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Laser diodes emitting up to 25 W at 808 nm

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***Abstract*. Crystals of high-power laser diodes are directly mounted on copper heat-removing elements. The maximum output power of 25 W is obtained many times in a 808-nm cw laser with the 150-μm-wide strip contact at 20 °C. After training tests at the output power of 6 W for 200 hours, the yield of acceptable samples was 80 %. No changes in the output parameters were observed after tests for 70 hours at the output power of 8.5 W. Tests are being continued.**

Keywords: *high-power laser diode, laser assembly, service life.*

1. Introduction

The aim of this paper is to increase the output power and provide the required service life of a laser diode as well as to enhance the technological effectiveness and reduce the cost of its assembly. Mounting operations of the laser crystal are rather complex and expensive and determine the output parameters of fabricated devices (the output power, the total efficiency, spectral parameters of radiation, reliability and service life). Mounting should provide not only the specified thermal regime of the laser crystal operation but also the control of thermoelastic stresses within the admissible limits for its reliable and long-term operation.

A laser crystal (a chip of a single laser or a laser array) initially experiences stresses due to the difference in the thermal expansion coefficients of heterostructure materials and due to the technological operations of mesastructure etching, contact deposition, polishing and finishing of a heterostructure, cleavage of mirrors and side faces, and deposition of protective antireflection and reflection coatings on crystal mirrors.

The problem of thermoelastic stresses is commonly solved by using either a very plastic solder (for example, based on indium) or an intermediate thermal compensator with the thermal expansion coefficient close to that of the laser crystal.

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By assembling chips on the indium solder, we failed to achieve repeatability of the results, the maximum output power was 6.3 W, and the laser could operate for no more than an hour. The degradation was caused by the creep of the solder, and as a result, the maximum resource power of the laser did not exceed 4 W [1].

Thermal compensators are fabricated either from dielectrics (BeO, AlN, SiC) or metal powders (copper – molybdenum, copper – tungsten). Their heat conduction is about 50 % of the heat conduction of copper. The most advanced thermal compensators are produced by Sumitomo Electric (Japan) from a copper – diamond composite and have the certified heat conduction that compares well with that of copper; however, the cost of these compensators with metallic coatings exceeds the cost of a laser crystal itself.

A significant disadvantage of thermal compensators is their low technological effectiveness because they require precision processing for obtaining a low surface roughness and a high-quality output crystal edge and should have a metal coating to transmit high pump currents (10 A and higher).

We have managed to solve the above-mentioned problems without the use of thermal compensators, which significantly enhances the technological effectiveness and reduces the cost of the assembly. We mounted laser crystals directly on copper heat-removing elements by using a hard solder.

When assembling laser crystals, one should take into account that the introduced thermoelastic stresses (in a soldered weld and in the regions of soldering upper electrodes) are superimposed on mechanical stresses existing in the crystal. In addition, to provide the long-term operation of a laser diode, it is necessary to produce a junction which is uniformly stable over the heat transfer area (thermal resistance of the laser) and the electric contact (series electric resistance of the laser).

Assembly operations increase the cost of a fabricated laser at least by 5 – 10 times for the 50-% yield of acceptable devices. To expand the applications of high-power laser diodes, it is necessary to increase considerably the yield of acceptable samples and to reduce their cost.

2. Crystals (chips) of high-power laser diodes and their assembling

The highest output powers of both single laser diode chips and laser arrays were obtained when the resonator length of the laser crystal was increased from 1 – 1.5 mm to 3 – 4 mm. This became possible by using superwide-waveguide heterostructures in which the internal loss is decreased down to

0.5 cm^{-1} [2]. Such long laser diodes made of these heterostructures have also other important advantages: a lower thermal load (proportional to the area of the active medium), a lower radiation load on the mirrors, and a lower radiation divergence in the plane perpendicular to the p – n junction. A two-fold decrease in the divergence (down to 20 ° – 25 °) allows the more efficient focusing of radiation, while the decrease in the thermal load under the condition of a uniform heat removal from the chip makes it possible to increase the output power in the resource regime. The chip used in this paper is shown in Fig. 1.

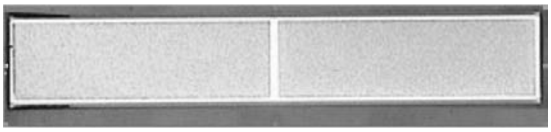

Figure 1. Chip view from the epitaxial structure side. The resonator length is 3 mm and the width is 0.5 mm.

Laser diodes were assembled in a clean room (class 10 000), a Fineplacer Lambda A6 setup (Finetech, Germany) for laser crystal soldering was placed under a Strangl laminar clean box (Germany) providing air cleanness class 100. Upper electrodes were welded by using an HB12 ultrasonic welder (TPT, Germany), which was also placed under the laminar box of class 100. The assembled laser (top view) is shown in Fig. 2.

The laser output power up to 10 W was measured ten times, and no signs of power saturation and crystal damage were observed. The laser mirrors were controlled with an optical microscope and a scanning electronic microscope (Fig. 3).

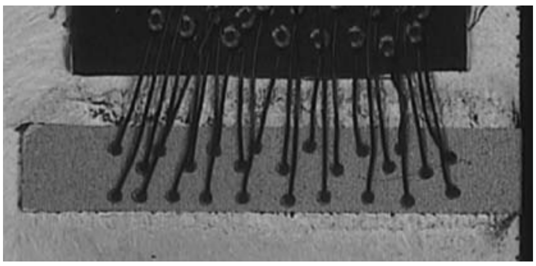

Figure 2. Top view of the assembled laser chip.

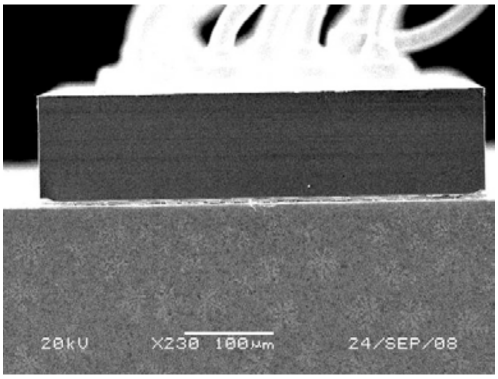

Figure 3. Scanning electronic microscope microphotograph of the assembled laser diode ($\lambda = 808$ nm). View from the output mirror side.

3. Output parameters of laser diodes

To determine the stability of the obtained optimum of the diagram of the laser crystal mounting process (the degree of deviation of the laser output parameters from optimal ones upon varying the main parameters of the assembling process near the optimum), we studied the parameters of lasers assembled at the 10-% variation of the temperature maximum and the 50-% variation of the assembling time. We found that near the optimum, the developed assembling process is rather stable, the scatter of the output power at the 8-A pump current being 7 – 8.3 W. The scatter of threshold current values was insignificant and the scatter of the slope of light – current characteristics was within 1.03 – 1.22 W A^{-1}.

By varying the regimes, we determined the optimal parameters of the process diagram. The light – current and volt – current characteristic of the samples assembled in the fixed regime, which is close to the optimal one, are reproduced at powers up to 6 W with the accuracy close to that of measurements, while at the output power of about 10 W the scatter in its values is about 10 % (1 W), which is probably caused by the inhomogeneities of the crystal thermal contact and the heat-removing element. Figure 4 shows the light – current characteristics of lasers assembled in the fixed regime.

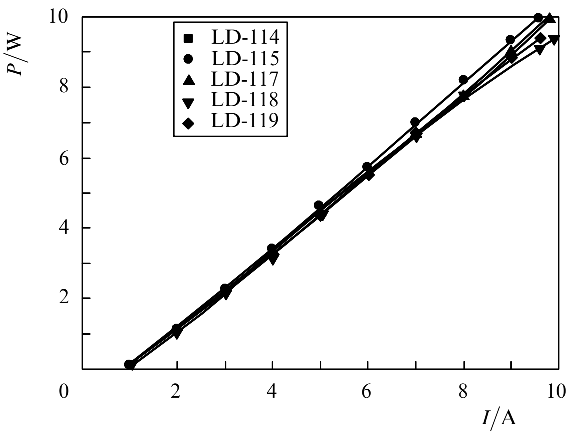

Figure 4. Light – current characteristics of a batch of laser diodes assembled in the fixed regime.

The output parameters (power and total efficiency) of the LD-117 laser are presented in Fig. 5. To measure powers above 10 W, we used an integrating sphere calibrated to the maximum power of 120 W; the certified linearity range of the measuring circuit was 10 – 120 W. The linearity range of measurements was tested by using a cw laser array emitting from 10 to 60 W. Calibration of the integrating sphere was additionally verified at the 10-W output power [the upper limit of the Laser Mate power meter (Coherent) and the lower limit of the linearity range of the integrating sphere]. Calibration of these two devices coincided within 2 % at the power of 10 W.

The maximum total efficiency of the laser was 53 % for the pump current of 13.3 A and the output power of 14.5 W. The output power of up to 25 W was achieved at the temperature of the heat-removing element 20 °C, the light – current characteristic being invariable during multiple tests.

A noticeable deviation of the light–current characteristic from the linearity was observed at powers above 12 W, which, as seen from Fig. 5, corresponds to the output power near the efficiency maximum. The strip contact width of the laser chip was 150 μm, hence, the total limiting repeatable output power of 25 W and the limiting power of 0.167 W obtained from one micron of the active medium width correspond to the best world results for laser diodes emitting at 808 nm [3].

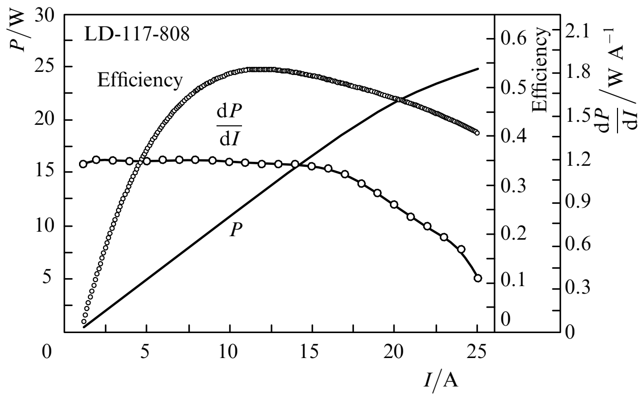

Figure 5. Dependences of the power, efficiency and slope efficiency on the continuous pump current. The temperature of the heat-removing element is 20 °C.

4. Life tests

Figure 6 presents the data of life tests of samples from one batch of lasers at the output powers of 6 and 8.5 W. During optimisation of the process diagram we selected the regimes at which all the failures of the lasers (identification of potentially unreliable devices) occur within a rather short time (up to 30 h), and thus, the prediction of the operating life of the lasers does not require expensive long-term tests, which reduce substantially the operating life of the laser. The obtained data indicate that no more than 100 h of tests are required to select reliable lasers.

The data presented in Fig. 6 give grounds to optimism because only three lasers out of 15 failed within 28 h at the power of 6 W, other lasers in the batch operated faultlessly within the next 170 h and did not show any changes in their output power. The power level of LD-117 and LD-118 lasers after 70 h of tests at the power of 8.5 W did not change, the tests are being continued. It is obvious that only after full-scale tests of a batch of no less than 100 samples within 1000–2000 h, it will be possible to answer the question about the real predicted operation life of these lasers and the reliability of the developed technology.

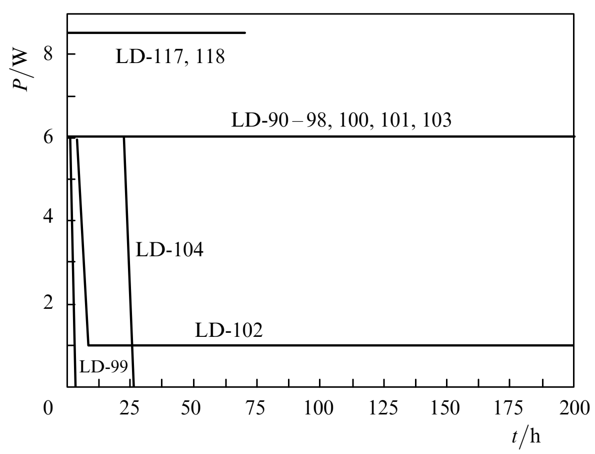

Figure 6. Data on the reliability of 15 samples of lasers assembled in one batch at the power of 6 W and two samples (LD-117 and LD-118) at the power of 8.5 W.

5. Conclusions

(i) A new method was developed for mounting crystals of high-power laser diodes without thermal compensators. C-mounts made of copper were used as heat-removing elements.

(ii) A high reproducibility of the parameters was obtained at their first measurement after the assembling (the output power of 10 W at the pump current of 10 A) and a rather high yield of acceptable samples was achieved (80 % at 808 nm) after the training tests within 200 h at the power of 6 W.

(iii) After tests within 70 h at the power of 8.5 W, the output power and the electric parameters of the lasers did not change and the damage of resonator mirrors was not observed. The tests at 8.5 W are being continued.

(iv) The maximum reproducible output power of the laser with a 150-μm-wide strip contact was 25 W, which corresponds to the best results achieved at the wavelength of 808 nm [3].

References

1. Bezotosnyi V.V., Bondarev V.Yu., Kovalenko V.I., Krokhin O.N., Pevtsov V.F., Popov Yu.M., Tokarev V.N., Cheshev E.A. *Kvantovaya Elektron.*, **37** (11), 1055 (2007) [*Quantum Electron.*, **37** (11), 1055 (2007)].
2. Bezotosnyi V.V., Vasil'eva V.V., Vinokurov D.A., Kapitonov V.A., Krokhin O.N., Leshko A.Yu., Lyutetskii A.V., Murashova A.V., Nalet T.A., Nikolaev D.N., Pikhtin N.A., Popov Yu.M., Slipchenko S.O., Stankevich A.L., Fetisova N.V., Shamakhov V.V., Tarasov I.S. *Fiz. Tekhn. Poluprovodn.*, **42** (3), 357 (2008).
3. Wei Gao, Zuntu Xu, Lisen Cheng, Kejian Luo, Andre Mastrovito, Kun Shen. *Proc. SPIE Int. Soc. Opt. Eng.*, **6456**, 64560B1 (2007).