Van der Waal Epitaxy of Bi_2Se_3 on GaAs: A Morphological Playground

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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.

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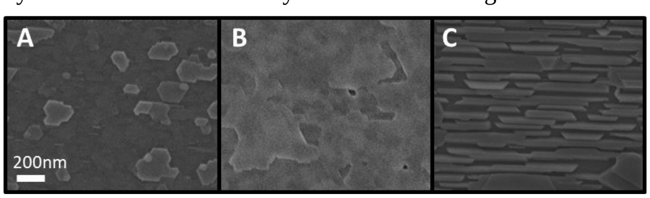

Figure 1: SEM images of Bi_2Se_3 films grown on GaAs substrates with A) a 10nm BIS seed layer, B) a 5nm Bi_2Se_3, and C) no seed

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Supplementary Pages (Optional)

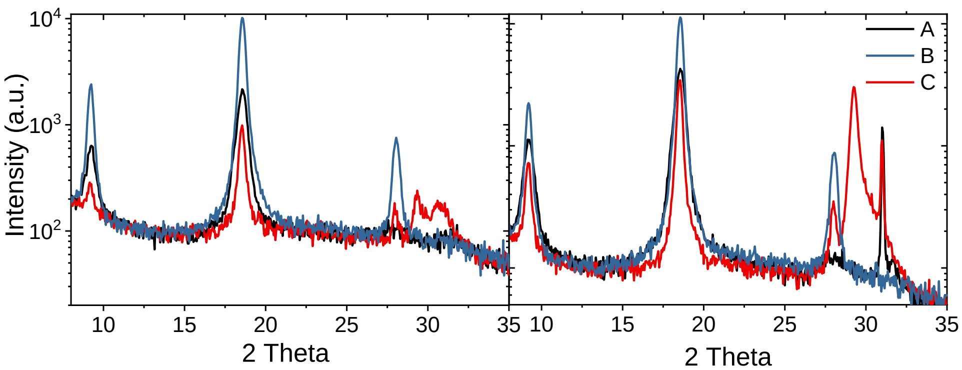

Figure S1: XRD scans of samples A-C with the GaAs substrate oriented A) parallel or B) perpendicular to the XRD beam path. Not the emergence of the (105) peak in sample C and its dependence on substrate orientation.