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Electronic structure of Bi(110) ultra-thin films grown on a Si(111)√3×√3-B surface

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1 Introduction

Bismuth (Bi) ultra-thin film has been attracted much interest because of its novel spin-polarized electronic structure originated from a large spin-orbit interaction. In particular, bilayer Bi(111) film is expected to behave as a two-dimensional topological insulator (2D-TI) with spin-polarized helical edge states[1]. Bilayer Bi(110) film is also suggested to become a 2D-TI when the film has black-phosphorus-like (BP-like) structure[2]. We have studied the growth of Bi(110) ultra-thin films on a Si(111)√3×√3-B surface by scanning tunnelling microscopy (STM) and found that the Bi(110) islands stably grow up to at least 20 monolayer (ML) height on a wetting layer with six rotational domains due to the commensuration with the substrate[3]. Both the even and odd-layer-height islands from the wetting layer grow with some preference of even-layer ones. There are two possible internal structures of the islands; bulk-like and BP-like structures, although the structure is unclear only from the STM observations. Recent theoretical band calculations for free-standing Bi(110) films below 8 ML suggest that the bulk-like structure has a Dirac-cone-like metallic state around the M point of the surface Brillouin zone whereas a band gap exists for the BP-like structure[4]. In the present study, we have investigated the band structure of Bi(110) ultra-thin films below 20 ML grown on a Si(111)√3×√3-B surface by angle-resolved photoelectron spectroscopy (ARPES) to reveal the internal structure of the islands.

2 Experiment

The experiments have been performed at SES200 station at BL-13B. The substrate Si(111)√3×√3-B surface was obtained after resistive flashing and consequent annealing at 980 K and 680 K, respectively, and gradual cooling to room temperature (RT). Bi was evaporated from a Knudsen cell. The substrate was kept at RT during the evaporation. ARPES measurements have been performed at RT with the incident photon energy of 51 eV along the Γ-M line of one of the six rotational Bi(110) domains. The growth of Bi(110) islands and morphology on the surface was confirmed by in-situ low-energy electron diffraction and ex-situ atomic force microscopy (AFM), respectively. The total coverage of Bi and Bi(110) island heights on the wetting layer were estimated from AFM images.

3 Results and Discussion

Figure 1 shows AFM images and corresponding band structures of Bi(110) ultra-thin films in Γ-M direction for 10 ML and 4.6 ML coverages, respectively. The heights of the islands on the two samples were estimated to be 13±5 ML and 7±4 ML, respectively, from AFM observations.

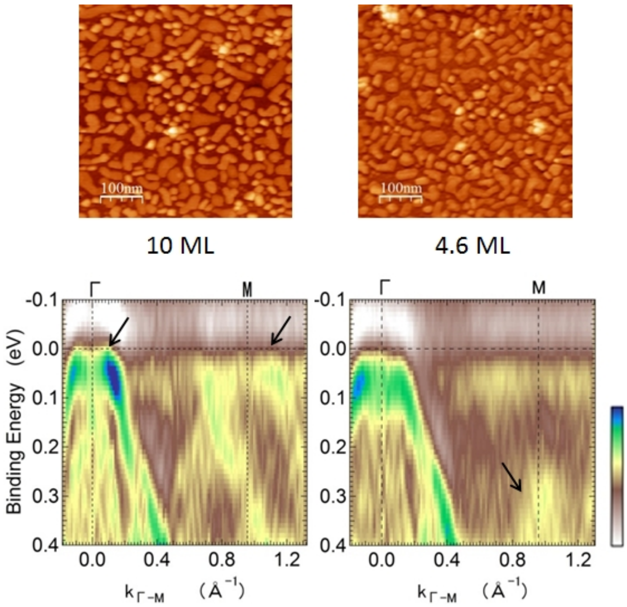

Fig. 1: AFM images and corresponding band structures of Bi(110) ultra-thin films in Γ-M direction for 10 ML and 4.6 ML coverages, respectively. The second derivatives of the photoelectron intensity maps are shown.

The thicker (10 ML) film has metallic hole-like states around the Γ and M points as shown by the arrows in the band structure. The dispersion of these states are similar to those reported on the bulk Bi(110) crystal[5] although the Fermi wave number is smaller. These metallic states disappear for the thinner (4.6 ML) film with less than 10 ML height islands. Dirac-cone-like band characteristic for the bulk-like structure was not observed around the M point although small signals still exist just below the Fermi energy (E_F). As shown by the arrow in the figure, the uppermost band around the M point appears at about 0.3 eV from E_F, which is similar to the calculated band structure for 8 ML height film of BP-like structure. Considering the preferential growth of even-layer-height islands in the STM observations, the present results suggest that the even-layer-height Bi(110) islands below 10 ML height have BP-like internal structure.

4 Summary

We have investigated the electronic structure of Bi(110) ultra-thin films grown on a Si(111)√3×√3-B surface. Thicker films have metallic surface states similar to those reported on the bulk Bi(110) crystal. Thinner films with less than 10 ML height islands do not have Dirac-cone-like state around the M point but rather have band structures similar to the calculated ones for BP-like structure.

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References

[1] S. Murakami, *Phys. Rev. Lett.* **97** 236805 (2006).
[2] Y. Lu *et al.*, *Nano Lett.* **15** 80 (2015).
[3] I. Kokubo *et al.*, *Phys. Rev. B* **91** 075429 (2015).
[4] G. Bian *et al.*, *Phys. Rev. B* **90** 195409 (2014).
[5] Ph. Hofmann, *Surf. Sci.* **81** 191 (2006).

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