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The influence of the UV-radiation on some physical properties of glass

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Examinations of changes in both the refractive index and the sizes of the optical glass samples resulting from the UV irradiation are reported.

1. Introduction

So far, as the consequence of irradiation are concerned, the photosensitive and photochromic glasses have gained a relatively high interest [1–3], the changes of their transmission being most commonly examined.

To examine small changes in refractive index associated with the respective changes in transmission, the glasses should be optically perfect and the used measuring methods accurate enough. In photosensitive glass which enables permanent changes in absorption and, as it may be also expected, great changes in refractive index it is difficult to obtain high homogeneity of the melt. Thus, these glasses are of no use for precise examinations. The photochrome glasses are characterized by no permanent changes.

Not long ago there were only few elaborations [4] concerning examinations of ultraviolet radiation interaction with the optical glass. In particular, the measuring methodology of UV radiation induced changes in the refractive index measurement and is the subject of papers [5–7].

The dependences reported below could be observed solely when high precision measurement method was employed in measurements performed on high quality glasses, for which the changes in the refractive index were permanent.

2. Methods of examinations

The subject of examination was the BaK 102 glass (according to Schott Catalog) of Optical Works in Jelenia Góra (Poland). Its composition is given in the Table.

The glasses were UV irradiated using the following mercury lamps:

1. 400 Watt lamp after removal of the protecting glass bulb.
2. HBO-200 Carl Zeiss lamp (Jena).
3. Quartz lamp of L6/58 Helios type.

The lamps differ slightly among each other in both intensity of lighting and spectral range.

Composition of the glass	SiO_2	B_2O_2	Na_2O	K_2O	ZnO	BaO	As_2O_3
Percentage by weight	58.7	2.95	3.46	9.9	4.74	19.65	0.6

Usually a part of the sample was irradiated with UV radiation as it is shown in Fig. 1. The non-irradiated part was covered with a metal foil and subjected to the same thermal interaction as the irradiated one.

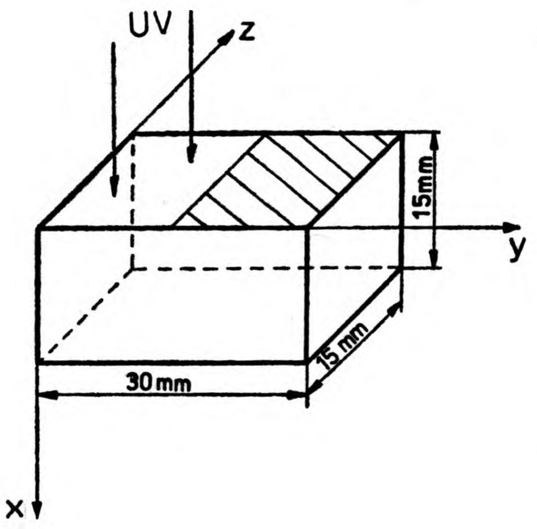

Fig. 1. Orientation of sample during irradiation

Due to the fact that the source of radiation was a burner of the mercury lamp of finite sizes located at the mirror focus the irradiating beam was not strictly collimated. The glass samples suffered from raised temperature due to irradiation from the irradiating lamp even if they were not heated additionally in the furnace. Some samples were irradiated via a heat filter to avoid the heating from the lamp. The changes obtained in this case were slightly smaller than those occurring without the filter. This proved that it was the radiation which caused the observed changes, their magnitude being influenced by the temperature.

The results of examinations of changes of refractive index observed in the BaK 102 glass by means of the interferometric methods are given below.

2.1. The method of deviation of fringes from their straightness

The interferograms were produced by using the Twyman-Green interferometer. By measuring the relative deformations of the fringes the changes of the refractive index in the zonally irradiated samples were estimated. The following formula was applied

$$\Delta n = \frac{1}{2z}\frac{\Delta p}{p}\lambda$$

where: λ — wavelength of the light used in examination (He-Ne laser, $\lambda = 633$ nm), z — thickness of the sample examined, $\Delta p/p$ — relative change of the interference order caused by irradiation. The examined samples located in a cuvette filled with an immersion fluid to eliminate the influence of the block geometry on the measurement of the refractive index, were measured twice: before and after the irradiation. The accuracy of the measurement at the centre of the 15 mm-thick sample amounted to $\delta(\Delta n) = 4\times 10^{-6}$. The samples were of the sizes $15\times 15\times 30$ mm.

2.2. Three-interferogram method

The distribution of the refractive index in the glass block and the changes of its sizes resulting from the irradiation were examined by using the Kowalik method [8], which enables to measure small differences of refractive index between the chosen points of the examined block as well as the difference in geometrical and optical thicknesses among the different points of this block. The obtained results of measurements of differences in refractive index averaged along the whole block thicknesses, as well as differences in geometrical thickness are relative values calculated with respect to the chosen reference point on the surface of the sample.

In order to determine the influence of UV radiation on the sample under test with respect to the chosen reference point of the sample, the differences in the thickness Δz_1 and refractive index Δn_1 were examined before the irradiation and the differences in thickness Δz_2 and the refractive index Δn_2 — after irradiation. The influence of UV radiation on the sample was determined by the following values:

$$\Delta z = \Delta z_2 - \Delta z_1,$$

$$\Delta n = \Delta n_2 - \Delta n_1.$$

Since the method applied allows us to calculate the changes with respect to the reference point of the sample, the values of interest Δz and Δn were determined with the accuracy up to a constant. For this reason only a part of the sample was irradiated, hoping that the changes in the region nonirradiated in which the reference point (region) is located will be small or will not appear at all. The glass samples of sizes $22\times 22\times 30$ mm were used. The measurement accuracy for the changes of refractive index amounted to $\delta(\Delta n) = 2\times 10^{-6}$, and that for the changes in the thickness — $\delta(\Delta z) = 20$ nm.

3. Results of examinations

The distribution of the changes of refractive index inside the samples irradiated with different mercury lamps and under different conditions were examined by the method of deviation of fringes from their straightness.

A part of the samples was irradiated in the way shown in Fig. 1. In Figures 2–4 the nonlinear changes of refractive index are shown as a function of the distance x from the y, z plane, i.e., from the surface on which the radiation inducing the changes of refractive index was incident.

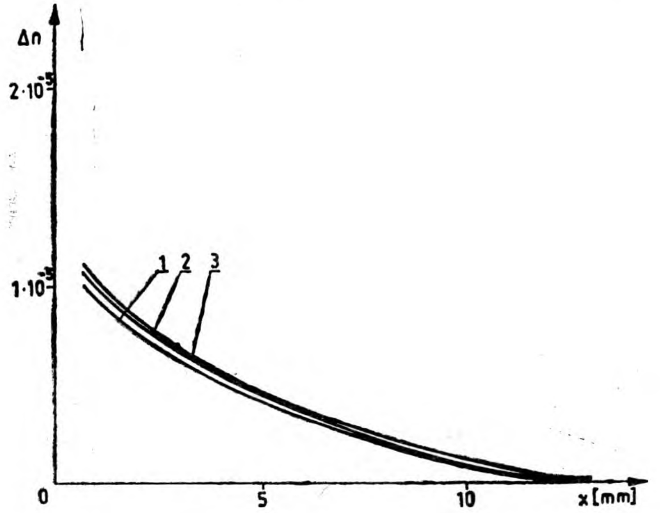

Fig. 2. Dependence of the changes of refractive index on the penetration depth of UV radiation for different exposure times: 1 — 20 min., 2 — 40 min., 3 — 60 min. During the irradiation the sample was kept at the 300 °C, the 400 Watt illuminating lamp was used

It has been observed that changes in the refractive index are greater when samples are irradiated at higher temperatures and for longer exposure times.

The changes of refractive index obtained due to irradiation of glass with the UV radiation depend upon the distance from the irradiated surface and are of exponential character. They may be decsribed by the formula

$$\Delta n = \Delta n_0 \exp(-x/A),$$

where Δn — change of the refractive index, x — depth at which the change is considered, Δn_0, A — parameters depending on the irradiation conditions.

Figure 5 presents the dependence of the changes of refractive index on the irradiated surface in the logarithmic scale. The exponential character of the dependence (except for the initial point close to the irradiated surface) is visible.

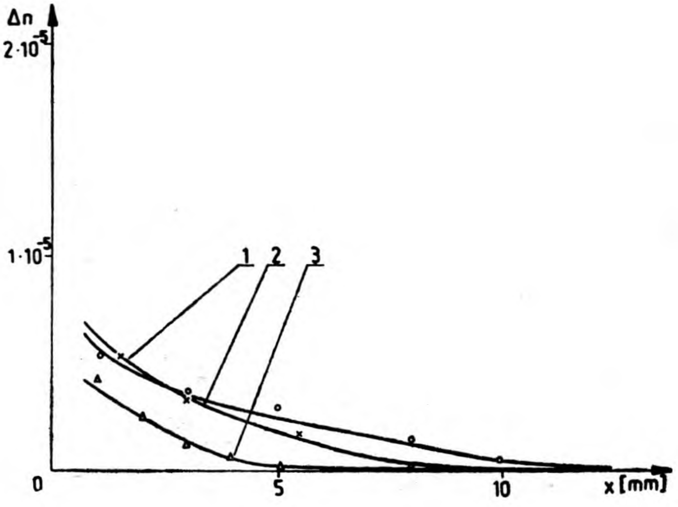

Fig. 3. Dependence of the changes of refractive index on the UV penetration depth for different kind of illumination lamps: 1 — 400 Watt illuminating lamp, 2 — HBO-200 lamp of Carl Zeiss (Jena), 3 — quartz lamp of L6/58 Helios type. During the irradiation the sample was kept at the 25 °C, exposure time — 1 h

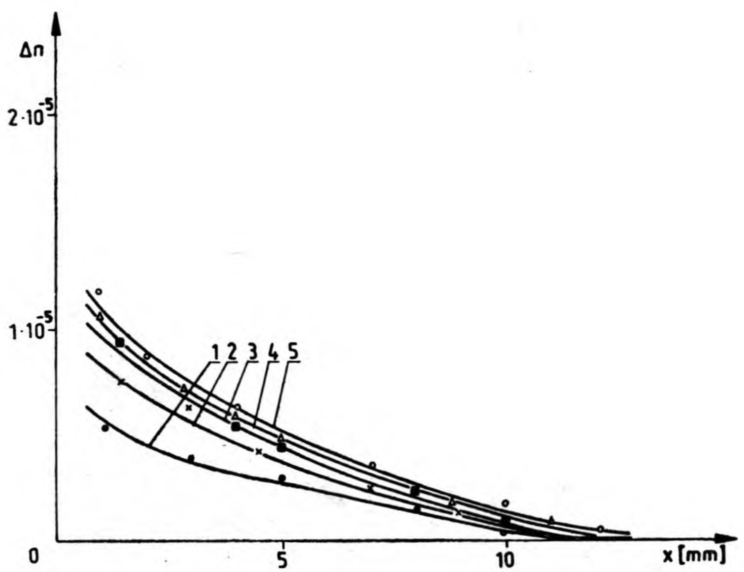

Fig. 4. Dependence of the changes of refractive index on the penetration depth of UV radiation for different temperatures at which the sample was kept during irradiation: 1 — 25 °C 2 — 50 °C, 3 — 100 °C, 4 — 160 °C, 5 — 210 °C. Exposure time — 1 h, the illuminating 400 Watt lamp was used

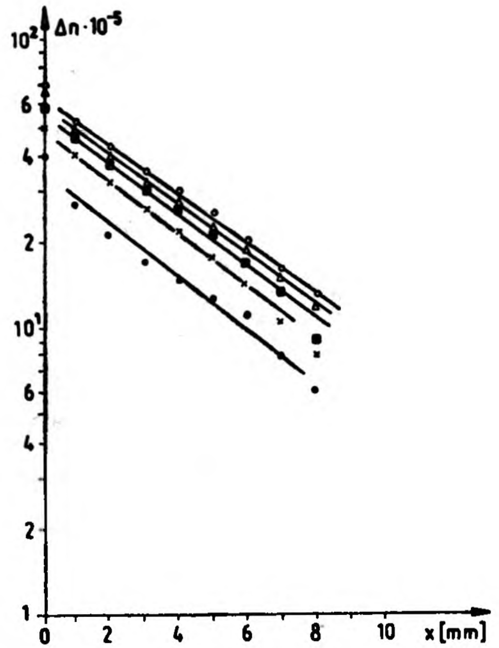

Fig. 5. Dependence of the changes of refractive index on the distance from the irradiated surface

The method of three-interferograms was used to examine the distribution of changes of refractive index and the thicknesses in glass samples in the two mutually perpendicular directions, i.e., in the direction of irradiation and that perpendicular to the latter. The samples were irradiated in the way shown in Fig. 6, where UV radiation hits the nonprotected part of the sample. The measurements indicated the changes of refractive index averaged along the whole thickness of the sample, as well as the changes in its linear sizes in both the

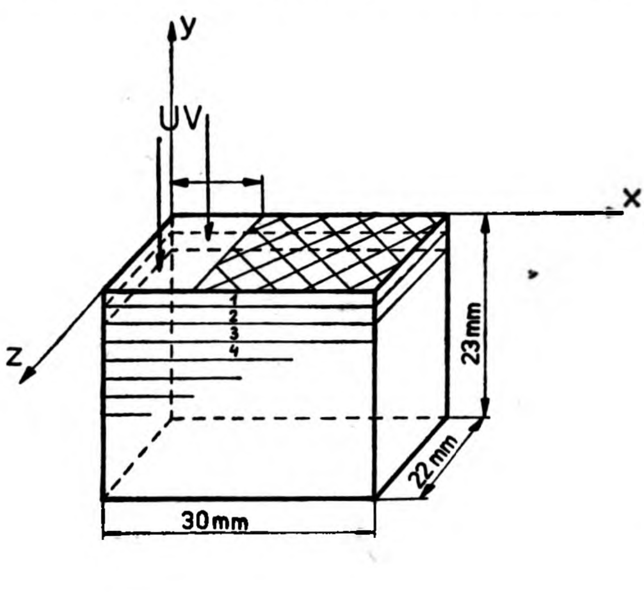

Fig. 6. Orientation of the sample during irradiation

direction perpendicular and parallel to the irradiation. The results for one of the samples examined are presented in Figs. 7–11. Part of the sample was irradiated with a 400 Watt lamp for 1 h. During the irradiation the sample was kept at 300 °C.

The measurements were performed along the scanning lines denoted by successive numbers in Figs. 6–9 in the direction perpendicular to irradiation. The reference point, with respect to which the changes of the refractive index and thicknesses were measured, is denoted by a circle (in Figs. 7–9 this point lies on the scanning line 9).

Figure 7 presents the changes of the refractive index in the x, y plane averaged over the whole thickness of the sample along the z-axis. The same results in a spatial system are shown in Fig. 8.

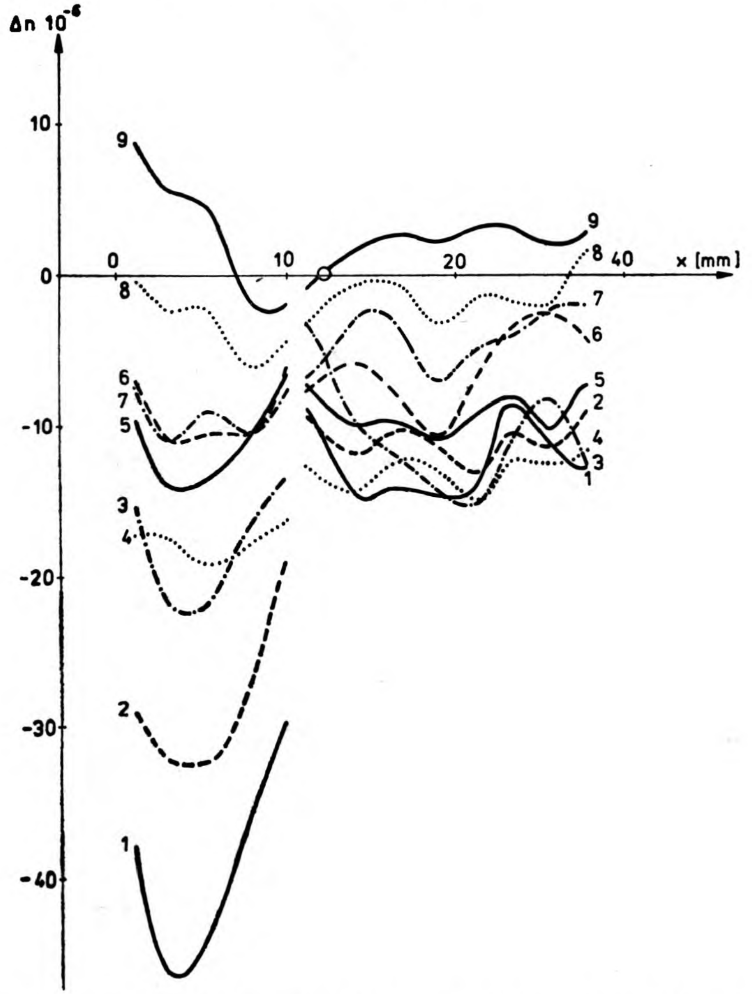

Fig. 7. Change of refractive index averaged along the total sample thickness for the successive scanning lines. The viewing direction perpendicular to that of irradiation

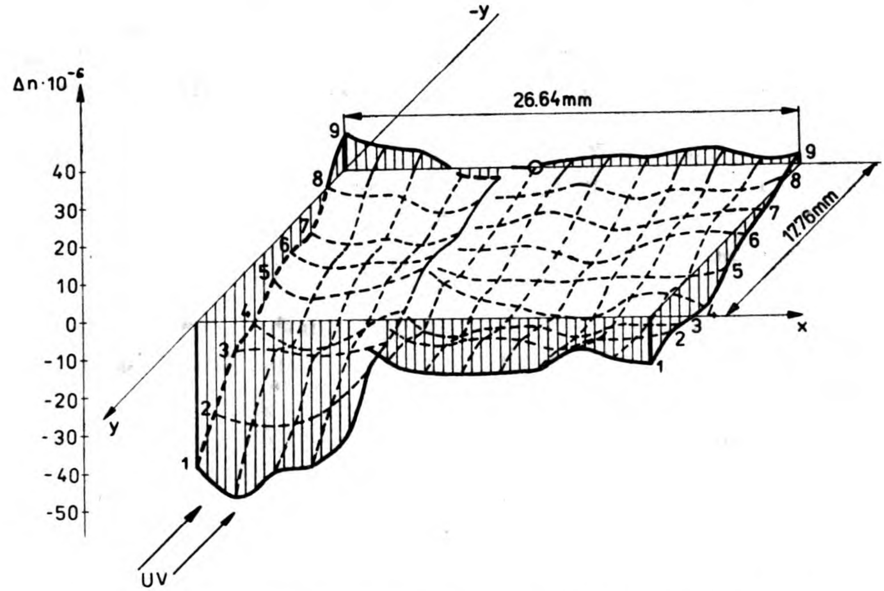

Fig. 8. Changes of refractive index in the x, y plane averaged along the sample thickness in the z-axis direction. Viewing direction perpendicular to that of irradiation. The numbers denote the successive scanning lines

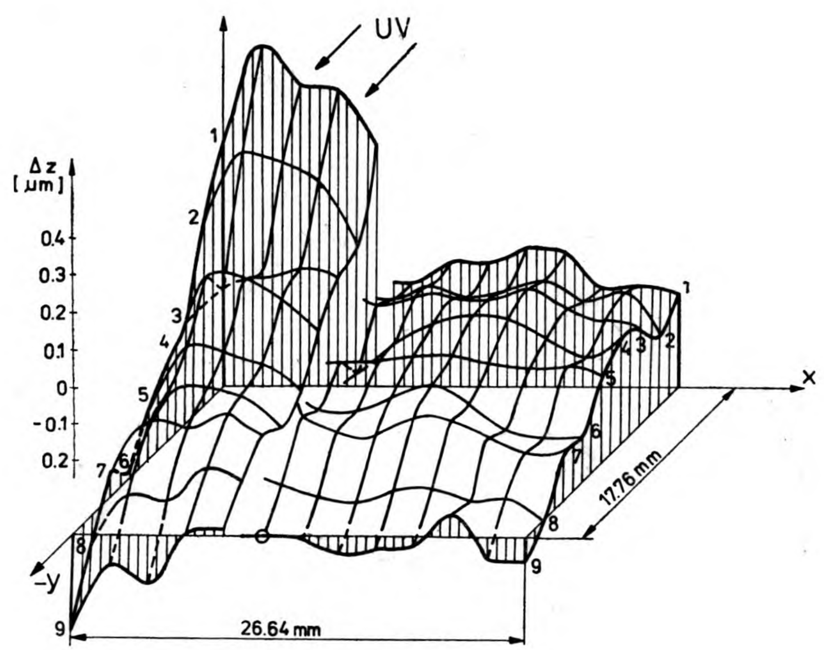

Fig. 9. Distribution of the thickness changes in the sample in the x, y plane. Viewing direction perpendicular to irradiation. The numbers denote successive scanning lines

Figure 9 shows the distribution of the changes in the direction perpendicular to the irradiation. For a better illustration of the changes examined the direction of the y-axis in Fig. 9 is inverted with respect to that in Fig. 8.

Similar changes of refractive index and thickness in the direction of viewing parallel to irradiation are presented in Figs. 10 and 11.

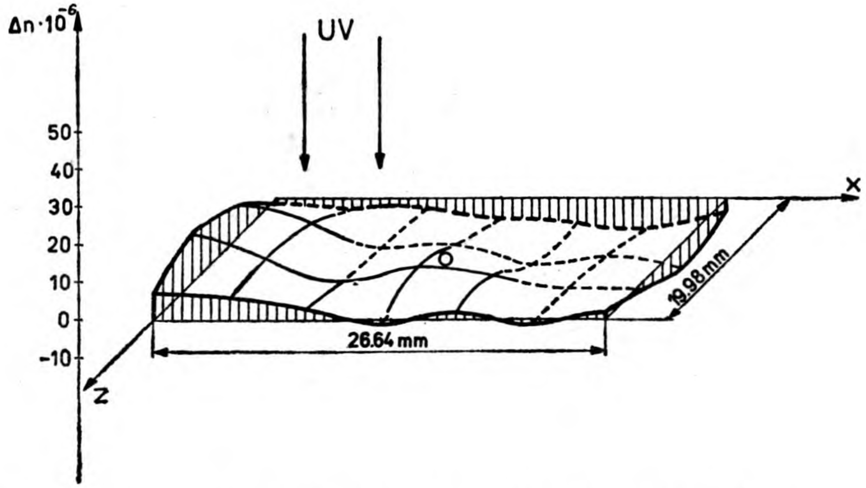

Fig. 10. Changes of refraction index in the direction of irradiation

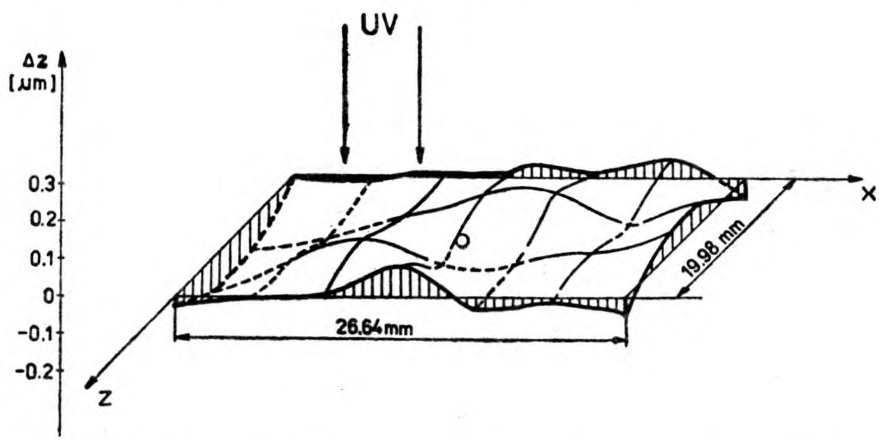

Fig. 11. Changes of the linear dimensions of the sample in the direction of irradiation

4. Conclusions

During the examinations permanent changes of refractive index of order of 10^{-5} were stated in the glass subject to UV irradiation. The changes in linear sizes of the samples associated with this irradiation were also observed. The dependence of the absolute changes of refractive index on the distance from the irradiated surface is of exponential character, except for the points close to the surface irradiated, which is an interesting result from the viewpoint of applications.

The UV irradiation-induced changes in the refractive index for all cases examined in our lab proved to be permanent at the room temperatures. Some samples were reexamined by the interferometric methods after two years and no measurable changes were observed.

The refractive index averaged along the sample thickness increases in the direction of irradiation, while the thickness of the glass block measured in the direction of viewing decreases with the depth of irradiation. The observed changes of refractive index occur in the whole volume of the sample, thus both in its irradiated and nonirradiated regions. This indicates the existence of piezo- and electrooptic effects. The observed effect of sample anisotropy being the result of UV irradiation suggests that some changes in birefringence should also appear due to the same irradiation. Such an effect was observed and presented in the earlier works [9, 10].

The obtained changes of the refractive index depend strongly on the glass composition. Recently, the examinations of the special doped glasses have been started in order to obtain greater changes in refractive index enabling their practical applications. For the glasses obtained the changes of refractive index are of order 10^{-3}. The results of this work were partly reported in paper [11].

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Влияние UV излучения на изменения некоторых физических свойств оптических стекол

Представлены результаты исследований изменений коэффициента преломления и размеров пробных оптических стекол, возникающих под действием UV излучения. Отмечены постоянные изменения коэффициента преломления порядка 10^{-5}, индуктированные UV излучением. Зависимость абсолютных изменений коэффициента преломления от расстояния от облученной поверхности имела экспоненциальный характер.