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980-nm, 15-W cw laser diodes on F-mount-type heat sinks

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Abstract. **We have studied the key optical emission parameters of laser diodes (emission wavelength, 980 nm; stripe contact width, 95 μm) mounted directly on F- and C-mount-type copper heat sinks, without intermediate elements (submounts). When effectively cooled by a thermoelectric microcooler, the lasers on the F-mount operated stably at output powers up to 20 W. The lasers were tested for reliable operation at an output power of 15 W for 100 h, and no decrease in output power was detected to within measurement accuracy. The experimentally determined maximum total efficiency is 71.7 % and the efficiency at a nominal output power of 15 W is 61 %. We compare parameters of the laser diodes mounted on C- and F-mounts and discuss the advantages of the F-mounts.**

Keywords: *high-power laser diode, efficiency, maximum reliable power.*

The ability to raise the maximum reliable power and brightness of laser diodes continues to be a challenge [1 – 7]. To enhance the effectiveness of heat dissipation and ensure reliable laser operation at higher output optical power levels, efforts are focused on improving the basic heterostructure design; the planar processing, passivation and protection of cavity mirrors; and mounting techniques. In particular, to improve the efficiency of lasers at λ = 980 nm from 65% to 70%, Crump et al. [1, 2] used a heat sink temperature as low as –50 °C. Temperatures below the dew point require the use of a vacuum chamber, which complicates practical application of the lasers. Xiaoning Li et al. [7] reported a comparative study of parameters of high-power 808-nm laser diodes mounted on F- and C-mounts. In continuous mode, they obtained maximum powers of 12.6 and 10.9 W, respectively. This result shows that F-mounts slightly increase the laser output power but does not help to assess the contribution of the heat sink geometry because, in addition to basic heat sinks, use was made of various thermal compensators – dielectric (from ceramics) in the case of the F-mount and composite metallic (from CuW) in the case of the C-mount – which of course had a significant effect on thermal conditions.

In this study, both types of heat sinks were fabricated using the same equipment, the same procedure, and one copper batch, with constant quality in processing their surfaces and fins, and differed only in geometry, which ensured experimental data better suited for comparison and the possibility of comparing them to calculation results. In the mounting process, we used identical laser chips from the same batch and the same gel pack. The lasers were mounted on F- and C-mount heat sinks with identical planarity parameters and roughnesses of the working and base heat sink surfaces. In our experiments, we used the same solder of the same thickness and similar thermal conditions of the mounting process.

Previously, we obtained a reliable output power of 10 W at a wavelength of 980 nm from laser diodes on a C-mount. The maximum efficiency of the lasers was on average 65% [8]. In that study, the thermal parameters of the lasers (the average temperature of the active layer and the temperatures of the output and high-reflectivity cavity mirrors) were calculated as functions of thermal load for C- and F-mounts. Later [9], we performed a comparative calculational analysis of thermal conditions for laser crystals on all known types of submounts, including conductive and dielectric thermal compensators and diamond submounts with high thermal conductivity.

In this paper, we present an experimental study of a laser chip on an F-mount and verify calculation results obtained previously [8] for laser crystals mounted directly on C- and F-mounts (without submounts).

According to previous calculations [8], the use of F-mounts is more advantageous because the heat flow from the active layer of the laser heterostructure is then more uniform than that in the case of C-mounts. The distinctions between these heat sinks are caused by the fact that, in C-mounts, the base heat sink surface is perpendicular to the heat sink surface of the main heat sink block, whereas in F-mounts these surfaces are parallel, so the heat flow is there substantially more uniform. This demonstrates the conceptual feasibility of lowering the active layer temperature at high thermal loads and considerably reducing the temperature difference along the length of the laser diode crystal, which may also have an advantageous effect on the thermal conditions of the crystal and improve the output parameters of the crystal.

Experimental verification of these ideas confirmed the above-mentioned advantages of F-mounts. From the viewpoint of laser chip mounting technology, the transition to F-mounts presented no serious difficulties: we only slightly corrected chip mounting thermal cycles, taking into account that F-mounts differ in geometry from C-mounts and have

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higher heat capacity. Also, we took into account their dimensions for ensuring a laminar inert-gas flow. In addition, we identified a number of distinctive features in bonding F-mounts on the main heat sink block. Detailed local temperature measurements with a temperature microsensor at high thermal loads in different zones of the F-mount design showed that, because two fastening screws were used, it was somewhat more difficult to ensure uniform tightening and, accordingly, a more uniform thermal contact with the main thermoelectric cooling block than in the case of a C-mount, where one fastening screw is used. To improve the thermal contact, we improved the planarity of the heat sink surface of the main block, reduced its roughness and used a torque screwdriver to control the tightening force. Clearly, to reduce the temperature difference across an F-mount, it is desirable to reduce its thickness, but fastening too thin a plate from plastic copper at its edges by two screws leads to deformation and buckling of the plate, which may impair heat removal from its centre (where the chip of the laser diode is located). Because of this, the optimal F-mount thickness was taken to be 2.5–3 mm.

Figure 1 shows light–current ($L-I$) curves of samples on C- and F-mounts. The lasers have almost identical threshold currents, and their $L-I$ characteristics are nearly linear up to an output power of 10 W. The slope efficiency of the laser on the F-mount is slightly higher. At pump currents above 10 A and, accordingly, output powers above 11 W, the distinctions between the $L-I$ characteristics increase and both become sublinear. At an output power of 20–21 W, we observed catastrophic optical damage (COD) in the lasers on the C-mount, whereas the lasers on the F-mount operated without COD at output powers up to 27–28 W. Note that the $L-I$ measurements were repeated many times, and the maximum output power was reproducible.

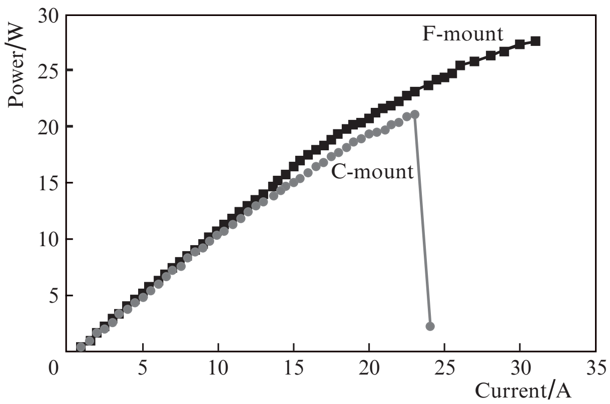

Figure 1. Light–current curves of laser diodes (wavelength, 980 nm; stripe contact width, 95 μm; cavity length, 4 mm) on copper C- and F-mounts.

Thus, the most important experimental result, illustrated by Fig. 1, is that the use of F-mounts increases the limiting output power. We believe that, along with the decrease in the average active layer temperature in the laser on the F-mount, an important role in increasing the limiting output power is played by the considerable decrease in the temperature of the output mirror and the temperature difference along the length of the crystal [8].

Examination of the output mirror under a microscope after ten test cycles to the maximum power did not detect any visible damage to the samples on the F-mount, whereas the mirrors of the lasers on the C-mounts had defects characteristic of COD.

Figure 2 presents the total efficiency vs. pump current data extracted from the measured light–current and current–voltage characteristics of the lasers on the C- and F-mounts. It is seen that, at pump currents under 3 A, the efficiency curves essentially coincide because, at low thermal loads, the thermal conditions of the lasers differ insignificantly. The maximum total efficiency

$$\eta_{\rm tot}^{\rm max} = \frac{\eta_{\rm d} J E_{\rm g}}{I_{\rm max}(V_{\rm th} + R_{\rm s} J)} \qquad (1)$$

is reached [10] at a pump current

$$I_{\rm max} = I_{\rm th} + J, \qquad (2)$$

where $I_{\rm th}$ is the threshold current; $J = \sqrt{I_{\rm th} V_{\rm th} / R_{\rm s}}$; $V_{\rm th}$ is the threshold voltage; $R_{\rm s}$ is the series resistance of the laser diode; $\eta_{\rm d}$ is the differental quantum efficiency; and $E_{\rm g}$ is the band gap. As follows from Fig. 2, the experimentally determined $I_{\rm max}$ values differ slightly: $I_{\rm max}$ = 5 A for the laser on the F-mount and $I_{\rm max}$ = 4.5 A for the laser on the C-mount. Since analysis with (1) and (2) is oversimplified, the contributions of various temperature-dependent parameters, in particular, those of $I_{\rm th}$, $\eta_{\rm d}$, $E_{\rm g}$, $V_{\rm th}$ and $R_{\rm s}$, to this effect are difficult to assess. We note only that $I_{\rm th}$ and $V_{\rm th}$ are measured at an insignificant thermal load, so the key role is probably played by the temperature dependence of $\eta_{\rm d}$, whereas the contributions of $R_{\rm s}$ and $E_{\rm g}$ are less significant.

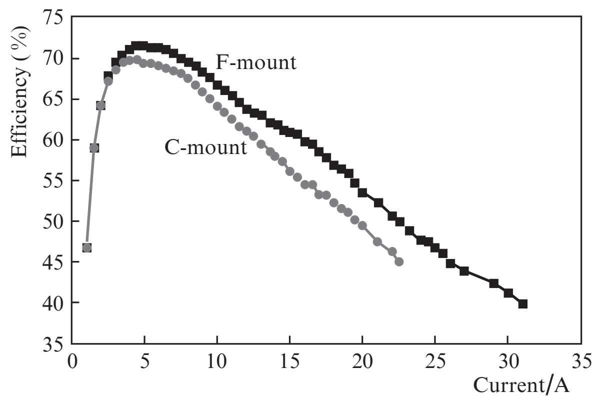

Figure 2. Total efficiency calculated using (1) as a function of pump current for laser diodes (980 nm, 95 μm, 4 mm) on copper C- and F-mounts.

According to (1), the higher maximum efficiency of the laser on the F-mount is also attributable to its higher slope efficiency, which is due to the more effective heat dissipation. The data in Fig. 2 demonstrate that, with increasing pump current, there is a tendency for the efficiency difference to increase, which also would be expected because, with increasing thermal load, the differences in slope efficiency, threshold current and photon energy increase. At an output power of 15 W, the efficiencies of the lasers on the F- and C-mounts were rather high: 61% and 56%, respectively. According to thermal simulation results [8], differences in efficiency and heat dissipation uniformity are more pronounced at higher thermal loads. In the case of the F-mount, the temperature difference along the length of the crystal is then considerably smaller, which is of particular importance for long laser cavities (in this study, the cavity length was 4 mm). It is probably this advantage of the F-mount which plays a key role in raising the maximum reliable output power and COD threshold power, which is due to the decrease in the temperature of the output mirror and the temperature gradient between the high-reflectivity and output mirrors. Moreover, a rather important role in raising the maximum reliable output power is played by the decrease in thermoelastic stress along the length of the crystal. Figure 3 presents power measurement results in a 100-h test of a laser diode on an F-mount at an output power of at least 15 W. During the first 15 h, we observed a slight increase in power, followed by slight oscillations. After 50 h of testing, the output power stabilised at a level of 15.1 W.

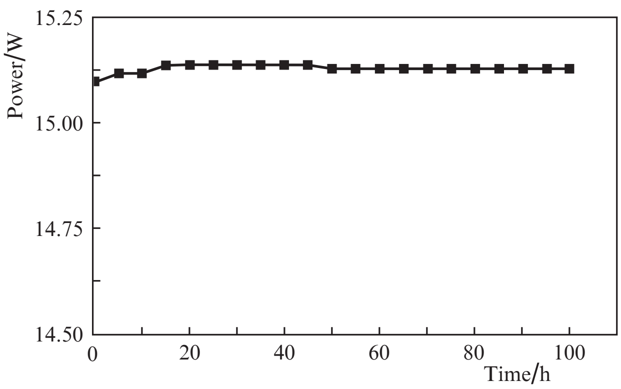

Figure 3. Short-term (100 h) reliable-operation test of a laser diode on an F-mount at an output power of 15 W.

Thus, we have fabricated experimental samples of high-power laser diodes using identical chips on C- and F-mounts, with a wavelength of 980 nm, stripe contact width of 95 μm and cavity length of 4 mm. The maximum output power of the laser diodes on the C- and F-mounts was 21 and 28 W, respectively. The output power of a laser mounted directly on a copper F-mount, without submounts, stabilised at a level of 15 W after 50 h of operation, at a test time of 100 h.

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