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Transverse-Mode Stabilized Laser Diodes Fabricated by MOCVD

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Transverse-mode stabilized visible-light-emitting (GaAl)As laser diodes were fabricated by a metalorganic chemical vapor deposition (MOCVD) technique. They are characterized by channeled light absorbing layer and n-GaAs current blocking layer grown on a flat double heterostructure, which require only a single-step photolithgraphic process. The laser diodes operated in a fundamental transverse-mode at light output powers up to 7 mW with a threshold current of 110~120 mA under CW operation. The lasing wavelengths were 786~788 nm. Beam divergences of the laser diode parallel and perpendicular to the junction plane were 8° and 30°, respectively.

1. INTRODUCTION

Metalorganic chemical vapor deposition (MOCVD) technique has many attractive features such as uniform thin film growth or sharp heterojunction interface etc. Fabrication of (GaAl)As/GaAs double heterostructure laser diodes has been attempted by utilising the MOCVD technique, and sufficient reliability has been obtained.[1)2)] This result indicates that (GaAl)As epitaxial layers grown by the MOCVD technique have good quality enough for the fabrication of reliable laser diodes. Several papers have been reported on transverse-mode stabilized laser diodes with a rigid index waveguide fabricated by MOCVD. However, index-guided visible lasers have not been reported.

In this paper, transverse-mode stabilized visible-light-emitting (GaAl)As laser diodes fabricated by two-step MOCVD growth are reported. The laser diodes operated in the fundamental transverse-mode at light output powers up to 7 mW with a threshold current of 110~120 mA. The lasing wavelength was 786~788 nm. Beam

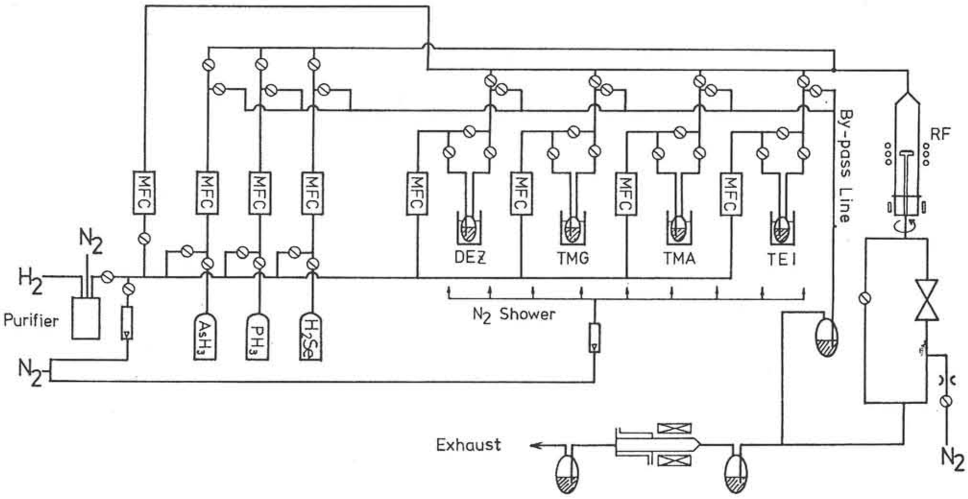


Fig. 1 Schematic diagram of an MOCVD crystal growth system.

divergences parallel and perpendicular to the junction plane were 8° and 30°, respectively.

2. CRYSTAL GROWTH

Fig. 1 shows a schematic diagram of an MOCVD crystal growth system. This system consisted of a cooled quartz vertical reaction tube. The substrate was placed on a graphite suseptor, and heated by radio-frequency induction at 750 °C.

The organometallic group Ⅲ species, trimethylgallium (TMG) and trimethylaluminum (TMA) were placed in stainless steel bubblers which were held in a controlled temperature bath at -10 °C and 20 °C, respectively. Accurately controlled flow of purified hydrogen gas was passed through each bubbler. The organometallic group Ⅱ specy diethylzinc (DEZ) as a Zn source for p-type doping was processed similarly. 10% hydrogen diluted arsine (AsH_3/H_2, 10%) was used as a source of As, and 10 ppm hydrogen diluted selenium hydride (H_2Se/H_2, 10ppm) was used as a source of Se for n type doping.

The total gas flow rate was 5.5 liters/min. Stable flow was achieved by the use of mass flow controllers. The Ⅴ / Ⅲ mole ratio in the growth atmosphere was 20 to 70.

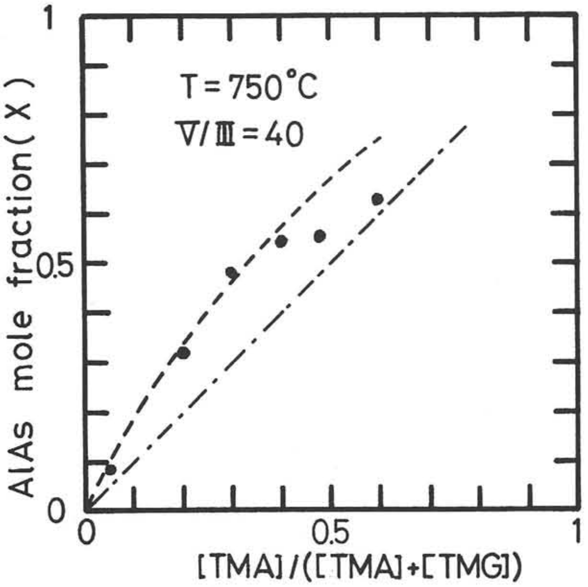


Fig. 2 Grown layer AlAs mole Afraction versus moleratio of [TMA] to sum of [TMA] and [TMG]in growth atmosphere.

Fig. 2 shows a grown layer AlAs mole fraction versus a mole ratio of [TMA] to the sum of [TMA] and [TMG] in a growth atmosphere. The AlAs mole fraction was determined by a X-ray double crystal method. Experimental data in Fig. 2 shows that the AlAs mole fraction in the grown layer is larger than the [TMA] mole ratio in the vapor phase. This can be explained by the difference in the aluminum and gallium diffusion coefficient in the stagnant layer just above the epitaxial growth layer. Fig. 3 shows the electron concentration versus the mole ratio of the selenium hydride to the arsine in the growth atmosphere. The electron concentration is proportional to the mole ratio of the selenium hydride to the arsine. The control of p-type doping was difficult because of very high doping efficiency of DEZ. Carrier concentration as low as $1.5x10^{17} cm^{-3}$ was achieved by diluting DEZ by hydrogen by-pass flow in spite of poor doping controllability.

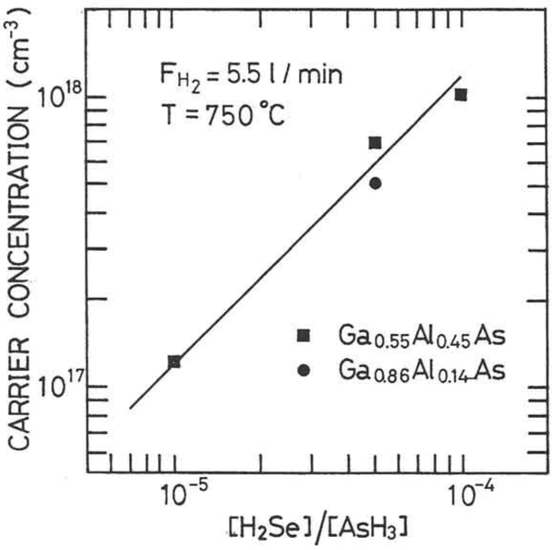
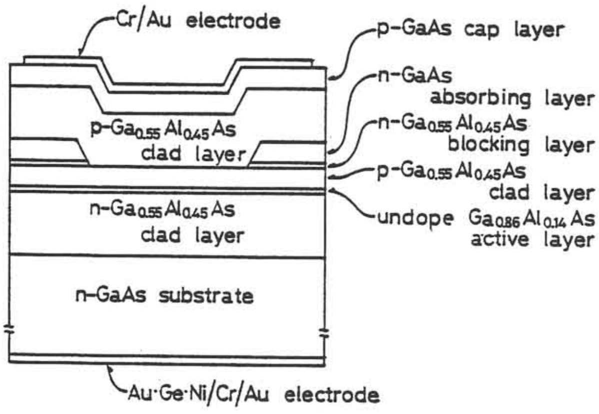


Fig. 3 Electron concentration versus mole ratio of selenium hydride to arsine in growth atmosphere.

3. DEVICE FABRICATION

Fig. 4 shows a cross sectional view of a laser diode. This structure is characterized by channeled n-$Ga_{0.55}Al_{0.45}As$ and n-GaAs layers fabricated over the flat double heterostructure. Penetration of light intensity into the GaAs epitaxial layer outside the channel is the primary mechanism for guiding a mode along the channel as in the case of CSP lasers. The n-$Ga_{0.55}Al_{0.45}As$ layer is effective to minimize leakage current due to minority carrier generated by light absorption in the n-GaAs epitaxial layer.



Transverse-Mode Stabilized MOCVD-LD

Fig. 4 Schematic cross section of a laser diode.

(GaAl)As wafers were fabricated by a two-step MOCVD growth. In the first growth step, five layers -- an n-GaAs buffer layer (Se doped $n=1x10^{18}cm^{-3}$, 0.5 µm thick), an n-$Ga_{0.55}Al_{0.45}As$ cladding layer (Se doped $n=5x10^{17}cm^{-3}$, 1 µm thick), a $Ga_{0.86}Al_{0.14}As$ active layer (undoped, 0.07µm thick), a p-$Ga_{0.55}Al_{0.45}As$ cladding layer (Zn doped $p=1.5x10^{17}cm^{-3}$, 0.3 µm thick), an n-$Ga_{0.55}Al_{0.45}As$ layer (Se doped $n=1x10^{18}cm^{-3}$, 0.1 µm thick), an n-GaAs layer (Se doped $n=1x10^{18}cm^{-3}$, 0.5 µm thick) -- were grown on [1 0 0] oriented Si-doped GaAs substrate ($n=10^{18}cm^{-3}$, 2cmx2cm). After the first growth, the epitaxial wafer was grooved from the n-GaAs epitaxial layer down into the p-cladding layer by chemical etching through a photoresist mask. The channel groove was aligned to the [0 1 $\bar{1}$] direction. The depth of the groove was 0.6 µm and the width was 3µm. In the second growth step, a p-$Ga_{0.55}Al_{0.45}As$ cladding layer (Zn doped $p=1.5x10^{17}cm^{-3}$, 0.5 µm thick), and a p-GaAs cap layer (Zn doped $p=5\sim10x10^{17}cm^{-3}$, 0.5 µm thick), were grown. We confirmed that it was able to grow single crystal (GaAl)As on (GaAl)As whose AlAs content was at least less than 0.5 . The capability of single crystal growth of (GaAl)As on a (GaAl)As layer is one of the unique feature of the MOCVD. A metal contacts of Au-Ge-Ni/Cr/Au (for n-electrode) and Cr/Au (for p-electrode) were then formed on the wafer. The laser diode was mounted on the heat sink with the p side down. The cavity length was 300µm.

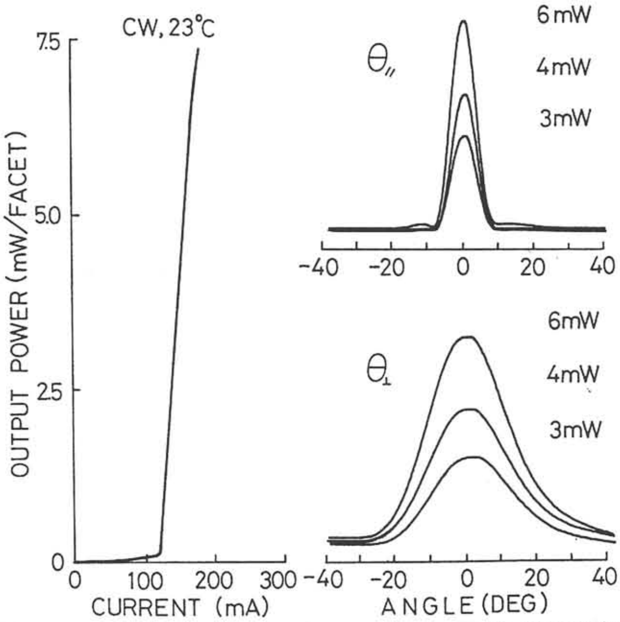


Fig. 5 a) Light output power versus injection current (I-L) characteristic and b) far field pattern of a laser diode at room temperature under CW operation.

4. DEVICE CHARACTERISTICS

Fig. 5 shows a light output power versus injection current (L-I) characteristic and far field patterns of a laser diode at room temperature under CW operation. Beam divergences parallel and perpendicular to the junction plane were 8° and 30°, respectively.

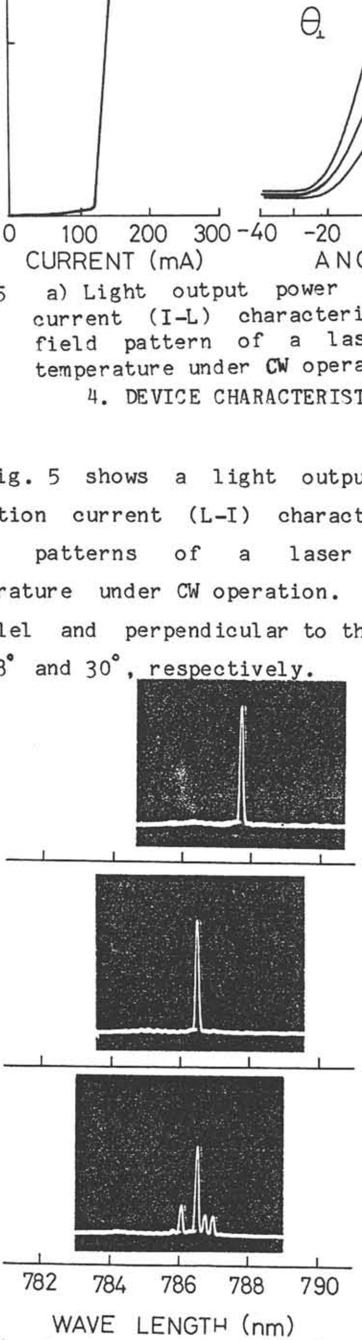


Fig. 6 Lasing spectra of a laser diode at light output powers of 2, 3, and 5 mW.

Fig. 6 shows the lasing spectra of the laser diode at light output powers of 2, 3, and 5 mW. The laser operated in a single longitudinal-mode at light output powers of above 3 mW. The lasing wavelength was 786~788 nm.
The laser diode operated in the stable fundamental transverse-mode up to a light output power of 7 mW.

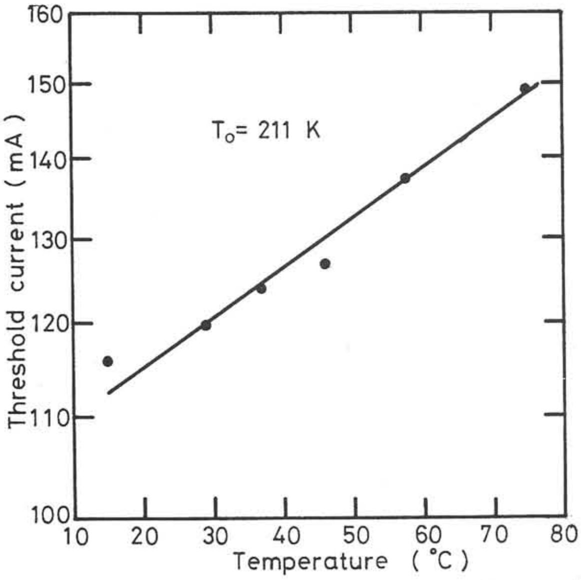


Fig. 7 Threshold current versus temperature characteristic of a laser diode.

Fig. 7 shows threshold currents versus temperature characteristic of the laser diode. The characteristic temperature was 211 K.

5. CONCLUSION

Transverse-mode stabilized double heterostructure laser diodes were fabricated by a metalorganic chemical vapor deposition(MOCVD) technique. Their structure requires only a single-step photolithographic process. The laser diode operated in a fundamental transverse-mode at light output powers up to 7 mW with threshold current of 110~120 mA under CW operation. The lasing wavelength was 786~788 nm. Beam divergences of the laser diode parallel and perpendicular to the junction plane were 8° and 30°, respectively.

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