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A Very Low Threshold Current, 780 nm Diffusion Stripe Laser Fabricated by Open-tube, Two-step Zn Diffusion Technique

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A Zn diffusion stripe laser is fabricated by the metalorganic chemical vapor deposition and open-tube, two-step solid phase diffusion technique. The diffusion stripe of the low p type carrier concentration is formed in the active region and the low internal loss of $15cm^{-1}$ is realized by these methods. The continuous wave threshold current at 20°C is 9.4mA. The lasing wavelength is 780nm. The laser operates in the fundamental transverse mode.

1. Introduction

It is important for optical systems to decrease the consumption of electric power. Decreasing the operating current of a laser diode as a light source, is one method to reduce the power consumption in the system. In low light output power operation, decreasing the threshold current is more effective than increasing the external differential efficiency to reduce the power consumption of laser. To date, various low threshold current laser diodes such as buried heterostructure[1,2], diffusion stripe structure[3-5] and quantum well structure[6] have been fabricated. To realize the low threshold current and fundamental transverse mode easily, the junction stripe lasers with an n type double heterostructure and a p type Zn diffused region, have been reported. However, the lasing wavelength of these lasers is mostly more than 850nm, which is not suitable for the widely used optical systems. The TJS (Transverse junction stripe) laser[7] lasing at the widely used wavelength around 780nm has been realized in the fundamental transverse mode. However, the threshold current is relatively high (about 20mA), which is considered due to the internal loss in the highly doped Zn diffused region in close vicinity to the optical waveguide. Therefore, the threshold current is expected to be decreased if this internal loss is reduced.

In this report, we present a Zn diffusion stripe laser diode of low internal loss, lasing in the wavelength range of 780nm. To reduce the internal loss, a MOCVD (metalorganic chemical vapor deposition) and a two-step, solid phase Zn diffusion[8] technique are applied in the fabrication of this laser.

2. Structure and Fabrication

Figure 1 shows the schematic structure of the laser which consists of the following layers; n-$Al_{.48}Ga_{.52}As$ (Se, $n=1E17cm^{-3}$) lower cladding layer, n-$Al_{.15}Ga_{.85}As$ (Se, $n=3E18cm^{-3}$) active layer, n-$Al_{.48}Ga_{.52}As$ (Se, $n=1E17cm^{-3}$) upper cladding layer, p-$Al_{.50}Ga_{.50}As$ (Zn, $p=5E17cm^{-3}$) current blocking layer and n-GaAs (Se, $n=1E18cm^{-3}$) ohmic contact layer. These layers are succes-

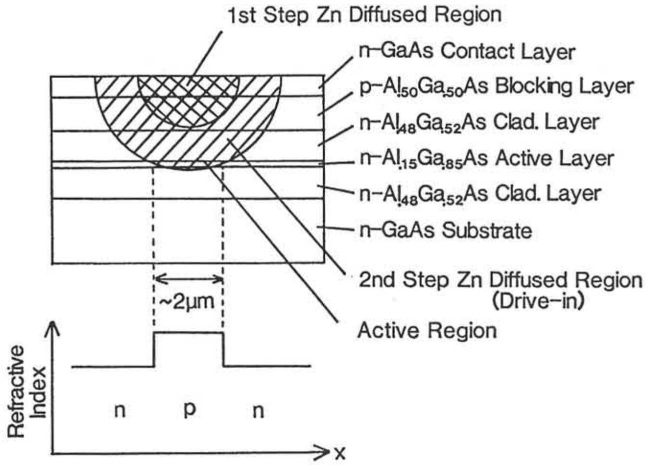

Fig.1 Structure and refractive index step of the laser

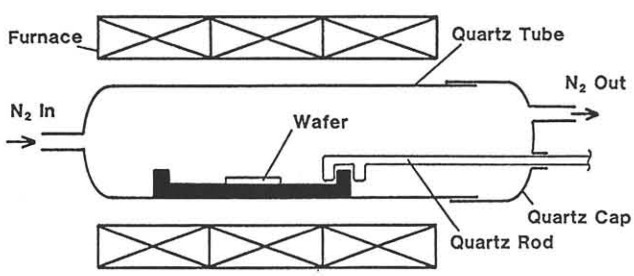

Fig.2 Apparatus used for the open-tube, solid phase Zn Diffusion

sively grown on a (100) n-GaAs (Si, $n=1E18cm^{-3}$) substrate by the MOCVD. The lateral waveguide and the p-n junction are formed by a Zn diffused stripe region. The Zn is diffused from source of Zn in an open-tube as shown in Fig.2.

The fabrication process of the Zn diffusion stripe is schematically shown in Fig.3. The diffusion stripe in the inner region of the laser is formed by the following steps:

(1) After the MOCVD growth, a Si_3N_4 film with a stripe slit is formed on the surface of the ohmic contact layer. A ZnO(90wt%):SiO_2(10wt%) film and a SiO_2 film are successively spattered on the wafer.

(2) For the diffusion of Zn, the wafer is heated in the N_2 ambient open-tube in the temperature range of 600-700°C. Zn is selectively diffused through the slit in the Si_3N_4 film into the epitaxial layers till the diffusion front is near the interface between the p-blocking layer and the n-upper cladding layer.
(1st step Zn diffusion)

(3) After removal of these films, a Si_3N_4 film is formed again to protect the surface of the wafer.

(4) The diffusion front is penetrated into the active layer by drive-in diffusion in the temperature range of 900-950°C.
(2nd step Zn diffusion)

After removal of the Si_3N_4 film, the electrodes are formed on both sides of the wafer. The cavity length of the laser is 300μm. The laser chip is mounted on a Si submount in a junction down configuration.

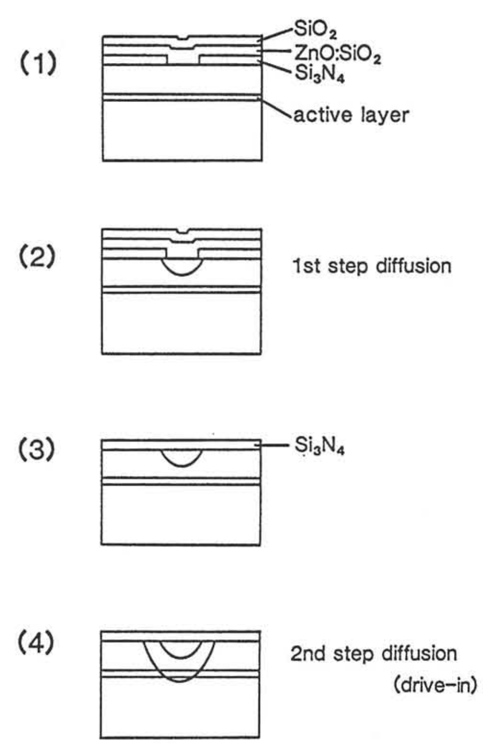

Fig.3 Steps for formation of the diffusion stripe

3. Result and Discussion

From the SIMS (secondary ion mass spectroscopy) profile and the shift of the PL (photoluminescence) peak wavelength in the Zn diffused region, the Zn concentration of the 1st diffused region and that of the 2nd diffused region are estimated to be about 1E20 and 1E19cm^{-3}, respectively. As the refractive index, N, of the p type 2nd diffused region in the active layer is a little higher as compared with that of the n type active layer, the lateral optical waveguide is formed as shown in Fig.1. Moreover, the optical absorption is reduced since the highly doped 1st diffused region is placed above the upper claddig layer.

Figure 4 shows the light output power versus current (L-I) characteristics of the laser under 20°C, CW (continuous waves) conditions. The threshold current is 9.4mA and the slope efficiency from the front facet is about 0.6W/A. The operating current at 5mW is 18mA. No kink is observed up to at least 10mW. From the difference between the external differential efficiencies of the uncoated laser and the coated one, the internal loss, α, and the internal differential efficiency, η_i, are estimated to be about 15cm^{-1} and 0.7, respectively. This α is smaller than the value of the TJS laser (25 cm^{-1}) [7] by about 10 cm^{-1}. The reason considered is that the scattering loss and the absorption are reduced more as compared with the TJS laser. In short, the scattering loss is reduced by the very smooth interfaces in the double heterostructure grown by the MOCVD: and the absorption due to the free carrier and the band shrinkage of the active layer in close vicinity of waveguide are reduced by the two-step diffusion stripe structure.

The dependence of the L-I characteristics on the temperature is shown in Fig.5. The threshold currents are less than 20mA up to 60° C. The operating current at 5mW is only 38mA even at 70°C. The characteristic temperature T_0 is about 84K for the ambient temperature lower than 40°C.

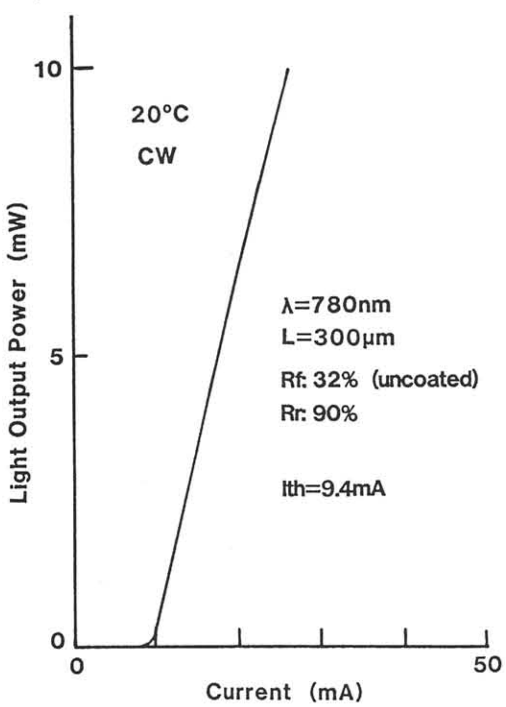

Fig.4 CW L-I characteristics at 20°C

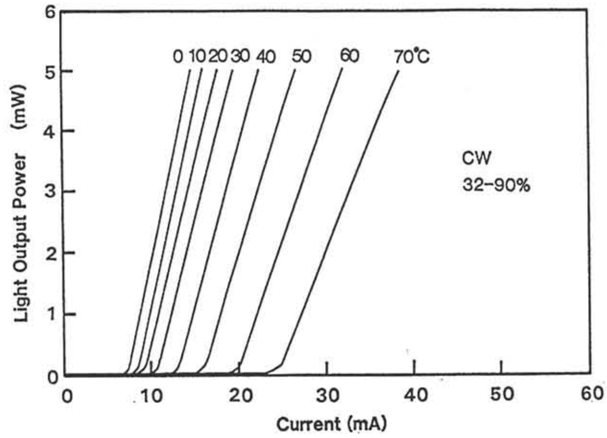

Fig.5 CW L-I characteristics at different temperatures

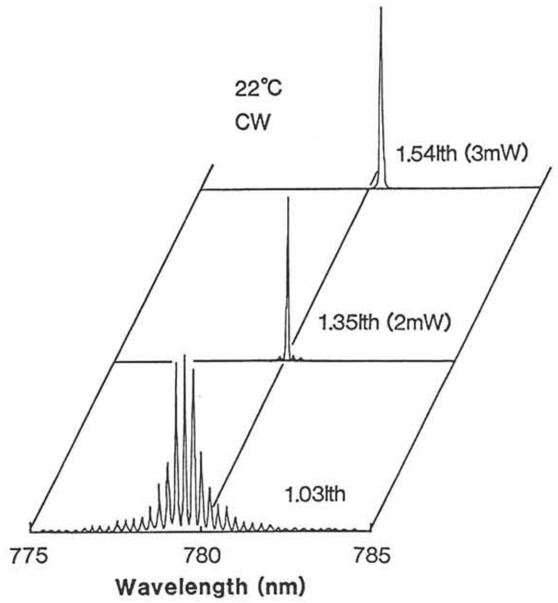

Fig.6 CW emission spectra of the laser for different outputs

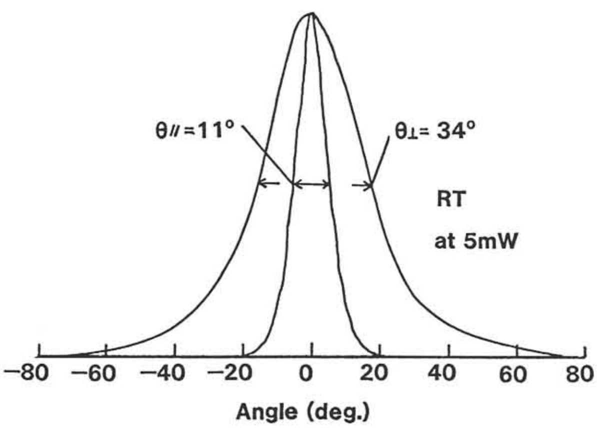

Fig.7 Far-field patterns of the laser

The CW emission spectra for different outputs are shown in Fig.6. The lasing wavelength is 780nm. Furthermore, the single longitudinal mode is clearly indicated for the output power over 2mW.

Figure 7 shows the far-field patterns of the laser at 5mW. The single-lobed far-field patterns show that the laser operates in the fundamental transverse mode. The full angles at half maximum power, parallel ($\theta_{\parallel}$) and perpendicular ($\theta_{\perp}$) to the junction plane, are 11° and 34° , respectively.

4. Conclusion

The diffusion stripe laser is fabricated by MOCVD and the open-tube, two-step solid phase diffusion technique. The internal loss is reduced by these methods. The low threshold current and the fundamental transverse mode operation are realized in the wavelength range of 780nm. This laser is expected to be useful for the OEIC and for optical systems which need lower power consumption.

5. References

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