling derived from steady-state experiments to define the error field correction strategy for the entire discharge.

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PRELIMINARY DESIGN OF OPTICAL EMISSION SPECTROSCOPIC (OES) DIAGNOSTICS FOR THAILAND TOKAMAK 1 (TT-1)

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Abstract. Thailand Tokamak 1 (TT-1) was successfully installed in 2023, and equipped with a few plasma diagnostics, namely, a set of magnetic coils, an HCN interferometer, and a CCD camera (A. Tamman and N. Somboonkittichai Plasma and Fusion Research 15, 2402067 (2020)). Due to the lack of several main plasma diagnostics, the access to perform the variety of plasma and fusion research topics is currently limited. One of them is the impurity radiation in an edge plasma. The project related to designing the optical emission spectroscopic (OES) diagnostics for TT-1 has been recently initiated and carried out. The emitted light passes through the window port, the main convex lens, and a set of near-fiber convex lenses to collimate their rays to be incident on each fiber core. The covering poloidal angle is between 120°– 240°. In the project, the design plans for general impurity monitoring, and observing intense radiation such as MARFE and disruptive radiation.

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DEUTERIUM PLASMA IMPLOSION EXPERIMENTS ON THE PFZ-200 PLASMA FOCUS WITH THE HELP OF INTERFEROMETER AND NOVEL SCHLIEREN DIAGNOSTICS.

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Abstract. In this contribution, we present deuterium implosion experiments on the PFZ-200 plasma focus. The experiments are performed with the initial deuterium gas pressure in a range of 280-360 Pa and the capacitor battery charging voltage of 18 kV corresponding with 2.6 kJ of electrical energy and a current of about 200 kA at the maximum of plasma compression. Instabilities and subsequent disruptions of the imploded plasma generate electric fields that accelerate deuterons. The beam-target nuclear fusion reactions of the accelerated deuterons lead to neutron emission with a yield of ~10^8 per single shot. The imploded plasma is investigated with the help of a diagnostic system including laser imaging (interferometry and schlieren). The novel modification of the schlieren diagnostics allows us to detect different laser-path-integrated density gradients of electron densities and comparing it with the electron densities estimated from Abel inversion from interferometry frames.

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STUDY OF THE RELATIONSHIP BETWEEN EMP PULSES AND FUSION NEUTRON PRODUCTION IN PLASMA FOCI

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Abstract. The PF-1000 plasma focus (IPPLM in Warsaw, Poland) was used to study the relationship between electromagnetic pulses (EMPs) and neutrons produced in the D(d,n)3He fusion reaction. The experimental setup was as follows: the working gas was deuterium with pressures of 120 Pa or 100 Pa and a charging voltage of 12-17 kV (most often 15 kV). The electric current at the time of maximum compression reached up to 1.3 MA. Although the PF-100 facility is relatively old, neutron yields were in the order of 1e10 (measured by the Ag activation counter). Scintillation detectors measured neutron production over time. Several antennas recorded EMP inside the large PF-1000 experimental chamber. These were antennas with a lower cutoff frequency (max. 1 GHz). Furthermore, ion diagnostics (CR-39 trace detectors with different Al filters) detected intense ion beams during several experiments. Their correlation with EMP was also studied.

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EFFECT OF X-RAY PRE-ABLATION ON IMPLOSION PROCESS IN DOUBLE-CONE IGNITION SCHEME

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Abstract. Double-cone ignition (DCI) scheme is a promising novel ignition method, which is expected to greatly save the driving energy and enhance the robustness of the implosion process. In this paper, ablation of the inner surface of the cone by the hard X-ray from coronal Au plasma is studied via radiation-hydrodynamics simulations. It is found for the first time that X-ray ablation of the inner wall and tip of the cone will form strong pre-plasma, which will significantly affect the implosion symmetry and cause the Au plasma to mix with the fuel, leading to the ignition failure. The mixing of Au in fuel at collision is given quantitatively, and the relationship between area density, Au distribution, hydrodynamic instabilities and Au pre-plasma behavior is analyzed. Then, a scheme of coating inner surface of the cone is proposed to reduce the X-ray pre-ablation, and it proves that the scheme can effectively reduce the material mixing and improve the collision result.

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A LARGE WALL ELECTRIC PROBE FOR PLASMA AND AMBIENT GAS DIAGNOSTICS

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Abstract. The operation of a large wall electric probe (LWP), the surface of which is not much smaller than the surface boundary of the plasma volume, is considered. Compared to a small standard Langmuir probe (SLP), a LWP can have greater sensitivity in measuring the electron energy distribution function (EDF) but can also potentially disturb the plasma. An LWP is ideal where measurement sensitivity is important and plasma disturbance by the probe is not significant. A specific case where LWP outperforms SLP is in the measurement of a nonlocal EDF at energies of free diffusion of electrons, that is, at energies significantly exceeding the thermal energies of electrons, to obtain information about the parameters of the plasma or surrounding gas. This study reveals that the plasma volume and probe configuration dictate whether either the first or second derivative of the probe current with respect to the probe potential is required to obtain the energetic portion of the EDF.

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THE EFFECT OF NITROGEN DOPING ON ELECTRICAL AND OPTICAL PROPERTIES OF CU2O FILMS PREPARED BY HIGH-RATE REACTIVE HIGHPOWER IMPULSE MAGNETRON SPUTTERING

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Abstract. Nowadays, transparent conductive oxides are widely used in many important applications. Whereas n-type transparent conducting oxides are well-researched and are already widely used, there is a lack of p-type counterparts with sufficient performance. Cu_2O-based materials are a good candidate for this as they contain only abundant and non-toxic elements. In this study, we systematically investigated the role of nitrogen incorporated in Cu_2O thin films on optical and electrical properties, namely optical band gap, concentration of charge carriers and their mobility. The Cu_2O:N films were prepared by reactive high-power impulse magnetron sputtering of Cu circular target (100 mm in diameter) in $Ar+O_2+N_2$ atmosphere. The pulse-averaged target power density was varied in the range of ≈ 20-1000 Wcm-2, and the fraction of N2in (Ar+N2) mass flow was in the range of 0-90%.

THE MILLER EXPERIMENT: A BRIDGE BETWEEN PLASMA SCIENCE AND PREBIOTIC CHEMISTRY

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Abstract. We propose to use the knowledge gained and established over the years in the low temperature plasma community to the Miller-Urey experiment, an iconic experiment revealing that a mixture of elementary gases exposed to an electric discharge shows first embryonic biomolecules. Plasma science can help to better establish the ionization and dissociation kinetics when compared to ab initio molecular simulations used in chemistry, in which the role of the free electrons, capable of creating radicals if a low temperature plasma physics approach is adopted, is replaced by the electric field induced dissociation of molecules.

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IMPACT OF DIFFERENT M-HIPMS PARAMETERS ON DEPOSITION RATE AND FLUX IONIZATION

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Abstract. Magnetron sputtering belongs to a physical vapour deposition technique. Direct current magnetron sputtering (DCMS) has a high deposition rate but suffers from low ionization of the flux to the substrate, which can lead to lower thin film quality. Opposite to this is high power impulse magnetron sputtering (HiPIMS) with a low deposition rate but high ionization of the sputtered species. One of the possible solutions to balancing these two techniques is the use of multi-pulse HiPIMS (m-HiPIMS), which uses several consecutive pulses with short off-times between them in a single period. Using m-HiPIMS, one can maintain a high deposition rate while achieving significantly higher ionization

flux than with DCMS. We studied metal ions sputtered by m-HiPIMS using biased quartz crystal microbalance. We varied different parameters of the pulse package, such as pulse length, off-time in-between pulses and number of pulses in the pulse package.

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SOME CONSIDERATIONS ON BASIC SHEATH PROPERTIES OF GAS DISCHARGES

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Abstract. The sheath of a gas discharge is a space charge region near the electrodes where significant electric field gradients exist and the charge carriers are strongly affected. It plays a crucial role in several aspects of plasma phenomena, like electron and ion acceleration, excitation and ionization, electrode processes (sputtering, secondary electron emission) and transport of species, momentum and energy. Understanding the properties of the sheath is essential for optimizing the performance of gas discharges for applications.

In this contribution, a few interesting aspects of plasma sheath properties will be discussed: (i) similarity between collisional-dominated Child-Langmuir sheath and matrix sheath, (ii) geometric and electric asymmetry of capacitively coupled rf-plasmas, (iii) particle, momentum and energy transport from plasma to solid surface through a sheath, (iv) dependence of the distance between standing striations on the geometry of a cylindric discharge.

ARGON METASTABLE PRODUCTION FOR OPRGLS USING DBD IN MIXTURE OF ARGON/HELIUM

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Abstract. The optically pumped all-rare-gas laser(OPRGL)utilizes metastable atoms of Ar, Kr and Xe as lasing medium, but high enough medium density is difficult to achieve for high power lasering. In the study, the suitability of DBDs for high density Ar($1s_5$) production in gas mixtures of He and Ar is evaluated by using repetitively pulsed voltage or sinusoidal voltages. It is verified the strating edge of the discharge pulses in pulsed DBD excites a sharp growth of metastable while the density decays in later phase of the pulses. Sinusoidal DBD is usually consist of sequence of discharge pulses and thus can generate metastable pulses many times in each period of voltage. By varying the gas mixing ratio and the sinusoidal frequency, the discharge pulses can be adjustable in width and rating. It is expected that an optimization state for metastable density maybe found for DBD in Ar/He by sweeping gas mixing ratio and voltage frequency.

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OPTICAL EMISSION SPECTROSCOPY OF BREAKING ARC PLASMA BETWEEN CONSUMABLE ELECTRODES

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Abstract. The investigation focuses on the optical emission spectroscopy of plasma generated by breaking arc between single-component Cu and composite Cu-W electrodes manufactured using shock sintering technology at temperature of 750 °C. The electrodes were subjected to arc currents of 4, 50, and 104 A. Optical emission spectroscopy with high spectral and temporal resolution was employed to investigate the plasma with copper and tungsten vapour admixtures. The temporal evolution of temperature in the plasma was determined by the Boltzmann plot technique based on the emission intensities of Cu I spectral lines. Temporal evolution of electron densities were determined from the full width at half maximum of Cu I 515.3 nm spectral line. These initial plasma parameters integrated over the volume of breaking arc were utilized to calculate the temporal evolution of plasma compositions and contents of metal vapours admixtures in discharge gap.

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SIMULATION OF A FREE BURNING ARC IN ARGON AT 200A ON COMSOL MULTIPHYSICS 6.1

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Abstract. Studied in welding, cutting, or nanoparticules, thermal plasmas thermal plasmas are fundamental in processing of materials and in energy industry, especially through arc discharge studies.

This type of plasma is not easy to study, especially through experimental studies where the setting up of experiments proves to be complex. Numerical simulation therefore appears to be one of the solutions, enabling us to obtain precise parameters on the arc that would otherwise be impossible to acquire. To begin simulating thermal plasmas, it is necessary to study a simple case, widely described in the literature, in order to validate a model, and then move on to more complex cases. The free burning arc case appears to be the most accessible. After validating the model by comparing it with other data in the literature, a parametric study is carried out to investigate the influence of numerous parameters to evaluate their impact on the temperature and particles velocity field.

EXPERIMENTAL COMPARISON OF PLASMA-ASSISTED GASIFICATION AND CONVENTIONAL ENTRAINED FLOW GASIFICATION IN A PILOT-SCALE GASIFIER

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Abstract. Entrained flow gasification has gained prominence as a technology for converting organic feedstocks into syngas, which can be used for the synthesis of chemicals. In recent years, there has been

a shift in the feedstock – from coal through biomass to residues. This has resulted in a deterioration of fuel properties. Simultaneously, there is an increasing demand for syngas quality as the focus moves from energetic use towards utilization for syntheses. Introducing plasma into the gasification process is one way to align with these contradictory trends.

This paper presents a comparative analysis of conventional and plasma-assisted entrained flow gasification. The study aims to evaluate the performance and efficiency of these two processes to further investigate the advantages and disadvantages of plasma integration. Critical operational parameters such as carbon conversion, wall temperatures, main and trace gas components are studied for that.

PLASMA GENERATED IN ORGANIC SOLUTION FOR FORMATION OF CONDUCTIVE POLYMER FILM

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Abstract. Process using plasma generated in a solution, as known in-solution plasma (iSP) process, is a method that excludes influences of air and can effectively interact between plasma and materials in a monomer-dominant environment. However, due to the arc-like plasma of iSP, carbonization of the organic solution occurs and it is very difficult to synthesize a conductive polymer with a π-conjugated structure. And many applications using iSP are still limited to nanoparticle synthesis. Herein, we propose an iSP reactor that generates DBD-based iSP to avoid carbonization of pyrrole solution. This reactor produced ionic precursors rather than fragmentation of pyrrole molecules during the iSP process. Additionally, polypyrrole (PPy) films are successfully synthesized under specific driving conditions. The morphology, chemical and electrical properties of these PPy films are investigated in detail. The mechanism by which films are synthesized through the iSP process is also suggested.

UNIFORM AND CONDUCTIVE POLYMERIC NANOCOMPOSITE FILM SYNTHESIZED BY ATMOSPHERIC PRESSURE PLASMA REACTOR

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Abstract. In atmospheric pressure (AP) plasma polymerization, increasing the effective volume of the plasma medium by expanding the plasma-generating region within the plasma reactor is considered a simple method to create regular and uniform polymer films. Here, we propose a newly designed AP plasma reactor with a bump-shaped wire electrode that can expand the discharge volume. Since discharge ignites only at the lower part of the triangular bump, as the number of bumps increases, the discharge volume can be successfully expanded. Although discharge imbalance due to differences in bump positions can adversely affect the uniformity of polymerized nanocomposite films, rotating the substrate using a turntable can greatly improve film uniformity. With this AP plasma reactor, polythiophene (PTh) nanocomposite films are synthesized and both the morphology and chemical properties of the PTh nanocomposite as well as the PTh film uniformity are investigated in detail.

HOW DO DIFFERENT TREATMENT CONDITIONS AFFECT THE SPORICIDAL PROPERTIES OF NANOPULSE GENERATED PLASMA?

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Abstract. Antimicrobial properties of non-thermal plasma (NTP) leading to its possible biological applications are still a subject of great interest. However, for practical application it is essential to understand how different conditions during the treatment affect the final antimicrobial effect. There are many publications focused on antibacterial efficacy, but there are only a few studies on the sporocidal properties of NTP discussing the parameters that may play a role during the treatment. In addition, it is complicated to compare the results published by different groups with each other due to differences in the species of microorganisms, sample preparation, etc. For this reason, the presented study used a robust and reproducible standard protocol based on well-defined samples of Bacillus subtilis spores. This method served well to investigate and compare the effect of different treatment conditions for a device based on a dielectric barrier discharge with a nanopulse power supply.

UNDERSTANDING CHANGES OCCURING TO PHYSICAL PROPERTIES OF WATER AS RESULT OF NON-THERMAL PLASMA ACTIVATION (SURFACE TENSION, VISCOSITY AND CONTACT ANGLES)

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Abstract. The interaction of water with non-thermal plasma results in the production of reactive species such as reactive oxygen and nitrogen species in water. Water synthesized in this manner is referred to as plasma activated water (PAW). These reactive species in PAW allow it to be used for a wide range of applications in the fields of sterilization, medical, agricultural, and food industries. As a liquid used for multiple applications, determining the physical properties of PAW will aid in identification of its potential future applications. PAW produced using gliding arc plasma has been used for this study; and surface tension, viscosity and contact angles of PAW are investigated here. Investigations conducted in this study shows that at room temperatures plasma activation results in the lowering of surface tension and contact angles made by water; and results in lowering of viscosity at lower temperatures and increase of viscosity at higher temperatures.

PREPARATION OF THIN FILMS BY REACTIVE MULTI-PULSE MAGNETRON SPUTTERING

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Abstract. The work is focused on the preparation and analysis of TiN and TiC coatings deposited with methods based on magnetron sputtering. Magnetron sputtering is a typical example of Physical Vapor Deposition technique. Meanwhile, magnetron sputtering was originally supplied with direct

current power (dcMS), in this work we aimed to study pulsed settings called High-Power Impulse Magnetron Sputtering (HiPIMS). In this method, the power supplied on the target has the form of a high power pulse followed by long off-time interval. Emphasis was put on the multi-pulse operation of HiPIMS, in which we supply the power in pulse train consisting of several pulses. We aimed to investigate several magnetron sputtering-based deposition settings, including dcMS, s-HiPIMS, and 2 variants of m-HiPIMS settings, in the case process parameters, hardness, surface structure, and crystallinity. We analyzed the results regarding the influence of the deposition process.

WOOD SURFACE CHARRING MEDIATED BY NON-THERMAL ARC DISCHARGE

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Abstract. The long-term durability of wood, especially in an outside area, requires a proper preservation treatment. Among various recently developed wood modification methods (acetylation, furfurylation, silicification) thermal treatment resulting in called thermally modified timber (TMT) represents probably the most environmentally safe approach. A low pyrolysis of wood is carried out at temperatures of 180-250 °C at low oxygen content to avoid wood combustion. Nevertheless, TMT suffers by weaker structural integrity due to thermal degradation of its constituents. A good compromise, allowing sufficient wood protection without sacrificing its volume mechanical properties, is achieved by a wood surface charring e.g., by a naked flame or hot contact plate. In this contribution, the wood surface pyrolysis mediated by non-thermal arc discharge along the wood surface will be introduced and compared with the conventional method of hot contact plate.

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EFFECTS OF NITROGEN CONTENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF HIGH ENTROPY NITRIDE COATINGS: DC MAGNETRON SPUTTERED CR-MN-MO-SI-Y-(N) SYSTEM

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Abstract. High entropy alloys are composed of at least five elements with a concentration of 5-35 at. %. Their derivative, high entropy nitrides, exhibit properties such as hardness within the superhard region, high fracture toughness together with impressive wear resistance, and thermal stability at elevated temperatures. Such properties are essential for protective coatings, which must withstand demanding conditions involving large forces and high temperatures. Our study aims to investigate the microstructure and mechanical properties of Cr-Mn-Mo-Si-Y-(N) coatings. These were prepared by direct current magnetron sputtering, a physical vapor deposition method that employs ions from plasma for target sputtering. Different deposition conditions such as varying nitrogen flow, substrate

temperature, and substrate bias were investigated. The analysis of the coatings was focused on evaluating chemical composition, surface morphology, crystallography, and mechanical properties.

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MODIFICATION OF POLYMER COMPOSITE FILLED WITH CARBON NANOMATERIALS BY OXYGEN PLASMA

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Abstract. Modification of the polymer matrix with carbon nanomaterials and subsequent irradiation in oxygen plasma with a fluence of 30×10^{20} atoms/cm^2 leads to a decrease in reflection coefficients by more than an order of magnitude. The specular reflection coefficient decreases by more than a factor of 2 over the entire area investigated, compared to the original polymer. The oxygen plasma source operates in the range of atmospheric air pressure from 1 to 6 10^{-5} Pa, which corresponds to the ionosphere layer from 80 to 210 km. Optical studies were carried out in the wavelength range of 0.2 - 25 µm. The obtained results prove the promising application of these composite materials as antireflective absorbing coatings in optical and optoelectronic systems of both spacecraft and ground applications.

FIRST RESULTS OF A NEW SYSTEM OF MAGNETIC COILS AT THE GOLEM TOKAMAK

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Abstract. A new system of magnetic coils was recently installed into the Golem tokamak. A poloidal ring with Mirnov coils was furnished by (i) an inner Rogowski coil, (ii) two inner toroidal field coils placed on the HFS and the LFS, and (iii) a diamagnetic coil. The inner Rogowski coil measures the plasma current being undisturbed by the current in the liner. Such the inner toroidal coils measure the toroidal field without the effect of the field penetrating through the liner. The most important contribution is promised by the diamagnetic coil which is aimed to establish the energy confinement time derived from the thermal energy. First results from testing this system will be presented in this contribution.

STUDY OF OZONE DESTRUCTION REACTION ON SURFACES

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Abstract. The ozone destruction was studied in a quartz cuvette. The time dependence of ozone concentration was measured by absorption spectroscopy. From this time dependence the pseudo first-order rate constant was derived. This rate constant depends on surface condition - the surface concentration of adsorbed oxygen atoms. This surface concentration was changed by reactions of adsorbed oxygen atoms with gaseous molecular oxygen just before the cuvette was filled by ozone. The decrease of atomic oxygen surface concentration leads to the decrease of rate constant for ozone destruction. The measured rate constants were in range $9.0 \times \exp(-5)$ 1/s to $9.8 \times \exp(-5)$ 1/s.

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IMAGING STUDY ON THE INITIATION PROCESS OF MICROSECOND PULSED POSITIVE STREAMER DISCHARGE IN WATER

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Abstract. The initiation process of microsecond pulsed positive streamer discharge in water has been investigated by using a shadowgraph technique. The experiments were carried out with a needle-to-plate electrode configuration at different water conductivities (200 to 1400 μS/cm in a step of 200 μS/cm) and applied voltages (22 to 38 kV in a step of 8 kV). At each certain condition, thirty discharge pulses were repeated with a frequency of 1 Hz. Four successive images were obtained from a single discharge pulse by using an ultrahigh speed frame camera system. Based on the obtained images, we found that a bubble of ~100 μm in radius firstly formed at the tip of the needle anode and then the electrical discharge ignited in the bubble. The radial expansion speed of the bubble before the discharge ignition is of ~2 km/s, which is much larger than 0.1 m/s, the radial speed of a superheated vapor bubble.

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ENHANCING PLASMA TORCH EFFICIENCY: WET STEAM COOLING

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Abstract. The efficient use of wet steam for plasma torch cooling and water plasma generation is important for reliable plasma generator design. Wet steam, due to phase transformation capability, improves heat removal at lower gas flow rates if compared to liquid water. To evaluate the wet steam cooling potential, a numerical model is proposed, incorporating governing equations (mass, momentum, energy, current, and Ampere's law) are expressed in the cylindrical coordinate system. The model is applied toinvestigatethe wet steam cooling feasibility for the anode of a direct current plasma torch with non-transferred arc. Electric arc modeling examines anode spot location and anode surface temperature distribution for a 120 A arc current and gas flow rates of 42, 90, and 140 l/min under steady flow conditions. Analysis of spatial vapor content distribution in the refrigeration channel highlights unfavorable conditions when wet steam becomes dry.

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TWO- AND THREE-DIMENSIONAL MODELING OF THERMAL PLASMA FLOW IN A NON-TRANSFERRED DC PLASMA TORCH

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Abstract. This paper numerically studies the thermal plasma flow in a well-type DC plasma torch operating with air via a steady two-dimensional axisymmetric as well as unsteady three-dimensional approach. A second-order accurate finite volume method is adopted to discretize the governing equations and SIMPLE algorithm is employed for decoupling velocity and pressure. The case of working current 140A and flow rates 140 SLM is numerically studied, where the investigated plasma torch is 690 mm long, and has a radius of 11 mm. Three-dimensional calculation predicts an arc length of 267 mm while two-dimensional simulation forecasts an arc length of 335 mm. It indicates that the three-dimensional nature of fast-moving rotating arc seems to be better described by a fully three-dimensional model rather than a two-dimensional one under axisymmetric assumption.

NUMERICAL MODELLING OF ION WIND IN DC POINT-TO-RING CORONA DISCHARGE

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Abstract. Ion wind, also known as electrostatic wind, is an electrohydrodynamic phenomenon induced by electrostatic forces. This occurrence involves the acceleration of charged particles generated by the discahrge under the influence of an electric field, resulting in the movement of surrounding air molecules and creating a type of airflow.

This study propose the numerical model based on the modelling of electrostatic field by Laplace's equation and on the Monte Carlo modelling of particle movement and transfering it's momentum to neutral particles. Simulation predictive accuracy are compared with experimental data for point-to plane and point-to-ring corona discharges for voltages approx. 6-8 kV and currents 50-100 μA with variable distances between the electrodes. The simulated results can partially explain the observed characteristics of generated ion wind.

ELECTRON-BEAM INDUCED EVAPORATION OF MICRODROPLETS FROM AN ARC DISCHARGE

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Abstract. Arc discharges are thin film deposition tools with a high growth rate. They are attractive to both academic research and industrial production. The flux of material from such a discharge contains microdroplets produced at the cathode, which are detrimental to the majority of thin film applications. Here, we suggest a design for eliminating these microdroplets using an electron beam. The feasibility of the proposed design is shown using a hybrid plasma model containing a plasma filter with an electron beam. The model solves a self-consistent system of equations for the balance of energy per droplet, potential and mass of the droplet, as well as considering the possibility of heating plasma electrons by the electron beam. It is shown that in such a system it is possible to completely evaporate droplets with a size of the order of 1 μm or less during their movement through the plasma filter. Important parameters for the overall performance of the system are discussed.

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STATIC FIELD IONIZATION OF A CYLINDRICAL CONFINED HYDROGEN ATOM: A QUANTUM MODEL FOR THE SIMPLEST NANOPLASMA

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Abstract. Our main goal is to determine how the cylindrical confinement conditions modify the properties of the confined hydrogen atom. We apply the diffusion Monte Carlo method to the study of the quantum states of a hydrogen atom confined into a cylindrical potential well and discuss the ionization of ground and excited states of the confined atom produced by an external electric field, including the determination of the potential energy surface and equilibrium position of the proton. Ionization becomes a more multifaceted phenomenon in the case of nanotube type confinement due to the different non-equivalent directions of application of the electric field.

As the finite cylinder geometry with longitudinal field is characteristic of a capacitively coupled electrical discharges, our model can be considered the simplest quantum analogue of a hydrogen plasma produced by an electric field in a discharge-like configuration, involving a single hydrogen atom.

Acknowledgement: *This research has been supported by the PNRR MUR project PE0000023-NQSTI (National Quantum Science and Technology Institute).*

STUDY OF RELATIVISTIC EFFECTS IN HIGH-INTENSITY LASER PLASMA SYSTEMS USING QED APPROACH

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Abstract. Quantum plasma is a state of matter that occurs at extremely high temperatures or densities. In order to interpret the dynamic behaviour of the quantum plasmas, there are 4 mathematical models employed to describe quantum plasma systems. The Wigner-Poisson model, the Schrodinger-Poisson model, the quantum hydrodynamic model and the quantum electrodynamic approach. In this paper, we have used the relativistic QED approach to develop a new model employing the covariant Lagrangian function and Euler-Lagrange equations to unveil a system between electromagnetic waves and spin plasma. The relativistic effects have been incorporated through the relativistic factor, the temporal component of four spin, and the coupling with the velocity field. Utilising a QED approach, relativistic kinetic equations catering to both spin +1/2 and -1/2 entities, have been established. The new model in relativistic quantum plasma will be useful in understanding astrophysical phenomena.

DYNAMICS OF SOLITARY WAVES IN ASTROPHYSICAL SPIN POLARISED QUANTUM PLASMAS

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Abstract. Quantum plasmas are observed in a variety of celestial bodies, including quasars, pulsars, neutron stars, brown dwarfs, white dwarfs, red dwarfs, and the accretion disks of black holes. Notably, these astrophysical environments display a wide diversity of charge species, often comprising ions, electrons, and positrons due to their intense energy levels.

This paper focuses on the dispersion characteristics exhibited by all three plasma species within these astrophysical environments by using QHD model incorporating quantum effects like Fermi pressure, Bohm Potential, spin of electrons and positrons and environmental effects like gravity and rotation. The spin polarization induced by the density difference of spin-up and spin-down electrons under the influence of magnetic field has also been taken into account. Employing the Korteweg-de Vries (KdV) method, we have studied the solitary waves and their solutions, providing a detailed understanding of their behavior.

DETERMINATION OF ION FLUX IN A MODELED CO2 PLASMA FOR SURFACE TREATMENT OF CELLULOSIC MATERIALS

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Abstract. A modified computer code, based on the "PIC" method, developed at the Plasma Theory and Simulation Group (Berkeley, University of California) was used for the purpose of simulating gas discharge in a reactor chamber with 1D cylindrical geometry. By modifying the base of effective cross sections, data on the potential gradient per unit distance between the energized and grounded electrodes of the CCP reactor were obtained. RF plasma is modeled with supply frequency of 13.56 MHz and set discharge powers of 20, 40, 60, 80, 100 W. This gave an insight into the volume of cathodes potential drop cylinder. The Monte Carlo simulation has been employed to determine the ionization rate coefficients for certain reduced electric fields in cylinder. Knowing both of those obtained data

with the number of electrons created in cylinder, the number of ions that threat the sample of the cellulosic surface per unit of its surface is determined per second for the applied discharge power.

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STUDY OF HIGH-FREQUENCY ELECTRODELESS MERCURY CAPILLARY DISCHARGE IN THE MAGNETIC FIELD

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Abstract. In this work, we analyzed 253,7 nm spectral line shapes of mercury, emitted from micro-size electrodeless mercury/xenon capillary light source in a magnetic field for their usage in Zeeman high-precision atomic absorption spectrometry. Different working positions of the lamp were observed. The mercury spectra were measured using a Fourier transform spectrometer at room temperature. Obtained profiles were presented in the form of a Fredholm integral equation of the first kind and separated from an instrumental function using a method based on Tikhonov regularization to solve ill–posed inverse tasks. The temperature of the plasma was determined. Hg cold spot temperature was measured for pressure determination. The Zeeman splitting of the energy level $^3P_1$ on the intensity of the magnet field was calculated for all stable isotopes of Mercury, and the value of the magnet field in the experiment was accurately determined as well.

Acknowledgement: *The research was supported by UL IAPS, the Latvian Council of Science Project No. lzp-2020/1-0005, and Latvian National State Research Programme project "Smart materials, Photonics, Technologies and Engineering Ecosystem [MOTE]" Nr. VPP-EM-FOTONIKA-2022/1-0001*

STREAMER-INDUCED VIBRATIONAL DISTRIBUTION FUNCTIONS OF N2 EXCITED STATES AT HIGH E/N

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Abstract. Vibrational distributions of electronically excited states obtained through dipole-allowed radiative transitions provide an important tool for studying the kinetics of non-equilibrium plasmas under various discharge conditions and provide benchmark data for the validation of advanced kinetic schemes for numerical models. Our testing discharge is a streamer monofilament developed in a dielectric barrier discharge configuration, powered by a specific high-voltage waveform based on periodic (10 Hz) bursts composed of two consecutive HV AC waveforms (1 kHz) and a nanosecond HV pulse. By varying the neutral gas pressure between 300 and 15 Torr, we can obtain reduced electric fields in a wide range (300-1500 Td). We present diagnostic procedures and analytical approaches to obtain the vibrational distributions of important electronically excited states using the acquisition and processing of optical emission spectra in a wide spectral range (200 - 1100 nm) with increased spatiotemporal resolution.

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UNDERSTANDING THE INTERACTIONS BETWEEN DUST PARTICLES AND PLASMAS: A KEY ASSET FOR HIGH POTENTIAL APPLICATIONS

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Abstract. The field of Complex Ionized Media (CIM) explores the physics behind the interactions between nano- to micrometer sized dust particles, plasmas, ionizing radiation and external electric fields. The governing plasma-systems may be non-quasi-neutral and varying in space and/or time. This contribution gives a brief introduction into the field and into several emerging applications of CIM. These applications include contamination control in semiconductor industry and in Extreme Ultraviolet (EUV) Lithography.

Discussed will be the formation and operation of photon-induced plasmas in EUV lithography equipment, and the impact of such plasma on the morphology - and governing release from surfaces - of lead and tin based contaminating particles. In addition, some latest ideas and results will be highlighted that focus on the development of novel diagnostics to measure electrical charge on plasma-immersed dust particles and on dust particles on plasma-facing surfaces.

TOWARDS VALIDATED SIMULATIONS OF CAPACITIVELY COUPLED RADIO-FREQUENCY PLASMAS

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Abstract. Capacitively coupled plasmas (CCPs) have key applications in plasma processing technologies, such as etching in microelectronics, deposition of thin films in photovoltaic industry, and surface functionalization in material science and medical technologies. These plasma sources also exhibit a variety of physics effects that make them attractive subjects of experimental and modeling / simulation studies. As many low-temperature plasma sources, CCPs are non-equilibrium systems, where populations of different charged and neutral species with markedly different velocity distribution functions co-exist. At low-pressures, particle (especially electron) transport becomes non-local, calling for methods of kinetic theory. Thanks to the advance of the experimental techniques and numerical computing capabilities more and more details of the physics of electrical discharges are being uncovered at the level of elementary processes and even at the level of individual particles, since simulations provide direct access to single particle properties, e.g., the velocity distribution function. Unfortunately, the results of state-of-the-art experiments and simulations are rarely cross-checked with each other, although such a comparison would aid the validation of discharge models, which is required for the correct interpretation of experimental observations and could ensure that simulations have a high predictive power. The talk will review some recent synergistic computational-experimental studies aimed at the validation of the discharge models, including measurements of the charged particle densities and energy distributions, surface coefficients, metastable atom densities, and optical emission from low-pressure CCPs operating in various gases.

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KINETICS OF MOLECULAR METASTABLES AND ATOMIC SPECIES IN NONEQUILIBRIUM PLASMAS IN A HEATED PLASMA FLOW REACTOR

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Abstract. A heated plasma flow reactor, with the flow excited by a ns pulse discharge operated at a high pulse repetition rate, is used to study the kinetics of excited metastable states of N2, highly excited vibrational levels of O2, and their coupling to the number densities of N, O, and H atoms. The discharge generates a diffuse volumetric plasma with well-defined boundaries, with ample optical access for laser diagnostics. This approach is employed for three kinetic experiments in nitrogen, O2-Ar, and N2-H2 mixtures. Time-resolved, absolute number densities of metastable nitrogen molecules, N2(A3Σu+,v), and molecular ions, N2+, are measured in nitrogen and N2-NO mixtures, at temperatures of T=300-1000 K. The measurements are made by Tunable Diode Laser Absorption Spectroscopy (TDLAS) and pulsed UV Cavity Ring Down Spectroscopy (CRDS). The results illustrate the generation and decay of N2(A), a precursor for metastable excited atoms, during the discharge burst. Time-resolved N2+ measurements in the afterglow exhibit the effect of associative ionization of excited species accumulated during the discharge. The results indicate that associative ionization is produced in collisions of metastable N atoms generated during the N2(A) quenching by the ground state atoms. Kinetics of O2 vibrational excitation is studied during the O atom recombination in an O2-Ar mixture partially dissociated by a burst of ns discharge pulses in a flow reactor, at T=400-800 K. Time-resolved vibrational level populations O2(v=8-20), are measured by ps Laser Induced Fluorescence (LIF), with absolute calibration by NO LIF. The O atom number density is measured by ps Two-Photon Absorption LIF (TALIF). The results exhibit a rapid initial decay of O2(v) populations generated by electron impact in the discharge, on ~10 μs time scale, due to the O2-O2 V-V exchange and V-T relaxation by O atoms. A significantly slower decay, on a time scale of ~1 ms, indicates the O2(v) generation by chemical reactions initiated by the O atom recombination. These trends are analyzed by the kinetic model, incorporating the state-specific electron impact excitation, V-V exchange, V-V relaxation, and chemical reactions. Kinetics of N and H atoms are studied in a "hybrid" ns pulse discharge overlapped with a sub-breakdown RF waveform, with the focus on the plasma-catalytic ammonia generation. Time-resolved N and H atom number densities are measured by ns TALIF. The ammonia yield is measured with and without Ni, Ru, and Rh /γ-Al2O3 catalysts placed in the plasma reactor. The RF waveform is used to isolate the effect of N2 vibrational excitation on the ammonia generation. Adding the RF waveform results in a well-defined, reproducible increase of the ammonia yield, measured over a "blank" alumina sample, as well as Ni, Ru, and Rh samples, by up to 25% compared to the ns pulse discharge operating alone. Parametric studies are used to determine whether this effect is caused by the surface reactions of vibrationally excited nitrogen.

EXPERIMENTAL AND COMPUTATIONAL INVESTIGATION OF A NANOSECOND-PULSED VOLUME DIELECTRIC BARRIER DISCHARGE IN HUMID AIR

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Abstract. Low-temperature plasmas (LTPs) are attracting significant interest from researchers in both academia and industry for a variety of applications, including plasma medicine and plasma-based sterilization. Understanding the complex interactions between LTPs and biological substrates is fundamental to improving and optimizing these treatments. Given the numerous parameters influencing both the plasma and the biological substrate, a comprehensive understanding of the plasma discharge physics under precisely controlled conditions is required. To achieve this goal, all the main interacting physical and chemical agents (RONS, electric fields, radiation, etc.) must be thoroughly characterized both temporally and spatially. In this contribution, we present an experimental setup that enables laser-based measurements of the electric field and the nitric oxide (NO) generated in an atmospheric pressure, nano-pulsed volume dielectric barrier discharge (VDBD). These measurements are then compared with predictions from numerical simulations. The electric field measurements are performed using electric field-induced second harmonic (EFISH) generation via a picosecond laser, which is also employed for laser-induced fluorescence (LIF) of nitric oxide. We have developed a global (volume-averaged) kinetic model to simulate the experimental setup operating in humid air (78% N2, 19% O2, 3% H2O) at atmospheric pressure in a diffuse regime. The model is constituted by ~5000 reactions including electron impact collisions, ionic charge exchanges, N2 vibrational kinetics and heavy species collisions. The reaction rates for the electron impact collisions are calculated using the LoKI-B Boltzmann solver for different values of the reduced electric field. The influence of a convective flux on the chemical kinetics was also considered. The reduced electric field measured during one discharge pulse is used as an input for the model. The experimental measurements are compared with simulations and are used to highlight the role of electron attachment in the plasma discharge.

IMPROVEMENT OF ELECTRICAL AND OPTICAL PROPERTIES OF CU_2O BASED P-TYPE TRANSPARENT CONDUCTIVE OXIDES

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Abstract. In this work, we have utilized different approaches to improve the optical and electrical properties of Cu_2O-based films. We investigated nitrogen incorporation into Cu_2O during its growth by high-power impulse magnetron sputtering (HiPIMS) at different pulse-averaged target power densities. Additionally, we utilized a high-power infrared laser to post-treat Cu_2O thin films prepared by high-rate reactive HiPIMS. We found that reactive HiPIMS is a promising method for forming nitrogen-doped Cu_2O films with tunable nitrogen concentration. For the optimized nitrogen content, the film exhibits electrical conductivity three orders of magnitude higher than for the pure Cu_2O film. In the case of laser post-treatment, we found that this method could be a promising way to increase hole mobility in Cu_2O-based materials without the requirements for high temperature and/or special working atmosphere.

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EFFECT OF ANNEALING ON NANOPARTICLE-BASED COMPOSITE CUO-WO_3 THIN FILMS FOR GAS SENSING

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Abstract. Conductometric gas sensors based on metal oxide semiconductors often require high operating temperatures to achieve adequate sensing responses without catalyst. Understanding the impact of temperature on the microstructure and fundamental processes within the sensor is hence crucial. In this study, we investigated the effect of annealing on individual thin films composed of n-WO_3 and p-CuO nanoparticles (NPs), as well as on a layered composite of n-WO_3/p-CuO NPs synthesized using a magnetron-based gas aggregation source. The films were annealed under synthetic air conditions in a furnace at high temperatures, followed by characterization studies. An increase in crystallinity and grain size were observed with annealing for the CuO and WO_3NP-based thin films. However, the composite sample exhibited a distinctive microstructural evolution with notable thermal stability, and completely crystallized into the CuWO4 phase at 550 °C.

HELIUM-ASSISTED GLANCING ANGLE DEPOSITION OF THIN FILMS OF TICUO$_X$ AND WO$_X$ FOR CONDUCTOMETRIC HYDROGEN SENSING

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Abstract. Addressing the challenges posed by the low sensitivity and selectivity of current hydrogen sensors, this study introduces helium-assisted sputter deposition for $TiCuO_x$ and WO_x films, aiming to improve hydrogen sensors' sensitivity and selectivity. $TiCuO_x$ films were produced using DC magnetron sputtering with a Ti target and a Cu strip, employing mixtures of argon, helium, and oxygen at 520 mPa. The GLAD technique created a columnar structure, increasing roughness and porosity for better hydrogen interaction. Helium was then introduced, replacing some argon, to further alter the $TiCuO_x$ films' surface properties. The following samples were annealed at 400 °C to crystallize and stabilize them for hydrogen detection. Initial tests indicate improved sensor response for $TiCuO_x$ and WO_x films. Structural analyses through SEM, XRD, and AFM revealed morphological and crystalline changes due to helium-modified plasma aputtering.

MAGNETRON SPUTTERED W-ZR-CU THIN-FILM ALLOYS: A STUDY OF PHASE TRANSITION, MECHANICAL AND ELECTRICAL PROPERTIES

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Abstract. In the dynamic field of material science, magnetron sputter deposition has significantly contributed to the fabrication of metastable metallic alloys. Our study is focused on the unexplored W-Zr-Cu system, investigating the structure and potential enhancement of properties of thin-film alloys prepared in this ternary system. Throughout the film series, we gradually increased the W content while keeping the atomic ratio of Zr:Cu equal to one. Our initial investigation revealed an abrupt transition from an amorphous to nanocrystalline phase in the W-Zr-Cu films when the W content exceeded 66 at. %. SEM cross-sectional images of the amorphous films showed vein-like features on the fracture surface, which are typical of metallic glasses. Further results on W-Zr-Cu ternary thin-film alloys will be presented, offering new insights into the material's phase transitions, mechanical strength, and electrical properties.

A ONE-STEP APPROACH FOR THE PRODUCTION OF ZRN@SIN NANOPARTICLES WITH TUNABLE PROPERTIES

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Abstract. Zirconium nitride (ZrN) is widely used as a hard, refractory material with promising optical properties. Adding a complementary compound may contribute to the perspective of unique materials with tunable features. This research employed a gas aggregation cluster source to fabricate ZrN nanoparticles (NPs) by DC magnetron sputtering in an Ar/N_2 mixture. Through subsequent in-flight coating via an RF magnetron sputtering of SiN, we achieved core@shell NPs represented by a cubic ZrN 'core' enveloped by a SiN 'shell' of controllable thickness. This allowed the optical properties to be tuned, resulting in a plasmonic red shift from the red/near-IR region with continuous color changes of the samples from green to purple. Enhanced thermal stability of optical properties was

observed with the presence of the SiN shell. In this manner, a one-step sputter-based technique can be successfully used for the production of overcoated NPs with novel properties for various applications.

Acknowledgement: *This research has been supported by the Charles University Grant Agency under Contract 372322.*

ZNO THIN FILMS PREPARED BY AR + O2 + ZN MIXING POWDER GAS AT LOW- PRESSURE HIGH-FREQUENCY PLASMA CHEMICAL VAPOR DEPOSITION METHOD

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Abstract. Semiconductor thin films are vital for modern electronic devices such as LEDs, transistors, and solar cells. They are typically produced by depositing atomic layers onto substrates like silicon wafers, valued for their conductivity and chemical resistance. However, there's a need for alternatives with suitable morphology and electrical properties. Zinc oxide (ZnO) shows promise due to its conductivity, non-toxicity, and abundance. Its high conductivity makes it ideal for solar cells. Chemical vapor deposition (CVD) is a promising technique for depositing high-quality ZnO films rapidly and with excellent surface modification. This study focuses on fabricating ZnO thin films on Si substrates using CVD with a gas mixture of argon, oxygen, and Zn powder.

Acknowledgement: *This research has been supported by Research Grant Program from the Amano Institute of Technology.*

SURFACE MODIFICATION OF PCR PLATES USING COLD AIR PLASMA AT ATMOSPHERIC PRESSURE AND INVESTIGATION OF ITS EFFECTS

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Abstract. PCR (Polymerase Chain Reaction) plates are frequently used in the fields of Medical Biology-Genetics and Molecular Biology-Genetics. PCR/qPCR plastics are usually made of polypropylene because polypropylene is inert and can withstand rapid temperature changes during thermal cycles. Therefore, the use of polypropylene is very common. However, during the use of PCR plates, DNA interacts with the surface and can denaturate on polypropylene. When the plates are used to store DNA, the DNA can decrease over time, both in quantity and quality, because the DNA is absorbed by the surface. It is possible to change the adsorption properties of PCR plates by controlling the surface tension values. Because plasma can control the surface energies of materials. In this study, the effect of cold air plasma at atmospheric pressure on reducing DNA adsorption on PCR plates was investigated.

ELECTROMAGNETIC PARTICLE-IN-CELL SIMULATIONS OF TECHNOLOGICAL PLASMAS

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Abstract. Many types of technological plasmas are operated at a low pressure with the driving electric field having a strong high frequency component so that the electrons are not in equilibrium with the electric field and thus demand a kinetic and nonlocal description. If at the same time the characteristic wavelength of the bulk or surface modes having an essential electromagnetic component becomes comparable to the system size, an electromagnetic model needs to be used. The talk will focus on using the implicit energy- and charge-conserving electromagnetic particle-in-cell numerical approach, which satisfies all these requirements and allows to simulate many of relevant plasma discharges self-consistently and with high fidelity. After recapping the method, two examples exhibiting electromagnetic, nonlocal and kinetic effects will be discussed: large capacitively coupled plasmas driven by very high frequency harmonics and microwave-driven plasmalines.

VERSATILITY OF MATERIAL PROCESSING WITH PLASMA JETS: FROM GLIDING ARC TO COLD ATMOSPHERIC PLASMA

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Abstract. Numerous configurations of atmospheric pressure plasma jets studied over the last five decades can be sorted into different groups based on the type of discharge (coupling and frequency), the geometry of electrodes, or working gas (J. Winter, R. Brandenburg, K. Weltmann, Plasma Sources Science and Technology 24 (6) (2015) 064001). The two major groups of jets used in atmospheric pressure processing of polymers are the cold atmospheric plasmas (CAP) and arc-based transitional plasmas. In CAP plasma jets, the power couples through a dielectric barrier, and the frequency varies from kHz to MHz. The setup has to limit transitions to arc discharge. Plasma is far from the local thermal equilibrium (LTE); the electron temperature is high, while the neutral gas temperature increases only moderately above the room temperature. These jets are standardly ignited in noble gases (Ar and He). The arc-based transitional plasma jets start as an arc discharge in the LTE cooled down by gas flow into a nonthermal plasma. They can also operate in air (D. P. Dowling, F. T. O'Neill, S. J. Langlais, V. J. Law, Plasma Processes and Polymers 8 (8) (2011) 718–727; M. Kehrer, A. Rottensteiner, W. Hartl, J. Duchoslav, S. Thomas, D. Stifter, Surface and Coatings Technology 403 (2020) 126389; P. Jelínek, K. Polášková, F. Jeník, Z. Jeníková, L. Dostál, E. Dvořáková, J. Cerman, H. Šourková, V. Buršíková, P. Špatenka, L. Zajíčková, Surf. Coat. Technol. 372 (2019) 45–55), which is more suited for industrial applications.

On the industrially relevant example of polypropylene (PP) plasma treatment, I will discuss the differences between three arc-based commercial plasma jets working in dry air and a cold RF plasma slit jet (RF-PSJ), whose main working gas is argon. The arc-based plasma jets exhibited interesting dynamics of plasma filaments when interacting with the surfaces. The fast camera imaging revealed that long plasma filaments of SurfaceTreat gliding arc jet traveled randomly along the surface (P. Jelínek, K.

Polášková, F. Jeník, Z. Jeníková, L. Dostál, E. Dvřáková, J. Cerman, H. Šourková, V. Buršíková, P. Špatenka, L. Zajíčková, Surf. Coat. Technol. 372 (2019) 45–55).

The RF-PSJ produced a plasma stream in the width of 15 cm that was not uniform but formed by self-organized plasma channels resembling the self-organized patterns of dielectric barrier discharge filaments (K. Polášková, D. Nečas, L. Dostál, M. Klíma, P. Fiala, L. Zajíčková, Plasma Sources Sci. Technol. 31 (12) (2022) 125014). With fast camera imaging, we observed that the filament appearance and dynamics depended significantly on the gas feeds (Ar, Ar/N2, and Ar/O2). As the breakdown voltage in pure Ar is relatively low compared to the applied one, new filaments formed frequently, disrupting the characteristic inter-filament distance and forcing the system to rearrange. The frequent ignition and decay processes in Ar led to short filament lifetimes (0.020–0.035 s) and their high jitter speed (0.9–1.7 m/s), as determined with an image processing custom code based on Gwyddion libraries (D. Nečas, P. Klapetek, Central European Journal of Physics 10 (2012) 181–188). The number of filaments was lower in the Ar/O2 and Ar/N2 mixtures. It was attributed to a loss of energy in the excitation of rotational and vibrational levels and oxygen electronegativity. Since the probability of low-current side discharges transitioning into the full plasma filaments was limited in these gas mixtures, the self-organized pattern was seldom disrupted, leading to lesser movement and longer lifetimes. Unlike in Ar or Ar/O2, the constricted filaments in Ar/N2 were surrounded by diffuse plasma plumes, likely connected to the presence of long-lived nitrogen species. We demonstrated in the polypropylene treatment that the self-organization phenomena affected the treatment uniformity.

The plasma gas composition and temperatures have been analyzed using optical emission spectroscopy and mass spectrometry to identify which plasma parameters influenced the PP modification. Compared to the other two arc-based jets, the Plasmatreat rotating plasma jet (PT-RPJ) and Surface-Treat gliding arc jet (ST-GA), the AFS PlasmaJet® (AFS-PJ) had a significantly different reactive species composition dominated by nitrogen oxides. It induced higher thermal loads, leading to surface damage. The other arc-based jets (PT-RPJ and ST-GA) created the PP surface with higher oxygen and nitrogen concentrations than the low-temperature RF-PSJ. It induced a higher adhesion strength measured on PP-aluminum joints (K. Polášková, A. Ozkan, M. Klíma, Z. Jeníková, M. Buddhadasa, F. Reniers, L. Zajíčková, Plasma Process. Polym. 20 (2023) e2300031).

The generation of higher harmonics in RF discharges reveals changes in the plasma processes and plasma-surface interactions. Thus, it can be used to monitor processes. We analyzed the non-linearity of the RF-PSJ using the VI probes and a novel method, the non-intrusive antenna measurements. In all three studied gas mixtures, Ar, Ar/O2, Ar/N2, the PSJ frequency spectrum consisted of the dominant fundamental frequency peak, relatively strong odd harmonics, and significantly weaker even harmonics. The non-linearity was sensitive to the gas mixture and the type of target, i. e. jet expanding into open space or interacting with floating dielectrics or dielectrics on the grounded electrode. Furthermore, we studied the effect of complex surfaces on plasma parameters and the treatment efficiency of RF-PSJ. Even though the distance between the jet slit outlet and the sample surface was kept constant, the treatment efficiency of the PSJ ignited in Ar and Ar/O2 gas feeds varied with the PP sample height due to differences in plasma parameters such as filament count and speed being affected by different distances to the ground, i. e. electric field. On the other hand, the Ar/N2 PSJ diffuse plasma plumes were less affected by the changes in the electric field, and the treatment efficiency was the same for both sample heights. Additionally, we observed a difference in the efficiency and uniformity of the PSJ treatment of the edges and the central areas in some working conditions.

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GROUND-STATE DENSITIES OF TI ATOMS AND IONS DETERMINED BY CAVITY RING-DOWN SPECTROSCOPY IN HIPIMS DISCHARGES

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Abstract. Cavity Ring-Down Spectroscopy (CRDS) tracks laser pulse intensity reduction in an optical cavity to calculate the line-of-sight average species' absolute density by comparing decay times with and

without absorbers. High-Power Impulse Magnetron Sputtering (HiPIMS) achieves high power densities (~1kW/cm2) on a sputtered target with short voltage pulses (~10–100μs) and repetition frequencies, fr, (~100Hz), generating high ionization degree material fluxes. CRDS was applied to Ti atoms and ions to analyze ground state multiplets (GSM) during HiPIMS sputtering of Ti target at various powers (different fr) and the same average power in a period. The GSM density distributions near the target were determined through laser-induced fluorescence. At fr=100Hz, Ti+ ions and Ti atom densities were 8.3E11cm-3 and 4.7E11cm-3 above the racetrack and target center, respectively. A notable GSM population inversion for Ti+ ions and an ionization degree of about 94% were detected

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PLASMA-ASSISTED CATALYTIC PROCESSES FOR CO2 SPLITTING AND REDUCTION

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Abstract. The rising concentration of carbon dioxide in the atmosphere is of substantial concern with respect to global warming. Conversely, CO2 is a carbon resource, which can be converted to value-added chemicals in plasma chemical processes. This contribution aims to present a comprehensive characterization of different small-scale DBD configurations for CO2 splitting and reduction to CO and HCOOH. Empty as well as packed bed reactors with and without catalysts are investigated. This type of reactors enable the direct interaction between plasma and catalyst. The influence of catalyst, catalyst carrier, electrical parameters, gaseous and liquid media and process pressure on conversion and energy efficiency will be shown. From the thermodynamic point of view, the formation reactions of CO and HCOOH are endergonic processes. The reaction behaviour of these processes does not follow spontaneous equilibrium. Nevertheless, important conclusions can be drawn by comparing the gas compositions before and after the plasma reactor with the aid of thermodynamic functions. The reduction of CO2 with H2 can be described qualitatively using the law of mass action.

SYNTHESIS OF VERTICALLY-ORIENTED MULTILAYER GRAPHENE BY PE-CVD USING PLASTIC WASTE AS CARBON PRECURSOR

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Abstract. Electrically conductive vertically oriented carbon nanoflakes on metallic substrates have attracted the attention of the scientific and professional community due to their good chemical and mechanical stability and huge surface-to-mass ratio. A standard method for depositing multilayered graphene sheets is plasma-enhanced chemical vapor deposition using hydrocarbon gases as precursors (Alenka Vesel, "Synthesis of vertically oriented graphene sheets or carbon nanowalls: review and challenges", Materials, Vol. 12, pp 2968-1-296811-8, 2019), and an alternative using graphite as a source of carbon (Rok Zaplotnik, "Carbon nanostructured materials and methods for forming carbon nanostructured materials", EP3802418 (B1), JP7156648 (B2), US11673807 (B2), 2023). The standard methods enable the synthesis of top-quality nanocarbon, but the drawbacks include the low deposition rate and ecological issues. From the ecological point of view, the optimal precursor for nanocarbon is organic waste. Nowadays, active carbon is synthesized from various sources, including organic waste, but inadequate conductivity limits its application in high-power density electrochemical devices, for example, supercapacitors. Recently, we invented a method for the rapid deposition of electrically conductive nanocarbon using plastic waste as the carbon precursor. The substrate is placed into a low-pressure radiofrequency plasma sustained in the H-mode. Plastic waste is fed into the plasma and is heated well above the melting point due to exothermic surface reactions. The polymer fragments desorb from the molten polymer and are partially ionized and dissociated in the dense plasma. The

fragments of large potential energy condense on the substrate, forming dense structures of randomly oriented multilayer graphene sheets. Neither gas-phase oligomerization of molecular fragments nor the formation of dusty plasma occurs in the powerful plasma at low pressure, so the electrical conductivity of the graphene sheets is preserved even after prolonged deposition. A deposition rate of about 100 nm/s is obtained, an order of magnitude larger than standard methods. The adequate conductivity enables the fast response of supercapacitors assembled from nanocarbon electrodes, and over 80% of the low-frequency capacitance is preserved up to the charging/discharging frequency of 100 Hz. The specific capacitance is over 100 F/m2, thus making the nanocarbon electrodes suitable for fast-response supercapacitors. Applying plasma sustained in different gases enables modification of the multilayer graphene sheets with dopants, for example, nitrogen (Alenka Vesel, “One-step plasma synthesis of nitrogen-doped carbon nanomesh”, Nanomaterials Vol. 11, pp 837-1-837-16, 2021). The method is much faster than classical techniques for depositing nitrogen-doped graphene structures (Alenka Vesel, “A review of strategies for the synthesis of N-doped graphene-like materials”, Nanomaterials Vol 10, pp 2286-1-2286-37, 2020).

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