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Metamorphic Growth of GaSb/AlGaSb on GaAs Substrates Using Antimonidation of Epitaxial Aluminum Nanofilms

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Abstract

The "6.1 Å family" of semiconductor materials (InAs, GaSb, AlSb) draw considerable attentions in high mobility, high speed electronic and optical devices nowadays. However, epitaxial growth on large-size substrates such as GaAs and Si faces the fundamental challenge of lattice mismatch. In this work, by using aluminum-transformed AlSb nanofilms, we successfully made a GaSb-based platform on GaAs substrate and we found the process named as "antimonidation" plays an effective role. Our work opens the window for growing hetero-structures on lattice-mismatched substrates for various device applications.

1. Introduction

In recent years, there have been great interests in material growth and device fabrication of InAs/GaSb/AlSb semiconductor heterostructures, such as field effect transistors, semiconductor lasers and infrared detectors. The related devices will be fabricated on either GaAs or GaSb wafers. GaAs wafers mass-produced with larger sizes, lower cost and mature technical levels become the most advantageous choice. To overcome the problem of large lattice mismatch between GaSb and GaAs, various meta-morphic buffer, such as compositionally graded layers [1, 2], superlattices [3], and low temperature (LT) layers [4, 5] have been used. The purpose of this investigation is to initiate a novel idea to deal with the issue. Taking use of the epitaxial aluminum (Al) nanofilm [6] and transforming it to an ultra-thin AlSb epitaxial layer through antimonidation, instead of using thick metamorphic buffer layers commonly seen in traditional approaches, effectively save epitaxial time and cost. The effects of antimonidation were investigated by reflection high-energy electron diffraction (RHEED), atomic force microscopy (AFM), X-ray diffraction (XRD), photoluminescence (PL). A sample grown on lattice-matched GaSb substrate is also presented for comparison.

2. Epitaxy Growth and Characterization Method

Our samples in this work were prepared in a Veeco Gen-II solid-source MBE system with a two-stage method. For sample A, the first stage is to prepare aluminum nanofilm template as follows [7]. After native oxide desorption on n+-GaAs substrate, a 200-nm-thick GaAs buffer was grown 3-nm aluminum grown on treated Ga-rich GaAs grew after residue arsenic was pumped out. The second stage, antimonidation, is to transfer aluminum films into AlSb films. This critical process started from opening the Sb shutter with low beam flux pressure at substrate temperature (Ts) about 400°C for 3 minutes. Ts was raised to 520°C at ~100°C/min and the Sb shutter was reopened (at Ts = 480°C) for 20 minutes at the beam flux pressure of about 1E-6 torr. After this antimonidation process, GaSb buffer, GaSb/AlGaSb superlattices, GaSb quantum well, and capping layer were grown successively at Ts = 500°C, as shown in Table I. As for the lattice-matched sample on GaSb substrate, denoted as sample B, we grew the same structure but 250 nm GaSb buffer layer instead.

Table I Epitaxial Structure

$GaAs_{0.2}Sb_{0.8}$ 10nm
$Al_{0.3}Ga_{0.7}Sb$ 100nm
GaSb 6nm
$Al_{0.3}Ga_{0.7}Sb$ 100nm
$Al_{0.3}Ga_{0.7}Sb$ 3nm /GaSb 3nm SL ×10 periods
GaSb 50nm
Antimonidation
LT 3 nm Al
n+ GaAs buffer 200nm
n+GaAs substrate

During the antimonidation process, the RHEED pattern turned spotty and dimmed upon opening the Sb shutter at low temperature and then gradually appeared brighter as Ts went up. When the Ga shutter was opened, the RHEED pattern became streaky rapidly and maintained the similar pattern to the end of growth. This indicates that the Al nanofilm transformed to 3-dimensional AlSb islands during the antimonidation process. It might produce dislocations and defects but did not destroy crystallization. This technique successfully realized the transformation of GaAs system into GaSb platform without using a thick metamorphic buffer layer.

3. Results and Discussions

Figure. 1 shows the surface morphology characterized by AFM in tapping mode. The roughness of sample A is about 0.65 nm to 0.8 nm, though two-times rougher than sample B on GaSb substrate, but good enough as a flat platform. XRD 2θ/θ scan is shown in Fig. 2. At the peak about 60°, the intensity of sample A is only twice weaker than that of Sample B. Note that the peak may be contribute to not only cladding layer but also the superlattice layers and substrate. The full width at half maximum (FWHM) of sample B is 417.6 arcsec, slightly smaller than the FWHM 644.4 arcsec of sample A. In short, both samples are well single crystalline.

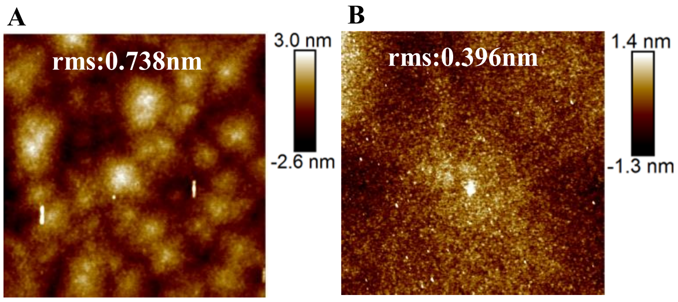

Fig. 1 AFM images in 5×5 μm² on samples A and B.

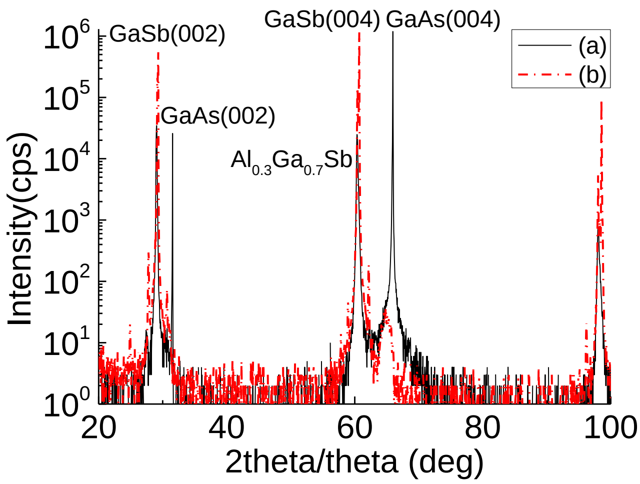

Fig. 2 XRD 2θ/θ scan on samples A (a) and B (b).

In addition to material properties, we have interests in how antimonidation buffer layer influences the optical property/quality by measuring the PL from the GaSb quantum well (QW). Figure 3 illustrates the emission in sample A (Fig. 3a). One is contributed to GaSb QW at about 1350 nm at 20 K. The other broad peak could arise from the defects/dislocations. Evidently, we can see dozens of times PL intensity difference between two samples. Worthily to mention, there are strong enough intensity to recognize light emission and background noise even at room temperature.

Accordingly, using antimonidation of epitaxial aluminum nanofilms as metamorphic buffer layer to endure large lattice mismatch between GaAS and GaSb is a time-saving, low-costing, and novel epitaxial approach although further

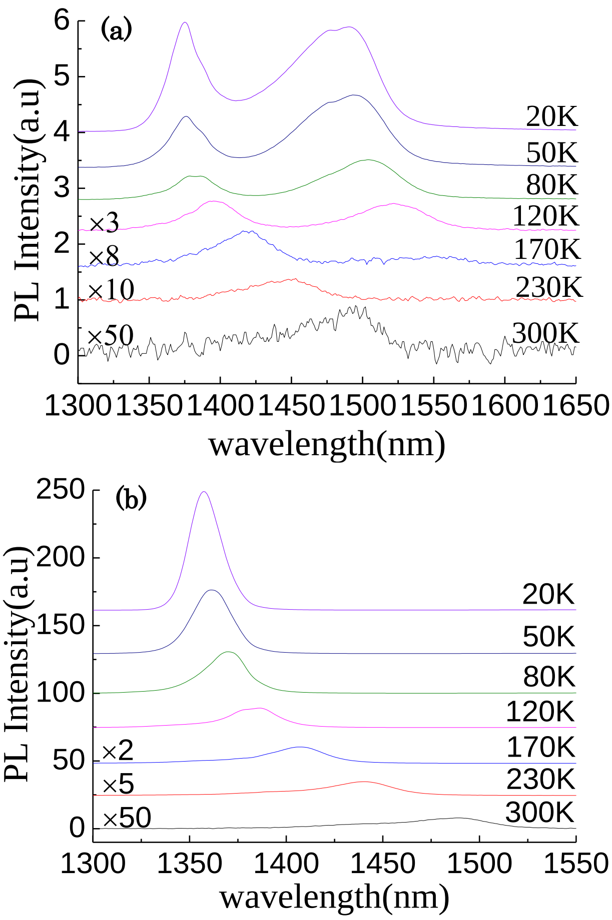

Fig. 3 PL measurement for samples A (a) and B (b).

improvement is certainly needed to realize room temperature device applications.

4. Conclusions

The study of using antimonidation to make successful metamorphic growth of GaSb/AlGaSb on GaAs substrates is presented. The properties of antimonidation sample are not too far from those of the latticed-matched sample grown on the GaSb substrate. It says that antimonidation is a novel method to fabricate antimony-based semiconductor hetero-structures. Optimizing the growth recipe and working on electronic and optical devices will be our next task.

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