Manipulating film and underlayer strain to understand vertical phase separation in GaAsBi.

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$GaAs_{1-x}Bi_x$ is an interesting optoelectronic material that opens up new band gap and lattice constant possibilities for near-, mid-, and far-IR applications. Although thin films of high Bi content $GaAs_{1-x}Bi_x$ (up to x=0.22 at <50nm [1]) have been grown on GaAs in the literature, it is still difficult to grow high Bi content materials that are thick enough to act as active layers in devices. Additionally, we find that materials grown >30nm phase separate into vertically segregated bands and have periodic Bi content. By lowering the compressive strain or adding tensile strain into our 250nm thick GaAsBi layers, we achieve increased Bi incorporation as well as reduced compositional variations, as demonstrated by TEM and atom probe tomography (APT). In this work, we expand our underlayer study, incorporating underlayers of AlGaAs and lower bismuth composition GaAsBi to decouple strain effects from changes in surface reconstruction and surface composition. We hypothesize that moving from high compressive strain to tensile strain in the epilayer provides a more favorable starting surface for both incorporation of Bi as well as for growing homogenous films.

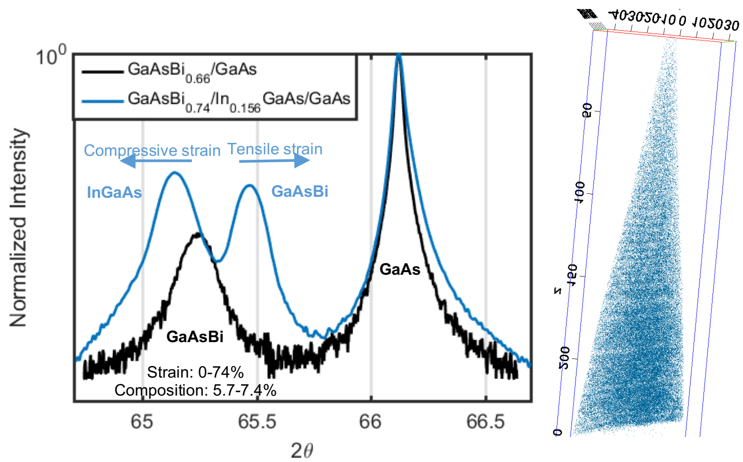

Fig1: (a) (004) line scans of GaAsBi/GaAs and GaAsBi/InGaAs/GaAs demonstrating increased Bi content in films grown on compressively strained InGaAs (b) APT rendering of bismuth atoms in our GaAsBi/GaAs structure. Periodic oscillations in bismuth content change through the thickness of the film.

We grew our layers with a Veeco GENxplor MBE using a valved As_4 cracker and a solid source effusion cell for group III elements and Bi. We measured lattice constants and estimated average bismuth content using 004 and 224 HRXRD scans, alongside spectroscopic ellipsometry to measure the room temperature band gap. We characterized the degree of strain relaxation by examining reciprocal space maps around the 224 asymmetric reflection. We additionally used TEM to identify defect centers and APT to measure bismuth variation along the growth direction. We examined structures of GaAsBi/(underlayer)/GaAs with underlayers of InGaAs, GaAsBi, and AlGaAs. We propose that strain engineering may be applied to increase Bi content in GaAsBi films, allowing for the growth of small band gap optoelectronic devices on GaAs substrates.

[1] R.B. Lewis, M. Masnadi-Shirazi, and T. Tiedje Appl. Phys. Lett.101 082112 (2012)

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Supplementary Pages

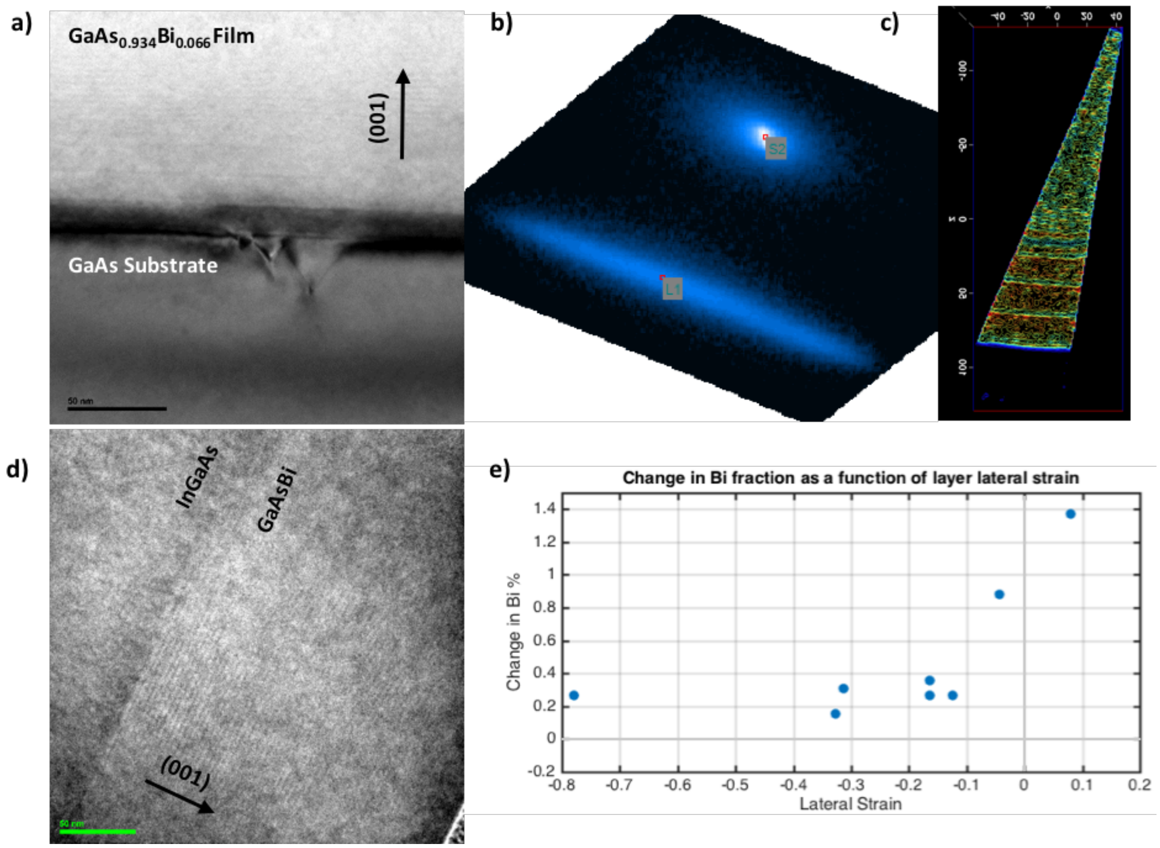

Fig2: (a) BF TEM down [110]ZA of 6.6% GaAsBi that relaxed on GaAs, forming defects at the interface. (b) 224 RSM of 6.6% Bi sample showing variation in both strain and composition. (c) APT "Heat map" of Bi content in our materials. Blue regions show little bismuth incorporation, while red regions show up to 12% Bi fraction. We see a change in the period of the compositional oscillations along the growth direction. (d) TEM down [110]ZA of 7.4% GaAsBi grown on InGaAs showing uniform Bi oscillations of ~4nm. (e) Plot of change in expected Bi fraction as a function of GaAsBi lateral strain. Change in Bi fraction defined as difference in Bi fraction from GaAsBi grown strained on GaAs under the same growth conditions. We see a benefit to decreasing lateral compressive strain or adding slight lateral tensile strain.