Preface

Based on the theory we developed in the early 1970s, a broad range of phenomena is considered for an optical surface of a solid body that is exposed to radiation arbitrarily varying in time and producing temperature gradients, thermoelastic stresses and thermal deformations on the surface layer. The examination is based on the relations between the quantities characterising the thermal stress state in any nonstationary regimes of energy input into a solid, which are similar to Duhamel's integral formula from the theory of heat conduction. A peculiar feature of the analysis of the thermal stress state in this case consists in the fact that this relation comprises time as a parameter, which in turn is a consequence of incoherence of the quasi-stationary problem of thermoelasticity. This phenomenon is particularly important for the optics of high-power, high-pulse repetition rate lasers, which are being actively developed. In the review we have recently published in Laser Physics, the thermal stress state of a solid is analysed. In this state, time is treated as an independent variable used in differentiation. Such an approach greatly reduces the possibility of the method. The review published contains data on the use of capillary porous structures made of various materials with different degrees of surface development. Moreover, such structures can be efficiently employed to increase the heat exchange at a temperature below the boiling point of the coolant. In the present review we discuss the dependences of the limiting laser intensities on the duration of a pulse or a pulse train, corresponding to the three stages of the state of the reflecting surface and leading to unacceptable elastic deformations of the surface, to the plastic yield of the material accompanied by the formation of residual stresses and to the melting of the surface layer. We also analyse the problem of heat exchange in the surface layer with a liquid metal coolant pumped through it. The theoretical estimates are compared with the experimental data. We discuss the issues related to the technology of fabrication of power optics elements based on materials with a porous structure, of lightweight highly stable large optics based on highly porous materials, multi-layer honeycomb structures and silicon carbide, as well as problems of application of physical and technical fundamentals of power optics in modern high-end technology.

These cooling techniques can be applied to other technologies. Consider the integration of a large number of laser diodes into one- and two-dimensional array structures radiating high-power laser radiation either incoherently or coherently with respect to each other. One difficulty of such arrays is in maintaining the temperature of radiating heterojunctions within a narrow range to ensure frequency stability of the radiation. Such array structures consist of a large number of laser diodes soldered to the surface of a perfectly prepared metal mirror at a high packing density on the radiating elements. As the array radiates high-intensity laser light (even at today's demonstrated efficiencies of greater than 60 %), heat exchangers should extract heat flows from the active medium of greater than 1,000 W/cm^2. At this level, the displacement of the radiation spectrum conditioned by a thermal increase of the radiating layer should not increase by more than 3 nm relative to the initial lasing wavelength, which corresponds to a change in temperature of the active layer of not more than 10 °C. The heat exchanger for such a device should have relatively low thermal resistance of not more than 0.1 °C/W.

To obtain these high values of heat removal in devices, high-thermal-conductivity materials such as beryllium ceramics or diamond (with thermal conductivities of 3.7 and 20 W/cm °C respectively) can be used. Unfortunately, the effort and cost to produce and treat these materials makes the process of array fabrication more difficult and expensive. Silicon carbide is frequently used as a thermally conductive material that can be polished to high quality. Besides its high thermal conductivity (in the best case close to that of copper), SiC has high electrical impedance, is environmentally safe and has high hardness—important for optical polishing. Both separate and combined heat-removal elements can be made from SiC as well as complete microchanneled or porous heat exchangers. The coefficient of thermal expansion of SiC is close to that of gallium arsenide, which is the basis of many laser-diode compositions. This similarity helps prevent the material from cracking during heat cycling caused by soldering. Optical-grade SiC is available in sizes up to 1 m in diameter.

Considerable effort has been focused on the development of efficient heat-sinking systems for one-dimensional and two-dimensional laser-diode arrays and improvement of the soldering technology for linear arrays. Research continues into phase-locked arrays of laser diodes, phase-locked systems with efficient injection of radiation into an optical fibre, new configurations for solid-state lasers such as disk and slab lasers and efficient beam steering of high-power laser beams. The development of scalable phase-synchronized two-dimensional arrays of laser diodes emitting high levels of radiation has been made possible in part as a result of advances in the field of high-power optics.

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http://www.springer.com/978-3-319-10752-3

High-Power Optics
Lasers and Applications
Apollonov, V.V.
2015, XV, 275 p. 95 illus., 22 illus. in color., Hardcover
ISBN: 978-3-319-10752-3