Functional Thin Films and Surfaces
Room Palm 1-2 - Session MB1-WeA

Thin Films and Surfaces for Optical Applications

Moderators: Rajiv Pethe, Vital Chemicals, USA, **Barbara Putz**, Empa Thun, Switzerland

2:00pm **MB1-WeA-1 Experimental and Theoretical Insights into UV-Active Chirality in Glancing Angle Deposited Zirconia Nano-Helical Metamaterial Platforms**, ***Ufuk Kilic [ufukkilic@unl.edu]***, *Matthew Hilfiker,* University of Nebraska-Lincoln, USA*; Shawn Wimer, Raymond Smith,* University of Nebraska - Lincoln, USA*; Christos Argyropoulos,* Pennsylvania State University, USA*; Eva Schubert, Mathias Schubert,* University of Nebraska - Lincoln, USA **INVITED**

Chirality, the property of handedness in molecules or objects that prevents them from being superimposed on their mirror images, is optically manifested as circular dichroism (CD)—the differential absorption of left- and right-handed circularly polarized light. However, chirality found in nature is inherently weak, challenging to spectrally control, and primarily active in the ultraviolet (UV) region of the spectrum [1-3]. Enhancing UV-active chirality, crafting UV-active photonic wave-guide systems and also detecting chiral molecules through metamaterial platforms remains a challenge, as most designs are optimized for the infrared (IR) to visible spectral ranges [3].

In this study, we fabricated ultra-wide bandgap (~5 eV) zirconia (ZrO_2) thin films using the glancing angle deposition (GLAD) method with electron beam evaporation. When the particle flux was directed at normal incidence (0°), uniform coating of flat ZrO_2 thin films were successfully fabricated. In contrast, directing the flux at an oblique angle (85.5°) with continuous substrate rotation (24 seconds per revolution) yielded spatially coherent, super-lattice nano-helices. Generalized spectroscopic ellipsometry (GSE) technique was used to extract frequency-dependent complex dielectric functions and identify band-to-band transitions spanning the near-IR to vacuum-UV (VUV) spectrum. Strong VUV-active CD responses were experimentally observed in ZrO_2 nano-helical metamaterials using Mueller matrix GSE. Additionally, visualization of both near- and far-field characteristics induced by circularly polarized illumination, along with the theoretical validation of the VUV-active chiroptical response, were investigated using finite element modeling (FEM) based full wave simulations. The systematic FEM calculations also revealed that the chiral properties could be tuned by (i) adjusting the structural parameters of the nano-helices and (ii) incorporating plasmonic subsegments into the helical structure.

Our research outputs suggest that the proposed metamaterial design holds significant potential for applications such as high-power chiro-optic photonic and electronic circuits, quantum information systems, UV-active topological insulators, and chiral sensing technologies.

[1] Kilic, U., *et al.*, *Nat. Commun.* 15, 3757 (2024).

[2] Kilic, U. *et al.*, Adv. Funct. Mater. 31.20: 2010329,(2021).

[3] Sarkar, S. *et al.,* Nano letters 19.11: 8089-8096,(2019).

2:40pm **MB1-WeA-3 Fabrication of High Quality Titanium Nitride Nanostructures for Plasmonics**, ***Spyros Kassavetis [skasa@physics.auth.gr]***, *Stavros Panos, Nikos Pliatsikas, Despina Tselekidou, Panos Patsalas,* Aristotle University of Thessaloniki, Greece

Transition metals nitrides (TMNs) emerge as alternative plasmonic nanomaterials suitable for a wide range of applications from photovoltaics to photonics and medicine. The TMNs are conductive ceramics that combine exceptional properties such as substantial electronic conductivity, high melting point (>3000 K) and tunable work function, while they are particularly stable in hostile chemical environments, high temperature, and strong electric fields. Among them, Titanium Nitride (TiN) emerges as significant candidate material for practical plasmonic applications (biosensors, catalysis and photochemistry, solar energy harvesting, photo-detection, and optical storage of information).

In this work, we focus on novel and cost-efficient fabrication techniques of alternative plasmonic nanostructures. TiN nanostructures with controlled spacing and tunable dimensions (thickness and lateral dimensions) were fabricated using a combination of Nanosphere Lithography (NSL) and several reactive magnetron sputtering (MS) deposition techniques such as DC, Closed-Field Unbalanced MS or Highly Power Impulse MS (HIPMS) with the aim to study the fundamentals that will unlock the fabrication of high quality TMNs nanostructures for plasmonic applications.

NSL appears as a very promising approach, due to its rapid implementation and compatibility with wafer-scale processes, combines the advantages of both top-down and bottom-up approaches and includes: (a) development of the nanospheres monolayer colloidal mask, (b) deposition of the desired material in the empty space between the nanospheres and (c) removal/lift-off of the nanosphere colloidal mask to “reveal” the deposited material. Specifically, a suspension of monodisperse polystyrene nanospheres (diameter, d=552 nm or d=175 nm) was spin coated on a substrate such as Si (001), glass, flexible or PET to form the colloidal mask. A UV ozone process was used to confine the triple-junction vias of the polystyrene mask. Subsequently, the selective growth of TiN was made by the above mentioned MS in Ar/N atmosphere by varying the TiN thickness from 10 to 30 nm, while the MS process parameters were also fine-tuned to increase the directionality of deposited species such as the negative bias voltage during the growth of the TiN.

The arrays of ordered TiN nanostructures appear after the lift-off of the mask. Atomic Force Microscopy characterization of the samples showed the fabrication of TiN nanostructures, with low concentration of point defects, similar structure with the continuous TiN films of high electrical conductivity and plasmonic performance, and durability at least up to 400° C.

3:00pm **MB1-WeA-4 Enhancing Optical Properties and Photocatalytic Performance withNanopatterned Anodized Aluminum Oxide on transparent substrate**, ***Fu-Gi Zhong [fugi.en12@nycu.edu.tw]***, *Shih-Hsun Chen,* National Yang Ming Chiao Tung University (NYCU), Taiwan

In recent years, the rapid advancement of nanotechnology has driven an increasing demand for high-performance nanostructured materials. Among various fabrication techniques, anodic aluminum oxide (AAO) films have attracted significant attention due to their excellent chemical and thermal stability, transparency, and tunable nanoporous structure. AAO features highly ordered nanopore arrays, making it an ideal template for functional thin films, especially in applications requiring high surface area and aspect ratios. By integrating functional ceramic or semiconductor coatings, materials deposited on AAO can self-assemble into nanostructures, further enhancing their optical and chemical reactivity and making them highly suitable for applications in sensors, photocatalysis, and other fields requiring heightened sensitivity and resolution.

This study focuses on the fabrication of AAO structures on transparent substrates, followed using Atomic Layer Deposition (ALD) to coat these structures with ZnO thin films, aiming to produce transparent, nanostructured porous films on both sides of the substrate. By integrating ZnO coatings with AAO structures, we plan to investigate light transmission and surface interaction properties, thereby enhancing optical performance and photocatalytic efficiency and making the films more suitable for high-sensitivity, multifunctional sensor and photocatalytic applications.

3:20pm **MB1-WeA-5 A Comparative Study: The Structural and Optoelectronic Properties of Al- and Ga-Doped ZnO Films Deposited by Atmospheric Pressure Plasma Jet**, ***Chih-Yun Chou [f10k45003@ntu.edu.tw]***, National Taiwan University, Taiwan

Aluminum-doped zinc oxide (AZO) and gallium-doped zinc oxide (GZO) are leading transparent conductive oxides (TCOs) for optoelectronic applications, valued for high transparency and conductivity. GZO provides superior carrier mobility and lower resistivity, while AZO is more cost-effective and less toxic.This study compares AZO and GZO films prepared via atmospheric pressure plasma jet (APPJ) deposition, allowing for precise parameter control to evaluate Al and Ga’s effects on ZnO film properties and their suitability in advanced optoelectronics.

Structural analysis using X-ray diffraction (XRD) and scanning electron microscopy (SEM) reveals both AZO and GZO films exhibit a hexagonal wurtzite structure with a *c*-axis orientation. The broader full-width at half maximum (FWHM) at (002) peak and higher strain in GZO films suggest more pronounced lattice distortion, likely due to Ga’s higher doping efficiency. Further, reducing the working distance, thereby increasing processing temperature, effectively eliminates surface particles in GZO films but not in AZO films. This temperature-driven improvement enhances the mobility of Ga atoms on the substrate surface, leading to a more cohesive and uniform film morphology in GZO.

Optoelectronic properties assessed via UV-Vis spectroscopy and Hall effect measurements indicate that GZO films maintain high visible-range transparency (>80%) compared to AZO films (>70%). In the near-infrared

range, GZO transparency decreases significantly (<40% at 1400 nm) due to its higher carrier concentration. Overall, AZO films show lower electronic performance, likely due to complex defect formation and increased impurity scattering, evidenced by higher Urbach energy (E_U) values (0.28-0.29 eV for AZO films and 0.26 eV for GZO). Decreased APPJ working distance enhances carrier mobility, improving the figure of merit at 550 nm for GZO from 11 × 10^{-3} Ω^{-1} to 26.4 × 10^{-3} Ω^{-1} and for AZO films from 0.4 × 10^{-3} Ω^{-1} to 0.8 × 10^{-3} Ω^{-1}.

In conclusion, while AZO and GZO films both possess favorable characteristics for TCOs, their electronic behaviors diverge markedly under APPJ processing. Al doping tends to introduce complex defects that limit carrier mobility and concentration, making AZO less suitable where high conductivity is essential. In contrast, GZO films achieve higher carrier concentration and mobility, making them more appropriate for applications where efficient charge transport is critical. The findings also emphasize the significance of the APPJ working distance parameter and underscore the importance of selecting appropriate dopants and understanding defect dynamics to optimize ZnO-based TCO performance.

3:40pm **MB1-WeA-6 Unveiling the Interplay of Structural, Optical, and Hydrophobic Properties of Sputtered Grown PTFE@AlSiN Thin Films**, *Raman Devi, Somdatta Singh,* ***Ramesh Chandra [ramesh.chandra@ic.iitr.ac.in]****,* IIT Roorkee, India

Radio frequency (RF) magnetron sputtering technique was used to develop PTFE@AlSiN thin films on glass substrates at temperatures ranging from 250ºC to 450ºC. Methods like X-ray diffraction (XRD), field emission scanning electron microscopy (FE-SEM), UV-Vis Spectroscopy, water contact angle (CA) measurements, and nanoindentation were used to examine the structural, morphological, optical, hydrophobic, and mechanical properties of PTFE@AlSiN at various substrate temperatures (250ºC-450ºC). XRD studies showed that the coating deposited with an Ar:N_2 ratio of 20:6 at various substrate temperatures formed a hexagonal phase, demonstrating its polycrystalline nature. A nanocomposite with microstructure has been formed by embedding AlN nanocrystallites in a soft amorphous matrix of Si_3N_4 provides better mechanical properties. The contact angle measurement method displayed an excellent contact angle of around ~118º (good hydrophobicity). According to optical transparency measurements, all coatings exhibited > 90% transparency in the visible spectrum. The PTFE@AlSiN coated at 450ºC had the highest hardness value greater than 25 GPa.

Keywords: optical transparency, magnetron sputtering, thin film, hydrophobicity; nanoindentation, hardness

4:00pm **MB1-WeA-7 Diffusion of Ni Within Polycrystalline Zinc Oxide Layer: An Approach Combining Different Techniques for a Nanoscale Analytical Response**, ***Hervé Montigaud [herve.montigaud@saint-gobain.com]****,* SVI, Joint Unit CNRS/ Saint Gobain, 41 quai Lucien Lefranc, Aubervilliers, France*; Justine Voronkoff,* Saint Gobain Research Paris, 41 quai Lucien Lefranc, Aubervilliers, France*; Ludovic Largeau,* C2N-CNRS/Université Paris-Saclay, France*; jacques Perrin - Toinin,* RWTH Aachen University, Germany*; Thierry Cretin,* Saint Gobain Research Paris, 41 quai Lucien Lefranc, Aubervilliers, France*; Ekaterina Burov,* SVI Joint Unit CNRS / Saint Gobain Aubervilliers, France

In the context of global climate change, the low emissivity glazing developed by glass makers contributes to tackle the thermal losses of the buildings. Within these systems for windows, the radiative part is reduced by a thin metallic silver layer included in a stack that reflects especially far-infrared. This 12nm-thick Ag layer is embedded between other nanometric layers such as nitride (SiNx), oxide (ZnO, SiOx, SnZnOx) and sub-nanometric metallic layer (NiCr), all deposited by magnetron sputtering. The structure and mainly the composition of each layer are influenced by the deposition conditions and also post-annealing step in the case of tempered glasses. Different interactions occurred at the interface between the substrate and the stack and between the layers such as inter-diffusion phenomena [1, 2,3]. It is crucial to follow the consequences onto the local composition of the layers to control the final performances of the glazing.

The present work focuses on the system composed by nickel chromium and zinc oxide layers, from its deposition to its annealing until 600°C. NiCr/ZnO layer stack was deposited on an Si wafer by magnetron sputtering and then annealed[4]. The diffusion of the nickel from the nanometric NiCr layer within the polycrystalline zinc oxide layer and Ni precipitation at the interfaces had been characterized. The local composition within the polycrystalline zinc oxide was addressed until the nanometer scale thanks to the combination of techniques such as Time of Flight Secondary Ion Mass Spectrometry (ToF-SIMS), AtomProbe Tomography (APT), Scanning Transmission Electron Microscopy (STEM), and by exploiting the added value of each one. For instance, we have studied the contribution of grain boundaries compared to nanocrystals on the Ni diffusion.

keywords

NiCr, ZnO, sputtering, diffusion, polycrystalline layer, ToF-SIMS, APT, STEM

references

1. R. Knut, R. Lindblad, H. Rensmo, O. Karis, M. Gorgoi, S. Grachev, J.-Y. Faou, E. Søndergård, Journal of applied physics 115, (2014) 043714
2. S. Ben Khemis et al. Thin Solid Films 733 (2021) 138811
3. J. Kulczyk-Malecka, P.J. Kelly, G. West, G.C.B. Clarke, J.A. Ridealgh, Thin Solid Films 520 (2011) 1368–1374
4. J. Voronkoff PhD, Sorbonne Université, 2020

4:40pm **MB1-WeA-9 Influence of SHI irradiation on the Photoluminescence and Dielectric properties of bilayer structured Au/GeO2 thin films for Optoelectronics applications**, ***Mahendra Singh Rathore [mahendra.rathore8944@paruluniversity.ac.in]****,*** *Anand Y. Joshi,* Parul University, India*; Srinivasa Rao N.,* MNIT Jaipur, India

Abstract

In the present work, the effects of swift heavy ion beam irradiation on the engineering the physical, optical, photoluminescence and dielectric properties of bilayer structured Au/GeO_2 thin films have been investigated. GeO_2 and Au thin films have been grown onto silicon substrate using electron beam evaporation. Eventually the prepared Au/GeO_2/Si thin films were irradiated with 100 MeV Ag ions at different ion fluences ranging from 1×10^{12} to 1×10^{13} ions/cm^2. The pristine and irradiated samples were characterized using XRD, RBS, SEM, AFM, UV-Vis reflectance and photoluminescence Spectroscopy. The dielectric properties, AC conductivity, dielectric and tangent loss were analyzed of the pristine and irradiated samples. The results reveal that the nucleation of Au NCs was observed with increase in fluence. The elemental composition and film thickness observed using RBS measurements. The surface morphology and topography results reveal that the nucleation of particles with increase in ion fluences. Broad PL band observed in visible region which corresponding to the green light emission due to the presence of Au NCs. The CIE curve plotted from the PL data. The oxygen vacancy related defect states as well as surface Plasmon resonance (SPR) induced absorption and subsequent electron injection from Au NPs to conduction band of GeO_2. The dielectric properties varied with irradiation. The variation in electronic transition of wide band gap GeO_2 NC's by nucleation of gold NP's are considered to practical application in optoelectronics devices such as wavelength detection and optical switching devices and have been discussed in details.

Keywords: Au/GeO_2 thin films, ion beam irradiation, XRD, RBS, Photoluminescence, Dielectric properties.

5:00pm **MB1-WeA-10 Influence of Post-Heat Treatment on Structural, Photocatalytic, Dielectric, and Tribological Properties of TiO_2/Al/TiO_2 Multilayer Thin Films**, ***Anand Joshi [anandyjoshi@gmail.com]****,*** *Mahendra Singh Rathore, Unnati Joshi,* Parul University, India

The purpose of this study was to evaluate the impact that post-heat treatment has on the structural, physical, photo-catalytic, and dielectric properties of multilayer structures of thin films composed of TiO2/Al/TiO2. Radiofrequency (RF) magnetron sputtering and direct current (DC) magnetron sputtering were used to deposit a multilayer of titanium dioxide and aluminum on glass and silicon substrates at room temperature. The flow rate of argon gas was kept constant. After that, the films that had been deposited were annealed in air for three hours at temperatures ranging from 200 degrees Celsius to 500 degrees Celsius. After that, samples that had been deposited and annealed were characterised by employing techniques such as X-ray diffractometer, scanning electron microscopy (SEM), and atomic force microscopy. The purpose of these techniques was to explore the structural and physical properties of the samples that had been deposited and annealed. The technique of energy dispersive spectroscopy was utilised in order to investigate the impact that temperature has on the constituent composition. Experiments were conducted in the presence of ultraviolet (UV) light and sunlight to investigate the catalytic behaviour of samples against MB and RHD dye. Temperature was found to be a significant factor in the improvement of the percentage of dye degradation. Both the unaltered and the annealed samples were subjected to analytical examinations of their dielectric characteristics, AC conductivity, dielectric loss, and tangent loss. Interdiffusion of Al atoms in TiO2 matrix as a result of annealing demonstrates an improvement in the characteristics and potential

usefulness of the material as a catalyst and electrode material for applications involving energy storage. In addition, a pin-on-disc tribometer has been utilised in order to evaluate the tribological characteristics of the coating. An in-depth discussion has been held regarding the potential mechanisms of tweaking the properties, as well as the potential applications of these qualities.

Author Index

Bold page numbers indicate presenter