ON THERMAL DISTORTIONS OF LASER RESONATORS IN THE CASE OF ACTIVE RODS IN THE FORM OF RECTANGULAR PLATES

E. M. DIANOV, Academician A. M. PROKHOROV

1970

SovietRxiv

Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

UDC 621.378.325

PHYSICS

E. M. DIANOV, Academician A. M. PROKHOROV

ON THERMAL DISTORTIONS OF LASER RESONATORS IN THE CASE OF ACTIVE RODS IN THE FORM OF RECTANGULAR PLATES

It is known that nonuniform optical pumping of active elements of solid-state lasers leads to the appearance of temperature gradients over the cross section of the rod. Thermal distortions of optical laser resonators arise for three reasons ([1]). The refractive index depends on temperature. Temperature gradients create stresses, which change the refractive index and lead to birefringence in the active medium. A change in temperature leads to a change in the length of the rod.

Numerous works, theoretical and experimental, have been devoted to the study of thermal distortions of laser resonators (see, for example, ([1]-[5])); however, in all these works active elements in the form of circular rods were studied.

In the present work we consider the thermal distortions of a resonator in the case of a neodymium-glass rod in the form of a rectangular plate. Neodymium glass is the principal laser material used for obtaining high radiation powers; therefore the problem of thermal distortions of resonators becomes especially important here. In addition, the possibility of varying the physical properties of the glass matrix by changing the composition of the glass makes it possible in principle to obtain a glass for which the various mechanisms leading to thermal distortions of the resonator compensate one another ([1]).

Fig. 1

Let us consider the rectangular plate shown in Fig. 1. Suppose that the temperature changes only through the thickness of the plate, i.e., $T = T(x)$. Following ([2]), we write the change in the length of the optical path of a ray propagating along the z axis through the point $x = x'$, caused by the applied temperature gradient. For light polarized along the x axis, this expression will have the form

$$\Delta p_x(x') = L\{(n-1)\varepsilon_{zz} + \beta_{T,\lambda}T(x') - B_{\|}\sigma_{xx} - B_{\perp}(\sigma_{yy} + \sigma_{zz})\}, \qquad (1)$$

where $T(x')$ is the temperature difference between the points $x = x'$ and $x = 0$; ε_{zz} is the strain component along the z axis; σ_{ii} are the stress components;

$$n$$

is the refractive index; $\beta_{T,\lambda} = \partial n/\partial T$;

$$B_{\|} = \frac{n}{E}\left[\frac{q}{V} - 2\nu\frac{p}{V}\right]; \quad B_{\perp} =$$

$$= \frac{n}{E}\left[(1-\nu)\frac{p}{V} - \nu\frac{q}{V}\right];$$

E is Young' s modulus; ν is Poisson' s ratio; q/V, p/V are photoelastic constants characterizing the change in the refractive index as a function of deformation in a direction parallel or perpendicular to the plane of polarization of the transmitted light.

We shall assume that the plate is completely free of external forces and constraints and that its thickness is much smaller than its length and width. In addition, we shall assume that the temperature distribution is a symmetric function,

i.e., $T(x) = T(-x)$. Under these conditions the components of strain and stress will have the form [6]

$$\varepsilon_{zz} = \frac{\alpha}{2h}\int_{-h}^{+h} T(x)\,dx,$$

$$\sigma_{zz} = \sigma_{yy} = \frac{1}{(1-\nu)}\left\{-\alpha E T(x) + \frac{\alpha E}{2h}\int_{-h}^{+h} T(x)\,dx\right\}, \qquad \sigma_{xx} = 0.$$

Here α is the coefficient of linear expansion.

Then expression (1) takes the form

$$\Delta p_x(x') = L\left\{\left[\beta_{T,\lambda} + \frac{\alpha E}{(1-\nu)}(2B_{\perp})\right]T(x') + \left[\alpha(n-1) - \frac{\alpha E}{(1-\nu)}(2B_{\perp})\right]\frac{1}{2h}\int_{-h}^{+h} T(x)\,dx\right\}. \qquad (2)$$

We are interested in the optical path difference Δ' of rays passing through the points $x = 0$ and $x = x'$. After calculation we obtain

$$\Delta'_x = L\left[\beta_{T,\lambda} + \frac{\alpha E}{(1-\nu)}(2B_\perp)\right]T(x'). \tag{3}$$

It is easy to obtain formulas analogous to (2) and (3) for light polarized along the y-axis,

$$\Delta p_y(x') = L\left\{\left[\beta_{T,\lambda} + \frac{\alpha E}{(1-\nu)}(B_\perp + B_\parallel)\right]T(x') + \left[\alpha(n-1) - \frac{\alpha E}{(1-\nu)}(B_\perp + B_\parallel)\right]\frac{1}{2h}\int_{-h}^{+h} T(x)\,dx\right\}, \tag{4}$$

$$\Delta'_y = L\left[\beta_{T,\lambda} + \frac{\alpha E}{1-\nu}(B_\perp + B_\parallel)\right]T(x'). \tag{5}$$

For comparison, let us write the optical path difference of rays propagating along the axis of a circular rod through its center and through points separated from the axis by a distance r, caused by the temperature gradient $T(r)$. In a cylindrical coordinate system the indicated optical path difference, for example for radially polarized light, has the form:

$$\Delta_r(r) = nL\left\{\frac{1}{n}\beta_{T,\lambda} - \frac{\alpha}{(1-\nu)}\left[\frac{R}{T(r)}(1+\nu)\left(\frac{p}{V} - \frac{q}{V}\right) - 2(1-\nu)\frac{p}{V} + 2\nu\frac{q}{V}\right]\right\}, \tag{6}$$

where

$$R = r^{-2}\int_0^r T(r)\,r\,dr.$$

It follows from (6) that the condition for the absence of thermal distortions ($\Delta_r(r) = 0$) in the case of a cylindrical rod with a radial temperature distribution depends, generally speaking, on the form of the dependence $T(r)$. At the same time it is known [3, 4] that the character of the distribution $T(r)$ depends on the pumping conditions, on the concentration of activator, etc., which makes it difficult to choose objective parameters of the glass matrix for which thermal distortions of the resonator would be absent.

From formulas (3) and (5) it is seen that, for a thin rectangular plate with a symmetric temperature distribution over its thickness, the condition for the absence of thermal distortions of the resonator does not depend on the specific

···of the form of the temperature distribution and is determined only by the parameters of the glass matrix.

Let us estimate the value of $\beta_{T,\lambda}$ from the condition $\Delta'_{x,y} = 0$ for values of $B_\perp$, $B_\parallel$, E, and ν equal, respectively, to $3.5 \cdot 10^{-7}$ cm$^2 \cdot$ kg^{-1}, $0.42 \cdot 10^{-7}$ cm$^2 \cdot$ kg^{-1}, $6.98 \cdot 10^5$ kg $\cdot$ cm^{-2}, and 0.225. These values, taken from (5), are typical for laser glasses. For $\alpha = 1 \cdot 10^{-5}/^\circ$C, $\beta_{T,\lambda} = -62 \cdot 10^{-7}/^\circ$C for light polarized along the x axis, and $\beta_{T,\lambda} = -35 \cdot 10^{-7}/^\circ$C for light polarized along the y axis.

Table 1

Glass grade	$\alpha \cdot 10^5/^\circ$C(10-50°C)	$\beta_{T,\lambda} \cdot 10^7/^\circ$C;$\lambda = 1.06\mu$
-3	1.02	−38
-7	1.01	−36
-24-5	1.00	−18
-28-2	0.92	−10
-46	0.98	−22
-36	0.91	3
-41	1.10	−70

Table 1 gives the values of α and $\beta_{T,\lambda}$ for a number of laser glasses of different compositions, taken from (7). Comparison of the calculated values of $\beta_{T,\lambda}$ with the table data shows that the glasses of the -3 and -7 types for light polarized along the y axis, and glass of the -41 type for light polarized along the x axis, satisfy the condition of minimal thermal distortions better than the others.

In conclusion, the authors thank V. B. Fedorov for useful discussions.

P. N. Lebedev Physical Institute
Academy of Sciences of the USSR
Moscow

Received
17 II 1970

CITED LITERATURE

1. E. Spitzer, Proc. IEEE, **54**, No. 10, 1249 (1966).

2. F. W. Quelle, Appl. Opt., **5**, No. 4, 633 (1966).

3. M. P. Vanyukov, V. I. Isaenko, et al., Zhurn. prikl. spektroskopii, **2**, No. 4, 295 (1965).

4. H. Welling, C. J. Bickart, J. Opt. Soc. Am., **56**, No. 5, 611 (1966).

5. G. D. Baldwin, E. P. Riedel, J. Appl. Phys., **38**, No. 7, 2726 (1967).

6. A. B. Boley, J. H. Weiner, *Theory of Thermal Stresses*, Moscow, 1964.

7. I. M. Buzhinskii, E. M. Dianov, S. K. Mamonov, L. I. Mikhailova, A. M. Prokhorov, DAN, **190**, No. 3 (1970).

Note: Figure translations are in progress. See original paper for figures.