P 1: Low Pressure Plasmas and their Application I

Time: Monday 11:00–12:45 Location: CHE/0089

Invited Talk P 1.1 Mon 11:00 CHE/0089

Ion Beam Sputter Deposition – Fundamentals and Applications — •Carsten Bundesmann — Leibniz Institute of Surface Engineering (IOM), Leipzig

There is an increasing demand for thin films with tailored properties, which requires the use and control of adequate deposition techniques. Ion beam sputter deposition (IBSD) is a PVD technique that is capable of fulfilling the technological challenges. It is based on ion-solid interaction: A low-energy ion beam (Eion ~ 2000 eV) is directed onto a target and target particles get sputtered due to energy and momentum transfer [1]. These particles condense on a substrate and a film is growing (see Fig. 1). In addition, scattered primary particles and reactive background gas particles may contribute to thin film growth. In comparison to other PVD techniques, IBSD offers a unique opportunity to tailor angular-dependent energy and flux of the film-forming particles and, hence, thin film properties by changing ion beam parameters (ion species and ion energy) and geometrical parameters (ion incidence angle and emission angle).

Using selected examples, this talk describes the systematics, including pros and cons, of IBSD: The correlation between process parameters, properties of the film-forming particles, and thin film properties. The most important process parameters are the scattering geometry and the primary particle species. Depending on the material, different film properties can be influenced. Examples are adhesion, structural properties, composition, surface roughness, mass density, optical properties, stress, and electrical resistivity.

[1] C. Bundesmann, H. Neumann, J. Appl. Phys. 124 (2018) 231102.

P 1.2 Mon 11:30 CHE/0089

On the role of the Poisson-Boltzmann equation in the modeling of high-power magnetrons — Kevin Köhn, Dennis Krüger, Denis Eremin, Liang Xu, and •Ralf Peter Brinkmann — Ruhr University Bochum, Theoretical Electrical Engineering

The Poisson-Boltzmann equation is a nonlinear differential equation that describes equilibria of conducting fluids. Using a variation principle based on the balances of particle number, entropy, and electromagnetic enthalpy, it can also be justified for a wide class of unmagnetized technological plasmas [Köhn et al., PSST 30, 105014 (2021)].

This study aims to extend the variation principle to magnetized discharges as used in high-power pulsed magnetron sputtering (HiPIMS). The example in focus is that of a high power circular magnetron. The discharge chamber and the magnetic field are assumed to be axisymmetric; the plasma dynamics need not share this symmetry. The domain is divided into the region of confinement, where the electrons can escape from their magnetic field lines only by slow processes such as drift and diffusion, and the remainder where the electrons are effectively free. A distinction is made between a fast thermodynamic and a slow dissipative regime. A variational principle is established for the fast regime which is similar in logic to its counterpart for unmagnetized plasmas but accounts for magnetic confinement by treating the individual flux tubes of the confinement domain as separate thermodynamic units. The resulting solutions obey a generalized Poisson-Boltzmann relation; they are thermodynamic equilibria of the fast regime but must be interpreted as dissipative structures in the slow regime.

P 1.3 Mon 11:45 CHE/0089

Plasma-modified $NiCo_2O_4$ nanowires with abundant oxygen vacancies as electrocatalyst for the oxygen evolution reactions — •He Li[1], Sadegh Askari[2], and Jan Benedikt[1] — [1]Institute for Experimental and Applied Physics, Kiel University, Kiel, Germany — [2]Department of Fiber and Polymer Technology, KTH Royal Institute of Technology, Stockholm, Sweden

The development of highly active and stable electrocatalysts for the oxygen evolution reaction (OER) is critical for the applications such as water splitting or production of rechargeable zinc-air batteries. Oxygen vacancy engineering has demonstrated great promises to regulate the OER performances of transition metal compounds. However, the facile and effective generation of oxygen vacancies is still a challenge. Herein, we fabricated a $NiCo_2O_4$ nanowire catalyst by the hydrothermal method and generated oxygen vacancies with various concentrations by Ar or H_2/Ar plasma treatment. The reactive radicals generated by plasma reduce the valence of metal ions in the oxides and create oxygen vacancy defects with high electrocatalytic activity. The H_2/Ar plasma-treated $NiCo_2O_4$ presents more surface oxygen vacancies and thus better electrocatalytic performance for OER. Our work offers a facile and efficient route to design efficient OER electrocatalysts for zinc-air batteries.

P 1.4 Mon 12:00 CHE/0089

Experimental validation of a 0-D computational model for characterisation of double inductively coupled plasma — •J. Jenderny[1], M. Osca Engelbrecht[3], H. Hylla[1,2], I. Korolov[1], D. Filla[1], L. Schücke[1,2], C. P. Ridgers[3], P. Awakowicz[1], and A. R. Gibson[2] — [1]Chair of Applied Electrodynamics and Plasma Technology, Ruhr-University Bochum, Bochum, Germany — [2]Research Group for Biomedical Plasma Technology, Ruhr-University Bochum, Bochum, Germany — [3]York Plasma Institute, Department of Physics, University of York, York, UK

A double inductively coupled plasma is studied to be compared to 0-D plasma chemical kinetics simulations. A focus is placed on oxygen-containing gas mixtures due to their ability to produce large fluxes of reactive species such as atomic oxygen and UV photons. Various experimental diagnostic methods are applied. A multipole resonance probe is used to measure electron densities and electron temperatures radially resolved. Tuneable diode laser absorption spectroscopy is used to measure the absorption profile of the transition Ar ($1s_5 \rightarrow 2p_6$) at 772.376 nm to yield gas temperatures. Absolutely calibrated optical emission spectroscopy is used to determine the absolute intensities of different O transitions. These values are compared to those obtained from a 0-D computational model. The model includes electron densities and a collisional radiative treatment of excited states of O. It is then used to provide information on the flux of photons at 130 and 135 nm. This work was funded by DFG project “Plasma inactivation of microbial Biofilms”, project number 424927143.

P 1.5 Mon 12:15 CHE/0089

Modeling electromagnetic phenomena in CCP VHF plasmas with an electromagnetic PIC-MCC code — •Denis Eremin[1], Thomas Mussenbrock[2], and Ralf Peter Brinkmann[1] — [1]Institute of Theoretical Electrical Engineering, Ruhr University Bochum, Bochum, Germany — [2]Institute of Applied Electrodynamics and Plasma Technology, Ruhr University Bochum, Bochum, Germany

Increasing the electrode radius and the driving frequency would be beneficial for industrial applications of the capacitively coupled plasma reactors operated at low pressures. Unfortunately, this leads to the emergence of various nonuniformities having detrimental effects on the processing quality. The underlying physics is related to the excitation of two types of surface modes interacting with electrons and energizing them through different mechanisms. The present work investigates this problem numerically with a novel implicit energy- and charge-conserving electromagnetic PIC code ECCOPIC2M. It is demonstrated that due to the observed complexity of the processes taking place in such devices, the particle-in-cell method seems to be the only means potentially suitable for predictive studies of the plasma uniformity in CCPs in the considered parameter range.

P 1.6 Mon 12:30 CHE/0089

Investigation of capacitively coupled radio frequency Ar/CF_4 discharges using a hybrid PIC/MCC simulation — •Katharina Nösges, Maximilian Klich, Sebastian Wilczek, and Thomas Mussenbrock — Ruhr University Bochum, Germany

Capacitively coupled radio frequency (CCRF) discharges are used in many dry etching processes in the semiconductor industry to realize micro- and nanometer-scale electronics. Low pressures of a few Pascal and voltages of about hundreds of volts are required to ensure anisotropic ion bombardment. Especially carbon tetrafluoride (CF_4) and mixed (Ar/CF_4) discharges are particularly important for etching. 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) with the inclusion of realistic particle-surface interactions. This approach considers the electrons kinetically and simultaneously solves the continuity equation based on the drift-diffusion approximation for all ion species. The transport coefficients, as well as the rate coefficients, can be determined with the help of swarm simulations. A closed group of particles moves in a background gas influenced by an externally applied constant electric field. The collective behavior gives information about transport features and collision probabilities. A variation of the electrode gap size and the applied voltage is then presented as a control tool to alter the discharge dynamics significantly. Additionally, it is shown that surface coefficients (i. e., electron reflection, and secondary electron emission) play a significant role.