18A, 19A/2011G085

Spin-polarized surface states localized in subsurface layers of Pb/Ge(111)

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Introduction

Discovery of the Rashba effect at solid surfaces has been attracting significant interests because of a possibility of new physics related with surface spin transport/accumulation. Here, the size of spin splitting is orders of magnitude larger than those in semiconductor heterojunctions. Most of the known surface Rashba systems were based on the surfaces containing heavy element atoms. However, recently, we have discovered the spin-polarized surface states localized in subsurface layers of the Ge substrate on Br/Ge(111), Tl/Ge(111) and Bi/Ge(111) due to the surface Rashba effect [1-3]. In the present study, we report that such spin-polarized surface states are also formed in one-monolayer Pb adsorbed Ge(111) (Pb/Ge(111)-β) system.

Experiment

Angle-resolved photoelectron spectroscopy (ARPES) and spin- and angle-resolved photoelectron spectroscopy (SARPES) were performed at KEK-PF BL19A. The sample temperature was maintained at room temperature during the measurements. A Ge(111) substrate was prepared by several cycles of Ar^+ bombardment with 0.5 kV and annealing up to 900 K for a few seconds. Pb was deposited onto the surface at room temperature, which was then annealed at 570 K for three minutes to prepare a well-ordered wide terrace of Pb/Ge(111)-β [4, 5].

Results and discussion

Figure (a) shows an ARPES image recorded with the photon energy of $h\nu$ = 25 eV along $\bar{\Gamma}\bar{M}$ direction of $(\sqrt{3}\times\sqrt{3})R30°$ surface Brillouin zone. We found three Ge-derived bands named S_a, S_b and S_c, where the bands disperse near the projected bulk band edges. These bands show no photon energy dependence, indicating that S_a–S_c are surface states and surface resonances. The shapes of the band structures are quite similar to that observed in Bi/Ge(111) [1] and Br/Ge(111) [2] except for the band energy. We note that the S_a band of Pb/Ge(111)-β crosses the Fermi level. The spin structures were investigated by SARPES, shown in Fig. (b). Here, the spin-polarized S_c band is clearly observed by SARPES. We first recognize that up- and down-spin states are degenerate at $\bar{\Gamma}$. Next, the down-spin states are found with the wave vector cuts of l_1 and l_2. On the other hand, the up-spin states are prominent for l_4 and l_5. The peak positions of the spin-up and spin-down of S_c are thus inverted with respect to $\bar{\Gamma}$. We therefore conclude that the S_c band shows the Rashba-type spin structure. Our findings clearly show that the significant spin polarization of the surface electronic states of semiconductor can be obtained.

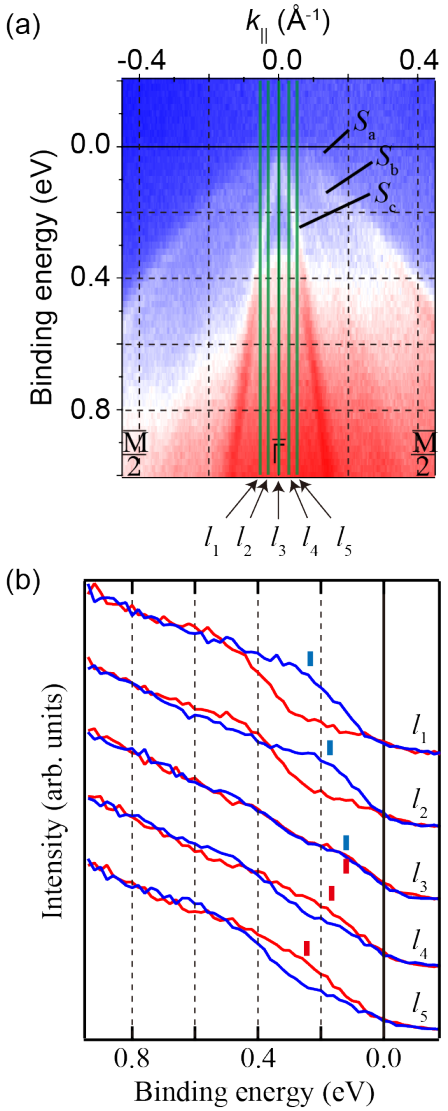

Figure (a) ARPES image of Pb/Ge(111)-β taken with the photon energy of 25 eV. (b) SARPES spectra taken along thin solid (green) lines, l_1-l_4, shown in (a). Red and blue spectra represent the up- and down-spin states, respectively.

References

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