Electronic states of Ge(001)-(4×2)-Pt structure studied by angle-resolved photoelectron spectroscopy

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Metallic nanowire consisting of a monatomic chain on semiconductor surfaces is one of the candidates for the extreme miniaturization of electronic circuits. There are of great interests for the reduction in size of electronic devices and also for the understanding of physical properties associated with one-dimensional systems.

In recent year, Gurlu *et al.* have reported that the monatomic nanowire is constructed on the Ge(001) surface by depositing a sub-monolayer Pt atoms [1]. The self-assembled nanowire is composed of the topmost ad-dimers of the Ge(001)-(4×2)-Pt structure in sub-micrometer scale without defects. It has also been reported that the nanowires undergo the Peierls-type phase transition around 80 K by the scanning tunneling microscopy/spectroscopy (STM/S) study [2]. On the other hand, the atomic configuration and the electronic states of the Pt/Ge(001) surface are still under debate. The reason is partly due to the lack of fabrication techniques for a well-defined Pt/Ge(001) surface. The well-defined surface is necessary to determine the atomic configuration and the electronic states.

Schäfer *et al*. have lately reported that the well-defined Pt/Ge(001) surface is obtained by the Pt deposition on the Ge(001) suface in the 'hot-substrate' condition [3]. By the reflection high-energy positron diffraction (RHEPD) study [4], we have found that the atomic configuration of the Pt/Ge(001) surface is explained by the nanowire (NW) model containing 0.75 monolayer (ML) of Pt atoms (Fig. 1), which is theoretically proposed by Vanpoucke *et al*. [5]. On the contrary, the electronic states of the Pt/Ge(001) surface is still unresolved. In the present study, we have investigated the electronic states by the ARPES.

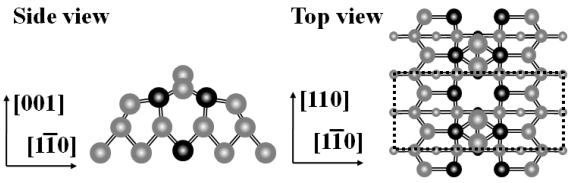

Fig. 1 Ball-and-stick representations of NW model. Black and gray balls show Pt and Ge atoms, respectively. The dotted square indicates the 4×2 unit cell. This model contains 0.75 ML of Pt atoms.

The ARPES observations were performed at BL-18A of KEK-PF (Institute for Solid State Physics, University of Tokyo). The ARPES spectra were measured along [110] direction at room temperature (RT). The linearly polarized light was used with the photon-energy of 34 eV. The angular and energy resolutions were less than 0.3° and 0.08 eV, respectively. To produce a well-defined Ge(001)-(4×2)-Pt structure, 1.2 ML of Pt atoms were deposited on the clean Ge(001) surface kept at 623 K [4], where 1 ML corresponds to 6.3×10^{14} atoms/cm^2.

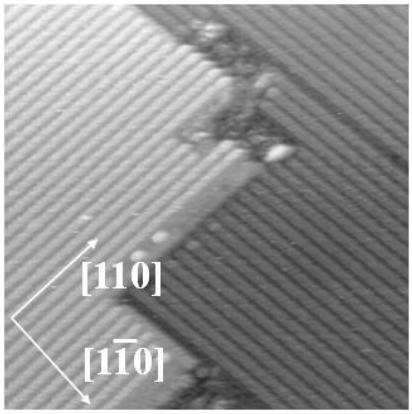

Fig. 2 STM image of well defined Pt/Ge(001) surface at RT. The size of the image is 50 × 50 nm^2. The sample bias voltage and the tunneling current were −1.5 V and 0.5 nA, respectively.

Figure 2 shows the STM image from the Pt/Ge(001) surface. Nanowires cover the whole

surface with a long range order of a p(4×2) periodicity [4]. The Ge(001)-(4×2)-Pt structure shows a double domain where the nanowires are lengthened along the [110] and the [$1\bar{1}0$] directions reflecting the double domain structure of the substrate.

Figure 3(a) shows the valence-band structure near the Fermi energy (E_F) obtained from the second derivative of the ARPES spectra [4]. In the experimental condition, the signals include both of the two domains. Below E_F, the parabolic surface-state is observed as indicated by the white allow. The weak intensity of a half of the parabolic state may be caused by using the polarized light. From the peak fitting with the Lorentz functions, the bottom of the parabolic state corresponds to the binding energy of -0.12 eV at the wave-number, k of 0.2 Å^{-1}. The metallic band also appears at k= -0.2 Å^{-1}. The both positions correspond to the J' point of the surface Brillouin zone (SBZ) as indicated in Fig. 3(b). The feature agrees with the calculated band structure of the NW model with the Pt coverage of 0.75 ML in Ref. 5. This result suggests that the Pt/Ge(001) surface is metallic along Γ-J' direction, that is, perpendicular to the nanowire. The metallic state may cause the quantum-well state in the trough between the nanowires [6]. Hence, the ARPES study also shows that the atomic configuration of the Pt/Ge(001) surface is explained by the NW model.

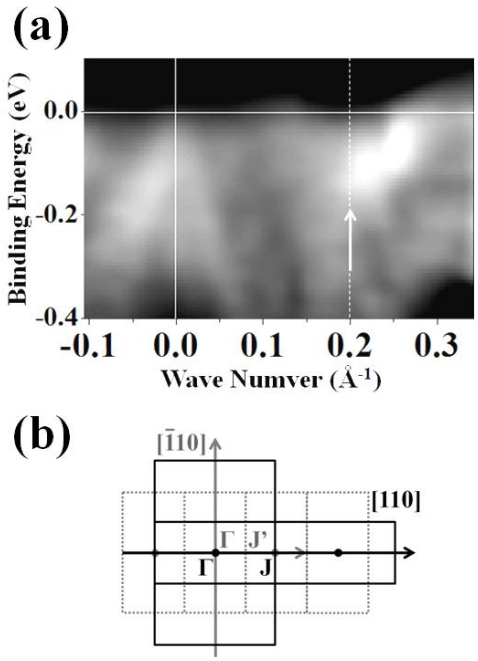

Fig. 3 (a) Valence-band structure of well defined Pt/Ge(001) surface close to E_F. Photoemission intensity is larger in the brighter area. The Γ point of SBZ is indicated by solid line. The white dotted lines are the zone boundaries of SBZs in another domain. (b) SBZs of p(4×2) surface. Two domains are indicated by solid and dashed lines.

References

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