Behavior of vitreous silica and fluorite under action of E-beam and KrF-laser radiation[1]

P.B. Sergeev, A.P. Sergeev, V.D. Zvorykin

P.N. Lebedev Physical Institute, N.G. Basov Division of Quantum Radiophysics, Leninsky Prospect, 53, Moscow, 119991, Russia. Phone (095)334-07-94. E-mail: psergeev@sci.lebedev.ru

Abstract – The purpose of the work consist in study of influence of E-beam (EB) and laser radiation (LR) on the optical characteristics of CaF_2 and vitreous silica.

The radiating resistance of the optical materials (OM) was checked under action of EB with duration 80 ns and fluency for a pulse ~2 J/cm^2. The total EB fluency (F) in experiments has exceeded 20 kJ/cm^2. In all samples EB induced optical density (OD) with growth of F left on saturation.

After EB irradiation at all samples the relaxation of OD was traced. Then these samples were irradiated by the KrF-laser radiation. The residual absorption in quartz samples with growth of LR fluency has decreased up to a new stationary level, which was in 1.5–3 times less than initial.

For the vitreous silica samples the values of absorption in a mode of influence on them only EB and EB simultaneously with LR at 248 nm are determined. In the second mode of operation the values of induced OD of quartz samples was approximately in 1.5–2 times less.

1. Introduction

The vitreous silica and fluorite are base materials for manufacturing windows of E-beam-pumped UV excimer lasers. The serviceability and outlook of these lasers is substantially defined by opportunities of its windows to work under action of electrons scattered from basic E-beam, x-ray and laser radiation. The purpose of the work consist in study of influence of the given factors on the optical characteristics of high-purity CaF_2 and synthetic fused silica such as QU-1, KS-4V and Corning 7980 (Standard Grade (farther C-0), KrF Grade (C-KrF), ArF Grade (C-ArF)).

In a part concerning long-term radiating stability of OM, the new data supplement results of our previous works on the given theme [1–4]. The irradiation of samples in new experiments was carried out by e-beam in the most rigid mode with energy 280 keV at fluency ~2 J/cm^2 for a pulse 80 ns.

The results with the laser radiation are presented for the first time. The details of these experiments will be described in the appropriate sections.

2. Long-term radiation stability of OM

The tests of radiating durability of OM samples were carried out under action of a pulsed e-beam of installation EL-1 [5] on an old technique [1–4]. In these experiments new samples of glasses (Corning 7980: Standard Grade, KrF Grade, ArF Grade) simultaneously with repeated check of QU-1, KS-4V and new high purity CaF_2 sample were tested.

Our experiments have shown, that the transmission and absorption spectra of Corning's glasses practically coincide with similar spectra of QU-1, presented earlier [2–3]. Therefore here we them do not shown. Besides has appeared, that at all tested glasses the spectra of OD in area approximately 180–350 nm at various influences change proportionally. Therefore changes of OD can be traced on one of wave-lengths from the given interval. It was convenient to us to do it on 250 nm. OD measured at 250-nm for investigated quartz samples is plotted as a function of F in Fig. 1.

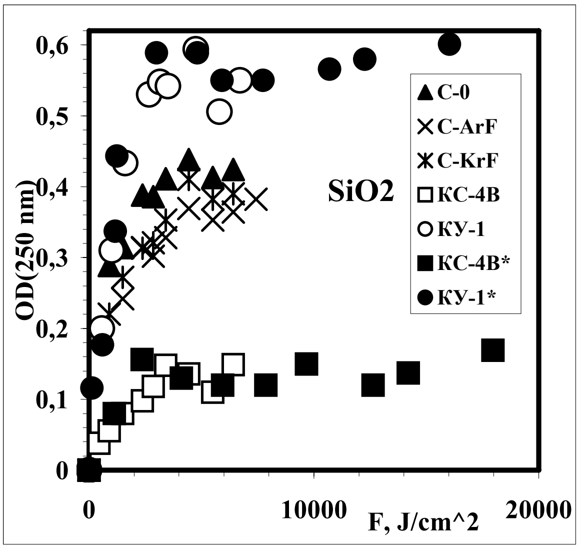

Fig. 1. E-beam induced OD(250 nm) for the vitreous silica samples as a function of F. EB energy is 280 keV, F_1~2 J/cm^2. The various badges at QU-1 and KS-4V designate results on different samples in different experiments

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It is seen that induced absorption in all samples reaches a stationary level with growth of F. Small deviations of OD from stationary values are caused by variations of average irradiation power and different delays in measurements of spectra after irradiation.

From tested glasses KS-4V is the most stable to influence of e-beam. The best Corning's glass (ArF grade) concedes to it on induced absorption at stationary level more than in 2 times.

The experiments have shown, that after ending of e-beam irradiation of quartz samples its OD(250 nm) decreased with time (from last pulse) under the law

$$OD(250)=A-B*\ln(t). \qquad (1)$$

In the Table 1 the values of the appropriate coefficients for investigated glass samples (Fig. 1) are submitted.

Table 1. The coefficients for equation (1)

Glasses	A	B
QU-1	0.82	0.024
C-0	0.53	0.01
C-KrF	0.45	0.009
C-ArF	0.45	0.0093
KS-4V	0.18	0.0045

The coefficients are received by experimental results on a time interval $4*10^3$–10^8 s at a storage of samples in darkness at room temperature. The conditions of a storage are the important factor. So the heating of samples approximately during 20 hours at T~500 C reduces the induced absorption to zero. As will be shown, the illumination is important also.

In the given experiments a new sample of CaF_2 from Vavilov's State Optical Institute was tested. It was cut of the central part of CaF_2 boule, which according to the manufacturer has the highest purity. It was irradiated by e-beam together with quartz samples in the same rigid mode. As at quartz samples with growth of F the induced OD at CaF_2 was saturated. The OD spectrum with the maximal absorption observed after an irradiation with F=7425 J/cm^2 in two hours after last shot is submitted in a Fig. 2.

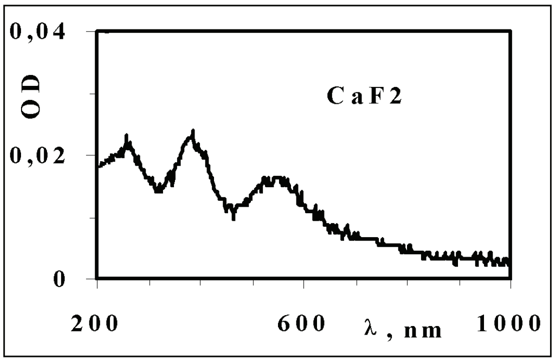

Fig. 2. E-beam induced OD in CaF_2 sample after its irradiation with F=7425 J/cm^2

It is similar to a spectrum, which we observed earlier on other samples [4], but the maximal value of OD has appeared even less, at a level 0.25.

In CaF_2 was observed fast relaxation of OD. In a first day after samples irradiation the values of OD(380) fell down on the average by 30%, and in three days they decreased practically in two times. It strongly complicates the study of the induced absorption in the given material.

3. Annealing of e-beam-induced absorption in vitreous silica by KrF laser irradiation

The absorption induced in OM by EB can be eliminated by heating. It is possible to do and with the help of LR. This part is devoted to studying of the effect of KrF-LR on residual absorption in OM.

In the experiments on laser annealing we used two samples of QU-1 glass irradiated earlier at EL-1 by EB with total fluency F=18.7 and 3.2 kJ/cm^2, as well as two samples of KS-4V glass with F=20.6 and 4.1 kJ/cm^2. The relaxation of e-beam-induced absorption in these samples had been monitored for about one and half year. Besides, we also used three samples of Corning 7980 glass. They were exposed to e-beam with the fluency F=6.4 kJ/cm^2.

The laser irradiation of the samples was carried out using a Lambda Physik EMG 150 MSC discharge excimer laser with FWHM pulse duration of 20 ns. The fluency of the KrF-LR on the samples was about 0.1 J/cm^2 per pulse. The samples were exposed to a certain number of pulses in a series, the pulses followed with repetition rate of 5–10 Hz, until providing a required total LR fluency, generally F_L~100 J/cm^2 in a series. After each series of laser pulses, the sample transmittance was measured. On the average, the time interval between the subsequent sets of laser pulses was about two weeks.

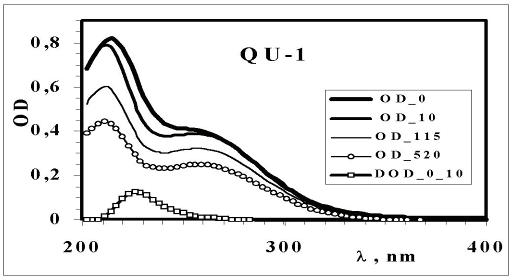

Fig. 3. Spectra of OD for various F_L for QU-1 sample and the difference between the OD_0 and OD_10 spectra (DOD). The number after "_" mark the value of F_L in [J/cm^2]

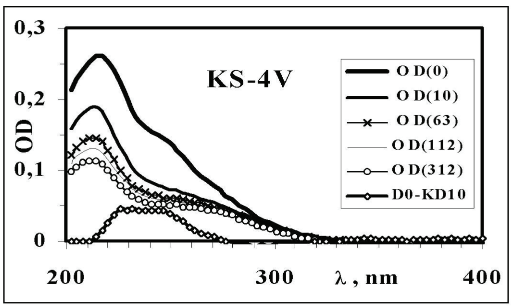

Fig. 4. Spectra of OD for various F_L for KS-4V sample

Figure 3 and 4 presents some OD spectra obtained after laser irradiation with different F_L for QU-1 and KS-4V samples. The Corning's samples spectra are similar to QU-1 spectra.

Analysis of the evolution of the OD spectra with growing KrF-LR fluency revealed following features in the behavior of the residual absorption in quartz samples.

1. Exposure to the 248-nm LR with intensity of 5–10 MW/cm^2 leads to reduction in the residual absorption throughout the whole UV spectral region.
2. Reduction in the OD with growing F_L is not regular. At the outset, when F_L is ≤100 J/cm^2, the quartz samples with large content of OH-group (QU-1, Corning 7980) show decrease in the absorption in the band with a maximum at 226 nm, whereas KS-4V glass (dry glass with low content of OH) shows decrease in the absorption within a broad band 226–259 nm (Figs. 3, 4). This is clearly illustrated by the "difference" spectra, for example DOD_0_10 in Figs. 3 and D0-K*D10 in Figs. 4, where coefficient K=OD_0(205nm)/OD_10(205nm). We assume that these absorption bands belong to the surface colour centres. The ease of their annealing also counts in favour of this assumption. After annealing of these centres, further growth of F_L leads to monotonic decrease in OD throughout the whole UV region. This indicates that the NBOH- and E'-centres, which are responsible for the absorption at the lines with maximums at 265 nm and 212 nm [6] are reduced simultaneously.
3. It is seen from Fig. 6 that, as F_L increases, OD(250 nm) in all investigated samples reaches certain final "steady-state" value which is less than the initial one approximately in 1.5 times (for QU-1 and Corning's glasses) or in 3 times (for KS-4V glass).

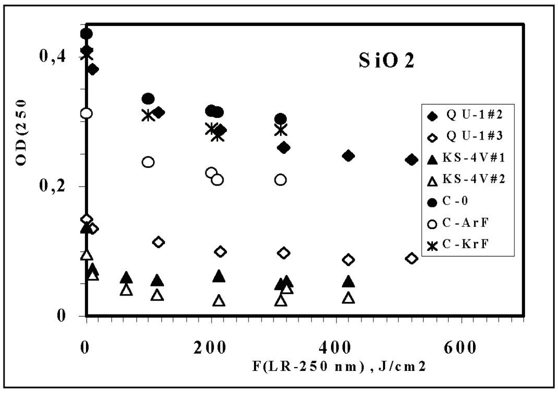

Fig. 6. Optical density at λ=250 nm of the quartz samples under study as a function of KrF laser radiation fluency

4. Simultaneous influence of EB and LR on quartz glasses

The influence of the KrF-LR on samples of quartz glasses after its irradiation by EB causes the reduction of the induced residual absorption. However, the question what will be with windows of the laser at usual work, when its simultaneously influenced by ionizing and LR, remains open. The purpose of the given experiments was to find the direct answer on this question.

The experiments were carried out on installation EL-1 [5]. The windows from investigated optical materials were put on its laser chamber. In usual conditions of work an energy density of scattered electrons and x-ray radiation at a window for a pulse makes F_I~0.1 J/cm^2 [7]. At usual shooting rate of installation (5.10^{-3} Hz) and such F_I the size of the maximal induced absorption even in samples QU-1, which has least radiation resistance of tested quartz glasses, does not exceed 9% in UV area. At a glass KS-4V the induced absorption at same meanings of F_I does not exceed 2–3 %, that is on the verge of sensitivity of spectrophotometers. In this connection in the given experiments it was necessary to increase the value of F_I approximately in 4 times

For this purpose in the laser chamber the constant magnets were installed, its magnetic field turned a part of the pumping EB to the one of the laser windows. The measurements of EB energy density with the help of calorimeters have shown, that the value of F_I at the surface of a window in this case equals 0.4 J/cm^2.

Instead of the second window of the laser the resonator mirror with R_b=100 % at 248 nm was installed. Second resonator mirror with Ro=44 % was installed outside of the laser chamber near to a output window made of the researched optical material.

The feature of the given experiment consist that additional diaphragm, established near 100% mirror inside the laser chamber, block half of laser beam. In result the laser generation occurred on one half of circle – section of the laser aperture. Thus only half of researched window was irradiated with LR, while the EB irradiated it completely. The comparison of the induced absorption in each window halves after a series of installation shots also allowed to reveal distinction in absorption at influence on its material only EB and EB simultaneously with LR. All other key distinctions in the experimental factors, which could have an effect for the induced absorption (material of a window and the conditions of its irradiation) so were reduced up to a minimum.

In connection with that the researched window settled down inside the laser resonator, intensity of laser radiation (and, accordingly, the laser energy density on it – E_w) developed from intensity of direct and opposite beams. The value of E_w at R_b=100% in this case is connected with output energy density of the laser (Eo) by the ratio $E_w = E_o(1+R_o)/(1-R_o)$. In view of that R_0=44% is received $E_w = 2.57 \cdot E_o$.

In these experiments the energy of output laser radiation was measured by colorimeter BKDM in each shot. The value of E_0 was determined by division of average value of output energy of the laser for all series of pulses with a researched window on the area of section of output beam.

The intensity of LR at a window (I_w) was calculated from expression $I_w=E_o/\tau$, where τ=80 ns is a pulse duration.

Three samples were tested on this technique: two Corning 7980 (C-0 and C-ArF) and KS-4V.

The samples stood on the laser chamber 6–7 days, during which on it ~400 shots were made. Complete energy density of EB on its surface for this time has achieved the value of F~160 J/cm^2. Average KrF-laser radiation energy density on irradiated window surface for a pulse was in these experiments E_w=035 J/cm^2 at intensity I_w=44 MW/cm^2. Approximately in one hour after last shot both halfs of a window were registered on the spectrophotometer.

The typical received OD spectra for C-ArF sample after it irradiation by only e-beam (E) and e-beam with laser radiation (L) are submitted in a Fig. 7.

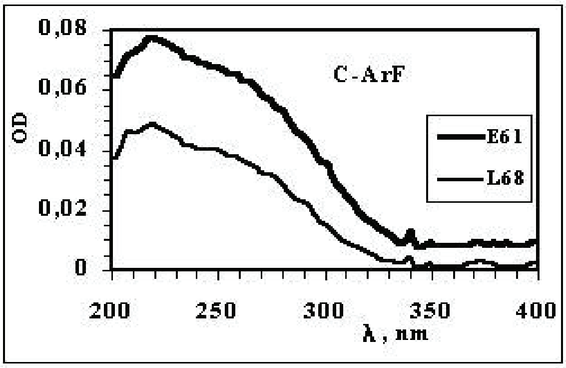

Fig. 7. OD spectra for appropriate halves of C-ArF sample

Here it is evidently visible, that at simultaneous influence of EB and LR induced optical density appears appreciably less. Quantitatively this distinction can be described by factor **K**, which we shall determine so:

K=$(OD(250)–OD(400))_L/(OD(250)-OD(400))_E$ (2).

Such definition of **K** allows to bypass uncertainty of a choice of a zero mark, arising, in particular, because of an laser cleaning of a surface. The designed thus **K** for a C-ArF sample has equal **1,5.** At a sample C-0 under the same experimental conditions the value of **K** has appeared equal **2**.

The sample of a glass KS-4V had a diameter of 60 mm and thickness of 13.2 mm. It has stood on a usual place in the laser chamber 7 days. On it 440 pulses were made. F_1 for a pulse from EB was, as well as on other samples, 0.4 J/cm^2. And E_w for a pulse at a sample KS-4V was 0.27 J/cm^2 at I_w=3.4 MW/cm^2. In these conditions at a sample KS-4V **K=1.55**.

The experiments on research of quartz glasses behavior at simultaneous influence on them of an e-beam and KrF-laser radiation still proceed. But already now it is possible to approve, that in quartz windows of e-beam-pumped KrF-lasers the residual absorption will be in 1.5–2 times less, than in case of influence on them only one e-beam or roentgen radiation.

5. Conclusion

In the work the behavior of modern optical materials for windows of excimer lasers with e-beam excitation are checked experimentally up at long influence of e-beam. Is established, that in CaF_2 and vitreous silica the e-beam induced residual absorption with time of an irradiation leaves on saturation. For investigated OM the speeds of the induced absorption relaxation after an irradiation are determined.

Is experimentally established, that the influence of the KrF-laser radiation on OM samples after their irradiation by an e-beam, and also during this irradiation, results in reduction of residual absorption in 1.5–3 times.

Received in work the complex of experimental results on radiation durability of modern high purity OM is necessary for deeper understanding of physics of radiation processes and for their modeling. These results will be useful to the manufacturers of optical materials, and also for the developers of laser and other sources of UV and VUV light.

References

[1] P.B.Sergeev, I.A.Mironov et.al., *in Proc.of 12th Intern. Confer. on Rad. Phys. and Chem. of Inorg. Materials.* 2003, pp.82–86.

[2] P.B.Sergeev, I.I.Cheremisin et.all Proc. of SPIE **5506,** 81 (2004)

[3] P.B.Sergeev I.I.Cheremisin et.al. Journal of Optical Technology **71,** 93 (2004)

[4] P.B.Sergeev, V.D.Zvorykin et.al. Journal of Optical Technology **72,** 85 (2005)

[5] P.B.Sergeev Journal of Soviet Laser Research, **14,** 237 (1993)

[6] L.Skuja, J. of Non-Crystalline Solids **239,** 16 (1998)

[7] V.S.Barabanov, N.V.Morozov, P.B.Sergeyev, J. of Non-Cristalline Solids **149,** 102 (1992)