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1.55 μm high-power large optical cavity lasers

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A high-power 1.55 μm large optical cavity laser structure is successfully prepared for the first time by reasonably designing its configuration and by using a proper single step liquid phase epitaxy so as to realize lasers with peak output power higher than 2 W per facet in pulsed operation at room temperature. The devices are also characterized by their lower threshold current ($J_{th} \leqslant 2.7$ kA/cm^2 for broad area contact structure) and high-temperature stability ($T_0 \approx 130$ K). At the same time they are of long-lived operation and are an ideal source of light in this spectral region.

In recent years, high-power diode lasers emitting at 1.3–1.55 μm have been highly considered because of their importance in long distance optical fiber transmission and other usage. However, so far most of high-power output lasers have focused on 1.3 μm region.[1–4] Only a few researchers have obtained high-power output lasers at about 1.55 μm.[5]

In this letter we report the design and fabrication of a high-power 1.55 μm InGaAsP-InP laser, for the first time, with a large optical cavity (LOC) and we prepared the devices successfully using single step liquid phase epitaxy (LPE).

Considering the effect of temperature rise in the active region on threshold current density and external differential quantum efficiency of the laser, we designed a LOC chip with six-layer structure on the basis of 1.3 μm InGaAsP-InP LOC lasers.[6]

The output power of short wavelength AlGaAs-GaAs lasers is limited by the material damage threshold of the output facet, while long wavelength InGaAsP-InP lasers are limited by the temperature of the active region.[7] In our LOC structure the thermal resistance and the series resistance of a unit cavity length can be reasonably assumed to be constant.[8] When a current density J_a is applied, the temperature rise of the active region is written as[9]

$$T_j = R_{tho}\{V_j D[J_a - J_{th}(T_j)][1 - \eta_d(T_j)] + R_{so} D J_a\}, \quad (1)$$

where V_j is the junction voltage and D is the width of the active region. R_{tho} and R_{so}, which are the thermal resistance and the series resistance of a unit cavity length are both constants and can be experimentally measured. $\eta_d(T_j)$ and $J_{th}(T_j)$ are external differential quantum efficiency and threshold current density at temperature T_j, respectively, and are both functions of temperature T_j.

When an applied current density J_a is equal to the threshold density of the laser $J_{th}(T_j)$, the temperature rise of the active region $T_j = R_{tho} R_{so} D J_{th}(T_j)$ means that the temperature rise is directly proportional to the threshold current density. Then the lower and more stable temperature rise T_j can be obtained because of lower threshold current density and higher characteristic temperature in the LOC structure.[6]

As the applied current density J_a increases and becomes greater than the laser threshold current density $J_{th}(T_j)$, the temperature rise in the active region T_j will increase. Therefore, to reduce the amount of heat generation and to enhance the heat transfer, the LOC structure is provided with a thinner active region (and a thicker waveguiding layer) and higher external differential quantum efficiency, thus the temperature rise of the active region is limited.

Lower internal losses and higher external differential quantum efficiency provided by the LOC structure explain why the laser can emit high-power output.

In the practical growth we found that the active layer can melt back during growth and the trend of such a melting back increases as the laser output wavelength increases. Therefore, we grow an intrinsic InGaAsP layer between the active and P-InP confinement layers whose band gap corresponds to the wavelength of about 1.25 μm. The layer plays a composition-transit role and prevents the active layer from being melted back. The antimeltback layer also improves the lattice match and contributes to decreasing the threshold current.

Intrinsic materials are used in both the active and waveguiding layers to minimize optical absorption losses. The thickness and doping level of various epilayers deter-

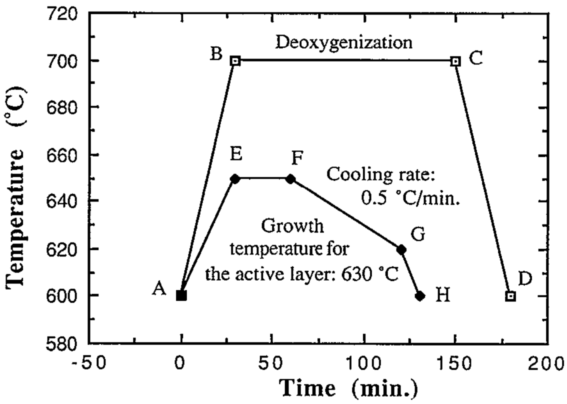

FIG. 1. Typical epitaxial growth schedule to grow the 1.55 μm high-power large optical cavity (LOC) laser structure.

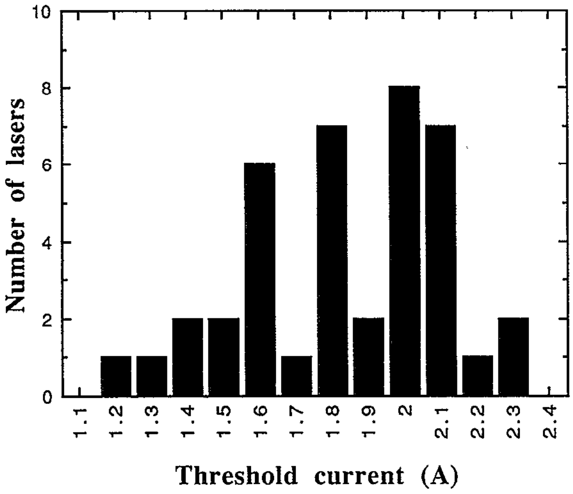

FIG. 2. Histogram of threshold current distribution for the 40 1.55 μm high-power large optical cavity (LOC) lasers.

mined by growth process improve the laser temperature characteristics and enhance its operation stability.

The InGaAsP-InP LOC structure was grown by using the LPE technique. Two-phase solution and horizontal sliding boat were used in the growth. To realize the six-layer structure design and to guarantee perfect growth of both active and antimeltback layers, we accepted a moderate degree of supercooling which was estimated to be about 5 °C.[10] The experiments certified that such a moderate degree of supercooling plays an important role in decreasing defects and in improving lattice match. We used a (100) n-type InP substrate to minimize the sensitivity of solid compositions in both active and antimeltback layers to the degree of supercooling of the melts and then to obtain accurate control of the epitaxial growth process as well as to obtain optimal lattice match. This orientation also allows the cleavage of the resonant cavities and other diode-preparing steps. The growth melts were maintained at 650 °C for 30 min to be homogenized and then cooled at

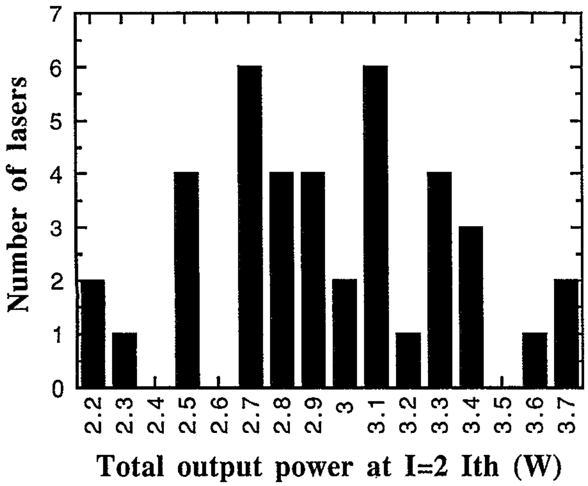

FIG. 3. Histogram of output power (at $I=2I_{th}$) distribution for the 40 1.55 μm high-power large optical cavity (LOC) lasers.

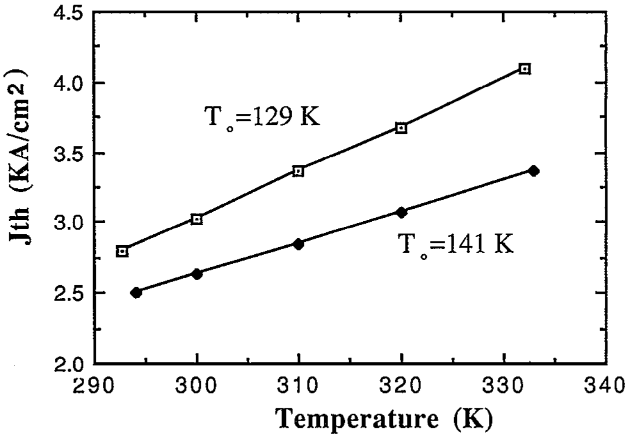

FIG. 4. Threshold current density as a function of temperature for the 1.55 μm high-power large optical cavity (LOC) lasers.

a cooling rate of 0.5 °C/min to grow various layers with the epitaxial growth schedule shown in Fig. 1. Six layers were successively grown: N-InP buffer layer (Te-doped, $N \approx 1 \times 10^{18}$ cm^{-3}, 3–4 μm); $In_{1-x'}Ga_{x'}As_{y'}P_{1-y'}$ waveguiding layer (undoped, 0.5–1.5 μm); $In_{1-x}Ga_xAs_yP_{1-y}$ active layer (undoped, 0.2–0.5 μm); $In_{1-x''}Ga_{x''}As_{y''}P_{1-y''}$ antimeltback layer (undoped, 0.1–0.2 μm); P-InP confinement layer (Zn-doped, $P \approx 2 \times 10^{18}$ cm^{-3}, 1–2 μm) and P^+-InGaAsP top layer (Zn-doped, $P \approx 2 \times 10^{19}$ cm^{-3}, 2–3 μm).

The broad area contact lasers were fabricated to evaluate their performances in pulsed operation. The laser cavity length was 350–400 μm and stripe width was 100–150 μm. The pulse width and repetition rate of the power supply were 200–250 ns and 5–10 Hz, respectively.

Figure 2 is a threshold current distribution histogram of 40 lasers from different wafers from which the threshold current for most lasers can be found to be within 1.6–2.1 A. There is a peak of about 2.0 A which corresponds to a current density of 2.7–3.5 kA/cm^2. Using an InGaAs detector as the receiving unit for 1.55 μm laser beam, the total output power of the above 40 lasers were measured at twice threshold current and the results are shown in Fig. 3. When drive current increases to 2.5 times the threshold current, some devices emit peak output power higher than 2 W per facet. The experiments on the temperature stability indicated that the 1.55 μm LOC lasers have their characteristic temperature of about 130–140 K (see Fig. 4).

We also experimentally observed and measured the aging process of the lasers. We kept the lasers running con-

TABLE I. Results of aging tests of three typical 1.55 μm high-power large optical cavity (LOC) lasers (at room temperature, duty cycle = 0.1%, and $I = 2\, I_{th}$).

No. of lasers	Peak power before test (W)	Dates of testing (day/month/year)	Operation hour (h)	Peak power after test (W)
0327A	2.44	28 Mar.–9 Jul., 90	2400	2.20
0414	2.56	16 Apr.–7 Jun., 90	1200	2.38
0503B	2.94	3 May–9 Jun., 90	1500	2.68

tinuously, day and night, at room temperature and at double the threshold current to observe and measure the declination in their output power for a long time. Table I shows the results of the experimental observation and measurement for the three typical lasers.

The experiments proved that a laser of this kind has not only the higher output power, but also the lower threshold current and good temperature stability and becomes an ideal source of light for some special needs in this spectral region.

[1] Y. Nakano, K. Takahei, Y. Noguchi, Y. Suzuki, H. Nagai, and K. Nawata, Electron. Lett. **17**, 782 (1981).

[2] M. Oron and N. Tamari, Appl. Phys. Lett. **42**, 139 (1983).

[3] K. Imanaka, H. Horikawa, A. Matoba, Y. Kawai, and M. Sakuta, Appl. Phys. Lett. **45**, 282 (1984).

[4] H. Horikawa, K. Imanaka, A. Matoba, Y. Kawai, and M. Sakuta, Appl. Phys. Lett. **45**, 328 (1984).

[5] W. T. Tsang, M. C. Wu, T. Tanbun-Ek, R. A. Logan, S. N. G. Chu, and A. M. Sergent, Appl. Phys. Lett. **57**, 2065 (1990).

[6] J. C. Zhong, B. R. Zhu, and R. H. Li, SPIE **1230**, 341 (1990).

[7] H. Yonezu, T. Yuasa, T. Shinohara, T. Kamejima, and I. Sakuma, Jpn. J. Appl. Phys. **15**, 2393 (1976).

[8] W. B. Joyce and R. W. Dixon, J. Appl. Phys. **46**, 855 (1975).

[9] S. Oshiba, A. Matoba, M. Kawahara, and Y. Kawai, IEEE J. Quantum Electron. **QE-23**, 738 (1987).

[10] N. Toyoda, M. Mihara, and T. Hara, J. Appl. Phys. **47**, 443 (1976).