INTRODUCTION

The development of microlithography and the wide application of UV lasers in data recording devices with the aim of increasing recording density has placed stricter requirements on the optical components of these systems. One of these requirements is the stability of lenses, prisms, mirrors, and other elements of an optical system to long-term action of UV radiation, i.e., invariability of the main characteristics of the materials of these elements: absorption coefficients, refractive indices, etc. At the same time, an important aspect of this problem is the prediction of possible changes in the parameters of a system and determination of the service time of optical elements. Currently, it has been established that long-term irradiation of silicate glasses (including pure quartz) by laser radiation with various powers and wavelengths leads to the occurrence of additional absorption and birefringence and wavefront distortion [1–9]. In this case, a change (either an increase or a decrease) in the glass density is observed, which depends on both the radiation power and the glass composition [5]. These effects accumulate over time and manifest themselves after long-term irradiation (several million pulses). They do not vanish after the irradiation and may exist for several months [2, 3]. The increase or decrease in the density of a glass is explained by a change in its structure due to the breaking and/or rearrangement of interatomic bonds upon multiphoton absorption of laser radiation [1, 4, 5]. As investigations show, high-intensity radiation causes strong perturbations of the glass structure, which manifest themselves in the generation of electron–hole pairs and excitons and (at higher intensities) in ionization of atoms. However, not all perturbations lead to stable, irreversible changes in the glass structure; some have a short-term character and manifest themselves only during irradiation. In this paper, we report the results of an investigation of the birefringence and darkening induced by UV radiation in silicate glasses and discuss possible mechanisms of this phenomenon.

EXPERIMENTAL

Figure 1 shows a schematic of the experiment. Samples were exposed to unpolarized radiation of a transversely pumped N₂ laser (λ = 337 nm, τ ~ 9 ns, P ~ 200 MW/cm², repetition frequency 20 Hz). The laser beam had an elliptical cross section 5 × 35 mm² in size. The laser radiation was focused on a sample using two mutually crossed cylindrical quartz lenses. The focused radiation had the shape of a slightly diffuse ellipse extended in the vertical direction with an area of ~8 × 10⁻³ mm². Changes occurring in the irradiated region were probed by unpolarized radiation of a He–Ne laser (λ = 633 nm). The probe beam, focused by a long focal length lens and modulated by an obturator, successively...
passed through a polarizer, a sample, and an analyzer and was detected by a highly sensitive photodetector. The axes of the polarizer and the analyzer were located perpendicularly to each other. The signal from the photodetector was supplied to a synchronous detector and then to a measuring system. The diameter of the focused probe beam in the sample did not exceed 150 µm. The lasing frequency was matched with the probe beam modulation. At the photodetector input, the UV laser radiation was cut off by a set of filters, and thus the possibility of its arriving at the photodetector was excluded. A special lift mechanism was used to gradually change the vertical position of the UV beam with respect to the probe beam. The dependence of the probe beam intensity on the position of the UV beam was recorded on an x–y recorder.

The F1087, K1082, and K8 high-purity silicate glasses and FK11 phosphate glass were used as objects of study. The silicate glasses contain up to 70% SiO₂ and the phosphate glass contains up to 70% P₂O₅ and various oxides of alkali metals. These glasses are characterized by a low content of impurities and the absence of absorption bands in the visible and near-UV spectral ranges. The width of their band gaps is from 4 to 6 eV. The glass samples were 20 × 12 × 2 mm³ in size and had well-polished surfaces.

RESULTS AND DISCUSSION

The investigation showed that, when UV radiation is switched on, the probe beam intensity decreases if both beams are incident on the same area of the glass surface. This effect has a short-term character; i.e., the probe beam intensity decreases only during UV irradiation and recovers its initial value when the irradiation is over. Long-term irradiation (about 1 h) leads to darkening of the sample, and the brown spot formed exists over several months. The spectrum of the additional induced absorption does not contain pronounced peaks and is located in the near-UV and visible spectral ranges. In all samples, the change in the probe beam polarization and occurrence of additional, induced, absorption under UV irradiation are accompanied by fast (several nanoseconds) luminescence in the range from the excitation wavelength to 800 nm [10].

A shift of the UV beam in the vertical direction both upward and downward with respect to the position of the probe beam leads to an increase in the probe beam intensity. Figure 2 shows the dependence of the probe beam intensity on the position of the UV beam (scanning was performed beginning with the sample edge.) As can be seen, when the UV beam approaches the probe beam, the probe beam intensity first increases; then (when the beams intersect each other) it decreases, increases again with increasing distance from the center, and regains the initial value at a distance of about 0.5 cm from the center (curve 1). As a result of multiply repeated upward–downward scanning of the UV beam, the curve observed smooths out (i.e., the difference between the maximum and the minimum decreases (curve 2)) and a brown trace is formed in the glass.

The irradiated region with a pronounced brown tint was scanned by linearly polarized radiation of a He–Ne laser. As a result, a change in the probe beam intensity during measurement through the analyzer was revealed. During scanning, as in the case of scanning by the UV beam, two peaks were revealed in the coordinate dependence of the signal intensity (rotation of the plane of polarization of the probe beam), which also correspond to the boundary between the irradiated and unirradiated regions.

As the experiment shows, the phenomenon observed can be divided into two components: a temporal one, which vanishes when UV irradiation is over, and a stationary one, which is accumulated over a long time. An analysis of the behavior of the time-dependent, transient component gives grounds to conclude that UV irradiation results in two processes: (i) occurrence of additional, induced, absorption, which leads to a decrease in the probe beam intensity, and (ii) change in the polarization of the probe beam, which increases its intensity. These processes affect the probe beam simultaneously when the probe and UV beams cross each other in a glass (i.e., at the center of the curve); when the UV beam radiation is shifted downward or upward with respect to the probe beam, only the second process affects the probe beam. The decrease in the probe beam intensity at its intersection with the UV beam indicates that the effect of the first process—occurrence of additional, induced, absorption—is much stronger than the effect of the change in the polarization. To determine the contributions of these processes, the region of passage of the probe beam through the sample was illuminated by an Ar⁺ laser (λ = 488 nm,