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Letter to the Editors

Time variation of the optical absorption of quartz KU-1 induced by gamma irradiation

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Abstract

The induced optical absorption in KU-1 quartz glass under gamma irradiation at the electron accelerator LU-10-20 was measured. It was shown that the absorption in the UV spectral region varies very quickly during the first few minutes after the start and after the interruption of the irradiation. In the middle and red parts of the visible spectrum the sample transparency changes very slowly or does not change at all.

1. Introduction

In all fusion equipments optical radiation was and will be used for plasma diagnostics. In large fusion devices and future reactors it may be used also in control systems. For this purpose it is necessary to have windows which have to conserve transparency under neutron and gamma irradiation in the case of a DT working gas mixture. As the best material for conditions of the experimental fusion reactor ITER, quartz glass KU-1 was chosen, fabricated at the Technical Glass Factory (the city Gus Chrustalny, Russia), with an OH group content of about 0.1 %. In a test of candidate materials the transparency measurements during and after irradiation must be provided, as it is well known that glasses after irradiation restore their transparency even in normal conditions.

In situ investigations of the irradiation effects on optical materials are considerably easier with gamma or relativistic electron radiation sources, where the irradiation space may be localized. A pulsed electron accelerator allows to study a time variation of the optical properties under gamma or electron irradiation. An electron accelerator application has both advantages and disadvantages. The main advantage consists of a good access to the irradiated sample and consequently the possibility to measure in situ its transparency degradation. The main disadvantage is the pulse structure of radiation: very high power in small duration pulses (in accelerator LU-10-20:3 ms separated by the time not less than 1 ms). Naturally some questions arise – what is the behavior of the studied parameter (the sample transparency) between the pulses, how does the pulse irradiation regime affect long irradiation results and what is the difference between results of measurements during and after irradiation.

Two years ago the first problem was solved at the accelerator LU-50 (pulse duration of 10 ns with a period of 20 ms) [1], where the duty factor is even less than that at LU-10-20. The sample transparency was measured with the time resolution of 10 ns and there was no noticeable change between the pulses in a measured transparency.

Two identical KU-1 specimens were irradiated up to about 10 kGy (Si), one at a stationary ^{60}Co gamma source and the second at the electron accelerator Lu-40 (Kharkov) [2]. Transparencies were measured after irradiation and their degradations in the near UV spectrum region were found the same (the gamma dose was not high enough to change transparency in other spectral regions).

In this work the time variation of the quartz KU-1 transparency spectral distribution was measured during and after interruption of the gamma irradiation at the dose rate of 40 Gy (Si)/s up to a dose of 1 MGy.

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2. Experimental conditions

Pure quartz glass KU-1 with OH contents of ≈800 ppm (diameter 14 mm, thickness 16 mm) was irradiated by gamma rays with an average energy of 1.3 MeV. Bremsstrahlung was generated in a water cooled tantalum target under the electron flux from the Linac LU-10-20 [3] which had the following parameters: average electron energy 6–8 MeV, average electron current 1 mA, pulse width 3 ms and pulse repetition frequency 1 kHz. The time average absorption dose rate in quartz was 40 Gy/s (during the pulse ≈13 kGy/s).

The spectral distribution of the specimen transparency in a region of $\lambda = 300$–800 nm was measured with the aid of a halogen loaded incandescent lamp, placed behind the shield, and a spectrometer with a photomultiplier detection of the light intensity. The sample KU-1 optical, density was defined as $\Delta^{-1} \log(I_0/I)$, where I_0 is the light intensity detected without the sample, and I the same but with the quartz sample. For the absorbed dose in the sample and the dose rate a certificated color dosimetric film [4] was used. The measured sample temperature increased after the irradiation start from ≈20°C and within 3–5 min reached the stable value of 70°C.

The KU-1 optical density was measured before and sometime during and after irradiation. The optical density spectral distributions are shown in Fig. 1. One cycle spectrum measurement took 0.32 s. The wavelength resolution was about 0.5 nm in the UV region and gradually changed up to about 5 nm in the region of 600 nm. To avoid a very large data spread the transparency and optical density were averaged over periods of 10 nm for $\lambda = 300$–430 nm and over 20 nm for $\lambda = 400$–700 nm.

The time variation of the KU-1 optical density for different wavelengths is shown in Fig. 2. The maximum dose of 1 MGy (Si) was achieved after 418 min from the irradiation start.

3. Discussion

The general view of the optical density spectral distributions (Fig. 1) conforms to all previous measurements [2,5]: very fast increasing at the short-wavelength part and almost invariable at longer wavelengths. But one can see that after the irradiation end the larger the wavelengt the long-wave edge of the absorption band, the center of which (215 or 260 nm) is outside the measured spectral region, is restored more quickly. The absorption band becomes narrow after irradiation. Apparently, color centers responsible for the band edge are less stable than for the middle part of the band. The temperature could not influence this effect as it changed insignificantly

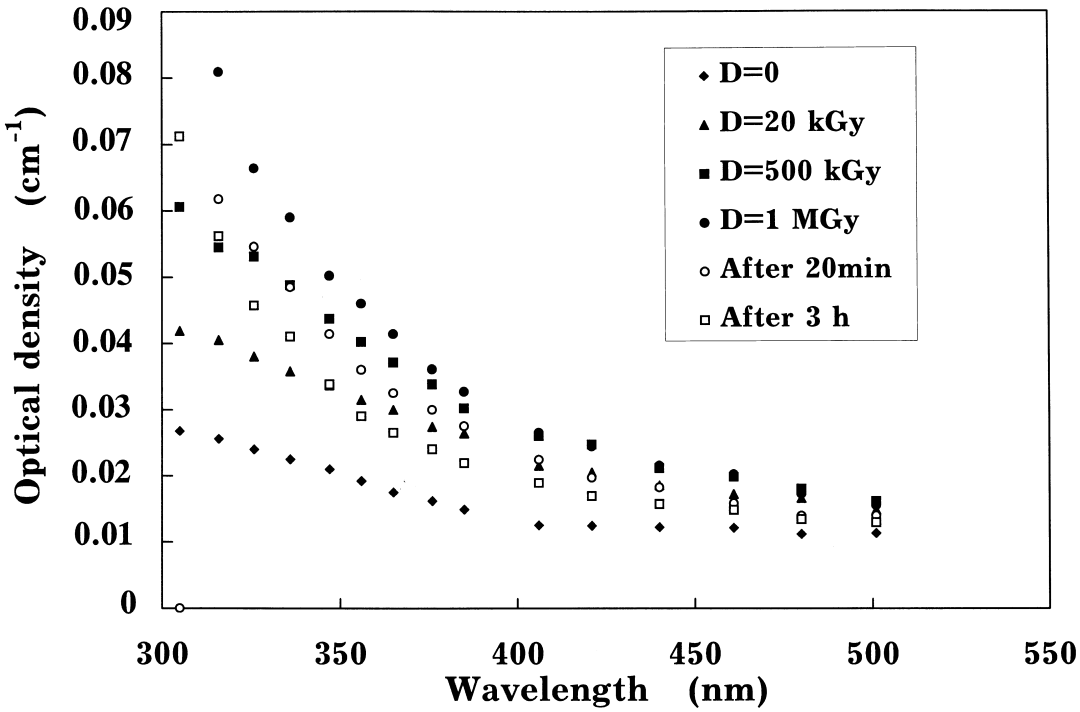

Fig. 1. Optical density spectral distribution of the KU-1 quartz specimen ($d = 14$ mm, $t = 16$ mm) at different times during and after gamma irradiation start at the dose rate of 40 Gy/s.

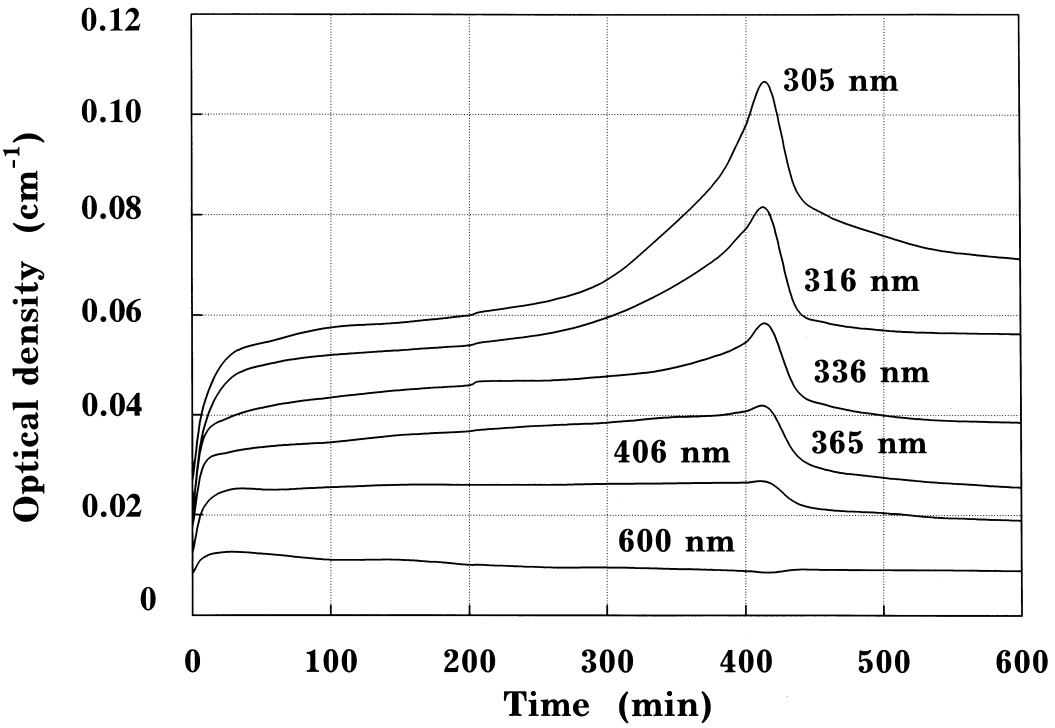

Fig. 2. Changes of the quartz KU-1 optical density for different wavelengths under gamma irradiation during 418 min up to a dose of 1 MGy (average gamma quanta energy 1.3 MeV, dose rate 40 Gy/s) and after irradiation.

(only from 20°C to 70°C) after the start and was constant during irradiation and could not change appreciably after irradiation. The data on the optical density for the KU-1 absorption band at 215 nm and the dependence on temperature during the irradiation [6], measured after the irradiation, allow us to presume that the fast transient absorption change (also in Fig. 2) is not connected with temperature.

Although the data given in Fig. 2 have no high accuracy, they show an unexpected behavior in time different in the wavelength regions $\lambda = 300$–400 nm and $\lambda > 400$ nm. In the short wavelength region the optical density sharply increased from the initial value during the first 3 min after the irradiation start. The shorter the wavelength the stronger is the optical density change. After the sharp change the optical density increased slowly, but then the change became faster up to the end of irradiation. An explanation of this effect was not found. Perhaps the reason is an upset of the balance between the excitation and annealing of defects (about 13 kGy/s in pulse is a dose rate at which annealing is possible [7]).

From the data of Fig. 2 it is possible to estimate the optical density change per period of accelerator operation (1 ms). During the first 8 min (roughly 5×10^5 pulses) of irradiation the optical density at $\lambda = 305$ nm reached 0.04 cm^{-1}. So the maximum optical density increase rate is approximately 10^{-7} cm^{-1}/pulse.

In the wavelength region $\lambda = 400$–600 nm the transparency change is small, and for $\lambda > 600$ nm (which is not shown in Fig. 2) it is within the measurement accuracy limits.

4. Conclusions

The results of KU-1 quartz optical density measurements during and after gamma irradiation at the linear accelerator with an average dose rate of 40 Gy/s up to 1 MGy (Si) allows us to draw the following conclusions:

- The optical density in the wavelength region $\lambda = 300$–400 nm measured after irradiation differs from the optical density during irradiation.
- The optical density after the irradiation start and after the irradiation interruption changes quickly within a few minutes.
- The optical density in the region $\lambda = 300$–400 nm changes slowly after a rapid increase during the first few minutes, but after some time, which is different for different wavelengths, the growth rate increases. This effect is inexplicable at the moment and requires additional investigation.
- After irradiation the edge of the absorption band changes its shape. Apparently, the absorption band becomes narrow at $\lambda < 300$ nm.

- In the wavelength region λ >400 nm the optical density is almost the same during and after gamma irradiation up to a dose of 1 MGy.

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