Extended Abstracts of the 20th (1988 International) Conference on Solid State Devices and Materials, Tokyo, 1988, pp. 307-310 **D-3-3**

A New Transverse-Mode Stabilized InGaAlP Visible Light Laser Diode Using p-p Isotype Hetero Barrier Blocking

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A new wave guide structure for InGaAlP transverse-mode stabilized visible laser diode has been successfully fabricated by two step MOCVD. A unique current confinement mechanism, using voltage-drop difference between isotype hetero junctions of p-GaAs/p-InGaAlP and p-GaAs/p-InGaP/p-InGaAlP was employed in this laser. Current-voltage characteristics of these hetero junctions have good agreement with theoretical calculation. Low cw threshold current of 40mA, and stable fundamental transverse-mode oscillation at up to 5mW were achieved. The oscillation wavelength was 666nm. The lasers have operated over 400 hours at 40°C, 3mW.

1. Introduction

InGaAlP visible light laser diodes are attractive light sources for optical information processing systems such as laser printers, barcode readers, and optical disc systems. Since the first room-temperature CW operation was achieved for InGaAlP lasers grown by metalorganic chemical vapor deposition (MOCVD) in 1985[1-3], much effort has been expended toward improving device characteristics[4-7].

Transverse mode stabilization is very important for its practical use. However, design of InGaAlP laser was limited to such a structure wherein the DH layers are grown flat, since the InGaAlP quaternary alloy needs strict lattice matching and it is difficult to grow this alloy on a stepped substrate.

A selectively buried ridge waveguide (SBR) structure laser is one of the most promising transverse-mode stabilized InGaAlP lasers which has a flat active layer[4-5]. Relatively low threshold current and high power operation were obtained with this structure[6]. However, fabricating of this laser required three-step MOCVD growth and deposition of dielectric film, such as SiO_2, to provide a blocking layer by selective growth.

GaAs/InGaAlP hetero junction has a large band discontinuity in the side of valence band[8]. For example, valence band discontinuity, ΔEv, between GaAs and InAlP is 0.63 eV. This paper shows transverse-mode stabilized InGaAlP visible laser diode using this band discontinuity for current confinement.

2. Laser structure

Figure 1 shows the band structure for InGaAlP laser at 2.5 V bias, calculated from the one dimensional band model, where the Fermi statistics for Γ and X band are considered.

When Al composition of cladding layer is relatively high, a large spike, due to a valence band discontinuity of p-GaAs/p-InGaAlP iso type hetero junction appears at the hetero interface as shown in Fig. 1(a). And this spike is expected to act as barrier for hole carrier. On the

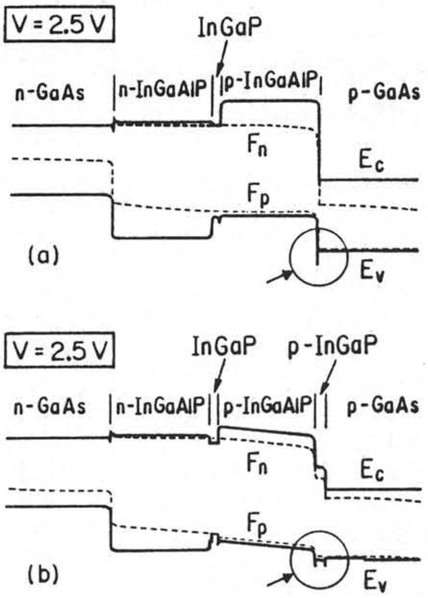

Fig.1 Band structures of the laser (a) wiyhout p-InGaP layer (b) with p-InGaP layer.

other hand, the spike height is reduced by introducing p-InGaP layer which has middle band gap between p-GaAs and p-InGaAlP, as shown in Fig. 1(b). Voltage-drop difference has a large effect on current-voltage characteristics as shown in Fig. 2.

Figure 3 shows the new transverse-mode stabilized InGaAlP laser. In this laser current confinement is achieved to leave the p-InGaP capping layer only at the top of the p-InGaAlP cladding layer as discussed above. The p-InGaAlP ridge stripe structure buried with p-GaAs is expected to provide a complex refractive index step along the junction plane.

This structure was fabricated by two step low-pressure MOCVD. First, four layers were 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 $In_{0.5}Ga_{0.5}P$ active layer (d=0.06 μm), a Zn-doped p-$In_{0.5}(Ga_{0.3}Al_{0.7})_{0.5}P$ cladding layer. After the first growth, and a Zn-doped p-GaAs contact layer was deposited by a second MOCVD growth after ridge stripe in the <01$\bar{1}$> direction was

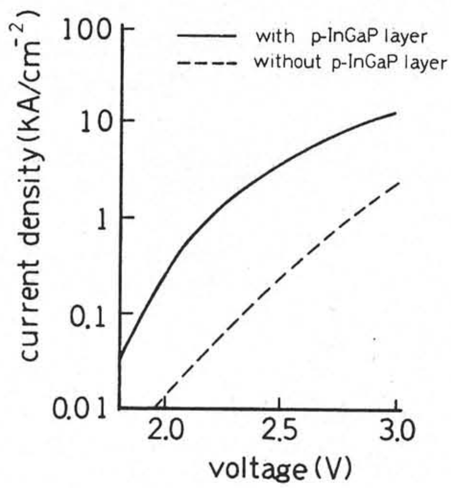

Fig.2 Calculated current-voltage characteristics of the laser.

formed by chemical etching. The p- and n-side ohmic contacts were AuZn/Au and AuGe/Au, respectively. The stripe width at the bottom of p-InGaAlP cladding layer is 5 μm and the cavity length is 300 μm.

3. Analysis of current confinement

Figure 4 shows the measured current-voltage (I-V) characteristics of stripe region (5 x 300 μm^2) and the blocking region outside the stripe (300 x 300 μm^2). Blocking effect which was expected from one dimensional band discontinuity model was confirmed over the 3 V range, experimentally.

P-GaAs/p-InGaAlP heterojunction was formed at the interface which was exposed

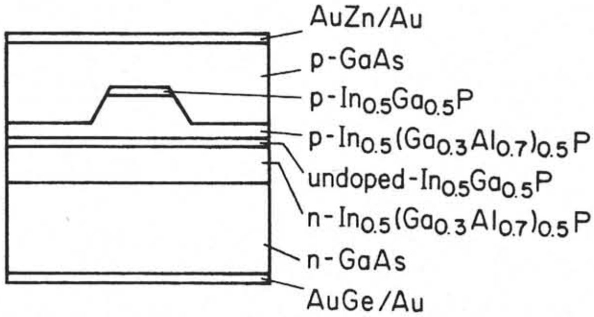

Fig.3 Schematic cross-sectional view of the laser structure.

to atmosphere and high temperature before second MOCVD growth. It was still unknown whether a large voltage drop at p-GaAs/p-InGaAlP heterojunction was due to its hetero barrier, or due to oxidation and damage of regrown interface. To investigate the influence of this regrown interface on blocking effect, I-V characteristics for two p-GaAs/p-InGaAlP structure samples were compared. Figure 5 shows I-V characteristics for p-GaAs/p-InGaAlP structure fabricated by one step continuous growth (a) and two step growth (b). However, slightly change was observed in the low current region of regrown interface (Fig. 5(b)), it shows that a large voltage drop was due to hetero barrier and not regrown interface.

4. Device characteristics

Figure 6 shows typical output power to current characteristics at 25^{o}C CW operation. The threshold current was 40 mA and the differential quantum efficiency was 40%/facet. The lowest threshold current was 34 mA. This low threshold current shows that sufficient current confinement was achieved in the device.

Figure 7 shows the output power dependence of the far field pattern parallel to the junction plane. There appears no change in the profile with increasing output power, and it indicates that stable oscillation in fundamental transverse mode is maintained up to 5 mW, by this wave guide structure. Astigmatism is about 10 μm, and oscillation wavelength was 666 nm.

The aging characteristics of this laser are shown in Fig. 8. The light output power was 3 mW with automatic power control. The ambient atmosphere was air and its temperature was 40^{o}C. The devices were not facet coated.

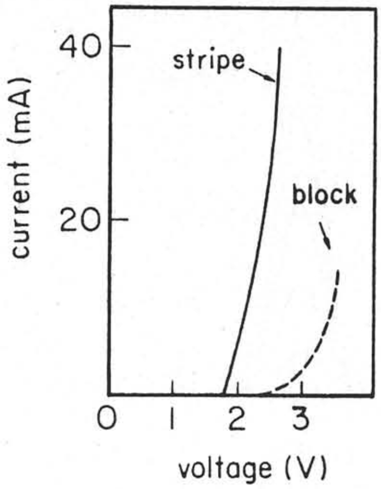

Fig.4 I-V characteristics of stripe region, and blocking region.

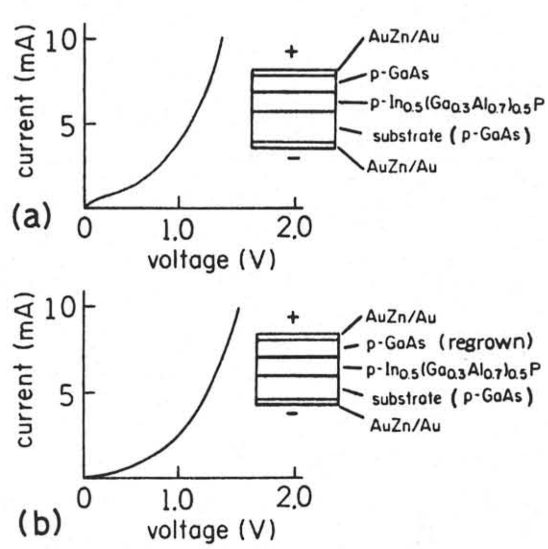

Fig.5 I-V characteristics for p-GaAs/p-InGaAlP structure fabricated by one step continuous growth (a), and two step growth (b).

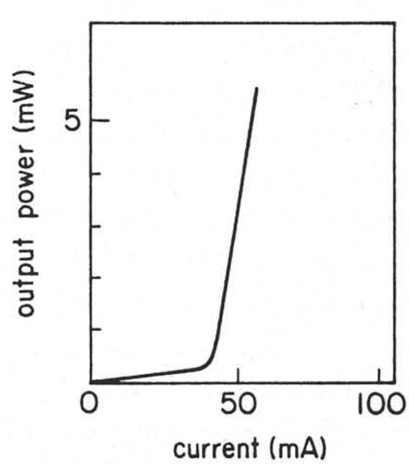

Fig.6 Output power vs. current characteristics.

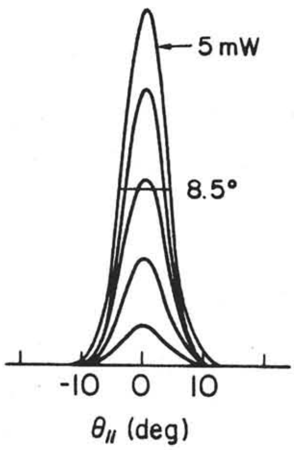

Fig.7 Far field profiles parallel to the junction plane.

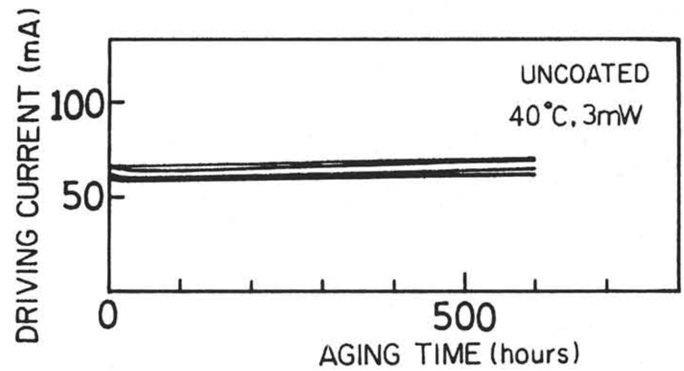

Fig.8 Aging characteristics of the lasers

The lasers have operated over 500 h without any significant degradation as shown in Fig. 8.

5. Conclusion

A new waveguide structure of InGaAlP transverse mode stabilized laser diode has been successfully fabricated by two step MOCVD. A unique current confinement mechanism, using voltage drop difference between iso type hetero junction of p-GaAs/p-InGaAlP and p-GaAs/p-InGaP/p-InGaAlP was employed in this laser. Current-voltage characteristics of these hetero junctions have good agreement with theoretical calculation. It was also confirmed that a large voltage drop at hetero junction of p-GaAs/p-InGaAlP was due to its hetero barrier and not due to oxidation or damage of regrown interface. Low CW threshold current of 40 mA and stable fundamental-transverse mode oscillation at up to 5 mW were achieved. The oscillation wavelength was 666 nm. The lasers have operated over 500 h at 40°C, 3 mW.

Acknowledgement

The authors would like to thank Dr. A. Hojo for his encouragement and useful suggestion, and Dr. Y. Kokubun for supplying of wafers.

References

1. M. Ishikawa, Y. Ohba, H. Sugawara, M. Yamamoto and T. Nakanishi, Appl. Phys. Lett. 48, 207 (1986).
2. K. Kobayashi, S. Kawata, A. Gomyo, I. Hino and T. Suzuki, Electron. Lett. 21, 931 (1985).
3. M. Ikeda, I. Nakano, Y. Mori, K. Kaneko and N. Watanabe, Appl. Phys. Lett. 21, 931 (1985).
4. M. Ishikawa, Y. Ohba, Y. Watanabe, H. Sugawara, Y. Yamamoto and G. Hatakoshi Trans. IECE Japan 69, 382 (1986).
5. M. Ishikawa, Y. Ohba, Y. Watanabe and G. Hatakoshi, Extended Abstracts of the 18th Conference on Solid State Devices and Materials, Tokyo (1986) 153.
6. M. Ishikawa, K. Itaya, Y. Watanabe, G. Hatakoshi, H. Sugawara, Y. Ohba and Y. Uematsu, Extended Abstracts of the 19th Conference on Solid State Devices and Materials, Tokyo (1987) 115.
7. M. Ikeda, H. Sato, T. Ohata, K. Nakano, A. Toda, O. Kumagai and C. Kojima, Appl. Phys. Lett. 51, 1572 (1987).
8. M. Watanabe and Y. Ohba, Appl. Phys. Lett. 50, 906 (1987).