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THE CONTRIBUTION OF ANTIMONIDE SURFACE RECONSTRUCTIONS TO HETEROSTRUCTURE INTERFACE ROUGHNESS

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Using RHEED and STM, we have studied surface reconstructions and formation of islands and interfaces for the 6.1Å family of compound semiconductors (InAs, GaSb, AlSb). The structure and stoichiometry of MBE-grown antimonide surfaces lead to growth and roughening mechanisms that are distinctly different from other III-V materials. When a new material is grown on an antimonide surface, some blurring of the resulting heterointerface must occur in the form of monolayer islands or atomic-scale intermixing.

1 Introduction

The 6.1Å family of compound semiconductors (InAs, GaSb, AlSb) shows great promise for device applications such as infrared detectors, lasers, and high-speed electronics. One key to successful implementation of these materials is the ability to grow abrupt interfaces. The antimonides present unique growth challenges, due to the high antimony stoichiometry of their surface recontructions. In this work, we discuss the role of III-Sb reconstructions in producing roughness or intermixing at heterointerfaces.

2 Surface Reconstructions

The III-V materials described here were grown by solid-source molecular beam epitaxy. Reflection high-energy electron diffraction (RHEED) was used to monitor surface symmetry and the evolution of growth (via intensity oscillations). Atomic-scale surface and interface structure was probed with scanning tunneling microscopy (STM) in both plan-view and cross-sectional modes.

The GaSb and AlSb (001) surface reconstructions present during MBE growth are composed of greater than one monolayer of Sb atoms [1]. We have observed two similar Sb-rich surface reconstructions, differing in their aluminum content (Fig. 1) [2]. The $\beta(4\times3)$ surface contains 1 7/12 layer of Sb and 1/12 layer of Group III atoms in the topmost layers. This surface is produced whenever the crystal growth is interrupted under typical beam flux and substrate temperature conditions. On the other hand, conditions of higher substrate temperature or lower antimony flux yield the structure $\alpha(4\times3)$, with 1 1/3 layers of Sb and 1/3 layer of Group III atoms on the surface. The reconstructions shown in Fig. 1 for AlSb have also been observed on GaSb. Preliminary STM results on InSb reveal a β(4×3)-like structure, although the RHEED pattern suggests that this surface may be highly disordered at all relevant substrate temperatures. For AlSb, the proposed structures and stoichiometries have been verified by first-principles calculations [2].

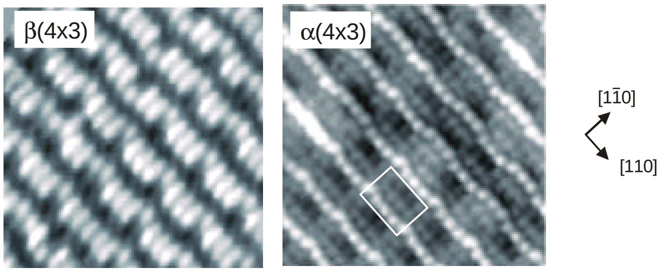

Fig . 1 Filled-state STM images of AlSb β(4×3) and α(4×3) (001) surface reconstructions. Images are 80 Å × 80 Å. A (4×3) unit cell is indicated on the right image.

3 Implications for Heterostructure Interfaces

Antimony-rich surface reconstructions are a source of compositional grading (intermixing) over several atomic layers around a heterointerface. For example, when InAs is subsequently grown on an antimonide, a fraction of the excess surface antimony is incorporated into the InAs layer [3]. Fig. 2 shows a cross-sectional STM image of an InAs-GaSb infrared detector superlattice, where Sb atoms are seen to penetrate several monolayers into the InAs. The observed concentration of Sb atoms correlates with the excess on the β(4×3) growth surface.

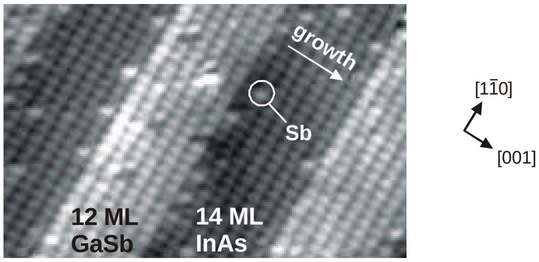

Fig . 2 Cross-sectional STM image of InAs-GaSb superlattice. Under these imaging conditions, only alternate layers and only Group V atoms are observed. Antimony appears bright within InAs.

The partial Group III coverages that exist on all zincblende III-V surfaces are an inherent source of interface roughness. We have previously discussed this issue for antimonide growth on the InAs surface [4], which has 3/4 of a full indium monolayer in the β2(2×4) reconstruction. By adding 1/4 monolayer extra indium to the surface prior to antimonide growth, one can produce nearly island-free interfaces. But in the opposite growth direction (InAs on antimonide), there is a fundamental complication: in order to produce InSb-like interface bonds (which provide superior electrical and optical performance), one must terminate the antimonide surface with antimony, precluding a final addition of excess Group III atoms to complete the final layer. We are presently exploring techniques to circumvent this limitation.

Finally, two homoepitaxy experiments emphasize the stoichiometry difference between the β and α surfaces and point to still another source of interface roughness. When a flat α-phase AlSb surface is suddenly exposed to a moderate antimony flux, the extra aluminum of the starting surface is pushed into a new layer of AlSb, producing a β-phase surface with islands [Fig. 3a].

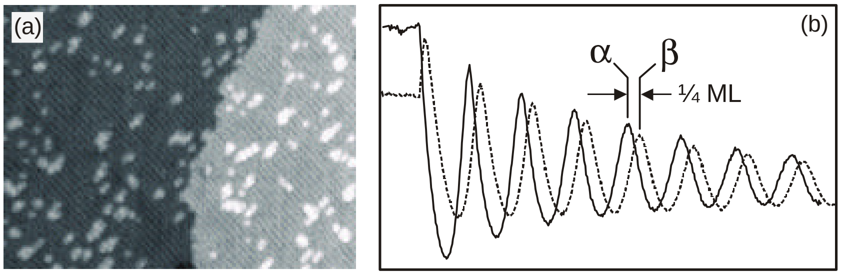

Fig. 3 (a) STM image (750 Å × 500 Å) of AlSb islands formed in conversion of α surface to β surface by exposure to Sb_4 vapor. (b) Phase shift in RHEED oscillations due to 1/4 monolayer difference in aluminum content of the pre-growth surfaces.

Similarly, RHEED oscillations recorded during AlSb growth initiated on flat α and β starting surfaces are shifted by approximately 1/4 monolayer, corresponding to the difference in initial aluminum coverage of the two surfaces [Fig. 3b]. These observations are a consequence of sudden changes in surface stoichiometry.

Acknowledgements

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