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Transient Radiation Effects in D.O.I. Optical Materials: Schott Filter Glass

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Abstract

Department of Energy and Defense Programs systems are becoming increasingly reliant on the use of optical technologies that must perform under a range of ionizing radiation environments. In particular, the radiation response of materials under consideration for applications in direct optical initiation (D. O. I.) schemes must be well characterized. In this report, transient radiation effects observed in Schott filter glass S-7010 are characterized. Under gamma exposure with 2 MeV photons in a 20-30 nsec pulse, we observe strong initial induced fluorescence in the red region of the spectrum followed by significant induced absorption over the same spectral region. Peak induced absorption coefficients of 0.113 cm^{-1} and 0.088 cm^{-1} were calculated at 800 nm and 660 nm respectively.

Acknowledgments

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Introduction

Department of Energy and Defense Programs systems are becoming increasingly reliant on the use of optical technologies that must perform under a range of ionizing radiation environments. While the radiation response of some passive components and systems has been investigated, the transient radiation response of new, multi-component laser materials, thin films, filters and active and passive non-linear materials is largely unknown. In this report, we examine the gamma-induced, transient radiation response of Schott S-7010 filter glass at 660 nm and 800 nm.

Filter glasses play an important role in the efficient design of laser cavities. In many laser schemes, filter glasses are placed around the laser rod to prevent solarization[1] and parasitic oscillations from depleting the gain in the laser rod[2]. These glasses are designed so that they pass the pump bands for optical pumping of the rod, and absorb both in the UV range and at the lasing wavelength for the device. Schott filter S-7010 is a silcate glass that has been ion-doped with samarium. The exact composition of the glass is proprietary, but previously published results indicate that the glass is co-doped with cerium[2-3]. The samarium dopant gives rise to strong absorption bands at 1.061 μm while the cerium dopant is a common solarization suppressor and UV absorber[1]. As such, this particular filter glass is especially appropriate for use in GSGG lasers which oscillate at 1.061 μm.

In general, the radiation sensitivity of silicates is dependent on the concentration of impurity and structural defect states in the glass[4-8]. Radiation effects in pure silica glass have been observed following total doses in the range of 10^5 to 10^9 rads from a ^{60}Co gamma source[9-10]. In this case, exposure of the samples to the ionizing radiation lead to changes in structural defect types and densities which in turn gave rise to changes in the optical absorption band structure of the glass. The addition of dopants into the silica structure will necessarily lead to an increase in the effect of ionizing radiation on the glass[11].

Experimental Methods

Ionizing radiation exposures were conducted at the Hermes III accelerator facility at Sandia National Laboratories, Albuquerque. Gamma pulses of approximately 2 MeV photons were delivered in pulses averaging 20 nsec in duration. The average dose per shot at the samples was 80 krad and the evolution of radiation-induced fluorescence and absorption signals was observed over a time frame ranging from 1 μsec to 10 msec. The experimental set-up is shown in figure 1. Samples and collimating optics were placed on a 4-ft. by 2-ft. optical breadboard in the test cell for the exposures. Optical fibers, shielded from the gamma source by 2 to 4 inches of lead shielding, were used to bring optical signals into and out of the test cell. Data were collected in a separate screen room outside of the test area with optical signals being delivered by the 25-meter long fiber cables. As can be seen in figure 1, white light from a halogen lamp was coupled into one or more optical fibers that carried the light into the test cell. Collimators out-coupled the light from the fibers, allowing it to propagate down the length of the table, passing through the selected samples to retroreflectors. Reflected light propagated back through the samples to the collimator optics where it was coupled back into the fiber. Beam splitters on the optical bench located in the screen room directed the returned white light onto two photo-multiplier tube (PMT) detectors. The desired detection wavelength was selected by aligning relatively narrow-band (15 nm FWHM) interference filters in front of the PMT detectors. Samples of Schott S-7010 filter glass were placed in the test cell and induced loss and fluorescence signals were observed at wavelengths of 660 nm and 800 nm. Sample thicknesses were nominally 12.7 mm. Given the double pass geometry of the optical path (see figure 1), the optical thickness was about 25 mm for each sample. Data acquisition was achieved using Hewlett Packard transient digitizers connected to the detector outputs shown in figure 1. The GSGG laser source operating at 1.061 μm, which is shown in the experimental set-up in figure 1, was not used in this series of tests on these samples.

Results and Discussion

The absorption spectrum of the filter glass prior to irradiation at the gamma facility is shown in figure 2. A strong absorption band can be seen near 1.061 μm, reaching a minimum transmittance of 6.13% at 1.070 μm. The transmission window in the visible pump region between 520 nm and 880 nm is also evident, as is the strong absorption region at wavelengths shorter than about 365 nm (transmittance less than 2%). Figures 3 and 4 show the effects of ionizing radiation on the transmittance of the filter glass at wavelengths of 660 nm and 800 nm respectively. The data in these figures has been corrected for spontaneous emission and induced absorption in the fiber cables and collimating optics. In figure 3 we clearly observe a strong (5x increase in signal intensity) red fluorescence signal immediately following the gamma pulse. This radiation-induced luminescence is fairly broad band with tails reaching out to 800 nm, as can be seen in figure 4. Red luminescence in these materials is not unexpected, it has been widely observed in silicates[12-14] and is generally associated with the presence of peroxy radicals and nonbridging oxygen-hole defect centers in the glass.

The luminescent band relaxes within the first 20 μsec following the gamma pulse and a large radiation-induced loss with a significantly slower decay rate is observed. The induced loss in this material reaches a maximum of a 20% to 25% decrease in the transmittance of the material at the test wavelengths (T=75%-80%). This corresponds to a maximum induced absorption coefficient of

0.088 cm^{-1} at 660 nm and 0.113 cm^{-1} at 800 nm. In addition, figures 3 and 4 show that the signal recovery is very slow with the transmittance rising to only 85% to 90% of its value in the pre-irradiation glass 10 msec after the gamma pulse. It is possible to fit the loss recovery curve with a double exponential to predict the time necessary for total recovery of the induced absorption. This has been done and we anticipate recovery after approximately 200 msec.

Conclusions

We have shown that Schott S-7010 filter glass has a strong transient response to ionizing radiation. A rapidly decaying induced red fluorescence is observed followed by substantial induced loss at the test wavelengths of 660 nm and 800 nm. In the latter case, the induced loss has a fairly slow recovery with a significant loss signal observable 10 msec after the gamma pulse. These results have a strong impact on the viability of this material for use in laser applications. The radiation-induced loss experienced by the material at laser pump wavelengths could seriously degrade laser performance in moderately high radiation fields.

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Figures

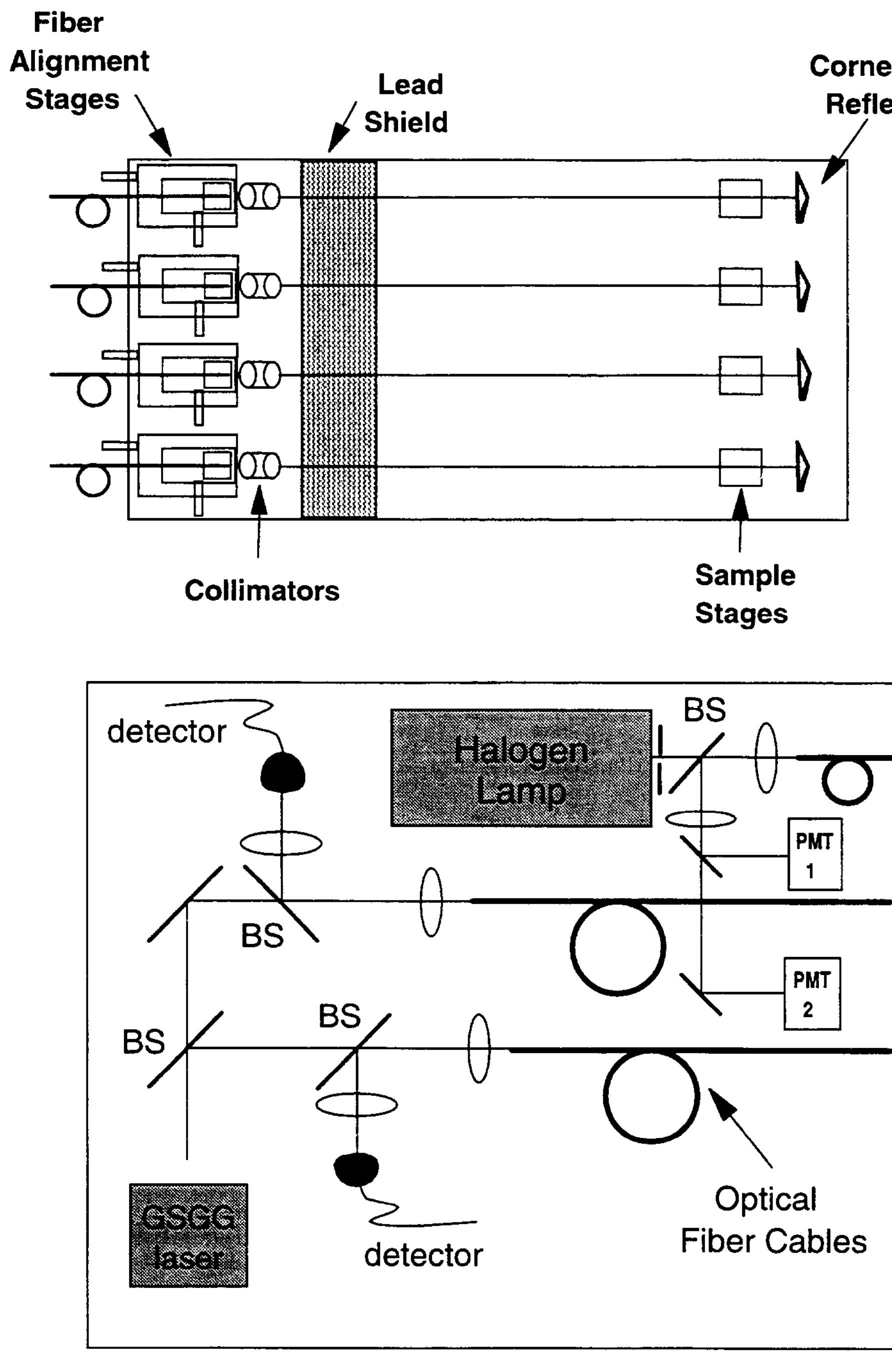


Figure 1: The upper optical bench holds the test samples and is located in the test cell. Optical signals are carried into the shielded screen room by 25 m fiber cables. Transient radiation-induced absorption and emission signals are recorded using the PMTs and photodetectors. Filters in front of the PM tubes are used to select the wavelength of interest from the white light spectrum emitted by the halogen lamp and coupled into the fiber channels.

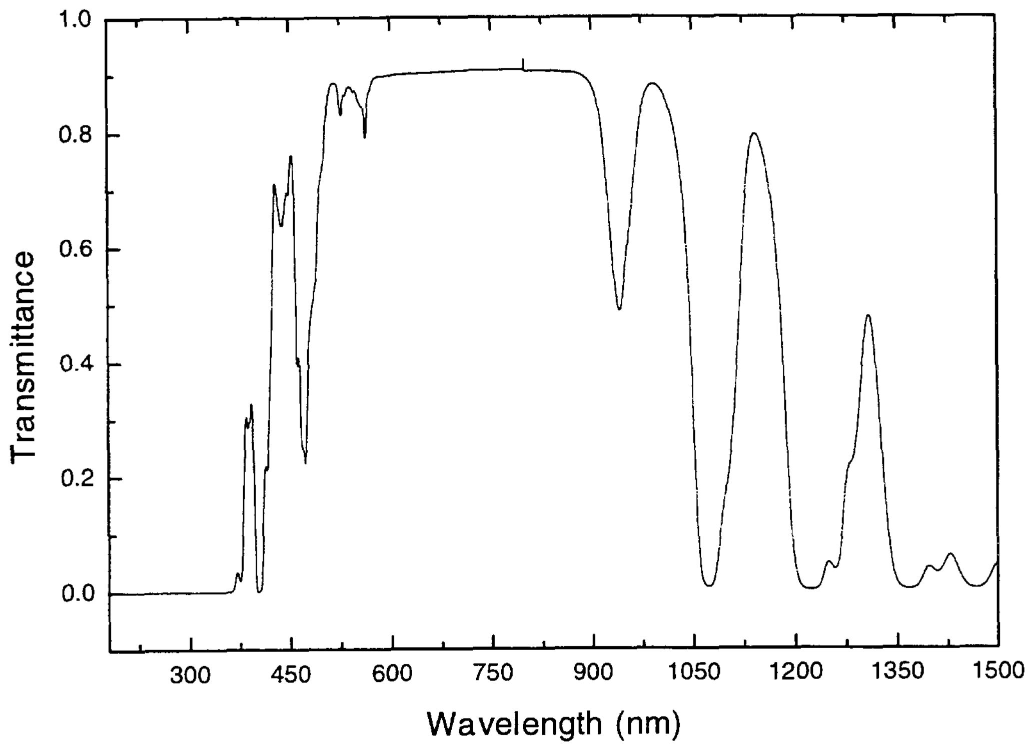
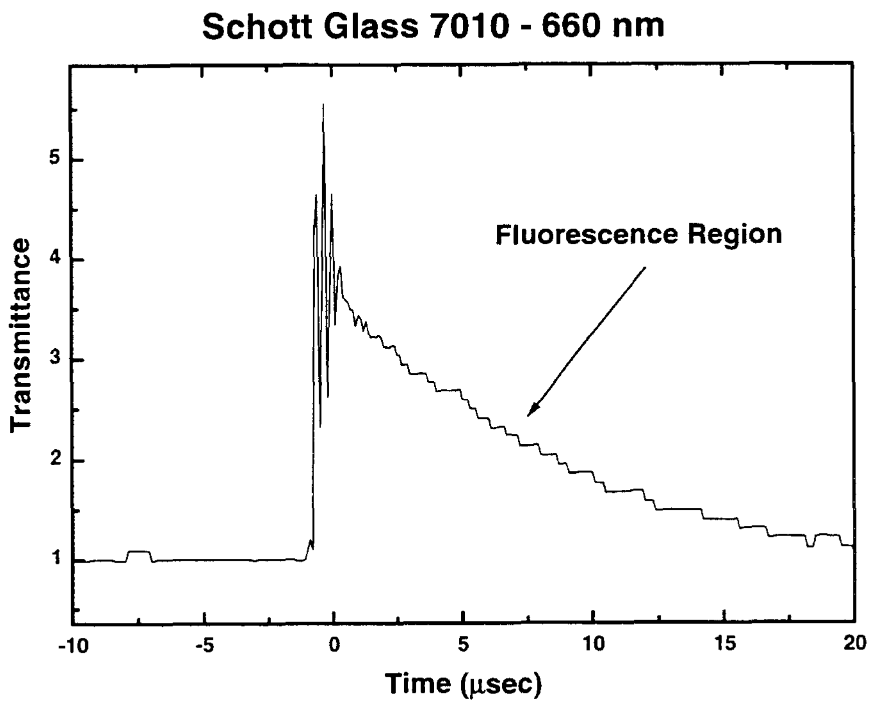


Figure 2: Transmittance of Schott filter glass S-7010. Strong absorption bands present in ultraviolet and at 1.061 µm in the glass. Predominant pass band occurs in the wavelength range of 520 nm to 880 nm.



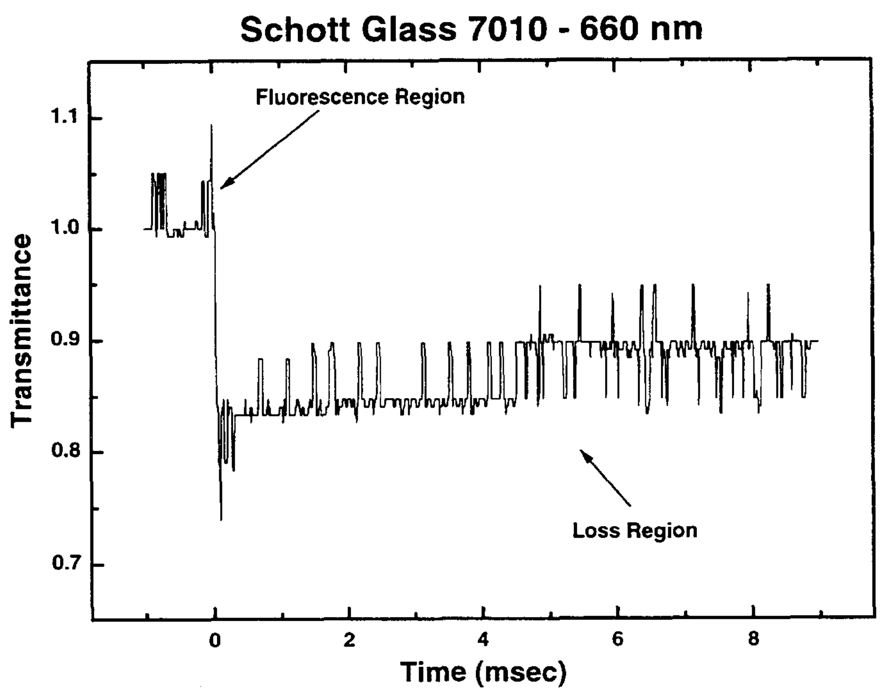
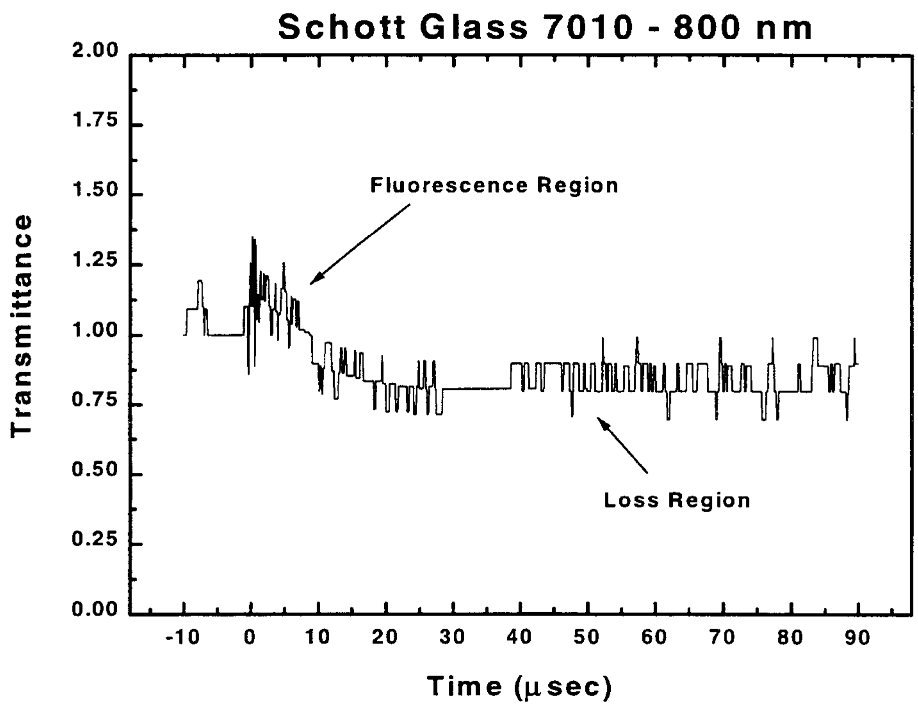


Figure 3: Radiation-induced fluorescence and absorption at 660 nm in Schott S-7010 filter glass. Gamma pulse occurs at time = 0.



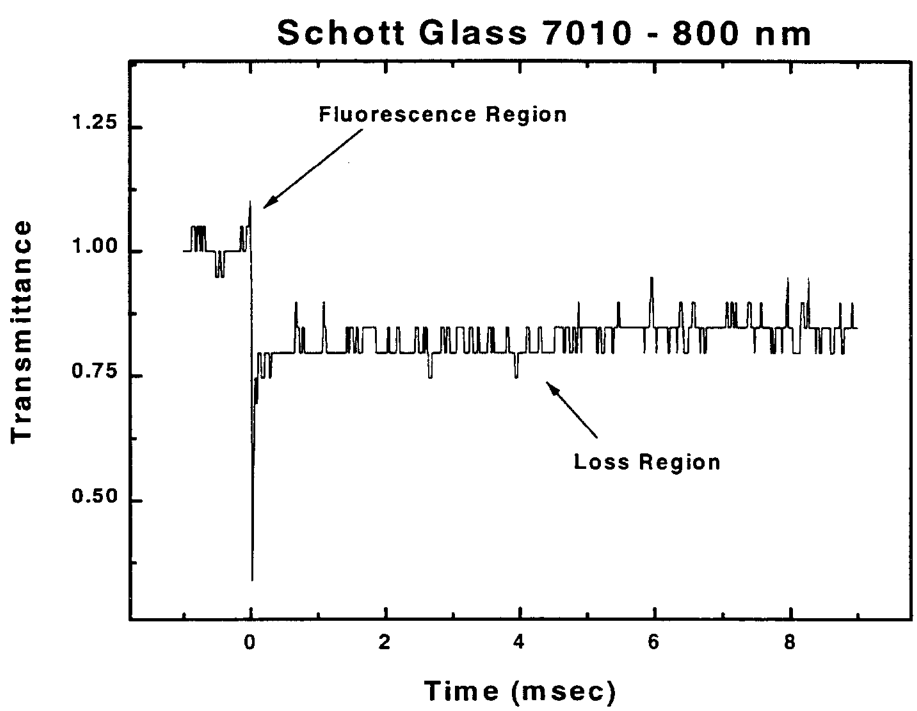


Figure 4: Radiation-induced fluorescence and absorption at 800 nm in Schott S-7010 filter glass. Gamma pulse occurs at time = 0.

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