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In-Situ UHV-STM Study of Formation Process of Ultrathin MBE Si Layer on GaAs(001)-(2x4) Surface

Naohiro Tsurumi, Yasuhiko Ishikawa, Takashi Fukui and Hideki Hasegawa

Research Center for Interface Quantum Electronics, and Graduate School of Electronics and Information Engineering, Hokkaido University, North 13 West 8, Sapporo 060, Japan
Phone: +81-11-706-7174, Fax: +81-11-716-6004, E-mail: tsurumi@ryouko.rciqe.hokudai.ac.jp

1. Introduction

Formation of an ultrathin Si layer on the III-V compound semiconductor surface by MBE at a relatively low temperature of 250-300℃ is a key step in the Si interface control layer (Si ICL)-based surface passivation method proposed by our group[1]. Although we have demonstrated the effectiveness of this passivation method for improvement of the electronic and optoelectronic properties of the III-V surfaces[2,3], formation process of the ultrathin Si layer and the resultant passivation mechanism are not at all understood in microscopic scale. In the previous UHV-STM works[4,5] on the behavior of Si atoms on GaAs surfaces are related to Si δ-doping and therefore Si was deposited at a higher temperature range of 400-560℃.

The purpose of this paper is to study the initial formation process of the ultrathin MBE Si layer on GaAs using *in-situ* STM in the atomic scale in order to understand and further to optimize the Si ICL-based passivation method.

2. Experimental

A UHV-based multi-chamber system was used where a solid source MBE chamber and a UHV-STM (JEOL JSTM-4600) chamber were connected by a UHV transfer chamber together with other chambers.

The GaAs epitaxial layers were grown at 580℃ by MBE and the samples were annealed in an As_4 flux. A well-ordered (2x4) β-phase surface was realized by suitable annealing. This (2x4) β-phase pattern was maintained during subsequent cooling by gradually reducing the As_4 flux intensity. Then, Si atoms were deposited at 300℃ in the presence of the residual As background pressure of 10^{-9}-10^{-8} Torr range without intentional supply of As_4 flux. The deposition rate of Si of 8.5×10^{11} atoms/cm^{2}s was used which is typical for Si ICL formation.

The samples were transferred to the STM chamber, and STM observations were made at room temperature in the constant current mode.

3. Results and Discussion

RHEED patterns

Figure1 shows the RHEED patterns of a sample before and after the deposition of Si (1/4 ML). As seen in Fig.1(b), the (2x4) reconstruction pattern was maintained after Si deposition with the reduction of the intensities of the fractional order streaks. This result is quite different from the previously reported case[4,5] of Si deposition under different preparation conditions where change of reconstruction to (3x1) was observed.

STM study

A typical filled state STM image taken on the initial GaAs(2x4) β-phase surface is shown in **Fig.2**. The image shows a highly ordered structure with a unit cell consisting of two As dimers and two missing-dimers. The depth of the missing-dimer trench was found to be 1 ML, indicating Ga atom is missing in the trench. These properties are consistent with a recent report[6].

Figure3 shows the examples of filled state STM images taken after the Si deposition ((a):1/8 ML in the background As pressure of 0.9×10^{-8} Torr, (b)1/4 ML in 1.5×10^{-8} Torr). Line-scan profiles taken along the lines a-d in Fig.3(a) are given in **Figs.4(a)-(d)**, respectively.

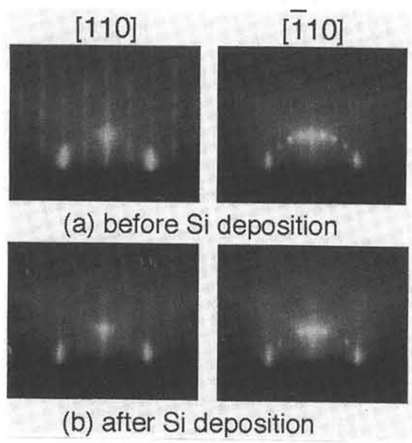

Fig.1. RHEED patterns before and after Si deposition.

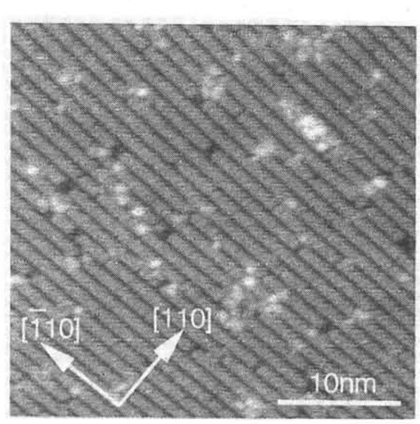

FIg.2. A typical filled state STM image taken on the initial GaAs(2x4) β-phase surface.

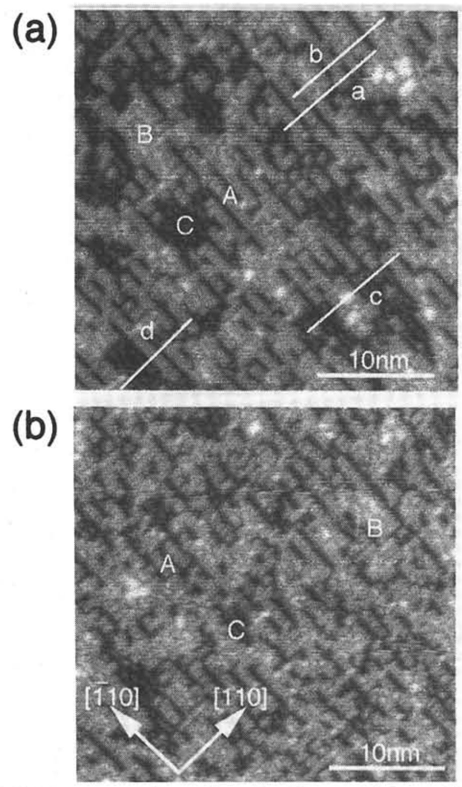

Fig.3. STM images taken after the Si deposition ((a):1/8 ML in the As pressure of 0.9×10^{-8} Torr, (b)1/4 ML in 1.5×10^{-8} Torr).

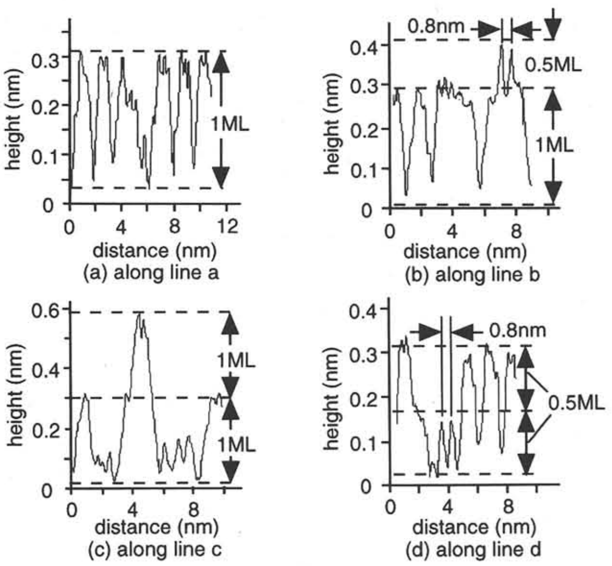

Fig.4. Line-scan profiles taken along the lines a-d in Fig.3(a).

Discussion

Based on the careful analysis of the STM images and line-scan profiles such as given in Figs.3 and 4, the following properties of the Si-deposited GaAs surface became clear.

(1) Si deposition created new regions on the surface without changing the initial basic pattern possessed by the (2x4) dimer arrays. Such an ordered growth is very different from previous reports where severe kink formation and randomization of dimers were reported[5].

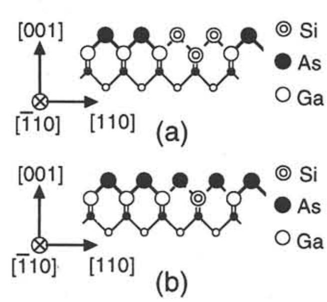

Fig.5. Possible models for the microscopic structure of the trench filling Region B.

(2) Three characteristic Regions, A, B and C shown in Figs.3(a) and (b), were found on the surface after submonolayer deposition of Si. Here, in Region A, the initial dimer row is maintained. In Region B, the initial dimer trench is filled and dimer rows are connected. Region C is the dark region where dimers disappeared. It was also noted that bright and less bright white spots appeared on the dimer array.

(3) Two possible models for the microscopic structure of the trench filling Region B are shown in Figs.5(a) and (b). A careful analysis of the total area and the line-scan profile of Region B has led to the conclusion that the model in Fig.5(b) is more likely.

(4) Region C was found to be the region where As atoms dissociated from the surface and Ga atoms are exposed due to low background As pressure, being similar to the observation by Avery *et al.*[7].

(5) Bright spots were identified to be As clusters which were also present on the initial surface whereas less bright and smaller spots were found to be Si atoms deposited onto As dimer rows. Thus, Si atoms are primarily bonded to As atoms on the entire surface except Region C.

(6) The result has indicated that the initial structure of Si ICL growth is extremely sensitive to the As background pressure. Thus, its control and optimization may allow further ordered growth of Si ICL.

References

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