第26卷 第3期
2005年3月

半 导 体 学 报
CHINESE JOURNAL OF SEMICONDUCTORS

Vol.26 No.3
Mar.,2005

AIN Monolithic Microchannel Cooled Heatsink for High Power Laser Diode Array

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Abstract: A novel AIN monolithic microchannel cooled heatsink for high power laser diode array is introduced. The high power stack laser diode array with an AIN monolithic microchannel heatsink is fabricated and tested. The thermal impedance of a 10 stack laser diode array is 0.121℃/W. The pitch between two adjacent bars is 1.17mm. The power level of 611W is achieved under the 20% duty factor condition at an emission wavelength around 808nm.

Key words: microchannel; monolithic; AIN
EEACC: 4320J; 4320M
CLC number: TN2 **Document code:** A **Article ID:** 0253-4177(2005)03-0476-04

1 Introduction

Laser diode arrays have being used widely as pumping sources in the field of solid-state lasers. When laser diode arrays operate in high duty factor mode or continuous wave (CW) mode, the average output power is very high. The high average power and the small emitting area result in a peak heat flux about 1kW/cm^2 at the interface where the diode material is soldered on. In order to maintain efficient and reliable operation, the temperature of the junction must be kept below ~50℃, therefore, low-thermal-impedance packing becomes very important.

At present, microchannel coolers are the most efficient method used to deal with the intense heat flux. This kind of aggressive thermal control can provide very low thermal impedance. For this case, the laser diode bars are bonded onto a multilayered heat sink and cooled by narrow channels. This kind of method using liquid coolant and laminar flow is very efficient for the diode cooling application. The silicon and copper microchannel-cooled heatsinks have been developed. Beach *et al.*[1] had reported a three-layer silicon microchannel heatsink in 1992, and the thermal impedance was 0.23℃/W. Loosen *et al.*[2] had reported a five-layer copper microchannel heatsink in 2000, and the thermal impedance was 0.29℃/W. The thermal conductivity of copper is very high, but using copper can not achieve monolithic packing. On an individual heatsink, only one diode bar can be mounted, so the packing density is limited. The silicon microchannel heatsink can achieve monolithic packing, in which many laser diode bars can be mounted on one heatsink structure. However, the fabricating of silicon microchannel is complex and difficult. To circumvent these drawbacks, a novel AIN ceramic microchannel structure for high power laser diode arrays has been proposed. The microchannels, in which flow water brings heat out, are fabricated on one panel of a monolithic AIN ceramic. On the other

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Received 8 July 2004, revised manuscript received 15 November 2004

panel grooves are used to fix laser diode bars. In this novel structure high density packing and low thermal impedance can be obtained. AIN ceramic has excellent electrical insulation, very good thermal conductivity, super thermal cycling stability, and good heat spreading, so it can be used as cooled heatsinks for high power laser diode arrays. Moreover, microchannels can be fabricated easily on the surface of AIN ceramic at present. Because of low lost, simple fabricating process, and better thermal performance, AIN ceramic microchannel is more attractive for high power laser diode arrays.

2 Configuration and thermal impedance analysis

Figure 1 shows a schematic diagram of AIN microchannel-cooled heatsink structure, in which the cooling microchannels and grooves used to fix bars could be fabricated simultaneously in a monolithic AIN substrate. AIN substrate is directly bonded onto a copper block. The thickness of the substrate is 1500μm. On the bottom side of the substrate, microchannels were made. Each microchannel is about 150μm wide and the pitch is 150μm. The depth and length of each microchannel are 1000μm and 10mm respectively. Totally 33 microchannels are made in the AIN substrate. On the top side of the AIN substrate 10 grooves were diced. By conventional process, the laser diode bars were fixed into the grooves. The pitch between two adjacent bars is 1.17mm. We also can find that a high level of precision and quality control is easily achieved over a lager-area substrate for this material.

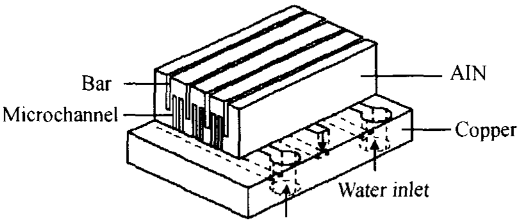

Fig. 1 Schematic diagram of AIN ceramic microchannel heatsink for stack laser diode array

The most important parameter of laser diode heatsink package is its thermal impedance. In the following detailed thermal analysis of the heat sink is performed. A simple representation of the thermal impedance is given by[3]

$$R_{\mathrm{th}} = R_{\mathrm{t\_cond}} + R_{\mathrm{t\_heat}} + R_{\mathrm{t\_conv}}$$

The three terms given in order are

(1) Impedance through AIN

$$R_{\mathrm{t\_cond}} = \frac{1}{A} \times \frac{D}{K_{\mathrm{AIN}}}$$

A is the area over which the heat is conducted, D is the distance between the coolant and the heated surface, K_{AIN} is the thermal conductivity of AIN.

(2) Caloric impedance of the coolant itself

$$R_{\mathrm{t\_heat}} = \frac{1}{\rho C_p f}$$

ρ is the density of coolant, C_p is the specific heat, f is the flow rate of coolant. $\rho C_{\mathrm{water}} = 4.18\mathrm{J}/(℃ \cdot \mathrm{cm}^3)$.

(3) Impedance through the coolant boundary layer[4]

$$R_{\mathrm{t\_conv}} = \frac{1}{Lhnp}$$

n is the number of microchannels, L is the length of microchannel, p is cross-sectional perimeter, h is the convective heat-tranfer coefficient.

Calculations are summarized in Table 1, and the total $R_{\mathrm{th}} = 0.1228$ ℃/W.

Table 1 Individual thermal-impedance contributions for AlN diode array

	$R_{\mathrm{t\_cond}}$	$R_{\mathrm{t\_heat}}$	$R_{\mathrm{t\_conv}}$
Unit	$(1/\mathrm{mm}^2) \times (\mu\mathrm{m}/(\mathrm{W} \cdot \mathrm{m}^{-1} \cdot ℃^{-1}))$	$1/(\mathrm{J} \cdot \mathrm{cm}^{-3} \cdot ℃^{-1})(\mathrm{cm}^3 \cdot \mathrm{s}^{-1})$	$1/\mathrm{mm}(\mathrm{W} \cdot ℃^{-1} \cdot \mathrm{mm}^{-2})\mathrm{mm}$
Value	$1/(2 \times 10 \times 10 \times 0.5) \times 150/170$	$1/(4.18 \times 14)$	$1/(10 \times 0.0145 \times 33 \times (2 \times 1000 + 150) \times 10^{-3})$
Result	0.0085 ℃/W	0.0171 ℃/W	0.0972 ℃/W

3 Result

Thermal resistance is the derivative of the temperature measured at the diode junction with respect to the thermal power dissipated at the junction. Figure 2 shows the different emission wavelength of the diodes at different dissipated thermal power with an inlet flow water temperature of 15 ℃ and the flow rate of 14cm^3/s. The dissipated thermal power was calculated by subtracting the measured optical output power from the supplied electrical power. Measuring the emission wavelength and utilizing the spectral shift in the diode emission wavelength versus the temperature rise of p-n junction: $\Delta\lambda = 0.3\Delta T$ nm, we can acquire the temperature augment of p-n junction under different power. In the experiment, the supply voltage (18V) and current (60A) were kept constant and the duty factor was varied to change the input power. Based on these data, the thermal resistance between the diode junctions and the coolant in the inlet was measured to be 0.121 ℃/W for the array.

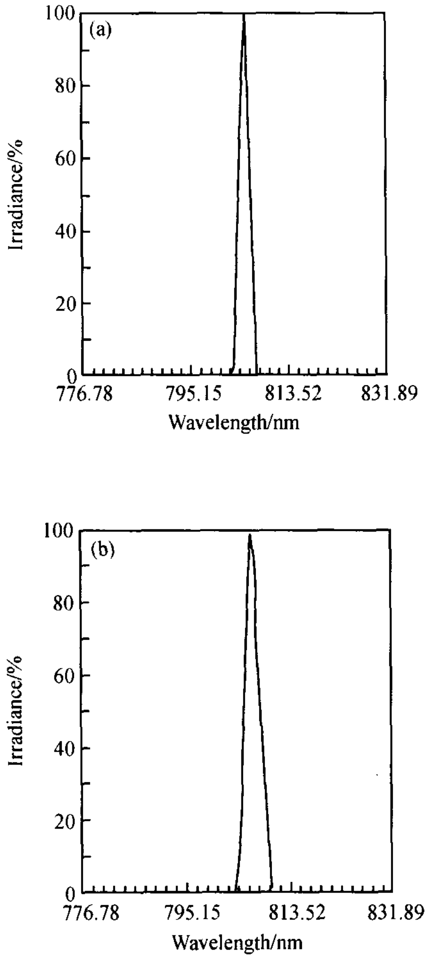

Fig. 2 Different emission wavelength of the diodes at different dissipated thermal power (a) Center wavelength is 805.30nm, duty factor is 1%, average output power is 5.7228W; (b) Center wavelength is 806.98nm, duty factor is 10%, average output power is 56.474W

The light-current characteristic is shown in Fig. 3 with an inlet temperature of 13 ℃. The flow rate was 14cm^3/s. The curve over the full range gives a slope efficiency of 12.6W/A. The power level of 611W was achieved at the supply of 61.5A under the 20% duty factor condition. Figure 4 shows the measured values of the stack array wavelength at this power level; the wavelength of the array is 808.43nm with a bandwidth of 2.27nm (full width at half maximum (FWHM)). This result shows that this kind of diode array could work stably under the 20% duty factor condition.

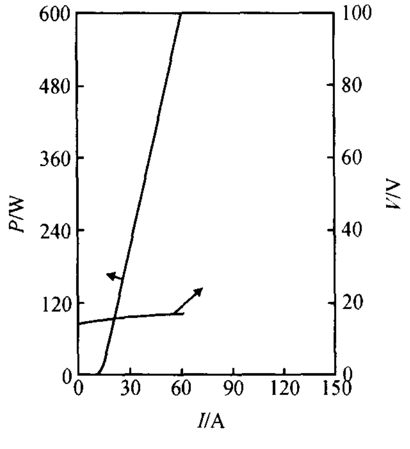

Fig. 3 Light-output characteristic of a ten-bar stack diode array

4 Conclusion

A novel AlN monolithic microchannel cooled heatsink for high power laser diode arrays has been demonstrated. The thermal impedance of the diode array is 0.121 ℃/W. The pitch between two adjacent bars is 1.17mm. Moreover, the diode array can

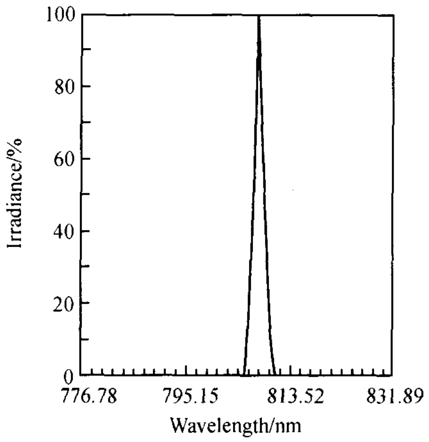

Fig. 4　Measured values of the stack array wavelength at 20 % duty factor　Center wavelength is 808.43nm.

work stably under the 20 % duty factor condition with the peak output power 611W. AlN monolithic microchannel cooled heatsink is much simple to manufacture and easy to achieve high-density packing. This structure of the heatsink can be further optimized to be used in the CW diode arrays. Experimental investigations in this area are presently underway. This kind of AlN monolithic microchannel cooled heatsink design could be well exploited for laser diode arrays that require high average power and high system reliability.

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应用于大功率激光二极管列阵的单片集成微通道制冷热沉

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摘要: 介绍了一种应用于大功率激光二极管列阵的新型单片集成微通道制冷热沉. 这种热沉已制造并经过测试. 10 叠层的激光二极管列阵的热阻为 0.121 ℃/W. 相邻两个激光条的间距是 1.17mm. 在 20 %高占空比条件下, 波长为 808nm 左右, 峰值功率可以达到 611W.

关键词: 微通道; 单片集成; AlN
EEACC: 4320J; 4320M
中图分类号: TN2　　**文献标识码**: A　　**文章编号**: 0253-4177(2005)03-0476-04

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2004-07-08 收到, 2004-11-15 定稿