LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

MASTER

LA-UR--83-1313

DE83 012740

TITLE: RADIATION DAMAGE IN OPTICAL FIBERS

AUTHOR(S): Peter B. Lyons, P-14
Larry D. Looney, P-14
James W. Ogle, P-14

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.
It has been reproduced from the best available copy to permit the broadest possible availability.

SUBMITTED TO: Los Alamos National Laboratory
Los Alamos Conference on Optics '83
Santa Fe, NM
April 11-15, 1983

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Radiation damage in optical fibers

P. B. Lyons, L. D. Looney, and J. W. Ogle

Los Alamos National Laboratory, P. O. Box 1663, MS D410, Los Alamos, New Mexico

Optical fibers provide important advantages over coaxial cables for many data transmission applications. Some of these applications require that the fibers transmit data during a radiation pulse. Other applications utilize the fiber as a radiation-to-light transducer. In either case, radiation-induced luminescence and absorption must be understood.

Most studies of radiation effects in fibers have emphasized time scales of interest in telecommunication systems, from the msec to hour range.^{1,2} Few studies have concentrated on response at times below 1 μ s. At Los Alamos, both laboratory electron accelerators and nuclear tests have been used as radiation sources to probe this early time region. Prompt luminescence was identified as predominately of Cerenkov origin.³ Neutron- and gamma-induced attenuation were shown to be comparable if both doses were expressed in units of absorbed dose.⁴ Plastic-clad-silica (PCS) fiber has been shown to be superior for radiation resistance to all-glass fibers in our studies to date.⁵

Considerable effort has been expended in modeling the transient attenuation of PCS fiber. Many features of the attenuation have been modeled with the geminate recombination theory, but this theory has not successfully modeled the very early time behavior below ~ 10 ns.⁶ In this early time region, the transient attenuation appears to follow an exponential recovery. This "exponential" component is independent of temperature, in marked contrast to the very strong temperature dependence of geminate recombination that is dominated by a temperature-sensitive diffusion constant.

While PCS fiber shows the greatest radiation resistance, PCS fiber has been difficult to reliably connectorize for routine field operations. For this reason, all-glass fibers have been studied as an alternative to PCS. Based on available literature and some preliminary tests at Los Alamos, we have concentrated on fluorosilicate clad, step index, pure silica core fibers. This paper reviews recent laboratory data for these fibers relative to the PCS fibers.

This paper also discusses use of a fiber (or any optical medium) as a Cerenkov radiation-to-light transducer. Since the radiation induces attenuation in the medium, the light output is not proportional to the radiation input. The nonlinearity introduced by this attenuation is calculated herein.

Experimental Method

A Febetron 706 is used to provide a 1.5 ns electron pulse that irradiates a small coil of the fiber under test. The electron beam is scattered by a thin Al foil at the exit of the Febetron to provide a more uniform deposition over the coil area. The fiber coil encircles a collimating aperture, behind which is a fast Faraday cup. The electron pulse is recorded on every Febetron pulse as a measure of electron dose.

A tunable dye laser with an optical parametric oscillator (Chromatix CMX-4 system) provides an intense source of light with wavelength adjustable between 500 and 2000 nm. The laser and Febetron are synchronized in time such that the Febetron pulse occurs during the laser output. Biplanar vacuum diodes (ITT F4014 or FW114A) detect the light signal before and after the dosed region. The first signal is derived either from scattered light out of a coil in the input fiber or by insertion of a bidirectional coupler into the input fiber. Both signals are recorded on oscilloscopes. The system is shown schematically in Figs. 1 and 2.

Relative dosimetry is provided by the Faraday cup. This cup output is normalized to absorbed dose by comparison to radiachromic film (Far West Technology, Inc., Goleta, CA). This film provides a low mass (~ 5 mg/cm²) monitor of absorbed dose. Calibration of the film with a ⁶⁰Co source confirmed the vendor's sensitivity data. The low electron energy (maximum 600 keV) of the Febetron 706 leads to concern over non-uniform dose within the fiber. This was tested by preparing a multilayer stack of the thin radiachromic films and thin Al foils. This stack was then exposed to multiple Febetron shots while the Faraday cup was recorded. The resulting data set, Fig. 3, established the converter from observed current to dose. The mass range of the typical fiber core is shown in Fig. 3 and indicates a reasonably uniform dose through the fiber.

Fig. 1. Schematic diagram of the apparatus used for transient attenuation measurements in optical fibers. The "fast" channel diode recording the output of the dosed fiber, was recorded on a 1 GHz Tektronix 7104 oscilloscope in addition to the slower Tektronix 7844 oscilloscope.

Fig. 2. Schematic diagram of the geometry at the exit port of the Febetron 706. The Faraday cup signal was recorded on a Tektronix 7104 oscilloscope.

Fig. 3. Depth dose curve for the Febetron 706 in the operational configuration. Radiachromic film sampled the dose between aluminum foils.

Experimental Data

The present work concentrated on measurements of four types of fluorosilicate clad fibers: three types of QSF-AS (Quartz Products Corp.) fiber, a super-wet fiber (SW, 1300 ppm OH), a standard fiber (STD, 200 ppm OH), and a super-dry fiber (SD, 30 ppm OH) and Raychem VSC fiber. The four fibers are compared in Fig. 4 to the PCS fiber (ITT PCS T303) that has consistently delivered our best short term performance. For each of the QSF fibers, data were acquired at several dose levels and are presented in Fig. 5. The ITT PCS fiber is again shown for reference.

Fig. 4. Transient attenuation measured for five fibers exposed to similar doses.

These fluorosilicate clad fibers represent the best all-glass fibers we have measured to date. Data for the three QSF-AS OH concentration levels is consistent with a hypothesis of improved performance at higher OH levels. However, since the production of these fibers uses different plasma conditions, variables other than OH impurity levels may be present. The Raychem VSC is comparable to the ITT PCS and represents the first all-glass fiber to equal the ITT PCS fiber performance in our tests.

Cerenkov Radiation Transducers

At Los Alamos, many experiments have utilized the Cerenkov effect in optical materials, including fibers, as a radiation detector. Ideally this detector would provide a light output proportional to the incident radiation. If, however, attenuation is induced in the material by the radiation, the resultant light output will be reduced. In this situation, the transducer becomes nonlinear.

An estimate of this nonlinearity can be simply derived if the induced attenuation is linear with radiation dose. For the fluorosilicate fibers emphasized in this paper, this assumption is not valid (cf. Fig. 5), but for PCS fibers this assumption is close to observation for doses above 20 kRad.

Consider a length L of fiber with index n , oriented perpendicular to a radiation front, such that all of the fiber is irradiated simultaneously, see Fig. 6. Transducer absorption, in the absence of radiation, is ignored. We define:

- $\dot{\phi}(t)$ = radiation pulse in rad/sec.
- $b(t)$ = attenuation at time t , per rad of dose delivered at $t = 0$. This assumes damage scales linearly with dose. $b(t)$ units are dB/cm·rad.
- $u(t)$ = attenuation coefficient of fiber, per cm, at time t after exposure. $u(t)$ units are dB/cm.
- $$u(t) = \int_0^t \dot{\phi}(\tau) b(t - \tau) d\tau$$
- ϵ = Cerenkov coupling coefficient in mW/cm·nm·Å
- $\Delta\lambda$ = Wavelength interval

Fig. 5. Transient attenuation of three QSF-AS fibers with different OH concentrations. Data for ITT T303 PCS is shown for reference. Note that attenuation does not scale with dose.

Fig. 6. Geometry assumed for transducer nonlinearity calculation.

From these definitions and the assumed geometry, the light output $S(t)$ in mw is:

$$S(t) = \epsilon \Delta \lambda \int_0^L \dot{\phi}(t - \frac{x}{v}) \left[10^{-0.1 \int_0^x b(t - \frac{y}{v}) dy} \right] dx \quad (1)$$

This equation is exact given a fiber perpendicular to a radiation front and $b(t)$ proportional to dose.

In many real cases, relatively short fiber lengths are irradiated. If the light transit time (L/v) through the irradiated section is short relative to a change in dose:

$$\frac{L}{v} \ll 1 \quad (2)$$

and if the light transit through the fiber occurs at a "constant" $\dot{\phi}$:

$$\frac{L}{v} \ll 1 \quad (3)$$

then we can ignore the use of retarded times in Eq. 1. $S(t)$ can be reduced then to

$$S(t) = S_0(t) \cdot f \quad (4)$$

with

$$f = (1 - e^{-Y})/Y \quad (5)$$

where S_0 represents the ideal transducer output with zero attenuation:

$$S_0(t) = \epsilon \Delta \lambda L \dot{\phi}(t) \quad (6)$$

and

$$Y(t) = 0.1 \ln 10 L \int_0^t \dot{\phi}(\tau) b(t - \tau) d\tau \quad (7)$$

The factor f then determines the departure from linearity. The transmission T through the entire dosed region, under these assumptions, is simply

$$T = e^{-Y} \quad (8)$$

Thus a measure of fiber transmission provides a direct measure of the factor Y needed in Eq. 5. Alternatively, models of $\dot{\phi}$ and b can be used to estimate f in any experiment.

Conclusion

Recent measurements of radiation-induced transient attenuation in fluorosilicate fibers have provided data for consideration of such fibers in severe radiation environments. The best of these all-glass fibers equals the best performance observed for any fiber in the Los Alamos testing program.

The nonlinearity in a Cerenkov radiation transducer is calculated for a general case and is shown to be related to the transmission through the material at any time for a special case.

References

1. G. H. Sigel, Jr., E. J. Friebele, M. E. Gingerich, Proceedings SPIE Vol. 296, 2 (1981).
2. E. J. Friebele and M. E. Gingerich, Applied Optics, 20 3448 (1981).
3. J. E. Golob, P. B. Lyons, L. D. Looney, IEEE Trans. on Nuc. Sci., NS-24, 2164 (1977).
4. P. B. Lyons, L. D. Looney, J. Golob, R. Robichaud, R. Seno, J. Madrid, L. Hocker, and M. Nelson, in Fiber Optics, edited by B. Bendow and S. Mitra, Plenum Press (New York, 1979) p. 379.
5. P. B. Lyons, R. E. Kelly, L. D. Looney, Proceedings of the Fiber Optics in the Nuclear Environment Symposium, edited by R. C. Webb, (Washington, 1980) Defense Nuclear Agency, DNA 5308P-2, Contract DNA 001-79-C-0081.
6. L. D. Looney, G. Turquet de Beauregard, P. B. Lyons, and R. E. Kelly, Proceedings SPIE Vol. 296, 17 (1981).