Bismuth-Induced Nanostructures on III-V Semiconductor Surfaces

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Bismuth-containing III-V semiconductor alloys are attracting widespread attention for various applications within optoelectronics, for band-gap engineering, and due to their large spin-orbit splitting. The latter gives rise to non-trivial topological properties and promise for application in spintronics and quantum computation. Compounds such as InBi or GaBi have been predicted to open an inverted band gap large enough to enable quantum applications at room temperature [1]. However, bulk growth of Bi-containing semiconductors is challenging, and III-V alloys with a Bi content of more than 20% could not yet be realized [2]. Instead, our approach is to obtain one-dimensional (1D) structures or two-dimensional (2D) layers with high Bi content by depositing Bi atoms onto the surfaces of III-V semiconductors. Depositing (larger amounts of) Bi onto semiconductor substrates at room temperature typically results in the formation of metallic Bi islands, as has been investigated for various III-V surfaces. Only very little is known, though, on the interface between III-V semiconductors and metallic Bi layers, or on Bi-induced surface structures with possibly semiconducting or topologically insulating properties.

Here, we will present results from Bi deposition onto different GaAs [3,4], InAs [5], and InSb surfaces, resulting in the formation of ordered 1D and 2D nanostructures of high Bi content, investigated by scanning tunneling microscopy and spectroscopy (STM/S), X-ray photoelectron spectroscopy (XPS), and angle-resolved XPS. Upon Bi deposition on InSb(111)B at elevated sample temperature, we see the formation of a surface layer characterized by Bi-Sb bonds and the presence of both Bi trimers and Bi monomers. Interestingly, the growth of this layer is self-limiting, as continuous Bi deposition does not increase the layer thickness, unless the sample temperature is lowered to room temperature, where the previously seen formation of metallic Bi islands is observed.

On GaAs(111)B, Bi deposition forms a honeycomb surface structure of Bi atoms, as shown in Fig. 1(a). In contrast to conventional Bismuthene, we find that these Bi atoms have strong covalent bonds to the As atoms of the underlying GaAs, but are only weakly bond to each other [3]. Further different behavior is observed on the surfaces of GaAs nanowires, consisting of segments of cubic zincblende and hexagonal wurtzite crystal phase. Here, we observe that Bi atoms replace As atoms and incorporate in the III-V lattice. However, while this results in random Bi positions or Bi-rich clusters near surface steps on the zincblende (110) surface (Fig. 1(b)), we find well-ordered 1D chains and 2D islands of pure GaBi on the wurtzite (11-20) surface, as seen in Fig. 1(c) [4].

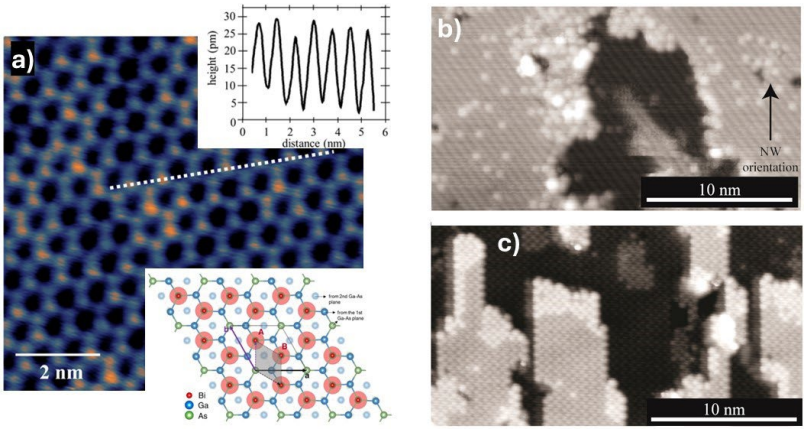

Fig.1. (a) STM image of Bi atoms in a honeycomb structure on GaAs(111)B. Insets show the height profile (top) and a model of the structure (bottom). From [3]. (b,c) STM images of Bi atoms incorporated in (b) zincblende GaAs(110) and (c) wurtzite GaAs(11-20) segments of a nanowire. From [4].

Based on STS and density functional theory results, we will further discuss non-trivial topological properties of these Bi-induced surface structures and pathways towards novel device applications.

References

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