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Index-Guide GaInNAs Laser Diode for Optical Communications

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1. Introduction

The 1.3-μm wavelength laser diode now used for optical communication mainly consists of a GaInPAs crystal grown on an InP substrate. However, in this material, it is difficult to exceed a characteristic temperature of 80 K, since the band discontinuity between the active layer and the cladding layer is not sufficiently high. Thus, improvement in the temperature characteristic is required for applications in future fiber-optic subscriber systems and optical interconnect systems [1].

We have proposed a new material, GaInNAs, that satisfies the need for a higher band discontinuity and a higher temperature characteristic [2]. The lattice constant of the GaN is smaller and the energy band gap is larger than those of GaAs. However, because of the energy-band-gap bowing, which makes the energy band gap of an alloy compound smaller than the averaged value based on the composition, the energy band gap decreases when nitrogen is added to GaAs. Therefore, unlike the case when In is added to GaAs, the energy band gap decreases with the decrease in the lattice constant. This makes it possible to form a laser diode with a 1.3-μm wavelength on a GaAs substrate, and a cladding layer can be used whose band gap is wider than that of cladding layer that can be grown on an InP substrate. We previously reported on a broad-area laser diode that uses GaInNAs as active layer and has a threshold current density of 888 A/cm^2 under room-temperature pulse operation[3]. In this paper, we report on low-threshold-current operation of a real-refractive-index-guide laser diode that uses this material.

2. Laser diode design and fabrication

Figure 1 shows a schematic of the laser diode fabricated in this work. The Al composition of the p- and n-type AlGaAs cladding layers was 30%. The active layer consisted of a GaInNAs single-quantum-well layer sandwiched between the GaAs guide layers. The amount of nitrogen that can be added while maintaining good crystal quality is fairly small since the atom size of nitrogen is much smaller than that of arsenic. Therefore, it was necessary to increase the In composition as much as possible while keeping the nitrogen concentration sufficient to obtain an operable GaInNAs laser diode. The In composition must be less than about 30% in a 7-nm thick GaInAs film, which is just under the critical film thickness. The In composition in our fabricated diode was 30% or less and the nitrogen concentration was about 0.4%.

The GaAs guiding layer was about 140 nm thick, which provided the maximum optical confinement for this cladding layer composition. The light confinement factor of the quantum well was about 1.68%. The crystal growth was done by gas-source molecular-beam epitaxy with a radical nitrogen source generated by radio-frequency plasma discharge. The p-AlGaAs cladding layer was chemically etched to form a ridged stripe, and a 0.2-μm-thick p-type cladding layer was left in the area not below the ridge. The real-refractive-index-guide laser diode was formed by burring the ridge stripe with a polyimide and depositing metal electrode by evaporation. The laser diode was mounted on a heat sink with the p side down.

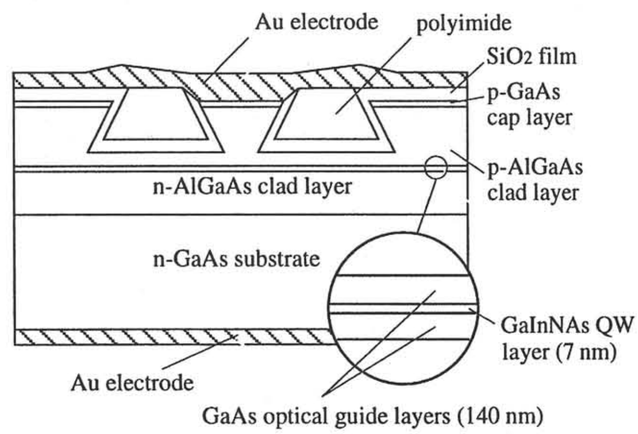

Fig. 1 Structure of the GaInNAs laser diode with a real refractive index guide

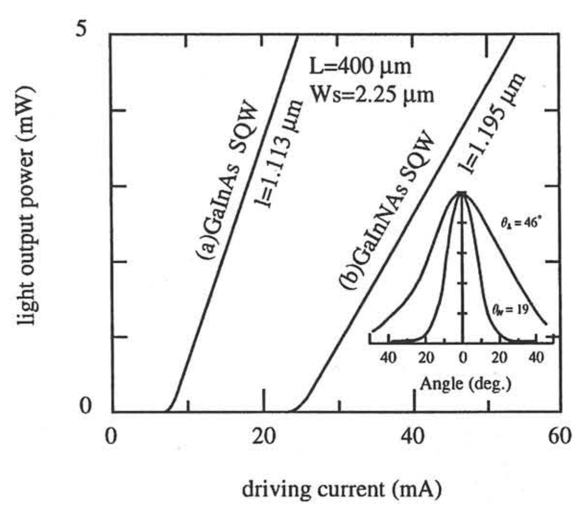

Fig. 2 Electric current versus light output power of a laser diode (a); GaInAs SQW laser diode with the lasing wavelength of 1.113 μm, and (b) GaInNAs laser diode with the lasing wavelength of 1.195 μm.
The far-field emission patterns for the GaInNAs laser are shown in the inset.

3. Characteristics of the laser diodes

Figure 2 shows the light output power versus the current of the laser diode under room-temperature continuous-wave operation. The width of the narrowest part of this laser diode was about 2.25 μm and the cavity length was about 400 μm. The threshold current of the laser diode was about 24 mA and the slope efficiency and the wavelength were 0.17 mW/mA and 1.195nm respectively. The light output power versus current characteristics of a GaInAs laser diode that did not contain nitrogen in the active layer are also shown in Fig. 2. The threshold current of the GaInAs laser diode was about 7 mA, about one-third that of the GaInNAs laser. Since the photoluminescence intensity of the GaInNAs was one-quayter of the GaInAs, we believe the reason for the higher threshold of the GaInNAs laser is that the crystallinity of the GaInNAs active layer was inferior to that of the GaInAs quantum well layer.

The far-field emission patterns of this device were smooth single-peak patterns (Fig. 2 inset), which shows that the refractive index guide worked successfully. The vertical and the horizontal far-field emission angles, respectively, were 46 degrees and 19 degrees. The characteristic temperature of this laser diode was about 100 K, as shown in Fig. 3, which is slightly lower than that of our previous broad-area laser diode. This may be because the electric resistance in this device is higher, due to its narrower contact area, than in the broad-area device.

We fabricated devices with cavity lengths of 300, 400, 600, 800, and 1000 μm to estimate device parameters such as the cavity loss and the gain coefficient. To avoid the influences of heat and differences in the elapsed time, we evaluated the characteristics of the fabricated devices by pulse operation at a frequency of about 10 kHz and a width of 300 nm. Figures 4 and 5 shows how the threshold current density and slope efficiency of these devices were affected by the cavity length. The device parameters shown in these figures are good enough to show the promise of this device for practical use.

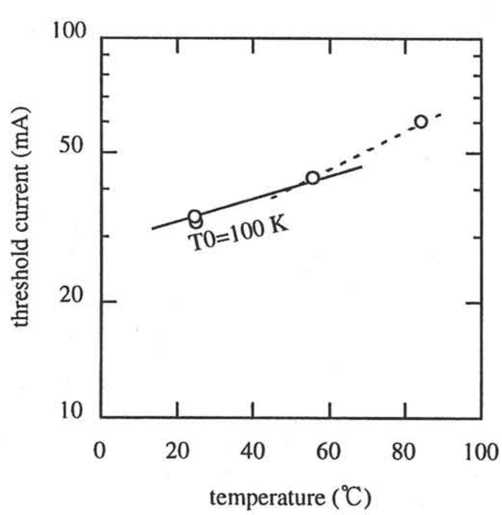

Fig. 3 Temperature dependance of the threshold current of the GaInNAs laser diode.

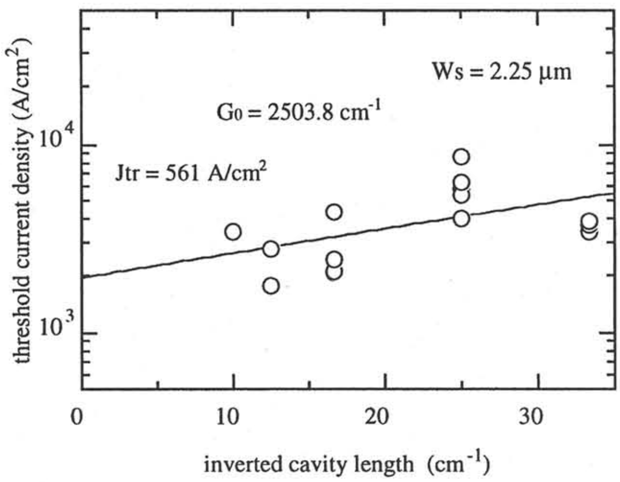

Fig. 4 Cavity length dependence of the threshold current density

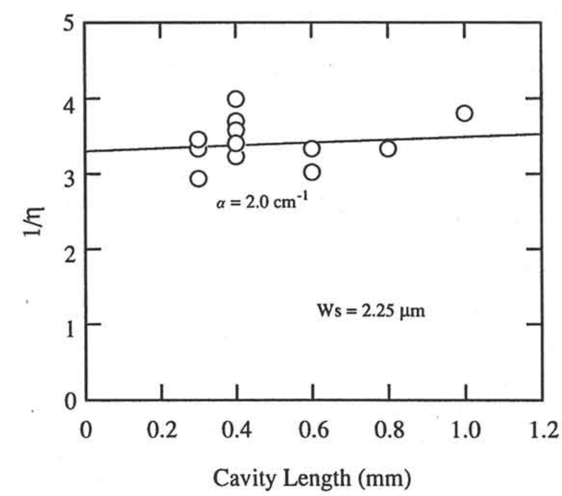

Fig. 5 Cavity length dependence of the slope effeciency

4. Conclusion

An AlGaAs/GaAs/GaInNAs single-quantum-well real-index-guide laser diode with a ridged waveguide structure was successfully fabricated. A threshold current of 24 mA under room-temperature continuous-wave operation was attained with this structure. Obtained device parameters --- To = 100 K, $\alpha = 2\ cm^{-1}$, Jtr = 561 A/cm^2, and $G_0 = 2504\ cm^{-1}$ --- show that this device is promising for use as high-characteristic-temperature laser diode for optical communication.

References

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