THERMO-OPTICAL CHARACTERISTICS OF GLASSES ACTIVATED WITH NEODYMIUM

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THERMO-OPTICAL CHARACTERISTICS OF GLASSES ACTIVATED WITH NEODYMIUM

Active elements of an OCG made of glass activated with neodymium are characterized by high optical homogeneity. The change in the refractive index over the transverse cross section of the rod does not exceed $1 \cdot 10^{-7}$ for a rod diameter of 2.5 cm.

However, such high homogeneity of the glass is not realized during operation of the OCG because the nonuniform pumping produces a temperature gradient, which, in turn, leads to the appearance of a refractive-index gradient. Recently the problem of thermal distortion of OCG resonators has become very urgent in connection with the development of glass lasers with high energy density.

In the work (^{1}), devoted to a theoretical analysis of thermal distortion of resonators, it is shown that the change in the optical path length of a ray, caused by a temperature change ΔT of an isotropic rod, for light polarized, for example, in the radial direction, has the form (in a cylindrical coordinate system):

$$\Delta P_r = L[\alpha(n-1)\Delta T + \beta_{T,\lambda}\Delta T - B_{\parallel}\sigma_{rr} - B_{\perp}(\sigma_{\theta\theta} + \sigma_{zz})]; \qquad (1)$$

here L is the rod length; α is the coefficient of linear expansion of the glass; n is the refractive index of the glass; σ_{ii} is the tensor of stresses produced by the temperature gradient;

$$B_{\parallel} = \frac{n}{E}\left[\frac{q}{V} - 2\nu\frac{p}{V}\right]; \qquad B_{\perp} = \frac{n}{E}\left[(1-\nu)\frac{p}{V} - \nu\frac{q}{V}\right];$$

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

The first term in (1) arises because of the change in the rod length with temperature. The term $\beta_{T,\lambda}\Delta T = \frac{dn}{dT}\Delta T$ represents the thermally induced change in refractive index in the absence of stresses, while the terms $B_{\parallel}\sigma_{rr}$ and $B_{\perp}(\sigma_{\theta\theta}+\sigma_{zz})$ describe the change in refractive index caused by the presence of stresses. In this case, for glasses the refractive index always increases with pressure, whereas the quantity $\beta_{T,\lambda}$ may be either positive or negative, which gives the fundamental possibility of compensating, by selection of the glass composition, the refractive-index changes caused by different mechanisms (^{2}). To evaluate glasses for OCG from this point of view, it is necessary to know the coefficients in equation (1).

It is known from the literature (see, for example, (^{2})) that the photoelastic constants of glass depend only weakly on its composition, whereas, according to (^{3}), the thermo-optical constant $W = \alpha(n-1) + \beta_{T,\lambda}$ can vary within wide limits with changes in the chemical composition of the glass. In this connection there arises the need for a simple and reliable method for determining the value W of glasses at the generation wavelength of a neodymium laser. It should be noted that the existing method for determining W (W is found-

···from measurements of a, n, and $\beta_{T,\lambda}$) is extremely laborious, and there are very few data in the literature on measurements of W for glasses in the near-infrared region.

Below, a new method will be described for directly measuring the thermooptical constant of glasses, and values of W will be given for a number of neodymium-activated glasses.

Measurements of the thermooptical constant of glasses were carried out in the temperature interval $10 \div 45^\circ$ at wavelengths $\lambda = 0.63$ and $1.15\,\mu$ using the interferometer schematically shown in Fig. 1.

The radiation source was an LG-126 helium-neon laser, operating at three wavelengths: 0.63, 1.15, and $3.39\,\mu$. Lenses L_1 and L_2 form a parallel light beam of specified cross section, which passes through the glass sample under study with dimensions $10 \times 60 \times 130$ mm^3. One broad face of the sample is washed with water at a constant temperature ($+10^\circ$), while water is supplied to the other, the temperature of which is changed sufficiently slowly from 10 to 45°; in this way a temperature gradient is created in the glass sample. Behind the sample is a diaphragm with two apertures for selecting light beams passing through regions of the glass with different temperatures. The aperture diameter is ~ 1 mm, and the distance between the apertures in our experiments was 7 mm.

Fig. 1. Schematic of the interferometer for measuring the optical path difference of light beams in a sample with an applied temperature gradient. LG-126 —helium-neon laser; L_1, L_2, L_3, L_4 —lenses with focal lengths of 20, 160, 1000, and 20 mm, respectively; O —sample of the glass under study with a device for creating the temperature gradient; D —diaphragm; E —screen for observing the interference pattern.

The interference of the selected beams is produced by means of the long-focus lens L_3, and lens L_4 gives an enlarged image of the interference pattern on the screen. In measurements at wavelength $1.15\,\mu$, the interference pattern was observed through an EOP.

In this interferometer arrangement, both beams pass through the same optical

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elements, which provides high stability of the interference pattern with respect to mechanical effects (vibrations, impacts).

In our experiments, the measured quantity is the number of fringes ΔN by which the interference pattern shifts when a temperature gradient arises in the sample. With the method of creating the temperature gradient in the sample described above, a linear temperature distribution is established in the sample, and the sample itself is in an essentially unstressed state. In this case stresses do not arise in the sample (^{4}). Then, according to (1), the change in optical path length will be described by the expression

$$\Delta P = \Delta N \lambda = L W \Delta T.$$

From this we immediately find the thermooptical constant W.

The measurement procedure was tested on a number of optical glasses with well-known values of W. The values we obtained for the thermooptical constant of these glasses at wavelength $0.63\,\mu$ are in good agreement with the data of GOST 13659-68 "Colorless optical glass. Physicochemical···" .

···properties. The "Parameters" were taken for a wavelength of $\lambda 0.656\,\mu$ and for the corresponding temperature interval.

After this, the thermo-optical constant was measured for a number of commercially produced glasses for quantum optical generators. The measurements were carried out at wavelengths $\lambda 0.63$ and $1.15\,\mu$, and the values of W for the wavelength $\lambda 1.06\,\mu$ were obtained by extrapolating the measured data. The measurement results are given in Table 1. Also given there are the values of $\beta_{T,\lambda}$, calculated from the known values of W, α, and n. For all the glasses studied, except LGS-36, the values of $\beta_{T,\lambda}$ are negative.

Let us estimate those values of $\beta_{T,\lambda}$ and W of a glass for which there will be no distortion of the wavefront of a wave propagating in such a glass in the presence of a temperature gradient.

Following Ref. (^{2}), let us write the difference in optical path lengths of rays passing through the center of a circular rod and through a point r for the case in which the ends of the long rod are not fixed and there is a temperature gradient $T(r)$. ($T(r)$ denotes the temperature difference between the center of the rod and points at a distance r from the center.)

Table 1

Glass grade	$\alpha \cdot 10^5/^\circ\mathrm{C}(10\div 50^\circ\mathrm{C})$	n,$\lambda\,1.06\,\mu$	$W \cdot 10^7/^\circ\mathrm{C}\lambda\,0.63\,\mu$	$W \cdot 10^7/^\circ\mathrm{C}\lambda\,1.15\,\mu$	$W \cdot 10^7/^\circ\mathrm{C}\lambda\,1.06\,\mu$	$\beta_{T,\lambda} \cdot 10^7/^\circ\mathrm{C}\lambda\,1.06\,\mu$
KGSS-3	1.02	1.534	22	16	17	-38
KGSS-7	1.01	1.541	24	18	19	-36
LGS-24-5	1.00	1.515	38	33	34	-18
LGS-28-2	0.92	1.522	45.5	35	38	-10
KGSS-46	0.98	1.526	42	27	30	-22
LGS-36	0.91	1.567	68	52	55	3
LGS-41	1.10	1.502	-16	-15	-15	-70

For radially polarized light,

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

where

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

The condition that $\Delta P(r)$ vanish for a parabolic temperature distribution and for the values of p/V, q/V, ν, and E equal, respectively, to 0.246, 0.130, 0.225, and $6.98{\cdot}10^5$ kg/cm^2 (these values are taken from (^{5}) for AOIux glass and are typical for crowns, to which most laser glasses belong) will have the form $\frac{1}{n}\beta_{T,\lambda} = -0.37\,\alpha$ for radially polarized light and $\frac{1}{n}\beta_{T,\lambda} = -0.28\,\alpha$ for tangentially polarized light. Substituting here the values n and α typical for laser glasses, equal to 1.52 and $1 \cdot 10^{-5}/^\circ$C, respectively, we obtain $\beta_{T,\lambda} = -56 \cdot 10^{-7}/^\circ$C and $W = -4 \cdot 10^{-7}/^\circ$C for radial polarization and $\beta_{T,\lambda} = -43 \cdot 10^{-7}/^\circ$C and $W = +9 \cdot 10^{-7}/^\circ$C for tangential polarization.

Thus, glasses with values of the thermo-optical constant within approximately $(-10 \div +10) \cdot 10^{-7}/^\circ$C will apparently have the minimum thermal distortions at room temperature. Comparison of these figures with the measured values of W shows that the···

Among other glasses, the condition of minimal thermal distortions is satisfied by KGSS-3 and LGS-41 glasses.

Let us note that the values of W for KGSS-3 and LGS-41 glasses can fall within the interval indicated above if the temperature of the first glass is lowered and the temperature of the second is raised.

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