Characterization of thick GaAsBi layers grown with strain-stabilization

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$GaAs_{1-x}Bi_x$ alloys are challenging to grow by molecular beam epitaxy due to the surfactant-like nature and low solubility of bismuth (Bi) in this system. The key to good Bi incorporation in GaAsBi is to provide enough Bi flux to the surface to stabilize a surfactant layer, but not so much as to induce Ga-Bi droplet formation. The point at which Ga-Bi droplets form, or the Bi saturation point, limits the maximum Bi fraction obtainable with the growth conditions used. Samples grown with Ga-Bi droplets have reduced Bi composition and significant lateral and vertical phase separation. Strain-stabilization, by growing on partially relaxed InGaAs buffer layers, can be used to overcome Bi saturation in $GaAsBi_{0.07-0.09}$ films. We propose that reducing the compressive strain decreases the total energy of the system, allowing more Bi to incorporate and Ga-Bi droplet formation to be avoided. We have explored this trend for various GaAsBi epilayer thicknesses, as shown in Figure 1. By growing on $In_{0.105}GaAs$ buffer layers, droplet-free films >100 nm can be achieved for Bi fractions x<0.09. This is an improvement over samples grown with high compressive strain on GaAs, where films of >100 nm are limited to compositions of x<0.07.

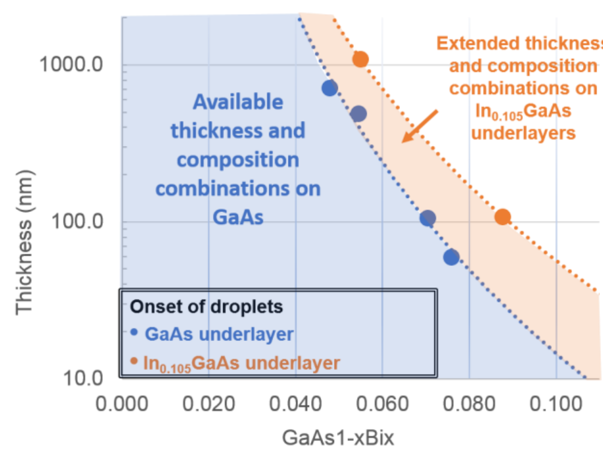

Fig 1: $GaAs_{1-x}Bi_x$ epilayer thickness as a function of bismuth composition for samples grown on GaAs underlayers (blue) and $In_{0.105}GaAs$ underlayers (orange).

In this work, we explore the connections between in-plane strain, Bi incorporation, droplet formation, and maximum GaAsBi film thickness. Samples were grown on a Veeco GENxplor MBE using a valved As_4 source and a solid source effusion cell for group-III elements and Bi. Bismuth fraction was determined by high-resolution x-ray diffraction combined with select samples confirmed through Rutherford Backscattering Spectrometry. Scanning transmission electron microscopy was used to characterize the phase separation brought on by droplet formation. Spectroscopic ellipsometry was used to characterize the absorption coefficient of thick GaAsBi films and identify Urbach tails associated with crystalline disorder. Lastly, initial doping studies comparing silicon vs. tellurium doping were explored to increase dopant incorporation in this material system. The ultimate goal of this study is to prepare the GaAsBi/InGaAs/GaAs system for optical device applications in the near-IR.

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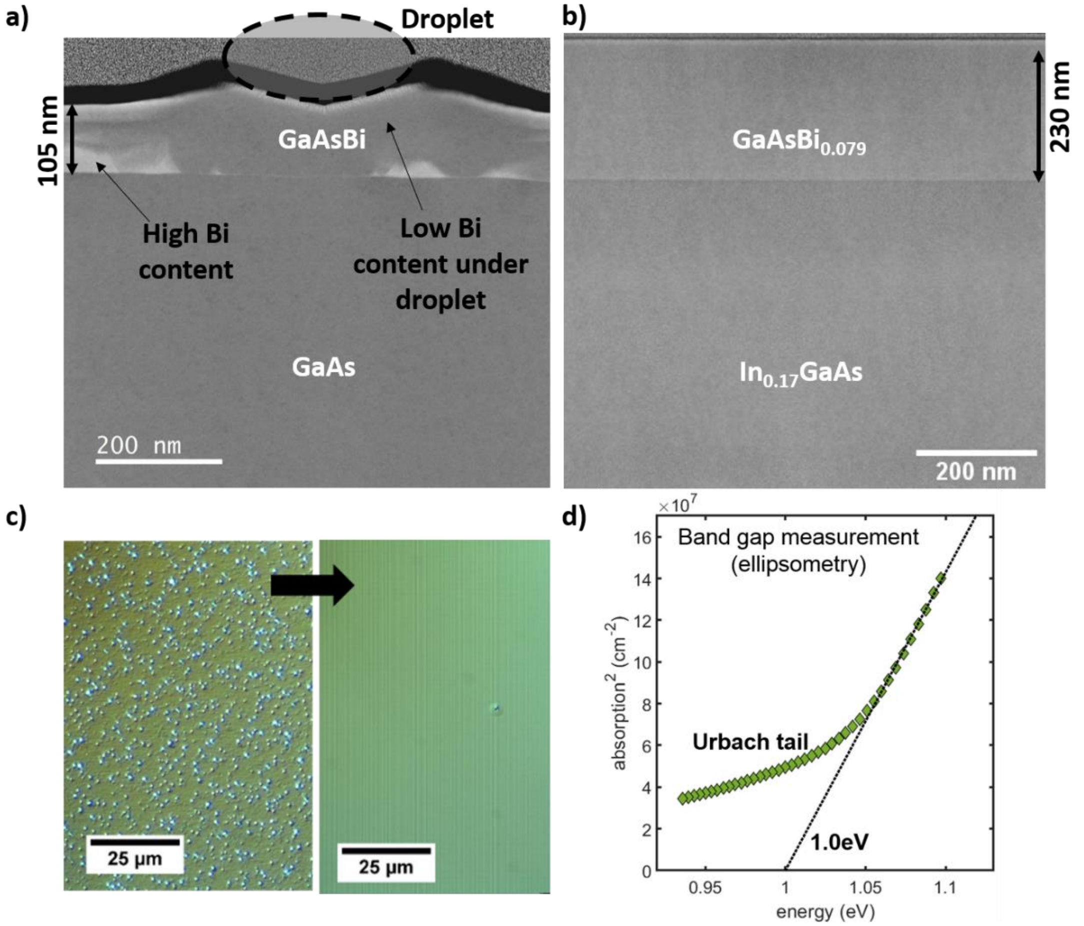
Supplementary Pages



(a) HAADF STEM image of Bi saturated GaAsBi sample. Ga-Bi droplet formation on the surface leads to both lateral and vertical phase separation. Specifically, in regions directly underneath the droplets the Bi content is significantly reduced due to Bi incorporation into the droplets, and the growth rate is enhanced due to excess Ga atoms from droplets.

(b) HAADF STEM image of sample with same growth conditions as (a) but grown lattice matched on 500nm of relaxed $In_{0.17}GaAs$. Sample appears homogenous and was able to be grown to a thickness of 230 nm. Background subtraction was performed on the image to remove contrast due to thickness variation in the TEM lamella.

(c) Optical microscopy (Nomarski) comparison of samples with the same growth conditions but different underlayers. By growing with reduced compressive strain using $In_{0.105}GaAs$ (right) instead of GaAs (left) the surface droplet density is significantly reduced.

(d) Absorption coefficient (squared) of GaAsBi sample shown in (b) as a function of energy, determined by spectroscopic ellipsometry. The material has a bandgap of 1.0eV but a significant Urbach tail, indicating possible crystalline disorder not shown in the HAADF STEM image.