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Composition Modulation in GaAs/GaSb Short Period Superlattices

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Quantum dots and/or wells are of much interest due to novel electronic properties and the potential for improvements in photovoltaic efficiency and optoelectronic devices. Spontaneous composition modulation in mixed cation systems, where the modulation occurs on the group III sublattice, has been reported previously [1]. Composition modulation is demonstrated here for the first time in mixed anion systems, where the modulation occurs on the group V sublattice.

Several different multilayer structures were grown on InP substrates in a Molecular Beam Epitaxy (MBE) chamber. A short period superlattice (SPS), which consisted of a 100-period $(GaSb)_n(GaAs)_m$ deposition with n, m = 1 or 2 monolayers, was grown on top of a nominally lattice matched InGaAs buffer layer. Samples were monitored during growth with RHEED and characterized using cross-section TEM, High Angle Annular Dark Field STEM and EDX. Fig. 1a shows an 002 dark field image of a $(GaAs)_2(GaSb)_2$ SPS (sample F193) with lateral variation of contrast due to both composition and strain. Individual SPS layers are visible, but are clearly non-planar. A HAADF STEM image shows only mass-thickness contrast and reveals weak lateral composition modulation in Fig. 1b. Sample G226 has a $(GaAs)_1(GaSb)_2$ SPS structure, and shows strong lateral composition modulation in the HAADF STEM image in Fig. 2a. An EDX line profile across the modulation (Fig. 2b) reveals As and Sb are modulating out of phase with a period of 23nm and a $GaAs_{1-x}Sb_x$, composition modulation of x=0.77 for Sb rich and x=0.33 for As rich regions. Sample G219 has the same $(GaAs)_2(GaSb)_2$ SPS as F193, but with a 4 second Sb soak prior to GaSb deposition. A HAADF STEM image in Fig. 3a shows lateral composition modulation, but it is tilted slightly from the sample normal, possibly due to steps at the growth interface. An EDX line profile in Fig. 3b shows a period of 15nm and a composition modulation of x=0.73 in Sb rich and x=0.55 for As rich regions. In all samples, RHEED observations showed surface roughening during deposition and high resolution TEM showed that the individual SPS layers are intermixed from the first few layers of the deposition as shown for G219 in Fig. 3c. In order to prove that the observed spontaneous composition modulation was not due to spinoidal decomposition, an alloy sample was grown under similar conditions to the SPS samples. A cross section TEM image in Fig. 4a shows smooth contrast and dislocations in the alloy film indicating a relaxed structure. No contrast was observed in the HAADF STEM image in Fig. 4b and an EDX line profile confirmed there was no lateral composition modulation.

We demonstrate lateral composition modulation in mixed anion GaAs/GaSb short period superlattices, and show that the composition modulation is due to the SPS and not due to spinodal decomposition. Lateral composition modulation is regular and periodic, with the period and amplitude varying with the SPS structure. The observed roughening of the film during growth likely plays a role in the development of lateral composition modulation.

References
[1] J. Mirecki Millunchick et al., *MRS Bulletin.* 22 n7 (July 1997) 38-43

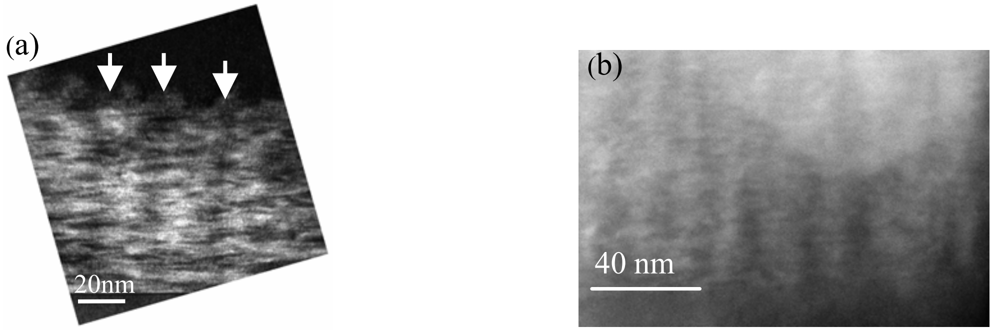

FIG. 1. F193 has a $(GaAs)_2(GaSb)_2$ SPS. (a) 002 Dark Field TEM shows strain and z-contrast. Lateral modulation (arrows) is shown by (b) HAADF STEM imaging to be composition modulation.

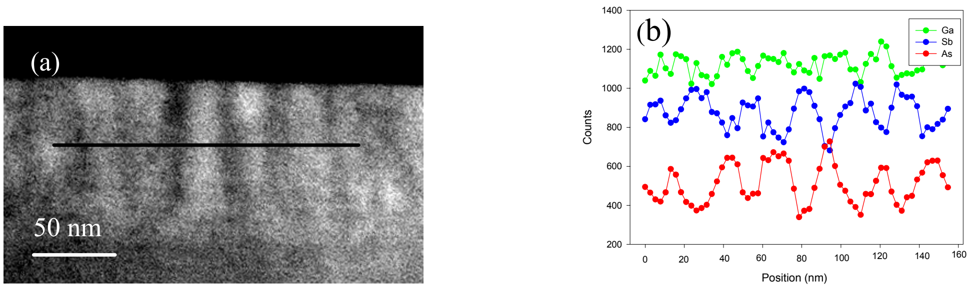

FIG. 2. G226 has a $(GaAs)_1(GaSb)_2$ SPS. (a) HAADF STEM shows strong lateral composition modulation. (b) An EDX line profile shows Sb and As modulating out of phase with period 23nm.

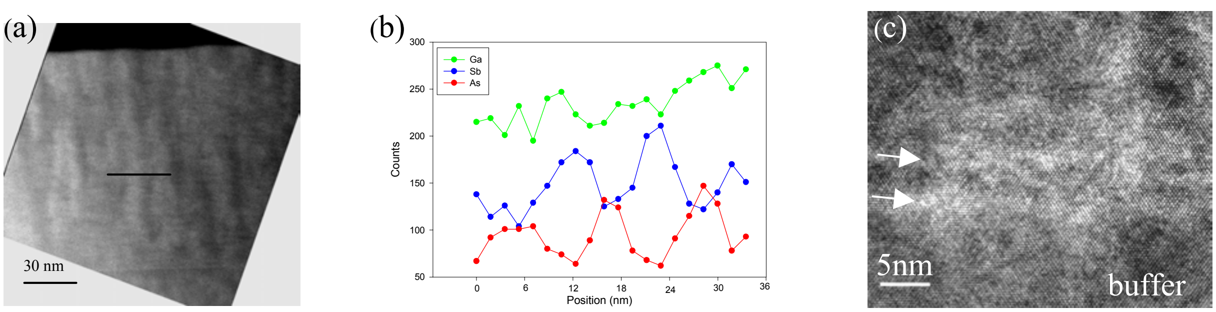

FIG. 3. G219 has a $(GaAs)_2(GaSb)_2$ SPS with a 4s Sb soak. (a) HAADF STEM shows lateral composition modulation. (b) EDX line profile shows Sb and As modulating out of phase with a period of 15nm. (c) HRTEM shows intermixing from the very first few layers of the SPS deposition.

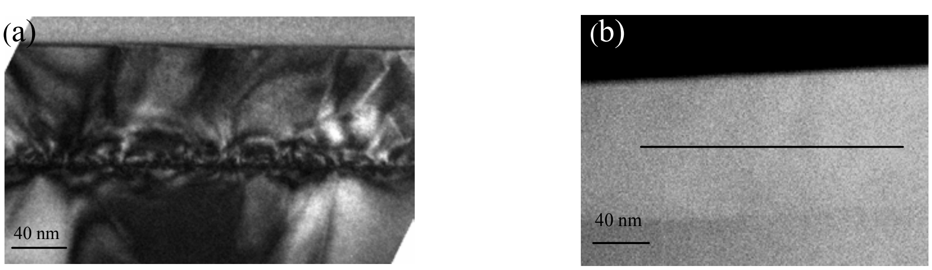

FIG. 4. Alloy. (a) TEM shows a relaxed structure with dislocations and (b) no HAADF contrast.

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