# Thermo-elastic stress in high-power laser bars

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**Abstract**. This article presents the results of three-dimensional modeling of thermo-elastic stresses arising during the operation of a powerful laser diode bars mounted on a CuW thermal compensator using AuSn soldering alloy in a wide range of thermal loads up to extreme values. Calculated distributions of thermo-elastic stresses at the output and highly reflective mirror of the laser bar is compared. An interpretation of the results obtained, in particular, higher values of thermo-elastic stresses on a less hot highly reflective mirror, in comparison with a hotter output mirror, is proposed.

## 1. Introduction

With an increase in the power of modern laser bars and laser arrays [1,2] based on them, the requirements for uniform radiating parameters along the aperture width also increases. This is due to the transition to an increase in the brightness level of multi-element laser sources by means of the spectral summing the output power of multiple emitters in individual laser bars [3,4], in sets of several laser bars, as well as two-dimensional matrices based on them. Factors that negatively affect the homogeneity of almost all the main emitting parameters (spectrum, power, polarization, and reliability) [5] are the inhomogeneously heating of the laser bar emitters and its consequence - thermo-elastic stresses, which, due to the complex geometry of the laser bar and inhomogeneous mechanically loads of emitters leads to a significant mismatch of the radiative parameters, which sometimes appeared itself even for neighboring emitters.

Such a desirable increase in the output power entails an increase in the thermal, optical, and thermo-mechanical loads on the laser bar as a whole, and especially on the at resonator mirrors. The output mirror of the laser bar, due to the fact that it is located on the edge where the massive heat sink element ends, undergoes the highest thermal load. The back - highly reflective (HR) mirror in comparison with the output mirror has a more favorable cooling regime. The influence of thermo-elastic stresses in the area of the output and HR mirrors is not well understood. The main aim of this work is to analyze the distribution of thermo-elastic stresses along the length of the laser bar resonator. To increase the uniformity of the output parameters of laser emitters along the emitting aperture, it is necessary to know what happens to thermo-elastic stresses along the length of the resonator in each of them, since the thermo-elastic stresses distributed along the length of the resonator of the emitter make a resultant contribution to the output parameters of each individual emitter.

Direct measurements can only approximately determine what distributions of thermal fields and stresses occur in the laser structure after its installation at the heatsink and case and during its operation. We can see the total contribution of all factors affecting the spectrum or polarization of the emitter, but to understand and separate the influence of each factor it is necessary to use modeling. The construction of 3D models [6–13] makes it possible to understand how heat deforms and strains the laser structure at various pump levels, and which parts of the laser bar are most susceptible to thermo-elastic stresses.

## 2. Model

The model of thermo-elastic stresses we developed allows us to clearly demonstrate the features that arise during the operation of the laser bar at various pump levels. To build a three-dimensional numerical model by the finite element method, the licensed Comsol Multiphysics package was used. In the model, a heat source has various powers in the active region of the laser bar, which simulated the thermal load experienced by the laser bar at different pump levels. We assumed that the laser bar in the model is mounted with AuSn solder on 300 microns thick CuW thermal compensator, which also is mounted through AuSn solder on a CS-mount copper heatsink. The bottom face of the CS-mount in the model has a constant temperature of 20°C (boundary condition), which corresponds to the conditions of the experiment. The model used the following physical parameters of the materials included in the assembly of the laser bar on the heatsink with thermal compensator which are presented in Table 1.

**Table 1.** Material constants.

| Material | *Elastic modulus (GPa)* | CTE (×10-6 m/K)) | *Poisson's ratio* |
|---|---|---|---|
| **GaAs** | 86 | 5.7 | 0.31 |
| **39Pb-61Sn** | 40 | 26 | 0.4 |
| **20Au-80Sn** | 68 | 16 | 0.405 |
| **CuW** | 260 | 7 | 0.3 |
| **Cu** | 128 | 16.5 | 0.36 |

## 3. Results and discussion

### *3.1. Thermal fields*

Having received the temperature distribution on the output mirror (shown Fig.1.a.) at various thermal loads, we took as the limit value of the thermal load for studying thermo-elastic stresses, the power of a heat source in the active region equal to 220W (shown at Fig.1.b.) At this power, the average temperature of the active region reaches 110°C, which is the limiting temperature for the operation of modern laser bars [13].

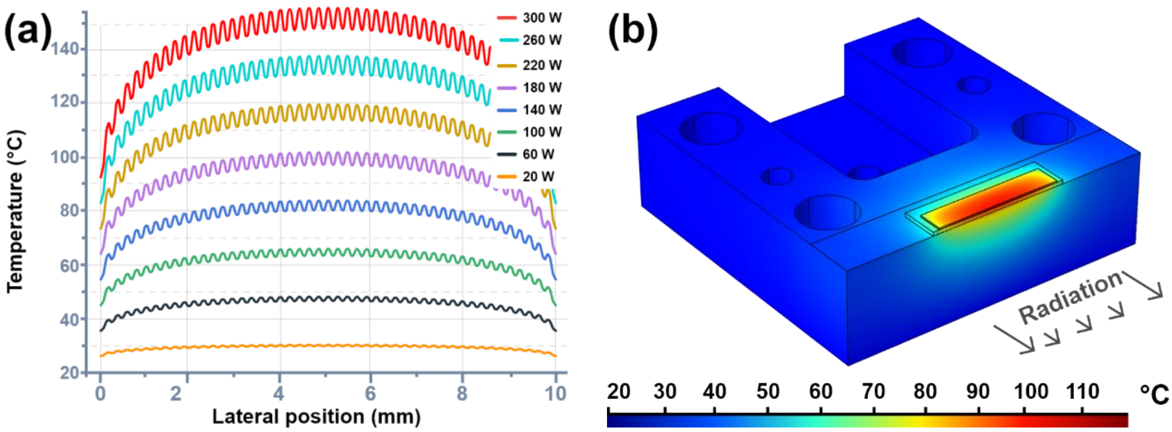


**Figure 1.** a) The temperature profile along the aperture of the output mirror at various heat loads. b) Three-dimensional temperature distribution in the laser bar at a thermal load of 220 watts.

Usually, huge attention is paid specifically to the output mirror of the laser [14], because the output mirror has a higher optical and thermal load compared to the HR mirror. Undoubtedly, the cooling efficiency of the output mirror is less favorable than for the HR mirror. The cooling efficiency of the output and HR mirrors is also reduced due to the fact that the laser diode bar chip is mounted on a temperature compensator with a thermal conductivity of not more than 200-250 W/m· K, which is almost half lower than that of a copper CS-mount, which leads to the extreme operation mode of the laser mirrors.

### *3.2. Deformation and thermoelastic stresses*

Studying the simulation results in terms of thermo-elastic stresses showed an interesting feature that makes it possible to take a fresh look at the operation mode of the HR mirror in comparison with the output mirror of the laser bar. In Fig. 2. a.b. picture is presented that is often used to estimate generalized thermo-elastic stresses according to von Mises (1) (where $\sigma_{ij}$ are the components of the projections of stresses on the axes) [15] in the active region of the laser bar at a thermal load of 220 W, where the magnitude of the amplitudes of stress is duplicated by the colour palette.

$$\sigma_i = \sqrt{\frac{(\sigma_{11}-\sigma_{22})^2+(\sigma_{22}-\sigma_{33})^2+(\sigma_{33}-\sigma_{11})^2+6\left(\sigma_{12}^2+\sigma_{23}^2+\sigma_{31}^2\right)}{2}} \quad (1)$$

The stress distribution in the active region of the laser diode array obtained from the model appeared like a complex amplitude surface, the shape of which is determined by both the thermal field profile and the assembly geometry. The stresses are larger in the center, because it is in the hottest area of the bar and subside to edges as less heated areas. The maximum stresses are located on the output and HR mirrors, which is expected. In the foreground Fig.2. a. there is an output mirror on which the stress in the emitters reaches 85 MPa, and between the emitters, in the passive areas, it decreases to 50 MPa. A very significant stress difference of 40%, while the temperature rise between these areas is less than 10%.

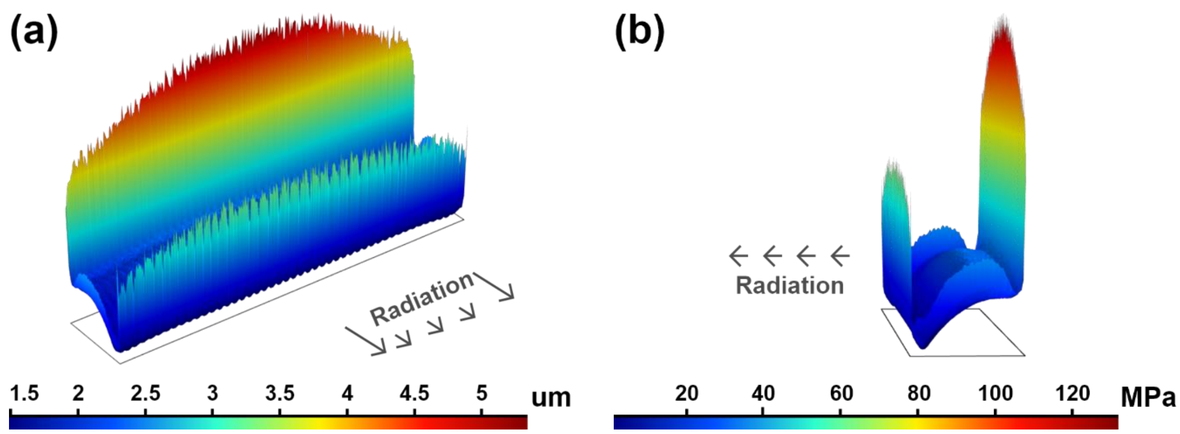


**Figure 2.** a) Isometric view of the generalized thermo-elastic stresses according to von Mises in the active region of the laser bar at a thermal load of 220W. b) Generalized von Mises thermo-elastic stresses in the active region of the laser bar at a thermal load of 220 W, the side view is the YZ projection along the emitter cavity of the laser bar.

In Fig.2. b. the stress distribution in the YZ-projection is shown along the resonator length of 2 mm. It is seen that along the length of the resonator, the stress first decreases to a minimum of 4 MPa at a distance of 200 µm from the output mirror and then gradually increase to 40 MPa in the direction of the HR mirror, undergoing a sharp grow near to 200 µm to the HR mirror, reaching 120 MPa on the HR mirror. The main feature that this model demonstrates is a significantly large amplitude of stresses precisely on the HR mirror, more than 120 MPa. At first glance, it may seem that the dominant factor determining thermo-elastic stresses is temperature, and the whole picture of thermo-elastic stresses distribution should be in full agreement with the distribution of heat in the laser bar. However, the model shows that the geometry of the arrangement and properties of the materials of the elements included in the assembly of the laser bar are very significant.

The stress distribution becomes clear if we study the deformation pattern of the entire laser bar assembly, consisting of a laser crystal, a submount, and a heat sink element in the planes of the output and HR mirrors. In Fig. 3. deformations of secant planes in a laser bar assembly in planes are shown in Fig.3. a. for output and in Fig.3. b. for HR mirrors. For clarity, the deformation is exaggerated by 40 times, the black contour is the deformable section of the laser assembly.

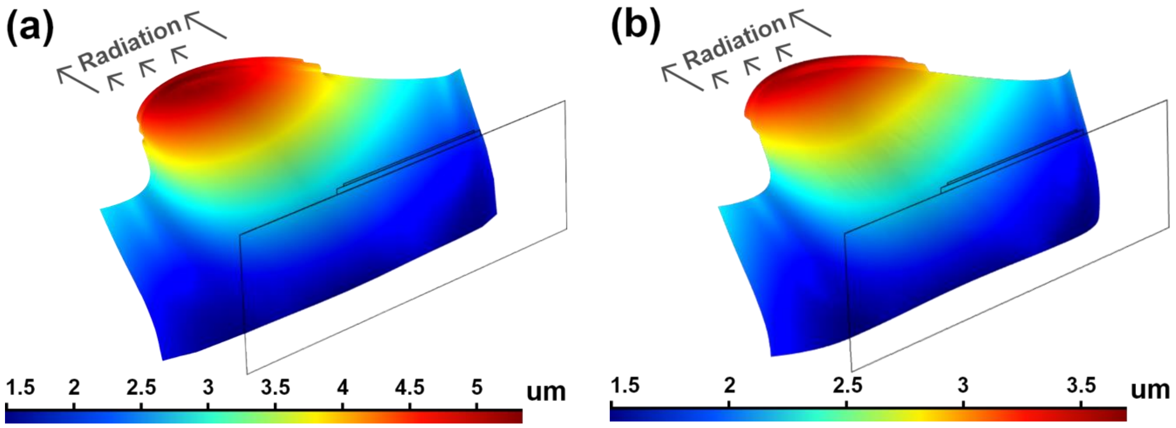


**Figure 3.** The deformation of the laser assembly a) in the plane of the output mirror, b) in the plane of the rear mirror.

The model shows that all elements of the laser assembly undergo deformation, and elements that are at a greater distance from the heat source experience the less deformation. However, we notice that the difference in temperature difference along the length of the resonator between the output and HR mirrors does not exceed 10°C, that is, within 10%, while the strain is 1.4 times different at the same regions. Since the plane cutting the laser assembly in the region of the output mirror has forward displacement to values of 5 μm, while the plane cutting the laser assembly in the region of the HR mirror was deformed and curved with a maximum displacement of 3.5 microns. Such a feature of deformation is caused of the final location plane of the plane of the output mirror at the edge of the heat sink assembly volume and final location plane of the HR mirror in the volume of the laser bar heatsink assembly. The plane of the output mirror has the ability to expand into the free space in front of the laser bar, while the plane of the HR mirror does not have the ability to relax, meeting the resistance of the laser bar assembly materials, which creates an increased value of thermo-elastic stresses at the HR mirror of the laser bar crystal.

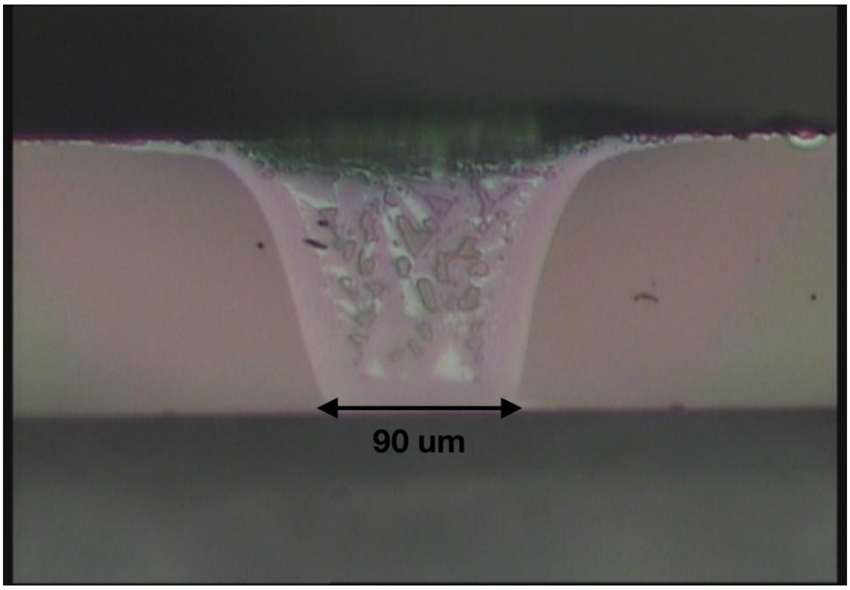


**Figure 4.** Photo of the destroyed rear mirror of a single diode tested at the limit values of the pump current.

Usually, increased attention is given to the output mirror when studying and optimizing the assembly design. However, it is necessary to take into account the fact of the maximum values of thermo-elastic stresses are located on the HR mirror. The experiments we conducted when testing single laser diode with an emitter width of 90 μm in the limiting modes of pump currents, with an output power in the continuous mode up to 25 W [16, 17], showed that not only the output mirror can be destroyed under extreme loads [18], but also the HR mirror. A photograph of the destroyed HR mirror of a single laser diode is shown in Fig. 4. The solidified melt of a mixture of materials of a semiconductor heterostructure and a HR mirror corresponds to the spreading form of current from the upper N-electrode to the P-substrate at the emitter width 90 μm. Which effect looks like as pinching of current at the local region beside the HR mirror due to high level of stress.

## 4. Conclusion

The calculations performed within the framework of the three-dimensional model of thermal fields that we developed and calculated distributions of thermo-elastic stresses in laser diode arrays allowed us to obtain a more detailed understanding of the fields of thermo-elastic stresses inside the active region of the laser structure along the cavity length, in particular, near the output and HR mirrors. The maximum stress values which are achieved at the output mirror are around 85 MPa and at the HR mirror around 120 MPa. An explanation is obtained for a significantly higher (by 40%) thermo-elastic von Mises stress load on the HR mirror as compared to the output mirror of the resonator. These calculated results are in agreement with our earlier experimental results on the study of the nature of the catastrophic damage of the HR resonator mirrors. We suppose that the HR mirrors damage has not optical nature but is connected with the effect of current pinching in the local area beside the HR mirror due to the high level of mechanical stress. Both theoretical and experimental results can be used to improve the design of laser bar assemblies in order to increase their output parameters and reliability.

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