Self-Selective Formation of 1D and 2D GaBi Structures on GaAs

Y. Liu,[1] S. Benter, [1] J. V. Knutsson, [1] S. Lehmann, [1] E. Young, [2] N. Wilson,[2] C. J. Palmstrøm, [2,3] A. Mikkelsen, [1] and R. Timm[1*]

[1] Department of Physics and NanoLund, Lund University, Box 118, 221 00 Lund, Sweden
[2] Materials Department, University of California – Santa Barbara, CA 93106, USA
[3] Dept. of Elect. & Comp. Eng., University of California – Santa Barbara, CA 93106, USA

Bismuth (Bi) incorporation and alloying in III-V semiconductors such as InAsBi and GaAsBi has become a popular topic during recent years, due to a number of promising properties including band gap engineering, a large spin-orbit splitting, and predicted band inversion and topological behavior in the case of high Bi concentrations [1,2]. However, the realization of alloys with high Bi content by epitaxial growth has remained challenging [3].

We follow a different approach and deposit Bi onto the surfaces of GaAs and InAs planar substrates and nanowires (NWs), aiming for a surface layer of high Bi content. We use scanning tunneling microscopy and spectroscopy (STM/S) for systematically studying Bi adsorption and incorporation for different Bi deposition temperatures and post-deposition annealing parameters. Nanowires give us an extra degree of freedom, since they can be grown containing both segments of cubic zincblende (Zb) and of hexagonal wurtzite (Wz) crystal phase, resulting in a variety of surface facets. Previously, we studied the deposition of Sb on GaAs NWs with STM/S and observed a preferential incorporation of Sb atoms into Zb {110} surface facets as compared to {11-20} Wz facets [4].

Here, we observe the incorporation of Bi atoms in the topmost layer of the GaAs surface through group-V exchange, replacing As atoms, upon Bi deposition on GaAs NWs at a temperature of 250°C. The NWs had been cleaned before by annealing in atomic hydrogen, which has been shown previously to remove the native oxide layer [4]. On the NW Zb segments, Bi atoms are scattered at random positions (though generally on As lattice sites), with an increase in density towards step edges of the surface terraces. On the Wz segments, however, the incorporated Bi tends to form one-dimensional GaBi chains and extended two-dimensional GaBi islands along the <0001> edges of surface terraces. A model for the incorporation of Bi through the step edges will be discussed, including differences observed between {11-20} and {10-10} Wz facets and for different densities of surface steps. Importantly, the ordered 1D and 2D GaBi structures are exclusively found on the Wz segments, which can be tailored in size through NW growth conditions, forming atomically sharp interfaces to Zb segments [5]. This lays the path towards the formation of ordered GaBi structures with atomic-scale precision.

[1] M. Ferhat, A. Zaoui, *Structural & electronic properties of III-V Bi compounds*, Phys. Rev. B **73**, 1 (2006).
[2] F.-C. Chuang et al., *Prediction of Large-Gap Two-Dimensional Topological Insulators Consisting of Bilayers of Group III Elements with Bi*, Nano Lett. **14**, 2505 (2014).
[3] L. Wang et al., *Novel Dilute Bismide, Epitaxy, Physical Properties & Device Appl.*, Crystals **7**, 63 (2017).
[4] M. Hjort et al., *Crystal Structure Induced Preferential Surface Alloying of Sb on Wurtzite/Zinc Blende GaAs Nanowires*, Nano Lett. **17**, 3634 (2017).
[5] J.V. Knutsson et al., *Electronic Structure Changes due to Crystal Phase Switching at the Atomic Scale Limit*, ACS Nano **11**, 10519 (2017)

* Author for correspondence: Rainer.Timm@sljus.lu.se

Suplementary Pages (Optional)

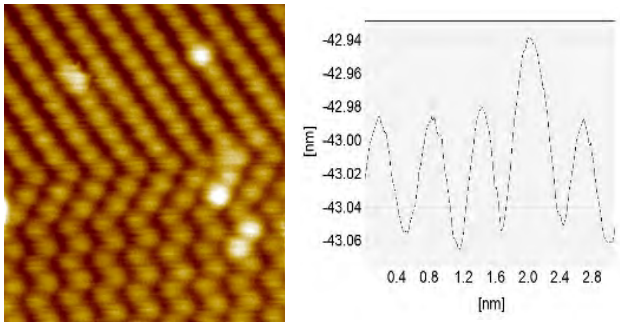

Figure 1: STM image of a GaAs NW surface with Zb {110} (top) and Wz {11-20} (bottom) facets, showing group-V atoms (negative sample bias). The bright spots are Bi atoms, sitting at group-V lattice sites. A height profile taken across one of the Bi atoms shows that it protrudes only 0.05 nm above the neighboring As atoms, far less than the atomic radius or the height of a monolayer. This demonstrates that the Bi atom is incorporated in the surface, and the larger Ga-Bi bond length compared to Ga-As leads to the small protrusion.

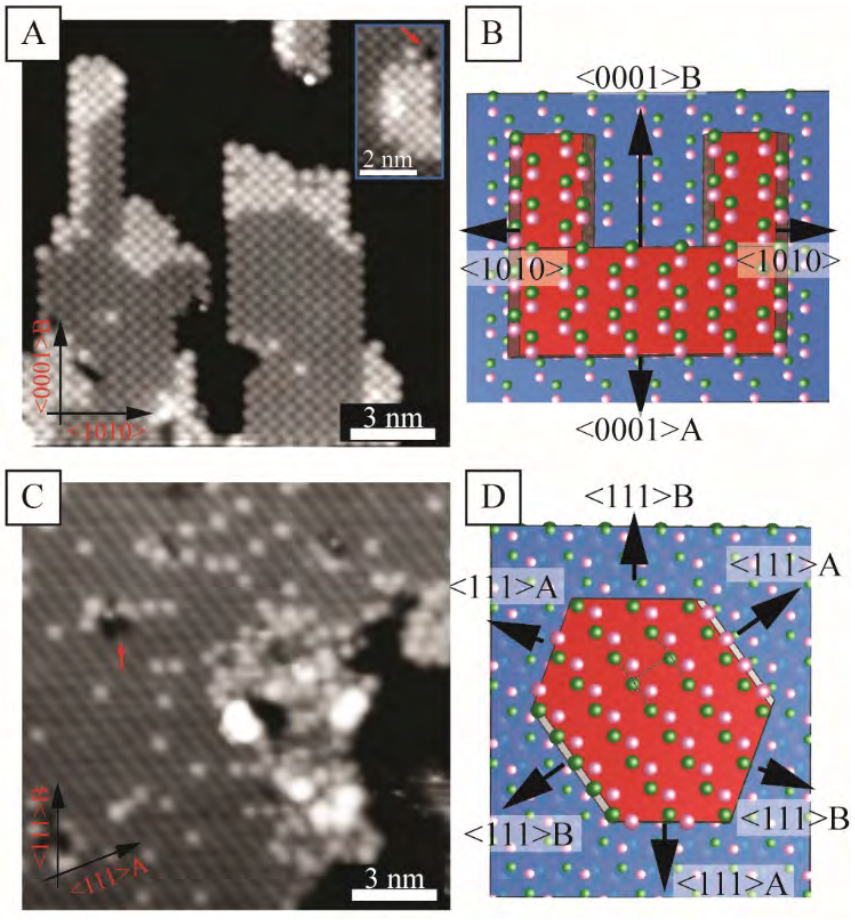

Figure 2: STM images and surface models of (A,B) Wz and (C,D) Zb segments of a GaAs NW. Bi atoms can clearly be seen due to the brighter image contrast. On the Zb segment (C), isolated Bi atoms are scattered across the surface, forming more Bi-rich clusters towards the step edge seen to the right. On the Wz surface (A), dense 2D GaBi structures can be seen, especially towards the top ends of the shown surface terrace, terminated by <0001>B steps. Note that the height difference between the brighter and darker parts amounts to less than 1 Å. STM images are obtained at a sample bias of -4.4 V and a tunneling current of 100 pA. In the surface model (B,D), the topmost layer is shown red, the layer below blue. Pink (green) spheres depict Ga (group-V) atoms.