Atomic scale characterization showing kinetic compositional instability and phase separation in MBE-grown InGaAs

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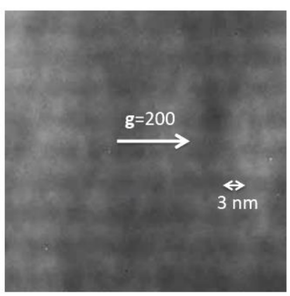
Phase separation in III-V semiconductor alloys remains a problem that limits the performance and quality of electronic materials. As the first stage in a comprehensive program addressing this issue, we have begun investigating an alloy system in which only the group III elements differ: InGaAs. Lattice-matched InGaAs alloy films were deposited at three temperatures (400, 450, and 500 C) by MBE on a (001) InP substrate. Using TEM, APT and XRD, we have found phase separation in all three growths to varying degrees.

According to the kinetic compositional instability (KCI) model developed by Glas [1], the critical temperature for kinetic spinodal phase separation in InGaAs is 814 C, a temperature well above the growth temperatures commonly used in InGaAs growths. Our XTEM measurements found that the amplitude of composition modulations averaged over the thickness of the XTEM sample are 0.7, 0.5, and 0.4 atomic percent for the growth temperatures 400, 450, and 500 C, respectively. APT indicates that the amplitude of composition modulation for the 400 C growth is approximately 1 atomic percent, a value that compares favorably with the 0.7 atomic percent measured by XTEM.

We have used KCI theory to evaluate the average amplitude of composition modulation for a given growth temperature by integrating the KCI vertical composition profile over thickness. The KCI model explicitly addresses the kinetics of the volatile near-surface region of the film, where surface undulations driven by surface diffusion introduce the kinetic component that undermines compositional stability beyond the point dictated by thermodynamics alone. This analysis finds that the kinetically unstable layer is approximately 2 nm thick when the lateral composition modulation wavelength is 3 nm. The thickness of this kinetically unstable layer corresponds to features marking both lateral and vertical composition, providing good evidence for the kinetic origins of the observed phase separation in the material.



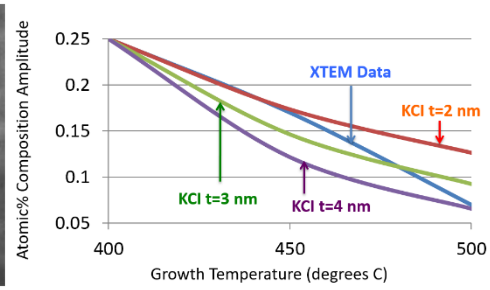


Figure 1: (left) Dark-Field XTEM image showing 3 nm and horizontal composition modulation wavelengths (right) Composition amplitude measured by XTEM compared with KCI theory for several values of kinetic layer thickness "t"

[1] F. Glas, Phys. Rev.B, 62, 7393 (2000).

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Supplementary Information

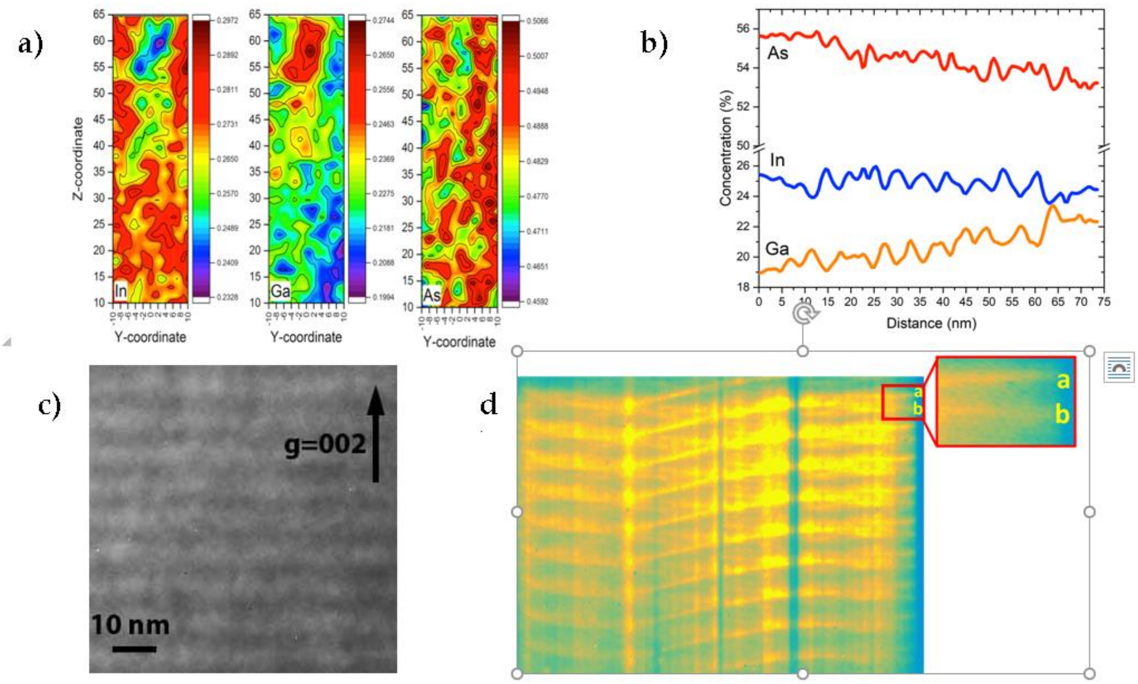

Figure 1 a) 2D composition contour plots for the region of interest, b) 1D composition profile along region of interest z, c) Dark-field XTEM image of phase separation in InGaAs film, d) 2d-SAXS image of 400 ^{o}C grown sample.