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RADIATION-INDUCED TRANSIENT ABSORPTION IN SINGLE MODE OPTICAL FIBERS

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INTRODUCTION

Multimode optical fibers have been applied to many data transmission requirements over the last 15 years. Many of these applications have required that the fibers operate in adverse environments, in some cases characterized by intense radiation levels. More recently, single mode fibers and their support technologies have advanced to the point where applications of these fibers are increasing throughout the world. Such single mode fibers offer significantly higher bandwidths than their multimode relatives. Single mode fibers will also be utilized under a range of adverse environmental factors.

Radiation-induced transient absorption has been extensively studied in multimode fibers and several recent papers and reviews have summarized our current knowledge.^{1,2} International collaborative studies have also contributed to the literature available on radiation effects in optical fibers,^{3,4} and have sought to improve our understanding of the influence of test conditions on radiation-induced absorption in optical fibers. To date, most of these studies have used multimode fibers. These international collaborations, under the auspices of the Nuclear Effects Task Group reporting to NATO Panel IV/ Research Study Group 12, have recently begun to include single mode fibers in their interlaboratory comparisons of radiation-induced absorption. This paper reviews the measurements conducted by the Los Alamos National Laboratory in support of these NATO efforts wherein radiation-induced transient absorption was measured over time ranges from a few ns to several μ s for two single mode fibers. Experimental conditions were varied to provide data for future development of standardized test conditions for single mode fibers.

EXPERIMENTAL CONDITIONS

The Los Alamos radiation effects measurements use a Hewlett-Packard Febetron Model 706 electron accelerator that has been modified to deliver an electron pulse of 1.5 ns duration onto an optical fiber. The coil of fiber was coaxial with a small (1.6mm) collimator that transmitted a fraction of the electron beam to a Faraday cup. The 600-keV end-point-energy electron beam was scattered by a thin (69 mg/cm²) aluminum foil at the exit of the Febetron to provide a smooth distribution of beam over the irradiated fiber coil. The fiber coil diameter was 3 cm. Double-sided adhesive tape was used to hold the fiber in the coil geometry. A length of fiber between 40 and 100 cm was irradiated. This geometry is shown in Fig. 1.

LOW DOSE RADIATION ABSORPTION GEOMETRY

Fig. 1. Geometry used for irradiation of optical fibers.
Further details are contained in the text.

The dose was documented with thin (50-micron) radiachromic films composed of a solid solution of hexahydroxy-ethyl aminotriphenylnitrile in nylon. (These films and a reader were purchased from Far West Technology, Goleta, CA.) The film reader was calibrated in rad (H_2O). Corrections were applied to compensate for the compositional difference between H_2O and the SiO_2 of the fiber.⁶ An intercomparison between radiachromic film dosimetry and microcalorimetry was successfully completed and reported in Ref. 6.

The electronic and recording system is depicted in Fig. 2. The transmitter used a cw laser diode. The Febetron was externally triggered. The Faraday cup signal was recorded on an internally triggered oscilloscope and then delayed to trigger another oscilloscope. Both oscilloscopes were Tektronix type 7104. The oscilloscope outputs were recorded on Tektronix C1001 CCD cameras. These cameras provided data to a Tektronix DCS01 Digitizing Camera system. For any one measurement, a series of receiver outputs were recorded:

- a) a baseline without the laser light,
- b) the laser without fiber irradiation, and
- c) the laser signal during irradiation of the fiber.

On the last measurement (c), the Faraday cup output was also recorded. The computer-generated outputs from one typical irradiation are shown in Fig. 3.

Fig. 2. Electronic and optical configuration for the experiments

Fig. 3. Digital camera output and processed output

For measurements in the first wavelength window near 850 nm, a Sharp LT-015-MF laser at 833 nm was used to provide a multimode output. The laser output was lens-coupled into the single mode fiber producing about 300 μ W power level in the fiber. After exiting from the irradiation chamber, the light from the single mode fiber was transmitted through an 850 nm x 12 nm interference filter. This filter plane was not perpendicular to the fiber axis to prevent back-reflections into the fiber. Immediately following the filter, the light was lens-coupled into the 100-micron multimode fiber pigtail of a Hewlett Packard 81519A receiver that provided a dc-400MHz bandwidth with a sensitivity of 1V/mW in the first window.

For measurements in the second wavelength window near 1300 nm, a Thomson SF610 multimode laser was used. Two different lasers were used, one emitting at 1303 and one at 1291 nm. The pigtail of either laser was welded onto the single mode fiber and launched about 220 μ W into the fiber. After exiting from the irradiation chamber, the light from the single mode fiber was transmitted through a 1300 nm x 10 nm interference filter. Again, that filter was not perpendicular to the fiber axis. Immediately after the filter, the light was lens-coupled into the fiber pigtail of another Hewlett Packard 81519A receiver that had been modified by replacement of the standard C30617E PIN diode with a C30980E PIN diode to provide detection sensitivity at the longer wavelengths. This modified receiver provided the same dc-400 MHz frequency response with a sensitivity of 1.6 V/mW at 1300 nm.

In both wavelength windows, two options were tested:

- Some measurements utilized a "mandrel-wrap" consisting of 5 turns of the single mode fiber on a 13 mm diameter rod. About 50% of the injected power was lost with this wrap. This wrap was incorporated just after the location where the transmitter light was injected into the single mode fiber.
- For some measurements, a "clad stripper" was added after the irradiation region, just prior to the interference filter. About 2.5 cm of the fiber buffer layer was removed for the clad stripping operation, and optical coupling gel was used to assure optical contact between the fiber cladding and a glass plate.

Two single mode fibers were drawn by Lightwave Technologies, Inc. using Dainichi Type SPWX low-OH preforms. One fiber was produced for each wavelength window. The first window fiber provided a wavelength cutoff near 700 nm, a numerical aperture of 0.12, and attenuation of 4.45 db/km. The second window fiber provided a wavelength cutoff near 1188 nm, the same numerical aperture, and attenuation of 0.7 db/km. Fiber diameter was 125 microns. The buffer layer diameter was 250 microns.

EXPERIMENTAL DATA

The fiber samples were irradiated with many electron pulses. Some electron pulses irradiated new fiber, while other pulses used pre-irradiated fiber. In Figs. 4 (and 7), the observed attenuation at a time of 100 ns after the Febetron pulse is plotted for first (and second) window measurements. The observed attenuation is normalized by the fiber dose and the data are plotted for a variety of fiber dose levels from different electron pulses. The different symbols refer to new and pre-irradiated fiber and to different combinations of the mandrel wrap and clad strip geometries. Even for the wide range of dose levels observed in these measurements, the variation of the transient attenuation with time was noted to be dose independent and that variation is plotted, after normalization to unity at 100 ns, in Fig. 5 (and 8). For two different dose levels, the absolute values of the transient attenuation are shown in Figs. 6 (and 9).

Fig. 4. Transient attenuation measured in the first window 100 ns after irradiation as a function of pulse dose. The attenuation is normalized by the dose.

Fig. 7. Transient attenuation measured in the second window 100 ns after irradiation as a function of pulse dose. The attenuation is normalized by the dose.

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Fig. 5. Relative transient attenuation measured in the first window, normalized to the attenuation documented at 100 ns. The shape of this curve was observed to remain constant over the range of doses investigated

Fig. 8. Relative transient attenuation measured in the second window, normalized to the attenuation documented at 100 ns. The shape of this curve was observed to remain constant over the range of doses investigated

Fig. 6. Radiation induced transient attenuation measured in the first wavelength window for doses of 10 and 50 krad (SiO_2).

Fig. 9. Radiation induced transient attenuation measured in the second wavelength window for doses of 10 and 50 krad (SiO_2).

DISCUSSION

From the data of Figs. 4 and 7, it is evident that the mandrel wrap and clad strip operations did not modify the transient attenuation. The absence of a mandrel wrap effect is not surprising, since with a single mode fiber the "mode-scrambling" introduced by the mandrel wrap can only serve to populate modes that are not propagated within the fiber core, and the mandrel wrap caused a significant (50%) loss in propagated light power. This power loss also implied that any instabilities in the mandrel wrap geometry would be translated into variations in the transmitted light level. These variations would introduce a noise source into the attenuation measurements, particularly for measurements at long times. The absence of a clad strip effect probably is critically dependent on the particular type of buffer applied to the fiber. If the index of that buffer layer served to trap light in the fiber clad layer, a large effect of clad stripping might be anticipated if the radiation-induced attenuation properties of the clad and core materials were different. The effect of trapped cladding modes could be of critical importance in

single mode measurements, where the majority of the volume of the fiber is occupied by the clad layers.

The data of Figs. 4 and 7 show no difference between new and pre-irradiated fiber. With most fibers tested at Los Alamos, differences between the transient attenuation of new and pre-irradiated fiber have been noted. In those cases, however, our procedure incorporated a pulsed laser diode as the light source. The use of the cw light source in these measurements may have contributed to the complete absence of any effect due to pre-irradiation. This continuous light may have provided photobleaching during the several minutes between electron pulses.

Figures 4 and 7 show the same behavior we have noted in many previous studies of multimode fiber, wherein the transient attenuation is highly nonlinear with fiber dose. Lower dose levels produce proportionately far more damage in the fiber as noted in these data. In past papers⁷, we've suggested that at least two phenomena could explain this nonlinearity, namely:

- a) a class of pre-existing defects could produce sites especially susceptible to radiation damage, and these pre-existing defect sites could become saturated at higher doses; or
- b) at higher doses, very rapid interactions between damaged areas from separate electron tracks could lead to the healing of induced defects and less apparent damage.

These two hypotheses should be equally applicable to the single-mode fibers tested in the current work.

Significant improvement in the absolute values of transient attenuation is evident for the second window measurements. In Figs. 10a and 10b, transient attenuation is plotted as a function of time for two dose levels (10- and 50- krad, respectively) and the two wavelengths characteristic of the two window regions. About three times less attenuation is observed for the longer wavelength.

Fig. 10. Comparison of the transient attenuation observed in the two wavelength windows for two different dose levels: a) 10 krad (SiO₂), and b) 50 krad (SiO₂).

In Fig. 11, a comparison between the transient attenuation measured in single- and multimode fibers is presented. The fibers of Fig. 11 used low-OH content Dainichi preforms. However, different preforms were used for the three fibers of Fig. 11, and significant compositional differences may have existed between these preforms, as well as different manufacturing conditions by the two companies that drew the fiber. Future research will be required to determine if "identical" fiber compositions and draw conditions yield comparable transient behavior when prepared in single- and multimode fibers.

Fig. 11. Comparison of the transient attenuation measured at a 50 krad dose in three fibers fabricated from low-OH Dainichi preforms. The two single mode fibers were studied in the present paper, while the multimode fiber was obtained from Dainichi, measured, and data reported in Ref. 8. As further clarified in the text, these fibers did not share a common preform and their performance will be influenced by differences in preform composition and in manufacturing procedures.

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