InAsN/InGaAs/InP Quantum Well Structures for Mid-Infrared Diode Lasers

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Many spectroscopic and medical applications require lasers with emission wavelength of 2-3 μm. Besides the traditional Sb-based alloys lattice-matched to GaSb substrate, strained InAsN/InGaAs quantum-well (QW) structure on InP substrate is a potential alternative for laser devices in this spectral range [1]. InAsN owns two important features, i. e., the band gap reduction due to the huge bowing parameters induced by the large differences in atomic sizes and electronegativities of N and As atoms [2] and the lattice-mismatch reduction when it is grown on InP substrates. Both features can extend the wavelength range of InAsN/InGaAs QW and make it a promising material for mid-infrared applications. In addition, the superior quality of InP substrates over GaSb substrates and the mature growth and processing technologies on InP-related alloys also provide advantages for laser diodes based on InAsN/InGaAs QW structures.

In this study, InAsN/$In_{0.53}Ga_{0.47}As$ multiple quantum wells (MQWs) and laser structures were grown on (100) InP substrates by using a VG V-80H gas-source molecular beam epitaxy (GSMBE). Besides the elemental In and Ga and thermally cracked AsH_3 and PH_3 sources, an EPI UNI-bulb RF plasma cell was used to generate active nitrogen species. The optimized growth temperature and growth rate for InAsN were 400°C and 1.5 μm/hr, respectively. Photoluminescence (PL) measurement on InAsN/InGaAs MQWs with various nitrogen compositions shows that the nitrogen increment in InAsN results in red-shift on the PL emission wavelength. X-ray diffraction measurement on these MQWs also indicates that nitrogen incorporation can reduce the net compressive strain of the MQW [3]. The PL integrated intensity of the InAsN QW with 3% nitrogen composition is comparable to that of the high-quality strained InAs/InGaAs QW [4]. However, further nitrogen incorporation degrades the PL intensity significantly. Therefore, 4-period InAsN/$In_{0.53}Ga_{0.47}As$ MQW with 3% nitrogen composition was chosen for the active medium of the laser. The detailed laser structure is shown in Fig. 1. After the GSMBE growth, the laser sample was annealed at 575°C for 20 min under N ambient in order to improve the crystal quality [5]. The PL spectrums of the laser structure before and after annealing are shown in Fig. 2. The structure was then processed into 50-μm-wide broad-area lasers. Laser oscillation under pulsed injection current was obtained from 10K to 260K. Fig. 3 shows the emission spectrum at 260K. As can be seen, the peak wavelength is at 2.42 μm. The threshold current density of the laser at 260K is 6.2 kA/cm^2, and the characteristic temperature is 110K for a temperature range from 50 to 260K. The laser performances indicate the potential of InAsN as a material for mid-infrared applications.

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Layer	Material	Thickness	Doping (cm^{-3})	
Protection	InP	30 nm	p-3×10^{19}	
Ohmic Contact	$In_{0.53}Ga_{0.47}As$	0.1 μm	p-3×10^{19}	
Cladding	InP	0.3 μm	p-8×10^{18}	
	InP	0.5 μm	p-1×10^{18}	
	InP	0.5 μm	p-5×10^{17}	
	InP	0.3 μm	p-2×10^{17}	
	InP	0.1 μm		
Barrier	$In_{0.53}Ga_{0.47}As$	86 nm		
Barrier	$In_{0.53}Ga_{0.47}As$	40 nm		}×4
Well	$InAs_{0.97}N_{0.03}$	3 nm		
Barrier	$In_{0.53}Ga_{0.47}As$	126 nm	undoped	
Buffer	n-InP	0.5μm	n-1×10^{18}	
Substrate	n^+-InP			

Fig. 1 Structure of the InAsN/InGaAs quantum well laser diode.

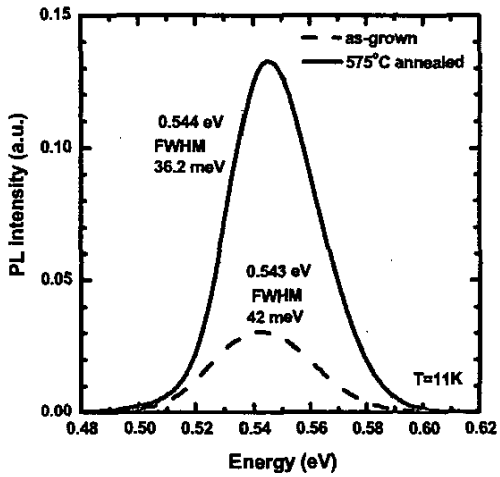

Fig. 2 11K PL spectrums of the as-grown and annealed 4-period InAsN/ InGaAs quantum well laser.

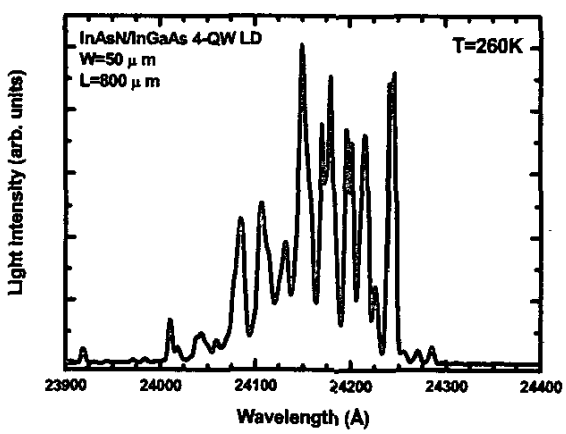

Fig. 3 Emission spectrum of InAsN/InGaAs diode laser operated at 260K.