MBE

Room Silver Creek - Session MBE-1TuA

Layered Materials

Moderator: Stephanie Tomasulo, Naval Research Laboratory

1:30pm **MBE-1TuA1 MBE Young Investigator Award Winner: TBD**,

2:00pm **MBE-1TuA3 Band Engineering to Achieve a Wide Band Gap Topological Insulator**, ***Ido Levy***, *C. Youmans, T. Garcia, H. Deng, S. Alsheimer, L. Krusin-Elbaum, P. Ghaemi, M. Tamargo,* City College of New York, City University of New York

Three dimensional topological insulators (3D TIs) are being widely researched today for their attractive and unique transport properties [1]. These materials present a bandgap in the bulk and highly conducting metallic surface states. Heterostructures of these TIs are predicted to show promising properties [2]. We have recently shown that a short period superlattice of two TI materials, such as Bi_2Se_3 and Sb_2Te_3, can present promising electrical properties, for example a decrease in carrier concentration in the bulk and an increase of resistance as a function of the superlattice period. This can be explained by the formation of a bulk bandgap in the superlattice due to confinement effects in each of the layers, as a result of their "broken gap" band alignment. A question remains as to the presence of the topological surface states in such a short period superlattice structure. To investigate this, magnetoconductance measurements were performed for the superlattice structure with the smallest periodicity; one that showed the reduced bulk conductivity previously observed. Fitting these data to the typically used Hikami-Larkin-Nagaka theory [3] suggests the presence of two two-dimensional conduction channels in the small period superlattice as expected for a 3D TI layer. Angle dependent magnetoresistance measurements and a fit of the dephasing length (l_ϕ) dependence on temperature both give further supporting evidence of the preservation of the topological surface states. Thus, we conclude that this short period Bi_2Se_3-Sb_2Te_3TI-TI superlattice behaves as a designer 3D TI with different properties to the two individual TI constituents, which are conducting in the bulk. Tight binding calculation for such short period TI-TI superlattices were performed and the results suggest that for the appropriate combination of materials, it may be possible to achieve a "designer" 3D TI with a bulk bandgap that is larger than the gaps of either of the component TI materials.

[1] Y. Xia et al., Nat. Phys. 5, 398 (2009)

[2] K.M. Masum-Habib et al., Phys. Rev. Lett. 114, 176801 (2015)

[3] S. Hikami et al., Prog. Theor. Phys. 63, 707 (1980)

2:15pm **MBE-1TuA4 Van der Waal Epitaxy of Bi_2Se_3 on GaAs: A Morphological Playground**, ***Theresa Ginley***, *S. Law,* University of Delaware

Molecular beam epitaxy of layered van der Waal (vdW) materials is a promising avenue for improving optic, optoelectronic, spintronic, and valleytronic technologies. These materials are characterized by strongly bonded layers in the *a*-*b* plane and weak vdW bonds between layers in the *c*-direction. During thin film growth the weak vdW bonds translate to weak interaction with the substrate. Unlike in strongly bonded traditional epitaxy, vdW materials can grow on substrates with vastly different lattice constants and crystal structures. However, the weak substrate interaction means that vdW epitaxy cannot be fully understood via the well-known mechanics of traditional MBE, and morphological control has proven challenging; vdW materials tend to grow in terraced "wedding cake" morphologies rather than the desired atomically smooth layers. These materials also preferentially grow in the (001) orientation with the vdW gaps parallel to the growth surface. Other orientations have proven elusive and require extensive pretreatment or patterning of the substrate. An in-depth exploration of vdW phase space is required to understand the growth dynamics of these material systems.

In this study we look at the topological insulator (TI) Bi_2Se_3 as a prototypical vdW material. Previous work on $(Bi_{1-x}In_x)_2Se_3$ (a trivial insulator for x>0.3) revealed a complex phase space with features ranging from ultra-smooth surfaces to nanowires.[1] Here, we focus phase space exploration on Bi_2Se_3 in order to discover novel morphologies that could take advantage of the TI behaviors in Bi_2Se_3. It has been found that using a seed layer plays a major role in the final morphology of the films. A film grown on a 10nm $(Bi_{0.5}In_{0.5})_2Se_3$ seed layer results in the formation of Bi_2Se_3 nanowires perpendicular to the substrate (film A). A film grown on a 5nm Bi_2Se_3 seed layer results in a smooth film (film B). Finally, growth with no seed layer results in needles of Bi_2Se_3 in the (105) orientation (film C). All three morphologies show some degree of orientation along the [110] axis of the GaAs substrate, known to be the fast diffusion direction for bismuth. Based on this research it is believed that vdW growth dynamics are dominated by the relative strength of film/adatom and substrate/adatom interactions. The growth to anneal ratio, substrate temperature, and film thickness have also been explored to better understand the growth mechanics and nanowire evolution in the Bi_2Se_3 material system.

2:30pm **MBE-1TuA5 Growth of GeTe and Sb2Te3 Interlayer Structures for Interfacial Phase Change Devices via Molecular Beam Epitaxy**, ***Adrian Podpirka***, *D. Shrekenhamer, C. Zgrabik, J. Pierce, J. Gagnon,* JHU/APL

Phase change memories (PCMs) are based on the bad glass forming ability and metastability of the thermodynamic and kinetic transition in chalcogenide materials. This relies on the electrical and optical properties changing substantially when the atomic structure of the materials is altered. This transition, between a significant electrical resistance in the amorphous phase and a highly conductive state in the crystalline phase, has lent itself to numerous applications that include optical storage (i.e. blue ray and CDs) to electronic devices (i.e. Intel x-point technology). A novel subset of these materials uses the superlattice structure in order to greatly reduce the switching current and total energy required, thereby overcoming the joule heating constraint common to conventional PCMs. These are known as interfacial phase change materials (iPCM). Though currently unsettled as to the origins of the mechanism, they have shown promise for use in microwave devices based on interlayer switching by reducing the thermal loads required. In this presentation, we investigate the growth of interfacial GeTe-Sb_2Te_3 structures via Molecular Beam Epitaxy (MBE) with differing orientations and various substrates (GaAs, Si, Al_2O_3) and report on the electro-optical properties associated with the morphological and structural changes in this material system. By varying the elemental flux and novel heating method, we are able to stabilize the superlattice structure in a 2D growth regime. The ability to grow via MBE on transparent substrates allows us to incorporate the iPCMs into next-generation optical devices.

2:45pm **MBE-1TuA6 Molecular Beam Epitaxy of Hexagonal Boron Nitride on HOPG**, ***Ping Wang***, *E.T. Reid, D.A. Laleyan, J. Gim, Q. Wen, Z. Liu, Z. Zhong, M. Kira, R. Hovden, Z. Mi,* University of Michigan

As a member of the III-nitrides as well as the two-dimensional (2D) material families, hexagonal boron nitride (hBN) has received tremendous attention in recent years, and has emerged as a promising candidate for many applications, including deep ultraviolet (UV) and 2D optoelectronics, 2D transistors, and quantum emitters. In the 2D materials group, graphite, graphene, and hBN are lattice-matched to within 2% and exhibit complementary electronic properties, with hBN having a wide bandgap and graphene being a gap-less semimetal [1]. Multilayer hybrid heterostructures based on graphene and hBN have been intensively studied by stacking layers exfoliated from highly-ordered pyrolytic graphite (HOPG) and hBN crystals. To realize well-stacked vertical 2D heterostructures and to achieve scalable devices, epitaxial growth of such configuration would be highly beneficial [2].

In this context, we have investigated the epitaxy of hBN on HOPG utilizing ultra-high temperature molecular beam epitaxy (MBE) equipped with a plasma-assisted nitrogen source. We have demonstrated the formation of hBN quantum dots (QDs) and flakes at different growth conditions. The initial nucleation of hBN takes place primarily at the HOPG atomic steps, where the height fluctuation provides nucleation sites on low surface energy planes, whereas nucleation rarely formed on the bare terraces. Auger electron spectroscopy (AES) confirms the presence of boron and nitrogen elements from the QDs and flakes with a B/N ratio nearly 1, indicating both of the dot- and flake-like nanostructures are BN. Atomic force microscopy (AFM) shows that most of the flakes are 1 ML hBN with a thickness of 3.5 Å, while the QDs have lateral sizes ~5-10 nm and heights ~2-5 nm. Strong excitonic emission at ~215 nm has been observed using a 193 nm excitation laser at room temperature. A detailed study of the structural and optical properties of hBN quantum dots is currently in progress and will be reported.

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