Plasma and Vapor Deposition Processes
Room Palm 1-2 - Session PP2-3-FrM

HiPIMS, Pulsed Plasmas, and Energetic Deposition III

Moderators: Arutiun P. Ehiasarian, Sheffield Hallam University, UK, **Tetsushide Shimizu**, Tokyo Metropolitan University, Japan

8:00am **PP2-3-FrM-1 Experiments and Modelling of High Power Impulse Magnetron Sputtering Discharges with Metallic Target***, **Jon Tomas Gudmundsson [tumi@hi.is]**, Kateryna Barynova,* University of Iceland*; Martin Rudolph,* Leibniz Institute of Surface Engineering (IOM), Germany*; Joel Fischer,* Linkoping University, Sweden*; Tetsuhide Shimizu,* Tokyo Metropolitan University, Japan*; Daniel Lundin,* Linkoping University, Sweden

High power impulse magnetron sputtering (HiPIMS) discharges with a number of metal targets have been explored experimentally followed by a further study using the ionization region model (IRM). The metal targets studied include, tungsten [1], chromium [2], zirconium [3], titanium [4], and copper [5]. Experimentally, the ionized flux fraction has been found to be in the range 10 - 80 %, and it is found to increase with increased discharge current density, and decreased working gas pressure. However, the deposition rate generally decreases with increased peak discharge current density. There is a trade off between high ionized flux fraction and high deposition rate, sometimes referred to as the HiPIMS compromise. An overview will be given on the experimental results for various target materials and dependence on varying operating parameters such as peak discharge current density and pulse length. The IRM allows for studying the temporal evolution of the discharge current composition, the electron power absorption mechanisms, the ionization and back-attraction probabilities of the sputtered species, the dominant recycling mechanism, and the working gas rarefaction. We discuss how the discharge current composition varies between different target materials, and how the recycled species, and the processes leading to working gas rarefaction, depend on the target sputter yield [4]. In particular we will discuss how the back-attraction probability of the sputtered species depends on the sputter yield of the target material [7].

[1] Swetha Suresh Babu et al., Plasma Sources Science and Technology, 31(6) (2022) 065009

[2] K. Barynova et al. Plasma Sources Science and Technology, submitted 2025

[3] Swetha Suresh Babu et al., Journal of Vacuum Science and Technology A, 42(4) (2024) 043007

[4] T. Shimizu et al. Plasma Sources Science and Technology, 30(4) (2021) 045006

[5] J. Fischer et al., Plasma Sources Science and Technology, 32(12) (2023) 125006

[6] K. Barynova et al., Plasma Sources Science and Technology, 33(6) (2024) 065010

[7] K. Barynova et al., Plasma Sources Science and Technology, 34(6) (2025) 06LT01

8:20am **PP2-3-FrM-2 Knowing and Controlling the Dynamic Plasma Potential and Sheath Voltage as Key Elements in Plasma-Based Deposition***, **André Anders [andre.anders@plasmaengineering.com]**,* Plasma Engineering LLC, USA **INVITED**

It is widely known that a space charge layer exists between plasma and a surface (target, substrate, wall, probe, etc.) which is called the sheath.The sheath voltage is the difference between the surface potential and the potential at the sheath edge, the boundary between plasma and sheath. Space charge is linked via the Poisson equation to an electric field which governs fluxes of charged fluxes and thereby energy delivered to the surface.There is nothing new so far, but in real life, for practical reasons, one uses (earth) ground as the reference, not the plasma potential.This can lead to confusion, especially as the plasma potential is not constant in space and time when using modern approaches to plasma-based deposition that involves magnetic fields and pulsed processing, such as bipolar HiPIMS.In this contribution, the establishment of plasma potential, or better the dynamic plasma potential distribution, will be explored and the consequences for film growth discussed.The local and dynamic plasma potential can be associated with numerous effects such cathode spot and anode spot formation (a.k.a. “arcing” and “fireball” in magnetron systems, respectively), the control of ion and electron flows, which affect a growing film’s microstructure, and also with unwanted effects such as sputtering of and arcing on chamber walls and other grounded components.Knowing and controlling the dynamic plasma potential and sheath voltage is therefore important to plasma-based deposition processes.

9:20am **PP2-3-FrM-5 Superposition of HiPIMS with RF on a Single Magnetron: Generation of High Ion Energies***, **Caroline Adam [c.adam@physik.uni-kiel.de]**, Luka Hansen, Tobias Hahn, Jessica Niemann, Daniel Zuhayra,* Kiel University, Germany*; Günter Mark, Jonathan Löffler,* MELEC GmbH, Germany*; Jan Benedikt, Holger Kersten,* Kiel University, Germany

High power impulse magnetron sputtering (HiPIMS) has shown significant potential for thin film deposition by providing high ionized flux fractions and ion energies. To optimize the deposition process, HiPIMS can be operated in superposition with an additional discharge on the same magnetron, such as DC or MF (mid-frequency pulses). This increases the deposition rate and enables low-pressure operation by using pre-ionization from the continuous discharge during the off-time between pulses.

In this study, a novel combination of HiPIMS and RF (radio-frequency, 13.56 MHz) is investigated in continuous superposition on the same magnetron, using a planar copper target in argon atmosphere [1]. The discharge is characterized at varied power ratios of HiPIMS and RF with plasma diagnostics employed to analyze the system. This includes measuring the combined HiPIMS/RF voltage signal and conducting optical emission spectroscopy (OES) to gain insights into the plasma composition. Two key factors influencing the microstructure of deposited films are the kinetic energy of particles bombarding the growing film and the substrate temperature. Substrate heating from the plasma is evaluated using a passive thermal probe (PTP) [2], a “non-conventional” calorimetric diagnostic that measures the total energy flux to the substrate surface. The kinetic energy is assessed through energy-selective mass spectrometry, including time-resolved operation. The results regarding the plasma parameters are compared with the morphology of the deposited copper films, analyzed using scanning electron microscopy (SEM).

The addition of an RF plasma provides pre-ionization for the HiPIMS pulses, which allows to reduce the process pressure. Time-resolved OES reveals the transition from the copper-dominated emission during the HiPIMS pulse to an argon plasma in in the HiPIMS off-time. The RF plasma exhibits a pronounced influence on the ion energy distribution, increasing the ion energy by more than 50 eV depending on the applied RF power. This effect is attributed to an increased plasma potential caused by the RF sheath, which accelerates ions in the sheath region toward the substrate, resulting in elevated ion energies. The potential of this process is demonstrated by the deposition of copper thin films, showing significant influence of the deposition mode for their properties [1].

[1] C. Adam *et al. Surf. Coat. Technol.* **520** (2026) 133060.

[2] H. Kersten *et al. Thin Solid Films* **377–378** (2000) 585–591.

9:40am **PP2-3-FrM-6 Low-Temperature Synthesis of Ti_2AC (A = Si or Ge) Max-Based Coatings via Highly Ionized Growth Techniques***, Arno Gitschthaler, Philipp Dörflinger, Rainer Hahn,* Christian Doppler Laboratory for Surface Engineering of high-performance Components, TU Wien, Austria*; Jürgen Ramm, Klaus Böbel,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein*; Szilard Kolozsvári, Peter Polcik,* Plansee Composite Materials GmbH, Germany*; Eleni Ntemou, Daniel Primetzhofer,* Department of Physics and Astronomy, Uppsala University, Sweden*; Dominik Fuchs, Andreas Limbeck,* Institute of Chemical Technologies and Analytics, TU Wien, Austria*; Peter Švec,* Institute of Physics, Slovak Academy of Sciences, Slovakia*; Anton Davydok, Christina Krywka,* Institute of Materials Physics, Helmholtz Zentrum Hereon, Germany*; **Helmut Riedl [helmut.riedl@tuwien.ac.at]**,* Institute of Materials Science and Technology, TU Wien, Austria

MAX phases are a unique class of nanolaminated compounds that combine metallic and ceramic properties, offering excellent electrical and thermal conductivity together with remarkable resistance to creep, oxidation, and corrosion. These characteristics make them highly attractive as protective and functional coatings for next-generation hydrogen technologies. However, conventional sputtering techniques struggle to provide suitable growth conditions at reduced synthesis temperatures, often leading to phase instability and the formation of competing phases. Despite more than two decades of research on Ti–A–C (A = Si or Ge) MAX coatings [1,2], it has yet to be achieved to deposit them under less harsh, more practical conditions. To address this issue, Ti_2-A-C (A = Si or Ge) thin films were deposited by cathodic arc evaporation (CAE) and high-power impulse magnetron sputtering (HiPIMS) of metallic TiA (A = Si or Ge) targets in reactive Ar/C_2H_2 plasma atmospheres. To understand the relationship between deposition parameters, chemical composition, and phase formation, the resulting films were comprehensively characterized using high-resolution techniques, including ToF-ERDA-calibrated GD-OES, 2D-BBXRD, and t-CSXRD measurements. Subsequently, these results are correlated with application near electrochemical tests. Overall, these analyses demonstrate, for the first time, that Ti_2-A-C MAX-based coatings can be successfully synthesized by reactive CAE and HIPIMS at temperatures as low as 550 °C and rise their potential for use cases in hydrogen technologies.

[1] Emmerlich J, Palmquist J-P, Högberg H, Molina-Aldareguia JM, Hultman L. Growth of Ti3SiC2 Thin Films by Elemental Target Magnetron Sputtering. J Appl Phys. 2004;96: 4817. doi:10.1063/1.1790571

[2] Högberg H, Eklund P, Emmerlich J, Birch J, Hultman L. Epitaxial Ti2GeC, Ti3GeC2, and Ti4GeC3 MAX-phase thin films grown by magnetron sputtering. J Mater Res. 2005;20: 779–782. doi:10.1557/JMR.2005.0105

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