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High Temperature 1.3μm AlGaInAs/InP Strained Multiquantum Well Laser Grown by Metalorganic Vapor Phase Epitaxy*

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Abstract　We have investigated the AlGaInAs/InP compressively strained layer separate confinement heterostructure multiquantum well (SCH-MQW) laser structure, which was grown by Low-Pressure Metalorganic Vapor phase Epitaxy. The T_0 of AlGaInAs/InP SCH-MQW buried-heterostructure lasers was up to 110K at temperatures between 20℃ and 60℃. The drop of slope efficiencies was only 0.54dB at temperatures between 20℃ and 80℃.

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1　Introduction

Long wavelength ($\lambda = 1.3/1.55\mu m$) semiconductor laser with wide operation temperature range is a key component in both digital and analog optical fiber communication systems as well as optical access networks. Although it has been demonstrated experimentally and theoretically that the laser threshold current, Auger recombination, and intervalence band absorption can be reduced by using the combination of biaxial strain and quantum confinement to reduce the in-plane hole effective mass[1]. The performance at high temperature is still unsatisfactory compared with that of a short-wavelength laser on a GaAs substrate. The poor performance is mainly due to a small conduction band offset ($\Delta E_c = 0.4\Delta E_g$) of InGaAsP/InP laser. It results in more than 1dB drop of the differential quantum efficiency of InGaAsP/InP lasers when the temperature

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rises from 25℃ to 85℃.[2] The poor differential quantum efficiency characteristics reduces both the system link power budget and modulation bandwidth.[3]

An attractive candidate for high temperature long wavelength laser diodes is the AlGaInAs/InP material system. The benefits of AlGaInAs/InP material system are that aluminum atoms can be exchanged with gallium atoms, for their lattice constants are nearly the same, while the strain and thickness of the epitaxial layer can be changed easily. In addition, the band gaps, refractive indices, and effective masses of the charge carriers are very similar to the InGaAsP/InP system.[4] However AlGaInAs/InP systems have a conduction band offset ($\Delta E_c = 0.72\Delta E_g$) larger than that of conventional InGaAsP/InP system, resulting in a smaller overflow of electrons at high temperature and high-speed operation. Recently, excellent characteristics of AlGaInAs/InP system, including a maximum continuous-wave (CW) operation temperature of 185℃[5] and a characteristic temperature T_0 of 120K[6] and 23GHz modulation band with T_0 of 105K,[7] have been reported.

In this paper, we investigate the fabrication and characteristics of 1.3μm AlGaInAs/InP separate confinement heterostructure multiquantum well (SCH-MQW) laser, which incorporate optimized strain-compensated active region, grown by low-pressure metalorganic vapor phase epitaxy (LP-MOVPE) with buried heterostructure (BH) stripe structure.

2 Device Structrue

The laser structure is shown in Fig. 1, which was grown by high-speed rotating low-pressure (2×10^3Pa) MOVPE technigue on a ⟨100⟩ oriented n^+-InP substrate in three-step epitaxial run. Trimethylaluminum (TMAl), Trimethylindium (TMIn) and Trimethylgallium (TMGa) were used for group Ⅲ sources; arisine (AsH_3) and phosphine (PH_3) were used for group Ⅴ sources. Diethylzinc (DEZn) and Silane (SiH_4) diluted to 2% in hydrogen were used as the n- and p-type dopants, respectively. Palladium-diffused hydrogen identified of -110℃ dew point was used as the carrier gas. The reactor was heated by five independently controlled infrared lamps. The Ⅴ/Ⅲ ratio was approximately 300 for InP and 130 for AlGaInAs, and the growth temperature was set at 655℃ for InP and 750℃ for AlGaInAs, respectively.[8]

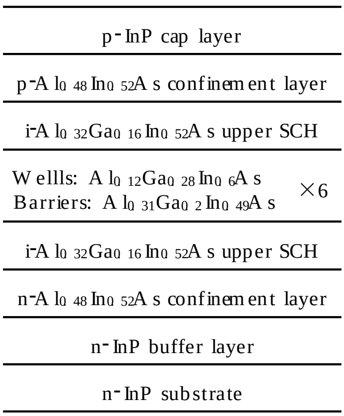

Fig. 1 Schematic diagram of AlGaInAs/InP SCH-MQW structure

Firstly, a 1.5μm n-InP (3×10^{18}) buffer layer was deposited on the substrate surface. The active region contained six 6nm thick 0.9% compressively strained AlGaInAs wells separated by 11nm thick -0.5% tensivelys strained AlGaInAs barriers with a bandgap of 1.05μm for strained compensation. The photoluminescence (PL) wavelength of the active region was adjusted to meet 1.3μm. The MQW active layer was sandwiched symmetrically with SCH comprising an undoped 100nm AlGaInAs (λ= 1.05μm) layer and 30nm doped InAlAs layer. The doping concentrations of the n-type and p-type InAlAs layers were 1×10^{18}cm^{-3} and 2×10^{18}cm^{-3} respectively. Finally, the upper coverage of 100nm p-InP (1×10^{18}cm^{-3}) cap layer was grown.

The information of the quality and compositions of the wafer was obtained from the rocking curve of high resolution X-ray diffraction (HRXRD) measurements by using the asymmetrical (004) reflection. The average strain of 5×10^{-4} and the 16.4nm periodicity including 5.8nm for the well and 10.6nm for the barrier were calculated from the separation of satellite peaks and pendellösung fringes in the HRXRD rocking curve in Fig. 2(a). These results well agreed with the prediction of the growth rate and coincided with the laser design calculated based on the normal rectangular potential model. The optical properties of wafer were studied by photoluminescence measurement at temperatures 300K and 10K. Figure 2(b) shows that the PL wavelength varies from 1.215 to 1.305μm for temperatures between 10 and 300K. The full widths at half maximum of PL spectrum are 20 and 40meV at 10 and 300K, respectively. It can be seen that the quality of the AlGaInAs material is close to that of conventional InGaAsP material.

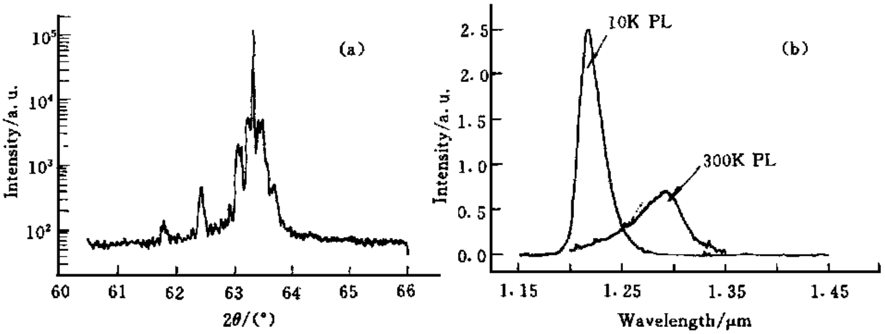

Fig. 2 The HRXRD rocking curve (a) and PL spectrum of MQW structure (b)

After the growth of MQW wafer, the mesa along ⟨110⟩ direction was prepared by wet etching. The width of the active region was controlled between 1.2μm and 1.5μm for fundamental transverse mode operation. The BH regrowth was accomplished by four layers of p-InP (N_d= 7×10^{17}cm^{-3}), p-InGaAsP (N_d= 7×10^{17}cm^{-3}, λ= 1.1μm), n-InP (N_a= 1×10^{18}cm^{-3}), and n-InGaAsP (N_a= 1×10^{18}cm^{-3}, λ= 1.1μm). After opening a 1.5μm width stripe window over the active strip, a p-InP (N_d= 2×10^{18}cm^{-3}) cladding layer and a p$^+$-InGaAs (N_a= 1×10^{19}cm^{-3}) contact layer were grown by LP-MOVPE.

3 Device Performance

The Au/Zn/Au and Au/Ge/Ni were evaporated onto the thinned wafer with thickness of 100μm as p-side and n-side metal contact, respectively. The wafer was cleaved into 300μm cavity length chips which were mounted p-side down on copper heat sink for characteristics measurement. The inset graph in Fig. 3 shows the light-current-voltage (*L*/*I*/*V*) characteristics of a typical laser chip at room temperature (RT). The forward voltage and series resistance were 0.95V and 6Ω, respectively. The threshold current was

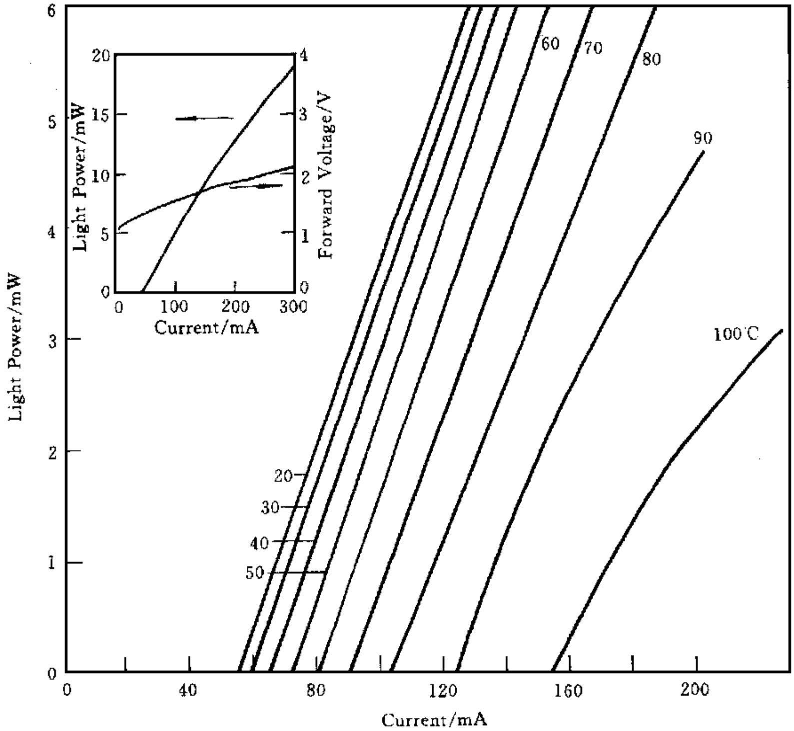

Fig. 3 The *L*-*I* curves at different temperatures and the inset figue is the *L*-*I*-*V* curve at RT

55mA with linear output power over 16mW. The single facet slope efficiency is 0.1mW/mA. For the evaluation of device temperature characteristics, the different temperature *L*/*I* curves were measured as shown in Fig. 3. Figure 4 shows the temperature dependence of threshold current and slope efficiency for AlGaInAs/InP MQW lasers under CW operation. The slope efficiency was measured at 1mW output power from the front facet and normalized to that obtained at 20℃. The characteristic temperature T_0 was 102K at temperatures between 20℃ and 80℃ and 60K at temperatures between 80℃ and 100℃. The drop of slope efficiencies between 20℃ and 80℃ was only 0.543dB, which is much better than 3dB drop normal for InGaAsP based laser. This means that the overflow of electrons in MQW region into SCH layers for AlGaInAs material system is less than that of InGaAsP material system due to the conduction band offset of AlGaInAs larger than that of InGaAsP.

However, the T_0 in high temperature range and threshold current are a little worse than the best records previously published.[5,6] There seems to be still some room for improvement of the crystal quality of our Al-containing layers and/or layer structures including the doping profile in our lasers. In particular, the relatively low T_0 in high temperature range is likely to be improved by optimizing the doping profile in the SCH layers. Further optimization of the growth condition and doping profile in the lasers will result in decreasing threshold currents of our 1.3μm lasers.

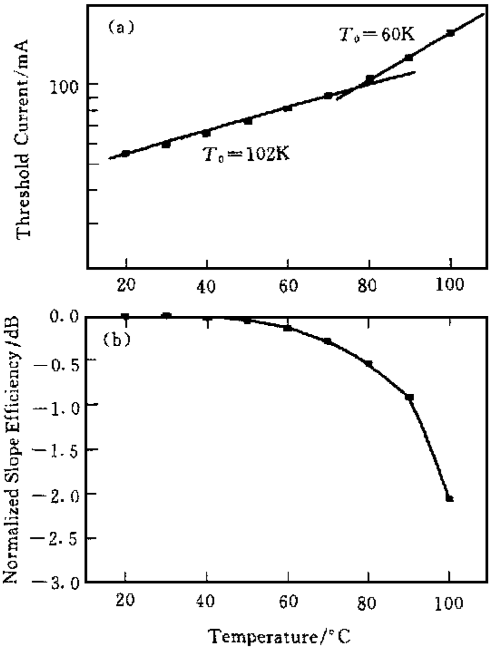

Fig. 4 Temperature dependence of threshold current and slope efficiency for AlGaInAs/InP MQW laser under CW excitation

4 Conclusion

We have successfully grown the 1.3μm AlGaInAs/InP SCH-MQW laser structure by LP-MOCVD. The T_0 of AlGaInAs/InP SCH-MQW BH lasers was up to 110K at temperatures between 20℃ and 60℃. The drop of slope efficiencies was only 0.543dB at temperatures between 20℃ and 80℃.

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