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ARPES study of low-dimensional structures on Tl/Ge(111)

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Introduction

Reconstructed semiconductor surfaces induced by metal adsorption have gained much attention because they have shown interesting physical properties particular to low-dimensional systems. Adsorption of thallium on Ge(111) induces two phases at room temperature [1]. The (3×1) surface at 1/3 ML has a one-dimensional chain structure, as observed on the alkali-metal induced (3×1) surfaces. On the other hand, the structure of the (1×1) surface at 1 ML is a pseudomorphic (1×1) structure, indicating that this surface may be a well-confined two-dimensional system in the surface region. Scanning tunneling spectroscopy (STS) measurements on these surfaces imply that these surfaces have a very narrow gap or a metallic character. We investigated the electronic structures of these surfaces by angle-resolved photoelectron spectroscopy (ARPES).

Experimental

The ARPES measurements were performed at beam line 18A. We used a vicinal Ge(111) substrate tilted from [111] by 1.5° toward the [$\bar{1}\bar{1}2$] direction for the preparation of the single-domain (3×1) surfaces. The substrate was cleaned by cycles of Ar-ion sputtering (700 eV) and annealing (<950 K) by direct current heating. Tl was deposited on the substrate from an alumina crucible. When the (3×1) surface was prepared, following the deposition, the surface was annealed to ~550 K for a few minutes. In the case of the (1×1) surface, moderate annealing (<400 K) was adopted in order to obtain a well-ordered surface and suppress the partial formation of the (3×1) structure. The sample surfaces were checked by low-energy electron diffraction (LEED) and ARPES. All the ARPES measurements were performed at room temperature.

Results and discussion

Figure 1 shows a set of spectra along the $\overline{\Gamma}-\overline{K}$ line for the Tl/Ge(111)-(1×1) surface. The data were taken at $h\nu = 22$ eV. The Fermi level (E_F) at an emission angle of ~29˚ corresponds to the $\overline{K}$ point. Three surface bands, which pass over gap regions of the projected bulk bands, are observed. They are labeled S1, S2 and S3, as shown in Fig. 1. S1 disperses to higher binding energies with a minimum energy of 1.5 eV at the $\overline{K}$ point. Although the dispersion of S2 is roughly parallel to that of S1 with the difference of ~1.4 eV, its minimum is located at ~0.7 $\overline{\Gamma K}$. S3 disperses to lower binding energies with a maximum

energy of 5.7 eV at the $\overline{K}$ point. Beside these bands, a nondispersive band lies at 0.9 eV. This is labeled as S_E in Fig. 1. This band is tentatively assigned to electronic states localized at step edges intrinsic to the vicinal substrate.

The S1 and S2 bands have a *p*-orbital character. The S1 band with higher energies is assigned to a dangling bond band. Our measurements show that the S1 band is not fully occupied in the surface Brillouin zone. That is, the (1×1) surface has a metallic character.

For the single-domain (3×1) surface, we obtained the ARPES spectra both parallel ($\overline{\Gamma}-\overline{C}$) and perpendicular ($\overline{\Gamma}-\overline{A}$) to the chains. A surface band observed on the $\overline{\Gamma}-\overline{C}$ line showed the E_F crossing near the $\overline{\Gamma}$ point. This is quite different from the results for the alkali-metal induced (3×1) surfaces which are semiconducting. In order to understand the origin of the difference, further analysis of the ARPES data is now in progress.
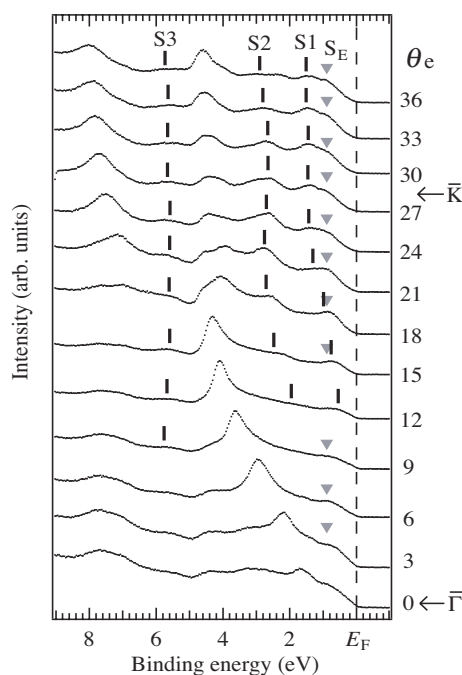

Fig. 1. ARPES spectra along the $\overline{\Gamma}-\overline{K}$ line for the Tl/Ge(111)-(1×1) surface.

References

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