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Bi-induced (2 × 6), (2 × 8), and (2 × 4) reconstructions on the InAs(1 0 0) surface

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Abstract

Low-energy electron diffraction (LEED), scanning-tunneling microscopy (STM), and synchrotron-radiation photoemission results show that Bi induces (2 × 6), (2 × 8), and (2 × 4) reconstructions on the InAs(1 0 0) surface with decreasing Bi coverage. The α2-like structural model, established previously for the clean InAs(1 0 0)(2 × 4) surface, is proposed for Bi/InAs(1 0 0)(2 × 4), and two Bi 5d core-level components of this reconstruction are interpreted within the context of this model. For the Bi/InAs(1 0 0)(2 × 6) surface we propose a tentative model where two topmost atomic layers consist of Bi atoms. Some possible reasons why Bi forms chain-like (2 × 6) and (2 × 8) reconstructions, instead of the prototypical c(4 × 4) stabilized normally by As on III-As(1 0 0), are discussed.

Keywords: Scanning-tunneling microscopy (STM); Synchrotron radiation photoelectron spectroscopy; Surface reconstruction; Indium arsenide (InAs); Single crystal surfaces

The epitaxial single-crystal layers of III-V semiconductors alloyed with bismuth (Bi), i.e., III-$V_{1-x}Bi_x$ have attracted increasing interest recently [1–3]. To obtain control of the epitaxial growth of these layers and to further our knowledge of the physical properties of the interfaces, it is important to understand the atomic and electronic structures of Bi-induced reconstructions on III-V(1 0 0) surfaces (see, for example, Ref. [4]).

The behaviour of Bi on polar III-V(1 0 0) surfaces, which usually serve as substrates for epitaxial growth, is less understood than for the carefully studied Bi/III-V(1 1 0) system [5–8]. To date, the interest has been mainly focused on thick Bi layers

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on GaAs(1 0 0) [9,10] rather than on Bi-induced reconstructions in the submonolayer and monolayer (ML) ranges, and to the best of our knowledge, no investigation has been reported for the Bi/InAs(1 0 0) surface.

In contrast, antimony (Sb) has been found to induce (stabilize) a (2×4) reconstruction on GaAs(1 0 0) and InAs(1 0 0), where the surface As dimers of clean III-As(1 0 0)(2×4) are replaced by Sb [11–20]. As molecular-beam-epitaxy (MBE) growth of III-V semiconductors largely proceeds via the (2×4) reconstruction, this phase is of particular fundamental and technological significance (e.g., Ref. [21] for a review). At higher coverages, Sb seems to stabilize a specific (2×8) reconstruction on the GaAs(1 0 0) surface [17,18,20]. Such a reconstruction has not been observed for any other III-V(1 0 0) system so far, and the mechanisms leading to (2×8) instead of the prototypical $c(4 \times 4)$ [22] are unclear.

In this letter, we report low-energy electron diffraction (LEED) and scanning-tunneling microscopy (STM) observations of Bi-induced (2×6), (2×8), and (2×4) reconstructions on InAs(1 0 0) with decreasing Bi coverage. In addition, synchrotron-radiation core-level photoemission was applied to investigate the Bi/InAs(1 0 0)(2×6) and (2×4) surfaces.

Photoemission was measured at the MAX-lab Synchrotron Radiation Center (Beamline 41). The light angle was 45° relative to the surface. Spectra were taken using a hemispherical electron-energy analyzer with an angular resolution better than 2° and instrumental resolution better than 0.2 eV. To study the surface sensitivity of spectral features, the electron-emission angle (from surface normal) was varied.

STM observations were made in another ultrahigh vacuum (UHV) system (Omicron). STM imaging was performed in the constant-current mode. The both UHV systems were equipped with LEED and Bi-deposition facilities. All the measurements were done at room temperature.

For photoemission, InAs samples were grown by MBE on epiready InAs(1 0 0) substrates. The InAs buffer layers were grown at 450 °C, with reflection high-energy electron diffraction (RHEED) showing a sharp 2×4 pattern which remained visible during the sample cooling. The InAs(1 0 0)(2×4) substrates were quickly transferred under UHV to the measurement chamber of the Beamline 41. For STM, a protective As-capping layer was deposited on the InAs buffer. Upon the sample transfer through air, the cap layer was removed by heating the sample in UHV up to 370 °C.

Within these two UHV systems, we obtained a 2×4 LEED pattern from the InAs surface after heating at 300–370 °C. The temperature was measured by an infrared pyrometer with an estimated error of ±30 °C. The further heating at 400–430 °C produced a sharp $4 \times 2/c(8 \times 2)$ pattern (hereafter 4×2) without any coexisting symmetry (Fig. 1(a)). These LEED observations agree well with previous studies [23].

Fig. 2(a) shows an empty-state STM image of clean InAs(1 0 0)(4×2). It is characterized by bright double rows which run in the [0 1 1] direction with a separation of about 17 Å correspond-

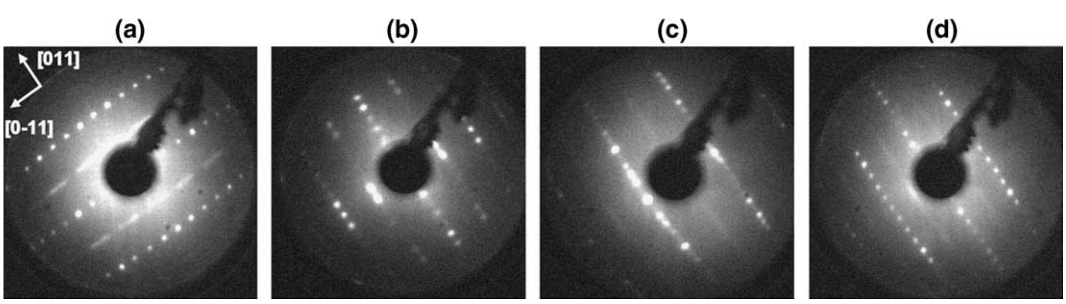

Fig. 1. (a) 4×2 [or $c(8 \times 2)$] LEED pattern (55 eV) from clean InAs(1 0 0) after the heating at 420 °C, (b) 2×6 [or $c(2 \times 12)$] LEED (45 eV) from Bi/InAs(1 0 0) after 320 °C, (c) 2×8 plus 2×4 LEED (52 eV) from Bi/InAs(1 0 0) after 360 °C, (d) 2×4 [or $c(2 \times 8)$] LEED (100 eV) from Bi/InAs(1 0 0) after 380 °C.