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InAs/GaSb superlattices grown by LP-MOCVD for ~10 μm wavelength infrared range

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ABSTRACT

A type-II InAs/GaSb superlattice (SL) was grown on Te-doped (1 0 0) GaSb substrate by low pressure metal organic chemical vapor deposition (LP-MOCVD). The samples were obtained at different growth temperatures and with different interface layers. By introducing an InAsSb interface layer between InAs and GaSb, a good surface morphology of the superlattice was achieved when the sample growth temperature was around 500–520 °C. The photoluminescence (PL) peak wavelength of the sample was 10.7 μm at 77 K, with FWHM of ~30 meV.

1. Introduction

Type II InAs/GaSb superlattice (SL) has been intensively studied as the third generation infrared photoelectronic detector material since it was first proposed in the late 1970s by Sai-Halasz et al. [1]. Many significant results have been achieved in recent years [2–6]. The band structure of InAs/GaSb SL is typical type-II band alignment, namely the conduction band of InAs is lower in energy than the valence band of GaSb, with electrons and holes confined into physically separate regions [7]. There are several advantages in this material system, such as low tunneling current due to the large electron effective mass [3], and suppressed Auger recombination due to large energy splitting between heavy-hole and light-hole valence subbands [8]. Infrared detectors fabricated by InAs/GaSb SL showed high quantum efficiency [9], and high operation temperature [10]. This material system is considered to be a promising candidate for the design of the detector operating in the short wavelength infrared (SWIR), mid-wavelength infrared (MWIR) and long wavelength infrared (LWIR) regions because the band gap can be adjusted by the thicknesses of InAs and GaSb layer [11–13]. Moreover, the detectors in the operation of 8–12 μm wavelength have a wide range of applications in the military, industrial and medical by reason of the low atmospheric absorption and the maximum radiation of a blackbody at 300 K according to Planck's law in this wavelength range [14]. So far, most of type II InAs/GaSb SLs reported for LWIR were grown by MBE. In this paper, the growth conditions of InAs/GaSb SL by LP-MOCVD were studied for ~10 μm infrared detection. Material surface, structure and optical characteristics were investigated by atomic force microscopy (AFM), transmission electron microscopy (TEM) and photoluminescence (PL). The quality of the InAs/GaSb SLs was systematically improved by optimizing the growth conditions.

2. LP-MOCVD growth

InAs/GaSb type-II SL was grown on Te-doped (1 0 0) GaSb oriented substrates in a horizontal LP-MOCVD reactor. The group V precursors used were trimethylantimony (TMSb) and 100% arsine diluted by hydrogen. The group III precursors used were trimethylgallium (TMGa) and trimethylindium (TMIn). The source temperature for TMGa, TMIn and TMSb was −17, 17 and −5 °C, respectively. Pd-diffused hydrogen was used as a carrier gas and the total H_2 flow rate was 4 L/min. The working pressure of reactor was maintained at 13.3×10^3 Pa during the growth. The substrate was placed on a rotating sample holder. It rotates at the speed of 60 rpm. Firstly, the TMSb flux was switched into the reactor at 300 °C in order to prevent GaSb substrates from decomposing before reaching the growth temperature. Then a 10 nm thickness of GaSb nucleation layer was introduced at 500 °C. The flux ratio of groups V and III was approximately 2. After the growth of GaSb nucleation layer was finished, the growth temperature was set in the range of 480–550 °C for the SL growth. The group V/III flux ratio chosen was 4 for the InAs layer and 2 for the GaSb layer, respectively. The growth rates of InAs and GaSb layers were kept about 10 nm/min. The thicknesses of InAs and GaSb layers were 10 nm, respectively. The number of SL periods was 10. Lastly, a 100 nm thickness of GaSb cladding layer was grown at 520 °C. Furthermore, we also prepared samples with different kinds of interface layer.

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3. Results and discussions

Fig. 1 shows the AFM images of the samples. The samples were grown at 480 °C, 500 °C, 520 °C and 550 °C, respectively. Good surface morphology can be achieved when the growth temperature is between 500 °C and 520 °C, illustrated in Fig. 1b and c. When the temperature was below 500 °C or above 520 °C, the rough surface can be observed, as shown in Fig. 1a and d. This is because when the temperature was low, the surface diffusion and crystal formation speed are slow, compared with sources arriving speed. It affects on physical bonding between nucleation and growth surface. However, when the temperature was too high, the energy of reactants or adsorption atoms is larger than crystal binding energy, leading to unstable growth and In element aggregation, which have been observed clearly in Fig. 1d.

Since the lattice constant of InAs and GaSb is 6.058 Å and 6.096 Å, respectively, there is −0.6% lattice mismatch between them, resulting in tensile strain. Therefore, the quality of the grown SLs is deteriorated as the SL period number increases, due to the accumulation of the tensile strain. Thus, InSb interface layer is often introduced to balance the stress and improve the crystal quality of the SL fabricated by MBE [15–18]. However, we found that the effect is inconspicuous in the SL grown with MOCVD growth method. Therefore, instead of inserting InSb, we introduce a two-monolayer (ML) $InAs_{0.89}Sb_{0.11}$ interface layer. During the SL growth, AsH_3 flux was switched off for 3 s after InAs layer depositing. Similarly, there was a dual-stage growth interruption of 0.1 s of TMSb flow followed by a 0.5 s AsH_3 flow after the growth of GaSb. The InAsSb composition was measured with an energy dispersive spectrometer (JSM-6700F). Compared with InSb interface layer, a good sample surface morphology with InAsSb interface layer was achieved, shown as the AFM images in Fig. 2c, where SLs samples without any intentional interface layer (in Fig. 2a) and with InSb interface layer (in Fig. 2b) are used for comparisons. There are three reasons to explain the improvement on the surface quality when InAsSb interface layer was employed for the InAs/GaSb SLs grown by MOCVD. Firstly, the growth temperature of InAs/GaSb SLs by MOCVD is higher than that grown by MBE. The low melting temperature of InSb (525 °C) requires low growth temperature, typically not greater than 475 °C, to prevent the sample surface morphology deterioration [19]. However, the optimized epitaxial growth temperature for InAsSb can be higher than that of InSb (depends on the As composition in the alloy) [20]. Secondly, with MOCVD system, essentially, much more attention must be paid to prepare high quality InSb layer, for example, precise control of V/III ratio [21]. Small deviations from this ratio can cause the condensation of either indium or antimony on the surface [22]. On the other hand, smooth surface is prone to be obtained when growing InAsSb, by optimizing expitaxy conditions. Lastly, the compressive strain of 6.2% relative to GaSb is arisen if InSb is used as interface layer. When $InAs_{0.89}Sb_{0.11}$ interface layer is introduced instead of InSb, 0.13% compressive strain is generated that partly

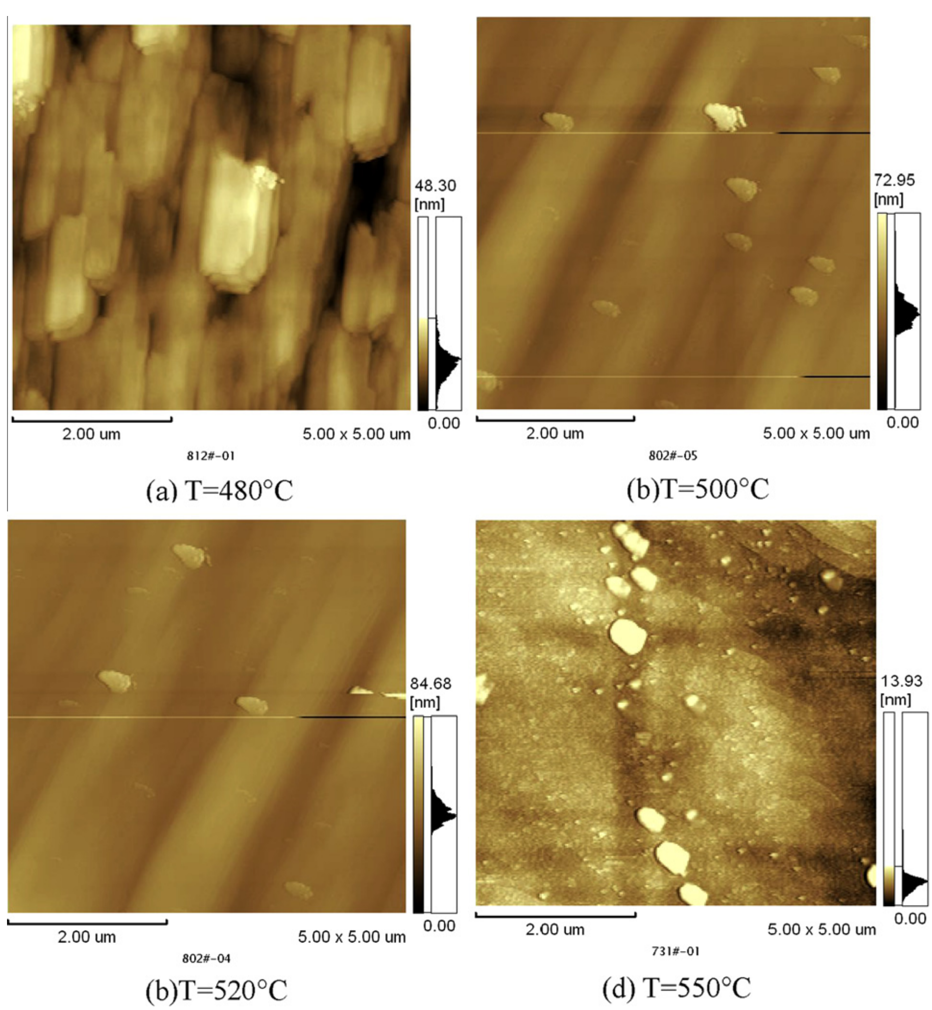

Fig. 1. AFM images of InAs/GaSb SL at different growth temperatures.