AlInGaAs/AlGaAs/GaAs strained quantum well lasers with high characteristic temperature

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The correlation between the gain material and the factors affecting characteristic temperature in high-power semiconductor lasers is comprehensively considered, and the AlInGaAs is adopted as the active area material. The AlInGaAs/AlGaAs/GaAs strained quantum well laser is designed and the whole structure of the device is given. Its highest operation temperature is 100 °C and the characteristic temperature is up to about 200 K when the temperature is within 20−40 °C. The output power is over 1 W at room temperature, and the lowest threshold current density is 126 A/cm^2.

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Semiconductor laser possesses many advantages such as compact size, light weight, simple modulation, and long lifetime[1,2], and is widely applied to military and civil affairs. But in the operation of semiconductor laser, the injected current will raise the temperature of the device, decrease its work efficiency, cause wavelength shift and shorten its longevity. How to decrease semiconductor lasers temperature sensitivity has been a region that people pay much attention to. The relation between working performance and temperature for semiconductor laser can be calculated as[3]

$$I_{\mathrm{th}}(T) = I_{\mathrm{th}}(T_1)\exp\left(\frac{T-T_{\mathrm{r}}}{T_0}\right) \qquad (1)$$

where T and T_1 represent different temperatures, $I_{\mathrm{th}}(T)$ and $I_{\mathrm{th}}(T_1)$ refer to the corresponding threshold currents at T and T_1 respectively, and T_0 is the characteristic temperature. Equation (1) indicates that the higher T_0 is, the smaller the $I_{\mathrm{th}}(T)$ temperature sensitivity is, i.e., its temperature stability is better. The T_0 value is related to material and structure of devices. So suitable material and structure should be considered carefully in order to increase T_0 value and improve laser temperature characteristics.

The factors affecting T_0 value are known as follows: laser active region bandgap, active region carrier leakage, Auger recombination probability, and intervalence band absorption. To design high T_0 value lasers, it is necessary to find out the relation between the above four factors and material and structure of semiconductor laser. In the experiment $\mathrm{Al}_x\mathrm{In}_{1-x-y}\mathrm{Ga}_y\mathrm{As}$ is chosen as the active layer. The reason is that it has a wide bandgap, and its Auger recombination probability and intervalence band absorption are smaller than narrow bandgap materials, which are in favor of heightening T_0 value. Meanwhile, its band offset is large, 0.47−0.7[4], and means better electron confinement, which can improve the temperature stability.

At last, by comprehensively considering the above factors, we have designed the high T_0 value laser with structure, shown in Table 1.

We grow the above structure with molecular beam epitaxy (MBE) method, and then evaporate $\mathrm{SiO_2}$ film with 100-nm-thick chips which are as insulate layer on the grown extension. The P-type electrode (width of 150 μm) is formed by standard eroding and selectivity etching[5]. Then the Ti/Pt/Au structure is sputtered to form P-type facet ohmic contact electrode. N-type facet is lapped to 100 μm with chemistry means and the Au/Ge/Ni

Table 1. Strained Quantum Well Laser Structure

Layer	Name	Material	Thickness (μm)	Doping (cm^{-3})
	Substrate	N-GaAs		
1	Buffer Layer	N-GaAs	1.0	Si, $\sim 1.0\times10^{18}$
2	Transition Layer	N-$\mathrm{Al_{0.3}Ga_{0.6}As}$	0.2	Si, $\sim 1.0\times10^{18}$
3	Bottom-Confining Layer	N-$\mathrm{Al_{0.7}Ga_{0.3}As}$	1.6	Si, $\sim 1.0\times10^{18}$
4	Bottom-Waveguide Layer	$\mathrm{Al_{0.5}Ga_{0.5}As}$	0.1	–
5	Base Layer	$\mathrm{Al_{0.4}Ga_{0.6}As}$	0.02	–
6	Active Layer	$\mathrm{Al_{0.23}In_{0.18}Ga_{0.59}As}$	0.01	–
7	Base Layer	$\mathrm{Al_{0.4}Ga_{0.6}As}$	0.02	–
8	Top-Waveguide Layer	$\mathrm{Al_{0.5}Ga_{0.5}As}$	0.1	–
9	Top-Confining Layer	P-$\mathrm{Al_{0.7}Ga_{0.3}As}$	1.6	Be, $\sim 1.0\times10^{18}$
10	Ohmic Contact Layer	P-GaAs	0.3	Be, $0.1-2.0\times10^{19}$

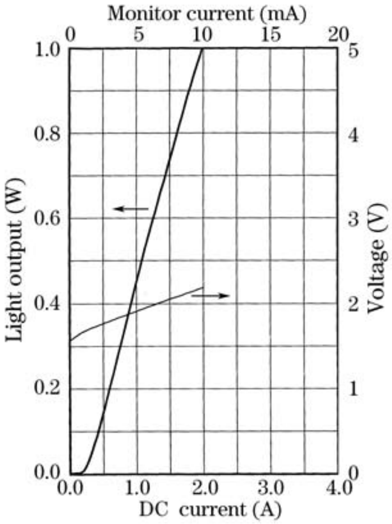

Fig. 1. Output power-drive current curve of lasers under room temperature.

structure is sputtered to form P-type facet ohmic contact electrode. After alloying and electroplating Au, we cleave wafer into laser chips. The back cavity face of laser is evaporated with HR film of 95% reflectivity, and the front cavity face is evaporated with AR film of 5% reflectivity. The chips are soldered p-side down to heat sink. N-type facet is evaporated with Au as the electrode and then packaged into a TO_3 case. The encapsulation fully uses metal to improve its reliability.

The output power-drive current (*P-I*) curve is measured and shown in Fig. 1. The laser wavelength is 808 nm, the threshold current is 0.29 A, and the output power is over 1 W. A semiconductor laser synthesized testing apparatus, a temperature-controlled thermostat and a temperature control apparatus are used to do the characteristic temperature experimentation.

We measured the *P-I* curve of lasers in the range of 20−100 °C. The data are substituted into Eq. (1) to calculate T_0 value under different temperatures. The results are shown in Table 2. In the range of 20−40 °C, the characteristic temperature of AlInGaAs/AlGaAs lasers is 200 K, which exceeds the reported 180 K under room temperature[6].

Table 2. Characteristic Temperature under Different Temperatures

Temperature (°C)	20−40	40−60	60−80	80−100
T_0 (K)	200	154	118	87

We all know the 808 nm laser has been researched for a long time, but the materials are usually AlGaAs/AlGaAs or InGaAsP/GaAs without strained layers. This kind of laser is very sensitive to temperature, so it is difficult to work well under high temperature and high power condition. In this work, we employ AlInGaAs/AlGaAs as the active layer to make strained quantum well lasers at 808-nm wavelength, and its working stability is greatly improved. Because the laser of AlInGaAs/AlGaAs adopts strained quantum well structure which shifts the energy band configuration, Auger recombination probability and intervalence band absorption are reduced.

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