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Electronic structure of the Pb-covered bilayer Ge film on Si(111)

Shinichiro HATTA[1,2*], Yukihiro HAYASHI[1],
Takashi NOMA[1], Tetsuya ARUGA[1,2]
[1]Department of Chemistry, Graduate School of Science, Kyoto Univ., Kyoto 606-8502, Japan
[2]JST CREST, Saitama 330-0012, Japan

Introduction

Crystal surfaces and monolayers exhibiting large spin splitting due to the Rashba spin-orbit interaction (SOI) have been studied intensively in the last decade. Among them, semiconductor surfaces with metallic spin-split states are desired, because it allows us to address the issue of electric transport under the Rashba SOI. Recently, the Pb/Ge(111)-β-($\sqrt{3}\times\sqrt{3}$)R30° surface was found to have a metallic surface state with large Rashba-type spin splitting[1]. The superstructure consists of the dense Pb monolayer (4/3 ML) on the bulk-truncated Ge(111) substrate[2]. On the other hand, the strained Ge(111) thin film grows epitaxially on Si(111). In this study, we explore the electronic structure of the Pb-induced superstructure on Ge/Si(111) using angle-resolved photoemission spectroscopy (ARPES) and spin-resolved ARPES (SR-ARPES).

Experimental

The ARPES and SR-ARPES measurements were performed at BL-19A using the hemispherical electron analyzer (PHOIBOS 150, SPECS) and the very-low energy electron diffraction (VLEED) spin detector. A Si(111) substrate was cleaned by annealing at ~1050°C. Ge was deposited on the room-temperature Si(111)-(7×7) surface followed by annealing at 900 K, yielding a sharp (5×5) low-energy electron diffraction (LEED) pattern. The superstructure is constructed of the single Ge bilayer with the well-known dimer-adatom-stacking-fault geometry. We deposited Pb of ~2 ML on the (5×5) surface. The ($\sqrt{3}\times\sqrt{3}$)R30° superstructure appeared after post-annealing at 540 K.

Results and discussion

Figure 1(a) shows the ($\sqrt{3}\times\sqrt{3}$) surface Brillouin zones. We measured the band dispersions along the $\Gamma_0M_0\Gamma_1$. Figure 1(b) shows the ARPES intensity map at M_0–Γ_1 measured at room temperature. It is found that a state, labeled S1, disperses from 0.7 eV to the Fermi level (E_F) in the bulk band gap. The Fermi wavevector of the surface state was determined to be 0.41 Å^{-1} from Γ_1. In Fig. 1(b), two other bands, labeled S2 and S3, are seen. The observed band structure is very similar to that of Pb/Ge(111)-β, indicating that the Pb/Ge overlayer on Si(111) has the same atomic geometry of Pb/Ge(111)-β.

Comparing details of the band dispersions on the two ($\sqrt{3}\times\sqrt{3}$) surfaces, it was found that the S1 dispersion on Pb/Ge/Si(111) is steeper than that on Pb/Ge(111)-β. According to the first-principles calculations, the S1 state is derived mainly from the in-plane Pb 6p orbitals. The increase of the dispersion may reflect the contraction of the Pb-Pb distances, since the unit cell of the single Ge(111) bilayer is smaller than that of bulk-truncated Ge(111) by 4%.

Another considerable difference was found on the spin splitting of S1. While the spin splitting on Pb/Ge(111)-β is 0.2 eV near E_F, splitting was not identified in the ARPES spectra of Pb/Ge/Si(111). Figure 1(c) shows the SR-ARPES spectra of Pb/Ge/Si(111) measured at 100 K. While the S1 feature is seen above 0.4 eV, the spin splitting is not resolved, indicating that it is considerably smaller than that of Pb/Ge(111)-β.

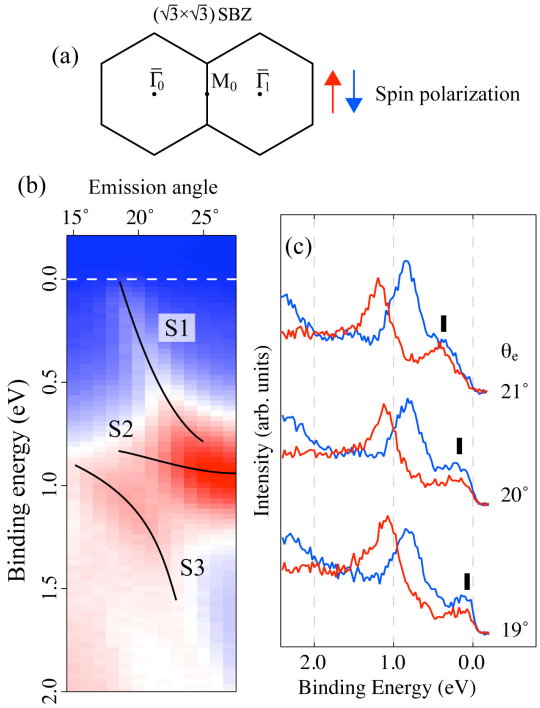

Fig. 1. (a) Surface Brillouin zones of ($\sqrt{3}\times\sqrt{3}$)R30°. (b) An ARPES intensity map as a function of emission angle and binding energy. (c) SR-ARPES spectra at the emission angles of 19°, 20° and 21°. The measured spin polarization is indicated by the colored arrows in

References

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* hatta@kuchem.kyoto-u.ac.jp