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Near Diffraction Limit High-brightness 850 nm Tapered Laser Diodes

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Abstract: High-power high-brightness tapered laser diodes emitting at 850 nm have been manufactured, and the beam quality of near diffraction limit has been achieved. The beam propagation factor M^2 is only 1.7 and the high brightness is up to 16.3 MW · cm^{-2} · sr^{-1} when the output power is 200 mW, and the values change to 2.8 and 9.9 MW · cm^{-2} · sr^{-1} under 1 W output. The electro-optical properties of tapered lasers are discussed. We have also studied the influence of tapered section length on output power. The results reported in this paper may become a step forward to new applications of tapered laser diodes.

Key words: 850 nm; tapered laser diode; high brightness; the beam propagation factor M^2
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1 Introduction

Laser diodes operating at 850 nm have attracted much attention for the properties of small size, high conversion efficiency, high reliability and low costs, which make it one of the ideal light sources for communication system. Especially, because it has a slight red exposure, it could be used for military applications in laser radar, laser ranging and laser guide [1-5] directly or indirectly. In any case, the high brightness of 850 nm laser diode, which combines high output power and high beam quality is necessary.

Taking the demands of high brightness into consideration, tapered laser diode, which combined a ridge waveguide (RW) with a tapered gain region, is a promising concept for nearly diffraction-limited beam quality at high output power [6-7]. The technique compatibility of the tapered laser with broad area (BA) laser makes the technology simple and the cost of the fabrication process moderate. Some tapered lasers at different wavelengths and with different structures have been reported. The 808 nm GaAsP/AlGaAs tapered lasers have been made with a nearly diffraction limited beam quality of $M^2 = 2.6$ at 9 W [6]. The InGaAs/AlGaAs tapered lasers at 976 nm with $M^2 = 1.6$ at 8.3 W have been achieved [7]. But, the feasibility of different tapered structures applying to 850 nm lasers and the properties of the lasers have not been studied.

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In this paper, 850 nm tapered diode lasers based on an AlGaInAs/AlGaAs chip with different RW lengths were fabricated. The properties of tapered lasers such as the power, spectra, far-field distribution and brightness at different power levels were studied, and the nearly diffraction-limited beam quality has been achieved.

2 Laser Structure

Fig. 1 is the schematic diagram of the tapered laser with cavity-spoiling grooves. The AlGaInAs/A1GaAs chip grown by low-pressure metal-organic chemical vapor deposition epitaxy (MOCVD) was used to fabricate the 850 nm tapered lasers. The major part of the chip is an AlGaInAs/AlGaAs graded-index waveguide separate confinement heterostructure strained quantum well (GRIN-SCH SQW). The concrete parameters of each layer are listed in Table 1. To characterize the performance of the chip, a stripe of 1 000 μm long, 150 μm width BA laser was fabricated, the threshold current density of which is 233.3 A/cm^2, while the full width at half maximum (FWHM) of the vertical far field angle is only 35° under a continuous wave (CW) current injection at 20 ℃. The results above reveal that the structure is suitable for manufacturing the high-power 850 nm lasers.

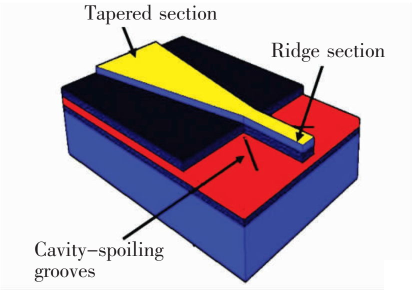

Fig. 1 Schematic diagram of the tapered laser with cavity-spoiling grooves

Table 1 The thickness and component of AlGaInAs/A1GaAs GRIN-SCH SQW epitaxial layers

Layer	Material	Mole fraction	Thickness/μm	CV level/cm^{-3}
11	GaAs		0.2	$N_p > 2E19$
10	Al_xGaAs	0.55 ~ 0.05	0.05	$N_p = 1E18$
9	Al_xGaAs	0.55	1.2	$N_p = 4E17 \sim 1E18$
8	Al_xGaAs	0.25 ~ 0.55	0.15	$N_p = 2E17$
7	Al_xGaAs	0.16	0.01	barrier
6	$(Al_xGa)InyAs$	0.13, 0.14	0.007	well
5	Al_xGaAs	0.16	0.01	barrier
4	Al_xGaAs	0.55 ~ 0.25	0.15	$N_n = 1E18 \sim 1E17$
3	Al_xGaAs	0.55	1.2	$N_n = 1E18$
2	Al_xGaAs	0.05 ~ 0.55	0.05	$N_n = 1E18 \sim 2E18$
1	GaAs		0.3	$N_n = 2E18$

To obtain a high power and single mode output, we had designed the geometric parameters of the RW section and the tapered section of 850 nm tapered lasers. First, the stripe width and corrosion depth of ridge waveguide should follow the first-order mode cut-off condition[8]. Second, for the tapered region to efficiently magnify optical power, the first-order mode should propagate adiabatically through the device without mode conversion. The full tapered angle is generally less than 6°[6-7,9]. Thus, the tapered lasers with 850 nm were fabricated in experiment with the cavity length of 2 500 μm and the width of 300 μm. The RW section is 3 μm wide, the left cladding thickness of the both sides of RW is 0.15 μm, meanwhile the full taper angle of the tapered sections is 4°.

3 Results and Discussion

The tapered lasers with different lengths of RW sections have been fabricated. The RW section are deeply etched and the lengths of which are 750, 1 000, 1 250 μm, respectively. The schematic top view of the lasers is shown in Fig. 2. The cavity-spoiling grooves were set on both side of the ridge section to prevent laser oscillation[10]. Tri-layer Ti/Pt/Au and Au/Ge/Ni contacts were evaporated onto

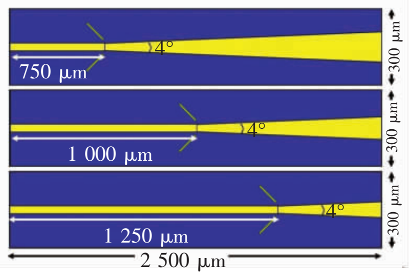

Fig. 2 Schematic top view of the tapered lasers with different RW section lengths

the p-side and n-side acting as electrodes, respectively.

In order to investigate the RW section length effect on the performance of the lasers, the power-current characteristics of tapered lasers with different length of RW section were measured at 20 ℃ under pulsed condition (50 μs, 100 Hz), and the results are shown in Fig. 3 (a). It indicates that the power-current curves for the lasers are similar to each other when the current is below 0.8 A, and the threshold current of the three devices are very close. The length of the RW section has little effect on the threshold current. But when the current increases continuously, the power-current curves of the lasers with 1 250 μm and 1 000 μm long RW section show a kink at 0.8 A and 1.5 A, and a sharp decrease at 2.5 A and 3.2 A in sequence. It can be deduced that the first kink comes from the filament and even self-focusing, and the later one from the catastrophic optical mirror damage (COD). Although a kink occurs in the curve of the laser with 750 μm RW section when the current is around 2.5 A, no COD happens even at the current of 4 A while the power reaches 870 mW. It is clear that the shorter the tapered section is, the smaller of the area injection current is. So, under the same current, the laser with shorter tapered section has a higher current density, which make it easy to cause filament and self-focusing[11]. And the laser with shorter RW section possess longer tapered length, which provide a wider emitting area for the same output power, and the wider emitting area could decrease the power density and low the rate of COD. In other words, longer tapered section laser could realize higher power output.

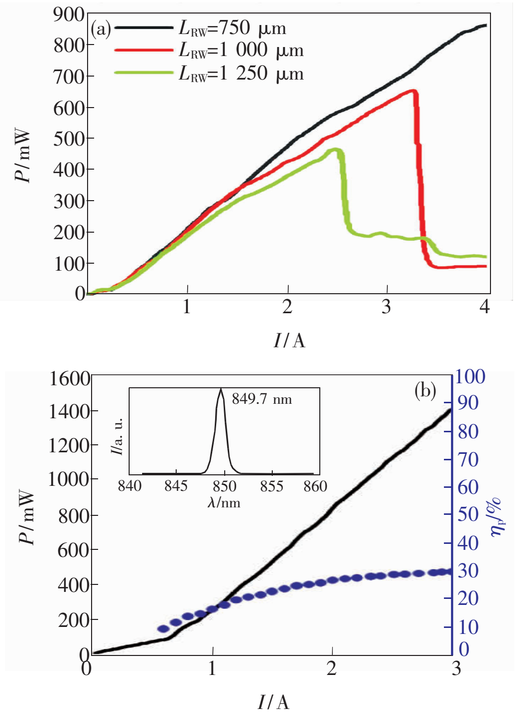

Fig. 3 (a) The power-current characteristics of the tapered lasers with different RW section lengths; (b) The power and conversion efficiency characteristics of the 850 nm tapered laser with 750 μm RW section in dependence of the injection current, the inset showed the optical spectrum of the tapered laser at 1 W output.

So the laser with 750 μm RW section was used to investigate the electro-optical properties of the this laser. To improve the performance, antireflection ($R_f = 5\%$) and high-reflection layer ($R_r = 98\%$) were coated onto the front and rear facet, respectively.

Fig. 3 (b) showed the power-current characteristics and the conversion efficiency of the laser under pulsed (50 μs, 100 Hz) condition at 20 ℃. The threshold current density of the laser is 490.2 A/cm^2, the slope efficiency is 0.58 W/A and the conversion efficiency is 30% when the output power is 1.40 W. The optical spectrum taken at 1 W output power is exhibited inset of Fig. 3(b). As shown in the figure, the peak is located at 849.7 nm and the FWHM is only 1 nm. This indicate the tapered laser could realize 850 nm high-power lasing output.

To further investigate the beam quality of the laser, the far field profiles, the beam propagation factor M^2 and the brightness at different power levels were determined using the moving knife-edge method

(Standard ISO/TR 11146-3) in CW mode at 20 ℃. Fig. 4 showed the lateral far-field divergence angles of 850 nm tapered diode lasers. The profile obviously changed with the output power. The divergence angle increased from 2.7° at 200 mW to 4.0° at 1 000 mW, meanwhile a shoulder emerged and strengthened with the increasing injection current, which could be attributed to the existence of the higher order mode.

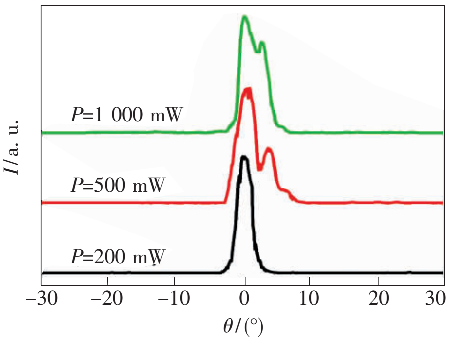

Fig. 4 The far field profiles of the 850 nm laser diode with 750 μm RW section at different output powers in CW mode at 20 ℃

By moving knife-edge, we can get the beam radius *W* along the direction of light propagation *Z*. So the waist radius W_0, and the waist position Z_0 could be achieved by the Gauss fitting of *W* and *Z*. The slope of the Gaussian curve is the far-field divergence θ. Beam propagation factor M^2 is the product of the beam waist radius W_0 and far-field divergence θ normalized by the ideal Gaussian beam with the same wavelength λ. The single-model TEM_{00} Gaussian beam ($W_{00}\theta_{00} = \lambda\pi$) of $M^2 = 1$ is the perfect laser beam, and the higher values of M^2 factors indicate the poorer quality of laser beams. The M^2 factor and the brightness B were shown in Eq. (1) and Eq. (2)[6-7].

$$M^2 = \frac{W_0\theta}{\lambda/\pi}, \tag{1}$$

$$B = \frac{P}{\lambda^2 \cdot M^2}, \tag{2}$$

The calculated beam propagation factor M^2 and the brightness of this laser diode in dependence of the output power were plotted in Fig. 5. When the output power is 200 mW, M^2 is as low as 1.7 which means the beam quality is near the diffraction-limit, meanwhile the brightness reached 16.3 $\mathrm{MW \cdot cm^{-2} \cdot sr^{-1}}$. The M^2 factor is 2.2 and the brightness is 12.6 $\mathrm{MW \cdot cm^{-2} \cdot sr^{-1}}$ at the power of 500 mW. Although, the M^2 increases and brightness decreases when the output power grows, the brightness still reaches 9.9 $\mathrm{MW \cdot cm^{-2} \cdot sr^{-1}}$ at 1 W output while the M^2 is up to 2.8. So we got the high brightness 850 nm tapered laser.

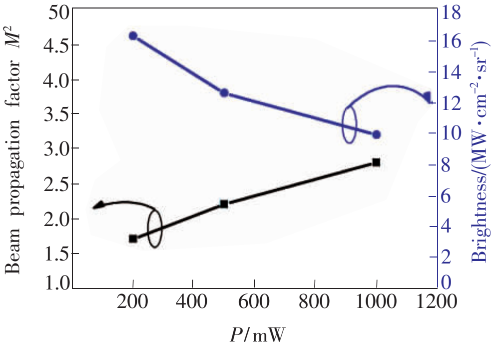

Fig. 5 Beam propagation factor M^2 and brightness of the 850 nm laser diode with 750 μm RW section in dependence of the output power in CW mode at 20 ℃

4 Conclusion

In summary, the high-power 850 nm tapered laser with nearly diffraction-limited beam quality is obtained. The beam propagation factor M^2 is only 1.7 and the high brightness is 16.3 $\mathrm{MW \cdot cm^{-2} \cdot sr^{-1}}$ when the output power is 200 mW. The M^2 factor and brightness of the laser could keep at 2.8 and 9.9 $\mathrm{MW \cdot cm^{-2} \cdot sr^{-1}}$ while the output power is 1 W. It has been proved that the laser with shorter RW section would have better performance also. This work may be the step for new applications of tapered diode lasers on 850 nm.

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850 nm 高亮度近衍射极限锥形半导体激光器

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摘要: 制备了具有低红暴优势的850 nm大功率高亮度锥形半导体激光器,获得了近衍射极限的激光输出。当连续输出功率为200 mW时,光束质量因子 M^2 仅为1.7,亮度高达16.3 MW·cm^{-2}·sr^{-1};当功率提高到1 W时,M^2 因子和亮度仍分别达到2.8和9.9 MW·cm^{-2}·sr^{-1}。此外,研究了锥形激光器的功率、光谱、远场分布等特性,并分析了不同脊形波导长度对锥形激光器自聚焦现象的影响。

关 键 词: 850 nm; 锥形激光器; 高亮度; 光束质量因子 M^2

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