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Quantum Wire Arrays in Compositionally Modulated InAs/AlAs Superlattices

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Compound semiconductor alloys have limited miscibility, which can lead to composition segregation during growth. This effect produces periodic lateral composition modulation in epitaxial InAs-AlAs [1] and other alloys [2]. Intense modulation is found in vertical $(InAs)_n/(AlAs)_m$ superlattices ($n \approx m \approx 2$) grown by molecular beam epitaxy [3]. Growth on (001) InP substrates leads to two modulation directions with only short InAs-enriched regions (~0.1 µm) [4]. Superlattices with global-average compositions slightly rich in InAs ($n > m$) have modulations ~8° from the in-plane <100> directions. Growth on substrates miscut 2° toward (100) selects the modulation near [100], resulting in vertical sheets enriched in InAs and extending nearly parallel to [010] with lengths approaching ~1µm.

We examined such a superlattice but with InAlAs random-alloy layers placed between sections of superlattice modulated nearly along [100]. A lattice-matched 100 nm-thick $In_{0.52}Al_{0.48}As$ buffer alloy was grown on the miscut InP, followed by superlattice sections, each with 10 vertical periods of $n = 1.90$, $m = 1.52$. Ten such sections were grown with 7.5 nm-thick InAlAs random alloy layers placed between them. The growth temperature rose a few degrees above 535°C, determined by an optical pyrometer at the initiation of growth. Figure 1 is a cross-section image obtained with (002) dark-field conditions for sensitivity to composition variations [3]. Composition modulation appears as light/dark variations that begin in the first superlattice section and reach a steady-state intensity by about the fourth section. The average lateral periodicity is 30 nm. The bright InAs-rich wires stack vertically above those below. Atomic steps on the miscut growth surface bunch together at some AlAs-rich regions between wires; the 2.7 nm drop indicated near the center of the image corresponds to ≈9 monoatomic steps. Such drops probably relate to how one modulation direction is selected. Slight contrast is seen in the alloy layers, especially above the stack; this may indicate some compositional variation induced by the modulated superlattice, or may be due to lattice strain. Figure 2 is a plan-view, (200) dark-field image showing the in-plane organization of the wire stacks. Wires up to ~1 µm long are found nearly parallel to [010], with the modulation direction ~8° from [100] toward [110] as before. These wires are of interest because their small cross section induces quantum confinement of electronic carriers, and they exhibit polarized optical emission and absorption [5].

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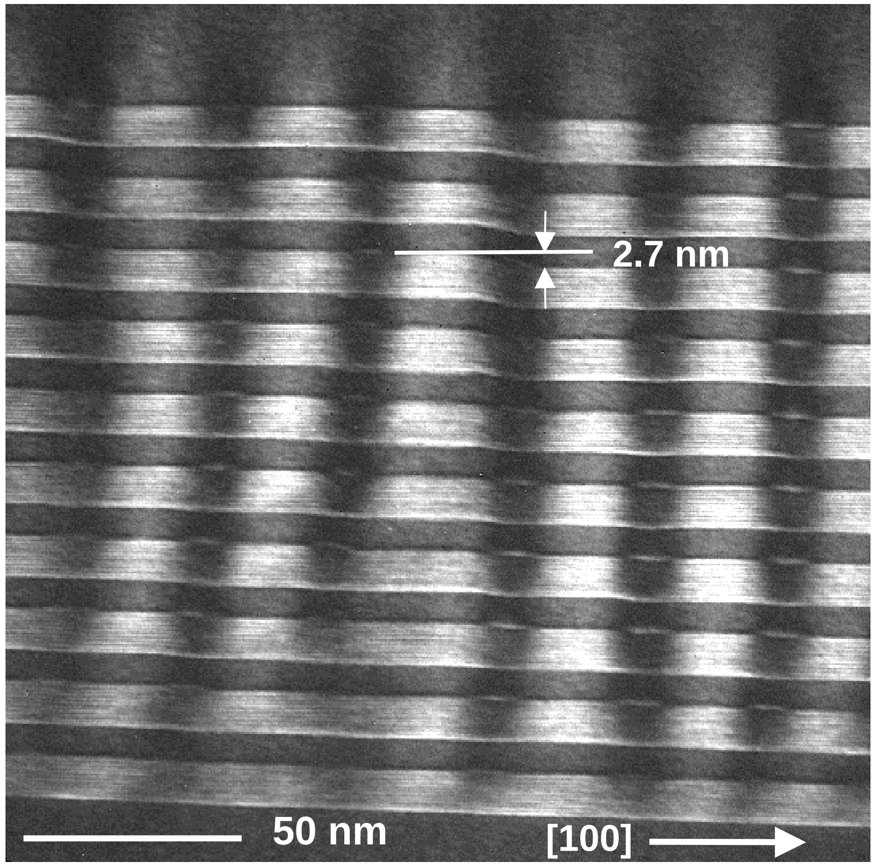

FIG 1. [010] cross-sectional image of quantum wires obtained using (200) dark-field conditions at 200 kV. Image is oriented with [001] vertical and the buffer layer tilted 2° below horizontal. Composition modulation in superlattice sections appears as bright/dark/bright.… contrast. InAs-rich wires (bright) are typically about 10 nm x 15 nm in cross-section. Note that the wires stack vertically in columns. Steps on the growth surface bunch together in the AlAs-rich regions between the wires, such as near the center where adjacent wires have a vertical drop between them, illustrated with the horizontal bar. Weak contrast is seen in the InAlAs alloy layers between sections and above the stack. (specimen EA0674).

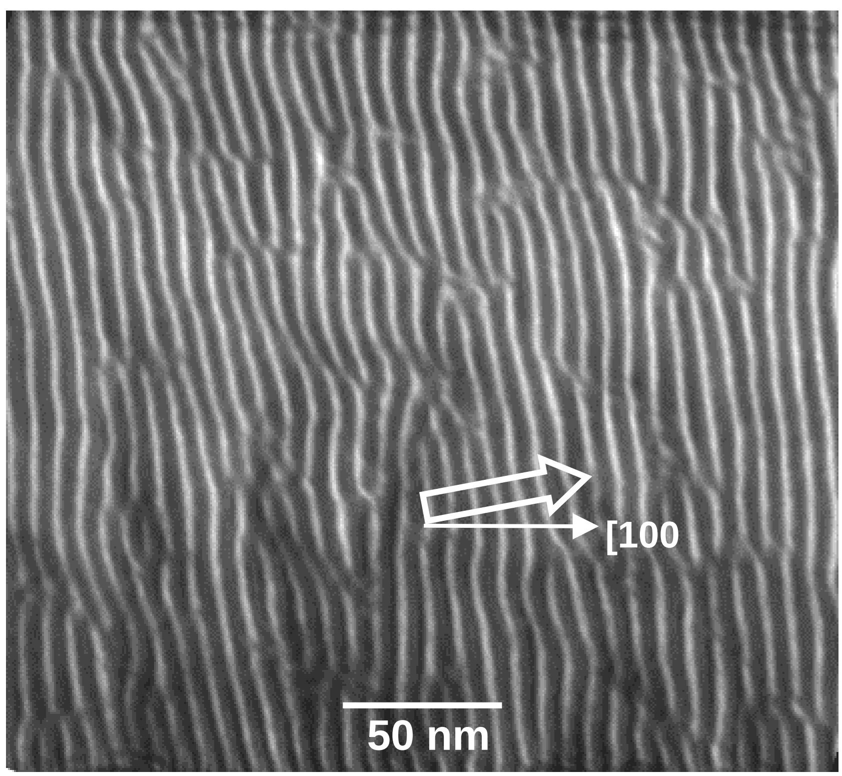

FIG 2. [001] plan-view image of quantum wires obtained with (200) dark-field conditions at 200 kV. InAs-rich wires appear bright, and extend for lengths up to ~1 μm. The average modulation direction (double arrow) is 8° from [100] toward [110]. In the varying pattern, some wires are cut off; others join adjacent ones. (specimen EA0674).

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