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1.3μm AlInGaAs Strained Single Quantum Well Laser Diodes with High Characteristic Temperature of 200K

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Abstract: A high characteristic temperature (T_0) of 200K from a 1.3μm AlInGaAs/AlInAs single-quantum-well laser diode with the asymmetric waveguide layer structure under CW operation at 20 to 80℃ was obtained, which is the best result reported in the laser diodes (LDs) of the same active materials structure and emitting wavelength. AlInGaAs as an active layer, therefore, is very promising for the fabrication of long-wavelength LDs with excellent high-temperature performance. It is found that the asymmetric waveguide layer structure can decrease optical absorption and improve the high-temperature performance and catastrophic optical damage threshold of LDs.

Key words: semiconductor LDs; AlInGaAs; characteristic temperature; threshold current; asymmetric waveguide layer

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1　Introduction

InGaAsP was used as the active layer of the semiconductor LDs applied to optical communications for a long time. However, poor temperature stability and a low characteristic temperature (about 60K) of the InGaAsP material seriously restrict the application of LDs operated at high temperatures. The additional cooling unit results in an increase in the seal cost and makes the stability of LDs worse. Poor stability primarily results from the smaller energy band split between the active layer and the barrier layer, leading to weaker confinement of the electrons and an increase in nonradiative recombination. Recently, in order to improve the temperature performance of LDs, different materials for the active layer were investigated, including the quaternary-system[1,2] of AlGaInAs and InGaAsN, which have a larger energy band split[3], leading to better carrier confinement and temperature performance. In this paper, using AlGaInAs as the active layer of compressive strained LDs, we optimize the design of an asymmetric waveguide layer structure and grow the structure by molecular beam epitaxy (MBE). Finally, 1.3μm laser diodes with a higher characteristic temperature are obtained.

2　Structure

Characteristic temperature (T_0) shows the dependence of semiconductor LDs on the temperature. The higher the T_0 value, the weaker the dependence of LDs on temperature becomes[4]. Thus, LDs with higher T_0 can operate under high temperature and high power. Usually, the main factors affecting the T_0 values are as follows[5,6]:

First is the loss of the carriers resulting from nonradiative Auger recombination. Second is the barrier leakage, namely, the carriers in the active layer leak into the cladding layer, climbing the barrier of the heterojunction. Third is the optical losses resulting from the valence bands. The last is the nonradiative recombination resulting from the interface and the defects.

Thus, according to the theory of quantum-well LDs, the device structure is optimally designed. The active layer uses the quaternary-system of $Al_xIn_{1-x-y}Ga_yAs$ for the following reasons.

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Table 1　Detailed structure of 1.3μm AlGaInAs laser diodes

Layer	Name	Material	Thickness/μm
10	Ohmic contact layer	p-InP	0.3
9	Top-confining layer	p-$Al_{0.7}In_{0.3}As$	0.6
8	Top-waveguide layer	$Al_{0.55}In_{0.45}As$	0.07
		$Al_{0.5}In_{0.5}As$	0.03
7	Barrier layer	$Al_{0.47}In_{0.53}As$	0.02
6	Active layer	$Al_{0.15}Ga_{0.19}In_{0.66}As$	0.01
5	Barrier layer	$Al_{0.47}In_{0.53}As$	0.02
4	Bottom-waveguide layer	$Al_{0.5}In_{0.5}As$	0.1
3	Bottom-confining layer	n-$Al_{0.7}In_{0.3}As$	0.6
2	Transition layer	n-$Al_{0.1\sim0.7}In_{0.9\sim0.3}As$	0.2
1	Buffer layer	n-InP	1.0
	Substrate	n-InP	

First, $Al_xIn_{1-x-y}Ga_yAs$ has a wide bandgap, in which the Auger recombination rate and the transition probability of the spin-obit split band to the heavy hole band are smaller than that of the narrow bandgap, in favor of an increased T_0 value. Second, the energy band split of the $Al_xIn_{1-x-y}Ga_yAs$ material, $\Delta E_c/\Delta E_g$, is larger. It was reported[3] that the $\Delta E_c/\Delta E_g$ of $0.47 \sim 0.7$ in the $Al_xIn_{1-x-y}Ga_yAs$ material better restricts the carrier leakage. For the AlGaInAs/InGaAs LDs, the $\Delta E_c/\Delta E_g$ is over 0.5[7] (emitting wavelength of 1.3μm), and T_0 is up to 140K at the wavelength of 1.2μm[8]. For the InAsP/InP LDs, the $\Delta E_c/\Delta E_g$ is over 0.48 (emitting wavelength of 1.3μm), and T_0 is up to 143K at the wavelength of 1.3μm[9].

In this work, the $\Delta E_c/\Delta E_g$ of AlGaInAs/AlInAs is designed to be 0.55, and the asymmetric waveguide layer structure is used to make the peak value of light intensity deflect from the quantum well, so the optical absorption of the carriers in the well is decreased, the threshold current is slowly increased with the temperature, and the T_0 of the LDs is further improved.

The detailed structure of 1.3μm AlGaInAs/AlGaAs strained quantum well LDs with asymmetric waveguide layer structure is shown in Table 1. The asymmetric waveguide layer structure appears in layers No.4 and No.8. The top-waveguide layer is different from the bottom-waveguide layer of $Al_{0.5}In_{0.5}As$ with 0.1μm thickness, which is made up of 0.3μm $Al_{0.5}In_{0.5}As$ and 0.7μm $Al_{0.55}In_{0.45}As$.

3 Fabrication and characterization

Based on the structure shown in Table 1, the LD was first grown on n-InP substrate by MBE. The photoluminescence (PL) spectrum of the LD after growth was tested at room temperature by using a 15mW Ar^+ laser (514.2nm). The PL spectrum is shown in Fig. 1. The LDs were then fabricated using the 5μm width of the carrier injecting area and the 500μm cavity length. In order to decrease the losses of cavity surface, 10% of the antireflection film and 95% of the high reflection film were coated on the front and the backside of the cavity, respectively. For comparison with the effect of asymmetric waveguide layer structure on performance of LDs, a symmetric waveguide layer structure of 1.3μm AlGaInAs/AlGaAs strained quantum well LDs was also fabricated.

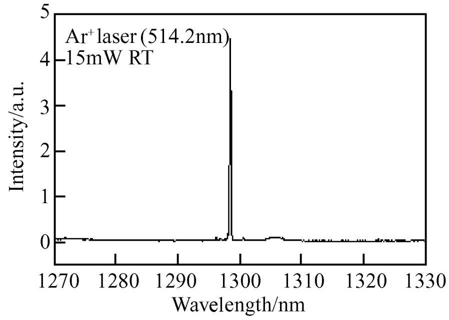

Fig. 1　PL spectrum of a AlGaInAs/AlInAs SQW laser

Subsequently, the chip bar after coating was cleaved to the LD unit with a width of 100μm, and then packaged. Finally, the output power and the spectrum curve of the LDs at 20℃ are shown in Fig. 2. The dashed curve indicates the symmetric waveguide LDs, and the real line indicates the asymmetric waveguide LDs. From Fig. 2, the threshold current and slope efficiency of the symmetric and asymmetric waveguide LDs are almost the same. At 20℃, the threshold current is 31mA, the threshold current density is 1.24kA/cm^2, and the slope efficiency is 0.7W/A. But the COD threshold value of the asymmetric waveguide LDs (55mW) is around 10% higher than that of the symmetric waveguide LDs. The reason is that the asymmetry waveguide layer structure can effectively decrease the absorption of the active layer, improving high-temperature performance and the COD threshold value of the LDs. The spectrum curve shows that the peak light intensity of the asymmetric waveguide LDs is slanting from the center of the horizontal and vertical direction,

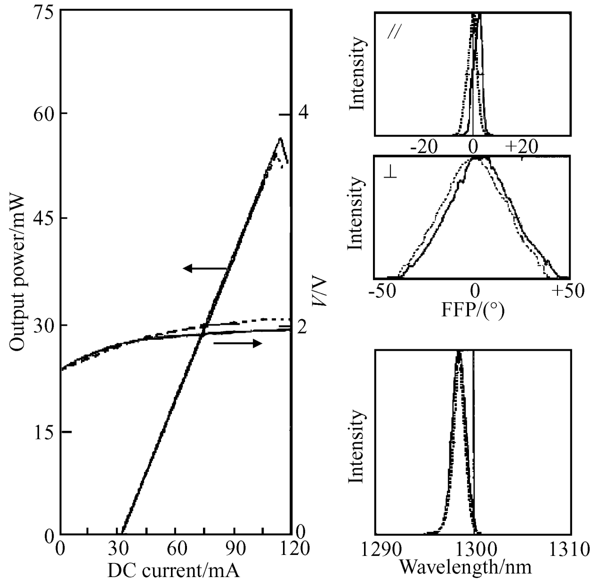

Fig. 2 Output characteristics curves of AlInGaAs/AlInAs LDs at 20℃ Dashed curve shows symmetric wave-guide LDs, and the real curve shows asymmetric wave-guide LDs.

which is just under the function of the asymmetric waveguide LDs. For the two kinds of the waveguide structures, the emitting wavelength is almost the same, around 1298nm (near 1300nm).

Figure 3 shows the temperature dependence on the threshold current. At the range of 20～80℃, the threshold current of the LDs increases from 31 to 41.8mA, and the threshold current density increases from 1.24kA/cm^2 at 20℃ to 1.67kA/cm^2 at 80℃. According to the threshold current as a function of temperature[10], the T_0 is calculated to be about 200K in the temperature range of 20～80℃, which is the best result reported in 1.3μm AlGaInAs LDs and is higher than the theoretically predicted value of 180K. In the

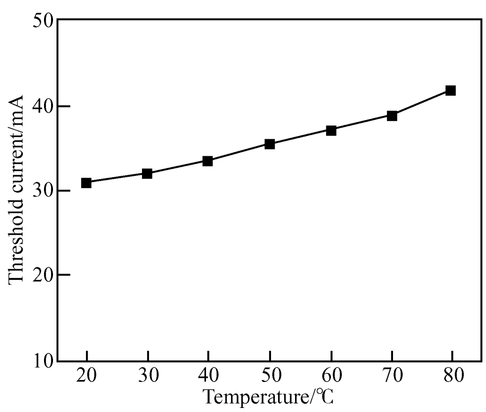

Fig.3 Temperature dependence of threshold current

theoretical calculation, the intrinsic value of T_0 was defined as 180K when electrons are perfectly confined in the well layer. The intrinsic value can exceed 200K, though, possibly because of the suppression of both the Auger-recombination process and the inter-valence-band absorption[11]. For example, a T_0 of over 200K has also been reported for a GaInAs laser[12]. Thus, the T_0 of 200K we obtained in an AlGaInAs laser is also conceivable. Due to lower threshold current density and smaller nonradiative recombination, a higher T_0 should be obtained by improving the crystalline quality of the growth.

4 Conclusions

By using a compressive strained AlGaInAs material with wide bandgap as an active layer instead of traditional InGaAsP material, the confining carrier ability was improved. The waveguide structure was optimized by adopting the asymmetric waveguide layer to decrease the optical losses of the cavity surface. The 1.3μm AlGaInAs/AlInAs single-quantum-well LDs with the lower threshold current and the higher T_0 were grown by MBE. The T_0 was 200K under CW operation at 20 to 80℃. The asymmetric waveguide layer structure decreased the losses of the cavity surface and the COD value of the LDs was 55mW. It was shown that AlGaInAs is the ideal material for the long-wavelength LDs applied to the optical communication, and operates with better stability at high temperatures.

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200K 高特征温度的 1.3μm AlInGaAs 应变单量子阱激光器

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摘要: 在 20～80℃范围内连续工作条件下,非对称波导层结构的 1.3μm AlInGaAs/AlInAs 单量子阱激光器的特征温度为 200K,这是目前国内报道的相同有源材料、相同发射波长的激光器中最高的特征温度值.因此 AlInGaAs 是长波长光纤激光器的理想有源区材料.研究表明非对称波导结构能降低光吸收,提高激光器的高温特性和 COD 阈值.

关键词: 半导体激光器; AlInGaAs; 特征温度; 阈值电流; 非对称波导层

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