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Angle-resolved photoemission study of ultrathin $Bi_{1-x}Sb_x$ films

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Introduction

Recently there has been growing interest in *topological insulators* or the *quantum spin Hall (QSH) phase*, which are insulating materials with bulk band gaps but have metallic edge states that are formed topologically and robust against any non-magnetic impurity [1]. In a three-dimensional material, the edge states become surface states and it was said that spin-split surface states of group V semimetals [2] are promising candidates for such edge states [1,3]. However as the bulk electronic structure of these materials is not exactly an insulator, the surface-state band dispersion does not fulfill the criteria for the QSH phase edge states. There have been some theoretical proposals to open a bulk band gap for these semimetals and to realize a topological insulator [1]. One of them was to alloy antimony (Sb) into bismuth (Bi). Therefore we have prepared ultrathin $Bi_{1-x}Sb_x$ films on a silicon (Si) substrate and measured the band dispersion using angle-resolved photoemission spectroscopy to see if a QSH phase could be realized experimentally.

Experimental

The Si substrate was cut from a mirror polished *n*-type Si(111) wafer (1-10 Ωcm) followed by conventional cleaning procedures in ultrahigh vacuum (UHV) to prepare a clean Si(111)-7×7 surface. Deposition of Bi and Sb was done by resistive heating to tantalum filaments surrounding graphite tube cells. First Bi was deposited onto the Si(111)-7x7 surface at room temperature and after the formation of the (001) phase (6 bilayers (BL)) [4], Bi and Sb were co-deposited. After the deposition, the films were annealed at ~500K which resulted in a $Bi_{1-x}Sb_x$ film showing a sharp 1x1 LEED pattern with strong spectral intensity. Photoemission measurements were performed at KEK-PF BL-18A. The homogeneity of the films (absence of segregation of Sb) and the ratio of Bi and Sb (x) were checked by measuring the Bi 5*d* and Sb 4*d* core level spectra at the photon energy of 50 and 80 eV. Angle-resolved photoemission measurements were performed at hυ=22 eV using a VG-Scienta SES-100 hemispherical analyzer at ~100K.

Results and discussions

Figures (a) and (b) show the band dispersion along theΓM direction for the 16 BL $Bi_{0.89}Sb_{0.11}$ ultrathin film (a), and that for the 50 BL $Bi_{0.85}Sb_{0.15}$ ultrathin film, respectively. The electronic structure near the Fermi level is dominated by the surface states and additionally, we can observe quantum-well states in (a). The surface-state band dispersion is similar to that of the unalloyed Bi surface state shown in Ref. [2] with four Fermi level crossings as shown in the figures. In the case of a QSH phase, there should be an odd number of Fermi level crossings theoretically [1]. Therefore we conclude that in our experimental condition, we could not realize the QSH phase. Further detailed studies changing the alloy composition and the film thickness as well as higher resolution measurements may be needed to confirm if topological insulators can be realized experimentally.

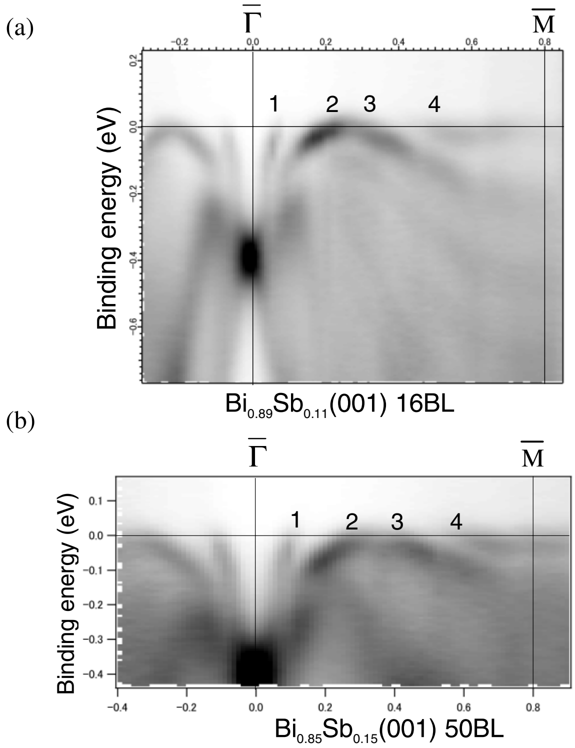

Figure: Band dispersion along the ΓM direction of the 16 BL $Bi_{0.89}Sb_{0.11}$ ultrathin film (a), and that for the 50 BL $Bi_{0.85}Sb_{0.15}$ ultrathin film.

References

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