PCSI
Room Canyon/Sugarloaf - Session PCSI-2SuA
Epitaxial Growth of Quantum Materials and Structures
Moderator: Seung Sae Hong, Stanford University

4:30pm **PCSI-2SuA-25 UPGRADED: Epitaxial Growth and Electronic Characterization of GdSb***, **Hadass Inbar**, S Chatterjee, M Pendharkar, Y Chang, M Bocheff, T Guo, T Brown-Heft,* University of California, Santa Barbara*; A Fedorov,* Lawrence Livermore National Laboratory*; D Read,* Cardiff University*; C Palmstrom,* University of California, Santa Barbara

In recent years, the class of rare-earth monopnictides (RE-Vs) has received renewed interest due to predictions of topological semimetal states[1] and observations of extremely large magnetoresistance (XMR)[2], phenomena holding great promise in novel physics devices and magnetic sensing technologies. The wide range of lattice constants and simple rock salt structure of RE-Vs also allows to easily incorporate them epitaxially with III-V semiconductors. Coupled to III-Vs, RE-Vs have potential applications as buried ohmic contacts, THz emitters and detectors, thermoelectrics, reaction barriers, and plasmonic heterostructures.[3] In the family of RE-Vs, GdSb shares the common features of antiferromagnetic type II ordering and unusually high magneto-resistance.[4] Due to the absence of orbital momentum in the $4f^7$ configuration of Gd^{3+} and the simple magnetic phase diagram, GdSb can serve as a model system for the study of the effect of biaxial strain on band dispersion in RE-Vs, and the interplay between magnetism and XMR.

In this talk, we will demonstrate the first epitaxial growth and characterization of GdSb thin films with thickness varied from 3-30 nm and biaxial strains ranging from -2% to +2% lattice-mismatch. We utilize molecular beam epitaxy to grow GdSb films on $In_{1-x}Al_xSb$ and Be-doped $In_{1-x}Ga_xSb$ buffer layers deposited on undoped and Zn-doped GaSb (001) substrates for magnetotransport and angle-resolved photoemission spectroscopy measurements, respectively. Reflection high-energy electron diffraction patterns observed during growth and *in-situ* X-ray photoelectron spectroscopy and scanning tunneling microscopy (STM) were used to determine the formation of a rock salt phase with the characteristic surface reconstruction of 1X1, indicating the absence of interfacial reactions between the GdSb films and underlying buffer layers. Surface morphology was examined with STM to confirm the growth of continuous films at thicknesses down to 3nm. To determine the in-plane lattice constant and strain of the GdSb thin films we have recorded reciprocal space maps on asymmetric reflections. The thickness dependence in lattice-matched buffers and the effect of biaxial strain on magnetotransport behavior and the bandstructure of GdSb will also be discussed.

[1] Duan, Xu, et al. Commun. Phys. 1 (1) (2018): 71.

[2] Tafti, F. F., et al. Nat. Phys. 12 (3) (2016): 272.

[3] Bomberger, Cory C., et al. JVST B 35 (3) (2017): 030801.

[4] Li, D. X., et al. Phys. Rev. B 54 (15) (1996): 10483.

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4:50pm **PCSI-2SuA-29 MBE Growth of $Zn_xCd_{1-x}Te$ on Cd_3As_2***, **Anthony Rice**, K Alberi,* National Renewable Energy Laboratory

The Dirac semimetal Cd_3As_2 has become a scientifically useful material, as it provides access to a variety of interesting phenomena ranging from topological superconductivity to massless Dirac fermions. It is also potentially useful for energy-related applications due to its high electron mobility and large phonon-phonon scattering. While thin film growth has become an increasingly popular route of synthesis, there have been no reports of epitaxial growth on Cd_3As_2, limiting the ability to develop full heterostructures. One barrier to epitaxy on Cd_3As_2 is the high vapor pressure of Cd_3As_2 (1e-7 mbar at only 135 ° C), which is well below the ideal growth temperature of most semiconductors [1].

The $Zn_xCd_{1-x}Te$ (111) system provides one promising option for overgrowth given that it can be lattice matched to the (112) surface of Cd_3As_2 and has a relatively low optimal growth temperature (240-300° C). Reflective high-energy electron diffraction (RHEED) patterns of epilayers grown on Cd_3As_2 exhibit a (2x1) reconstruction, even with a growth interruption. These patterns are consistent with As-terminated CdTe observed following high temperature annealing under As [2]. CdTe epilayers growth at Cd_3As_2-compatible substrate temperatures (~120° C) are rough, but further growth at 240° C yields smoother surfaces, as seen in atomic force microscopy. X-ray diffraction confirms Cd_3As_2 remains following the higher temperature growth step, suggesting complete coverage is achieved. Higher temperature anneals under As further smooth and passivate this surface, while similar anneals under Te result in disappearance of a RHEED pattern and loss of the Cd_3As_2 layer. Introduction of moderate Zn content into CdTe results in complete surface coverage but also very large features, likely a result of very low Zn adatom mobility at these temperatures. Our results provide a starting point for incorporating Cd_3As_2 into a variety of device structures.

[1] V.J. Lyons and V.J. Silvestri, J. Phys. Chem. **64**, 2266 (1960)

[2] Y. Nakazawa, M. Uchida , S. Nishihaya, S. Sato, A. Nakao, J. Matsuno , and M. Kawasaki, APL Mater. **7**, 071109 (2019)

4:55pm **PCSI-2SuA-30 Interfaces and Growth of NbTiN-AlN Heterostructures on Sapphire as Epitaxial Josephson Junctions***, **Chris Richardson**, A Thomas, A Alexander, C Weddle,* Laboratory for Physical Sciences*; B Arey, M Olszta,* PNNL

Plasma assisted Molecular beam epitaxy (PAMBE) is used to grow niobium titanium nitride alloys ($Nb_xTi_{1-x}N$) and wide bandgap nitride (AlN) superconductors directly on c-plane sapphire wafers. This combination of nitride materials provides sufficient degrees of freedom that synthesis of an epitaxial Josephson junction may be possible while satisfying the device requirements for superconducting quantum circuits. Thin films of various $Nb_xTi_{1-x}N$ alloys are grown using the abrupt metamorphic growth paradigm and show the ability to tune the lattice parameters and critical temperatures of the superconducting films. Surface topology, degree of twinning, and superconducting loss are used to evaluate the fitness of these layers.

A prototype NbTiN/AlN/NbTiN (superconductor-insulator-superconductor) Josephson junction structure has been grown. The structural, superconducting, and current-votlage characterization of these heterostructures will be presented.

5:00pm **PCSI-2SuA-31 Growth of AlN Barriers in Al/AlN/Al SIS Josephson Junctions by Low Temperature Atomic Layer Epitaxy***, **Charles R. Eddy, Jr.**,* U.S. Naval Research Laboratory*; D Pennachio, J Lee, A McFadden,* University of California, Santa Barbara*; S Rosenberg,* U.S. Naval Research Laboratory*; Y Chang, C Palmstrom,* University of California, Santa Barbara

Superconductor-Insulator-Superconductor (SIS) structures are of increasing interest for the creation of Josephson junctions that can serve as the basis for quantum qubit transmons, which hold significant promise for quantum computing technologies. Traditionally, these devices have been developed using amorphous AlO_x in $Al/AlO_x/Al$ structures and have enabled fundamental demonstrations of transmon performance. However, improved performance may be expected with an epitaxial insulator. Even in these structures, the nature of the superconductor/substrate interface and the superconductor/ambient interface limits coherence and, consequently, qubit performance.

In an effort to address this challenge, we employ low temperature atomic layer epitaxy (ALEp) to grow crystalline AlN insulators on crystalline aluminum films. Smooth epitaxial aluminum films are grown by evaporation on cryogenically-cooled, buffered GaAs(001) substrates [1]. These epitaxial surfaces are "frozen" using a low temperature nitridation atomic layer process (ALP) before the samples are ramped to 300° C for low temperature ALE of AlN using semiconductor grade trimethylaluminum and UHP argon and nitrogen inductively coupled plasmas (ICPs). In this study, we evaluate the structural effects of variations in the initial nitridation ALP, growth conditions of ALEp AlN barriers, and SIS barrier thickness using transmission electron microscopy. We have found that at one end of the spectrum, a simple 5 cycle nitridation ALP of epitaxial aluminum at ~90° C, where each cycle is a 30 second exposure to 300W UHP argon/nitrogen (200/75 sccm) ICP , consumes a significant fraction of the aluminum to make an amorphous AlN insulator that is roughly 2 nm thick. When this surface is subjected to another low temperature Al evaporation, the top Al films are a mixture of amorphous and polycrystalline. When the same nitridation ALP is employed and followed by 5nm of ALEp AlN growth at 300° C, a similar amount of the aluminum film is consumed and an amorphous ALEp AlN layer results. Finally, when the nitridation ALP is reduced to a single cycle of nitridation, less of the aluminum film is consumed and the 5nm AlN ALEp film shows polycrystallinity with small regions demonstrating sharp, potentially epitaxial interfaces. This result suggests that proper ALP nitridation of the epitaxial aluminum can support epitaxial growth of AlN by ALE. Further studies of the influence of number of cycles, cycle duration, plasma chemistry and plasma power on both the nitridation ALP and AlN ALEp will be presented.

[1] S. Gazibegovic et al., Nature 548, 434 (2017).

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