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Influence of GaAs(0 0 1) pregrowth surface morphology and reconstruction on the growth of InGaAs layers

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ABSTRACT

The influence of pregrowth surface morphology and reconstruction upon the growth of $In_{0.15}Ga_{0.85}As$ alloy layers was investigated. After obtaining different pregrowth surfaces, depositions of InGaAs were carried out by molecular-beam epitaxy (MBE). The real space ultrahigh vacuum scanning tunneling microscopy (STM) images showed the disciplinary changes between GaAs and InGaAs surface morphology. Reflection high energy electron diffraction (RHEED) has also been used to estimate InGaAs deposition. As STM images and RHEED oscillations showed, heteroepitaxial surface quality greatly depends on initial state of surface even form the earliest stages of deposition. Two reasons of the effects are proposed, a conjecture for the formation of surfaces morphology and its influence on subsequent growth is also proposed.

1. Introduction

To obtain unique and high electronic and optical properties structures, many growth parameters have been investigated intensively for InGaAs/GaAs heteroepitaxy [1–6]. About the importance of surface reconstruction in the field of nanostructure formation, InAs/InP(001) heteroepitaxy has been studied by group of Jones [7]. And the evolution of elongated (In, Ga) As–GaAs(1 0 0) islands with low indium content has also been discussed [8]. However, efforts have been spent almost all on studying of the three-dimensional (3D) island growth caused by accumulated epitaxial strain energy from the lattice mismatch all the time. In the early stage of heteroepitaxy growth in the III–V compound semiconductors, the initial growth process is layer-by-layer, two-dimensional (2D) island growth, typical of molecular beam epitaxy (MBE) [9]. Nevertheless, surface morphology and reconstruction are studied little in the field of its influence on the subsequent heteroepitaxy growth, even on the three-dimensional (3D) island growth. In this paper, we discuss the influence of GaAs surface morphology and reconstruction on the structural properties of InGaAs subsequently deposited.

2. Experimental procedure

Experiments were carried out in an ultra-high vacuum (UHV) facility ($5–8 \times 10^{-11}$ Torr throughout) which contains a solid-source molecular beam epitaxy (MBE) chamber and a scanning tunneling microscope (STM) chamber (Omicron). Without any chemical cleaning, commercially available “epi-ready,” n^+ (Si doped 10^{18} cm^{-3}) GaAs(0 0 1) substrate with miscut smaller than 0.05° was loaded into the MBE system. The native oxide was desorbed from the GaAs substrate surface by slowly heating up to 580 °C under As_4 flux until the reflection high energy electron diffraction (RHEED) showed a clear and abrupt pattern. A 1.5 μm thick GaAs buffer layer was deposited on the substrate at 560 °C to flatten the surface with a growth rate of 350 nm/h. The beam flux ratio of As_4 to Ga (V/III) for the buffer layer growth is 20. Silicon was deposited as a dopant with a density of 1.0×10^{18} cm^{-3}. The substrates were annealed at 560 °C under 8.5 μTorr As_4 beam equivalent pressure (BEP) for 40 min to produce a flat surface without islands.

To study the influence of pregrowth surface morphology and reconstruction on the growth of InGaAs layer on a GaAs(0 0 1) surface, a procedure was developed. First, to have a group of different initial surfaces, the substrate temperature was lowered from 560 °C, which is the temperature for deposition and anneal of GaAs buffer layer, to 440 °C at different temperature lowering rate without changing any As_4 BEP. Next, 15 monolayer (ML) InGaAs layers

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with low indium content (15%) were deposited on the annealed surface. RHEED oscillations were recorded during the deposition and RHEED patterns were obtained after the deposition. Then sample was annealed at 440 °C for 15 min until surface ripening had almost completed. The sample was then quenched to room temperature using a procedure that freezes in the surface morphology present at the higher temperatures. After the above procedure, the samples were then transferred to the STM chamber without breaking UHV. The above procedure was applied to each sample. In our experiment, the first sample was grown on a clean GaAs substrate; the following samples with a regrowth of 0.5 μm GaAs buffer layer and different cooling rate were grown on the previous sample. A series of $In_{0.15}Ga_{0.85}As$/GaAs samples with different temperature lowering time (3 min, 18 min and 36 min) have been carried out. The high degree of reproducibility of RHEED oscillations and STM images indicates that this procedure is reliable. Several filled-state STM images were acquired with sample bias of −3.0 V and tunneling current of 10–100 pA at room temperature.

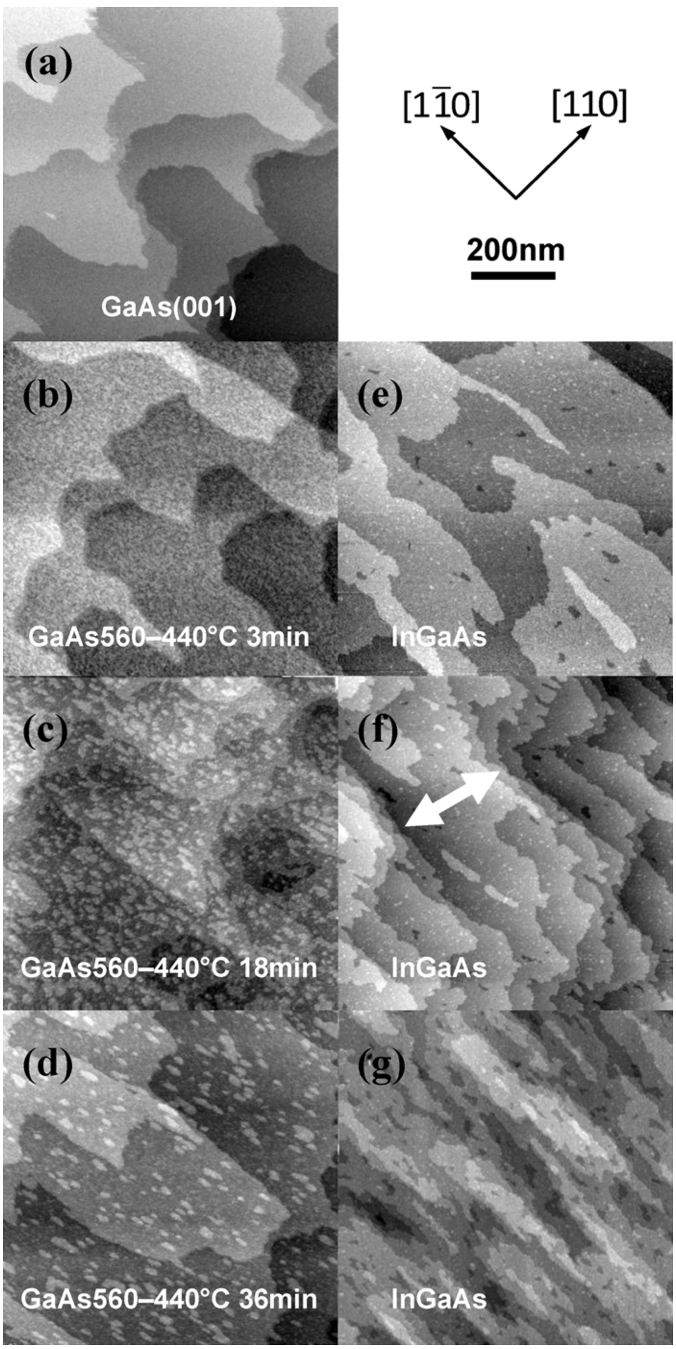

Fig. 1. Filled-state (−3.0 V, 80PA) STM images (1 μm × 1 μm) of the surface morphology (a) a flatten GaAs(0 0 1) (2 × 4) surface prior to reduce the substrates temperature and (b)–(d) generated by reducing the GaAs(0 0 1) substrates temperature with different constant speed from 560 °C to 440 °C before and after $In_{0.15}Ga_{0.85}As$ deposition on (e)–(g) 1 μm × 1 μm filled-state (−2.7 V, 150 pA) STM images of the surfaces shown in (b)–(d) respectively.

3. Results and discussions

By lowering the substrate temperature with different rate from 560 °C to 440 °C without changing As_4 BEP, different GaAs(0 0 1) surface morphology and reconstruction have been obtained, which are the starting surfaces for $In_{0.15}Ga_{0.85}As$ deposition. 1 μm × 1 μm STM images were obtained both before and after the deposition (Fig. 1). RHEED oscillations were recorded during the deposition (Fig. 2). Small size STM images (200 nm × 200 nm) were obtained for details of the surface morphology and reconstruction (Fig. 3). In all the experiments, RHEED patterns showed (1 × 3) reconstruction clearly during annealing after InGaAs layer growth.

In Fig. 1(a)–(d), four filled-state (−3.0 V, 80 pA) 1 μm × 1 μm STM images are displayed, the images showed the changes in surface morphology with different temperature lowering conditions [(a) cooling down to room temperature immediately after the annealing to freeze the GaAs(2 × 4) surface morphology at 560 °C; (b) cooling from 560 to 440 °C in 3 min, (c) 560–440 °C in 18 min and (d) 560–440 °C in 36 min]. The images were shown in gray scale where each color change represents a one monolayer height change (i.e., 0.3 nm). Fig. 1(e)–(g) shows 1 μm × 1 μm filled-state (−2.7 V, 150 pA) STM images of 15ML $In_{0.15}Ga_{0.85}As$ layer grown on the annealed GaAs surfaces that shown in Fig. 1(b)–(d), respectively. In Fig. 1(e), wide terraces was obtained. More and narrower terraces were found in Fig. 1(f), the arrow in Fig. 1(f) showed step bunching; and Fig. 1(g) showed a rough surface with multi-level islands and no wide terraces any more. Fig. 2(a)–(c) presents the RHEED oscillations of 15ML $In_{0.15}Ga_{0.85}As$ deposited on GaAs(0 0 1) surfaces shown in Fig. 1(b)–(d) respectively at a substrate temperature of 440 °C. From the above morphology results, we found that if a slower rate was used in temperature lowering from 560 °C to 440 °C, a rougher $In_{0.15}Ga_{0.85}As$ surface will be obtained. In

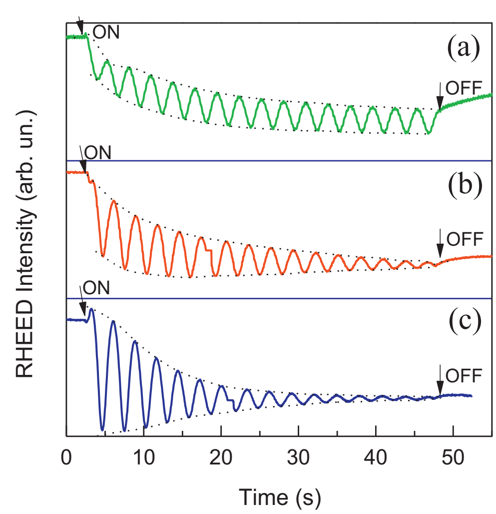

Fig. 2. RHEED oscillations of $In_{0.15}Ga_{0.85}As$ grown on [(a)–(c)] pregrowth GaAs(0 0 1) surface shown in Fig. 1 (b)–(d) in turn at 440 °C for 15ML. The dotted lines represent the enveloping lines which indicate the damping of oscillations. Each oscillation begins when Ga source shutter has been opened (arrow ON), and ends when closed (arrow OFF).