InAs/GaSb type-II superlattice grown by MOCVD for long-wavelength infrared detection

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Recently, many characteristics of the InAs/GaSb type-II superlattice(SL) have been investigated. However, little research work has been devoted to the source flux control, which is very important for improving the property of the SL. Based on the technology of metal organic chemical vapor deposition (MOCVD) on GaSb substrate, which has a better cost effectiveness for large-scale production, SL with excellent crystal quality is proposed in this paper. Furthermore, the importance of source flux control is analyzed by comparison of the low-temperature photoluminescence (PL) spectra of the SL grown with a special source flux control and that with a simple source flux control. The x-ray diffraction(XRD) data and the surface morphology obtained by atomic force microscopy(AFM) show that the SL designed by us has smooth surface, and the peak sense wavelength of the SL is around 10 μm.

(Received August 24, 2011; accepted September 15, 2011)

Keyword: B1.InAs/GaSb, A3.superlattices, A3.source flux control, A3.MOCVD, A1.PL spectra

1. Introduction

Compared with MBE, MOCVD not only can grow ultra-thin and sharp epitaxial layer,but also be convenient to large-scale produce for the simple equipment and easy operation. So MOCVD has more practical than MBE. The next important breakthrough in semiconductor optoelectronics would be superlattice, quantum well, quantum wire, quantum dot materials and devices in-depth study, which all rely on such ultra-thin layer of MOCVD growth technology.

Infrared detector is the core component of the infrared systems and play a leading role in the development of infrared technology. At present, the most using of infrared detector materials is HgCdTe. However, many countries have been searching new materials to replace HgCdTe due to its major drawbacks such as difficulty in growth, nonuniformity, instability, large tunneling currents, and high Auger recombination rate. InAs/InGaSb SLs have been proposed by Smith and Mailhiot [1]. It is noticed that the band gap of InAs/GaSb type-II superlattices can be tailored to obtain a wide range to sense the wavelength from 2 μm to 30 μm. Compared to HgCdTe. The InAs/GaSb type-II SLs are further favored with lower tunneling currents, high work temperature, low Auger recombination rate and better uniformity [2-7]. Although the structure of SLs have been proposed for several decades, the experiment reports based on SLs is very few in China.

2. Theory

This type-II SLs has staggered band alignment such that the conduction band of the InAs layer is lower than the valence band of the GaSb layer (Fig. 1). n this SL,the electrons are centered in the InAs layer and the holes are centered in the GaSb layer, so the recombination life of the carriers will be longer. The electron and hole exist in a same energy system and form a electron-hole system. This creates a situation in which the energy band gap of the type-II SLs can be adjusted to form either a semimetal or a narrow band gap semiconductor material by tuning the thickness of the layers and alloy composition. Theoretical models provide essential guidance for the SLs design. The most common method of calculating the band structure of type-II SLs is based on Hamiltonian with an envelope function approximation formalism. The SLs are assumed as a perfectly periodic system with the envelope-function approximation, so the standard formalism for bulk periodic solids, including K.p theory, is directly applicable to SLs. The only input parameters for the theory are those of the bulk materials involved in the SLs. The quantificational relationship between band gap and materials of SLs is then obtained. Based on this theory we can design appropriate SLs period and thickness of layer to make the band gap of SL below 120 meV for the sensing wavelength up to 10 μm. In this paper, layers with equal thickness are designed. As the thickness of layer is between 50 Å and critical thickness, the SL can sense the long wavelength of λ_c>10 μm [1]. Fig. 2 show the band gap of InAs/GaSb SLs grown along the [111] orientation as a function of layer thickness for equally thick InAs and GaSb which was calculated by D. L. Smith [1].

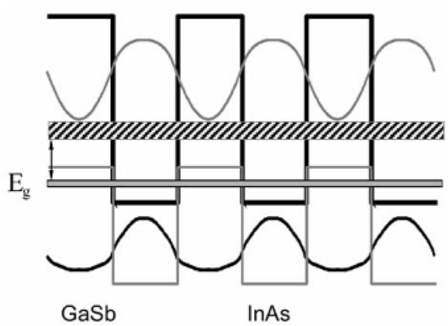

Fig. 1. Band edge diagram illustrating the confined electron and hole minibands which form the energy band gap.

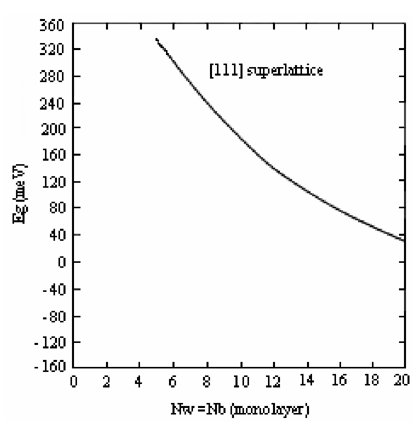

Fig. 2. Bandgap of InAs/GaSb[111]superlattice as a function of layer thickness. The SL consists of equally thick InAs and GaSb layers. The thickness of monolayer as unit.

Theoretical and experimental results show the band gap and energy band structure can be tailored by controlling of the thickness and period of SLs layers. With the thickness of SLs increasing, the electron confinement energy decreases while the hole confinement energy increases. As the SL thickness increases to some level, the electron energy level will be caused to fall below that of the hole level, the SLs band gap may be zero or even negative [8].

3. Experiment and results

The InAs/GaSb binary type-II SL were grown by metal organic chemical vapor deposition (MOCVD) under the low pressure (100 Torr), and the MOCVD machine is developed by ourselves. The epi-GaSb substrate is n-doped (100) orientation and single-sided polishing. GaSb substrate should be first treated under 585 ^{o}C to remove the oxide on the surface. Based on the existing equipment and conditions, we have designed appropriate growth parameters and optimized the process according to the relationship between Eg and the layer thickness. As a first step, a thin GaSb buffer layer was grown on the GaSb substrates. Then approximately 0.1μm thick GaSb layer was grown. After that, a series of SL layers were grown on GaSb layer. The SL period number was designed to be 10, and thickness was intended to be 8～10 nm of equal InAs and GaSb. Finally, approximately 0.1 μm thick GaSb layer was grown. Fig. 3 show the SL structure we have grown.

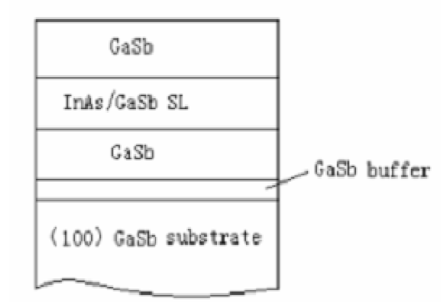

Fig. 3. The diagram of InAs/GaSb SL structure.

The growth temperatures were 500 ^{o}C for GaSb buffer layer, 520 ^{o}C for GaSb layer and 520 ^{o}C for SL. The growth times were 1min for GaSb buffer, 10 min for GaSb layers, and 1min for every InAs or GaSb layer of SL.

During the growth of the SL, a special source flux control was adopted in order to obtain a sharp interfaces and limiting cross contamination in the layers, as shown in Fig. 4.

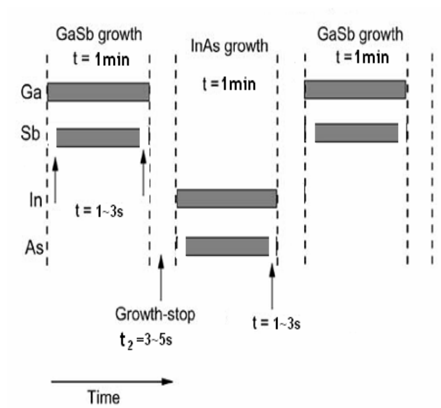

Fig. 4. Flux diagram of the organic source, SLM is standard litre per minute.

The detailed design was that a short switching time (t1=1~3s) of A_3H_3 and TMSb was provided before and after growing InAs and GaSb, and a short switching time (t2=3~5s) was also provided between growth layers changes to obtain better interfaces. In order to study the dependence of SL material characteristics on the source flux control, two groups of SL samples were grown. One group is grown under a special source flux control as shown in Fig. 4 and the other with a simple source flux control of turning on and/or off the source at the same time. Moreover, the 77k temperature PL spectra of these two group samples are compared.

The PL spectra (see in Fig. 5) were measured using a fourier transform infrared spectrometer running in step-scan mode at a temperature of 77 K [9]. The pumping light was 514.5 nm line of an Ar+ laser with the pumping power being set at 80 mW. The spectrometer was configured with a Ge/KBr beamsplitter and HgCdTe detector for mid-infrared region. The spectral resolution was 16 cm^{-1}.

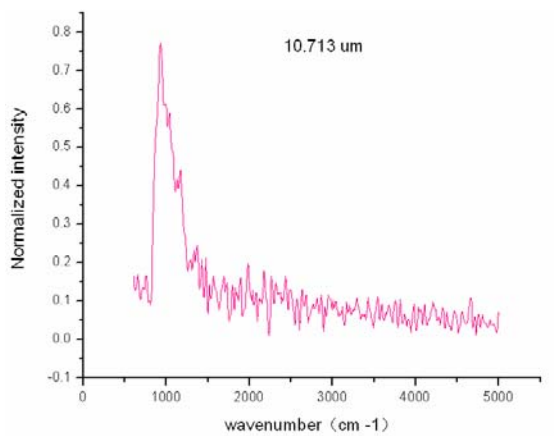

Fig. 5. The PL spectra of the SL grown adopting the source flux control at 77K.

The wavenumber is the reciprocal value of wavelength in Fig. 5. From the figure one can see that the photoluminescence intensity is the most as the wavenumber is close to 1000, and the corresponding photoluminescence wavelength is near 10.713 μm. The full width at half (FWMH) is about 41.8 meV, which is much narrow. However, the PL peak is not obviously observed in the SL grown with a simple source flux control. The result indicates the proposed SL grown with the special source flux control，which has better energy band, good epitaxial layer quality and uniformity, can sense wavelength of 10 μm.

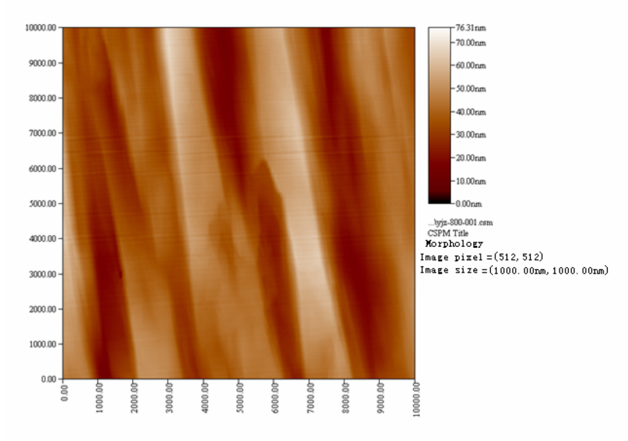

Fig. 6. The AFM image of the surface of the InAs/GaSb SL.

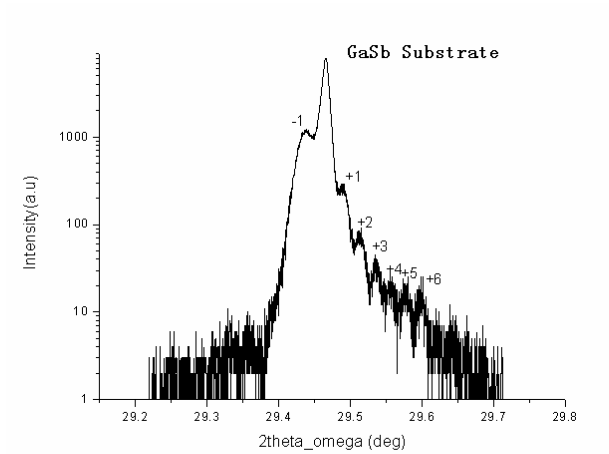

Fig. 7. A narrow angle range of x-ray diffraction (XRD) data of the SL layers.

Theoretical and experimental results show electronic and optical properties of SL are influenced by the surface morphology and quality of epitaxial layers. After growth, the surface morphology and SL quality of the samples was studied with an AFM and XRD. Fig. 6 shows the AFM image of a 10 μm×10 μm scans of the SL surface. The image indicates that surface of the SL is much smooth and clear. A narrow angle range of x-ray diffraction (XRD) data of the SL layers show in Fig. 7. The six sharp diffraction peaks of the XRD image of growth layers indicate the relaxation phenomenon didn't happen in the growth layers. The symmetric diffraction peaks wasn't observed on the left of the GaSb peak, because the weak intensity of SL diffraction peak was shieldinged by the epitaxial layer diffraction peak.

Compared the experimental results with the theoretical data, we find that in order to get the same band gap of the SL material, the real thickness of SL in the experiment is often higher than the calculated value [10-12]. In addition to the algorithm approximation, the main is due to theoretical calculations using a series of idealized assumptions, such as the ideal SL, an exact match lattice with sharp, smooth and defect-free interfaces, etc. [8]. However, in practice these assumptions are unlikely to achieve, so there are some deviations between the experimental value and theoretical value.

4. Conclusion

Based on the theory about SLs, we have reasonably designed the period and growth parameters of the InAs/GaSb SL, and successfully developed a period of 16~20nm with equal thickness of InAs and GaSb layer using MOCVD. Their 77K temperature PL spectra of the SL grown respectively with the special and simple source flux control are compared. With the AFM method and x-ray diffraction method for its surface morphology and SL quality analysis, the results indicate that the SL materials with our improved growth process have a good surface morphology and epitaxial layer quality, and can respond to long-wave of 10 μm.

Acknowledgements

This work was supported by the national Natural Science Foundation of China, No.60676039 and 60707018.

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