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Quasi-CW performance and reliability of dual laser bars on a micro-channel cooler

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Abstract. High power density as the critical performance of laser diode pumps significantly affects both efficiency and power of a solid state laser. In this report, we designed a new packaging structure that two laser bars bonded on the top and bottom of a MCC, respectively, to achieve higher power density at the same bias current or the same power density at a reduced bias current with respective to one laser bar on a MCC. We achieve 1KW output power at a lower bias current 450A with 2.3W/A slope efficiency from a dual-bar MCC at a duty cycle of 8% (200 μs/400 Hz). Other performances like spectral width broadening, wavelength shift and reliability about 1KW quasi-CW high power laser diodes and 5KW for one vertical stack with five dual-bar micro-channel coolers (MCCs) also are discussed. The reliability of dual-bar MCC packaging structure is also studied by life-time testing, and the output peak power of all devices degraded less than 5% after working for 1353 hours.

Keywords: High power, Quasi-CW, Semiconductor Lasers, Micro-channel cooler

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1 Introduction

High-power laser diodes have been utilized for many applications, like medical, industry, etc. Especially for pumping solid state lasers, high-power density is the critical performance to be necessarily improved. However, given that the peak power of laser systems has increased, large injection current brings much obstacle in the development of a semiconductor laser bar as a pumping source. It has been reported that a transient rise of the active region temperature of an LDA due to injection current causes the thermally induced chirp that plays a more signification role in spectral-width broadening. [1] The spectral width of a laser diode array (LDA) significantly affects efficiency of a laser system for pumping solid-state lasers. Another obstacle in the application of pumping solid state laser is high current power supply. Therefore, as the
increasing of output power density, reducing the injection current density is the primary target in the application of high power semiconductor laser diodes.

In this paper, a novel method to improve the output power density of a LDA without increasing the injection current density was experimentally studied. Unlike the traditional packaging structure that a laser bar is bonded on a micro-channel cooler (MCC) with indium solder, as shown in Fig 1, the novel packaging structure has two laser bars bonded on the top and bottom of a MCC respectively, as shown in Fig 2. One laser bar is epi-down bonded on the top of a MCC while another one is epi-up bonded on the bottom of the MCC.

![Fig. 1 Structure schematic of a laser bar bonded on a MCC with indium solder.](image1)

![Fig. 2 Structure schematic of two laser bars bonded on the top and bottom of a MCC with indium solder.](image2)

It has been reported that a laser bar epi-up bonded on a MCC is unreliable due to higher thermal resistance resulting from the laser waveguide far away from the heat-sink. Two different packaging structures including a laser bar epi-down and another one epi-up bonded on two MCCs, respectively, have been experimentally studied for comparison. Thermal simulations of two packaging structures have been done to verify our experimental results. The package of two laser bars on a MCC has been achieved and tested. A vertical stack with five dual-bar MCCs has been designed, studied and discussed.
2 Experiment and discussion

Two different packaging structures including a laser bar epi-down and another one epi-up bonded on two MCCs, respectively, have been done and characterized. The materials consist of a laser bar (10 mm wide, 0.125 mm thick, and 1.5 mm cavity length, Fill Factor 80%, 34 emitters), a Cu-foil as cathode, an insulator and a MCC heat sink as anode, as shown in Fig. 1. Two different packaging structures were tested for peak power, wavelength and spectrum at a duty cycle (DC) of 8% (200 μs/400 Hz) with an injection current up to 430A.

Experimental results show that the output power of a laser bar epi-up bonded on a MCC is lower than a laser bar epi-down bonded on a MCC, as shown in Fig. 3.

![Graph showing peak power vs. current for epi-up and epi-down structures.]

**Fig. 3** Peak power of two packaging structures (epi-up and epi-down).

According to the centroid wavelength and spectrum width of epi-up and epi-down bonding, the wavelength of epi-up bonding red shifts more 2nm than epi-down, and the spectrum of epi-up is broader than epi-down, as shown in Fig. 4.
It has been shown that the performance of a laser bar epi-up bonded on a MCC is inferior to epi-down bonding, including peak power and spectrum. The main reason is that a laser bar epi-up bonded on a MCC has higher thermal resistance due to the laser waveguide far away from the heat sink. The heat has to propagate through the semiconductor substrate for the epi-up bonding[2], resulting in higher injunction temperature in the active region of laser bars is in good agreement with our simulation results as shown in Fig. 5. Higher injunction temperature reduces the peak power [3] and a higher transient rise of the active region temperature makes the spectral width broader.

**Fig. 4** Spectra of two packaging structures (epi-up and epi-down)

**Fig. 5** Transient thermal simulation results of the junction temperature for two different packaging structures.
Another experiment is two laser bars bonding on the top and bottom of a MCC, respectively, as shown in Fig 2 & 6.

**Fig. 6** The novel packaging structure that two laser bars bonding on the top and bottom of MCC.

Since the laser bar bonded on the bottom of a MCC wavelength red shifts more than the one bonded on the top. In order to obtain a narrow spectrum without a side peak, selecting the suitable cold wavelength of unbound laser bars is necessary. Table 1 shows 4 experiments that changing the cold wavelength of the bottom laser bar and keeping the top one unchanged.

**Table 1** Four samples with different cold wavelengths of laser bars on the bottom of a MCC.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser bar on the up</td>
<td>932.37nm</td>
<td>932.37nm</td>
<td>932.37nm</td>
<td>932.37nm</td>
</tr>
<tr>
<td>Laser bar on the bottom</td>
<td>932.37nm</td>
<td>931.37nm</td>
<td>930.37nm</td>
<td>929.95nm</td>
</tr>
<tr>
<td>Centroid wavelength(nm)</td>
<td>939.81nm</td>
<td>939.42nm</td>
<td>938.78nm</td>
<td>938.54nm</td>
</tr>
<tr>
<td>Full width at half-maximum (FWHM)</td>
<td>4.64nm</td>
<td>4.65nm</td>
<td>4.74nm</td>
<td>4.88nm</td>
</tr>
<tr>
<td>FW90% Energy</td>
<td>8.3nm</td>
<td>7.73nm</td>
<td>7.5nm</td>
<td>7.26nm</td>
</tr>
</tbody>
</table>

**Fig. 7** The spectrum of four samples with different cold wavelength of laser bars on the bottom of a MCC.
Due to the junction temperature of laser bar bonded on the bottom of a MCC is higher 10 °C than the one on the top, as shown in Fig. 8, the wavelength red shift more than 2nm than the laser bar bonded on the top of a MCC. Then the spectrum of the sample will be broadening when the spectra from two laser bars overlap. As shown in Fig. 7, sample 1 shows the broadest spectrum because the cold wavelength of the laser bar bonded on the bottom is the same as that of the one on the top while the spectral width gets narrower as the cold wavelength of the laser bar bonded on the bottom decreasing, as shown in the sample 2, 3 and 4 of Fig.7. Therefore, in order to get a narrow spectral width, the cold wavelength of the laser bar bonded on the bottom of a MCC should 2nm shorter than that of the one on the top.

![Transient thermal simulation results of two bars bonded on the top and bottom of a MCC, respectively.](image)

**Fig. 8** Transient thermal simulation results of two bars bonded on the top and bottom of a MCC, respectively.

By using the dual-bar packaging structure, the peak power 940nm 1034W at a DC 8% (200 μs/400 Hz) with 450A injection current have been achieved, as shown in Fig. 9.
The dual-bar structure can be used to form a vertical stack, as shown in Fig. 10, which can reach almost 5KW for one vertical stack with five MCCs. The test results are shown in Fig. 11.

Fig. 9 PVI characteristics of two bars bonded on the top and bottom of a MCC, respectively.

Fig. 10 Structure schematic and prototype of a vertical stack constitutes with five MCCs.
Fig. 11 PI characteristics and spectrum of a vertical stack with five dual-bar MCCs.

The life time testing has been done at room temperature with a DC of 8% (200 μs/400 Hz), and 300A peak injection current for 1353 hours, as shown in Fig. 12. The output power of all samples degraded less than 5% after working for 1353 hours.

Fig. 12 Life time test of six dual-bar MCCs.

3 Conclusion

High power density is the critical performance of laser diode pumps in a solid state laser. In this report, we designed a new packaging structure that two laser bars bonded on the top and bottom of a MCC, respectively, to achieve higher power density at the same bias current or the same power density at a reduced bias current with respective to one laser bar on a MCC. According to
the experimental and simulation results, the junction temperature of laser bar bonded on the bottom of a MCC is higher 10 °C than the one on the top, resulting in a wavelength red shift of 2nm more than that of the laser bar bonded on the top of a MCC. Then after selecting the cold wavelength of unbound laser bars, the narrow spectrum without a side peak can be achieved. Quasi-CW output peak power levels of 1KW and 5KW are experimentally obtained for one dual-bar MCC and one vertical stack with five dual-bar MCCs at a DC (duty cycle) of 8% (200 μs/400 Hz) with an injection current of 450A. The reliability of dual-bar MCCs has also been studied by life-time testing at room temperature at 300A and 8% DC, and the output peak power of all devices degraded less than 5% after working for 1353 hours.

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References