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InGaAs/GaAs/InGaP Strained Quantum Well Lasers Grown by Metalorganic Chemical Vapor Deposition

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Abstract　Aluminum-free strained $In_{0.2}Ga_{0.8}As/GaAs/In_{0.49}Ga_{0.51}P$ single quantum well lasers with an emission wavelength of 985nm are presented. The laser material was grown by metalorganic chemical vapor deposition. An extremely low threshold current density of 150A/cm^2 is obtained for 100μm-wide stripe lasers having a cavity length of 800μm. The internal quantum efficiency and the internal loss are 78% and 5cm^{-1}, respectively. The measured vertical beam divergence angle from the laser is about 45°.

PACC: 4255P, 6855, 7865, 8115H

1　Introduction

Strained InGaAs/GaAs quantum well (QW) lasers with emission wavelength of 980nm are currently receiving considerable attention because they yield a lower noise figure, higher gain coefficient than 1.48μm InGaAsP laser in the application of the erbium-doped fiber amplifier (EDFA) pumping sources[1,2]. In addition, the InGaAs/GaAs strained quantum well lasers have lower threshold current and high slope efficiency. AlGaAs is usually used as cladding layers in most of the InGaAs/GaAs QW lasers. But in recent years, aluminum-free materials for the claddings are used to improve the reliability of InGaAs/GaAs strained quantum well lasers. $In_{0.49}Ga_{0.51}P$ lattice-matched with GaAs, was introduced as a substitution for AlGaAs cladding layers grown by low-pressure metalorganic chemical vapor deposition (LP-MOCVD)[3~6] or gas-source molecular beam epitaxy (GS-MBE)[7~10].

The advantages of InGaAs/GaAs/InGaP QW lasers are as follows. Since it is aluminum-free, less surface oxidation during the fabrication process and laser operation is ex-

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pected. The low surface recombination velocity will enhance catastrophic optical damage (COD) threshold of the laser facets and improve the reliability of the lasers. Furthermore, the successfull selective chemical etching between GaAs and InGaP layers makes the ridge-waveguide structure processing much more easily controlled. In this paper, we report on the strained InGaAs/GaAs/InGaP single quantum well lasers grown by MOCVD.

2 Laser Structure and Material growth

The substrate used was Si-doped (100) n$^+$-GaAs wafers, tilted 6° towards the ⟨111⟩ A plane, with the etch pit densities of less than 500cm^{-2}. The layer structure of the InGaAs/GaAs/InGaP laser is as follows (see Fig. 1): a 0.3μm-thick n$^+$-GaAs buffer layer, a 1.0μm-thick n-In$_{0.49}$Ga$_{0.51}$P lower cladding layer, an undoped 0.1μm-thick GaAs lower waveguide layer, an undoped 7nm-thick In$_{0.2}$Ga$_{0.8}$As quantum well as the active layer, an undoped 0.1μm-thick GaAs as the upper waveguide layer, a 1.0μm-thick p-In$_{0.49}$Ga$_{0.51}$P upper cladding layer, a 0.1μm-thick p$^+$-GaAs cap layer, and a 30nm heavily doped p^{++}-GaAs ohmic contact layer for minimizing the contact resistance.

The laser material was grown by low-pressure MOCVD in an AIXTRON-200 system at a constant temperature of 700℃, except for the top GaAs layers grown at 600℃ to increase the Zn incorporation. The source materials were trimethylgallium (TMG), trimethylindium (TMI), arsine (AsH$_3$) and phosphine (PH$_3$). Dimethylzinc (DMZ) and silane (Si$_2$H$_8$) were used as the n- and p-type dopants, respectively.

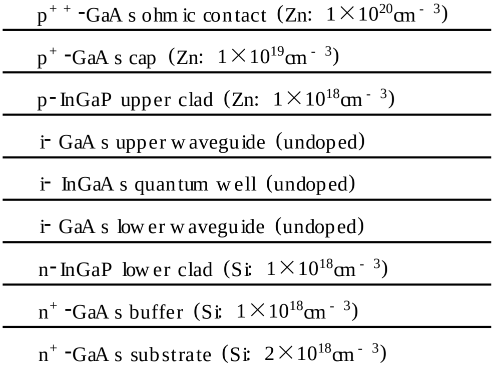

Fig. 1 The layer structure of the InGaAs/GaAs/InGaP laser

Since the layer structures contain relatively thick InGaP cladding layers, it is essential to have close lattice matching to the GaAs substrate. It is experimentally observed that the lattice mismatch ($\Delta a/a$) of the relatively thick (1.0μm) InGaP layers must be less than 2×10^{-3} to avoid degradation in laser performance.

3 Device Fabrication and Laser Performance

The laser structure is evaluated by fabrication and characterization of wide stripe (100μm wide) devices. The devices are fabricated by chemical etching through the p$^+$- and p^{++}-GaAs layers outside the 100μm stripe to prevent current spreading. A 120nm-thick SiO$_2$ was deposited over the entire p-surface by Plasma-Enhanced Chemical Vapor Deposition (PECVD). Then the wafer was processed into 100μm-wide broad stripes by using standard photolithography techniques. After the p-contact consisting of Ti/Pt/Au was deposited, the wafer was thinned to a thickness of about 100μm, then the n-contact consisting of AuGe/Ni/Au was deposited. The lasers were then cleaved into bars with various cavity lengths. The tested devices were mounted p-side down on a copper heat-sink using indium solder.

Figure 2 shows the plot of the threshold current density against various cavity lengths for the fabricated lasers. The threshold current density is 150A/cm^2 at a cavity length of 800μm. When the cavity length extends to 1200μm, the threshold current density decreases to 130A/cm^2 due to the decreased facet optical loss.

From the relationship of the reciprocal of the external quantum efficiency versus the cavity length for the fabricated lasers, an internal quantum efficiency and total internal loss of 78% and 5cm^{-1} are deduced, respectively. It is expected that the use of InGaAsP (> 1.5eV) waveguide layer or a step graded index separate confinement heterostructure will improve the carrier injection efficiency, and consequently enhance the internal quantum efficiency compared with the GaAs waveguide layer structure shown in Fig. 1.

From the perpendicular far-field intensity profile, we know that the beam divergence or far-field angle at full width of half maximum (FWHM) is about 45°. The large vertical beam divergence is attributed to the strong optical confinement in the laser structure. To meet the demand of the device in system applications, it would be necessary to reduce the beam divergence so that high fiber coupling efficiency could be achieved. This can be obtained by reducing the optical confinement in the single quantum well laser structure. It is very important to design the waveguide layer structure with narrow far-field angle and low threshold current.

Figure 3 gives the lasing spectrum measured at 200mW for the 100μm×800μm broad stripe laser device. The emitting wavelength is 985nm and the FWHM is 3nm.

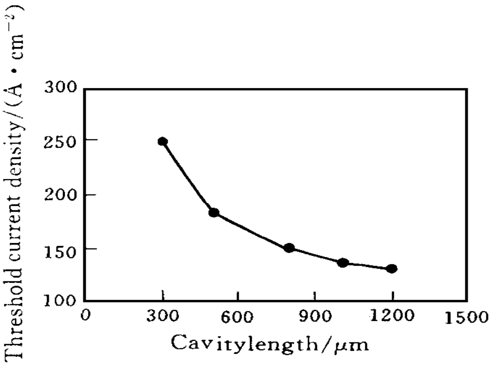

Fig. 2 Threshold current density of InGaAs/GaAs/InGaP strained quantum well lasers as a function of cavity length

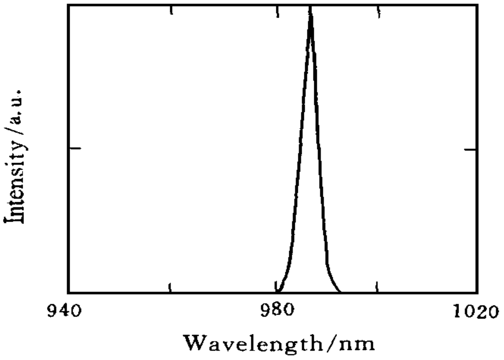

Fig. 3 Measured lasing spectrum for the InGaAs/GaAs/InGaP laser device

The initial aging tests for the Al-free lasers have demonstrated better reliability than the Al-containing lasers. The detail of the aging test results and the improvement in laser performance will be reported elsewhere.

4 Conclusion

In conclusion, we report on the room temperature CW operation of strained $In_{0.2}Ga_{0.8}As/GaAs/In_{0.49}Ga_{0.51}P$ single quantum well lasers grown by MOCVD. The broad area lasers show extremely low threshold current density of $150A/cm^2$ at a cavity length of $800\mu m$. Our results demonstrate that MOCVD is also suitable for growing the 980nm InGaAs/GaAs lasers with $In_{0.49}Ga_{0.51}P$ as the cladding layers.

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