Modelling of temperature profiles and stress in CW laser diode bars

V V Bezotosnyi, V P Gordeev, V A Oleshchenko

1 P.N. Lebedev Physics Institute, Russian Academy of Sciences, Moscow, Russia
2 National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia

E-mail: vs.gordeev@yandex.ru

Abstract. We present the results of 3D thermal regimes modelling of CW laser diode arrays (LDA) assembled on the CS-mount type heat sinks. The dependences of the LDA temperature profiles on the fill factor (FF) of the LDA aperture at different levels of thermal load in different sections on LDA, including those inaccessible for direct experimental measurement calculated and discussed.

1. Introduction

Semiconductor LDA have found a wide range of practical applications, ranging from medical devices in surgery and laser hair removal, to materials processing and laser inertial thermonuclear fusion. LDA’s are compact, efficient, the output parameters of LDA continue to improve, thus expanding applications at the forefront of scientific and technical progress. Unfortunately, in many cases of practical applications, the conditions of LDA’s operation do not allow to achieve the most effective heat flux removal from semiconductor crystal. This is a main limiting factor for the output power, especially in high-power CW operation. To increase the output power and reliability it is necessary to optimize the distribution of thermal energy released in the emitting clusters of the array. Not uniform distribution of heat and the mechanical stresses accompanying them in LDA leads to a loss in the quality of radiation, which also significantly limits their applications efficiency, particularly in systems of incoherent spectral summation of LDA radiation in order to achieve high brightness and high power.

Thus seems useful to study the temperature profiles and mechanical stress in the LDA under different operational conditions and their dependences on the main constructive parameters: FF, cluster width, pitch, optical resonator length, etc. in order to optimize these parameters for the increase of the output power, improvement of power uniformity from cluster – to cluster as well as to improve the spectral characteristics. This optimization is also valuable for guaranteed service lifetime.

The Comsol Multiphysics software environment was used for three-dimensional modeling of the thermal regime of CW LDA assembled at CS-mount type heat sinks by the finite element method. The dependences of temperature profiles on filling of the LDA aperture by radiating clusters (FF) and the number of clusters in the LDA at different levels of thermal load were studied. LDA width was 10 mm, FF varied in a commonly used range of 30% - 70%, modeled number of clusters was 20, 47 and 67 and resonator length 1.5 and 2 mm. Conditions of operation - CW pumping, conductive cooling, boundary condition - a constant temperature of the down face of the CS-mount equal to 20 °C.
corresponding to an experimental condition of water cooling with a chiller. The model contains the following assumptions - uniform heat transfer from the active area of LDA to the bottom of the heat-conducting element and the planar geometry of the heat transfer boundary. The range of parameters variations were determined by the characteristics of experimental samples of LDA produced and studied in [1-4].

2. Simulation result
The simulation was conducted with a 10% step variation of the fill factor, depending on the power, thermal load and the number of clusters. Figure 1 shows a General view of a three-dimensional model of deformations in LDA assembled at a CS-mount heat sink type, operating at a typical CW thermal load 60 W, corresponding to the experimental conditions for devices operated in the reliable regime.

For a more convenient understanding of the qualitative picture of arising thermo-elastic stress, the deformation values presented at figure 1, were reinforced by 40 times. This picture clearly shows the nature of LDA strain. The central part of the upper surface of C-S mount and its front face are deformed upwards and outwards respectively, relative to their position in the "cold" LDA (in the absence of thermal load) as a result of non-uniform heating of the LDA crystal. That non-uniform profile is formed by more temperature rise in central part of LDA in comparison with peripheral parts.

Figure 2 shows the typical temperature profile of the LDA depending on the fill factor at a fixed thermal load power of 60 W and 47 clusters. The temperature values are given for output mirror plane at the position of the active layer. The obtained distribution of the temperature profile line indicates the inhomogeneous character of the thermal field associated with the width and spacing of the emitting clusters. This graph also shows that the temperature in the central part of the LDA is much more than in the peripheral part. The temperature difference is about 10 °C. Temperature steps in the central part of LDA between emitting clusters and passive areas are about 2.5 °C. With an increase in FF from 0.3 to 0.7, the temperature steps amplitude is reduced by about 2 times. The absolute temperature of the clusters also decreases, at the same time the width of the cluster temperature peaks increases, exhibiting the smoothing of the temperature distribution.

![Figure 1. Model of laser diode bar](image)

Figure 1. Model of laser diode bar
Such changes in temperature values for different FF under fixed thermal load can be explained by the difference in the heat flux density because the conditions of the heat transfer are improved with the FF increase due to the increase of the emitting clusters surface area.

An important parameter for understanding the thermal processes in LDA is the temperature difference between the central and peripheral radiating clusters. This difference shows the degree of temperature non-homogeneity of the LDA in operation, which, in turn, affects the value of mechanical stresses, leading to a loss of radiation spectrum quality and change in other important parameters, in particular, reliability and service life.

**Figure 2.** Temperature profile at 60W thermal load for 47 cluster LDA

**Figure 3.** Temperature of the central and side emitter for 47 clusters LDA at 60 W and 100 W thermal load in FF range 0.3-0.7
At the base of the calculated data, the dependence of the temperatures of the central and peripheral clusters of the LDA on the filling factor were obtained. The graph of this dependence presented in figure 3 for a fixed thermal load power of 60 W and 100 W and 47 radiating clusters in LDA. As can be seen from the graph, according to an increase in the filling factor, the temperature tends to decrease. At FF = 70 % it is approximately 42 °C for the central cluster at 60 W of thermal load, while the temperature at the same thermal load is about 35 °C for the peripheral cluster.

According to the obtained data, the dependence of the temperature difference between the central and peripheral clusters on the number of clusters in the bar was built, the graph of this dependence at a fixed thermal load of 60 W is shown at figure 4.

![Figure 4](image_url)

**Figure 4.** Temperature difference between central and side clusters in cluster number range 20-67 and FF range 0.3-0.7

According to the graph, with the increase in the number of clusters, the temperature difference tends to "saturation", the nature of that dependence is nonlinear. Such dependence character can be explained by the effective smoothing of the temperature field as the heat transfer area is filled with emitting clusters corresponding to the increase in number and density of heat sources. The total temperature difference in the whole range of the emitting clusters number 20-67 is not more than 1.5 °C. With increasing FF in the range of 0.3-0.7, the temperature difference decreases from 0.5 °C to 0.25 °C for 20 and 67 clusters.

3. Conclusion

3D simulation of temperature profiles and induced thermoelastic stress in LDA, assembled on CS-mount type heat sink in the range of CW thermal load power 20 – 100 W, was performed using finite element method. Temperature distribution in LDA in the range of FF 0.3 - 0.7 and emitting clusters number in the range 20-67 was obtained. At a fixed thermal load, increasing FF leads to a decrease in the cluster maximum temperature, equalization of the temperature field and induced thermo-elastic stress. The temperature field in the LDA laser crystal exhibit effective smoothing with the increase of the number of emitting clusters due to a more uniform filling of the heat spreading area by heat sources.
References

[1] Bezotosnyi V V, Kozyrev, A A, Kondakova, N S, et al. 60-W continuous wave laser diode arrays emitting at a wavelength of 808 nm. Bulletin of the Lebedev Physics Institute 2016 V43 I12 p369-370.

[2] Bezotosnyi V V, Kozyrev A A, Kondakova N S, et al. Quasi-CW 808-nm 300-W laser diode arrays. Quantum Electronics 2017 V47 I1 p5-6.

[3] Bezotosnyi V V, Gordeev V P, Krokhin O N, Mikaelyan G T, Oleshchenko V A, Pevtsov V F, Popov Yu M, Cheshev E A. Modelling and experimental study of temperature profiles in cw laser diode bars. Quantum Electronics 48(2) 115–118 (2018).

[4] Bezotosnyi V V, Gordeev V P, Oleshchenko V A Pumping level impact on optical power and spectra uniformity of CW laser diode bars. Quantum Electronics 48(6) 502-505 (2018).