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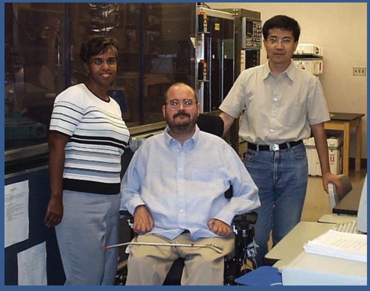

Authors (from left) Donna Stokes, Kevin Bassler, and Jianhua Li

Effect of Interfacial Bonds on Morphological Instability of Slightly Lattice Mismatched Epitaxial Thin Films

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Using x-ray diffraction, we have investigated the strain and composition of InAs/GaSb superlattices grown on GaSb or InAs (001) substrates with InSb or GaAs interfacial bonds. An ordered InAs nanowire array is formed in the superlattice on GaSb (001) with InSb interfacial bonds, while the superlattice on InAs (001) with GaAs interfacial bonds remains planar. We have determined the composition and strain in both superlattices and found that the InAs layers are under compressive strain, rather than under the expected tensile strain or strain-free as we expected. We suggest that the strain state of the interfacial bonds is crucial for the morphological instability. This may provide a new channel in which to manipulate the self-assembling of nanowire structures.

The formation of self-organized semiconductor nanoscale structures, based on the morphological instability of strained films grown using molecular beam epitaxy, has been observed in many III-V systems. Instability occurs at some critical layer thickness, which is large for many III-V systems with a misfit of less than 1% (>150 Å), when the misfit strain energy is reduced more than the surface energy is increased. However, unusual instability phenomena have been observed in some non-common anion strained III-V single layers and heterostructures. For example, $In_{0.45}Ga_{0.55}As$/InP (001) with a misfit of 0.5% demonstrates instability at an early stage of the growth. Similarly, InAs/GaSb (001) heterostructures have a misfit of 0.62%, but instability is observed at a thickness of a few monolayers.

In this work, two $(InAs)_{13}/(GaSb)_{13}$ superlattices, one with In-Sb interfacial bonds and one with Ga-As interfacial bonds, have been analyzed. Cross-sectional scanning tunneling microscope images showed that the sample with In-Sb interfacial bonds formed an array of nanowires, as shown in **Figure 1**. However, the sample with Ga-As interfacial bonds remained planar. **Figure 2(a)** shows the reciprocal space map around the GaSb (-224) substrate reciprocal lattice point for the nanowire sample. **Figures 2(b)** and **(c)** show line scans along the Q_x||[-110] and Q_z||[001] directions (indicated by the dashed lines in the map). The appearance of high-order two-dimensional satellites in these scans indicates the long-range ordering of the nanowire array. X-ray results from the planar superlattice sample (not shown) show one-dimensional satellites as expected.

Theoretical simulations of the x-ray results for the nanowire sample based on a structural model derived from **Figure 1** were performed considering the shape function of the nanowires — including the spacers, the scattering amplitude of a single nanowire, and the strain distribution in the nanowire array — through a direct solution of the equations of linear continuum elasticity. The simulations, also shown in **Figure 2**, yield that (1) the "InAs" nanowires were actually an $InAs_{0.88}Sb_{0.12}$ alloy due to Sb contamination and/or segregation, with a positive mismatch of +0.21%, and (2) the In-Sb interfacial bonds have a large positive mismatch of +6.28% with respect to the substrate.

For the planar sample, the x-ray rocking curve revealed that the "InAs" layers were also $InAs_{0.88}Sb_{0.12}$ alloy layers with a mismatch of +0.83%, which is much larger than that of the layers grown on the GaSb substrate. This sample is different because it contains Ga-As interfacial bonds, which experience a large negative mismatch of -6.69% with respect to the InAs substrate.

For the nanowire sample, the $InAs_{0.88}Sb_{0.12}$ and the InSb interfacial have a positive misfit. Thus, it is favorable for them to relax together. The strain energy is proportional to the layer thickness; therefore, the high misfit strain in the InSb interfacial reduces the critical layer thickness of $InAs_{0.88}Sb_{0.12}$, making it possible for instability to occur in just a few monolayers. For the planar sample, the $InAs_{0.88}Sb_{0.12}$ and the GaAs interfacial have opposite misfits. Relaxation of these two materials involves atomic displacements in opposite directions; therefore, it is unfavorable for them to relax together to form a planar sample. This suggests that it may be possible to manipulate the self-assembling of nanowire structures through the control of the strain relationship with respect to the substrate between the superlattice layers and interfacial bonds.

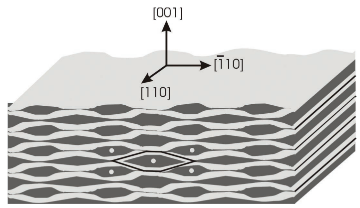

Figure 1. A reconstructed 3D structure of the nanowire array in the nanowire sample based on XSTM measurements. The dark areas are "InAs" and the bright areas are "GaSb." Enclosed in the solid lines is a nanowire model used in our simulation. The bright circles mark a super face-centered-rectangle unit cell that the nanowires form.

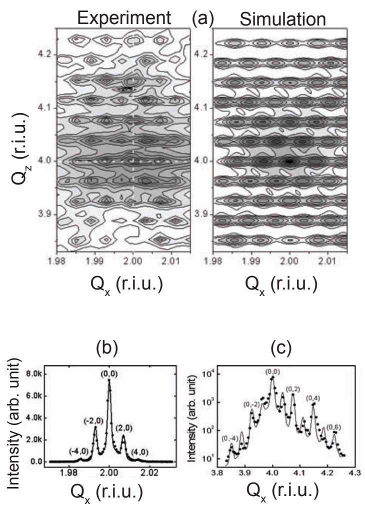

Figure 2. Experimental and simulated (a) x-ray reciprocal space map around (-224) reciprocal lattice point (b) Q_x||[-110] scan (dots) corresponding to the dashed horizontal line in the map and (c) Q_z||[001] scan (dots) corresponding to the dashed vertical line in the map. (m,n) indicates the lateral and vertical orders of the satellites.