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InGaAlP Transverse Mode Stabilized Visible Laser Diodes Fabricated by MOCVD Selective Growth

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Transverse mode stabilized InGaP/InAlP visible laser has been demonstrated with a new waveguide structure. A self-aligned structure was fabricated by a three-step low-pressure metalorganic chemical vapor deposition (MOCVD), which included a selective regrowth of a GaAs layer. Fundamental transverse mode oscillation has been achieved with the threshold current of 48 mA (threshold current density of 1.7 KA/cm^2) and the oscillation wavelength of 656 nm.

1. Introduction

600 nm band visible light emitting laser diodes are very attractive light sources for high density optical information processing systems such as optical disk memories and audio/video disk equipments. InGaAlP quaternary alloy is one of the most promising material for this wavelength range lasers, since InGaAlP has the widest direct band gap among III-V alloys with complete lattice matching to GaAs. Room temperature cw operation was reported with gain-guided double heterostructure (DH) lasers grown by metalorganic chemical vapor deposition (MOCVD), which had InGaAlP quaternary cladding layers.[1)-5)] For practical apprications of InGaAlP lasers, transverse mode stabilization and threshold current reduction are indispensable.

Recently, we have reported first room temperature cw operation of transverse mode stabilized InGaP/InGaAlP visible light lasers.[6)] The self-aligned wave guide structure was fabricated by two-step MOCVD, which included GaAs selective regrowth technique. Fundamental transverse and single longitudinal mode oscillations were obtained. However, relatively high threshold current and noise characteristics are not adequate as video disk application.

On the other hand, InAlP ternary cladding layer can be very effective in reducing the threshold current. Since InAlP offers the largest band gap difference from active layer material, good carrier and optical confinements can be expected. However, it has been extremely difficult to grow low resistivity p-type InAlP layer by MOCVD, and there are no report on current injection lasers with InAlP cladding layer.

In this paper, we report an improved wave guide structure InGaP/InAlP lasers and their device performances. The lasers were fabricated by three-step low-presssure MOCVD.

2. Device fabrication

Figure 1 shows the new structure of InGaAlP transverse mode stabilized laser. The wave guide structure consists of a ridge shaped p-type InAlP

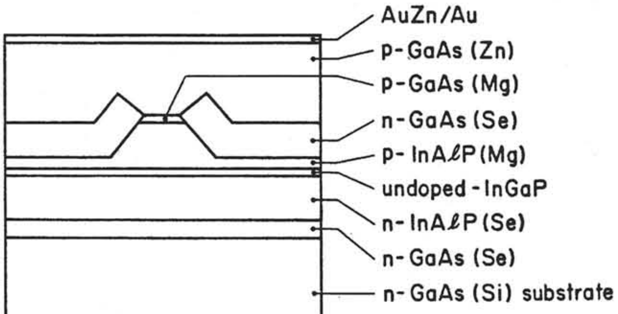


Fig.1. Schematic cross-sectional view of the laser structure.

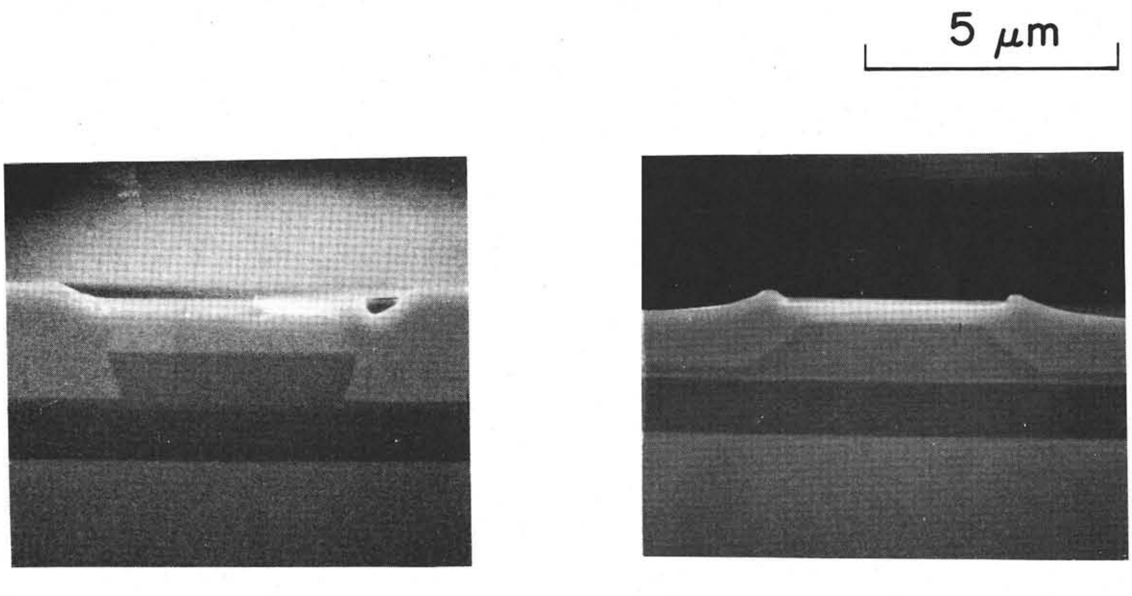
cladding layer and light absorbing n-type GaAs layer. Since the light absorbing layer is close to the active layer outside the ridge stripe, a complex refractive index difference is expected between the ridge stripe and the outside region. Therefore, the transverse mode can be confined within the ridge region. The n-type GaAs layer also promotes confinement of the injection current within the ridge stripe region.

This structure was fabricated by three-step low-pressure MOCVD. The source materials were trimethylindium (TMI), trimethylgallium (TMG), trimethylaluminium (TMA), PH_3 and AsH_3. The doping sources were cyclopentadienylmagnesium (Cp_2Mg) and dimethylzinc (DMZ) for p-type layers and H_2Se for n-type layers. Most of the growth conditions are similar as previously reported.[7] Detailed growth conditions will be described elsewhere.

First, five layers were grown on a (100) oriented Si-doped GaAs substrate: (i) a Se-doped n-GaAs buffer layer (0.5 μm, 5×10^{17} cm^{-3}), (ii) a Se-doped n-$In_{0.5}Al_{0.5}P$ cladding layer (1.0 μm, 5×10^{17} cm^{-3}), (iii) an undoped $In_{0.5}Ga_{0.5}P$ active layer (0.07 μm), (iv) a Mg-doped p-$In_{0.5}Al_{0.5}P$ cladding layer (1.0 μm, 1×10^{18} cm^{-3}) and (v) a Mg-doped p-GaAs cap layer (0.5 μm, 2×10^{18} cm^{-3}). The resistivity of p-type InAlP layer was 0.7 Ωcm at carrier concentration of 1×10^{18} cm^{-3}, which is sufficient for p-type cladding layer.

After the first growth, a SiO_2 layer (1000 Å) was deposited onto the wafer, and ridge stripe in the $\langle 011\rangle$ or $\langle 01\bar{1}\rangle$ direction was formed by successive chemical etching of p-GaAs layer in H_2SO_4:H_2O_2:H_2O (8:1:1, 20°C) and p-InAlP layer in H_2SO_4 (conq, 60°C). Mirror-like InAlP surface and good controlability was obtained by H_2SO_4 etching.

In the second growth, a Se-doped GaAs layer (1.0 μm, 1×10^{18} cm^{-3}) was grown without removing the SiO_2 mask. The GaAs did not grow on top of the SiO_2 and ridge stripe was selectively buried. Figure 2 shows scaning electron microscope cross-sectional images after the GaAs selective regrowth for $\langle 011\rangle$ and $\langle 01\bar{1}\rangle$ stripe type. For the $\langle 011\rangle$ stripe, the regrowth surface was almost flat, but no regrowth occurred on the side surface of the ridge stripe. For the $\langle 01\bar{1}\rangle$ stripe, regrowth occured on the ridge side as well as on the (100) oriented surface. Since the growth rates were almost the same in both cases, surface flatness was not as good as compared with the $\langle 011\rangle$ stripe type.



$\langle 011\rangle$ Stripe Type $\langle 01\bar{1}\rangle$ Stripe Type

Fig.2. Scanning electron microscope cross-sectional images after the GaAs selective regrowth for $\langle 011\rangle$ and $\langle 01\bar{1}\rangle$ stripe type.

A flat surface, however, was obtained for <01$\bar{1}$> stripe type by third growth of a Zn-doped p-GaAs contact layer (3.0 µm, 1×10^{18} cm^{-3}), after removing of the SiO_2 mask. Ohmic contacts were made on the p-side and n-side with AuZn/Au and AuGe/Au, respectively. The cleaved chips were mounted on copper heat sinks in a p-side down configuration. The p-GaAs contact layer facilitated p-side ohmic contact and reliable p-side down mount.

This structure has some advantages as a MOCVD grown InGaAlP transverse mode stabilized laser. (1) Since the InGaP/InAlP DH layers are grown on the flat substrate through the GaAs buffer layer, high quality DH layers can be obtained. (2) This structure has no Al containing regrowth interface at the current injection region. So the surface treatment before the regrowth is not severe. (3) It is easy to change the ridge shape by mask width and etching depth, so the refractive index difference between the stripe region and the outside region is controllable. (4) This structure is obtained by a self-aligned fabrication process. (5) <01$\bar{1}$> stripe type can be effective in obtaining a low noise characteristic with the narrow injection and the wide optical guide.

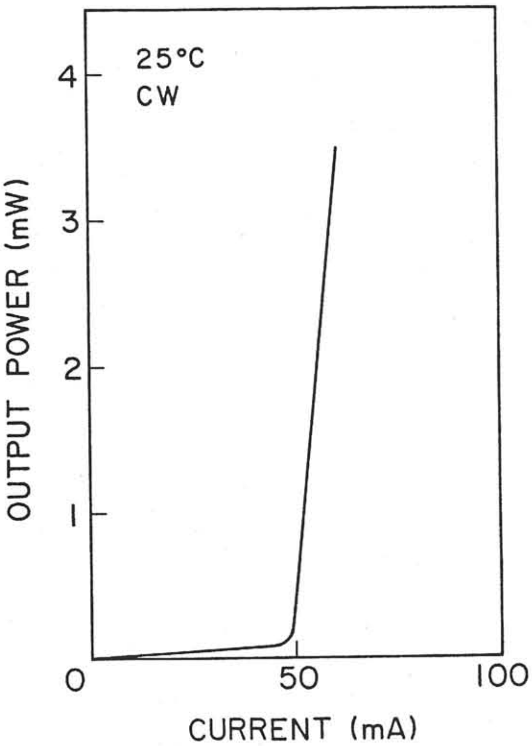


Fig.3. Output power vs. current characteristic at 25°C cw operation.

3. Device characteristics

Device characteristics were measured for 250 µm cavity length <01$\bar{1}$> stripe type laser. The stripe width at the bottom of the p-InAlP cladding layer was 5 µm. The distance between the InGaP active layer and the n-GaAs light absorbing layer was 0.2 µm.

Figure 3 shows a typical output power to current characteristic at 25°C cw operation. The threshold current was 48 mA and the differential quantum efficiency was 20 %. Using the same DH wafer, the lowest threshold current density of 1.7 KA/cm^2 was obtained for the broad contact stripe laser (40 µm x 500 µm), which is the lowest value for InGaAlP lasers. This is due to good carrier and optical confinement with InAlP cladding layer.

Figure 4 shows the lasing spectrum. The oscillation wavelength was around 656 nm at 25°C cw operation. The spectrum shows a self-pulsation pattern. A low noise characteristic was obtained by this structure laser. The relative intensity

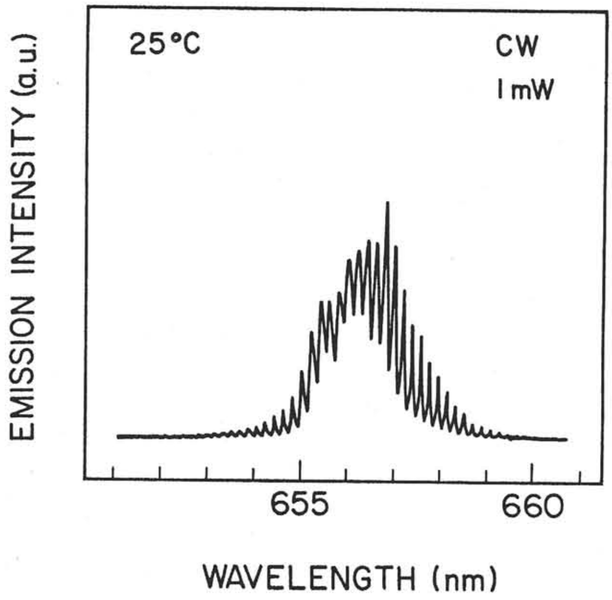


Fig.4. Lasing spectrum at an output power of 1 mW.

noise was less than 5×10^{-14} Hz^{-1} for optical feedback upto 3 % at 2 mW cw operation. This value satisfies the specification for video disk application.

Figure 5 shows the far field pattern. The beam divergences parpendicular and paralle to junction plane were 48° and 7°. It indicates that a fundamental transverse mode oscillation was achieved by the wave guide structure. The astigmatism was about 10 μm, which was less than the value of 40-60 μm for the same stripe width gain guided lasers. The lasers operated over 900 hours at the condition of 25°C, 1 mW without significant degradation.

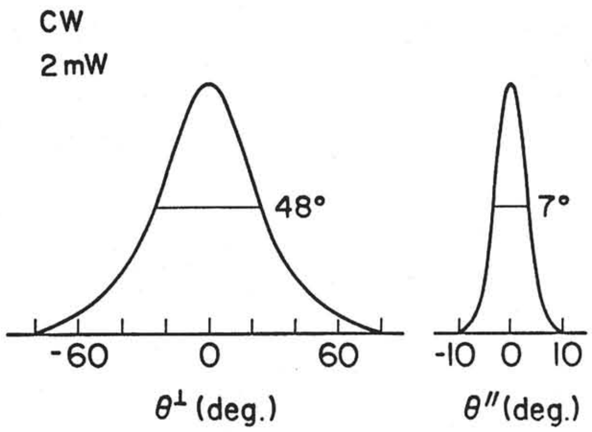


Fig.5. Far field pattern at an output power of 2 mW.

4. Conclusion

Transverse mode stabilized InGaP/InAlP visible light emitting lasers were successfully fabricated by three-step low pressure MOCVD, which included the selective regrowth of the GaAs layer. Fundamental transverse mode oscillation was achieved with threshold current of 48 mA and oscillation wavelength of 656 nm. Low noise characteristic and low astigmatism were also obtained.

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