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High Power Operation of InGaAlP Visible Light Laser Diodes with an $In_{0.62}Ga_{0.38}P$ Active Layer

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Highly reliable high-power operation of transverse-mode stabilized InGaAlP laser diodes has been achieved with a selectively buried ridge waveguide structure and a very thin (150Å) $In_{0.62}Ga_{0.38}P$ active layer. A strained $In_{0.62}Ga_{0.38}P$ layer was employed in order to improve the temperature characteristics during high-power operation. A maximum light output of 106 mW was obtained for the laser with anti-reflection and high-reflection coatings. High-power CW operation at an output power of 40 mW was maintained even at a heat-sink temperature of 80°C. Stable CW operation exceeding 1000 h has been achieved with a 30 mW output at 50°C.

1.Introduction

High-power visible-light laser diodes[1]-[3] are key components in applications relating to optical information processing. High-power operation of a transverse-mode stabilized InGaAlP laser diode was realized for a selectively-buried-ridge waveguide (SBR) structure[1] and a heterobarrier blocking (HBB) structure[3]. In these lasers, use of a thin active layer had a great effect on the reduction of optical power density at the laser facet. However, such a thin active layer causes a carrier overflow from the active layer to the p-cladding layer, which restricts high-power operation at high temperature.

The authors have introduced a strained active layer in order to realize high-power operation at high temperature. This paper reports on the high-power operation, at over 100 mW, of a transverse-mode stabilized InGaAlP laser diode with a thin (150Å) $In_{0.62}Ga_{0.38}P$ active layer.

2.Structure for High-power Operation

The maximum light output of SBR laser diodes is limited by catastrophic optical damage(COD) in the laser facet. Use of a thin active layer has a large effect on reducing optical power density at the laser facet, resulting in an increase in COD level. However, such a thin active layer causes a carrier overflow from the active layer into the p-cladding layer, which restricts high-power operation at high temperature. Carrier overflow can be reduced by increasing the conduction-band heterobarrier at the interface of the active layer and the p-cladding layer. A highly doped p-cladding layer was shown to increase the heterobarrier height[4]. Another method of obtaining a large heterobarrier height is to increase the bandgap difference between the active layer and the p-cladding layer. An InGaAlP double-heterostructure with a strained $In_{0.5+\delta}Ga_{0.5-\delta}P$ active layer has been developed in order to realize a large bandgap difference[5]. High-power operation at high temperature was realized by this method. Although the $In_{0.5+\delta}Ga_{0.5-\delta}P$ was not lattice-matched to the GaAs substrate, highly reliable operation at high temperature resulted[5] from introducing a thin (200Å) active layer, which is also preferable for high-power operation.

Increasing the composition-shift value, δ, which is possible by introducing a thinner active layer, has been investigated in order to obtain a higher output power.

Figure 1 shows a cross-section of the transverse-mode stabilized InGaAlP laser diode with an SBR structure and a strained active layer. The laser was fabricated using a three-step low-pressure metalorganic chemical vapor deposition (MOCVD). The double-heterostructure consisted of a 1.45 μm Si-doped n-$In_{0.5}(Ga_{0.3}Al_{0.7})_{0.5}P$ cladding layer, a 150 Å undoped $In_{0.62}Ga_{0.38}P$ active layer, and a 1.45 μm Zn-doped p-$In_{0.5}(Ga_{0.3}Al_{0.7})_{0.5}P$ cladding layer. The stripe width was 5 μm and the cavity length was 600 μm. An anti-reflection (10%) coating made of Al_2O_3 and a high-reflection (90%) coating made of Al_2O_3/Si multi-layers were formed on the front and the rear facets, respectively, by rf sputtering.

The indium composition ratio of the InGaP active layer was shifted by 0.12 from the lattice-matched condition in order to obtain a high heterobarrier. The bandgap energy for the $In_{0.62}Ga_{0.38}P$ active layer, estimated by photoluminescence measurements, was about 50 meV smaller than that for $In_{0.5}Ga_{0.5}P$. The lattice-mismatch value for this composition(δ=0.12) is 1%.

3.Results and Discussion

Figure 2 shows the light-output power versus current characteristic for continuous wave(CW) operation of the composition-shifted SBR laser. The threshold current was 65 mA and the external differential quantum efficiency was 1.0 W/A. The resulting maximum light-output power, 106 mW, was limited by COD. The oscillation wavelength was 690 nm at 3 mW. This is about 20 nm longer than in the case of an $In_{0.5}Ga_{0.5}P$ active layer. The large mismatch, 1%, was made possible by reducing the active layer thickness to the very small value of 150Å. This reduction in active layer thickness is suitable for the purposes of high-power operation.

Figure 3 shows the temperature dependence of the laser's I-L characteristics. High-power operation at 40 mW was maintained even at 80 °C. This remarkable improvement in high-power operation temperature is thought to be an effect of the reduced electron overflow, which in turn results from the increase in the heterobarrier height at the interface between the active layer and the p-cladding layer.

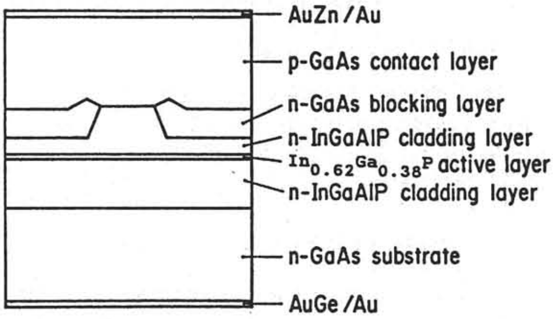

Fig.1 SBR laser configuration

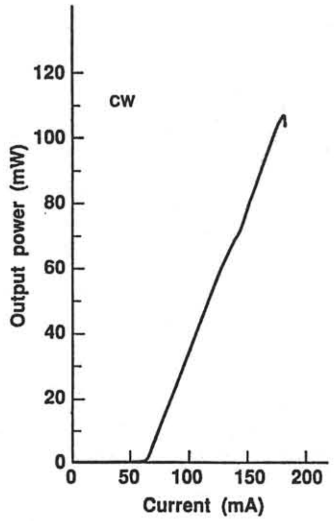

Fig.2 Light-output power vs current characteristic of SBR laser

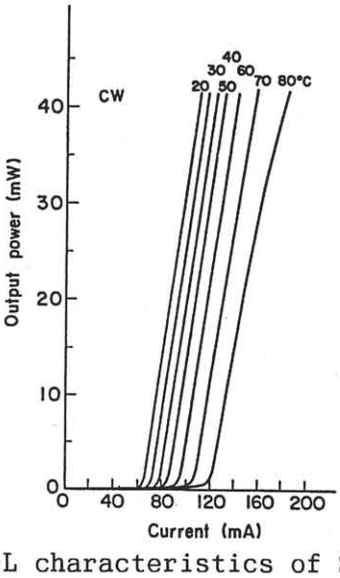

Fig.3 I-L characteristics of SBR laser under CW operation at various temperatures

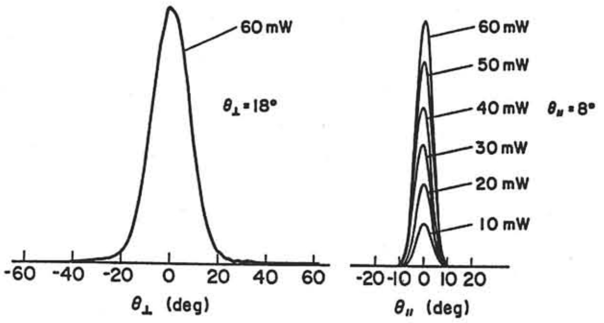

Fig.4 Far-field patterns in directions parallel and perpendicular to junction plane

Figure 4 shows the far-field patterns of the laser under CW operation. No change in the profile parallel to the junction plane appeared when the output power was increased, which indicates that stable oscillation in the fundamental transverse-mode was maintained up to 60 mW by this structure. The full-width at half-maximum of the beam divergence was 8° parallel to the junction plane and 18° perpendicular to it, resulting in a small aspect ratio of 2.2.

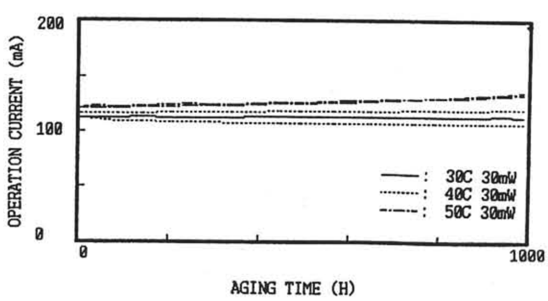

Fig.5 Life test results for SBR lasers

Figure 5 shows the life-test results for the strained SBR lasers under 30 mW output power at 30-50 °C. Although, $In_{0.62}Ga_{0.38}P$ was not lattice-matched to the GaAs substrate, no remarkable increase was observed in the operation current. This high reliability is considered to be the effect of the improvement in temperature characteristics described above. The lasers have seen stable operation for over 1000 h.

4. Conclusion

The authors have fabricated high-power SBR laser employing a very thin (150Å) $In_{0.62}Ga_{0.38}P$ active layer and a highly doped p-cladding layer. With this structure, a maximum light output of 106 mW and stable CW operation exceeding 1000 h for 30 mW output at 50 °C have been achieved. The double-heterostructure with an $In_{0.62}Ga_{0.38}P$ active layer and a highly doped p-cladding layer had large effect on improving the temperature characteristics even for a laser with a very thin active layer.

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