P 2: Low Pressure Plasmas I

Time: Monday 10:30–12:30 Location: KI 1.174

Invited Talk P 2.1 Mon 10:30 KI 1.174

Key Features of Reactive High Power Impulse Magnetron Sputtering — •Daniel Lundin — Laboratoire de Physique des Gaz et Plasmas - LPGP, UMR 8578 CNRS, Université Paris Sud, Université Paris Saclay, 91405 Orsay Cedex, France

For many thin film applications, such as optical coatings, energy-related coatings, hard coatings, etc., the coated layers are not single metal thin films, but rather compound coatings obtained from at least one metal (e.g. Al, Ti) or a non-metal (e.g. C, B) and a reactive gas (e.g. O2, N2). This talk will address a promising thin film deposition technology called high power impulse magnetron sputtering (HiPIMS), and how this method differs from conventional processes. Key features in reactive HiPIMS, such as eliminated/reduced hysteresis and stable high-rate deposition in the transition mode, will be discussed. It will be shown that the discharge current evolution plays an important role, which we will analyze by investigating the combined processes of self-sputter recycling and process gas recycling using results from recent plasma process modelling in combination with experimental plasma characterization. Above a critical current density, a combination of self-sputter recycling and gas-recycling is generally required. The relative contributions of these recycling mechanisms, in turn, influence both the electron energy distribution and the stability of the discharges. A new framework including a generalized recycling map will be introduced to quantify these effects.

P 2.2 Mon 11:00 KI 1.174

Probing the Electron Density of Spokes in a HiPIMS Plasma Using Target Inserts — Ante Hecimovic, •Julian Held, Volker Schulz-von der Gathen, Wolfgang Breilmann, Christian Maszl, and Achim von Keudell — Experimental Physics II, Ruhr-University Bochum, Germany

In High power impulse magnetron sputtering (HiPIMS) a magnetron discharge is operated with short, high-voltage pulses, creating a highly dense plasma. Those pulses have a length in the order of 100 μs and power densities of several kW cm^{-2}. At high discharge currents, the plasma emission is not homogeneous but is instead organized into distinct zones of high plasma emission, which rotate in ExB direction a few mm above the target surface. These so called "spokes" are thought to improve ion transport to the substrate and might therefore be the key to improve the deposition rate. The strong emission indicates an elevated electron density. However, it would disturb the plasma considerably to position a probe in the vicinity of the target. Therefor, no direct measurement of the electron density inside the spokes has been performed. In this contribution, small electrically isolated inserts in the target surface were used to probe the local current density. Simple sheath theory was then applied to derive the electron density at the sheath edge. The electron density was in the order of 10^{19} m^{-3} and scaled linearly with discharge current. The electron density was elevated by about 50% when a spoke was present above the insert.

P 2.3 Mon 11:15 KI 1.174

Correlation of current shape and surface poisoning in reactive high power impulse magnetron sputtering by means of X-ray photoelectron spectroscopy — •Sascha Monjé[1], Vincent Layes[1], Carles Corbella[1], Achim von Keudell[1], Teresa de los Arcos[2] und Volker Schulz-von der Gathen[1] — [1]Experimental Physics II, Ruhr-University Bochum, Germany — [2]Technical and Macromolecular Chemistry, Paderborn University, Germany

High power impulse magnetron sputtering (HiPIMS) has established itself as one of the premier methods for depositing high quality hard coatings. Reactive gases can be added to the discharge to produce hard ceramic coatings. These gases can react with the target surface which is called "target poisoning". It has often been claimed that target poisoning is accompanied by a strong change of the current waveform but direct experimental verification is still needed. This was addressed by connecting spatially resolved X-ray photoelectron spectroscopy (XPS) measurements with measurements of the current waveform. The XPS characterization was performed after an in-vacuum transfer of the target to avoid any oxidation or contamination. A chromium target was used for the discharge. The Ar/O2 mixture, the input power and the frequency were varied to evaluate the racetrack oxidation state in different discharge regimes. The transition from poisoned to metal mode by increasing the power can be achieved using a frequency of 20 Hz. This transition can as well be seen in the current shape of the discharge which converges to its non-reactive form. This is a first approach to investigate the assumed correlation.

P 2.4 Mon 11:30 KI 1.174

Reactive magnetron sputtering of Ta-doped SnO_2 polycrystalline films at low temperatures: carrier transport and role of negative ion bombardment — •Stefan Seeger, Klaus Ellmer, Rainald Mientus, and Michael Weise — Optotransmitter-Umweltschutz-Technologie e.V., Köpenicker Str. 325, 12555 Berlin

Tin oxide (SnO_2) is significantly cheaper and chemically more resistive compared to the often used tin-doped indium oxide (ITO). In principle, low resistivities of doped SnO_2 are possible, caused by its isotropic 5s orbitals which are advantageous for good TCO transport properties. In this work conductive and transparent $SnO_2 : Ta$ films were deposited at low substrate temperatures by reactive DC and RF magnetron sputtering from a ceramic target ($Sn98at\%Ta2at\%O_2$) in Ar/O_2 , Ar/N_2O, and H_2O gas mixtures. The films were X-ray amorphous for substrate temperatures below about 200 °C. While the amorphous films are remarkably conductive ($5x10^{-3}\Omega cm$), the crystallized films exhibit higher resistivities due to grain boundary limited electrical transport. Also, for larger film thicknesses, caused by the heating of the films by the energy influx from the film species and the plasma, crystallization occurs. The width of the process window with respect to the reactive gas partial pressure depends on the type of the reactive gas and is wider for N_2O and H_2O. A prospective application of such X-ray amorpous $SnO_2 : Ta$ films are low temperature transparent and conductive protection layers, for instance to protect semiconducting photoelectrodes for water splitting.

P 2.5 Mon 11:45 KI 1.174

Modelling of chemical vapor deposition to improve tungsten fiber reinforced tungsten composites (Wf/W) — •L. Raumann[1], J.W. Coenen[1], J. Riesch[2], Y. Mao[1], H. Gietl[2,3], T. Höschen[2], C. Linsmeier[1], and O. Guillon[1] — [1]Forschungszentrum Jülich GmbH, 52425 Jülich — [2]Max-Planck-Institut für Plasmaphysik, 85748 Garching b. München — [3]TU München, 85748 Garching

Due to the unique combination of excellent thermal properties, low sputter yield, hydrogen retention and activation, tungsten is the main candidate for the first wall material in future fusion devices. However, its intrinsic brittleness and its susceptibility to operational embrittlement is a major concern. To overcome this drawback, tungsten fiber reinforced tungsten composites featuring pseudo ductility have been developed. Bulk material can be successfully produced utilizing chemical vapor deposition of tungsten fabrics. However, a fully dense composite with a high fiber volume fraction is still a huge challenge. Therefore, a model is currently developed in Comsol including the complex coupling of transport phenomena and chemical reaction kinetics. To validate the model with experimental data, fibers were deposited in heated tubes under controlled parameter variation. The temperature and tungsten growth rate were measured along the fibers and inner tube surfaces for different heater temperatures, partial pressures and gas flows. With the experimental results the prediction of the model has been improved. As next step the model will be applied to design infiltration experiments to fabricate fully dense Wf/W composites with a high fiber volume fraction.

P 2.6 Mon 12:00 KI 1.174

Spectroscopic investigations of plasma nitrocarburizing processes with a mid-infrared frequency comb — Norbert Lang[1], Alexander D. F. Puth[1], Grzegorz Kowan[2], Stephan Hamann[1], Jürgen Röpcke[1], Piotr Masłowski[2], and •Jean-Pierre H. van Helden[1] — [1]Leibniz Institute for Plasma Science and Technology, Greifswald, Germany — [2]Institute of Physics, Nicolaus Copernicus University, Torun, Poland

We report on the use of mid-infrared broadband direct frequency comb spectroscopy (DFCS) as a novel plasma diagnostic applied to spectroscopic investigations of plasma nitrocarburizing processes. With DFCS many molecular species can be detected simultaneously with high sensitivity and time-resolution yielding comprehensive data on their kinetics in the plasma and their interactions with a surface. Active screen plasma nitrocarburizing (ASPNC) is an advanced technology for the hardening of steel components using pulsed N_2-H_2 plasmas with an active screen made of solid carbon to produce carbon-containing species, which support the generation of anti-corrosive layers of high quality. However, many plasma chemical phenomena are far from completely understood. Therefore, spectroscopic investigations are being carried out in a downscaled plasma reactor based on an industrial scale ASPNC reactor. Our frequency comb operates around 3.2 μm (2900-3500 cm^{-1}), the fingerprint region for key process species such as NH_3, C_2H_2, C_2H_6, HCN, and CH_4 molecules. We will discuss the workings of DFCS and the influence of pressure, screen plasma power, and gas mixture on the concentrations of these species.

P 2.7 Mon 12:15 KI 1.174

***In-situ* measurement of optical properties of metallic surfaces using the Doppler-shifted emission of fast neutral atoms in a low density plasma** — •Sven Dickheuer[1], Oleksandr Marchuk[1], Christian Brandt[2], Andrei Goriaev[1], Mykola Ialovega[1], and PSI-2 Team[1] — [1]Forschungszentrum Jülich GmbH - Institut für Energie- und Klimaforschung - Plasmaphysik, Partner of the Trilateral Euregio Cluster (TEC), 52425 Jülich, Germany — [2]Max-Planck-Institut für Plasmaphysik, 17491 Greifswald, Germany

The knowledge about the optical properties of metallic surfaces during plasma exposition is crucial for many plasma diagnostics. In fusion plasmas, for instance, reflection properties of the plasma facing mirror and plasma wall components have a strong impact on the signal in the visible range. Until now no technique exists, which is able to monitor the modification of the optical properties without any additional calibration sources. We present an *in-situ* technique to measure the reflectance, its dynamic evolution and the polarization of different metallic surfaces (e.g. C, Al, Ti, Fe, Mo, Rh, Pd, Ag, Sn and W) in a H/Ar mixed plasma. The measurements are performed in the linear plasma device PSI-2, operating in the electron density range of $10^{11} - 10^{12}$ cm^{-3} and electron temperature range of $4 - 10$ eV. The optical properties are measured by analyzing the Doppler-shifted emission of fast hydrogen atoms, backscattered from the metallic surface, at different lines-of-sight at 656.279 nm (Balmer-α line). The comparison between measured reflectance and theoretical data shows a very good agreement (within 10 %).