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MBE Growth and Characterization of InGaAsSbN Quantum Well Laser Diodes at 2 μm Wavelength Region grown on InP Substrates

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1. Introduction

Semiconductor lasers operating at 2 μm wavelength region are very important for gas analysis, chemical sensing and medical diagnostics. So far, most of these lasers have been developed for GaSb based material systems. It is very convenient to get 2 μm wavelength lasers using InP based material systems, since the technology for InP-based lasers has been well developed during the research on 1.3-1.5 μm lasers for optical communication systems. From these points of view, dilute nitride III-V compound semiconductors, such as InGaAsN and InGaAsSbN grown on InP substrates have attracted much attention because of application for high-performance quantum well lasers operating at 2 μm wavelength region. Recently, we reported laser operation of InGaAsSbN quantum well laser diodes grown on InP substrates by molecular beam epitaxy (MBE)[1]. In this paper, MBE growth and characterization of InGaAsSbN quantum well lasers with different Sb composition were reported. It was found that increase in the Sb composition induces a marked red-shift of the emission wavelength as well as a reduction of the lasing threshold current density.

2. MBE growth

The InGaAsSbN quantum well diodes were grown on Sn-doped n-type (100) InP substrates by plasma assisted MBE. They consist of a Si-doped n-type lower $In_{0.52}Al_{0.48}As$ cladding layer, a Si-doped n-type lower $In_{0.52}Ga_{0.09}Al_{0.39}As$ guiding layer, an un-doped $In_{0.8}Ga_{0.2}As_{1-x-y}Sb_xN_y$(10nm)/$In_{0.52}Ga_{0.09}Al_{0.39}As$(3nm) double quantum well active layers, a Be-doped p-type upper $In_{0.52}Ga_{0.09}Al_{0.39}As$ guiding layer, a Be-doped p-type upper $In_{0.52}Al_{0.48}As$ cladding layer, and a Be-doped p-type $In_{0.53}Ga_{0.47}As$ cap layer. All layers, except the strained InGaAsSbN quantum well active layers, are lattice-matched to InP substrates. Two kinds of quantum well diodes were grown with different Sb mole fraction of 0.014 and 0.14. The Nitrogen mole fraction of the InGaAsSbN layer was fixed at 0.014 for both diodes. The growth temperature was 505°C. In, Ga, and Al metals were used as groupⅢ beam sources, while tetramers As_4 and Sb_4 were used for groupⅤ beam sources. Nitrogen was supplied using electron cyclotron resonance (ECR) plasma source. The nitrogen gas flow rate is 0.7 sccm with the ECR power of 40W. The background pressure during growth is about $6x10^{-3}$ Pa. The InGaAsSbN quantum well diodes have a broad-stripe structure of 100 μm width. AuGeNi and AuZnNi were used as n-electrodes and p-electrodes, respectively. The cavity length is about 600 μm.

3. Characterization

Figure 1 shows the electroluminescence (EL) spectra of the InGaAsSbN quantum well diodes with Sb=0.014 (hereafter diode A) and Sb=0.14 (hereafter diode B) at 10K with the low injection current of 50 mA. EL measurements were carried out using a standard lock-in amplifier technique. EL was detected by a cooled InSb photo-detector. It is known from this figure that increase in Sb composition induces a marked red shift of the emission wavelength, where the emission wavelength of the diode A is 2.02 μm, while that of the diode B is shifted to 2.25 μm. The energy shift is about 50 meV. Furthermore, the full width at half maximum (FWHM) of the EL spectrum of the diode B (30 meV) is narrower than that of the diode B (40meV). It was reported that Sb not only act as surfactant to improve quantum well planarity, but induces a marked red shift of the emission wavelength

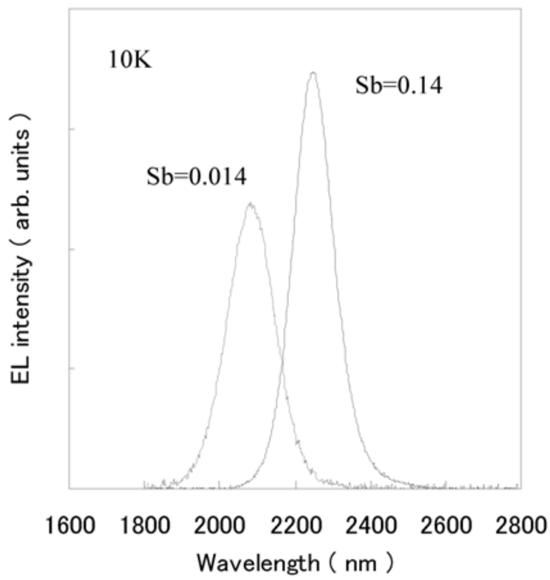

Fig.1 EL spectra of the InGaAsSbN Quantum well laser diodes.

in case of the InGaAsSbN quantum well structure grown on GaAs substrates[2,3]. The present results also suggest that the interface properties of the InGaAsSbN quantum wells on InP substrates were improved with increasing Sb composition.

Laser operation was obtained for both quantum well diodes upon post-growth rapid thermal annealing (RTA). RTA was carried out at 700°C for 20 s in a nitrogen cover-gas environment. This RTA induced a blue shift (~20 meV) of the emission wavelength and about one order enhancement of the EL intensity. Figure 2 shows the lasing spectra at 90K for both laser diodes under pulsed condition. The lasing wavelength is 1.94 μm for the diode A, while it shifts to 2.07 μm for the diode B, corresponding to the increase in Sb composition. Figure 3 shows the temperature dependence of the threshold current density in the temperature range from 10K to 90K. The threshold current density at 90K of the diode A is 2.35 KA/cm^2, while it reduces to 1.48 KA/cm^2. The To value estimated in the temperature range from 50K to 90K is 58K for the diode A and is 62 K for the diode B, respectively. The reduction in the threshold current density for the didoe B is mainly due to the improvement of the interface properties of the InGaAsSbN quantum wells. At present, the threshold current density is relatively high and lasing operation above 100K was not obtained for both laser diodes. Further improvements of the crystal quality of the InGaAsSbN quantum well layer, as well as optimization of the laser structure are still necessary to obtain laser operation at room temperature.

4. Conclusion

In conclusion, InGaAsSbN quantum well diodes operating at 2 μm wavelength region with different Sb composition were grown by MBE on InP substrates and their emission properties were studied. It was found that increase in the Sb composition induces a marked red-shift of the emission wavelength as well as a reduction of the lasing threshold current density.

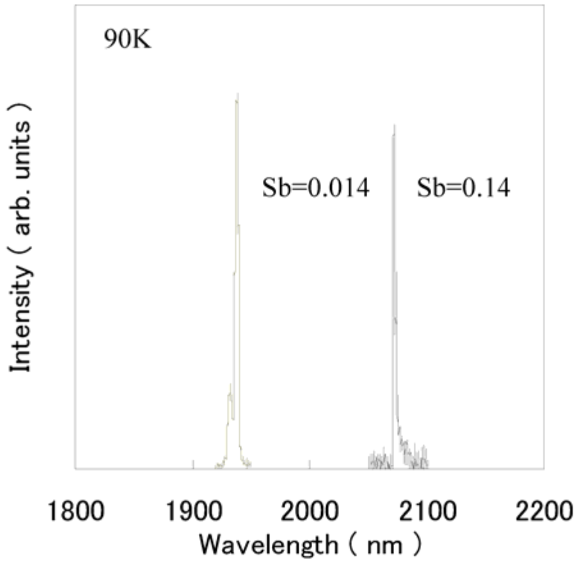

Fig. 2 Lasing spectra of the InGaAsSbN quantum well laser didoes at 90K

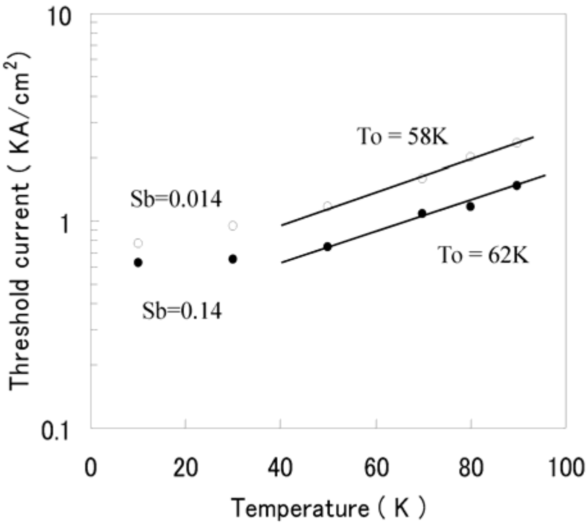

Fig.3 Temperature dependence of the hereshold current density

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