Chapter 1
Introduction

On the basis of the theory we developed in the early 1970s, a broad range of phenomena is considered in the book 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 non-stationary 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 the 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 book 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. Book represents 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, multilayer honeycomb structures and silicon carbide, as well as problems of application of physical and technical fundamentals of power optics in modern high-end technology.

V.V. Apollonov, *High-Power Optics*, Springer Series in Optical Sciences 192,
DOI 10.1007/978-3-319-10753-0_1

The second part of the book is devoted to the problem of high power high repetition rate lasers pulse periodic laser systems, which in the nearest time will find a lot of applications in the field of space ecology, long range energy transfer, heavy machinery, space engineering, nuclear technologies and many others. Book has considered in details a new approach to the problem of a laser jet engine creation, which is based on the resonance merging of shock waves generated by an optical pulsating discharge, produced by such a lasers. To obtain an optical pulsating discharge, we suggested the usage of high-power pulse-periodic laser radiation, which can be generated by wide aperture carbon dioxide, chemical and mono-module disk type solid-state laser systems. Future developments of the disk laser technology as the most effective and scalable to the level of many hundreds of kW as well are under consideration in the book.

The history of power optics is inextricably associated with the creation of a single-mode CO_2 laser ($P = 1.2$ kW), operating in the master oscillator–power amplifier regime and employing the principle of a quasi-optical transmission line, at the Laboratory of Oscillations of the P.N. Lebedev Physics Institute headed at the time by A.M. Prokhorov. Its creator was A.I. Barchukov, who worked with a team of young scientists on the problem of scaling of single-mode electric-discharge laser systems [1–5]. Due to the research conducted on such a laser system, we managed to study many physical phenomena occurring when high intensity radiation interacts with matter, including with the elements of the optical path of laser systems, which subsequently greatly facilitated creation of high-power lasers. Then, in the early 1970s, we paid attention to a phenomenon that was to limit undoubtedly the further growth of the power generated by lasers being developed [6]. More than 20 years of fundamental and applied research devoted to the study of this phenomenon and to the solution of problems associated with it allow a conclusion that its essence consists in the following. An optical surface of a highly reflecting power optics element (POE) or any element of an optical path does not fully reflect radiation falling on it. A small portion of energy (fractions of a percent, depending on the wavelength) is absorbed by this reflecting element and turns into heat. As the output power increases, even a small amount of it is sufficient to induce thermal stresses in a POE. Thermal stresses distort the geometry of the reflecting surface, affecting thereby, for example, the possibility of long-distance delivery of radiation and its concentration in a small volume. The discovered effect of thermal deformations of a POE required a theoretical study of the problem that had not been solved in such a setting ever before. Very useful was the experience in solving the problems of thermoelasticity, gained by the theoretical department headed at that time at by B.L. Indenbom at the Institute of Crystallography, USSR Academy of Sciences. Minimisation of the thermoelastic response of the optical surface of the POE exposed to intense laser radiation is one of the key problems of power optics. Improving the efficiency of laser systems, increasing the output power and imposing stricter requirements to the directivity of generated radiation fluxes are inextricably linked with the need to design and create a POE with elastic distortions $\lambda/10 \div \lambda/20$ (λ is the wavelength) at specific radiation loads up to several tens of $kW{\cdot}cm^{-2}$ [7–10].

Interest in power optics and its physical, technical and technological solutions is unabated to this day. An almost simultaneous creation of first lasers in the USA and the USSR gave birth to annual symposia on Optical Materials for High-Power Lasers (Boulder, USA) and Nonresonant Laser–Matter Interaction (Leningrad, USSR). Regular meetings of scientists and engineers, as well as proceedings of the symposia have had a significant impact on the development of research in the field of power optics in many countries [11–13].

The data presented in this book allow one to reconsider important aspects of temperature gradients, thermoelastic stresses and thermal deformations in POEs, resulting from the exposure of their surfaces to high-power laser radiation. In this case, use is made of 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 these relations comprise time t not as an independent variable, which is used in the differentiation (as, for example, in review [14]) but as a parameter, which is a consequence of incoherence of the quasi-stationary problem of thermoelasticity presented below. Thus, by using the theory we developed in the early 1970s, we consider in this review a wide range of phenomena related to the thermal stress state of a solid-body surface exposed to radiation arbitrarily varying in time [15–21]. This consideration is particularly important for the optics of high-power, high-pulse repetition rate laser systems that are being actively developed. In review [14] we analysed important for the development of high-power optics problems of using capillary-porous structures with different degrees of development for the enhancement of heat transfer surface with water temperatures below the boiling point. The review published [14] contains data (important for the development of high-power optics) on the use of capillary porous structures with a different degree of the surface development, which can be efficiently employed to increase the heat exchange at a temperature below the boiling point of the coolant. The evaporation–condensation mechanism of heat transfer in the POE on the basis of porous structures and the idea of lowering the boiling temperature under reduced pressure of the coolant in cellular materials, developed by us at the same time [14, 21], are considered in details.

References

1. A.I. Barchukov, N.V. Karlov, V.K. Konyukhov, Y.B. Konev, B.B. Krynetskii, V.M. Marchenko, Y.N. Petrov, A.M. Prokhorov, D.V. Skobel'tsyn, A.V. Shirkov, FIAN Report, Moscow (1968–1970)
2. A.I. Barchukov, Y.B. Konev, A.M. Prokhorov, Radiotekh. Electron. **15**, 2193 (1970)
3. A.I. Barchukov, Y.B. Konev, A.M. Prokhorov, Radiotekh. Electron. **16**, 996 (1971)
4. V.V. Apollonov, A.I. Barchukov, V.K. Konyukhov, A.M. Prokhorov, FIAN Report, Moscow (1971)
5. V.V. Apollonov, A.I. Barchukov, V.K. Konyukhov, A.M. Prokhorov, FIAN Report, Moscow (1972)

6. V.V. Apollonov, A.I. Barchukov, V.K. Konyukhov, A.M. Prokhorov, Pisma. Zh. Eksp. Teor. Fiz. **15**, 248 (1972)
7. V.V. Apollonov, A.I. Barchukov, A.M. Prokhorov, in *Proceedings on First European Conference on Lasers and Applications*, Drezden, GDR, 1972
8. V.V. Apollonov, A.I. Barchukov, V.K. Konyukhov, A.M. Prokhorov, Sov. J. Quantum Electron. **3**(3), 244 (1973)
9. V.V. Apollonov, A.I. Barchukov, A.M. Prokhorov, in *Proceedings on Second European Conference in Lasers and Applications*, Drezden, GDR, 1973; Preprint FIAN No. 157, Moscow, 1973
10. V.V. Apollonov, A.I. Barchukov, A.A. Lubin, A.M. Prokhorov, A.V. Shirkov, FIAN Report, Moscow (1973)
11. A.J. Glass, A.H. Guenther, Appl. Opt. **12**, 34 (1973)
12. S.J. Cytron, Memorandum Report M73-17-1, Philadelphia, PA (1973)
13. D.H. Jacobson, W. Bickford, J. Kidd, R. Barthelemy, R.H. Bloomer AIAA Paper No 75-719 (1975)
14. V.V. Apollonov, Laser Phys. **23**, 1 (2013)
15. V.V. Apollonov, A.I. Barchukov, A.M. Prokhorov, Radiotekh. Electron. **19**, 204 (1974)
16. V.V. Apollonov, A.I. Barchukov, A.M. Prokhorov, IEEE J. Quantum Electron. **10**, 505 (1974)
17. V.V. Apollonov, E.M. Shefter, Preprint FIAN No 105, Moscow (1974)
18. A.I. Barchukov, Doctoral Dissertation, Moscow, FIAN, 1974
19. V.V. Apollonov, A.I. Barchukov, N.V. Karlov, A.M. Prokhorov, E.M. Shefter, Sov. J. Quantum Electron. **5**, 216 (1975)
20. V.V. Apollonov, Candian Dissertation, Moscow, FIAN, 1975
21. V.V. Apollonov, Doctoral Dissertation, Moscow, FIAN, 1982

Springer

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