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High-Temperature CW Operation of 630nm Band InGaAlP Visible Light Laser Diodes

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Improvement in the temperature characteristic of InGaAlP laser diodes oscillating below 650 nm has been investigated. The maximum temperature (Tmax) for CW operation has been drastically improved by the reduction of the electron overflow, adopting highly p-type doping for the cladding layer. In the 650 nm wavelength range, Tmax increased up to 70 °C. The shortest wavelength of 636 nm for room temperature CW operation has been successfully achieved. The threshold current was 102 mA and a 3 mW CW operation was attained up to 48°C.

1. Introduction

Short wavelength laser diodes have many attractive applications as a light source for information processing systems, such as laser printers, optical disc systems and bar-code readers. Shorter wavelength laser operation has a better advantage in obtaining small focused spots and improving luminosity for the human eye. The InGaAlP quaternary alloy compound, which can be lattice-matched to GaAs, is the most promising material for 0.6 μm wavelength range visible laser diodes. Since the first room temperature CW operation was achieved for InGaAlP lasers by metalorganic chemical vapor deposition (MOCVD) [1)-3)], much effort has been expended towards shortening the wavelength [4)-6)]. However, there have existed some difficulties in obtaining shorter wavelength oscillation, because only a smaller band gap energy difference can be expected between the active layer and cladding layers. And it has still been unknown whether the quaternary active layer affects the laser characteristics or not.

This paper reports the improvement in the temperature characteristic of InGaAlP laser diodes by the reduction of the electron overflow, adopting highly p-type doping for the cladding layer. High-temperature CW operation below 650 nm has been obtained.

2. Model for the effect of high p-doping

A model for the improvement in the temperature characteristic by high p-doping of the cladding layer was considered as follows. The band discontinuity in the conduction band side of the InGaP/InGaAlP heterojunction is relatively small compared with GaAs/GaAlAs [7)]. Tmax is limited to a low temperature in shortening the wavelength, because electron overflow into the p-cladding layer from the active layer increases and the threshold current is increased. When the p-cladding layer is highly doped, the Fermi level of the valence band side moves towards the valence band. The hetero barrier between the active layer and p-cladding layer effectively increases and the electron overflow is reduced. On the other hand, the authors have reported that the band gap energy of InGaAlP increases at high acceptor concentration due to disordering [8]. This is considered to be also effective for increasing the hetero barrier height.

3. Experiment

The epitaxial layers were grown by low-pressure MOCVD. The source materials were trimethylindium, trimethylgallium, trimethylaluminum, PH_3 and AsH_3. The doping sources were dimethylzinc and SiH_4 for the p-type and n-type layers, respectively. First, a double hetero structure (DH) was grown on a Si-doped GaAs substrate: a Si-doped n-$In_{0.5}(Ga_{0.3}Al_{0.7})_{0.5}P$ cladding layer, an undoped $In_{0.5}(Ga_{1-x}Al_x)_{0.5}P$ active layer, a Zn-doped p-$In_{0.5}(Ga_{0.3}Al_{0.7})_{0.5}P$ cladding layer. The Al composition (x) in the active layer was varied from 0 to 0.2 corresponding to the wavelength of the 670-630 nm band. The acceptor concentration of the p-cladding layer was varied from 2.5 to 7×10^{17} cm^{-3}. The SBR [9] and HBB [10] type ridge wave-guide structure lasers were fabricated. The stripe width at the bottom of the p-cladding layer was 5 µm and the cavity length was 400 µm. The p- and n-side ohmic contacts were AuZn/Au and AuGe/Au, respectively. The cleaved chips were mounted on Cu heat sinks with an In solder in a p-side-down configuration.

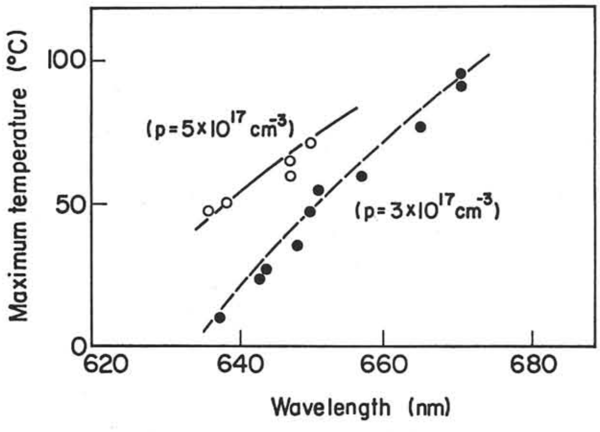

Fig.1 Acceptor concentration dependence of the maximum temperature for CW operation against oscillation wavelength.

4. Results and discussion

Figure 1 shows the acceptor concentration dependence of the maximum temperature (Tmax) for CW operation against oscillation wavelength. Tmax was drastically improved over a wide wavelength range by high p-type doping. Figure 2 shows the characteristic temperature (T_0) of the lasers oscillating at 650 nm against acceptor concentration.

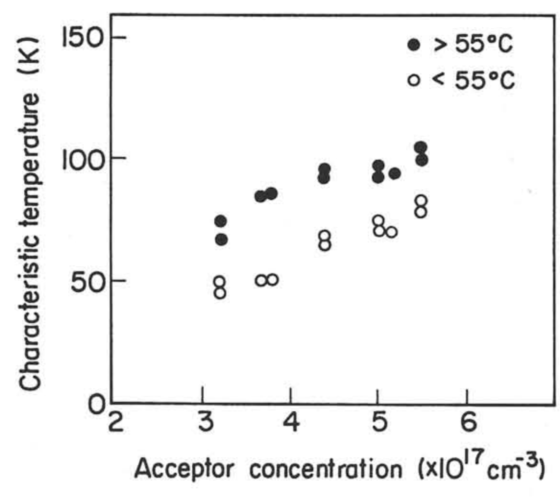

Fig.2 Characteristic temperature against acceptor concentration (650 nm).

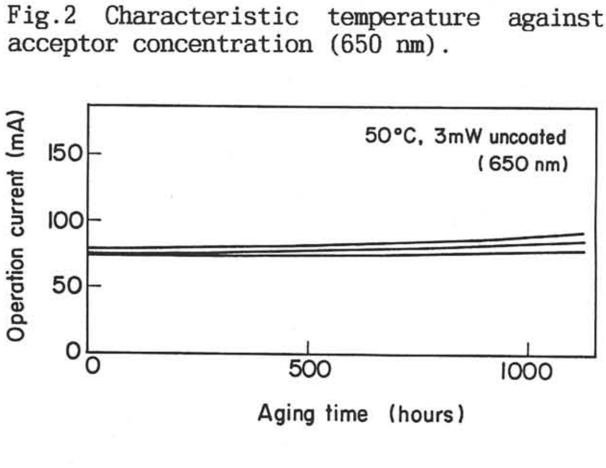

Fig.3 Aging characteristic of the uncoated lasers at 50°C, 3 mW (650 nm).

T_0 value was obtained for pulsed operation. A higher characteristic temperature was obtained by higher acceptor concentration. These results show that electron overflow is the dominant reason for the deterioration of temperature characteristic of shorter wavelength InGaAlP laser diodes. It has been confirmed that high p-type doping of cladding layer is effective in reducting electron overflow as predicted above. As shown in Fig.2, Tmax above 70 °C was achieved for the 650 nm band lasers, which made possible carrying out aging tests at a high temperature. Figure 3 shows the aging characteristic of uncoated 650 nm lasers at 50°C. The authors have reported the existence of a facet degradation mode in InGaAlP laser diodes [11]. In this case, the active layer contained Al (0.1), but no rapid degradation mode was observed. The lasers operated for more than 1000 hours.

Figure 4 shows the temperature dependence of output power against the current characteristic for CW operation of a 630 nm band laser with highly p-doping (5.5×10^{17} cm^{-3}). The threshold current at 20°C was 102 mA. The slope efficiency was 0.43 mW/mA for one facet. The threshold current also strongly depended on the acceptor concentration of the p-cladding layer. The threshold current (pulsed operation) of the laser doped at 2.5×10^{17} cm^{-3} was 200 mA. A CW operation of 3 mW was attained at up to 48 °C. Figure 5 shows the temperature dependence of the threshold current CW and pulsed operation. T_0 gradually decreased from 73 K between 20°C and 30°C to 43 K between 60°C and 70 °C. This inclination was different from the lasers oscillating above 650 nm. It shows that electron overflow is still dominant in the 630 nm band even when the

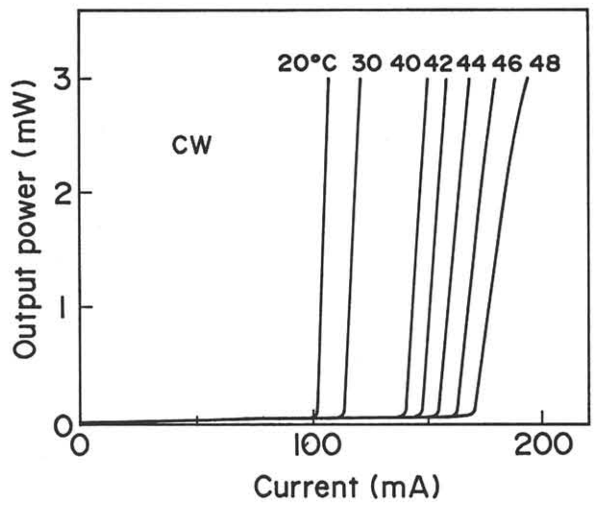

Fig.4 Temperature dependence of output power against CW current characteristic of 630 nm band laser.

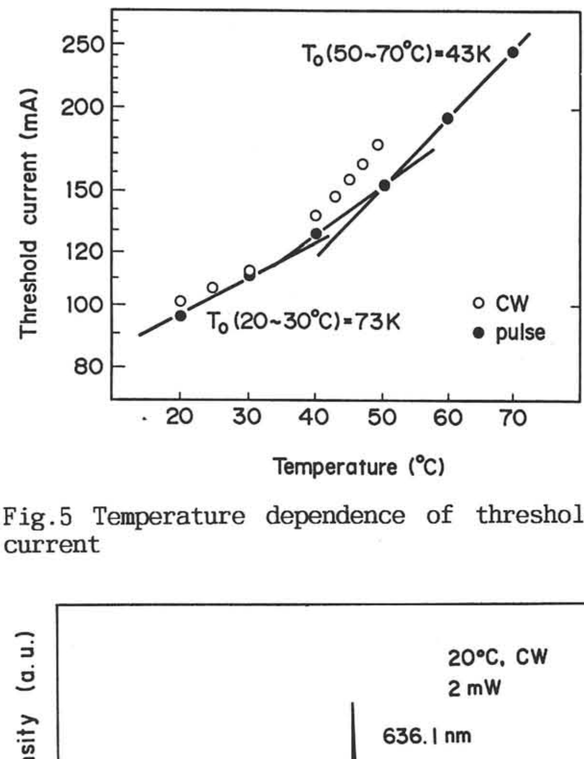

Fig.5 Temperature dependence of threshold current

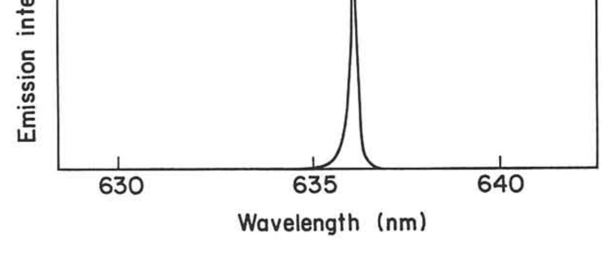

Fig.6 Spectrum of CW operation at 20 °C, 2mW.

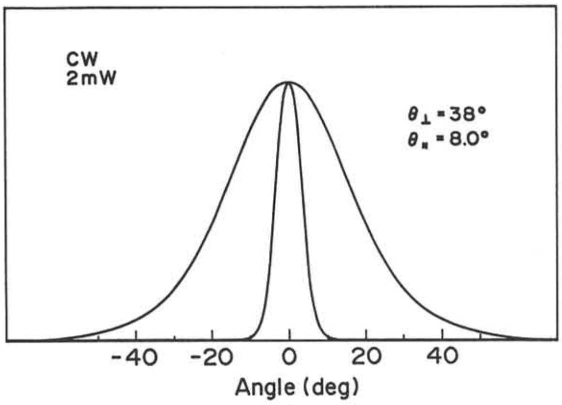

Fig.7 Far field patterns in both the lateral and vertical directions to the junction plane

p-cladding layer is highly doped. Figure 6 shows the oscillation spectrum at 20 °C, 2 mW by CW operation. A single longitudinal mode oscillation at a wavelength of 636.1 nm was obtained. This oscillation wavelength is the shortest for room temperature CW operation of laser diodes ever reported. Figure 7 shows a far field pattern of this laser at 2 mW by CW operation. Full width at half maximum angles of perpendicular and parallel to the junction plane were 39° and 8.5° respectively. No side lobe nor ripple was observed, which shows that a fundamental transverse mode oscillation was achieved even in the 630 nm band.

5. conclusion

An improvement in the temperature characteristic of InGaAlP laser diodes oscillating below 650nm was investigated. The Tmax for CW operation has been drastically improved by the reduction of the electron overflow, adopting highly p-type doping for the cladding layer. In the 650 nm wavelength range, Tmax increased up to 70 °C. The lasers have operated for more than 1000 hours at 50°C. No significant degradation mode due to the quaternary active layer has been observed. The shortest wavelength of 636 nm for room temperature CW operation has been successfully achieved. The threshold current was 102 mA and CW operation 3 mW was attained at up to 48 C.

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