Functional Thin Films and Surfaces
Room Town & Country A - Session MB1-MoA

Thin Films and Surfaces for Optical Applications

Moderators: Jörg Patscheider, Evatec AG, Switzerland, **Juan Antonio Zapien**, City University of Hong Kong

1:40pm **MB1-MoA-1 Improvements to Multilayer Dielectric Coatings to Enable Internal Confinement Fusion at the National Ignition Facility (NIF)**, ***Colin Harthcock (harthcock1@llnl.gov)***, Lawrence Livermore Laboratory, USA **INVITED**

Since the advent of the laser, it has been theorized that high power lasers could be used as drivers for inertial confinement fusion (ICF), which has the possibility of revolutionizing our energy generation and dependance.As such, the US Department of Energy (DOE) has invested in this technology since the early 1970s, culminating in the building of the National Ignition Facility (NIF) from 1997 - 2009. However, it was quickly understood that the damage to the multilayer dielectric (MLD) interference coatings in the laser system may be key fluence and power limiting components. As such there was a huge, interdisciplinary effort to understand laser matter interactions leading to damage and the associated laser-damage prone precursors and mitigations. In this talk, we will discuss the basic layout of the NIF laser system and the associated coatings. Notable were the issues with the coating of high quality, meter-sized optics with good uniformity and high damage performance – this necessitated the use of electron beam evaporation for many of the high fluence, large aperture mirrors. For each of these MLD coating types, we will discuss the typical issues, typical damage-prone precursors and the associated mitigations. For many of the mirrors, nodular-type defects have been shown to increase the local electric field, absorption and greatly decrease the damage resistance of the coating. Furthermore, we will discuss other defects, such as stoichiometric issues, crystallinity, and nanobubbles.

2:20pm **MB1-MoA-3 Investigating Thin Ito Films for Light Detectors at Cryogenic Temperatures**, ***Giorgio Keppel (giorgio.keppel@lnl.infn.it)***, *O. Azzolini, C. Pira, A. Kotliarenko, M. El Idrissi, D. Ford,* Legnaro National Laboratories, Italian National Institute for Nuclear Physics, Italy

Indium tin oxide (ITO) is a widely used transparent conductive oxide thin film. ITO shows promising behaviours in various applications, such as biosensors, flat panels, and photovoltaics, due to its excellent electrical conductivity and optical transparency [1]. However, there has been limited recent research on its performance and characterisations at low temperatures [2].

In our study, we propose using ITO thin coatings for bolometric light detectors, which are currently used in cryogenic experiments for detecting rare events. It includes the direct detection of dark matter and the search for neutrinoless double-beta decay. Calorimetric detectors provide a straightforward solution for photon detection at cryogenic temperatures (mK) [3]. According to the authors' knowledge, there are preliminary measurements of ITO films below 12 K [2].

In our work, ITO thin films were deposited onto silicon wafers and quartz samples by magnetron sputtering technique using ITO target at room temperature on DC mode. The 90 to 900 nm deposited samples were characterized using X-ray diffractometry (XRD) to study their crystallinity and stoichiometry and scanning electron microscopy (SEM) to analyze their morphology and growth behaviour. The electrical characteristics of the ITO films were evaluated at both room temperature and cryogenic temperature (77 K and 4.2 K) using an upgraded resistive measurement system [4].

As a result, we present a study on the electrical properties of thin ITO coatings at cryogenic temperatures below 12 K in correlation with their optical properties. Additionally, we demonstrate the initial findings on developing silicon-based light detectors that incorporate ITO films and utilize the Neganov-Luke effect.

[1] Aydın, Elif Burcu et al. TrAC Trends in Analytical Chemistry, 97(2017): 309-315.

[2]Pawlak, et al., P. Sensors,17(2017),51.

[3] Novati, V., et al. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 940, (2019) 320-327.

[4]D. Ford et al.. LNL Annual Report (2022),162.

2:40pm **MB1-MoA-4 Key Success Factor of Solid-Phase Crystallization Through Postannealing Under Atmospheric Conditions on Amorphous Conductive W-Doped In_2O_3 Ultra-Thin Films with Thicknesses of Less Than 10 Nm**, ***Rajasekaran Palani (palani.rajasekaran@kochi-tech.ac.jp)***, *T. Yamamoto,* Kochi University of Technology, Research Institute, Japan*; M. Maehara, Y. Okada, K. Kinoshita,* Sumitomo Heavy Industries, Ltd., Industrial Equipment Division, Japan

In this work, for wide applications of W-doped In_2O_3 (IWO) films, we investigate the structural, electrical, and optical properties of amorphous and polycrystalline W-doped In_2O_3 (WO_3: W content of 1 wt. % (=0.6 at.%)) ultra-thin films. First, amorphous (*a*-IWO) films with thicknesses (*t*) ranging from 5 to 50 nm were deposited on glass substrates without intentionally heating of the substrates by reactive plasma deposition with dc arc discharge. Then, under atmosphere-condition for 30 min, we carried out the solid-phase crystallization (SPC) of *a*-IWO films at different temperatures of 200 and 250ºC. Experimental results yield that the postannealing temperature is a key factor to improve the properties of polycrystalline IWO (*p*-IWO) films. Concerning the effects of the SPC on structural properties of ultra-thin IWO films, we used in-plane X-ray diffraction (XRD: Rigaku SmartLab) which is very effective to study the microstructure characterization of the thin films. Electrical and optical properties were determined by Hall-effect (Nanometrics HL5500PC) and UV-Vis-NIR spectrophotometer measurements (Hitachi U-4100), respectively. We observed not sharp diffraction peaks but just broad ones in case of as-deposited IWO films with *t* of a 10 nm or less. As a result of the SPC concerning IWO films with *t* of 7 and 10 nm, we found the polycrystallized IWO films, regardless of the postannealing temperature (T_p); those films have a cubic bixbyite crystal structure (space group of *Ia*-3). In-plane XRD measurement results showed as follows: for 10-nm-thick *p*-IWO films at different T_p, we found that an increase in T_p promoted (111) directed orientation, whereas we observed no above effect of T_p for 7-nm-thick *p*-IWO films. Hall-effect-measurement results showed that the transformation from *a*- to *p*-IWO films reduces carrier concentration (n_e) together with enhanced Hall mobility (μ_H) at any given *t*. This implies that SPC decreased the density of *n*-type donor defects, oxygen vacancies. The analysis of the data of optical absorption coefficients indicated the distinct difference in the effects of T_p on the electrical and structural properties between 7- and 10-nm thick *p*-IWO films. For 10-nm-thick IWO films, an increase in T_p enhanced the crystallographic (111) orientation between grains. On the other hand, for 7-nm-thick IWO films, the above increase remarkably improved the lattice order in the grains: We, thereby, have achieved μ_H of 60.5 $cm^2/(Vs)$ and n_e of 0.81×10^{20} cm^{-3} higher than those of 10-nm IWO films. In order to tailor electrical properties combined with optical properties of IWO films, the optimization of postannealing is essential.

4:00pm **MB1-MoA-8 Multifunctional Bragg-Reflector-Enhanced Electrochromic Devices with Adjustable Optical Performance**, *M. Crouan, B. Baloukas, O. Zabeida, J. Klemberg-Sapieha,* ***Ludvik Martinu (ludvik.martinu@polymtl.ca)***, Polytechnique Montréal, Canada

Electrochromic (EC) all-solid-state devices (ASSDs) are of great interest in various industrial applications, such as smart glass for buildings, airplane windows, lenses, and mirrors. These devices possess allow one to dynamically change their optical properties, transitioning from a bleached state to a colored state through a redox reaction following the application of a low voltage. Due to the inherent properties of EC materials, ASSDs exhibit significant absorption and transmission modulation and, as a result, a limited capacity for reflection modulation. Yet, achieving a reflection increase upon coloration can offer new functionalities in terms of aesthetics and the development of innovative optical filters.

The implementation of EC Bragg mirrors (ECBM) using WO_3 and ITO bilayers in an ASSD hence holds significant promise as a means of reaching a substantial increase in reflection at specific wavelengths during coloration. In this work, we compared a conventional ASSDs with various ECBM configurations incorporated into an ASSD. Specifically, via a comprehensive optical modeling study, we designed an ASSD which changes from a transparent anti-reflective state to a mirror-like opaque state within the visible spectrum. The fabricated antireflective ASSD with 2-bilayers of WO_3/ITO displayed an increase in R_{lum} from 1.4% in the bleached state to 8.9% in the colored state. By minimizing the constraints on the antireflective properties, we achieved a reflection increase of 19.8% upon coloration, opening new possibilities for dynamic optical interference filters.

4:20pm **MB1-MoA-9 Quantitative Strong Optical Nearfield Enhancement by Coupling Bloch Surface Wave Packet and Localized Surface Plasmon of Aunp for Surface-Enhanced Raman Spectroscopy**

M. Phoo, A. Adesina, Y. Foo, City University of Hong Kong*; M. Zerrad,* CNRS, Central Marseille, France*; C. Amra,* CNRS, Centrale Marseille, France*; **Juan Antonio Zapien (apjazs@cityu.edu.hk)**,* City University of Hong Kong

We present the ultra-high near-field enhancement (EF~10^8) that results from exciting Localized Surface Plasmon in gold nanoparticles (AuNP) using the high-Q photonic resonance from a Bloch Surface Wave (BSW) stack. The BSW stack is composed of a16 dielectric SiO_2 and Ta_2O_5 layers with total thickness ~2 um. Optical characterization is performed by spectroscopic ellipsometry (SE) in the spectral range (400-1200 nm). Excellent agreement between the SE data and modelling from i) standard Fresnel equations and matrix transfer formalism (FE- model) and ii) Finite-Difference Time-Domain (FDTD) method demonstrate efficient coupling between the photonic (BSW) and plasmonic (LSP) modes. Furthermore, the BSW stack enables high photonic confinement acting as an energy reservoir inside the multilayer stack; the high Q, ~5000, BSW photonic mode efficiently pumps the AuNP LSP, resulting in total near-field enhancement ~10^8. Our experimental results and modelling demonstrate dual sensing with chemical identification, from Surface-Enhanced Raman Scattering (SERS), with simultaneous quantification, via BSW sensing.

4:40pm **MB1-MoA-10 Strongly Thermochromic VO_2-Based Smart Coatings for Room-Temperature Applications Prepared on Glass**

***Michal Kaufman (mkaufman@kfy.zcu.cz)**, J. Vlček, J. Houška, S. Farrukh,* University of West Bohemia, Czechia

Vanadium dioxide (VO_2) exhibits a reversible phase transition from a low-temperature monoclinic VO_2 (M1) semiconducting phase to a high-temperature tetragonal VO_2 (R) metallic phase at a transition temperature of approximately 68 °C for the bulk material. The automatic response to temperature and the abrupt decrease of infrared transmittance without attenuation of luminous transmittance in the metallic state make VO_2-based coatings a promising candidate for thermochromic smart windows reducing the energy consumption of buildings.

To meet the requirements for large-scale implementation on building glass, VO_2-based coatings should satisfy the following strict criteria simultaneously: a deposition temperature close to 300 °C, a transition temperature close to 25 °C, an integral luminous transmittance T_{lum} > 60%, a modulation of the solar energy transmittance ΔT_{sol} > 10%, long-term environmental stability, and a more appealing color than yellowish or brownish colors in transmission.

The paper deals with a scalable sputter deposition technique for the preparation of strongly thermochromic YSZ/W and Sr co-doped VO_2/SiO_2 coatings on standard soda-lime glass at a relatively low substrate surface temperature (320 °C) and without any substrate bias voltage. The W and Sr co-doped VO_2 layers were deposited using a controlled high-power impulse magnetron sputtering of a V-W target combined with a simultaneous pulsed DC magnetron sputtering of a Sr target in argon-oxygen gas mixtures. The bottom antireflection Y-stabilized ZrO_2 (YSZ) layers were deposited using a controlled reactive high-power impulse magnetron sputtering of a Zr-Y target, while the top antireflection SiO_2 layers were deposited using a reactive mid-frequency bipolar dual magnetron sputtering of two Si targets.

The fundamental principles of this technique, and the design, structure and optical properties of the thermochromic coatings are presented. The coatings exhibit a transition temperature of 22-25 °C with an integral luminous transmittance T_{lum} up to 64% (at almost the same luminous transmittance above the transition temperature) and ΔT_{sol} =11%. Such a combination of properties, together with the relatively low deposition temperature (320 °C), has not yet been published by other teams for thermochromic VO_2-based coatings prepared by a scalable deposition technique compatible with the existing magnetron sputter systems in glass production lines and in large-scale roll-to-roll deposition devices.

5:00pm **MB1-MoA-11 Nanostructured Metal Thin Films with Enhanced Mechano-Optical Properties for Solar Radiation Isolation**

A. Xomalis, NTNU Trondheim, Norway*; **Barbara Putz (barbara.putz@empa.ch)**,* Empa, Swiss Federal Laboratories for Materials Science and Technology, Thun, Switzerland*; X. Zheng,* KU Leuven, Belgium*; A. Groetsch,* Empa, Swiss Federal Laboratories for Materials Science and Technology, Thun, Switzerland*; G. Vandenbosch,* KU Leuven, Belgium*; J. Michler, J. Schwiedrzik,* Empa, Swiss Federal Laboratories for Materials Science and Technology, Thun, Switzerland

Thin metal films on flexible polymer substrates are used widely in satellite missions as they show extreme thermal isolation and high interface strength at a minimum specific weight. Here, we show how nano-structuring of Al thin films on polyimide can create plasmon resonances, allowing interplay with visible radiation while reflecting the unwanted infrared responsible for device heating. Focused ion beam milling was used to create areas of a repetitive ring pattern in Al thin films (100 nm thickness), with variations of the ring diameter (1.9 and 2.2 μm), periodicity (2.4 and 3.1 μm) and trench thickness (partially or fully perforation the Al films). Uniaxial tensile tests with *in situ* optical measurements reveal that the nano-patterning of the thin films results in crack-free domains, leading to resilient optical resonances withstanding applied strains up to ∼20%. We also perform nanoscale electromagnetic and mechanical simulations to evaluate the thin films' mechano-optical behaviour. Our simulations well fit the experimental positions of strain localization, resulting in crack formation and thin film damage. The central parts of the ring pattern in the structured thin films remain crack-free at applied strains exceeding the crack onset strain of unpatterned, continuous coatings by >84%. Fragmentation analysis shows how, in contrast to unpatterned films, the developing crack pattern and spacing can be tailored by choosing appropriate structural parameters. Such small-footprint, resilient, and lightweight devices are highly desirable for heat rejection, communications, and spectroscopies in harsh environments.

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