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SPECIAL CHARACTERISTICS OF HIGH POWER SEMICONDUCTOR LASER OF MATRIX STRUCTURE PACKAGED IN VIETNAM

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Abstract. *The semiconductor diode laser chips AlGaAs of the matrix structure (linear bars arrays structure), having an output opticalpower of 2W were packaged at the semiconductor laser labrotary - Institute of Materials Science. We have studied some its properties such as: the temperature dependence of laser threshold, output optical power; the transfer heat of laser chip and pump current of laser. The study of spectral structure showed that the operating wavelength area of laser and structure of the longitudinal multimode depend on temperature and pump current. The above results allow to improve the packaging technology of the high power semiconductor laser chips, and then to open possibilities of its applications in Vietnam.*

I. INTRODUCTION

In the last decades, semiconductor lasers had been used in many fields such as: optical communication, military, health, environment and science studies. The applications in optical communication and enviornment usually require the lasers having low output power from 3 mW to 10 mW. However in recent years, the applications, especially in health and environment require lasers having high ouput power up to ten watts. Therefore, the studies of the high power semiconductor lasers are being interested, especically, the studies in packaging technology to increase the output optical power, lifetime and stability of laser. In this paper, we introduce a packaging technology and some investigated results on characteristics of the high power semiconductor laser such as: the dependence of threshold current and output optical power on operating temperature. The operating modes in pulse or continuous regime, the transfer heat of laser, spectral structure of laser at different operating modes and temperatures were investigated. Based on the above results, we improved the good packaging technology for the lasers applicable in practice.

II. PACKAGING HIGH POWER SEMICONDUCTOR LASER CHIPS

The laser chip includes 20 parallel active strips and each strip has small active region with the size of 0.3 μm $\times$ 5 μm (Fig. 1a). To make high power laser operating either in continuous or impulse regime, that is applicable in practice, we need to carry out the following processes: welding electrodes for laser chip, subsequently welding this laser chip on heat-sink substrate and encapsuling. The positive pole of laser chip is a heat-sink substrate welded to the p-type semiconductor layer of AlGaAs laser chip in vacuum by indium or tin doped indium (with ratio 1:1) with a thickness of about from 10 μm to 15 μm. This welding material layer is soft. It has the thermal expansion coefficient as same as heat -sink substrate and the p-type semiconductor layer and makes good ohmic contact between them. So laser chip is not breakable down when this weld material shrinks or stretch at different temperatures. The heat-sink substrate is made of pure copper that smoothly polished. This heat-sink substrate and welding material make the heat due to pumping current immediately transferre to the substrate and rapidly diffuse. Negative pole of the laser is gold string with the diameter of $\Phi = 50$ μm welded on n-type semiconductor layer of the laser chip by heat-pressing machine WEST-BOND. To protect the welding materials from oxidization at high temperature ($T > 180$°C) and in different environments, all technology steps were done in clean gas. This ensures for the good connection of elements to heat-sink substrate and increase life-time of the laser. After welding and encapsulating processes, the high power laser chip with the diameter of $\Phi = 1$ cm and $\Phi = 1.4$ cm are shown in Figs. 1b and 1c.

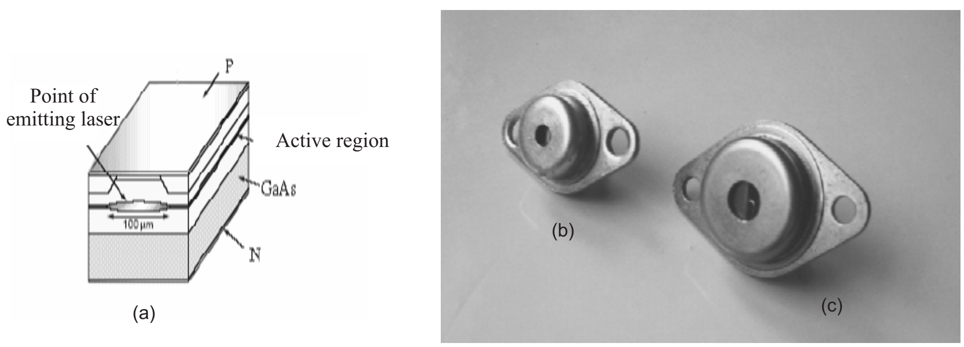

Fig. 1. Image of one active region of laser chip (a) and two high power semiconductor lasers with the diameters of $\Phi = 1$ cm (b) and $\Phi = 1.4$ cm (c) after packing

III. RESULT AND DISCUSSION

III.1. Dependence of laser output optical power on pumping current (P-I characteristic)

In this paper, the dependence of output optical power on pump current of two lasers welded by different materials has been investigated. The curves of the dependence are showed in Fig. 2. The output optical power of laser chip welded by indium with thickness of layers less than or equal 15 μm shows: the lasing threshold at 20°C is 250 mA, but the output optical power is not linear. The output optical power decreases from 200 mW to 100 mW when the pump current increases from 700 mA to 1100 mA, respectively (Fig. 2a). However, if the laser chip was welded by indium and tin material with 1:1 ratio, the P-I characteristic is linear (Fig. 2b).

The lasing threshold is also 250 mA at 20°C, but the P-I characteristic is linear (output optical power increases when pump current increases) and up to 2 A current, the output optical power reaches to 800 mW with linear part of curve.

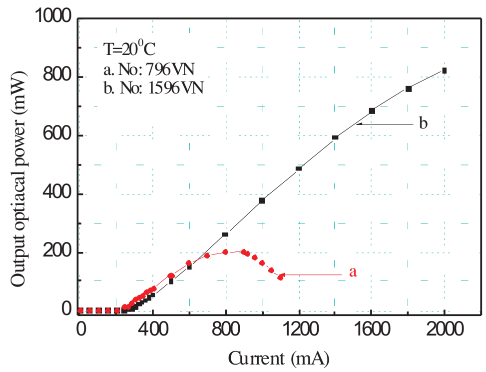

Fig. 2. The P-I characteristics of two lasers at 20°C: No. 796 VN (a), No. 1596 VN (b)

According to theoretical and experimental studies, the small size of diode lasers results in a relatively high thermal resistance (R_{th}), which is usually defined as the division between temperature rise of active region and difference of input electrical power (P_{in}) and output optical power (P_{out}) [1]

$$R_{th} = \frac{\Delta T}{P_{in} - P_{out}} \tag{1}$$

When increasing temperature of active region in diode laser, the carrier confinement is reduced and the non-radiation recombination processes are increased. The Fig. 2 shows the P-I characteristic of two lasers which have the same structure and wavelength but different packaging technology. The No. VN 796 laser was welded by unsuitable packaging technology (i.e., ratio of indium and tin and their thickness are unsuitable), the temperature of laser increases following the increasing of pumping current. However, the spread heat of this laser is lower than the increasing heat in it. Therefore, when the pump current increases, the output optical power reduces (Fig. 2a).

The No. 1596 VN laser was welded by suitable packaging technology (ie, ratio of indium and tin and their thickness are suitable), the temperature generated by pumped current as soon as spreads into heat-sink substrate. So the P-I characteristic of this laser is linear (Fig. 2b). Based on that result, the packaging technology influences so much in physical characteristics of high power semiconductor laser. Therefore, we have chosen the good packaging technology for high power laser chips.

In order to estimate this packaging technology, we also investigated the dependence of output optical power on pump current of two laser chips that have the same structure but different packaging technology: one laser chip was packaged by Max-Born Institute in Germany (Fig. 3a) and other was packaged by semiconductor laser Lab, Institute of Materials Science in Vietnam (Fig. 3b). Based on those P-I characteristics, we find that lasing threshold and output optical power of two given lasers are the same.

That result proves our packaging technology for high power laser chips is good and can apply in practice.

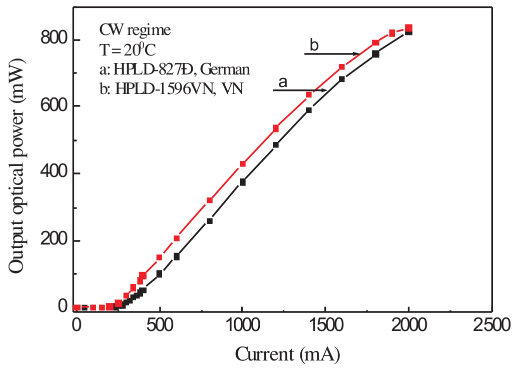

Fig. 3. The dependence of P-I characteristics on pumping current at same temperature of two lasers: laser No. 827G (a); laser No. 1596VN (b)

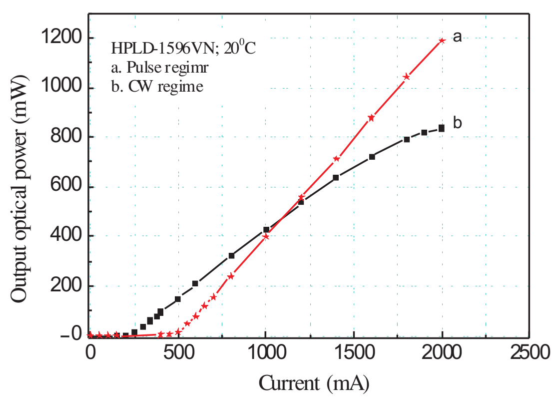

Fig. 4. The dependence of P-I characteristics on pumping current of laser No. 1596VN in pulse regime (a) and CW regime (b).

For further study on the influence of pump current on laser power, we studied the operation of laser No. 1596VN in pulse regime (Fig. 4a) and in CW regime (Fig. 4b) with DC current. Fig. 4a describes the output optical power in pulsed regime with short pulse (below 4 μs) and at low repeated frequency (1:100), thus neglecting of diode laser heating on active region. The Fig. 4 shows that the lasing threshold in pulsed regime is double but output optical power is lower than in CW regime in current below 1000 mA. However, at higher pumping current 1000 mA, the output optical power in pulse regime is higher

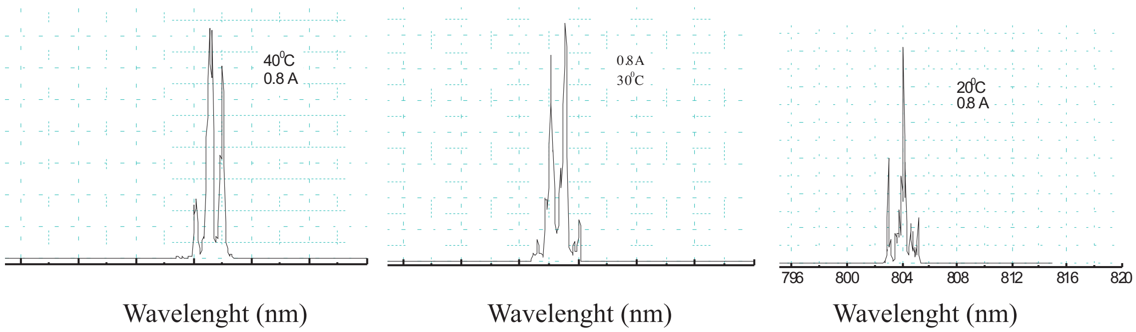

Fig. 5. Spectral structures of the No. 1596VN laser at different temperatures in CW regime

than in CW regime. For example, in pulse current of 2000 mA, the pulse power equal about 1.5 times of the power in CW regime. The threshold density of diode laser is given by following equation [2]:

$$J_{th} = \frac{qVn_{th}}{\tau_e} + J_L \tag{2}$$

where, q – electricity, V – the volume of active region, n_{th} – the threshold carrier density, τ_e – the lifetime of electron and J_L – the leak current. According to Eq. (2), the threshold density depends on the threshold carrier density n_{th}, n_{th} and the pump current. In short pulse regime and low repeated frequency, to reach the density inversion in active region and lasing threshold, so the laser pumping current in pulse regime is higher than in CW regime. However, in current above 1000 mA, the output optical power in pulse regime is greater than in CW regime. Comparing the η value (η= dP/dI) between two regimes, the laser operates in pulse current has η higher than in continuous current. η value influence on conversion efficiency between the output optical power and input electrical power. If η is low, the conversion efficiency will low. The difference of output optical power in two operation regime is explained as follows.

Using the temperature dependence of threshold and differential efficiency, the power-current characteristic can be described approximately by the following expression [3].

$$P = \eta_d \exp\left(-\frac{R_{th}\left[I\left(V_d + IR_s\right) - P\right]}{T_1}\right) \times \left[I - I_{th}\exp\left(\frac{R_{th}\left[I\left(V_d + IR_s\right) - P\right]}{T_0}\right)\right] \tag{3}$$

where, P – the output optical power, I – the pump current, R_s – the series resistance, and V_d the voltage across the p-n junction, R_{th} the thermal resistance, T_0 – the temperature at lasing threshold.

When diode laser is pumped by short pulse and low repeated frequency, the heating of diode laser is neglected. The temperature rise of active region is calculated as the product of the thermal resistance and the waste input power [4]. Nevertheless, when pumping current increases, the temperature also increases. So, a higher thermal resistance does not only lead to the strong increase of temperature of active region but also limit the maximum output optical power. To reach the high power laser devices that can be applied in practical system in continuous pump current, we have to improve the packaging technology.

III.2. Spectral structure of laser

The spectra of diode lasers after packaging not only give us the wavelength range, spectral contour but also show more detail information about the influence of temperature on laser power and spectral structure. In this investigation, the operating temperature of lasers are changed from 20°C to 50°C with a fixed pump current. The laser spectral structure in Fig. 5 showed that laser operates at wavelength range of (800 ± 10) nm with longitudinal multi-mode and spectral width of laser does not change at different temperatures ($\Delta\lambda = 3.5$ nm both at 20°C and 50°C) [4] With pump current of 800 mA, when increasing temperature, laser spectrum shift toward long wavelength. At 20°C, the wavelength $\lambda_1$of the first laser mode is 802.5 nm, when temperature increases to 50 °C, the wavelength λ_2 of this mode changes to 811 nm. If operating temperature of laser changes in range of ΔT = 30°C, the laser wavelength shifts toward long wavelength in range of $\Delta\lambda = 8.5$ nm. The dependence of wavelength shift on the increase of laser temperature is defined by formula $\frac{\Delta\lambda}{\Delta \mathrm{T}} \approx 0.28$ nm/°C

According to above results we conclude that the laser chips may be applied in practical systems which depends very much on packaging technology. Carying out well this packaging technology lead to increase not only output optical power but also stability operation and lifetime of laser.

IV. CONCLUSION

The obtained results about lasing threshold, output optical power dependenced pulse and CW regime pump current, spectral structure and wavelength shift of laser when temperature changes show that, we can package high power lasers chips in Vietnam. These laser can be used in pracical applications at wide temperature range from 10°C to 50°C in pulse regime without using Peltier cell. These commercial lasers with output optical power of 2W is suitable for applications in the domains such as: military, health, environment and science studies.

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