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Thermal resistance of 980 nm high-power laser diodes assembled at C-mounts and F-mounts

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Abstract. We present the experimental results regarding the thermal resistance measurements for 100 μm stripe laser diodes emitting in 980 nm spectral range. The dependence of laser thermal resistance on pumping current was measured for series of identical laser chips with resonator length 4 mm and stripe width 95 mkm assembled directly at copper C-mounts and F-mounts without thermo-compensating submounts inside the output power range 10 W and 15 W accordingly. The appropriate method of spectral envelope peak definition was used for output power range 5-15 W in which we observed spectral peculiarities associated with appearance and competition of several peaks at the spectral envelope. We have proposed an explanation of the obtained dependency based on their correlation with the dependence of the total efficiency of the laser on the pump current.

1. Introduction
Higher total efficiency, higher output power and brightness of high-power laser diodes are the aims on the way to expand the fields of their applications first of all in materials processing as well as navigation and communications [1-3]. Reliable output power around 15 W and even 20 W from 100 μm wide stripe now not seems a dream. We observed quite stable operation of several 980 nm 100 μm stripe 4 mm resonator length chips assembled in our laboratory directly at copper F-mounts during several hours at 20 W CW and got for such selected samples reliable CW operation at 15 W output power without decrease during 100 hours tests [3]. At the base of thermal transfer calculations [4,5] and practical experience of assembling several hundreds of such high-power laser chips at different type heatsinks and submounts we realized clearly that one of the key tasks is to insure efficient heat transfer via the first interface, between the laser chip and the heatsink. So, in order to make the next step towards the increase of output power we need to increase the efficiency of heat transfer at the first step from laser active region to a heatsink because thermal energy is concentrated in quite thin quantum well and quite narrow stripe. At the way to the heatsink the heat flow must propagate in solder layer having a thickness around 3-4 μm and through two interfaces of solder with laser chip and with the heatsink, The uniformity and high quality of bulk solder layer and these 2 interfaces are the key technological tasks. After passing the solder layer, thermal flow density becomes much lower. At 20 W output optical power extremely high heat density around 6-7 GW/ cm ^{3} is generated inside the active region under heat flux more than 6 kW/ см^2 .This CW heat flow must be efficiently

removed into a heatsink. At the moment several ways for forced cooling in such extremely hard conditions are implemented – thermoelectrical cooling, microchannel liquid cooling and heat tube or heat camera cooling. The different particular types of forced cooling can be optimal for different cooling schemes, power ranges and heatsinks geometry.

2. Thermal resistance of the laser diode

One of the basic parameters widely used for evaluation the cooling efficiency is thermal resistance. For not-emitting electronic components, it is the ratio of its temperature rise to power supply input rise. For light-emitting devices, especially such as laser diode-with high efficiency, more than 50 % of electrical supply power is converted to optical emission and acts as radiation cooling mechanism of the laser chip. Thermal resistance R_{therm} of laser diode is defined by expression (1).

$$R_{therm} = \Delta T / \Delta P_{therm} \tag{1}$$

where ΔT -the laser chip active layer temperature rise, ΔP – the increase of electrical power supplied by a laser driver, $P_{therm} = I U - P_{opt}$, I – pumping current, U- voltage, P_{opt} – emitted optical power.

In our recent work [6] thermal resistance dependence on pumping current was measured for high-power range up to 15 W CW for 980 nm laser chips assembled at F –mount heatsinks.

3. Experimental results

We repeat here the main result at Fig.1 for reader convenience. First of all, R_{therm} is obvious not-linear and quite complex function of pumping current due to non-linear dependence of peak wavelength against pumping current. Curve A at Fig.1 is added for comparison with the basic case of linear spectral peak wavelength dependence. Unfortunately, in [6] we had possibility to measure only small lot of 3 samples assembled on F-mount heatsinks.

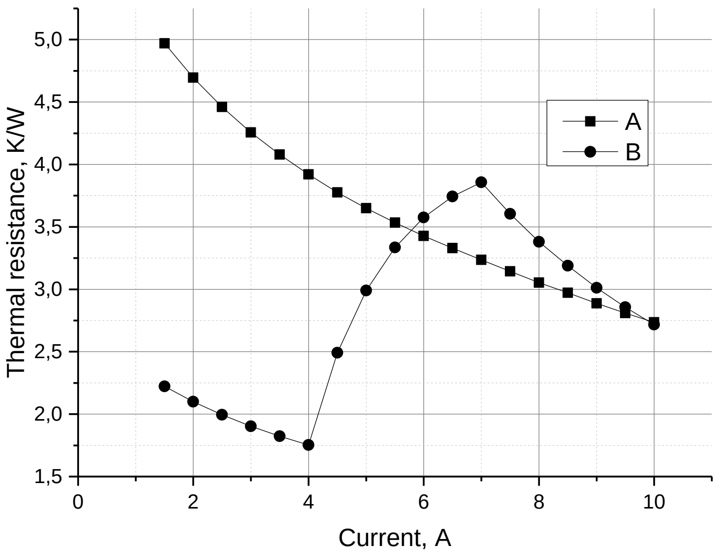

Figure 1. The thermal resistance of 980 nm laser assembled at F-mount heatsinks. A–"ideal curve" for linear peak wavelength dependence, B- experimental results.

So, to ensure the reliability of the results obtained for F-mounts, here we present similar results for a uniform lot of 10 samples of identical type chips from one gel-pack assembled at C-mounts. The corresponding results on peak wavelength dependence for typical 3 samples from that lot of 10 lasers assembled at C-mounts are presented at Fig. 2. We can say that at pumping currents 1-4 A the peak wavelength increase in a linear manner with a slope less comparable with current range 5 -10 A. These results are in principle similar regarding the laser samples assembled at F-mounts.

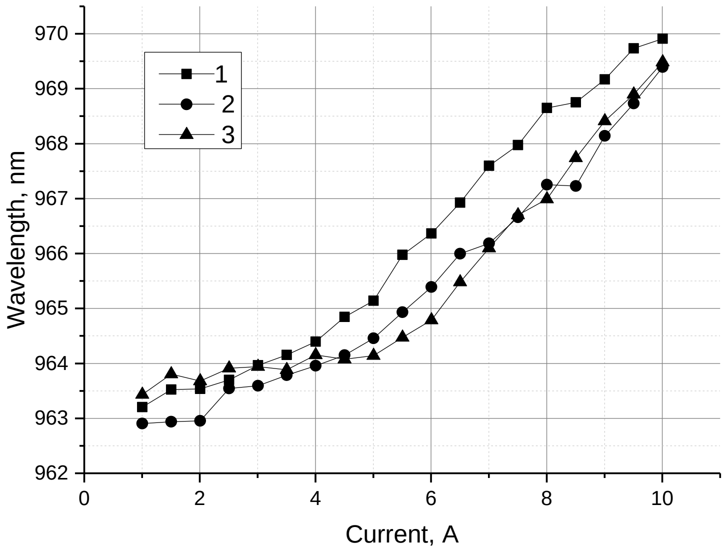

Figure 2. The peak wavelength of 980 nm 3 laser samples assembled at C-mount heatsinks.

The main difference between C-mount and F-mount samples is obvious. For F-mounts in the current range up to 10 A, that we observed 3 main different slopes of peak wavelength dependence on pumping current and for C-mounts in the same current range up to 10A only 2 pronounced slopes. But in both cases the nominal current at which we observed the change of initial slope of peak wavelength dependence was the same, around 4-5 A. The pumping current I_{max} at which we observe the maximum of total efficiency η_{tot} according to our simple analysis was the same - (2), (3) and (4).

$$J = \sqrt{I_{th} U_{th} / R_s} \tag{2}$$

$$I_{\max} = I_{th} + J \tag{3}$$

$$\eta_{tot}^{\max} = \frac{\eta_d J E_g}{I_{\max}(U_{th} + R_s J)} \tag{4}$$

In our opinion, the similar results obtained for 3 tested lasers at F-mounts and 10 lasers at C-mounts present the evidence that not monotonous dependence of thermal resistance on pumping current is a regular and quite important feature of laser diodes. We must keep it in mind in the analysis of several important laser diode characteristics associated with the influence of heat generated inside the active layer. At high currents exceeding 6-10 I_{th} thermal resistance continue to decrease with higher pumping due to the decrease of series resistance R_s. This feature is the same for total efficiency, at very high pumping currents it continues to decrease with lower slope also due to a decrease of R_s.

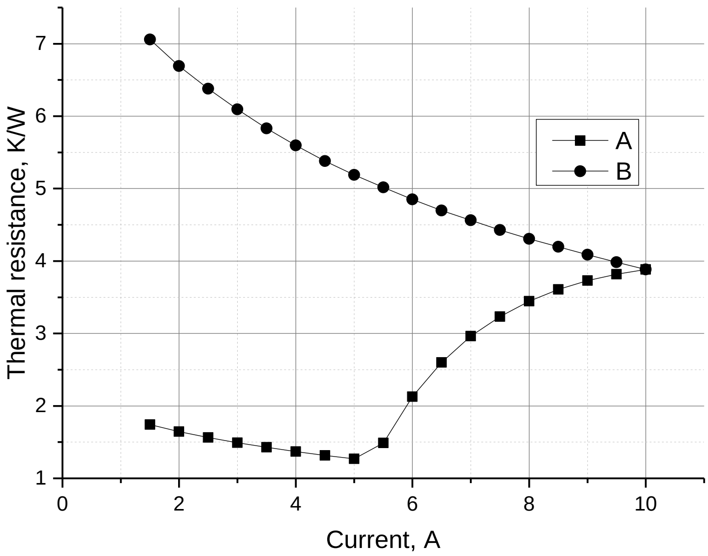

Figure 3. The typical thermal resistance of lasers assembled at C-mount heatsinks. A–“ideal curve” for linear peak wavelength dependence, B- experimental results.

The main features of thermal resistance measured for C- mounts is clear in Fig,3. The curve exhibit the decrease in current range from I_{th} to I_{max}, increase at higher currents and finally coincide with “ideal” curve for linear peak wavelength dependence at value 3.9 K/ W.

4. Conclusions

We carefully examined spectral characteristics of laser diodes in power range up to 10 W CW for C-mount samples and up to 15 W CW for F-mount samples. Spectral peculiarities were observed at output power more than 5-6 W CW for both types of samples. We also measured non- monotonous dependence of emission wavelength on pumping current for both types of samples. We overcome the problem of correct spectral maximum definition by the simple method proposed in [6]. Our experimental data indicate that for identical laser chips are emitting in the spectral range 980 nm and assembled at F-mount as well as at C-mount heatsinks, thermal resistance is also a non-monotonous and quite complex function of pumping current. If we assume the “ideal” linear dependence of emitting wavelength maximum on pumping current, thermal resistance decreases monotonously according to back-proportional law. Real experimental data for both types of samples indicates that thermal resistance correlates with the dependence of total efficiency on pumping current. In the current range from threshold I_{th} to a current corresponding to the maximum of total efficiency $I_{max,}$ thermal resistance decreases in accordance with the increase of total efficiency because more part of pumping power is emitted from laser chip outside. At higher pumping currents we observed thermal resistance increase due to saturation and subsequent decrease of total efficiency at pumping above the current $I_{max.}$

It means that we can adequately use the definition “thermal resistance” to evaluate the quality of laser chip assembling and effectiveness of different cooling schemes only if we compare its value at the same pumping current. Formally for pumping currents 4-5 A close to I_{max}, we obtained the values of R_{therm} around 1.75 K/ W for F-mount and 1.25 K/ W for C-mount samples. These values are similar and even better than the best-published results for the same samples assembled at composite diamond –copper sub mounts with high thermal conductivity and efficient microchannel cooling [2]. At the same time, we suppose to compare the values at pumping current 10 A more adequate and realistic, where the appropriate values are 2.75 K/ W for F-mounts and 3.9 K/ W for C-mounts. These values are slightly more than 1.5-2 K/ W achieved in [2] but better than 4.25 K/ W obtained in [7]. We believe that managed to get such not bad results using the technology of direct bonding of laser chips to copper heatsinks due first of all to the improvement of interface quality and appropriate improvement of the heat transfer efficiency at interfaces between the laser chip and the heatsink.

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