Spin-polarized metallic surface states on Tl/Si(111)-(1×1)

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Introduction

The spin polarized electronic states observed on non-magnetic two-dimensional electron systems is one of the exotic low-dimensional physical phenomena. The effect that leads to the formation of spin-polarized electron bands, which originate from the spin-orbit interaction and the symmetry broken, are called Bychkov-Rashba (EB) effect or simply Rashba effect [1]. This 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 Rashba effect has not only a fundamental physical interest but also an interest in its application since this is the key concept for operating spintronic devices, devices in which the spin degree of freedom of an electron is used in addition to its charge degree of freedom. In our former study we have found that the spin-polarization vector of the Rashba spin, which was believed to be parallel to the surface and perpendicular to the wave vector, can rotate and point along the surface normal direction depending on the symmetry of the surface in a semiconducting system [5].

In this study, we show that a metallic surface state with upstanding spin can be formed on a surface with C_3 symmetry by using spin- and angle-resolved photoelectron spectroscopy (SARPES).

Experimental details

The SARPES measurements have been performed at beamline BL-19A at KEK-PF, a beam line equipped with a very low energy electron diffraction (VLEED) system [6], using a photon energy of 21.2 eV. The metallic surface on a semiconducting substrate was prepared in the following way. We first cleaned a Si(111) substrate by annealing at 1520K in ultra-high vacuum, and deposited 1.5 ML of Tl on top of it. After that we annealed the surface at approximately 500 K to form the Tl/Si(111)-(1x1) surface, and doped electron to the surface.

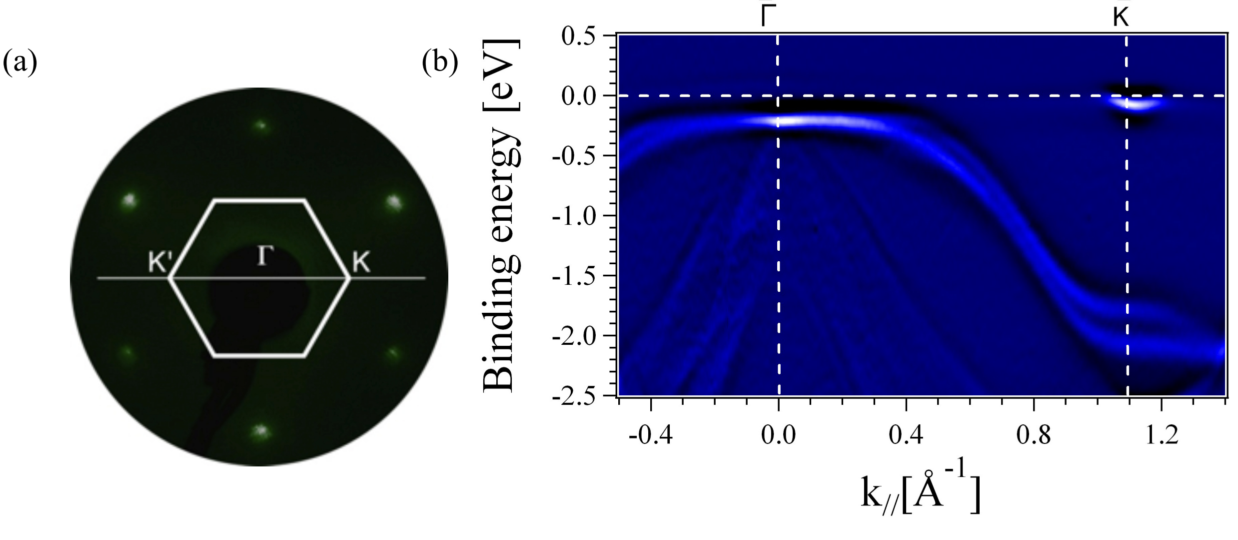

Figure 1: (a) LEED pattern of the Tl/Si(111)-(1x1) surface. (b) Band structure of Tl/Si(111)-(1x1) measured using a photon energy of 30eV.

Results and discussion

Figure 1(a) shows the LEED pattern and surface Brillouin zone (SBZ) of the obtained surface. The spin-integrated ARPES study of electron doped Tl/Si(111)-(1×1) surface measured along the Γ-K-M direction is shown in Fig. 1(b). The shapes of the no metallic bands resemble the one of non-doped Tl/Si(111)-(1×1) [5]. A peculiar Rashba splitting with spin polarization vector perpendicular to the surface was observed on the no metallic surface-state at the K point. Since this peculiar upstanding Rashba spin originates from the C_3 symmetry of the K point, a similar spin orientation is expected for the metallic band at the K point.

The SARPES spectra measured around the K point are shown in Figure 2(a). The spectrum obtained at an emission angle (θe) of 31° roughly corresponds to the K point at the Fermi level. A metallic band, whose binding energy (E_B) is approximately 0.1 eV at the K point, is clearly seen in the spectra of down spin state, while no metallic state is observable in those of up spin state in Fig. 2(a). On the other hand, a metallic band is only observed in the spectra of up spin state in the SARPES spectra around the K' point (Fig. 2(b)). Together with these metallic bands, spin-polarized states that were reported to have spin-polarization vector perpendicular to the surface [5] are also observed at E_B~2.0 eV. Taking the spin-polarization vectors of these states and the geometry of the experimental setup, we conclude that the polarization vector of the observed spin-polarized metallic bands is perpendicular to the surface.

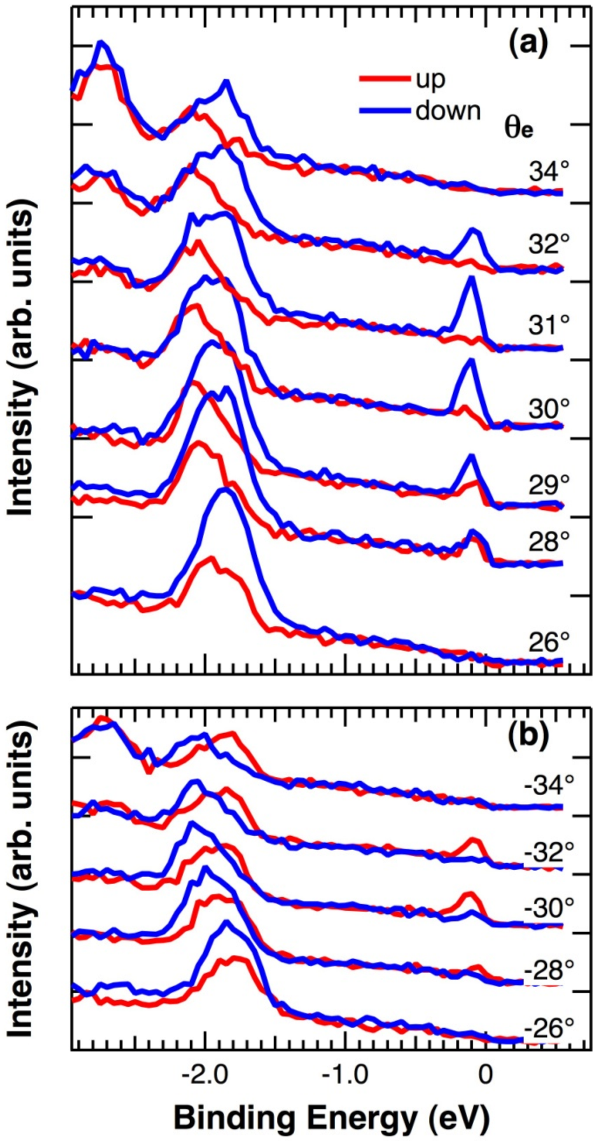

Figure 2: SARPES spectra measured using a photon energy of 21.2 eV around the (a) K and (b) K' points.

References

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