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Changes of refractive index in glass induced by UV-irradiation and a new possibility of their determination

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1. Introduction

In the course of exploitation the glass elements are usually subject to irradiation by of different wavelengths. Most frequently the irradiating light spectrum ranges from visible- to UV-ragion but also the irradiation by high quantum energy radiation like X-rays and gamma-rays may happen. This irradiation may result in some changes in optical properties of glass which may worsen the quality of the optical elements and systems (made of it) during their exploitation.

On the other hand, it becomes more and more clear that some kinds of irradiation may create new possibilities of production of wanted effects in glass in a controlled way. Here, the photochrome glasses may be mentioned as an obvious example [1, 2]. These glasses seem to be in growing demand.

Obviously, if the wanted changes in glass are to be controlled the problem of suitable measurement method becomes of considerable importance. While the changes in absorption are relatively easy to measure, the measurement of changes in refractive index distribution as a function of the wavelength may be connected with serious difficulties. The purpose of this paper is to indicate a possibility of measuring the very small changes in refractive index provided that they are of periodic nature.

2. Experimental method

The starting point of the method suggested is the irradiation of the examined glass plates via a periodic mask of spatial frequency, say 5 pair lines/mm. This irradiation induces a complex internal structure determined, among others, by changes in refractive index and absorption while both these changes depend locally upon the radiation dosis used to irradiation. In order to visualize these changes as well as to examine them quantitatively the fact may be employed that the light beam propagating in a medium tends to collect the information about the macrostructure of the latter. In our case the plate was illuminated by a monochromatic collimated light beam in the setup shown in

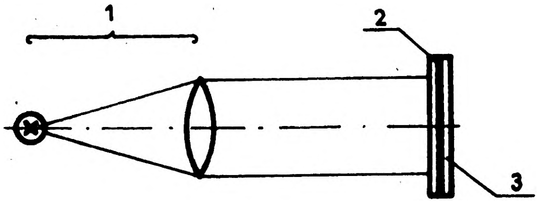

Fig. 1. Optical setup to irradiation of the glass plates: 1 - HBO-200 lamp, 2 - mask (muster grating), 3 - glass plate to be irradiated

Fig. 1 which is here reproduced from paper [1] . As a result a diffraction pattern appears at a given distance from the plate examined. This pattern contains information about the structure of the irradiated glass plate, in particular about the amplitude of the refractive index distribution induced by irradiation.

3. Experimental results

Some examples of diffraction patterns generated by the glass plates formerly irradiated by UV light beams via a muster grating were given in [3]. The information presented in Fig. 2 are of the same character as those reported in [3] and are given here for the sake of introduction. They include: the intensity distribution in diffraction pattern generated by a muster grating (mask) recorded on a photographic plate (curve 1), (this mask was used to modify suitably the UV light beam used for inducing irradiation of the glass plates), the intensity distribution in the diffraction pattern produced by BK101 glass plate formerly UV-irradiated via the muster-grating (curve 2), the same for BK107 glass plate (curve 3).

In Figures 3 and 4 the dependences of the amplitude-to-background ratio in the diffraction patterns generated by the glass plates with induced grating structures upon the used wavelength λ are shown for BK101 and BK107 glass samples, respectively (curves 1). For the sake of comparison the increment $n(\lambda)$ has been calculated on the base of Kramers-Kronig formulae, the absorption changes within the 200-400 nm interval being given [4] and the results are presented in the form of the curves 2. Additionally, the dependence of the positive increments of the absorption coefficient $\Delta K(\mathrm{cm}^{-1})$ upon the wavelength λ is shown (curves 3).

In Figure 5 the amplitude-to-background ratio is shown for the case of a glass plate irradiated first by gamma-radiation (curve 1), and next exposed to visible irradiation via mask using the XBO-100 Xenon lamp with a 400 nm edge filter to cut out the ultraviolet . The irradiation of glass by gamma-radiation results in some changes in optical density D, the dependence of which on the wavelength is illustrated with the help of the curve 2. The curve 3 gives, in turn, the resulting change in absorption coefficient.

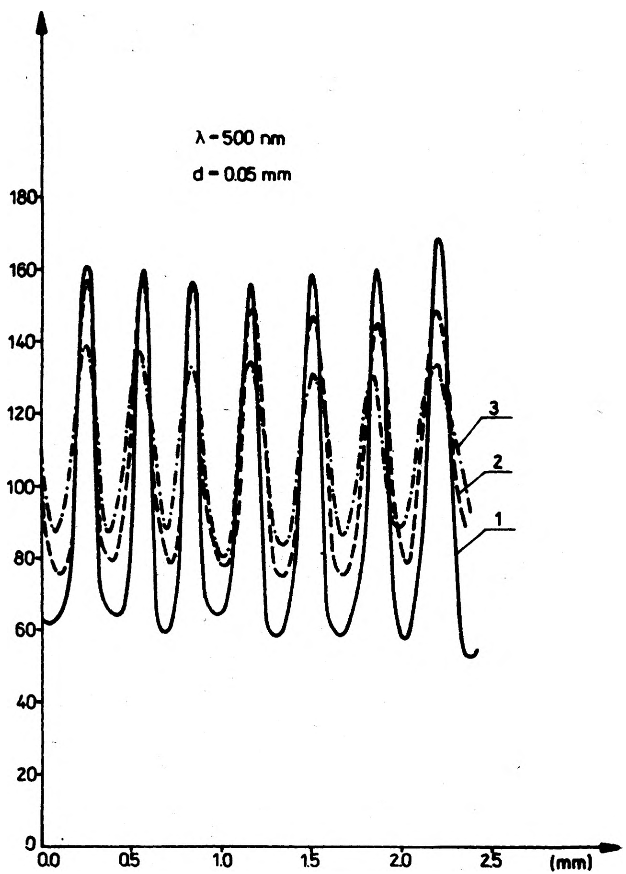

Fig. 2. Diffraction patterns generated respectively by: the mask (curve 1), the BK101 glass plate (curve 2), the BK107 glass plate (curve 3). Intensity given in conventional units

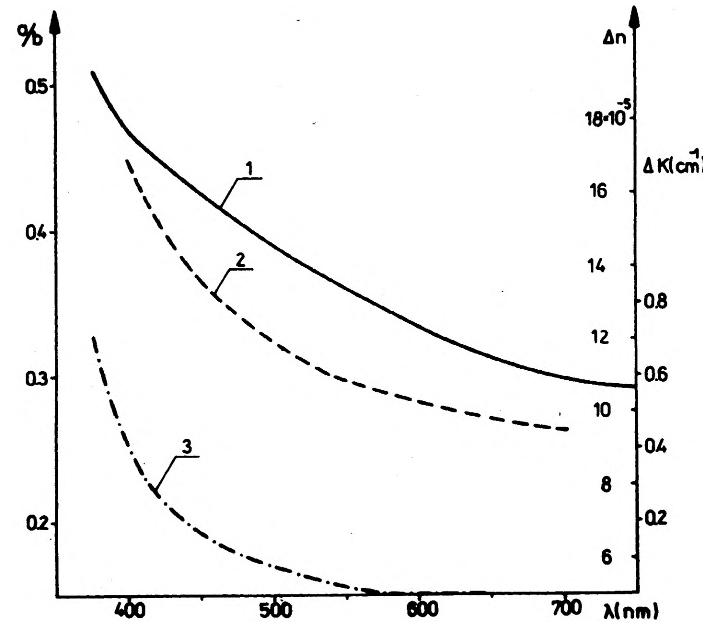

Fig. 3. Dependences of the amplitude-to-background ratio a/b (curve 1), Δn (curve 2), and $\Delta K(cm^{-1})$ (curve 3) upon the wavelength λ, all for BK101 glass plates

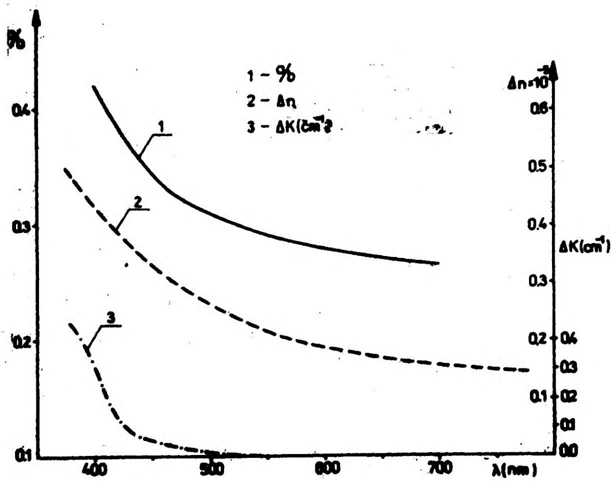

Fig. 4. Dependences of the amplitude-to-background ratio a/b (curve 1), Δn (curve 2), and $\Delta K(cm^{-1})$ (curve 3) upon the wavelength λ, all for BK107 plates

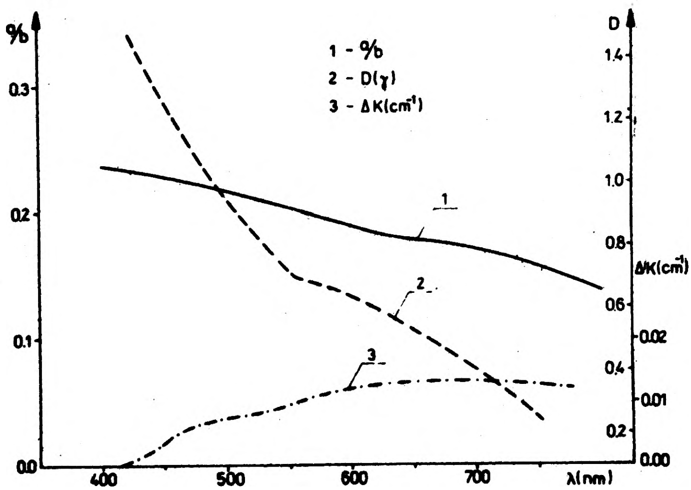

Fig. 5. Dependences of the amplitude-to-background ratio (curve 1), optical density D (curve 2), and $\Delta K(cm^{-1})$ (curve 3), all for BK glass plates exposed formerly to gamma-irradiation

The change is negative and corresponds to a decrease of the glass coloration. Since the maximum of the absorption band introduced by the gamma irradiation is located in the near UV range, it may be believed that $\Delta n(\lambda)$ in the visible range is of positive sign and of normal run. The irradiation of the glass plate by visible light beam resulted in diminishing of the absorption and $\Delta n(\lambda)$ both, induced by former irradiation by gamma rays.

A relation, similar to that presented in Figure 5 for BaK4 glass, is shown in Figure 6 for ZK1 glass plates of thickness d = 3 mm. These plates were also formerly irradiated by gamma radiation (Fig. 6b). In the plate (1) the grating was induced by its irradiation with a HBO-200 lamp in the way analogous to that applied to BK101 and BK107 glas-

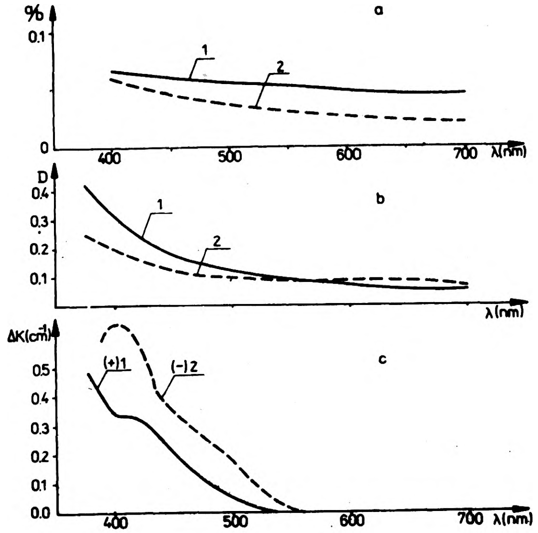

Fig. 6. Dependences of the amplitude-to-background ratio (a/b), D and $\Delta K(cm^{-1})$ upon λ in two ZK1 glass plates exposed formerly to gamma irradiation and next irradiated by visible + UV light beam (first sample - curves 1), and the visible (only) light beam (second sample - curves 2)

ses. As a result of this irradiation a positive increment of absorption was obtained which may be observed in curve 1 in Fig. 6c. For this sample (1) the dependences on the wavelength of the following quantities are given: the amplitude-to-background ratio (curve 1) in Fig. 6a, optical density D (curve 1 in Fig. 6b), and absorption increment ΔK (curve 1 in Fig. 6c). For the plate 2 the same HBO-200 lamp was used as a light source but the ultraviolet region was cut out by a suitable edge filter. This resulted in negative increment of absorption. For this sample the three analogous dependences are represented by the curves 2 in the same figures.

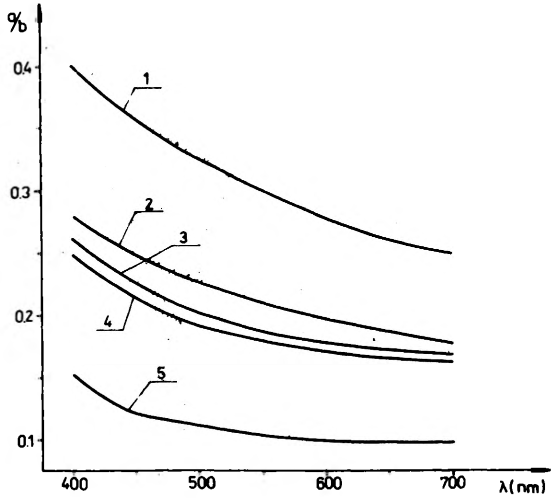

Fig. 7. Dependence of the amplitude-to-background ratio upon the wavelength λ for BK101 glass plates subject to annealing: 1 - initial measurement, 2 - measurement after the first 0.5 h period of annealing at the 473 K temperature, 3 - measurement after the second 0.5 h period of annealing at the 573 K temperature, 4 - measurement after the third 0.5 h period of annealing at the temperature 673 K, 5 - measurement after the fourth 0.5 h period of annealing at the temperature 773 K

In Figure 7 the amplitude-to-background ratio a/b vs. the wavelength λ is shown for the BK101 plate. The curve 1 refers to the plate with induced grating structure immediately after the inducing exposure. Next, the plate was subject to annealing in a furnace for four subsequent halve-an-hour periods of time, while the annealing temperature was changed stepwisely from 475 K to 773 K, each step being equal to 100 deg. The brazing action of the elevated annealing temperature with respect to the induced grating structure in the plates may be well observed.

4. Conclusions

The similarity of the curves $a/b(\lambda)$ and $\Delta n(\lambda)$ indicates their strong correlation. The small values of $\Delta n(\lambda)$ were difficult to measure by using traditional methods. Therefore, the computational methods were usually used instead. By measuring the amplitude-to-background ratio and taking advantage of the correlation indicated above the wanted function $\Delta m(\lambda)$ may be determined experimentally. Even the very small changes of refractive index $\Delta n(\lambda)$ may be measured in this way provided that they are periodic. Above we have given only an idea. The technical aspects of the methods may be easily improved.

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