Plasma and Vapor Deposition Processes
Room Palm 1-2 - Session PP4-FrM

Deposition Technologies for Carbon-based Coatings

Moderators: Philipp Immich, IHI Hauzer Techno Coating B.V., Netherlands, **Biplab Paul**, PLATIT AG, Switzerland

8:20am **PP4-FrM-2 Insights Into Solid Lubrication Processes of DLC Films Thanks to Analytical Tribology***, **Julien Fontaine [julien.fontaine@ec-lyon.fr]**, Antoine Normant, Jules Galipaud, Frédéric Dubreuil,* LTDS, CNRS / Ecole Centrale de Lyon, France **INVITED**

Diamond-Like Carbon coatings may behave as very good solid lubricants, providing a good combination of tribological environment and coating composition is ensured. For instance, highly hydrogenated amorphous carbon (a-C:H) films may lead to super low friction regime ($\mu < 0.01$) under ultra-high vacuum, at least for a limited time. What are the tribological phenomena that allow for such performance, and what brings an end to this unique regime?To answer such questions, a traditional approach consist in performing some surface analysis after the experiments, inside and outside the wear tracks. These analyses are frequently morphological, structural or chemical, sometimes mechanical. While these informations are paramount for the understanding of the surface degradations during sliding, they don't provide information about the respective roles of these degradation on the evolution of the tribological response of the contact.In this work, we use a high resolution environment-controlled tribometer, based on a six axes force sensor, to probe the tribological response of a steel pin / a-C:H film contact, either by crossing existing wear tracks or by shifting the tracks to slide on pristine surfaces. This original approach helps understanding the respective role of surface modifications on the a-C:H coated flat or on the facing steel pin on the achievement of superlow friction. These experiments are combined with more traditional analytical means, like in situ XPS, AES and REELS analyses or ex situ SEM or AFM observations.The growth of a carbon-rich tribofilm on the steel counterpart appears necessary, but not sufficient to reach superlow friction. Changes on the topography and chemistry of the a-C:H film seems also paramount, with a smoothening of the a-C:H asperities and an increase of the sp^2 Carbon content. The respective role of these phenomena on the solid lubrication process of a-C:H film will be discussed.

9:00am **PP4-FrM-4 Diamond Like Carbon (DLC) Ablators for Fusion Energy***, **Nicolas Vargas [nicolas.vargas@ga.com]**, Kuo-Chun Chen, Priya Raman, Martin Hoppe, Fred Elsner,* General Atomics, USA

On December 5, 2022, after 4 decades of technical improvements, NIF reached "ignition" for the first time, achieving a 150% energy yield and with it unlocking the promise of unlimited energy supply for human society.This historical achievement was enabled by the many esoteric and ultra-high precision Inertial Confinement Fusion (ICF) components General Atomics manufactures and assembles into complex target assemblies, which are subsequently fielded, on national facilities such as the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL).Each target assembly has an ablator capsule at its center. HDC (high-density carbon), a form of nanocrystalline diamond, is the current choice for the ablator in these experiments. However, as NIF laser power scales up, Diamond Like Carbon (DLC) ablators are looking increasingly attractive.

Diamond Like Carbon (DLC) material has captured the interest of the laser fusion community due to its unique properties. DLC's amorphous microstructure, high density, and ability to be doped makes it an attractive choice for ablator material. At General Atomics, we developed a Hollow Cathode Radio Frequency Plasma Assisted Chemical Vapor Deposition (HC-RF PACVD) system to deposit DLC coatings on both flat and spherical substrates.

Our DLC capability, with precisely tuned hydrocarbon and carrier gas compositions, enables the deposition of thick, dense, and smooth Diamond-Like Carbon coatings for experiments in Inertial Fusion Technology. In this presentation, we will provide an overview of our major results to create free-standing DLC capsules, including the fabrication, characterization and post processing techniques.

This work performed under the auspices of General Atomics under Internal Research and Development.

9:20am **PP4-FrM-5 Multifunctional Nanocomposite Coatings: Aerosol Assisted Plasma Deposition***, **Alexis Aussonne [alexis.aussonne@lcc-toulouse.fr]**,* LCC, Laplace, France

Amorphous carbon thin coatings are widely used to protect surfaces due to their high hardness and their chemical resistance[1]. They can be deposited by various PVD methods such as ion beams[2], magnetron sputtering[3] or by PECVD[4] by injection a gaseous precursor into a plasma. PECVD allow to control the structure of the carbon coating by choosing the precursor. However, the continuous injection of gas does not allow to work with complex precursors such as mixtures, solutions containing reactive molecules or colloidal solutions.

An alternative way to inject the precursor in the plasma chamber would be by directly injecting a liquid as an aerosol in a pulsed manner. This would allow to work with liquids of a much more complex composition and thus reaching interesting coatings. Furthermore, by injecting colloids it is possible to deposit various nanocomposite[5] coating encapsulating various kind of nanoparticles (metallic, oxide, sulfide).

Herein we report the carbon deposition by a low pressure RF plasma with pulsed injection of a pentane aerosol. Carbon layers were characterized by Raman and Infrared spectroscopies. Additionally, colloidal solutions of MoS2 nanoparticles stabilized in pentane were injected to deposit nanocomposite thin films.

(1)Ito, H.; Yamamoto, K. *Mechanical and Tribological Properties of DLC Films for Sliding Parts*.

(2)Aisenberg, S.; Chabot, R. Ion-Beam Deposition of Thin Films of Diamondlike Carbon. *J Appl Phys* 1971, *42* (7), 2953–2958.

(3)Sanchez, N. A.; Rincon, C. Characterization of Diamond-like Carbon Ž DLC . Thin Films Prepared by r . f . Magnetron Sputtering. 2000, 7–10.

(4)Nobuki Mutsukura, K. Y. Deposition of DLC Films in CH,/Ar and CH,/Xe r.f. Plasmas. *Diam Relat Mater* 1995.

(5)Carnide, G.; Cacot, L.; Champouret, Y.; Pozsgay, V.; Verdier, T.; Girardeau, A.; Cavarroc, M.; Sarkissian, A.; Mingotaud, A. F.; Vahlas, C.; Kahn, M. L.; Naudé, N.; Stafford, L.; Clergereaux, R. Direct Liquid Reactor-Injector of Nanoparticles: A Safer-by-Design Aerosol Injection for Nanocomposite Thin-Film Deposition Adapted to Various Plasma-Assisted Processes. *Coatings* 2023, *13* (3), 630–648.

9:40am **PP4-FrM-6 Amorphous Carbon Thin Films for Electron Multipacting Mitigation in the Large Hadron Collider Vacuum System***, **Valentine Petit [valentine.petit@cern.ch]**, Pedro Costa Pinto, Mathias Gegg, Christos Kouzios, Giovanni Marinaro, Andrea Rocchi, Guillaume Rosaz,* European Organization for Nuclear Research, Switzerland

In modern particle accelerators with high intensity and positively charged beams, electron multipacting due to the exponential multiplication of electrons in the vacuum beam pipes results in the build-up of so-called electron clouds. In the Large Hadron Collider (LHC) at CERN, electron clouds lead to beam quality degradation, pressure rises and heat loads to the cryogenic sections hosting the superconducting magnets. Electron clouds are recognized as a critical limitation to reach the very high beam intensity required for the High-Luminosity upgrade of the LHC (HL-LHC).

To tackle this phenomenon, several mitigation approaches have been developed in the last decades, including clearing electrodes, confinement of electrons by solenoids or lowering of the Secondary Electron Yield (SEY) of the beam pipe surface, the quantity governing the multiplication of electrons. This last approach has been successfully implemented by coating the beam pipes with amorphous carbon thin films, which exhibit an SEY close to unity.

This contribution presents the development and prototyping phases towards the implementation of a coating technology to deposit amorphous carbon along several kilometers of narrow beam lines in-situ, i.e., without removing the superconducting magnets from their positions in the LHC tunnel, located 100 meters underground. The films are deposited by sputtering, using a tandem of 4 mobile targets, powered in HiPIMS mode, that are displaced along the beamlines. We report on the design of the coating system, on the characterization of the coatings, particularly under electron irradiation at 15 K, and on the optimization of the process parameters, considering the constraints for upscaling the technology to kilometers of vacuum pipes within the geometrical constraints of the LHC cryo-magnets.

10:00am **PP4-FrM-7 With Carbon Coatings towards CO_2 Neutrality - Industrialization in Electrochemical and Tribological Applications***, Martin Kopte [kopte.martin@vonardenne.com],* VON ARDENNE GmbH, Dresden, Germany **INVITED**

To date the global mining of fossil fuels continues to increase. As those resources are an integral part of almost any production value chain the CO2-equivalent of products needs to be accounted for in a clean balance sheet in every single production step and all the materials involved. The medium-term self-amortization of the CO2-equivalent of “active” products, that e.g. can replace fossil energy sources, is a desirable goal towards CO2-neutrality. Whereas “passive” products are required to be fabricated in the most efficient and sustainable manner, to keep the footprint as low as possible.

With PVD methods products can be refined to greatly increase in performance efficiency, self-amortization rate and sustainability. Typically, the additional effort of coating is already justified by the functionalization of the product itself. More and more the coating technologies must withstand a thorough review not only for the sake of cost effectiveness but also in terms of its contribution to the CO2-equivalent.

Carbon – inherently a good material choice – comes in wide variety of modifications with adjustable properties (e.g. electrical and mechanical) and hence can not only be used in a wide spectrum of electrochemical and tribological applications and thus targeting the scope of sustainable carbon-dioxide-free energy and energy saving solutions.

Paving the way to CO2-efficient industrialization of PVD-carbon coating equipment involves a careful consideration of many variables. This work touches on the challenges when it comes to the best choice of optimized materials, processes, methods etc. for engineering and scaling of competitive and efficient coating tools.

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