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Temperature-controlled self-organized InP nanostructures grown on GaAs(1 0 0) substrate by MOCVD

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Abstract

The self-organized InP nanostructures grown on GaAs(0 0 1) substrates by metalorganic vapor deposition were examined in detail using atomic force microscopy. By properly selecting growth temperature, three kinds of nanostructure, islands, pits and ripples were formed. For growth temperature of 400–450 °C, the surface morphologies were governed by islands; but, for the growth temperature of 500 °C, the formation of surface ripples instead of islands was presumably due to the combination effect of temperature-controlled surface kinetics and strain effect. On the other hand, the observation of enhanced growth of pits upon a high-temperature annealing (at 685 °C for 90 s) indicated that the strained InP epitaxial film would be morphologically stabilized by taking the form of pits formation.

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1. Introduction

Semiconductor structures with reduced dimensionality remain an important and active area of research. It has been well established that [1–4] strain relaxation processes in highly strained heteroepitaxial films tends to roughen the film surfaces by take the form of nanoscale structures. And such nanostructures have also been intensively investigated for possible technological applications. For example, the spontaneous formation of coherent 3D islands has been utilized to produce quantum dot devices without the deleterious effect of post-growth processing [5–7]. Also surface ripples have been shown to be correlated with lateral composition modulation [1,8,9], yet another avenue to spontaneous nanometer-sized structures.

It has been well established that the deposition of InP on GaAs results Stranski–Krastanow growth. The reduction of total energy in the strained epilayer/substrate system induces the 3D islands formation, but it is the simplest scenario and in practice the morphology structures should be complicated by the competing mechanism between temperature-controlled surface kinetics (adatom diffusion, surface reconstruction, etc.) and strain-induced fluctuations. In this work, we examined the surface morphology of strained InP epitaxial layers which were directly deposited on semi-insulating exactly (0 0 1)-oriented GaAs substrates at growth temperatures between 400 and 500 °C. Furthermore, the dissimilar surface structures were compared between samples with and without annealing process. The aim was to determine the correlation between the surface morphology and the growth conditions during InP/GaAs heteroepitaxy, which would provide an avenue to spontaneous and stable nanostructures.

2. Experimental procedure

The samples were grown in a Thomas Swan 3 × 2 in. CCS low-pressure metalorganic chemical vapor deposition

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(LP-MOCVD) system with vertical reactor. Trimethylgallium (TMGa), trimethylindium (TMIn) were used as group III precursors and arsine (AsH_3), and phosphine (PH_3) as group V precursors. H_2 was used as carrier gas. The reactor pressure was kept 100 Torr and the total gas flow was 13 SLM. After loading, all the GaAs wafers were firstly deposited with a 200 nm thick GaAs layer at 685 °C to ensure a smooth surface for the following layer growth, followed by the growth of a ~15 nm thick InP using the V/III ratio of 240. The growth temperatures of InP layer were varied in the range of 400–500 °C and the growth rates were estimated as 1.6–2.0 ML/s. In order to compare the surface structures between the as-grown and annealed InP films, we presented the results corresponding to two growth runs labeled A and B. For samples A, after the growth of InP layer, the samples were directly cooled down under PH_3 flux to the room temperature as quick as possible in order to avoid post-growth annealing. For samples B, a 90 s annealing step at the temperature of 685 °C was adopted following the deposition of InP epitaxial layer. During annealing, PH_3 was used as protected flux to prevent the adatoms desorbing from the sample surface due to high annealing temperature. Atomic force microscopy (AFM) images of $1 \times 1\,\mu m^2$ size are used to measure the surface morphology and determine the size, shape of InP islands.

3. Results and discussion

3.1. *Effect of temperature*

Fig. 1(a)–(c) shows AFM images of InP grown on the GaAs substrates at temperatures of 400, 450, and 500 °C, respectively. Significant changes in the surface structures from island to ripple formation are visible with varying temperatures. When the growth temperature is less than 500 °C, the small and closely packed InP islands dominate the morphology of films, as seen in Fig. 1(a) and (b). On the other hand, a ripple morphology appears instead of the typical island morphology when the growth temperature is increased to 500 °C, as seen in Fig. 1(c).

As comparing the islands of Fig. 1(a) with that of Fig. 1(b), the AFM images show an increase in the island size with increased temperature. According to the depth profiles (not shown), the average diameters of the islands in Fig. 1(a) and (b) are 15 and 40 nm, respectively; the heights of both cases are nearly 3 nm and vary slightly. This increase in size is presumably due to the fact that higher temperature provides more adatom energy, which favoring the atomic diffusion on the surface. At lower temperature, diffusion lengths are so short that the diffusing adatoms cannot reach the existing nucleation sites (islands) [10,11] and tend to form new small islands. As increasing the

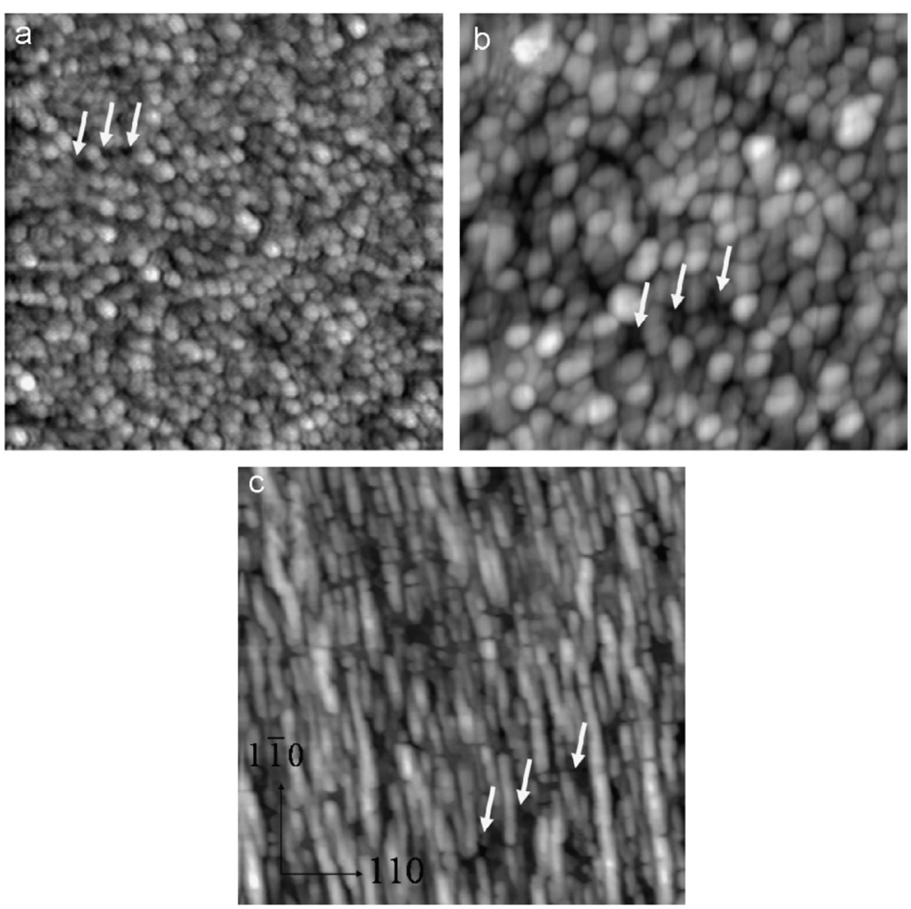

Fig. 1. $1 \times 1\,\mu m^2$ AFM images of samples A with deposition temperature of (a) 400 °C, (b) 450 °C, and (c) 500 °C. Arrows indicate pits-like voids.