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High Power Operation of InGaP/InAlP Transverse Mode Stabilized Laser Diodes

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High power cw operation over 20mW of transverse mode stabilized InGaP/InAlP red-light-emitting laser diodes have been acheived. Selectively buried ridge waveguide (SBR) structure was fabricated by three step low pressure metalorganic chemical vapor deposition. Fundamental transverse mode oscillation up to 27.5mW (cw) and 105mW (pulsed) were obtained with thin active layer laser. Threshold current was about 50mA. Oscillation wavelength was 649-651nm. Permisible power density was also estimated with gain guided laser. Pulsed operation over 500mW, which corresponds to power density of $5MW/cm^2$, was obtained. These results show SBR structure is the promissing one for the high power operation of InGaAlP lasers.

1.Introduction

600nm wavelength range InGaAlP red-light-emitting laser diodes are attractive light sources, which improve the performances of optical information processing equipments, such as optical disks and high speed laser printers. They will be also applicable as compact red laser light sources in substitution for He-Ne gas lasers. As shorter wavelength semiconductor lasers, InGaAlP lasers have been expected to be comparable with practically used GaAlAs or InGaAsP lasers in threshold current, reliability, output power and transverse mode stabilization.

After the success of the room temperature cw operation of InGaAlP lasers[1)-3)], cosiderable work has been done on to acheive transverse mode stabilization[4),5)], high reliability[5),6)] and short wavelength cw operation[5),7)]. We have reported a transverse mode stabilized InGaP/InAlP laser which has a selectively buried ridge waveguide (SBR) structure[5)]. Relatively low threshold current was obtained with this structure laser. However, beam divergence aspect ratio and output power were not so sufficient.

For high power operation of InGaAlP lasers, stabilizing the transverse mode and knowing about the permissible power density determined by catastrophic optical damage (COD) are important. In this presentaion we report the COD characteristics of InGaP/InAlP gain guided structure lasers. We also discuss about beam divergence and threshold current dependence on active layer thickness, and demonstrate transverse mode stabilized high power operation of SBR structure lasers with relatively thin active layer.

2.Laser structure

Figure 1 shows the shcematic of the SBR structure laser. The waveguide structure consists of a ridge shaped p-type InAlP cladding layer n-GaAs current blocking layer. An effective refractive index step from 10^{-3} to 10^{-2} is formed by this structure. Since the GaAs current blocking layer acts as a light absorbing layer and gives a large optical loss for higher order transverse mode, transverse mode can be stabilized.

Crystal growth was performed by low-pressure metalorganic chemical vapor

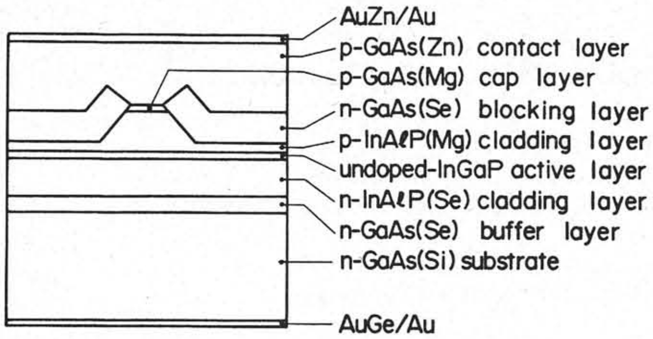

Fig.1 Schematic cross sectional view of InGaP/InAlP SBR structure laser.

deposition. The source materials were trimethymetalorganics (TMI, TMG, TMA), PH_3 and AsH_3. Cyclopentadienylmagnesium and dimethylzinc were used as doping sources for p-type layer and H_2Se was used for n-type layer. Double heterostructure consists of an undoped InGaP active layer (0.02μm - 0.1μm), a Se-doped n-InAlP cladding layer (1.0μm, $5x10^{17}cm^{-3}$) and Mg-doped p-InAlP cladding layer (1.0μm, $1x10^{18}cm^{-3}$). A Se-doped n-GaAs current blocking layer (1μm, $1x10^{18}cm^{-3}$) was grown by selective regrowth with a SiO_2 mask. Detail of the growth conditions and device fabrication process are similar as previously reported[5)].

3.COD level for InGaAlP laser

Permisible power density of InGaP/InAlP laser was estimated by pulsed operation for inner stripe[1)] gain guided structure laser. Double heterostructure was as same as the SBR laser. Active layer thickness was 0.07μm and stripe width was 9μm. Laser characteristics were measured with as cleaved chip with cavity length of 250 μm. Pulse width was 300nsec and repetition rate was 1kHz. Spot size perpendicular to the junction plane was 1.0μm by near field pattern observation.

Figure 2 shows an output power vs. current characteristic of the lasers. Threshold current was about 100mA and differential quantum efficiency was about

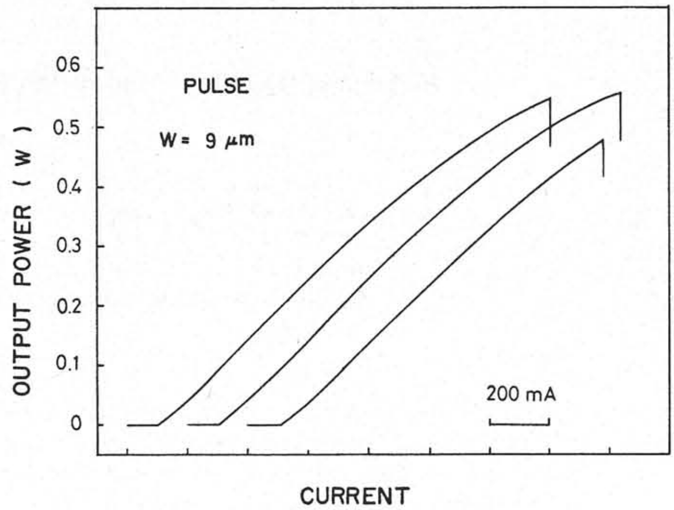

Fig.2 Output power vs. pulsed current characteristic of gain guided lasers.

20%/facet. COD was observed at about 0.5W. Trace of the damage was observed at laser facet by scanning electron microscopy and optical microscopy. Maximum output power was 0.55W which corresponds to power density of $5MW/cm^2$. This COD level is comparable to or higher than those of GaAlAs lasers.

4.High power operation of SBR laser

Active layer thickness is important parameter to optimize the laser characteristics. Threshold current and beam divergence angle depend on the active layer thickness through the optical confinement factor within the active layer. Optical confinement also relates to maximum output power. Thin active layer is preferable for high power operation.

Figure 3 shows threshold current density (J_{th}) and full width at half maximum (FWHM) of beam divergence angle perpendicular to the junction plane for some active layer thickness lasers. J_{th} was measured with broad oxide stripe laser which had 40μm stripe width and 500 μm cavity length. Minimum J_{th} of $1.7kA/cm^2$ was obtained for active layer thickness of 0.07μm and 0.1μm. J_{th} increased with reducing the active layer thickness. However, J_{th} for 0.04μm thickness

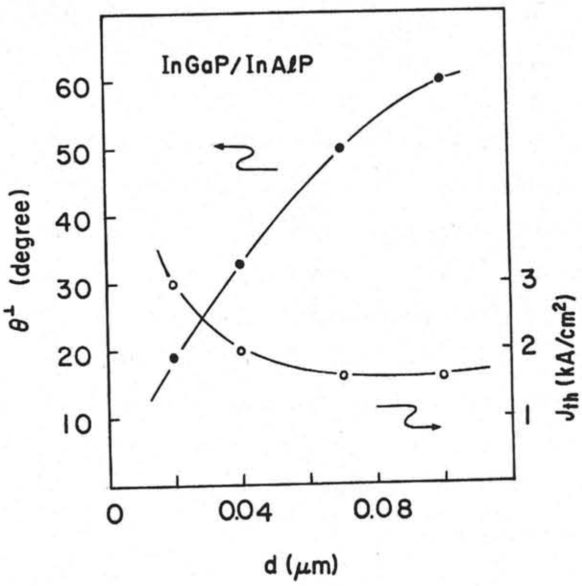

Fig.3 Threshold current density and FWHM angle of beam divergence perpendicular to the junction plane dependence on active layer thickness.

layer was 2.0kA/cm^2, which is not so much problem in increasing threshold current. Beam divergence angle was measured with 5μm stripe SBR structure lasers. FWHM angles parallel to the junction plane were found to be 7° , which did not depend on the active layer thickness. FWHM angle perpendicular to the junction plane was reduced by adopting the thin active layer. These relations show a good fit with the theoretical results.

High power cw operation with stable fundamental transverse mode was obtained with 0.04 μm active layer thickness lasers. Figure 4 shows output power vs. current characteristic for 5μm stripe width and 250μm cavity length laser. No facet coat was performed. Threshold current was 50mA and differential quantum efficiency was about 27%/facet. CW operation upto 27.5mW was achieved without any kink.

Figure 5 shows the far field pattern at up to output power of 20mW. FWHM angle was 32° for perpendicular and 7° for parallel to the junction plane. Stable fundamental transverse mode oscillation was obtained.

Figure 6 shows the cw oscillation spectra at some output power. Center of the oscillation wavelength was 649nm at 3mW and 651nm at 15mW with longitudinal multi mode. Spectrum width reduced at high output power.

Figure 7 shows pulsed output power vs. current characteristic and far field pattern parallel to the junction plane with 5μm stripe and 300 μm cavity length laser. Fundamental transverse mode oscillation up to 105mW was achieved without any facet coat. Threshold current was 75mA and differential quantum efficiency of 30%/facet were

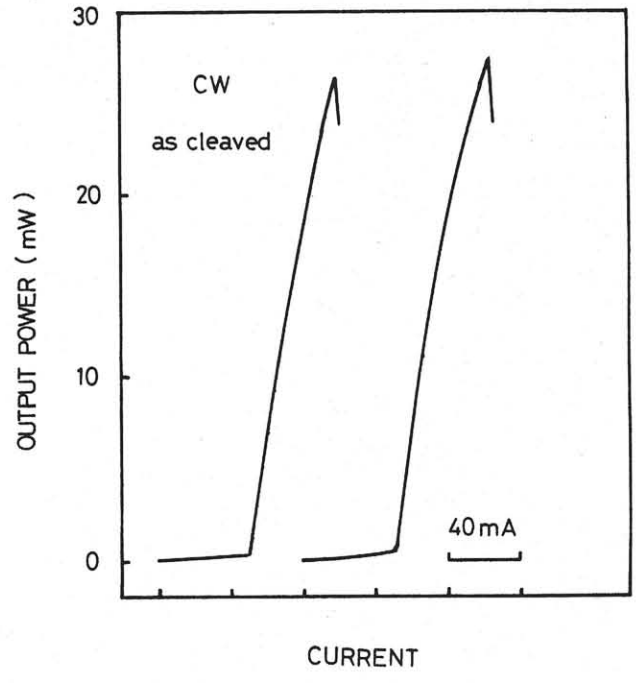

Fig.4 Output power vs. dc current characteristic of SBR laser with 0.04μm active layer.

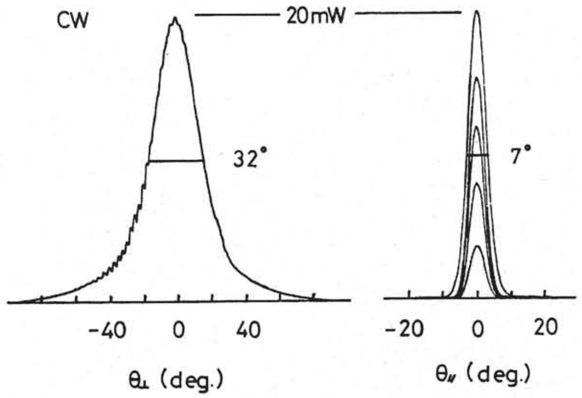

Fig.5 Far field pattern of SBR laser.

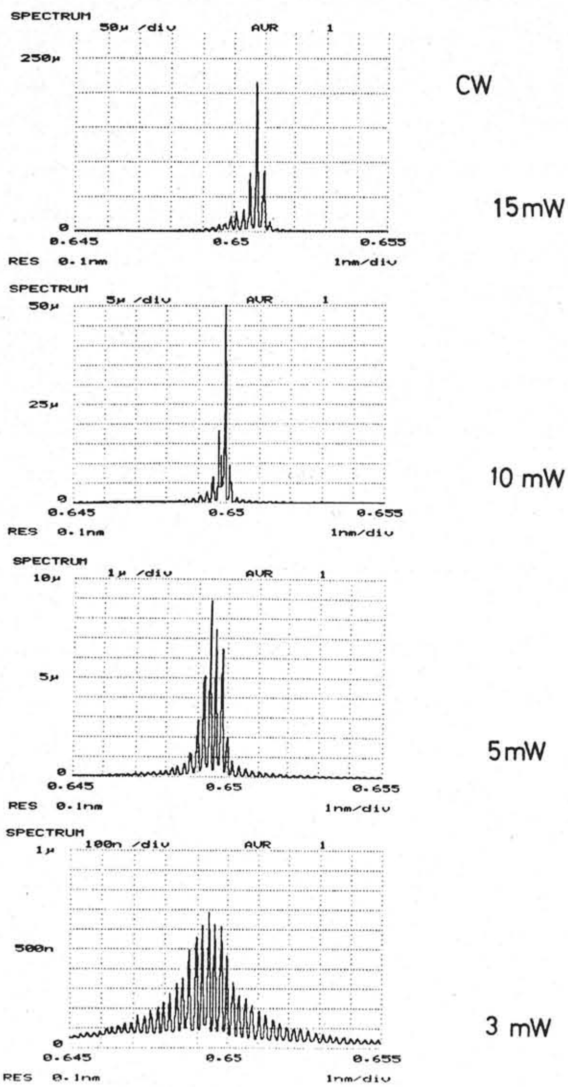

Fig.6 CW oscillation spectra of SBR laser.

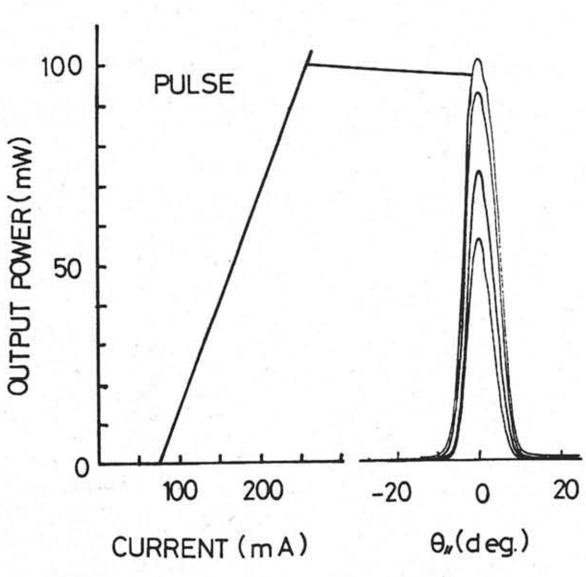

Fig. 7 Output power vs. pulsed current characteristic of SBR laser.

obtained.

5.Conclusion

High power cw operation over 20mW of transverse mode stabilized InGaP/InAlP was achieved with selectively buried ridge waveguide (SBR) structure laser. Stable fundamental transverse mode oscillation up to 27.5mW (cw) and 105mW (pulsed) were obtained with relatively thin active layer laser. Permisible power density for InGaP/InAlP laser was also estimated to be about $5MW/cm^2$ without any facet coat. These results show InGaAlP lasers have comparable potentiality to GaAlAs lasers in high power operation and SBR structure is suitable for InGaAlP high power lasers.

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