Tuesday Morning, September 23, 2025

Electronic Materials and Photonics
Room 207 A W - Session EM1+AP+CPS+MS+PS+QS+SM+TF-TuM

Emerging Frontiers in Quantum Materials and Devices
Moderator: Mollie Schwartz, MIT Lincoln Laboratory

8:00am EM1+AP+CPS+MS+PS+QS+SM+TF-TuM-1 Optical Integration for Trapped-Ion Systems, *Daniel Stick,* Sandia National Laboratories **INVITED**
First demonstrated in 2006, surface ion traps provide a platform for storing 2D arrays of ions and have been widely adopted across the trapped-ion quantum computing community. To take advantage of the scalability enabled by these devices, on-chip waveguides have been developed over the last decade to replace traditional bulk-optics that can only illuminate a single line of ions. Here I will describe integrated photonics experiments that bring together multiple elements to control larger arrays of ions, as well as new approaches to addressing the I/O challenge of bringing the many optical signals across the ultra-high vacuum boundary. These advances are necessary for supporting the large number of ions needed for trapped-ion quantum computing, as well as for making deployable optical clocks.

8:30am EM1+AP+CPS+MS+PS+QS+SM+TF-TuM-3 Rapid, Atomic-Scale Smoothing of GaSb(111)A Surfaces During Molecular Beam Epitaxy, *James Rushing,* **Paul Simmonds,** Tufts University
InAs/Ga(In)Sb quantum wells (QWs) with a broken gap band alignment can behave as a quantum spin hall insulator (QSHI) with an insulating bulk and topologically protected helical edge states [1-2]. QSHIs could be a key component in spintronic and topological quantum computing applications [2-3]. Producing a topological phase transition in InAs/Ga(In)Sb QWs requires precise control of QW thickness, composition and quality, particularly at the heterointerfaces. Additionally, our calculations suggest QWs grown on (111) surfaces could provide benefits over (001) due to the higher symmetry and out-of-plane polarization effects of this surface.

While exploring the MBE growth of InAs/Ga(In)Sb QW heterostructures on GaSb(111)A, we discovered an exciting and confounding phenomenon that seems to be unique to crystal growth on III-Sb(111)A surfaces. Ga(In)Sb(111)A frequently exhibits an extremely rough morphology characterized by pyramidal peaks covering the entire surface. We show that rough III-Sb surfaces (pyramidal features >70nm in height; rms roughness >10nm), can be smoothed to atomically flat surfaces (<3nm height features; <0.5nm rms roughness) in a matter of seconds by exposing them to an arsenic over-pressure. We first observed this phenomenon when rough GaInSb(111)A surfaces became atomically flat after capping with just 8nm of InAs. After reducing the thickness of this InAs layer to a single monolayer and still observing he same surface smoothing effect, we found that we could achieve almost identical results by simply exposing the rough GaSb(111)A to an arsenic flux. These results suggest that arsenic is the primary mover in these profound morphological changes. Our recent results show that the smoothing can be accomplished with As_4 or As_2, and with a wide range of arsenic beam equivalent pressures, from 5×10^{-7} to 1×10^{-5} Torr.

We will describe our efforts to gain control and understanding of this phenomenon through the modulation of arsenic exposure time, flux, and terminating III-Sb material. This powerful new MBE technique will allow us to reliably achieve smooth heterointerfaces in (111)-oriented InAs/Ga(In)Sb QWs for novel, high-quality QSHIs. More broadly, we believe that this approach will enable the growth of a wide array of III-Sb-based nanostructures on (111)A surfaces for other electronic and photonic applications.

1. Krishtopenko and Teppe. *Science Advances* **4**, eaap7529 (2018)
2. Avogadri et al. *Physical Review Research* **4**, L042042 (2022)
3. Du et al. *Physical Review Letters* **119**, 056803 (2017)

8:45am EM1+AP+CPS+MS+PS+QS+SM+TF-TuM-4 Benchmarking different NbTiN sputtering methods for 300 mm CMOS-compatible superconducting digital circuits, *Adham Elshaer, Jean-Philippe Soulié, Daniel Perez Lozano, Gilles Delie, Ankit Pokhrel, Benjamin Huet,* IMEC Belgium; *Margriet J. Van Bael,* KU Leuven and Imec, Belgium; *Daan Buseyne,* KU Leuven, Belgium; *Blake Hodges, Seifallah Ibrahim, Sabine O'Neal,* Imec USA; *Zsolt Tökei,* Imec Belgium; *Anna Herr, Quentin Herr,* Imec USA
The NbTiN films presented here are CMOS-compatible and were developed for metallization purposes in superconducting digital circuits [1-5]. Those circuits use NbTiN for Josephson junctions and capacitors electrodes, as well as for wiring. Superconducting digital circuits initially relied on Nb in the early days. NbTiN is a better candidate/replacement due to its higher thermal budget and better chemical stability [1-5]. In this study, the properties of superconducting NbTiN thin films deposited using two different sputtering methods have been compared. One method used multiple targets (MT) co-sputtering (Nb and Ti targets), while the other used a NbTi single target (ST). Benchmarking metrics used for comparison include: superconducting, electrical, as well as morphological properties. All films show a high Tc, ranging from 13.3 K to 15.1 K. Compared to MT, ST NbTiN films showed consistently lower resistivity and better sheet resistance (Rs) wafer-level uniformity (49 points wafer-map). For instance, 50 nm MT film had a Rs relative standard deviation (Stddev%) of 15.5%, while for the ST NbTiN films, Rs Stddev% showed a 2-fold improvement at 7.8%. Upon annealing of the ST NbTiN films at 650℃, the Rs uniformity further improved, reflected by a lower Stddev% at 4.5%. AFM data show similar results for MT and ST films, ~1.07 nm and 1.09 in the center and 0.73 nm and 0.71 nm at the edge of the wafers, respectively. Furthermore, XRD theta-2theta scans have been performed showing the 200 and 111 peaks for NbTiN orientations. Results show that the MT and ST films have different/signature 200/111 peak intensity ratios for the as deposited films. ST NbTiN films have a lower 200/111 peak ratio. However, after annealing at 650℃, the ST films 200/111 peak ratio increases, and surpasses that of the MT NbTiN films. This change suggests a change in the ST film disorder and grain size after annealing. The impact of the ST NbTiN film thickness on properties has also been studied. The Tc shows an increase as a function of thickness, from 9.6 K for 7 nm, to 14.3 K for 50 nm, up to 14.9 K for 200 nm films. Certainly, the ability to tune the superconducting properties of NbTiN, makes them appealing from a stack engineering perspective. Both MT and ST NbTiN properties can be tailored using deposition conditions such as: power, partial pressure and post deposition annealing [3]. However, MT NbTiN films 300 mm wafer-level Rs non-uniformity represents a limiting factor for scaling superconducting devices. Annealed NbTiN ST films on the other hand, show a 3.4-fold Rs wafer uniformity improvement while maintaining properties tunability.

9:00am EM1+AP+CPS+MS+PS+QS+SM+TF-TuM-5 Controlling the Properties of Epitaxially Grown Topological Semimetals, *Kirstin Alberi,* National Renewable Energy Laboratory **INVITED**
Three dimensional topological semimetals (TSMs) exhibit a wide range of interesting properties, including high carrier mobility, large magnetoresistance, anomalous transport behavior, broadband optical absorption and non-linear optical responses. Epitaxial thin film synthesis offers a practical platform for manipulating composition, defects and disorder in these materials, offering a window into approaches for manipulating their properties. In this talk, I will discuss insights into the relationships between structure and composition and the resulting properties revealed through careful control of growth conditions. Focused examples include the impact of point defects and impurities on electron transport in the Dirac TSM Cd_3As_2 and the formation and behavior of domain boundaries in the Weyl TSM TaAs.

9:30am **EM1+AP+CPS+MS+PS+QS+SM+TF-TuM-7 Photon Down-Conversion of Yb-Doped CsPb(Cl1-xBrx)3 to Low-bandgap Metal Halide Perovskites**, *Yutong Ren,* Princeton University*; Igal Levine,* The Hebrew University of Jerusalem, Israel*; Dan Oron, David Cahen,* Weizmann Institute of Science, Israel*; Antoine Kahn,* Princeton University

Quantum cutting represents a transformative strategy to mitigate thermalization losses that typically occur when high-energy photons are absorbed by semiconductors.[1,2] Recent advances have extended this concept from rare-earth doped crystals to semiconductor–rare-earth hybrid systems, particularly those utilizing halide perovskite absorbers, thereby exploiting their exceptional optoelectronic properties.

In this study, we focus on Ytterbium (Yb) -doped $CsPb(Cl_{1-x}Br_x)_3$, a metal halide perovskite that absorbs visible light and exhibits intense near-infrared (NIR) photoluminescence—a clear signature of efficient quantum cutting. Upon excitation with visible light, the doped perovskite converts the absorbed energy into two NIR photons, with the emission energy closely matching the optimized bandgap of a Sn–Pb based perovskite absorber. This spectral alignment is critical for enabling effective energy transfer between the quantum cutting layer and the absorber.

Our investigation focuses on elucidating the structural and electronic properties of the interfaces between Yb-doped $CsPb(Cl_{1-x}Br_x)_3$ and Sn–Pb based perovskite films. By employing a suite of advanced spectroscopic techniques—including ultraviolet photoelectron spectroscopy, inverse photoemission spectroscopy, time-resolved photoluminescence (tr-PL), and time-resolved surface photovoltage (tr-SPV)—we systematically examine how the quantum cutting layer, the absorber layer, and their interfacial region collectively influence energy transfer efficiency. In particular, the complementary tr-PL and tr-SPV analyses unambiguously determine the dominant interfacial charge transfer and recombination processes, and thus gain control over the interfacial charge transfer. By integrating Yb-doped $CsPb(Cl_{1-x}Br_x)_3$ with customized Sn–Pb perovskite absorbers, our approach shows promise for pushing the boundaries of conventional efficiency limits while also offering a cost-effective strategy for enhanced energy conversion.

1. Wegh, R. T. et al. Quantum cutting through downconversion in rare-earth compounds. *J. Lumin.* **87–89**, 1017–1019 (2000).

2. Kroupa, D. M. et al. Quantum-cutting ytterbium-doped $CsPb(Cl_{1-x}Br_x)_3$ perovskite thin films with photoluminescence quantum yields over 190%. *ACS Energy Lett.* **3**, 2390–2395 (2018).

9:45am **EM1+AP+CPS+MS+PS+QS+SM+TF-TuM-8 Implementation of a Truly 2D Model to Describe the Weak Antilocalization Behavior of Topological Insulators**, *Ryan Van Haren, Aubrey Hanbicki, Adam Friedman,* Laboratory for Physical Sciences

Topological insulators continue to garner interest for potential and functionally-prototyped applications in next-gen electronic, spintronic, and quantum devices. In many of these applications, the topological surface states play a critical role. Transport through the surface states is often quantified by fitting to quantum corrections to the conductance that appear at low temperature. The model commonly used for these fittings is the Hikami-Larkin-Nagaoka (HLN) model, a quasi-2D model that does not account for the Dirac nature of the topological surface state. In the years following the discovery of topological insulators, theoretical work was performed that calculated the quantum corrections while taking into account the unique properties of the topologically protected surface states[1]. This Dirac fermion model provides powerful insight into the surface state transport by quantifying the Fermi velocity and the phase coherence length, among other parameters, but adoption of this model has been slow due to it being more complicated to utilize than the HLN model. In this work, I will present my method for implementing the Dirac fermion model in practice on weak antilocalization data from topological insulator thin films of $Bi_{0.85}Sb_{0.15}$ and previously published topological insulator thin films[2]. I will contrast the Dirac fermion model fits with the HLN model fits and show how the derived Fermi velocity agrees well with values derived from ARPES measurements reported in literature. I will make the argument that, while the HLN model still has its uses, analysis of weak antilocalization behavior in topological insulators is incomplete without utilization of the Dirac fermion model.

(1) Adroguer, P.; Liu, W. E.; Culcer, D.; Hankiewicz, E. M. Conductivity Corrections for Topological Insulators with Spin-Orbit Impurities: Hikami-Larkin-Nagaoka Formula Revisited. *Phys. Rev. B* **2015**, *92* (24), 241402. https://doi.org/10.1103/PhysRevB.92.241402.

(2) Van Haren, R.; Lederman, D. Suppressed Weak Antilocalization in Topological Insulator--Antiferromagnetic Insulator $(BiSb)_2Te_3$-MnF_2 Thin Film Bilayers. *Phys. Rev. B* **2024**, *110* (20), 205409. https://doi.org/10.1103/PhysRevB.110.205409.

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