1.3-μm uncooled 10 Gb/s directly modulated MQW AlGaInAs/InP laser diodes

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In this paper, we report a novel 1.3-μm uncooled AlGaInAs/InP multiple quantum well (MQW) ridge waveguide laser diodes. By optimizing the design of MQW structure and facet coatings, together with the application of reversed-mesa ridge waveguide (RM-RWG) structure, polyimide planarization, and lift-off processes technology, an uncooled 1.3-μm, 10-Gb/s directly modulated MQW ridge waveguide laser diode was successfully fabricated. The threshold current and the slope efficiency were 7 mA and 0.48 mW/mA, respectively. The directly modulated bandwidths of 11 and 9.2 GHz were achieved at room temperature and 80 °C, respectively.

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The recent increase of information traffic demands optical communication system to operate at 10 Gb/s and above even for local area networks (LAN) and metropolitan area networks (MAN). An uncooled high-speed directly modulated laser is a key component for these network applications, which is used in optical transceivers in order to reduce cost, size, and power consumption.

The key for the high-speed directly modulated lasers is to increase the relaxation oscillation frequency as well as reduce the device stray capacitance. In order to realize the uncooled operation at high temperature, AlGaInAs material has been investigated as a promising candidate to improve temperature dependence of basic laser characteristics such as the threshold current and slope efficiency due to its large conduction band offset ($\Delta E_\mathrm{c} = 0.72\Delta E_\mathrm{g}$). Compared with the conventional InGaAsP material system, the AlGaInAs material system also has the advantage of realizing high speed modulation due to its high relaxation frequency.

In this paper, we report a novel 1.3-μm uncooled AlGaInAs multiple quantum well (MQW) ridge waveguide laser diode. In order to get high relaxation oscillation frequency and low capacitance, we optimized the design of MQW structure and facet coatings, and adopted reversed-mesa ridge waveguide (RM-RWG) structure, polyimide planarization, and lift-off processes technology. With the RM-RWG structure of the laser diode, we can maintain the small size of the ridge neck width by using the larger upper ridge width. This is helpful for the laser diode to reduce both the electrical and thermal resistances at the same time. Because of the low dielectric constant of ployimide ($\sim$ 3.4) compared with $\mathrm{SiO_2}$ ($\sim$ 3.9), the parasitic capacitance of the laser diode is reduced. This increases the relaxation frequency, and consequently raise the directly modulated bandwidth of the laser diode.

The schematic structure of the polyimide planarized reversed-mesa ridge waveguide laser diodes is shown in Fig. 1. The AlGaInAs MQW active layer and surrounding graded index separated confinement heterostructure (GRIN-SCH) layer were grown onto the n-type InP substrate with low-pressure metal organic chemical vapour deposition (MOCVD). The active layer consists of six 5-nm-thick 1.2% compressively strained AlGaInAs quantum wells separated by 8.5-nm-thick lattice-matched AlGaInAs barriers. The photoluminescence (PL) wavelength was adjusted to be around 1290 nm, considering the lasing wavelength shift from the PL wavelength. The cladding layer consisted of 60-nm-thick InAlAs and outer InP layers. The doping concentrations of the InAlAs cladding layer were $5 \times 10^{17}/\mathrm{cm}^3$ for p-type and $1 \times 10^{18}/\mathrm{cm}^3$ for n-type, respectively.

The epitaxial wafer was then processed into Fabry-Perot ridge waveguide lasers with reversed-mesa structure. The reversed side walls were performed using a HBr-containing reagent $\mathrm{H_3PO_4}$. The width of the ridge neck was restrict to be about 1.8 μm while maintaining the upper ridge width about 4.5 μm (see Fig. 2), in order to reduce both the electrical and thermal resistances at the same time. After ridge formation, the trenches at two sides of the ridge were filled with polyimide by a self-alignedment process. The top electrode was fabricated using lift-off method, and the radius of which was shrunk to be about 80 μm in order to reduce the capacitance of the laser diode (see Fig. 3). The cavity length

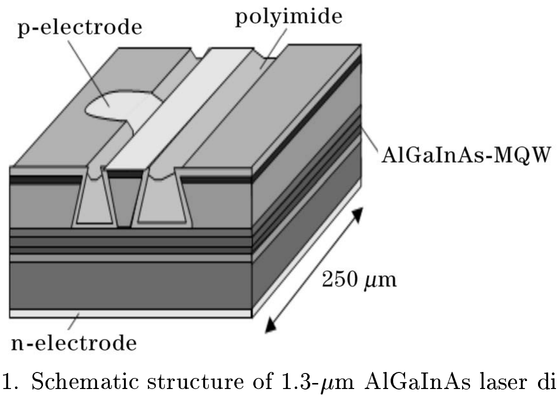

Fig. 1. Schematic structure of 1.3-μm AlGaInAs laser diode.

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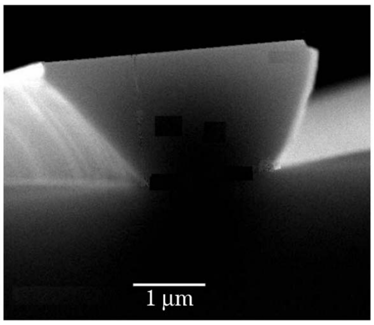

Fig. 2. RM-RWG structure of the laser diode.

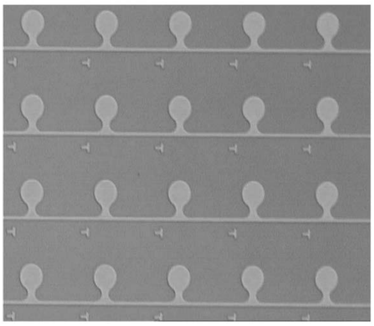

Fig. 3. Minimized electrode fabricated using lift-off method.

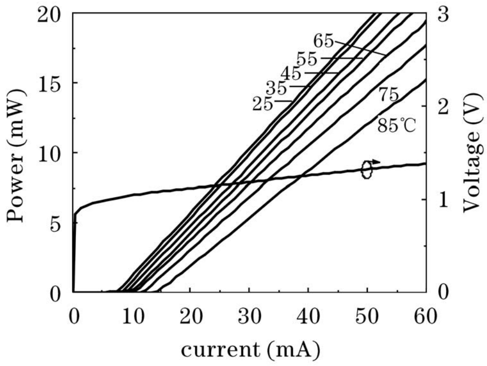

Fig. 4. Output power versus current at different temperatures.

was set to be 250 μm, and the high-reflection coating with amorphous Si and SiO_x dielectric film stack (reflectivity ~90%) was evaporated on to the back facet.

Laser chips were then bonded to a SiC heatsink on an AlN carrier. Figure 4 shows the light output power versus current (P-I) characteristics for the cavity length of 250 μm at different temperatures. The series resistance was 6 ohm, the threshold current and the slope efficiency were respectively 7 mA and 0.48 mW/mA at 25 °C. At 85 °C the slope efficiency was 0.33 mW/mA and the output power was measured to be more than 15 mW at 60 mA. The characteristic temperature T_0 of the threshold current from 25 to 85 °C was about 95 K. This value is much higher than that of conventional InGaAsP lasers due to the large conduction band offset ($\Delta E_c = 0.72\Delta E_g$) of AlGaInAs material system and the optimization of the MQW active region structure.

In Fig. 5(a), the small signal frequency responses at different bias currents measured at room temperature are shown. The 3-dB bandwidth in excess of 11 GHz was achieved with a low bias level of 45 mA. For comparison, we also measured the laser diodes without polyimide planarization, the 3-dB bandwidth of which was only about 8.7 GHz at the same bias level. It shows that the polyimide planarization is an efficient way to raise the 3-dB bandwidth as reducing the capacitance of the laser diode. Figure 5(b) shows the small signal frequency responses at 80 °C. With a bias level of 45 mA, a 3-dB bandwidth of 9.2 GHz was achieved.

Figure 6 shows the 10-Gb/s ($10^{31} - 1$ pseudo-random binary sequence (PRBS)) eye-diagrams for the 250-μm-

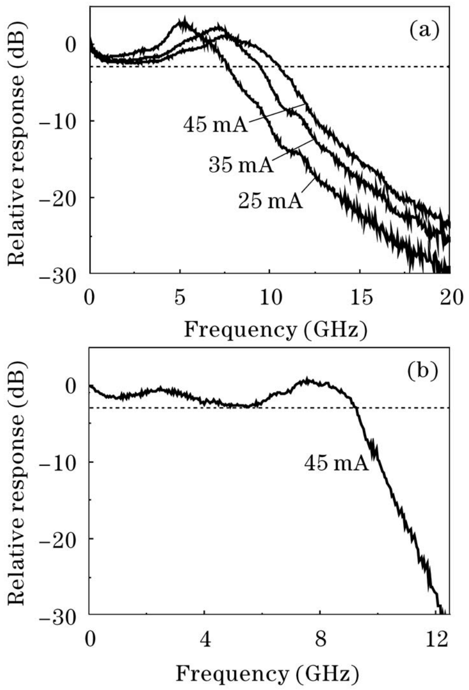

Fig. 5. Small signal frequency responses for 250-μm long device at 25 °C (a) and 80 °C (b).

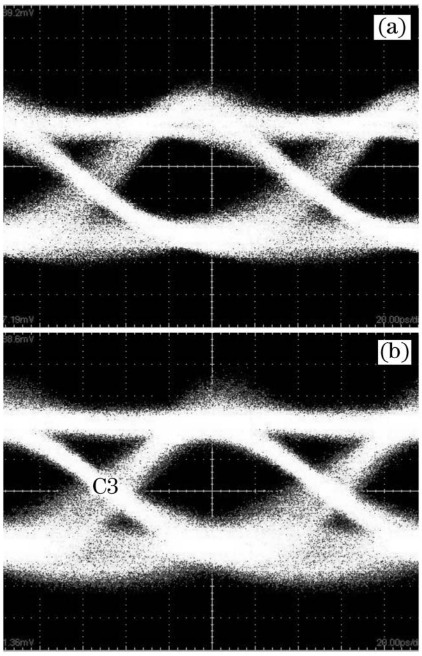

Fig. 6. Eye-diagrams for 10-Gb/s uncooled direct modulation at 25° (a) and 80 ° (b).

long device measured at 25 and 80 °C with modulation current amplitude of 40 mA, and the direct current (DC) bias set at about 30% above the threshold. In both cases, an extinction ratio of > 8 dB was achieved, although the increased closure is observed for the higher temperature case.

In summary, compressively strained 1.3-μm AlGaInAs/InP MQW ridge waveguide lasers were fabricated. By optimizing the design of MQW structure, together with the application of reversed-mesa ridge waveguide structure, polyimide planarization, and lift-off processes technology, large bandwidths of 11 and 9.2 GHz were achieved at room temperature and 80 °C, respectively. The threshold current was 7 mA and the slope efficiency was 0.48 mW/mA at 25 °C. Large characteristic temperature of more than 90 K from 25 to 85 °C was realized. The device has possible applications in low-cost transmitters for high-bit-rate optical links.

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