

Sb ON In/Si(111) PROCESSES WITH DYNAMICALLY OBSERVABLE LEEM, SELECTED AREA LEED AND CHEMICALLY ANALYZED SR-XPEEM

The formation of the hetero-interface of semiconductors is of importance not merely as industrial requirement but also in the fundamental research aspect. To understand such growth behavior, the knowledge of spatially resolved local properties, such as the structure and chemical state, is required. Low energy electron microscopy (LEEM) and photoemission electron microscopy (PEEM) are quite suitable for this purpose. Low energy electron diffraction (LEED) patterns from the selected local area whose size is on the order of 0.1-1 μm , can be observed using the same LEEM optics to get local structure information. By combining with intense synchrotron radiation (SR), local chemical state analysis is possible using PEEM [1]. Experiments were carried out using a spectroscopic photoemission and low energy electron microscope (SPELEEM) installed in the soft X-ray beamline BL27SU [3].

Figure 1(a) shows a bright-field LEEM image of the prepared In/Si(111) surface. The bright area is the $\sqrt{31} \times \sqrt{31}$ region and the dark area the 3×3 region. The narrower terraces completely show the $\sqrt{31} \times \sqrt{31}$ structure, and the 3×3 terraces are observed centrally with the decoration by the $\sqrt{31} \times \sqrt{31}$ structure at the step edges. Figures 1(b)-1(d) show the bright-field LEEM images during Sb growth on it. The contrast becomes uniform in the initial stage of adsorption, and the first contrast reversal can be observed in Fig. 1(b).

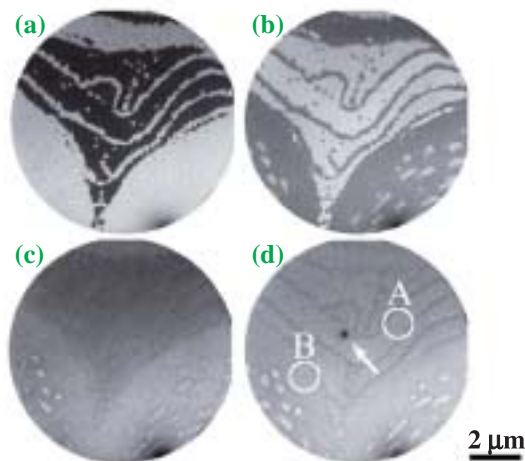


Fig. 1. Series of bright-field LEEM images during Sb adsorption on In/Si(111) surface at around 300 °C. The electron energy was 10.4 eV and the field-of-view was 10 μm . (a) Original In/Si(111) 3×3 (dark) and $\sqrt{31} \times \sqrt{31}$ (bright) surfaces. The Sb coverages are approximately (b) 0.42 ML, (c) 0.7 ML and (d) 0.75 ML.

Two-dimensional islands with the same contrast as that in the initial 3×3 surface also forms on the initial 3×3 surface. By increasing further the amount of Sb deposition, the contrast becomes uniform again, and the second contrast reversal takes place as shown in Fig. 1(c). Such contrast change in bright-field LEEM images is due to the change of the surface structure by Sb adsorption on the 3×3 and $\sqrt{31} \times \sqrt{31}$ structures. After the second contrast reversal, the contrast becomes uniform again and the black dot, which is indicated by the arrow, appears as shown in Fig. 1(d). The deposition of Sb was ended here and this surface was investigated using selected area LEED, SR-XPEEM and selected area XPS.

Figures 2(a) and 2(b) show the SR-XPEEM images taken for In 3d and Sb 3d photoelectrons, respectively. The energy resolution corresponds to 0.6 eV energy width. The photon energy was 530 eV for In 3d and 580 eV for Sb 3d, then the kinetic energy of the photoelectrons imaged was 83.2 eV for In 3d and 49.3 eV for Sb 3d. Duplicated images exposed for 1200 s were simply added to minimize the image blur by sample drift and to get sufficient signal-to-noise ratio. Figure 2(c) shows the bright-field LEEM image taken at an electron energy of 49.3 eV as the reference. The contrast observed in Figs. 2(a) and 2(b) is reversed. The dark region in Fig. 2(c), where the In/Si(111) 3×3 surface was initially located, shows much higher In 3d intensity than the bright region, and vice versa for Sb 3d photoelectrons. The bright region in Fig. 2(c) was initially the In/Si(111) $\sqrt{31} \times \sqrt{31}$ surface, in which the coverage of In is larger than that in the In/Si(111) 3×3 surface. The In 3d intensity distribution in SR-XPEEM image is opposite to the initial In/Si(111) surface.

The difference in the amounts of In and Sb in the dark and bright areas could simply explain the contrast of the SR-XPEEM images. In this case, the removal of In atoms by Sb exposure is required. That is, the In-Si bond is broken and the Sb-Si bond is newly formed. The In-Si bond breaking followed by the formation of the Sb-Si bond occurred. In the present study, the black dot appeared in the LEEM image as shown in Fig. 1(d). The intensity of In 3d photoelectrons around the black dot in the SR-XPEEM image (Fig. 2(a)) is higher than that in the surrounding region. Moreover, the Sb 3d intensity around the black dot in Fig. 2(b) is low. Therefore, the black dot that appeared

Materials Science: Structure

in Fig. 1(d) is considered to be the In island, although it is not known whether the island is a pure In metal one or not. At higher Sb coverage, the formation of a lot of In islands was observed and the surface showed no distinct In 3*d* peaks in the XPS spectrum. Therefore, the formation of an Sb-terminated Si(111) surface by the replacement of In atoms is the most plausible scenario in the present experimental condition.

According to the above mentioned scenario, the chemical interaction of In and Sb atoms with Si might be modified. Then, it is quite interesting to get the local chemical information on the surface. The selected area XPS spectra were investigated for the purpose. Figures 3(a) and 3(b) show the selected area In 3*d* and Sb 3*d* XPS spectra, respectively. The probed areas are indicated by circles in Fig. 1(d). The solid lines show the selected area XPS spectra obtained at the area labeled as A, and the dotted lines at the area labeled as B. The intensity of In 3*d* photoelectrons from area A is larger than that from area B, and vice

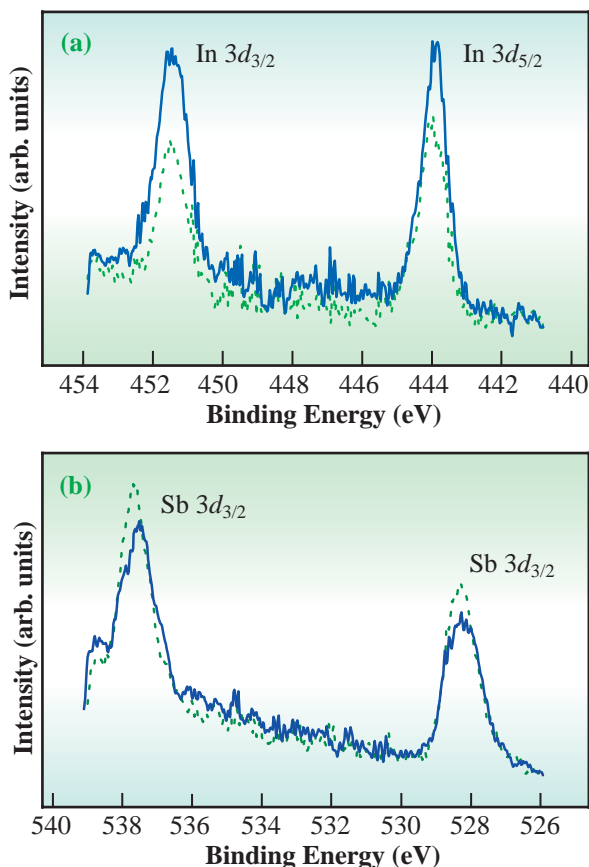


Fig. 3. Selected area (a) In 3*d* and (b) Sb 3*d* XPS spectra obtained in circles shown in Fig. 1(d). The solid lines show XPS spectra taken in A, and the dotted line those in B. The photon energy was 530 eV for In 3*d* and 580 eV for Sb 3*d*.

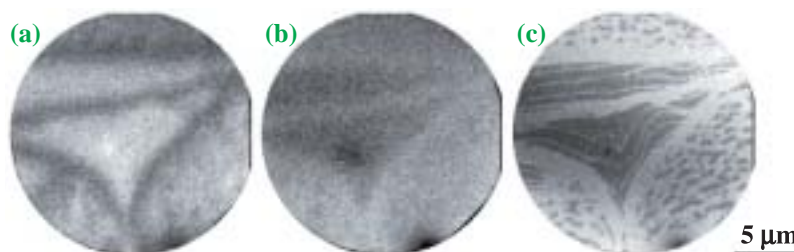


Fig. 2. (a) and (b) show SR-XPEEM images for In 3*d* and Sb 3*d* photoelectrons, respectively. The photon energy was 530 eV for In 3*d* and 580 eV for Sb 3*d*. The field-of-view was 20 μm. (c) Bright-field LEEM image of the same region as reference. The electron energy was 49.3 eV.

versa for the Sb 3*d* signal. The difference in intensity here denotes the quantitative contrast difference in the SR-XPEEM images shown in Fig. 3. The chemical shift, however, is hardly observed in both In 3*d* and Sb 3*d* spectra. Although the 3×3 and $\sqrt{31} \times \sqrt{31}$ surfaces exist on the initial In/Si(111) surface, the chemical environment is almost the same in both surfaces, which has been confirmed by the combined study of selected area XPS using LEEM. The replacement of In atoms by Sb adsorption would result in the simple intensity reduction in In 3*d* signal on both surfaces without any chemical shift. Once the replacement takes place, the chemical interaction of Sb with Si is uniquely determined. Then, the chemical shift for Sb spectra would not be expected as well in the initial stage.

The In coverage in the In/Si(111) $\sqrt{31} \times \sqrt{31}$ surfaces is larger than that in the In/Si(111) 3×3 surface. After Sb exposure, In 3*d* intensity in the initial $\sqrt{31} \times \sqrt{31}$ surface becomes smaller than that in the initial 3×3 surface. This indicates that the exchange rate between In and Sb depends on the surface structure. The exchange in the $\sqrt{31} \times \sqrt{31}$ surface proceeds faster than that in the 3×3 surface as the experimental finding. The reason for the different exchange rates, however, is not well understood at present.

T. Koshikawa^{a,*}, F.-Z. Guo^b and T. Yasue^a

^a Fundamental Electronics Res. Inst. & Academic Frontier, Osaka Electro-Communication University
^b SPring-8 / JASRI

*E-mail: kosikawa@isc.osakac.ac.jp

References

- [1] T.H. Schmidt *et al.*: Surf. Rev. Lett. **5** (1998) 1287.
- [2] H. Hirayama *et al.*: Appl. Surf. Sci. **33-34** (1988) 193.
- [3] F.-Z. Guo, T. Wakita, H. Shimizu, T. Matsushita, T. Yasue, T. Koshikawa, E. Bauer, K. Kobayashi: J. Phys. Condens. Matter **17** (2005) S1363.