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Scanning Tunneling Microscope Study of (001) InP Surface Prepared by Gas Source Molecular Beam Epitaxy

B. X. Yang, Y. Ishikawa, T. Ozeki, and H. Hasegawa

Research Center for Interface Quantum Electronics and Department of Electrical Engineering, Hokkaido University, N13 W8, Sapporo, 060 Japan

(001)InP surface prepared by gas source molecular beam epitaxy (GSMBE) was studied by ultrahigh vacuum scanning tunneling microscopy (UHV-STM). It was found that the P-stabilized (001)InP (2x4) reconstructed surface possesses the missing-dimer structures with at least two microscopic arrangements, α phase and β phase, depending on P coverage, similar to the As-stabilized (001)GaAs (2x4) surfaces. The missing-dimer structures existed even on the partially oxidized surface showing a (1x1) RHEED pattern.

1. INTRODUCTION

The ultrahigh vacuum scanning tunneling microscope (UHV-STM) is a powerful tool for investigating the atomic arrangement on solid state material surfaces. In particular, combination of UHV-STM with a molecular beam epitaxial (MBE) growth apparatus makes it possible to directly observe the microscopic features of reconstructed III-V compound surfaces which are crucial for the growth of high-quality materials and their interfaces. So far many studies[1-6] have been done on GaAs and related materials, but no study has been made on InP surfaces.

The purpose of this paper is to report, for the first time, a UHV-STM study of (001) InP surfaces prepared by gas source (GS) MBE using tertiarybutylphospine (TBP) as the phosphorus source. It was found that P-stabilized (001)InP (2x4) reconstructed surfaces possess at least two kinds of phases, α and β, of missing dimer arrangements, depending on P coverage, similar to the GaAs (001) surfaces.

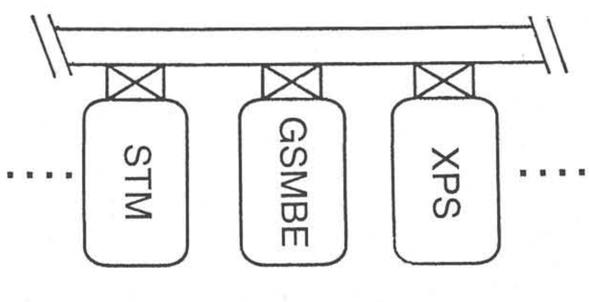


Fig.1 UHV-based multi-chamber system.

2. EXPERIMENTAL

The experiment was carried out in a UHV-based system shown in **Fig.1**, where UHV-STM (JEOL JSTM-4600), GSMBE, and x-ray photoelectron spectroscopy (XPS) are connectedly by a UHV transfer chamber (back pressure < $5x10^{-10}$). The InP layers (about 100 nm) were grown by GSMBE on (001) n^+InP substrates using TBP and metallic In as the sources. Growth was monitored by reflection high-energy electron diffraction (RHEED). RHEED patterns during the growth were streaky (2x4). STM measurements were carried out at room temperature with a constant-current mode (0.2 nA) at sample bias of -2

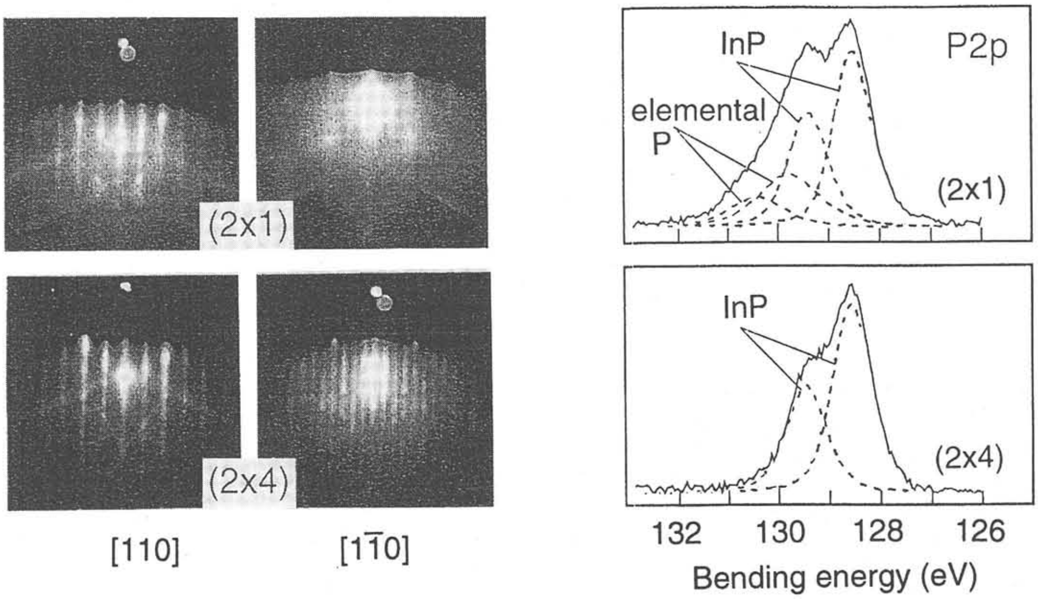
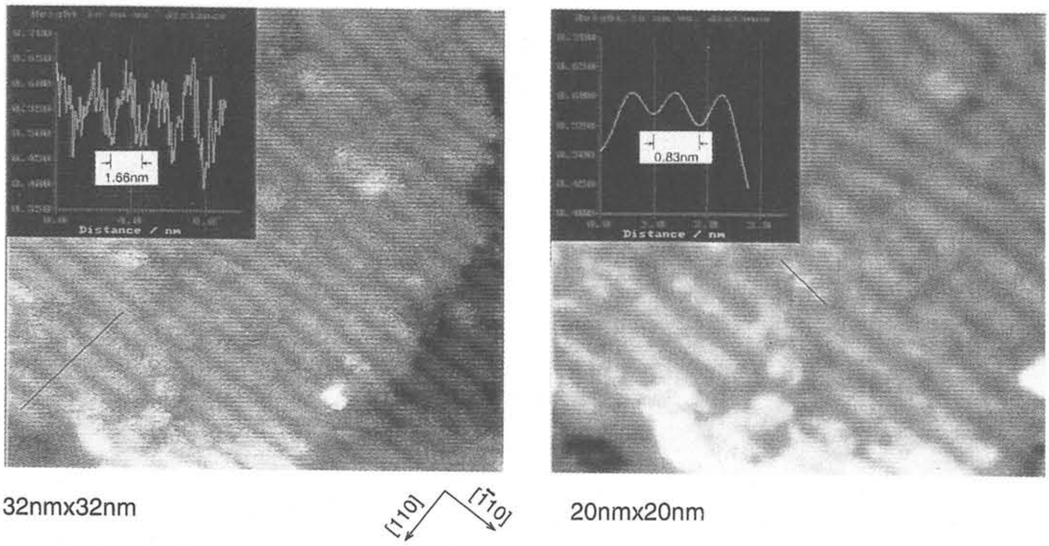


Fig.2 RHEED patterns and XPS spectra of a (2x1) surface after cooling (above) and the (2x4) surface obtained by heating the (2x1) surface at 330°C (below).



(a) (b)

Fig.3 STM images of a (2x4) surface obtained by annealing (2x1) surface at 360 °C. The insets show the line-scans along the lines indicated. High-frequency noise is removed in the inset of (b).

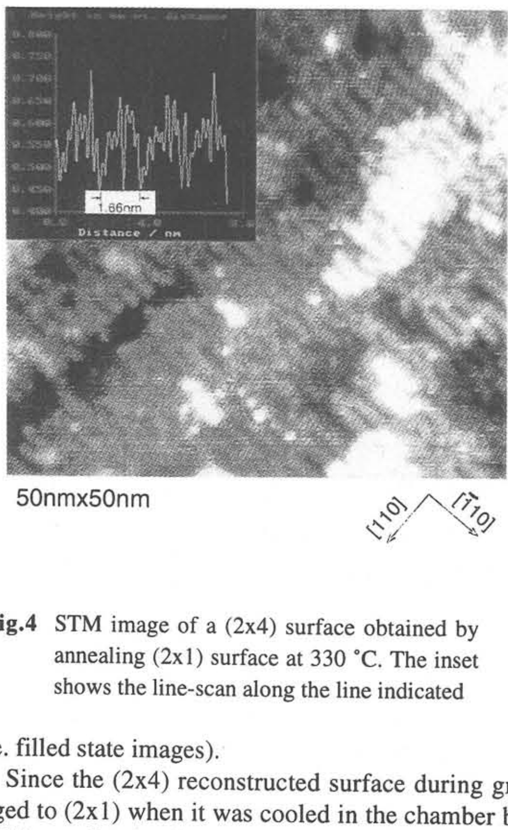


Fig.4 STM image of a (2x4) surface obtained by annealing (2x1) surface at 330 °C. The inset shows the line-scan along the line indicated

V (i.e. filled state images).

Since the (2x4) reconstructed surface during growth changed to (2x1) when it was cooled in the chamber below 300 °C immediately after growth, the (2x4) reconstructions at room temperature were obtained by annealing the (2x1) surface in the GSMBE chamber after the residual P was sufficiently removed. **Figure 2** shows the RHEED patterns and XPS spectra of the (2x1) surface after cooling and the (2x4) surface obtained by heating the sample at 330 °C. It is clear from Fig.2 that heating removes elemental P on the (2x1) InP surface[7] that is deposited on the surface during cooling.

Three kinds of InP (001) surfaces were prepared, i.e., two kinds of clean (2x4) reconstructed surfaces obtained by above method at different annealing temperatures of 330 °C and 360 °C, and one (1x1) partially oxidized surface prepared by shortly exposing the as-grown (2x1) surface in air and then heated in the chamber. The surface reconstructions prepared by this procedure maintained when the samples were cooled to room temperature.

3. RESULTS AND DISCUSSION

3.1 STM images of Clean (001) InP Surfaces

Figures 3 and **Fig.4** show the STM images of two (2x4) surfaces obtained by annealing (2x1) surface at a higher temperature 360 °C and at a lower temperature of 330 °C, respectively. The line-scans at the places indicated by the solid lines are also shown in the insets. It can be seen that the images in Fig.3 and Fig.4 are similar with clear periodic dark and bright lines along [1$\bar{1}$0] direction. The periods were found to be 1.66 nm in [110] direction and 0.83 nm in [1$\bar{1}$0] direction, corresponding precisely to a (2x4) unit cell. Kink structure observed on the GaAs (2x4) surface[1], are also visible. The bright and dark lines correspond to P-dimer rows and missing P-dimer rows, respectively. Furthermore. a step can be seen at the right-below corner of Fig.3 (a). The step height was confirmed to be 0.3 nm, equal to the one monolayer (ML) height of (001) InP, demonstrating the very good vertical distance resolution of the present STM.

Figures 5 (a) and (b) show the enlarged line-scans in Fig.3 (a) and Fig.4, respectively. It can be seen that, although the amplitudes of the two curves are nearly the same as approximately 0.15 nm, being equal to one atomic layer height (i.e. half of ML), their shapes are very different. The line-scan in Fig.5 (a) is a sine-like curve with the distances of higher and lower parts in one period are nearly the same, whereas that in Fig.5 (b) is considerably different with the ratio between the distance above the center line and that below center line being 3:1. This

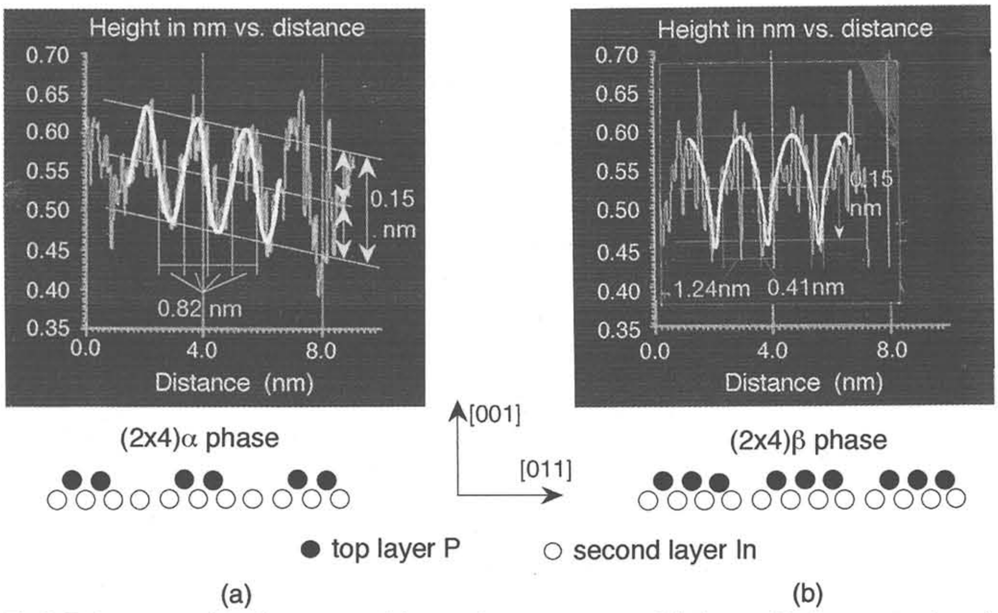


Fig.5 Enlargement of the line-scans and the atomic arrangement models for two (2x4) reconstructions. (a) from Fig.3(a); (b) from Fig.4.

difference in the line-scan curves can be explained by the different missing-dimer proposed for (2x4) reconstructed (001) GaAs[8], as shown at the bottom of each line-scan curve in Fig.5 (a) and (b). The curve in Fig.5 (a) corresponds to two dimer rows and two missing-dimer rows with P coverage being 0.5. This is known as the (2x4)α phase. On the other hand, the curve in Fig.5 (b) corresponds to only one missing-dimer row with the P coverage of 0.75. This is known as the (2x4)β phase. The occurrence of two different phases seems to correspond to the difference in the P coverage, judging from the different annealing temperatures, although limited accuracy of our XPS analysis could not confirm this difference directly.

3.2 Surface Structure of Partially Oxidized Surface

Figure 6 shows the STM image of the partially

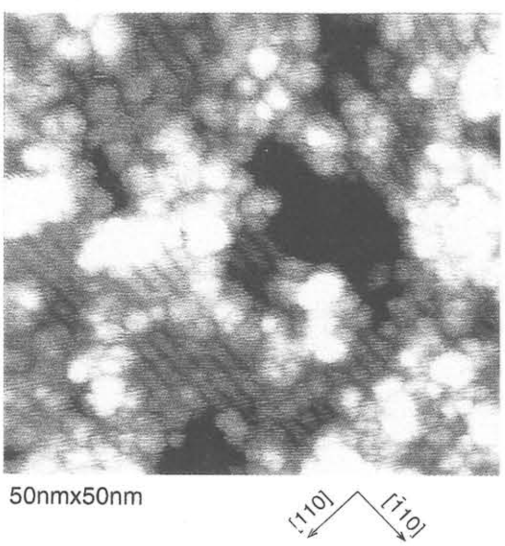


Fig.6 STM image of the partially oxidized (001) InP surface prepared by air-exposing the (2x1) surface and then heating in UHV chamber.

(oxidized (001) InP surface prepared by air-exposing the (2x1) surface and then heating it in UHV chamber at 430 °C for 10 min. Although the surface showed diffusive (1x1) RHEED pattern, and XPS analysis showed existence of significant amount of oxides, well defined (2x4)α structure could still be recognized partially with patchy structures coming most probably from the oxides. This demonstrates surprising stability of microscopic missing dimer arrangements on the InP surface.

4. CONCLUSIONS

(001)InP surface prepared by GSMBE was studied by UHV-STM. It was found that the P-stabilized (2x4) reconstructed (001)InP surfaces possess the missing-dimer arrangements with at least two microscopic structures, α phase and β phase, depending on P coverage. Such missing-dimer structures even existed on the partially oxidized surface showing a (1x1) RHEED pattern.

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