

[1 1 1]B-oriented GaAsSb grown by gas source molecular beam epitaxy

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Abstract

We report the GaAsSb bulk layers and GaAsSb/GaAs quantum wells (QWs) grown on (1 1 1)B GaAs substrates by gas source molecular beam epitaxy. We found that Sb composition in the GaAsSb epilayers is very sensitive to the substrate temperature. The composition drops from 0.35 to 0.16 as the substrate temperature increases from 450 to 550 °C. The [1 1 1]B-oriented GaAsSb epilayers show phase separation when the substrate temperature is lower than 525 °C. For a GaAsSb/GaAs multiple quantum wells (MQWs) structure composed of five periods of 5 nm GaAs_{0.73}Sb_{0.27} QW and 30 nm GaAs barrier, the room temperature photoluminescence emission is located at 1255, 80 nm longer than the [1 0 0]-oriented sample with the same Sb composition. The peak wavelength shows significant blue shift as the excitation level increases, which evidences the type-II band alignment in this heterostructure.

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1. Introduction

Strained zincblende heterostructures grown along $\langle 111 \rangle$ direction have drawn considerable interest because of the large internal fields generated by the piezoelectric effect in such structures. It has been shown that the large piezoelectric field can substantially change the properties of the heterostructures and lead to nonlinear optic and electro-optical effects which have found applications in a number of nonlinear optical and electronic devices such as self-electro-optic effect devices [1,2]. In addition, the acousto-optical and electro-acoustic couplings in quantum well (QW) structures with piezoelectric field have been shown recently [3–5]. Ultrasonic waves propagation along the [1 1 1] direction can be induced by the piezoelectric field induced by a short light pulse, which would play an important role for future piezoelectric device application. Previous studies on strain-induced piezoelectric field were mostly on InGaAs/GaAs heterostructures. In this work, we report our studies on the growth of [1 1 1]B-oriented GaAsSb and GaAsSb/GaAs strained QW. The larger piezoelectric constant of GaSb [6], as compared with that of InAs, and the spatial charge field due to the type-II band

alignment of GaAsSb/GaAs system [7] are expected to result in stronger piezoelectric field and more pronounced coupling effects.

2. Experiment

In this study, the samples were grown on semi-insulating (1 1 1)B GaAs substrates with 2° off-cut toward [1 0 0] direction and exact (1 0 0) GaAs substrate by using VG V80 gas-source molecular beam epitaxy (GSMBE). For comparison, besides the (1 1 1)B GaAs substrate, (1 0 0) GaAs substrate was also bonded on the same moly-block for deposition. Arsenic source was from thermally cracked arsine (AsH₃) and the antimony (Sb) source was provided by a Veeco (EPI) Sb cracked K-cell. The cracking temperature for Sb beam was 1050 °C, and the species were Sb₁ and Sb₂ [8]. Standard effusion cell was used to supply Ga beam.

The substrates were desorbed at 620 °C, and coated with a 300-nm-thick GaAs buffer layer at 600 °C. The 1- μ m-thick GaAsSb bulk layers were then deposited on the buffer layer at their prearranged substrate temperature ranging from 450 to 550 °C. The AsH₃ pressure was fixed to 900 torr. Beam equivalent pressures (BEP) of Ga and Sb beams are 6.0×10^{-7} and 8.7×10^{-7} mbar, respectively. The growth rate, determined by the flux rate of Ga, was

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1 $\mu\text{m}/\text{h}$. GaAsSb/GaAs multiple quantum wells (MQWs) were grown under the same growth condition. The substrate temperature was 490°C . The structure of the MQW is composed of five periods of 5 nm GaAsSb QW separated by a 30 nm GaAs barrier and a 100 nm GaAs cap layer overgrown on top of the QWs.

Characterizations of the grown samples include high-resolution X-ray diffraction (HRXRD), absorption measurement and photoluminescence (PL) measurement. For the absorption measurement, the light source from a tungsten–halogen lamp (PTI A1010H) was dispersed by a SPEX-500M spectrometer. The transmitted light was collected by an InGaAs photodetector. For the PL measurement, a diode-pumped 532 nm laser was used as the excitation source. The luminescence was dispersed by a the SPEX-500M spectrometer and collected by the InGaAs photodetector.

3. Results and discussions

Fig. 1(a) and (b) show the HRXRD rocking curves of the GaAsSb bulk layer grown on (100) and (111)B GaAs substrates, respectively. As can be seen, the [111]B-oriented GaAsSb epilayers suffer from phase separation when the substrate temperature is lower than 525°C . For the single phase (100) GaAsSb samples, we measured their asymmetric (115) and ($\bar{1}\bar{1}5$) DXRD rocking curves (not shown) to determine their lattice constant along the growth plane. The four (100) GaAsSb samples grown below 550°C were close to fully relaxed, while the (100) GaAsSb sample grown at 550°C is partially relaxed. For the single phase (111)B GaAsSb, we also characterized its (115) rocking curve. The result shows that this sample is also partially relaxed. Detailed results are summarized in Table 1. As can be seen, the Sb composition is very sensitive to the substrate temperature. It drops from 0.35 to 0.16 as the substrate temperature increases from 450 to 550°C . This behavior could be due to the sublimation energy difference between Sb and As [9]. The higher sublimation energy for Sb makes its evaporation dominate the composition when temperature increases.

There have been several reports concerning the phase diagram of GaAsSb ternary compound in literatures [10,11]. From these calculations, the spinodal Sb compositions for 450 and 550°C are 0.20 and 0.24, respectively, which means that most of our samples are within the unstable region of the phase diagram. One should note that these calculations are based the assumption of thermodynamic equilibrium. In MBE growth, which is commonly thought to be far from thermodynamic equilibrium, the growth kinetics may play an important role in determining the material structure. Our finding suggests that the Sb adatom on (111)B plane may have much better surface mobility than on (100) plane. The worse surface migration ability on (100) plane may limit the extent of phase separation in these (100) samples. The spare of phase separation in the (111)B GaAsSb sample grown at 550°C

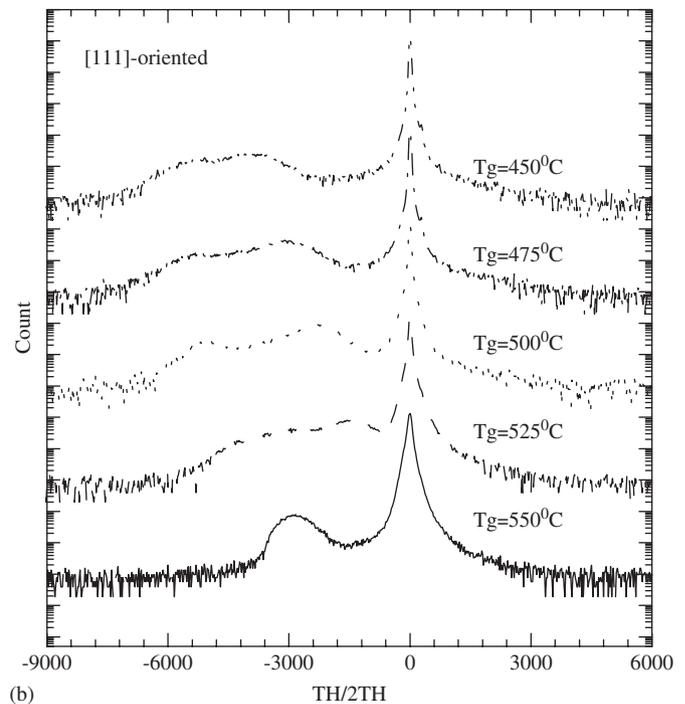
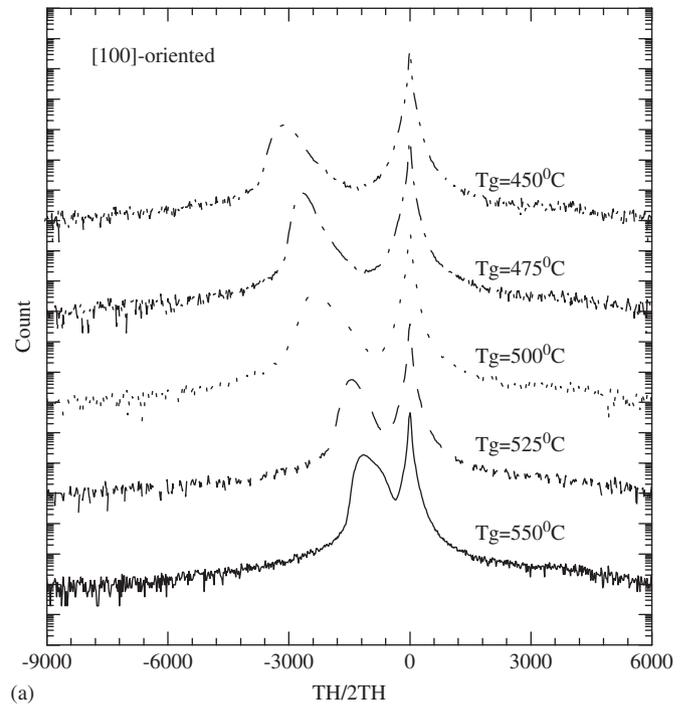


Fig. 1. (a) HRXRD (004) rocking curves of GaAsSb epilayers grown on [100]-oriented GaAs substrates (b) HRXRD (333) rocking curves of GaAsSb epilayers grown on [111]B-oriented GaAs substrates. The substrate temperature ranges from 450 to 550°C .

may have two reasons. First, the Sb composition of this sample is less and outside the unstable region of the phase diagram. Second, this sample is partially strained according to our XRD analysis. The effect of strain may decrease the critical temperature of spinodal point [12] and drives the

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