SARPES study of the spin-polarized surface bands on Br/Ge(111)-(1×1)

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1. Introduction

Spin-polarized electronic states are gathering much attention because of the possible application to spin transport [1]. The spin splitting of the surface states due to the Rashba effect [2] is one of the subjects extensively studied for such spin transport. Most of the studies of the surface spin polarization have been performed on the materials containing heavy elements, such as Bi and Pb. The spin polarization derived from light elements has been assumed to be very small and hence paid less attention.

Recently, we have discovered the spin-polarized surface states on Bi/Ge(111) [3]. The first-principles calculation showed that the spin-polarized states are localized in Ge subsurface layers, suggesting that the similar spin-polarized states would be formed on other Ge(111) surfaces irrespective of the atomic number of the adsorbate atoms. Further investigation on Ge(111) surfaces would give detailed information about the spin-polarized states localized in subsurface region. Along this line, we have investigated the spin-polarized electronic structure on the Ge(111) surface terminated by Br, which belongs to the same row as Ge in the periodic table.

2. Experimental

The spin- and angle-resolved photoelectron spectroscopy (SARPES) experiments were performed in ultra-high vacuum system at BL19A of KEK-PF with a SPECS Phoibos-150 hemispherical analyzer equipped with a homemade high-yield spin polarimeter using spin-dependent very-low-energy electron diffraction (VLEED) [4]. The clean Ge(111) surface was prepared by repeated cycles of Ar ion sputtering and annealing up to 900 K until a sharp low-energy electron diffraction (LEED) pattern was obtained. Molecular Br_2 was produced by an electrochemical AgBr cell [5] and typical fluence was 40 μA min. During exposure, the Ge(111) sample was kept at 540 K. The sample was maintained at 540 K after stopping the exposure, which yielded sharp (1×1) LEED patterns. The atomic structure of Br/Ge(111) is shown in Fig. 1 (b).

3. Results and discussion

Figure 1(a) shows the band dispersion near Γ along ΓK measured by ARPES (taken at Kyoto). We identified two surface bands, S_1 and S_2. They were observed at almost the same energies with two different photon energies.

We measured the spin-resolved momentum distribution curves (MDCs) at a binding energy of 0.2 eV (see the dashed line in Fig. 1(a)) along $\bar{\Gamma}\bar{K}$. The VLEED spin polarimeter was set to be sensitive to the spin polarization perpendicular to ΓK and the surface normal. This spin polarization direction is consistent with that expected from Rashba effect.

Triangle markers in Fig. 1(a) represent the peak positions in the spin-resolved MDCs. There are two pairs of peaks at ±0.02 $Å^{-1}$ and ±0.15 $Å^{-1}$. The outer pair corresponds to S_1 and the inner pair to S_2. The spin polarization direction corresponding to each peak is inverted with respect to Γ. The spin-polarization inversion is consistent with the surface mirror symmetry, showing that these spin polarization is not due to the photoelectron excitation process [6]. The first-principles calculation reproduced the observed spin-polarized surface bands and showed that the spin-polarized bands are formed by the Shockley-type mechanism [7].

References

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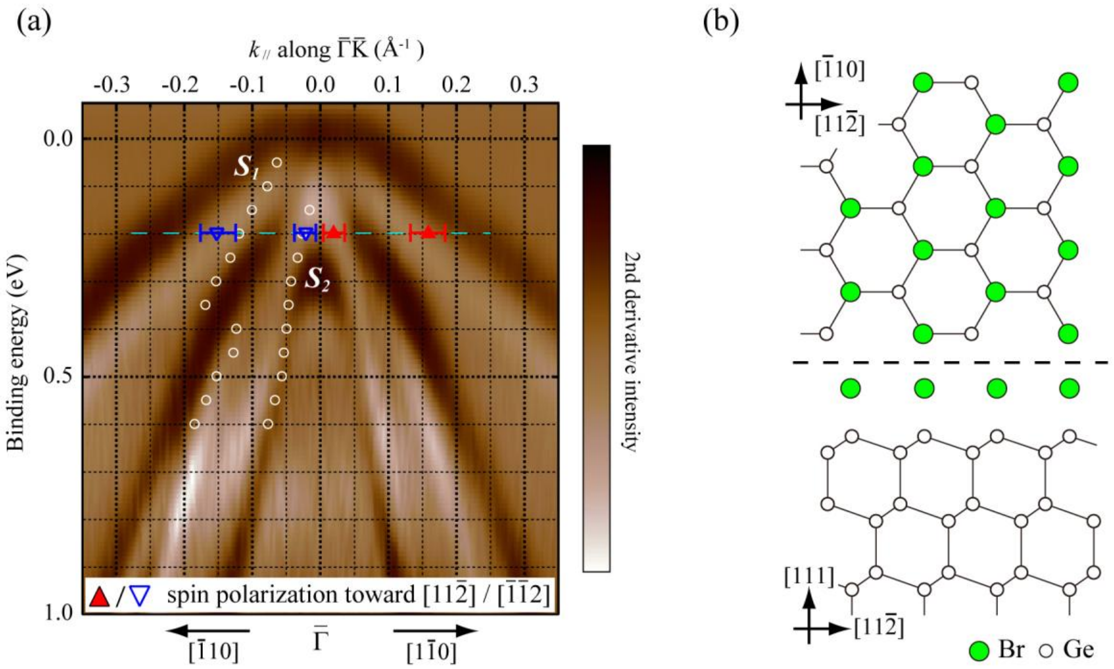

Figure 1 (a) Second-derivative ARPES image measured with $h\nu$ = 21.2 eV (grayscale) with ARPES peak positions taken with $h\nu$ = 40.8 eV (white circles). A dashed line indicates the region where the spin-resolved MDCs were measured. Triangles represents the peak positions on the spin-resolved MDCs. (b) The top and side views of the Br/Ge(111)-(1×1) surface.