MOCVD growth of AlGaInP/GaInP quantum well laser diode with asymmetric cladding structure for high power applications

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In order to improve the characteristics of the general broad-waveguide 808-nm semiconductor laser diode (LD), we design a new type quantum well LD with an asymmetric cladding structure. The structure is grown by metal organic chemical vapor deposition (MOCVD). For the devices with 100-μm-wide stripe and 1000-μm-long cavity under continuous-wave (CW) operation condition, the typical threshold current is 190 mA, the slope efficiency is 1.31 W/A, the wall-plug efficiency reaches 63%, and the maximum output power reaches higher than 7 W. And the internal absorption value decreases to 1.5 cm^{-1}.

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High-power laser diodes (LDs) operating at wavelengths around 808 nm have gained more and more importance for applications such as pumping of solid state lasers and material cutting or welding. The main advantages of these lasers are high conversion efficiency in connection with low heat dissipation, small size, low cost, and high reliability. In any case, higher power is the necessary prerequisite. Now, the most widely used structure for the purpose is broad-waveguide separate confinement heterostructure (BW-SCH) or the structure with a super-large optical cavity[1−4]. These symmetric structures have a large equivalent transverse spot size d/Γ, where d is the active layer thickness and Γ is the optical confinement factor. It is highly desirable to increase the value of catastrophic optical mirror damage (COMD). Thus, it has been achieved the purpose to increase the maximum output power of the diode laser. Botez has analyzed the broad-waveguide structure in theory and given the expressions to optimize the thickness of the waveguide layer[5]. However, the improvement of the d/Γ value by lowering the optical confinement factor is limited because of the injected-carrier leakage and higher optical mode. The existing symmetric structures are also subject to mode instabilities due to the weak mode confinement and thermal lens[6].

In order to overcome the problems, asymmetric broad-waveguide (BW) structures have been proposed[7−9]. Shigihara *et al.* have reported the high power 980-nm LDs with the asymmetric BW structure[7,8]. In this letter, we report an asymmetric 808-nm LD with Al-free active region.

The optical absorption out of the active layer is proportional to the doped consistency. To decrease the absorption, we can lower the doped consistency, but this will cause higher electric resistance and voltage. We design the asymmetric BW structure based on the fact that the optical absorption in n-type semiconductor materials is lower than that in p-type semiconductor materials[10]. The asymmetric BW laser structure is schematically shown in Fig. 1. In the asymmetric BW structure, the n-cladding layer is different from the p-cladding layer, and the waveguide layers around the quantum well (QW) are also different. The structure can pull the peak of optical intensity away from the QW[11] and allow the optical field to spread into the n-cladding layer side, which will be beneficial for reducing the optical absorption in the active region.

The asymmetric BW laser structure was grown by low-pressure metal organic chemical vapor deposition (LP-MOCVD). A 10-nm-thick InGaAsP QW surrounded by the GaInP waveguide layer was located close to the p-$(\mathrm{Al}_{0.3}\mathrm{Ga}_{0.7})_{0.5}\mathrm{In}_{0.5}\mathrm{P}$ cladding layer. The lower waveguide thickness was 0.4 μm while the thickness of upper waveguide was 0.3 μm. A 1.0-μm-thick $(\mathrm{Al}_{0.1}\mathrm{Ga}_{0.9})_{0.5}\mathrm{In}_{0.5}\mathrm{P}$ layer was used as the n-cladding layer, allowing the optical field to spread into the n-cladding layer side, thus resulting in the reduction of the optical absorption in the p-cladding layer side. Moreover, a 50-nm-thick high-bandgap material $(\mathrm{Al}_{0.5}\mathrm{Ga}_{0.5})_{0.5}\mathrm{In}_{0.5}\mathrm{P}$ acted as a barrier layer between the upper waveguide layer and the p-cladding layer in order to prevent the injected-carrier leakage to the p-cladding layer. Meanwhile, the QW and the waveguide

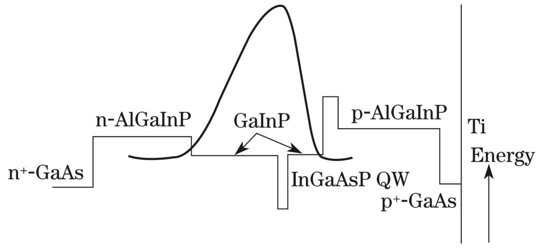

Fig. 1. Schematic conduction band edge and optical mode profile of the asymmetric structure.

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layer constituted the Al-free active region.

The symmetric BW laser structure was also grown by LP-MOCVD for comparison. In the structure, we used 1.0-μm-thick $(Al_{0.4}Ga_{0.6})_{0.5}In_{0.5}P$ as the cladding layers and 0.4-μm-thick GaInP as the waveguide layers.

All layers of the structure were grown on (100) GaAs substrates. The source materials were trimethylindium, trimethylgallium, and trimethylaluminum for the group III elements; arsine and phosphine for the group V elements; and diethylzinc, silane diluted to 0.02% in hydrogen for the dopants. Palladium-diffused hydrogen was used as the carrier gas. The growth pressure was 50 mbar and the growth temperature was 650 °C.

Broad-area lasers with 100-μm-wide stripe and 1000-μm-long cavity were fabricated with the wafers grown on GaAs substrates. The LDs were coated with 5% anti-reflection (AR) coating on the front facet and 95% high-reflecton (HR) coating on the rear, and were bonded with a p-side down configuration on the Cu heatsink.

All the parameters of the devices were measured under continuous-wave (CW) condition at room temperature.

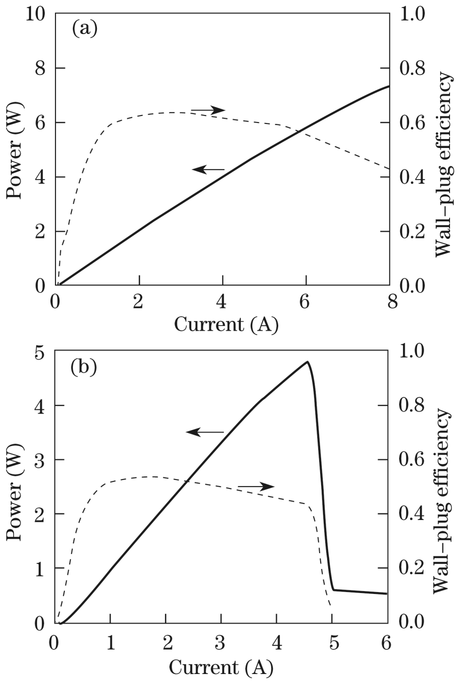

Fig. 2. CW output power and wall-plug efficiency at room temperature for (a) asymmetric BW laser and (b) symmetric BW laser.

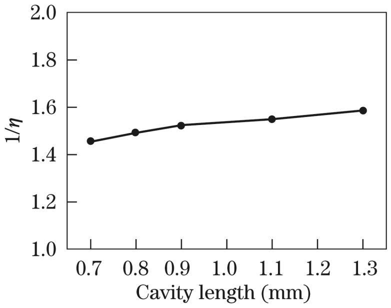

Fig. 3. Reciprocal external differential quantum efficiency as a function of cavity length for the asymmetric structure with the stripe width of 100 μm.

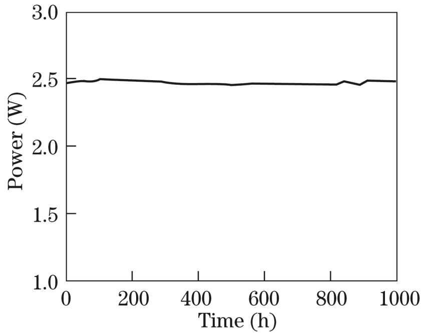

Fig. 4. Lifetime test of asymmetric BW lasers with 100-μm stripe width. Current is 2.5 A, temperature is 50 °C.

The typical power-current (P-I) characteristics of the asymmetric BW laser and the wall-plug efficiency are shown in Fig. 2(a). Figure 2(b) shows the characteristics of the symmetric BW laser. The threshold current and the slop efficiency of the asymmetric BW laser are 190 mA and 1.31 W/A, respectively. Furthermore, the LD has a maximum wall-plug efficiency of more than 60%. At the driving current of 8 A, the optical output power of the laser reaches 7 W. However, the highest output power of the symmetric BW laser only reaches 5W and the maximum wall-plug efficiency is 53%.

We also calculated the internal loss α_i of the laser without coating using the function of the cavity length and slope efficiency. The function can be expressed as

$$\frac{1}{\eta_d} = \frac{1}{\eta_i}\left(1 + \alpha_i \frac{1}{\frac{1}{2L}\ln\frac{1}{R_1 R_2}}\right), \qquad (1)$$

where η_d and η_i are the differential quantum efficiency and the injection efficiency, L is the cavity length, R_1 and R_2 are the reflectivity of the front and rear facets, respectively. The internal loss α_i of the asymmetric BW laser decreased to 1.5 cm^{-1} from 3.2 cm^{-1}, which is that of the symmetric BW laser, as shown in Fig. 3.

At last, we tested the lifetime of the LDs at a current level of 2.5 A at the temperature of 50 °C. We only found a very low degradation rate over 1000 h. Figure 4 shows the result for 100-μm-wide stripe devices with 1000-μm cavity length. At present, much longer aging time tests are being performed.

In conclusion, the lasers with asymmetric structure have been proposed in order to satisfy the increase of output power and the reduction of the internal loss α_i. The internal loss α_i of the lasers with 100-μm-wide stripe decreases to 1.5 cm^{-1}, and the output power reaches 7 W at the driving current of 8 A with the maximum wall-plug efficiency of 63%.

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