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 Houska, University of West Bohemia, Czechia, **Spyros Kassavetis**, Aristotle University of Thessaloniki, Greece

8:00am **MB2-3-ThM-1 Piezoelectric MEMS – from Advanced Material Systems to Novel Device Architectures***, **Ulrich Schmid [ulrich.e366.schmid@tuwien.ac.at]**, Daniel Platz, Michael Schneider,* TU Wien, Austria **INVITED**

In a compact introduction, I will motivate the benefits of piezoelectric thin films for MEMS and will give a short overview to state of art device applications.

Next, I will highlight latest results on the electrical, mechanical and piezoelectrical characterization of sputter-deposited aluminium nitride (AlN) including the impact of *e.g.,* substrate pre-conditioning. I will present test structures for determining piezoelectric coefficients (d_{33}, d_{31}) down to an accuracy of about 0.1 pm/V on wafer level. The impact of AlN doping with yttrium which leads to an increase of the moderate piezoelectric coefficient of pure AlN, as known with scandium, will complete the material-related part of my talk.

Next, these films are integrated into fabrication processes of silicon MEMS devices. In combination with a tailored electrode design, cantilever-type resonators are realized featuring Q-factors up to about 350 in water (@1-2 MHz). This enables the precise determination of the viscosity and density of fluids up to dynamic viscosity values of about 300 mPas. Besides this application, such high Q-factors are most essential when targeting mass-sensitive sensors, thus paving the way to *e.g.,* nanosized particle detection even in such highly viscous media like oil. In addition, the characterization of bitumen with dynamic viscosities up to the 10.000 mPas range is demonstrated with these piezoelectric MEMS resonators.

Besides sensing, the field of MEMS actuators is covered. I will present some selected results on buckled, bistable plate-type MEMS devices that allow continuous switching between the two stable states by integrated piezoelectric thin film actuators for realizing *e.g.,* compact ultrasound emitters. Specific features of this device architecture will be discussed**.**

8:40am **MB2-3-ThM-3 MEMS Magnetoelectric Resonators: Pushing the Limits of Magnetic Field Detection.***, **Davinder Kaur [davinder.kaur@ph.iitr.ac.in]**, Pradeep Kumar,* Indian Institute of Technology Roorkee, India

Nowadays, flexible magnetoelectric (ME) heterostructures comprising lead-free piezoelectric are of considerable interest for commercializing wearable electronic devices such as energy harvesters, nonvolatile memory, implantable medical diagnostics, and sensors. Here, we fabricate a highly flexible, cost-effective, nanostructured magnetic field sensor comprising an AlN/Ni-Mn-In ME heterostructure over Ni foils. The functionality of the AlN/Ni-Mn-In/Ni heterostructure has been investigated by measuring the magnetodielectric MD (%) and magnetoelectric coupling (α_{ME}) coefficient with Ni-Mn-In thickness, anisotropy, and flexibility. The thickness ratio of piezoelectric AlN (~400 nm) and magnetostrictive Ni-Mn-In (~385 nm) layers has been optimized to achieve the high performance of the magnetic sensor. The encapsulation of the Ni-Mn-In layer drastically enhances the performance of the fabricated heterostructure. The highest MD ~ 2.95% and α_{ME}~ 3.2 V/cm·Oe have been recorded with an equal thickness ratio of AlN and Ni-Mn-In layers. It could be ascribed to the large magnetostrictive strain transferred to the AlN piezoelectric layer, which enhances the induced ME voltage. Moreover, the nonzero value of α_{ME} at zero bias magnetic field has been observed and related to the piezomagnetic coefficient (q) grading in the Ni-Mn-In(+q)/Ni(−q) ferromagnetic system, which enhances the strength of magnetoelectric coupling. The fabricated device has easily detected the ultralow magnetic field of up to or less than ~1 μT. In addition, the anisotropic functionality of the device has been explained by measuring the magnetodielectric and magnetoelectric characteristics in parallel and perpendicular dc bias fields. Further the surface acoustic wave (SAW) delay line-based piezo resonator has been fabricated over highly flexible AlN/Ni-Mn-In/Kapton for flexible MEMS application. The fabricated device resonates at ~1.40 GHz. The effect of the external magnetic field on the resonance frequency (f_R) of the device has been investigated and tunability (ΔfR/fR) ~9% was observed. The device displays high sensitivity of ~0.94 Hz/nT at room temperature.

Keywords:Ferromagnetic shape memory alloys, flexible magnetic sensor, lead-free piezoelectric, magnetostrictive effect, surface acoustic waves (SAW).

9:00am **MB2-3-ThM-4 Synthesis and Piezoelectric Properties of Wurtzite $Al_{1-x-y}Sc_xGd_yN$ Heterostructural Alloys***, **Julia Martin [jmartin6@nrel.gov]**,* National Renewable Energy Laboratory, USA*; Cheng-Wei Lee, Nate S.P. Bernstein,* Colorado School of Mines, USA*; Thi Nguyen,* Rensselaer Polytechnic Institute, USA*; Ande Bryan, Eli Cooper, John S. Mangum,* Colorado School of Mines, USA*; Sage R. Bauers, Andriy Zakutayev, Keisuke Kazawa,* National Renewable Energy Laboratory, USA*; Prashun Gorai,* Rensselaer Polytechnic Institute, USA*; Rebecca W. Smaha,* National Renewable Energy Laboratory, USA

Wurtzite AlN-based ternary nitride alloys are a promising platform to realize functional materials, particularly ferroelectrics and optical emitters, that can smoothly integrate with conventional microelectronics. Here, we explore substitution of multiple elements into AlN forming quaternary nitride alloys as a strategy for enabling new multifunctional materials. Through a computationally-guided approach, we successfully predict the phase diagram of these pseudo-ternary heterostructural AlN–ScN–GdN alloys as a function of effective temperature and experimentally grow $Al_{1-x-y}Sc_xGd_yN$ thin films via combinatorial sputter synthesis for the first time. We find that for $x + y \lesssim 0.35$, $Al_{1-x-y}Sc_xGd_yN$ crystallizes into a wurtzite structure which is consistent with the calculated phase diagram. Further, we computationally probe whether co-substitution induces cooperative effects on these alloys' piezoelectric and ferroelectric properties, finding that it is beneficial for reducing the polarization switching barrier. We also calculate that $Al_{1-x-y}Sc_xGd_yN$ thin films should display ferroelectric switching that could be realized experimentally in the future. This is supported by our experimental measurements of a high optical band gap, enhanced piezoelectric coefficient, and a change in the calculated polarization switching mechanism. Overall, our work sets the foundation toward quaternary wurtzite-nitride-based multifunctional materials, including piezoelectrics, ferroelectrics, and possibly multiferroics.

9:20am **MB2-3-ThM-5 Sputter Coating of High-Quality Vo2 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_2) thin films is a topic of great interest for applications in smart windows, memristors, and neuromorphic computing applications. VO_2 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_2 films can be achieved, complex pre- or post-growth processing is required. In this work, we show that direct sputter deposition of VO_2 on flexible Kapton substrates results in a straightforward methodology to achieve flexible MIT films. A pre-deposited Al_2O_3 layer on Kapton enhances film adhesion, and the resulting flexible VO_2 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_2 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_2 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_2 films exhibiting robust MIT, with promising applications in tactile sensors and electromechanical devices.

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9:40am **MB2-3-ThM-6 Glancing Angle Deposition of WOx and Cu-doped TiO2 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_2 and WO_x films, targeting the enhancement of active surface area and, therefore, sensor sensitivity improvements.

Cu-doped TiO_2 and WO_3 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_3 and TiO_2, is also given.

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