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SPACE-TIME EXTENTS OF OPTICAL DISTORTIONS IN THE CYLINDRICAL ACTIVE ELEMENT OF A HIGH-POWER SOLID-STATE LASER

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Results of investigations of the space-time structure of distortions in the glass active element of a high-power solid-state laser with and without cooling of the active element are reported. A possibility is shown and the domains of applicability are determined for correction of spherical distortions by adjustment of a telescopic resonator.

The efficiency of a laser system depends not only on the output power of the emitter but also on the optical quality of lasing [1]. Distortions of the wave front (WF) are one of the main reasons for deterioration of the directivity of laser radiation [1]; therefore, correction of the WF structure for maximum smoothing without using the complicated methods of active compensation of distortions [2] is a very important problem.

An optimum mechanism of "passive" compensation of phase distortions is constructed on the basis of reliable information on the space-time WF structure, which is of particular importance for pulsed-periodic systems. To get this information, it is necessary to determine the front structure in some way and to trace the dynamics of its development [3]. Next, an analysis can be based, for instance, on spectral decomposition of the WF function with separation of the most significant spatial distortions and their weights [4].

In considerations of optical distortions in the cylindrical active element of a solid-state laser three main factors are distinguished, which exert a direct influence on the distortions [5]: a temperature dependence of the refractive index of the glass, changes in the geometry of the active element, and distortions due to induced birefringence. Apparently, for active elements with large overall dimensions (with a diameter greater than 30 mm), the first and the last factors exert the most influence.

Figure 1 depicts radial sections of the phase versus the all factors obtained by numerical simulation of a two-dimensional unsteady temperature field and the corresponding stress fields. Calculations were carried out for a cylindrical active element 45 mm in diameter and 914 mm long made of glass GLS-6. A nonuniform temperature profile was provided by pulsed optical pumping with a total lamp energy of 90 kJ. Figure 1a corresponds to a time interval of 1 sec, while Fig. 1b pertains to the period of 40 sec after a pumping pulse under zero-cooling conditions. The same radial distributions of the phase are shown in Fig. 1c but in the presence of cooling over its outer side surface 40 sec after a pumping pulse. Experimental interferometry-aided diagnostics of the lateral phase shift have confirmed such a behavior of the phase in the radial section.

As evident from the graphs in Fig. 1, the temperature dependence of the refractive index of glass exerts the greatest influence on formation of the general structure of phase aberrations in a rod with such dimensions. Distortions due to induced birefringence are oppositely directed and their absolute scatter is insignificantly smaller.

In a first approximation, the total phase in the aperture region can be described by a sphere [5], which is rather easily compensated by changing (with the sign of the front curvature taken into consideration) the distance between the mirrors of the unstable telescopic resonator [1]. Figure 2 shows the focusing property of a telescopic system as a function of the displacement of one of the resonator mirrors. In the same figure, a special resonator with an active Nd-doped glass element is depicted. The telescopic optical system can ensure efficient compensation

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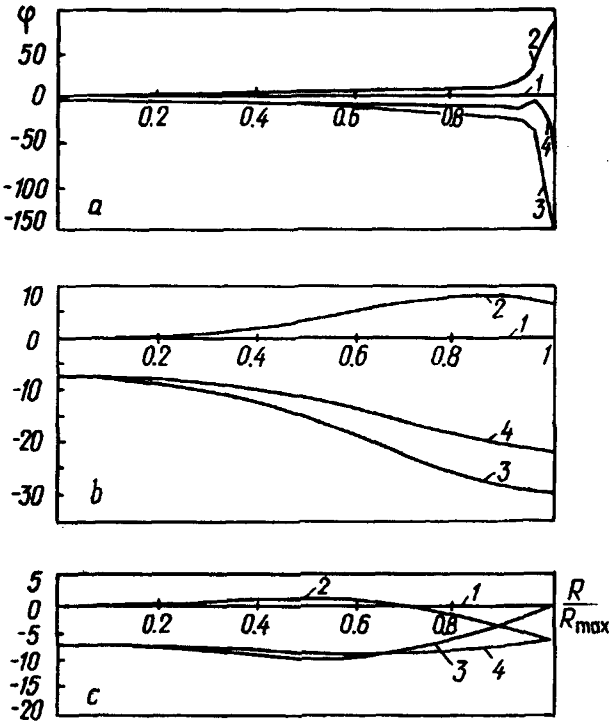


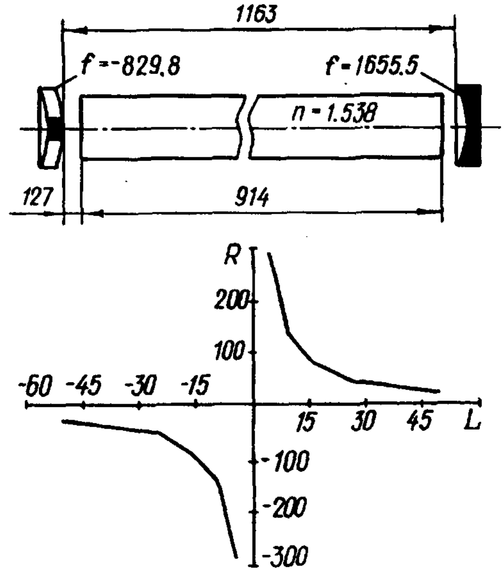


Fig. 1. Radial sections of the phase versus geometry of the active element (1), induced birefringence (2), temperature gradient of the refractive index (3), combination of all factors (4). φ, rad.

Fig. 2. Focusing property of the telescopic system as a function of defocusing of the telescopic resonator. R, m; L, mm.

of wave front sphericity with a curvature radius of several hundreds of meters, which is accomplished by appropriate adjustment of the distance between the mirrors.

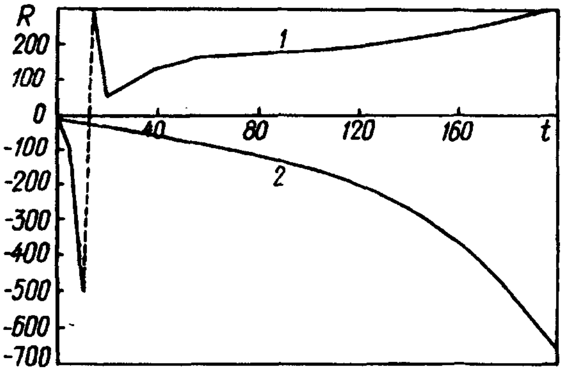
An optimum sphere was separated out of the obtained two-dimensional wave fronts by the least-square method. In calculations, the separated sphere was subtracted from the initial WF, which allowed us to exclude the influence of large-scale spherical distortion. Figure 3 shows the radius of the optimal spherical distortion, separated from the WF, at different periods of time from the moment of bringing the laser pumping system into operation with and without rod cooling.

In the absence of rod cooling, the temperature becomes equalized to some mean level. But in the case of rod cooling over its outer lateral surface, its temperature is reduced to that of the cooling liquid, i.e., to the initial temperature. Cooling changes the direction of the sphere convexity starting, approximately, from the twentieth second, and at a certain moment of time the sphere radius tends to infinity (curve 1 in Fig. 3 has a discontinuity). The disappearance of this scale measure at that moment of time does not mean complete equalization of WF distortions, though the mean integral level of distortions has a local mean value determined by the rates of light pumping and cooling and also by the thermophysical parameters of the glass (Fig. 1c).

As is seen in Fig. 3, the time of complete WF levelling off (the sphere radius tends to infinity) is larger with rod cooling than without it. Thus, 180 sec after a pumping pulse, the absolute radius of the WF sphere is equal, approximately, to 500 m in the case of rod cooling and to 300 m without it. This difference increases significantly with an increase of the pumping energy.

As an integral criterion of WF distortions, it makes sense to take the Stral number, which is calculated by the known relation [5]

$$\mathrm{Sh} = 0.5\ [1 + \cos(1.75 S_0)] - 0.08\ [\sin(1.75 S_0)],$$



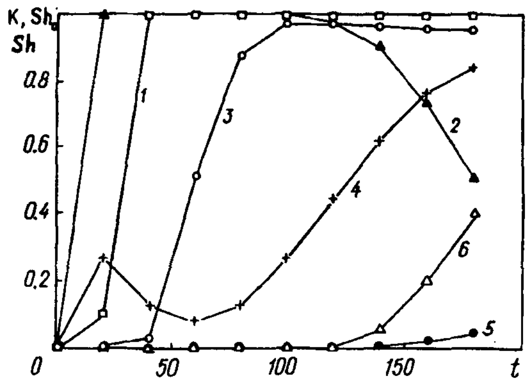


Fig. 3. Radius of spherical distortion with (1) and without (2) rod cooling versus time. t, sec.

Fig. 4. Criterion K (1, 2) and Sh_0 (3, 4) and Sh (5, 6) numbers versus time for rod cooling and without it.

where S_0 is the root-mean-square WF variation. Introducing the criterion of effectiveness of separation of the spherical component in the form

$$K = (Sh_0 - Sh)/Sh_0 ,$$

where Sh_0 is the Stral number based on the residual spread of the phase after sphere separation and Sh is the Stral number of the initial WF, we can determine the time interval within which WF adjustment is most effective. Figure 4 depicts K as a function of time for rod cooling and without it. Here, the pumping energy is 30 kJ. For comparison, the same figure provides the Stral numbers of the initial fronts and the fronts from which the spherical component is separated. As is seen, in the case of cooling the adjustment is effective starting from the 30th second after a pumping pulse; in the absence of cooling, from the 20th to the 100th second, after which the WF distortion will depart from sphericity more and more.

Apparently, though cooling retards equalization of integral distortions, the WF structure approaches, as possible, a spherical form which is very important for providing effective compensation.

The mechanical strength of modern laser glasses allows their use for implementation of a pulsed-periodic regime. The optimum pulse repetition frequency depends both on the material strength of the active element and on the required quality of generated radiation. It should be noted that beam quality can limit considerably the pulse repetition frequency.

Pulsed-periodic pumping leads to summation of the temperature distribution obtained upon volume energy release during a pumping pulse and the available temperature distribution in the rod by the time of a new pulse [5]. If the rod is completely heat-insulated, then each subsequent pumping pulse causes a proportional increase in the mean integral temperature of the rod. Cooling will remove some portion of heat for the neighbouring pulse intervals. In this case, a quasistationary thermal regime develops, in which the change in the radius of the approximating WF sphere will be within the limits of some constant interval. Figure 5 shows the time variation of the curvature radius of the approximating sphere at the moment of initiation of each subsequent pumping pulse with a repetition rate of 20 sec. As is seen, even in the absence of rod cooling, after approximately 11 pulses the WF curvature radius reaches, by the moment of each subsequent pumping pulse, a level of 13 m and becomes independent of the subsequent pulses. However, it should be remembered that in the absence of cooling each pumping pulse leads to rod heating by, on the average, 2°C. But cooling does not change radically the behavior of the front curvature; the asymptotic level of the curvature radius is approximately 20 m in this case, but its convexity is oppositely directed.

Thus, it is found that disturbances in the cylindrical active element of a high-power solid-state laser are responsible for different space-time extents of WF distortions. It is found that the spherical aberration, which is a consequence of the dependence of the refractive index of the laser glass on temperature and induced birefringence,

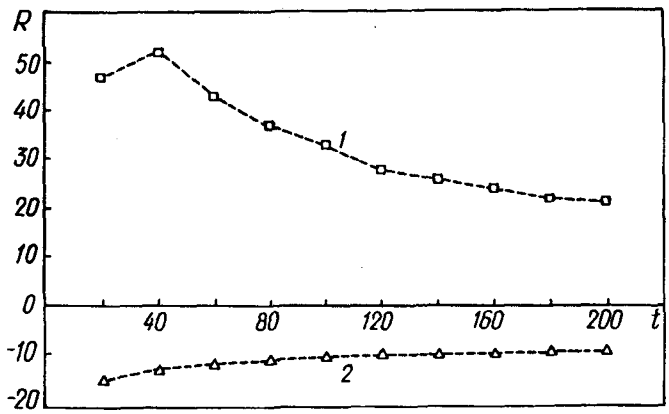


Fig. 5. WF curvature radius as a function of time for pulsed-periodic regime with (1) and without (2) rod cooling.

plays the most important role. Cooling over the outer lateral surface reverses the sphere curvature; in this case, the time of complete WF levelling increases. After a pumping pulse, the character of the spatial distortions is preserved in the course of time; only the absolute value of phase spread decreases. The pulsed-periodic mode of laser operation is distinguished by quasistationary distortion, which has an almost constant WF curvature radius by the moment of each subsequent pumping pulse.

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