Electronic structure of the α-Bi/Si(111)-(√3×√3) surface

Yuta Yamamoto1, Takuya Kuzumaki1, Yusuke Tanaka2, Kunihiro Hotta1, Ayumi Harasawa3, Nobuo Ueno1, Kazuyuki Sakamoto1*
1Graduate School of Advanced Integration Science, Chiba University, Chiba 263-8522, Japan
2Department of Chemistry, Nagoya University, Nagoya 464-8602, Japan
3The Institute for Solid State Physics, the University of Tokyo, Chiba 277-8581, Japan

The electronic structure of a 1/3 monolayer Bi adsorbed Si(111)-(√3×√3) surface (the α-phase) has been investigated by angle-resolved photoemission measurement. A large Rashba spin splitting with a Rashba parameter ($\alpha_R$) of 2.2 eVÅ was observed at the $\Gamma$ point.

Introduction

On a two-dimensional (2D) system such as surface, a spin polarized 2D electron structure that originates from a combined effect of structural inversion asymmetry (SIA) and spin-orbit interaction (SOI) is formed even for nonmagnetic materials. This effect, which is called the Rashba-Bychkov (RB) effect [1] or simply Rashba effect, is the key concept for spintronic devices, devices that use the spin degree of freedom of an electron in addition to its charge to add substantially new functionalities in electronic devices. The RB effect was observed on clean surfaces of noble metals [2] and heavy group V elements [3], and has reported to be enhanced in systems in which heavy element atoms are adsorbed on light element substrates [4]. The heavy element Bi adsorbed light element Si surface is a candidate to show exotic RB effect. Bi adsorption induces two different (√3×√3) phases on Si(111) depending on the coverage. The (√3×√3) surface formed at a coverage of 1 monolayer (ML) is called the β-phase, and the one formed at 1/3 ML is called the α-phase (the atomic structures of the two phases are shown in Fig. 1 [5]). Of these two phases, the β-phase has been reported to show peculiar RB splitting that originate from the C3v symmetry of this surface [6]. The α-phase has the same symmetry, and thus has possibility to show interesting phenomena as well. Further, a study on systems that are formed by the same elements and have the same symmetry but with different adsorbate coverage would give important information about the origins of the exotic RB effects.

Experimental details

The angle-resolved photoelectron spectroscopy (ARPES) measurements have been performed at BL18A of KEK-PF, using a photon energy of 40 eV. In order to obtain a clean surface, the sample was annealed at 1520 K by direct resistive heating in the vacuum chamber. After the annealing, the sample showed a sharp (7x7) LEED pattern with low background intensity, and no trace of contamination has been observed in the photoelectron spectra. The α-Bi/Si(111)-(√3×√3) (hereafter α-√3) surface was prepared by depositing Bi on a clean Si(111) surface at a substrate temperature of 600 K, followed by an annealing at 900 K. The formation of the α-√3 surface was confirmed by LEED and photoemission.

Figure 0: Schematic illustrations of (a) the α-Bi/Si(111)-(√3×√3) surface and (b) β-Bi/Si(111)-(√3×√3) one.
**Results and Discussion**
Figure 2(a) shows the surface Brillouin zones (SBZs) of the Si(111)-(1x1) and $\alpha$-$\sqrt{3}$ surfaces, and the energy band structure of $\alpha$-$\sqrt{3}$ measured along the $\Gamma$-$\bar{M}$ direction is shown in Fig. 2(b). A large RB splitting is clearly observed in Fig. 2(b) at the $\Gamma$ point. The momentum offset of the band top ($k_0$) is ca. 0.09 Å$^{-1}$, and the Rashba energy ($E_R$; the energy difference between the band top and the binding energy at the $\Gamma$ point) is ca. 0.1 eV. By using these values and the relation between the Rashba parameter ($\alpha_R$) and $k_0$ and $E_R$, $\alpha_R \approx 2E_R / k_0$, we obtained $\alpha_R \approx 2.2$ eVÅ. This value is almost the same as that of the RB splitting observed at the $\bar{M}$ point on the $\beta$-phase (2.3 eVÅ) [6] though the Bi coverage is quite different on the two surfaces. This result suggests that the amount of adsorbate would not contribute to the origin of the large RB effect observed on heavy element adsorbed light element substrates.

**Summary**
We have investigated the electronic structure of the $\alpha$-$\sqrt{3}$ surface by ARPES. A large Rashba spin splitting with $\alpha_R \approx 2.2$ eVÅ, whose value is almost the same as that of the RB splitting observed on the $\beta$-phase, was observed at the $\Gamma$ point.

![Figure 2](image_url)

Figure 2: (a) Surface Brillouin zones (SBZ’s) of Si(111)-(1x1) (solid lines) and ($\sqrt{3}$x$\sqrt{3}$) (dashed lines). (b) Band structure of the $\alpha$-$\sqrt{3}$ surface measured using a photon energy of 40 eV.

**References**