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Isotropic growth islands of $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ epilayer grown by metalorganic chemical vapour deposition

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Abstract

The quaternary $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ epilayer was grown on GaSb substrate by metalorganic chemical vapour deposition (MOCVD). On the epitaxial surface smooth and perfect three-dimensional islands were observed by atomic force microscopy (AFM). A good crystalline quality was characterized by single-crystal X-ray diffraction pattern and double-crystal X-ray rocking curve. When the growth rate of the growth nucleus is larger than the growth rate of the high-index facet, the mode of island growth is isotropic.

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Keywords: MOCVD; Kinetics of nucleation

1. Introduction

III–V antimonide compounds are of interest for a number of applications including optical communications employing fluoride-based fibers [1], laser radar exploiting atmospheric transmission windows, and remote sensing. For most of these applications, operation at room temperature is very important for attaining the desired system performance at reasonable cost [2]. The quaternary GaInAsSb alloys are the most promising candidate materials alternative to the HgCdTe system for use in infrared detectors. The alloys with direct band gaps adjusted between 1.7 and 4.3 μm can be grown lattice-matched on GaSb, InP and InAs substrates, which may provide the basis for emitters and detectors over this entire region.

However, the performance of these devices is often limited by the crystallographic defects caused during epitaxial growth. 3D islands are always produced during epitaxial growth and have an adverse effect on electronic and optoelectronic properties of the devices. Thus, the growth process of the islands must be well-understood in order to decrease them by controlling the key parameters.

The $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ was grown by metalorganic chemical vapour deposition (MOCVD), and 3D islands of the isotropic growth were

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observed by atomic force microscopy (AFM). AFM is a suitable tool for the investigation of epitaxial surface because of its high resolution and capability of giving quantitative information about surface topography. The surface morphology and the crystalline state were obtained by scanning electron microscopy (SEM), single-crystal X-ray diffraction pattern and double-crystal X-ray rocking curve. The isotropic growth model of 3D islands was discussed.

2. Epitaxial growth

The $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ epilayer was grown on GaSb substrate by MOCVD using a conventional atmospheric pressure horizontal reactor. The sources of Ga, In, Sb and As atoms were trimethylgallium (TMGa), trimethylindium (TMIn), trimethylantimony (TMSb) and arsine (AsH_3) diluted to 10% in hydrogen, respectively. TMGa,TMIn TMSb were held at − 12°C, 17°C and − 10°C, respectively, by using temperature baths and carried by Pd-diffused hydrogen into the reactor. The substrate was n-type GaSb, oriented 2°-off (1 0 0), towards [1 1 0]. The GaSb substrate was chemically polished by a solution of $HNO_3:HCl:CH_3COOH = 0.2:2:20$ before being put into the reactor. The growth temperature was 595°C. The III/V ratio was 0.201, TMGa/(TMGa + TMIn) ratio was 0.101, TMSb/(TMSb + AsH_3) ratio was 0.165. The growth time was 60 min. The epitaxial thickness was 1.5 μm, and the lattice mismatch was 1.47%.

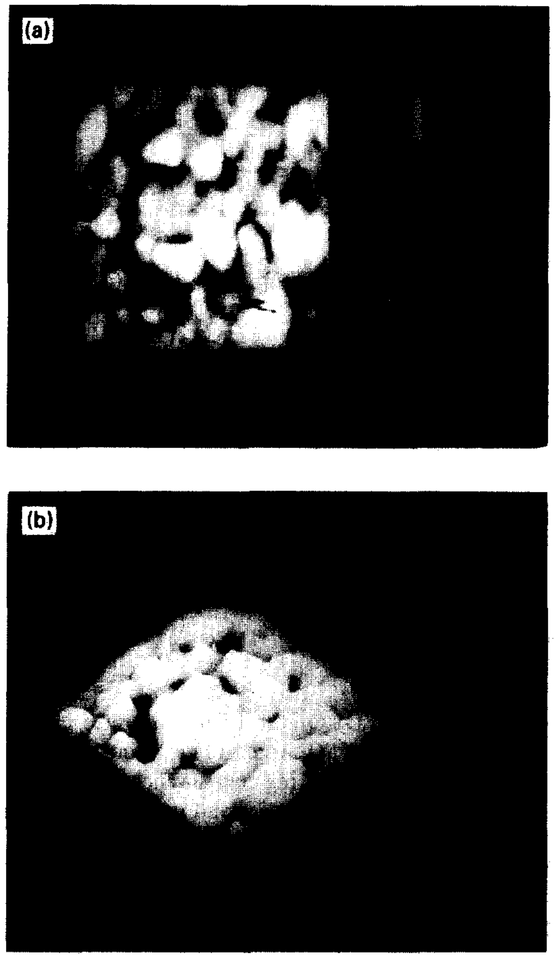

Fig. 1. (a) The AFM image of the $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ epilayer grown by MOCVD with 20.15 x 20.15 μm^2 observed area; (b) The three dimensional image of Fig. 1a. Lot of smooth and perfect 3D islands were observed keeping an original hemisphere-like shape.

3. Characterization of the epilayer

To the $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ epilayer, a mirror-like surface was observed using optical microscopy. At low-resolving power of SEM, the surface morphology was still mirror-like. But blurred 3D islands appeared in the other SEM image magnified 3000 times. AFM, as a new experimental tool, may provide information about surface structures for well-understood growth process by MOCVD. AFM observations were made in air at room temperature with tap mode. When AFM was used to image the GaInAsSb epitaxial surface, the blurred 3D islands became smooth and perfect and were as shown in Fig. 1a and Fig. 1b, and the islands were about 200 nm high with a diameter of 3 μm.

Fig. 2a presents the single-crystal X-ray diffraction patterns, and the full-width at half-maximum (FWHM) was 22 arcmin. of the mixed Cu $k\alpha_1$ and Cu $k\alpha_2$ diffraction peak. For the double-crystal X-ray rocking curve in Fig. 2b the FWHM was 20 arcmin which illustrates the good crystalline

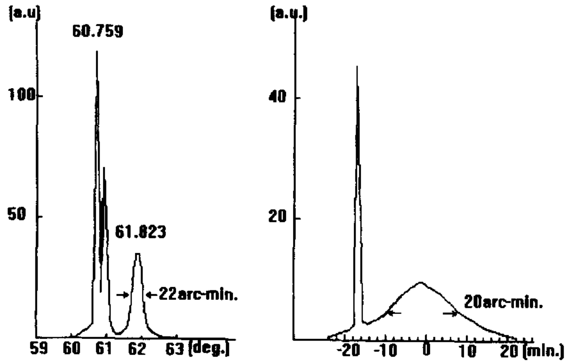

Fig. 2. (a) The single-crystal X-ray diffraction pattern of the $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ epilayer; (b) The double-crystal X-ray rocking curve of the $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ epilayer. It showed a good crystalline quality.

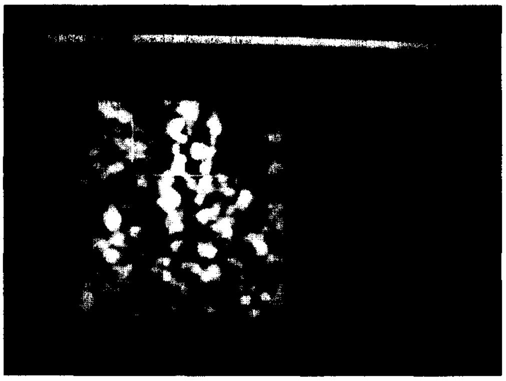

Fig. 3. The AFM image of a GaSb substrate with $1.87 \times 1.87\ \mu m^2$.

quality of the epilayer; since the double-crystal X-ray rocking curve of the GaInAsSb epilayer with a lattice-mismatch of 1.47% is difficult to obtain. From the observations of Fig. 2a and Fig. 2b, it is suggested that the 3D islands have a good crystalline quality.

4. The preparation of the GaSb substrate

After the commercial GaSb substrate was chemically etched by a solution of $HNO_3:HCl:CH_3COOH = 0.2:2:20$ for about 15 min, the surface was observed by AFM. On the mirror-like surface there were a lot of islands, in which the large islands were about 2.5 nm high with a diameter of 150 nm, and the small islands were about 1.2 nm high with a diameter of 70 nm as shown in Fig. 3. Although the polished surface of GaSb substrate is mirror-like, there were a lot of surface-defects-like islands with magnitude 100 nm for about 100 nm diameter of a polishing compound required to polish GaSb substrate surface. The islands may be buried under a critical thickness during epitaxial growth.

5. The discussion of growth mode of the 3D islands

When GaInAsSb epilayer begins to grow, it grows coherently on a GaSb substrate with the lattice parameter of the epilayer strained to the lattice parameter of substrate. At the same time, the islands, which were formed by polishing and chemical etching, do not have a higher surface energy to produce the nucleation growth and may be gradually buried. Since the height of islands is 2.5 nm, and the critical thickness of $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ is about 70 nm, after the islands are completely buried, the epitaxial growth is still in the 2D growth mode. The epitaxial thickness increases with increasing strain energy and stress field to the critical thickness h_c, where the first misfit relieving dislocation is produced [3]. At the critical thickness, the accumulated strain energy imposes the equilibrium situation which corresponds to a 3D configuration of the epilayer [4]. Then, the two-dimensional growth fails and 2D plus 3D Stranski–Krastanov mode occurrs. Tersoff et al. [5] found that the islands can exhibit dramatic self-organization; and sizes and spacing actually become more regular with each successive layer. For successive layers, the island size and spacing become progressively more uniform, and two or more islands that are very close will be replaced by a single island [5]. Indeed, island sizes are highly dependent on growth conditions.

During epitaxial growth the islands are surrounded with the facets. Within a certain range of thermodynamics, the growth rates of the facet planes are extremely sensitive and are strongly affected by differently oriented surfaces. The decrease in polarity effects is obvious as the surface deviates from a (1 1 1) toward a (1 0 0) [6]. The facets of the higher-index orientations have much larger growth rate. Bongers et al. [7] studied the temperature dependence of facet growth rate, relative to the (1 0 0) planar growth rate, in LP-MOCVD InGaP growth. At all temperatures, the (1 1 1)A facet has the largest growth rate. The growth rate of other facets are different with different index orientations. The growth rate of the (1 0 0) plane is the slowest. When the growth rate of the higher-index orientation is larger than the growth rate of the lower index-orientation, the 3D island growth has an anisotropic-growth mode. Cheng et al. [8] reported the anisotropic growth of 3D islands to form pyramids, and we reported the other anisotropic growth of pyramids with pit [9].

On the other hand, within the other range of thermodynamics, the growth rate is not sensitive to the directions of facet planes. For 3D islands all dislocations and stacking faults are located at the highest apex position, indicating that they play the role of growth nucleus with a large growth rate [10]. When the growth rate of growing nucleus is larger than the growth rate of high-index plane, the growth of 3D islands display an isotropic-growth mode. When the coverage is increased, the nucleation of the 3D islands continues to grow keeping the original hemisphere-like shape and finally form smooth islands as shown in Fig. 1. Because the growth rate of the 3D island isotropic-growth mode is far inferior to that of the anisotropic-growth mode, the surface with 3D island isotropic-growth mode is still mirror-like, and the pyramidal hillocks in anisotropic growth mode may be observed by optical microscopy.

6. Conclusion

The mirror-like $Ga_{0.16}In_{0.84}As_{0.80}Sb_{0.20}$ epilayer was grown by MOCVD. But a lot of smooth and perfect 3D islands were observed by AFM on the epitaxial surface. A good crystalline quality was obtained by single-crystal X-ray diffraction pattern and double-crystal X-ray rocking curve. When the growth rate of the growth nucleus is larger than the growth rate of the high-index plane, growth the mode of the 3D islands is a isotropic. 3D islands finally form smooth and perfect 3D islands keeping the original hemisphere-like shape.

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