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Characterization of AlInAsSb/GaInAsSb Multiple Quantum Wells Grown by MOVPE

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1. Introduction

Recently, AlSb-based quantum wells lattice-matched to InP substrate have received much attention because of their special features such as large conduction-band offset and large refractive-index difference [1-2]. Several groups have demonstrated distributed Bragg reflectors (DBRs) incorporating various Sb-based heterojunctions such as AlAsSb/GaAsSb, AlPSb/GaPSb and AlAsSb/InGaAs [2-5]. The large refractive-index difference of Sb-based DBRs promises the possibility for the fully epitaxial growth of vertical cavity surface emitting lasers (VCSELs) with relatively low number of mirror periods.

In addition, due to the high conduction-band offset, AlAsSb/InGaAs has been proposed to be a promising material system for resonant tunneling diodes [6-8]. AlInAsSb/GaInAsSb heterojunction is also a suitable candidate for the above-mentioned applications. In this paper, we report the growth and characterization of $Al_{0.66}In_{0.34}As_{0.85}Sb_{0.15}/Ga_{0.64}In_{0.36}As_{0.84}Sb_{0.16}$ MQW structures grown by metalorganic vapor phase epitaxy (MOVPE).

2. Experiment

The AlInAsSb/GaInAsSb MQW structure was grown by MOVPE system on (100)-oriented Fe-doped InP substrate. Growth was performed in a horizontal reactor. The growth pressure and temperature were 100 torr and 650 degree C, respectively. The MQW structure consisted of a 0.5-μm-thick undoped InP buffer layer, 10 periods of undoped $Al_{0.66}In_{0.34}As_{0.85}Sb_{0.15}/Ga_{0.64}In_{0.36}As_{0.84}Sb_{0.16}$ MQW and finally a 0.2-μm-thick undoped InP capped layer. The sources of Al, Ga, In, Sb, P, and As atoms were trimethylaluminum (TMAl), trimethylgallium (TMGa), trimethylindium (TMIn), trimethylantimony (TMSb), phosphine, and arsine, respectively.

The growth procedures of the MQW structure are given in Table I. The growth sequence began with an undoped InP buffer layer. After the growth of the buffer layer, the TMI was switched off and the flow rate of PH3 was immediately decreased from 150 sccm to 30 sccm. At the end of a 10-second interruption, PH3 was switched off and TMAl, TMIn, TMSb and AsH3 were simultaneously switched into the chamber to grow AlInAsSb layer. After the growth of AlInAsSb layer, TMA and TMI were switched off. After a 10-second interruption, TMG and TMI were switched into the chamber for the growth of GaInAsSb layer. During the growth of MQW structures, TMSb and AsH3 were kept in the chamber and their flow rates remained constant. Due to the introduction of 10-second interruptions, high crystalline quality and quantum-well periodicity are revealed from the spectra of the DCXRD and SIMS.

The solid composition of the quaternary alloy was determined by JEOL (JXA-8800M) electron-probe microanalysis (EPMA). The uncertainty of the measured composition was within 0.01 compared to standards of calibration. The lattice mismatch of the quaternary alloy, to InP substrate, was determined from double crystal X-ray diffraction measurement (DCXRD), and the mismatch was less than 0.03%. The growth rate of the quaternary material was measured from cleaved and etched samples by scanning electron microscope. The confirmation of growth rate was then performed by DCXRD. Secondary ion mass spectrometry (SIMS), using Cs+ ions as the primary beam, was also performed for the MQW structure. For the PL measurement, the sample was mounted in a cryostat at the temperature of 8 K. A 514.5 nm argon ion laser was used as a pump source. And then the PL spectra were analyzed by a Spex focal length = 3/4 m spectrometer and detected with a liguid-nitrogen cooled Ge detector.

Table I Growth conditions for the AlInAsSb/GaInAsSb MQW structure

	Time (s)	Flow Rate (sccm) TMAl	TMG	TMIn	TMSb	PH_3	AsH_3	V/III Ratio
InP	1250			376		150		146
Interruption	10					30		
AlInAsSb	75	60.5		144	50		4	15.4
Interruption	10				50		4	
GaInAsSb	21		20.4	144	50		4	12.3
Interruption	10				50		4	

3. Results and Discussion

Fig. 1 shows the DCXRD (400) rocking curve of the 10-period $Al_{0.66}In_{0.34}As_{0.85}Sb_{0.15}$ (30 nm) / $Ga_{0.64}In_{0.36}As_{0.84}Sb_{0.16}$ (13.5 nm) MQW structure. In the measured curve sharp and intense X-ray satellite peaks could be clearly seen, indicating high quality of the MQW structure.

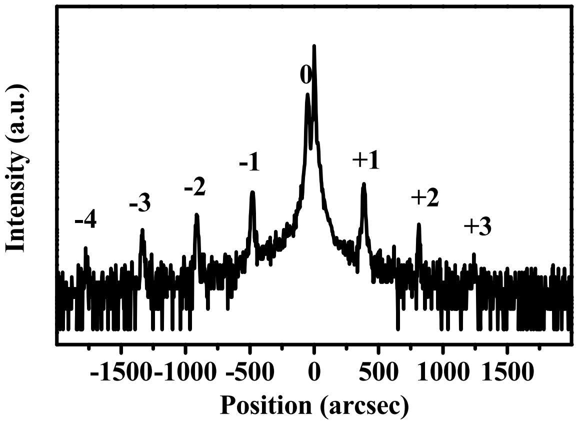

Fig. 1 The (400) rocking curve of 10-period $Al_{0.66}In_{0.34}As_{0.85}Sb_{0.15}$/ $Ga_{0.64}In_{0.36}As_{0.84}Sb_{0.16}$ MQW structure.

The period of the MQWs has been determined from the spacing of the satellite peaks shown in Fig. 1 is in good agreement with the predicted spacing based on the product of growth rate and time. The SIMS depth profile of the MQW structure is also shown in Fig. 2. The depth scale was calculated from the total sputtered depth, assuming a constant sputtering rate. Modulation is clearly seen for Al, Ga, and As profiles, but very little for In and Sb profiles.

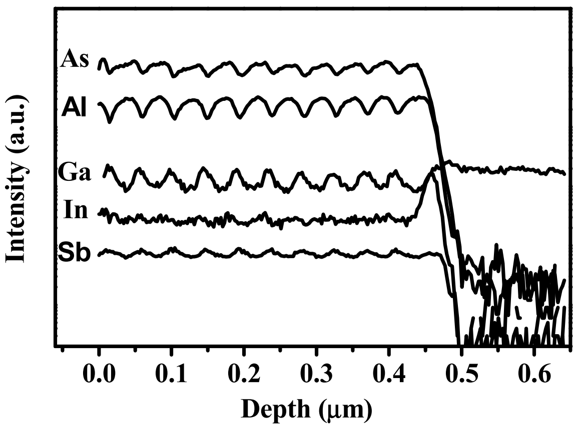

Fig. 2. The SIMS depth profile of a 10-period $Al_{0.66}In_{0.34}As_{0.85}Sb_{0.15}$/ $Ga_{0.64}In_{0.36}As_{0.84}Sb_{0.16}$ MQW structure.

Fig. 3 shows the 8K PL spectra of four MQW structures with the well widths of 5, 6, 8.5, and 13.5 nm, respectively. All samples were illuminated by the same intensity of laser excitation with the power density of 1 W/cm^2. A single peak was observed in the PL spectra within the scanning range for all MQW samples. It was identified as the exciton transition from the first electron subband to the first heavy-hole subband. The PL peak energy increases from 802.7 meV to 964.9 meV while the well width decreases from 13.5 nm to 5 nm. The presence of the quantum size effect is evidenced by the increase of the PL peak energy with the decreasing well width.

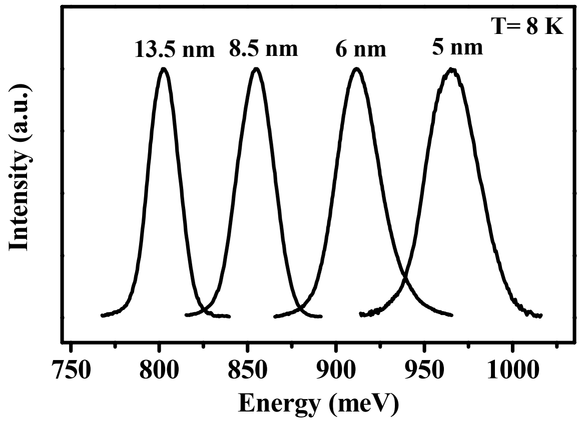

Fig. 3 Low-temperature (8 K) PL spectra of four 10-period $Al_{0.66}In_{0.34}As_{0.85}Sb_{0.15}$/ $Ga_{0.64}In_{0.36}As_{0.84}Sb_{0.16}$ MQW structures with well widths of 5, 6, 8.5, and 13.5 nm, respectively.

4. Conclusions

In summary, we have reported the growth and characterization of AlInAsSb/GaInAsSb MQW structures by MOVPE. DCXRD, SIMS and low-temperature PL were used to characterize the MQW structure. High crystalline quality and quantum-well periodicity are revealed from the spectra of the DCXRD and SIMS. PL exhibits a single peak corresponding to excitonic transition between the first electron subband to the first heavy-hole subband confined within the GaInAsSb wells. These results indicate high quality AlInAsSb/GaInAsSb MQW structures could be grown by MOVPE.

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