P 21: Low Pressure Plasmas and their Application II

Time: Thursday 14:00–15:30 Location: ELP 6: HS 3

Invited Talk P 21.1 Thu 14:00 ELP 6: HS 3

The collisionally modified Bohm criterion: Insight or illusion? — •Ralf Peter Brinkmann — Ruhr-Universität Bochum

In low pressure plasmas, where the Debye length λ_D is much smaller than the mean free path λ, the transition from the quasineutral plasma to the electron-depleted sheath is governed by the Bohm criterion [1]: Ions exit the plasma into the sheath with a speed $v_B = \sqrt{T_e/m_i}$. (T_e denotes the electron temperature and m_i the mass of the ions.) Long-standing debates surround the application of the Bohm criterion in plasmas where the λ_D/λ ratio is not small, prompting questions about the necessity of adjusting the critical velocity.

This contribution investigates a stationary model of a plasma-sheath transition where the electrons are in Boltzmann equilibrium and the ion motion is governed by the ambipolar field, the space-charge field, collisional friction, and inertia. Within the quasi-neutral presheath, the ambipolar field prevails over friction, while in the sheath, the space charge field balances the inertia. The mathematical description of this scenario results in a differential equation for the ion speed v_i as a function of a transformed spatial coordinate q. A removable singularity at a specific ion speed resembles a *collisionally modified Bohm criterion* [2]. The presentation will explore the physical significance of this feature, examining whether it truly reflects system characteristics (*insight*) or simply arises as a mathematical artifact (*illusion*).

[1] D. Bohm, in *The Characteristics of Electrical Discharges in Magnetic Fields*, A. Guthry and R.K. Wakerling (eds.) New York (1949)
[2] R.P. Brinkmann *J. Phys. D: Appl. Phys.* **44**, 042002 (2011)

P 21.2 Thu 14:30 ELP 6: HS 3

Optically trapped microparticles in a dual-frequency capacitively coupled rf discharge — •Jessica Schleitzer, Viktor Schneider, and Holger Kersten — Institute of Experimental and Applied Physics, Christian-Albrechts-University, Kiel, Germany

Many different diagnostics can be used to measure the spatial distribution and temporal evolution of plasma parameters. Over the past decade, the concept of utilizing externally injected small microparticles as non-invasive probes, influenced by various forces and energy fluxes in plasmas, has been implemented. Especially the manipulation of microparticles by an optical tweezer is of great interest, as it enables the microprobe to be positioned in areas of the plasma that are typically inaccessible by conventional diagnostic methods, such as the plasma sheath. In this study, optically trapped microparticles in an optical tweezer are used to investigate the sheath of a dual-frequency CCRF discharge. This discharge is known, in particular, for its ability to control the ion flux and the ion energy almost separately. It is generated by a superposition of two consecutive harmonics with variable phase angle between them. The crucial parameter to measure when employing optical tweezers is the external force acting on the microprobe. This force is determined by observing the displacement of the particle within the optical trap, while the confined microprobe is moved through the plasma and sheath. On the basis of the force profiles, the strength of the electric field force in the sheath as a function of the phase angle between the two harmonics, the extent of the sheath, as well as the particle charge evolution within the sheath are determined.

P 21.3 Thu 14:45 ELP 6: HS 3

Electron dynamics in partially magnetized low pressure plasma discharges — •Lukas Vogelhuber, Denis Eremin, Kevin Köhn, Dennis Krüger, and Ralf Peter Brinkmann — Department of Electrical Engineering and Information Science, Ruhr University Bochum, D-44780, Bochum, Germany

Partially magnetized plasma discharges in magnetron configurations are versatile and offer a wide range of applications in science and industry. These applications range from space propulsion systems that utilize Hall-effect thrusters to the deposition of thin films in the physical vapor deposition technology using "high power impulse magnetron sputtering" (HiPIMS). Their magnetic field configuration is described in cylindrical geometry (r, θ, z) with the magnetic field lines in the r-z plane. In such magnetron discharges, plasma non-uniformities are observable in the form of the rotating spokes phenomenon moving in the azimuthal (θ) direction. These structures exhibit a heightened ionization rate and increased potential, altering the electron dynamics in these regions and the overall plasma dynamics. The focus of this talk is the investigation of electron dynamics of partially magnetized electrons under the influence of a simplified but realistic axisymmetric magnetic field in the r-z plane. As a key diagnostic method serves the magnetic moment in higher-order approximations to understand the energization process of electrons under such conditions. Understanding the electron trajectories in these regions influenced by the spatially inhomogeneous magnetic field may contribute to future understanding of the adiabatic and non-adiabatic energy gain of electrons.

P 21.4 Thu 15:00 ELP 6: HS 3

Atomic oxygen measurements with THz absorption spectroscopy, ps-TALIF, and CRDS: A comparison — Jente R. Wubs[1], Uwe Macherius[1], Andy S. C. Nave[1], Laurent Invernizzi[2], Kristaq Gazeli[2], Guillaume Lombardi[2], Xiang Lü[3], Lutz Schrottke[3], Klaus-Dieter Weltmann[1], and •Jean-Pierre H. van Helden[1] — [1]Leibniz Institute for Plasma Science and Technology (INP), Greifswald, Germany — [2]Laboratoire des Sciences des Procédés et des Matériaux (LSPM), CNRS, Université Sorbonne Paris Nord, Villetaneuse, France — [3]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Berlin, Germany

Terahertz (THz) absorption spectroscopy with quantum cascade lasers (QCLs) has recently been developed and implemented as a new diagnostic technique for investigating ground state atomic oxygen densities in plasmas. It is based on the detection of the $^3P_1 \leftarrow {}^3P_2$ fine structure transition at approximately 4.75 THz (i.e., approximately 63 μm). In this contribution, we will compare the results obtained with this method with those obtained by picosecond two-photon absorption laser-induced fluorescence (ps-TALIF) at 226 nm, as this is currently the most established method for measuring atomic oxygen densities, and cavity ring-down spectroscopy (CRDS) using the forbidden $^1D_2 \leftarrow {}^3P_2$ transition at approximately 630 nm. All measurements were performed on the same low-pressure capacitively-coupled radio frequency plasma generated in pure oxygen, for a variation of the applied power and gas pressure.

P 21.5 Thu 15:15 ELP 6: HS 3

Investigation of geometric asymmetric electronegative capacitively coupled radio frequency discharges using a hybrid PIC/MCC simulation — •Katharina Noesges, Maximilian Klich, Sebastian Wilczek, and Thomas Mussenbrock — Ruhr University Bochum, Germany

Capacitively coupled radio frequency (CCRF) discharges are pivotal in numerous etching processes in the semiconductor industry. Operating at low pressures in the range of a few Pascals and requiring voltages of about hundreds of volts, these discharges facilitate anisotropic ion bombardment essential for precision etching. Carbon tetrafluoride (CF_4) discharges are significant in this context. These discharges are investigated using a one-dimensional hybrid particle-in-Cell/Monte Carlo collisions (PIC/MCC) simulation in the low-pressure regime (p = 6.67 Pa), assuming a spherical geometry. This approach considers the electrons kinetically and simultaneously utilizes the drift-diffusion approximation to solve a continuity equation; one each for the ion species. This work examines the influence of varying electrode gap sizes and applied voltages, demonstrating that the electronegativity strongly affects the electron dynamics. Because of the geometric asymmetry, a strong electric field reversal during the sheath collapsing phase accelerates many electrons toward the powered electrode. A spatially and temporally resolved analysis of the high-energy electron density reveals a sharp beam structure formed by electrons near the electrode. This beam structure is an accumulation of electrons accelerated by the expanding boundary sheath towards the grounded electrode.