

## Functional Thin Films and Surfaces

### Room Palm 3-4 - Session MB2-3-ThM

#### Thin Films for Emerging Electronic and Quantum Photonic Devices III

**Moderators:** Jiri Capek, University of West Bohemia, Czechia, Spyros Kassavetis, Aristotle University of Thessaloniki, Greece

8:40am **MB2-3-ThM-3 From Passive to Active Structurally Controlled Optical Coatings for Energy, Eyewear and Sensor Applications**, Bill Baloukas, Martin Crouan, Brandon Faceira, Aleksandra Pajak, Phillip Rumsby [phillip.rumsby@polymtl.ca], Oleg Zabeida, Jolanta Klemberg-Sapieha, Ludvik Martinu, Polytechnique Montréal, Canada

Control of energetic interactions at the surface of the growing thin films allows one to selectively adjust their micro- and nanostructure. This is particularly important when synthesizing optical films by vapor-based techniques such as reactive sputtering (including HiPIMS), evaporation (including Glancing Angle Deposition), Plasma-Enhanced Chemical Vapor Deposition, Atomic Layer Deposition, Ion Beam Assisted Chemical Vapor Deposition, and Gas Agglomeration Cluster formation. As a result, this has become increasingly attractive for judicious fabrication of nanostructured optical filters with controlled film porosity, crystallinity, anisotropy, plasmonic effects, thermo-mechanical properties and other features of both passive as well as active (dynamic – e.g., electrochromic or thermochromic) coating materials with new functionalities.

This presentation will illustrate the progress and new opportunities in structurally controlled passive and active optical coating systems using a holistic approach from design to fabrication and device performance. This will specifically be highlighted by our work on high-performance low-emissivity and smart windows for energy saving in the building sector, energy control in micro/nanosatellites, hybrid (organic-inorganic) coatings and switchable electrochromic systems for ophthalmic lenses including novel transparent flexible electrodes, plasmonic optical filters for gas sensing, and other advanced optical coating devices.

#### References:

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2. Z. Krtous, O. Polonskyi, P. Pleskunov, M. Cieslar, B. Baloukas, L. Martinu, J. Kousal, "Sensing of Organic Vapors with Plasmonic Distributed Bragg Reflectors", *ACS Appl. Mater. Interfaces* **17** (18) (2025) 27126–27135.
3. M.-A. Dionne, B. Baloukas, O. Zabeida, J. Klemberg-Sapieha, L. Martinu, "Fabrication and Performance of Randomly Patterned Tri-Layer Flexible and Transparent Electrodes", *Optical Materials* **166** (2025) 117200.
4. P. Rumsby, B. Baloukas, O. Zabeida, and L. Martinu, "Enhanced Durability and Antireflective Performance of Ag-Based Transparent Conductors Achieved via Controlled N-Doping", *ACS Applied Materials & Interfaces* **16** (2024) 24039–24051.
5. A. Shelemin, Z. Krtous, B. Baloukas, O. Zabeida, J.E. Klemberg-Sapieha, L. Martinu, "Fabrication of Plasmonic Indium Tin Oxide Nanoparticles by Means of a Gas Aggregation Cluster Source", *ACS Omega* **8** (2023) 6052–6058.

9:00am **MB2-3-ThM-4 Glancing Angle Deposition of WO<sub>x</sub> and Cu-doped TiO<sub>2</sub> Thin Films for Improved Conductometric Gas Sensing**, Akash Kumar [akashkumarneutronics@gmail.com], University of West Bohemia, NTIS, India; Stanislav Haviar, University of West Bohemia, NTIS, Czechia; Nirmal Kumar, University of West Bohemia, NTIS, India

The emerging hydrogen industry is stimulating efforts in developing new materials for various purposes, including the quest for efficient, sustainable, and low-power hydrogen detectors. Many such devices rely on metal oxide semiconductor materials, which are easily integrable into devices and relatively cheap but suffer from some challenges, such as low sensitivity and selectivity.

This study explores the possibility of exploiting a Glancing Angle (GLAD) sputter deposition of Cu-doped TiO<sub>2</sub> and WO<sub>x</sub> films, targeting the enhancement of active surface area and, therefore, sensor sensitivity improvements.

Cu-doped TiO<sub>2</sub> and WO<sub>3</sub> films were deposited using conventional reactive DC magnetron sputtering, employing circular titanium and tungsten targets in a mixture of argon and oxygen. Cu-doping was achieved by using a composite target. Films were post-annealed prior to sensing characterization. The Glancing Angle Deposition (GLAD) technique was employed to induce a characteristic columnar nanostructure, thereby increasing the films' porosity and so leading to a desired increase in active surface area. Multiple parameters were tuned to enhance the sensing response, including the angle of deposition (80°, 85°, 88°), thickness (50–300 nm), and reactive sputtering parameters.

Synthesized films were thoroughly analyzed by SEM and XRD. Sensing response measurements revealed an interesting fact: that neither the surface roughness nor the surface area improves the response to the sensing gas monotonically. In the presented paper, we discuss the geometrical reasons as well as the synthesis parameters that influence the sensing characteristic. The comparison of the two materials, WO<sub>3</sub> and TiO<sub>2</sub>, is also given.

9:20am **MB2-3-ThM-5 Sputter Coating of High-Quality VO<sub>2</sub> Metal-Insulator Transition Films for Flexible Electronics**, Juan Andres Hofer [juhofer@ucsd.edu], University of California San Diego, USA; Ali C. Basaran, General Atomics, USA; Tianxing Damir Wang, Ivan K. Schuller, University of California San Diego, USA

The metal-insulator transition (MIT) in vanadium dioxide (VO<sub>2</sub>) thin films is a topic of great interest for applications in smart windows, memristors, and neuromorphic computing applications. VO<sub>2</sub> thin films are accompanied by substantial changes in the electronic and optical properties across the MIT, and these changes can be induced by external stimuli such as voltage, strain, or temperature. While several studies have shown that flexible and freestanding VO<sub>2</sub> films can be achieved, complex pre- or post-growth processing is required. In this work, we show that direct sputter deposition of VO<sub>2</sub> on flexible Kapton substrates results in a straightforward methodology to achieve flexible MIT films. A pre-deposited Al<sub>2</sub>O<sub>3</sub> layer on Kapton enhances film adhesion, and the resulting flexible VO<sub>2</sub> films show up to 4 decades of change in resistance across the MIT. Temperature and substrate-induced strain during growth affect substantially the quality of the films. The resulting VO<sub>2</sub> flexible devices show ultra-low power consumption for resistive switching, up to two orders of magnitude lower than in samples grown on traditional substrates. We also demonstrate that the VO<sub>2</sub> MIT characteristics can be governed by mechanical deformation, resulting in a novel method to induce resistive switching and decrease power consumption. This study reveals a straightforward approach for direct growth of high-quality flexible VO<sub>2</sub> films exhibiting robust MIT, with promising applications in tactile sensors and electromechanical devices.

**Funding Acknowledgment:** This material is based upon work supported by the Air Force Office of Scientific Research under award number FA9550-22-1-0135.

10:20am **MB2-3-ThM-8 - In Situ Electron-Beam-Induced Selective-Area Growth of Tellurium Films by Molecular Beam Epitaxy**, Ossie Douglas [dro3@usf.edu], University of South Florida, USA; Peter Snapp, NASA Goddard Space Flight Center, USA; Ali Ashraf, University of South Florida, USA

Recently, thin films of elemental tellurium (Te) have gained increasing attention due to their intrinsically anisotropic crystal structure and morphology-dependent semiconducting properties. Molecular beam epitaxy (MBE) is an established technique for producing chemically pure, wafer-scale Te films with high morphological precision. However, post-processing of Te films for device fabrication typically relies on masked lithographic techniques, which can inadvertently degrade film quality and electrical performance. While selective-area growth approaches have been explored to mitigate these effects, mask-based methods introduce additional pre-processing complexity and crystallographic constraints. An in situ selective-area growth technique offers a pathway to reduce fabrication complexity while preserving intrinsic film properties.

Here, we demonstrate an in situ process for selective-area growth of Te thin films on muscovite mica (MuM) dielectric substrates using an electron beam generated by a reflection high-energy electron diffraction (RHEED) gun integrated within an MBE system. Spatially selective growth is achieved without physical masking, resulting in millimeter-scale lateral patterning of nanometer-thick Te films, confirmed by optical characterization. Directional control of film growth is realized through azimuthal alignment of the substrate relative to the incident electron beam. The resulting feature dimensions are found to depend strongly on electron beam voltage, exposure duration, and substrate temperature. This approach demonstrates

# Thursday Morning, April 23, 2026

controllable Te film shape and thickness during growth, highlighting new opportunities for direct-write epitaxial patterning within MBE systems.

10:40am **MB2-3-ThM-9 High Tunability in Crystallographic Design of Thin Films Enabled by Atomic Imprint Crystallization**, *Koichi Tanaka [ktanaka@anl.gov]*, Argonne National Laboratory, USA; *Xella Doi, Connor Horn, Chloe Tsang, Supratik Guha*, University of Chicago, USA

In general, properties of thin films are dependent on their crystal orientation, and the most common approach to control the crystal orientation of thin films is to utilize epitaxial growth on single-crystalline substrates. Although a variety of materials have been synthesized on single-crystalline substrates using chemical and physical vapor deposition (CVD, PVD), epitaxial growth methods allow us to grow materials into only one fixed orientation predetermined by the substrate orientation, and typically with limited tunability in terms of area or orientation.

In this talk, we report area-selective, orientation-tunable crystallization processes of amorphous Si utilizing atomic imprint crystallization (AIC), where an amorphous Si layer is crystallized by solid phase epitaxy from an external single-crystal Si template. Using a flat template, the top surface of an amorphous Si is crystallized following the crystal orientation of the template wafer up to 5 mm diameter, indicating that the crystallization of the amorphous Si can be initiated by an external template wafer. Using micro-patterned single-crystalline Si templates, limited areas (~50  $\mu\text{m}$  diameter) of an amorphous Si film, where the film surface and patterned template surface are in contact, are crystallized via SPE to create an array of crystallographically aligned dots embedded in amorphous matrix. Combining the AIC from the top surface and conventional SPE from the substrate, we developed new crystallization processes to fabricate unique microstructures such as a twisted interface with a tunable twist angle and an array of crystalline dots embedded in single-crystalline matrix with tunable in-plane rotation angle. The results demonstrate the area-selective, orientation-tunable crystallization process enabled by AIC, controlling crystallographic properties of thin films, which can open up new materials design capabilities for variety of applications in materials science including but not limited to electronics and quantum device applications.

11:00am **MB2-3-ThM-10 Thin Film Processing Strategies for High-Throughput Autonomous Materials Discovery and Development**, *Christopher Muratore [cmuratore1@udayton.edu]*, University of Dayton, USA; *Brian Everhart, Drake Austin, Nicholas Glavin*, US Air Force Research Laboratory, USA

The talk highlights automated experimental tools enabling synthesis and characterization of hundreds of samples per day. This approach, where experimentation is much faster than simulation has the potential to flip the traditional 'order of operations' for materials discovery where experiment feeds model during initial iterations. One high-throughput format relies on scanning lasers with broad ranges of power, scan rates, and focal positions to induce physical and chemical transformations within materials. Laser heating parameters may be set to approximate quasi-equilibrium heating as in a furnace, or induce extreme heating and cooling rates, thereby broadening the range of accessible compositions and crystal structures dictated by kinetics of both chemical reactions and crystallization. Deposition tools may also be used to create a broad range of compositions on the sample surface. Once a combinatorial sample with a desired range of compositions and laser illumination conditions is processed, it can be manually or autonomously subjected to the combination of high-throughput characterization tools required for evaluation of the properties specified by the user. Autonomous systems enable users to specify a desired property and the system iterates processing and characterization data to 'make decisions' about optimization of conditions to realize the user-specified input. For example, an automated Raman spectroscopy system enables rapid collection of key data points (grain size, defect density, thickness, etc.) for technologically important optical, electronic, and energy materials. Some specific case studies include fundamental kinetics studies showing migration-limited crystallization kinetics amorphous materials can be directly observed. Pre-cursor materials for downstream processing can be converted directly into reaction intermediates with the appropriate non-equilibrium laser energy input to reduce process activation energy and process temperature required for high-quality materials. For photocatalysis materials rapid, non-equilibrium process conditions were identified demonstrating optimized performance with mixtures of phases.

11:20am **MB2-3-ThM-11 Designing Porosity for Function: Polymer-Templated Metal Oxides for Catalysis and Broadband, Wide-Angle Optics**, *Elena V. Shevchenko [eshevchenko@anl.gov]*, University of Chicago, Argonne National Laboratory, USA; *Diana Berman*, University of North Texas, USA

**INVITED**

Nanostructuring metal oxides through controlled porosity provides a powerful route to simultaneously enhance surface reactivity and tailor optical response. By introducing interconnected nanoscale voids into inorganic frameworks, it becomes possible to maximize accessible surface area while engineering light propagation, scattering, and refractive index profiles. Such materials are increasingly important for catalytic, electrocatalytic, sensing, and photonic technologies. This talk will present polymer-directed strategies for fabricating nanoporous metal oxide coatings with precisely controlled architecture and composition. In this approach, sacrificial polymer scaffolds define pore morphology prior to oxide formation. Inorganic precursors infiltrate the template from solution or vapor phases, yielding conformal oxide networks that preserve structural integrity after template removal. The method is compatible with single- and multicomponent systems, enabling the formation of hierarchical structures and functional heterointerfaces.

By tuning pore size, connectivity, and composition, we demonstrate how nanoscale architecture directly governs catalytic activity, charge transport, and light-matter interactions. In particular, controlled refractive index gradients and tailored pore distributions enable broadband antireflective coatings that maintain excellent optical performance across a wide range of incident angles. The resulting materials combine high catalytic efficiency with angularly robust optical functionality, illustrating how rational porosity design transforms metal oxides into multifunctional platforms for energy and photonic applications.

## Author Index

**Bold page numbers indicate presenter**

**— A —**

Ashraf, Ali: MB2-3-ThM-8, 1  
Austin, Drake: MB2-3-ThM-10, 2

**— B —**

Baloukas, Bill: MB2-3-ThM-3, 1  
Basaran, Ali C.: MB2-3-ThM-5, 1  
Berman, Diana: MB2-3-ThM-11, 2

**— C —**

Crouan, Martin: MB2-3-ThM-3, 1

**— D —**

Doi, Xella: MB2-3-ThM-9, 2  
Douglas, Ossie: MB2-3-ThM-8, 1

**— E —**

Everhart, Brian: MB2-3-ThM-10, 2

**— F —**

Faceira, Brandon: MB2-3-ThM-3, 1

**— G —**

Glavin, Nicholas: MB2-3-ThM-10, 2  
Guha, Supratik: MB2-3-ThM-9, 2

**— H —**

Haviar, Stanislav: MB2-3-ThM-4, 1  
Hofer, Juan Andres: MB2-3-ThM-5, 1  
Horn, Connor: MB2-3-ThM-9, 2

**— K —**

Klemberg-Sapieha, Jolanta: MB2-3-ThM-3, 1  
Kumar, Akash: MB2-3-ThM-4, 1  
Kumar, Nirmal: MB2-3-ThM-4, 1

**— M —**

Martinu, Ludvik: MB2-3-ThM-3, 1  
Muratore, Christopher: MB2-3-ThM-10, 2

**— P —**

Pajak, Aleksandra: MB2-3-ThM-3, 1

**— R —**

Rumsby, Phillip: MB2-3-ThM-3, 1

**— S —**

Schuller, Ivan K.: MB2-3-ThM-5, 1  
Shevchenko, Elena V.: MB2-3-ThM-11, 2  
Snapp, Peter: MB2-3-ThM-8, 1

**— T —**

Tanaka, Koichi: MB2-3-ThM-9, 2  
Tsang, Chloe: MB2-3-ThM-9, 2

**— W —**

Wang, Tianxing Damir: MB2-3-ThM-5, 1

**— Z —**

Zabeida, Oleg: MB2-3-ThM-3, 1