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A Single Mode 980nm InGaAs/GaAs/AlGaAs Large Optical Cavity Quantum Well Laser with Low Vertical Divergence Angle*

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Abstract: To achieve high optical power as well as low vertical divergence angle, a new kind of optimized large optical cavity (LOC) structure is applied to a ridge waveguide 980nm InGaAs/GaAs/AlGaAs multi-quantum well laser. The optical power density in the waveguide is successfully reduced. The maximum output power is more than 400mW with a slope efficiency of 0.89W/A and the far-field vertical divergence angle is lowered to 23°.

Key words: semiconductor laser; quantum well; large optical cavity; waveguide; ridge waveguide
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1 Introduction

980nm single lateral mode InGaAs/GaAs/AlGaAs quantum well lasers have attracted intense attention as pumping sources for the erbium-doped fiber amplifiers (EDFA). We hope pumping lasers emitting more power to get sufficient gain in EDFA and smaller vertical beam divergence angle which improve the optical coupling efficiency from laser chip to fiber. These two characteristics are also very important for other diode lasers used as light sources for optical communication, optical storage and so on. We have finished several studies to achieve high efficiency 980nm laser diode[1,2]. But there are still many restriction to obtain higher output power, one of them is the catastrophic optical damage (COD) of laser cavity under high power operation. By using LOC structure, the optical power density in the waveguide can be reduced and higher output power can be obtained under the same COD level. Meanwhile, the vertical beam divergence angle can also be reduced by optimizing the LOC structure properly[3,4]. We have demonstrated a new kind of LOC structure in high power broad stripe 980nm InGaAs/AlGaAs/GaAs[5] and Al-free active region lasers[6]. In this paper, we report a newly optimized LOC single lateral mode 980nm InGaAs/GaAs/AlGaAs ridge waveguide laser with narrow vertical divergence angle and high power. The full width half maximum (FWHM) of vertical divergence angle was reduced to 23° and the maximum output power reached as high as 400mW with a sufficient high slope efficiency of 0.89W/A, which showed good material property.

2 Device structure

The refractive index distribution and theoreti-

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cal optical field distribution of the LOC waveguide are shown in Fig. 1. The main difference between this LOC structure and conventional single quantum well (SQW) structure is that two waveguide layers W and J between the quantum barrier and one of the cladding layers were added. The function of these two layers is to widen the optical distribution peak so that the optical power density in the waveguide and the far-field divergence angle can be reduced. To obtain the best result, i. e., the width of the optical distribution peak is as large as possible, the whole structure must be designed carefully to form a flat-top optical distribution in the center of the waveguide (see Fig. 1), which means the effective refractive index of the guided mode (N_{eff}) should be equal or very near to the refractive index of layers W (N_w). Under this condition, the transverse light propagation coefficient in layer W will be zero or near to zero and the optical power density in this layer is nearly constant.

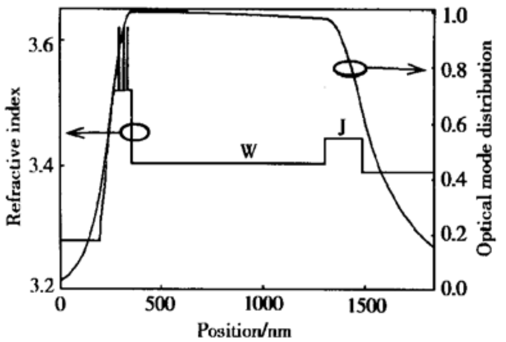

Fig. 1 Refractive index and optical mode distributions of the LOC structure

When the optical distribution becomes wider, the confinement factor becomes smaller. So we increase the number of quantum well to obtain sufficient gains. As a consequence, transparent current density will increase. Because the mobility of electron is much larger than that of hole in GaAs/AlGaAs materials, layers W and J are put at n-side in the waveguide. In order to reduce the absorption of free carriers, the optical field should decay quickly in upper cladding layer. We accomplish it by adopting high Al fraction AlGaAs material as p-cladding layer. There are also some other advantages of high Al-fraction upper cladding layer: the leakage of electrons is suppressed and the p-cladding layer can be thinner[7]. Thinner p-cladding layer will reduce not only heat resistance with p-side down configuration, but also threshold current in ridge waveguide structure, which will be discussed below. When the general structure of the LOC waveguide is determined, we can adjust N_{eff} to N_w by changing the Al fraction and thickness of layer J slightly. It should be noticed that the difference of Al fraction between layers W and J is not too much large in order to reduce the barrier effect on electronic transportation. The flat-top optical distribution in W is very sensitive to N_{eff} because the deviation of N_{eff} by 10^{-3} order can severely change the distribution, as well as the vertical divergence angle. This means the material growth must be controlled precisely.

The thickness of layer W is important. If it is increased, the vertical divergence angle (θ) of output light will decrease. But the confinement factor will decrease simultaneously, which means higher threshold current density (J_{th}). A proper thickness of layer W should be chosen to compromise θ and J_{th}. Theoretical results of far-field optical pattern are shown in Fig. 2, which gives a FWHM value of 22.7° when the thickness of layer W is 800nm. The confinement factor is 1.55%.

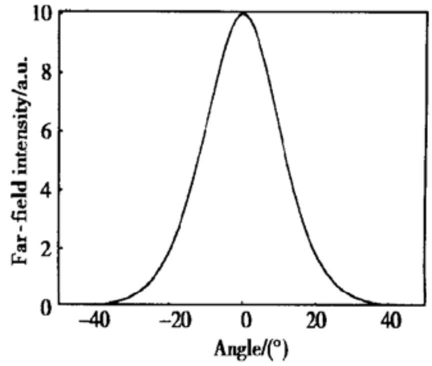

Fig. 2 Calculated vertical far-field pattern

The laser has a structure of ridge waveguide, which is formed by means of wet etching. One of the most important structure parameters of a ridge waveguide laser is the residual thickness of upper cladding layer at both sides of the ridge. To reduce lateral current diffusion, we should etch the upper cladding layer as deep as possible, i. e., the residual thickness of upper cladding layer should be small enough. But in a conventional ridge waveguide laser, if the residual thickness is too small, the lateral difference of N_{eff} will be large enough to allow high order lateral mode. In the newly optimized LOC structure, since the Al fraction in upper cladding layer is much higher than that of other layers, the optical field decays fast in it. This means that the upper cladding layer has relatively small contribution to N_{eff}, therefore, N_{eff} is not sensitive to the residual thickness. Then the residual thickness of upper cladding layer can be smaller than conventional ones with same N_{eff} difference and at the same time the lateral current diffusion is suppressed sufficiently. To control the etching depth precisely, we inserted an InGaAsP etching-stop layer in upper cladding layer.

3 Device fabrication and performance

The laser was grown by metalorganic chemical vapor deposition (MOCVD). The LOC structure consists of a 0.2μm n-GaAs buffer layer, a Si-doped 1.5μm n-$Al_{0.25}Ga_{0.75}As$ lower cladding layer, a 180nm $Al_{0.16}Ga_{0.84}As$ layer, a 0.8μm undoped $Al_{0.225}Ga_{0.775}As$ layer, three $In_{0.2}Ga_{0.8}As$ strained quantum wells with GaAs barriers, a 70nm undoped $Al_xGa_{1-x}As$ graded index (GRIN) waveguide layer, where x changed from 0 to 0.41, a Zn-doped 1.23μm p-$Al_{0.45}Ga_{0.55}As$ upper cladding layer and a 0.2μm p^+-GaAs layer for Ohmic contact. In upper cladding layer, an InGaAsP (E_g = 1.61eV) etching stop layer was inserted 30nm above the GRIN layer. After material growth, ridge waveguide with 4μm stripe width was formed by standard photolithography and wet chemical etching. SiO_2 was deposited as insulating layer as well as defined the metal contact stripe. After deposition of TiPtAu as p-electrode, the wafer was thinned to 100μm, then n-electrode was deposited by using AuGeNi/Au. The wafer was cleaved to bars. The cavity length was 600μm. HR and AR film was deposited on each facet of the bar by electron cyclotron resonance chemical vapor deposition (ECR-CVD). The reflectivities are 95% and 5%, respectively. After being cleaved, the chips were mounted on copper heatsinks with the configuration of p-side down.

Figure 3 gives the power-current, voltage-current characteristics, far-field pattern and emission spectrum measured under CW condition at room temperature. The threshold current is 44mA and the serial resistance is 1.24Ω. The maximum output power exceeds 400mW. The slope efficiency is 0.89W/A, which remains relatively high value compared with previously published result[5]. This result indicates that the material property is very good so that the photon loss and nonradiation recombination are very small in the waveguide, especially in layer W where the optical intensity is very large. The FWHM of divergence angle vertical to the junction plane is 23°, which is correspondent to the theoretical result and less than that of the conventional ones whose typical FWHM is larger than 30°[1]. The FWHM angle parallel to the junction plane is 8.3°. As a return of the characteristics of high power and small divergence angle, the threshold current is several times larger than that of the conventional SQW lasers, whose typical value are 10~20mA.

4 Conclusion

We demonstrated a single lateral mode 980nm InGaAs/GaAs/AlGaAs ridge waveguide laser with new LOC structure. The output light power exceeded 400mW and the FWHM of vertical divergence angle was reduced to 23°. The slope efficiency was 0.89W/A.

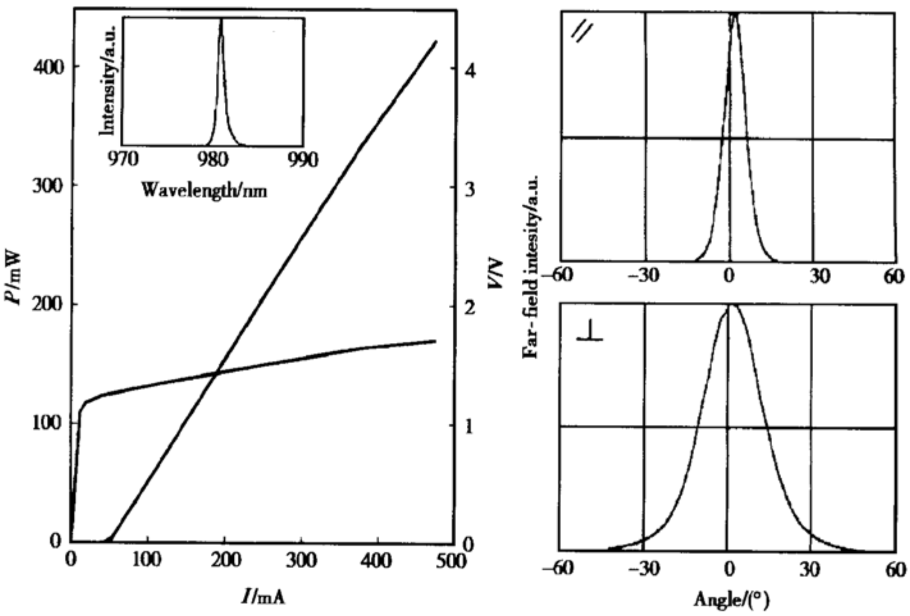

Fig. 3　Measured P-I, V-I curve, far-field pattern and emission spectra

References

[1] Xu Zuntu, Yang Guowen, Xu Junying, et al. High power conversion efficiency InGaAs/GaAs/AlGaAs strained layer quantum well lasers grown by MBE. Chinese Journal of Semiconductors, 1999, 20(3): 194(in Chinese) [徐遵图, 杨国文, 徐俊英, 等. MBE 生长高光功率转换效率 InGaAs/GaAs/AlGaAs 应变量子阱激光器. 半导体学报, 1999, 20(3): 194]

[2] Xu Zuntu, Yang Guowen, Zhang Jingming, et al. High efficiency Al-free 980nm InGaAs/InGaAsP/InGaP strained quantum well lasers. Chinese Journal of Semiconductors. 2000, 21(5): 417

[3] Dutta N K, Lopata J, Berger P R, et al. Performance characteristics of GaInAs/GaAs large optical cavity quantum well lasers. Electron Lett, 1991, 27(8): 680

[4] Temmyo J, Sugo M. Design of high-power strained InGaAs/AlGaAs quantum-well lasers with a vertical divergence angel of 18°. Electron Lett, 1995, 31(8): 642

[5] Zhang Jingming, Xu Zuntu, Ma Xiaoyu, et al. Novel high power quantum well lasers with integrated passive waveguide. Chinese Journal of Semiconductors, 1999, 20(10): 926

[6] Xu Z T, Zhang J M, Ma X Y, et al. High-efficiency low-vertical-divergence-angle 980nm Al-free active region lasers with novel large optical cavity and asymmetrical cladding layer. In: Plane Semiconductor Lasers IV, Proc SPIE, 2000, 3947: 66

[7] Yang Guowen, Xu Junying, Xu Zuntu, et al. Theoretical investigation on quantum well lasers with extremely low vertical divergence and low threshold current. J Appl Phys, 1998, 83(1): 8

小垂直发散角大光腔980nm单模InGaAs/GaAs/AlGaAs量子阱激光器*

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摘要: 通过采用经过优化的新型大光腔结构, 脊形波导980nm单模InGaAs/GaAs/AlGaAs多量子阱半导体激光器在保持大功率光输出的同时获得了较小的垂直发散角. 结果表明波导中的光功率密度可以降低, 获得了大于400mW、斜率效率0.89W/A的输出光功率, 垂直方向远场发散角也降低到23°.

关键词: 半导体激光器; 量子阱; 大光腔; 波导; 脊形波导

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