Radiation Hardness of Optical Fiber

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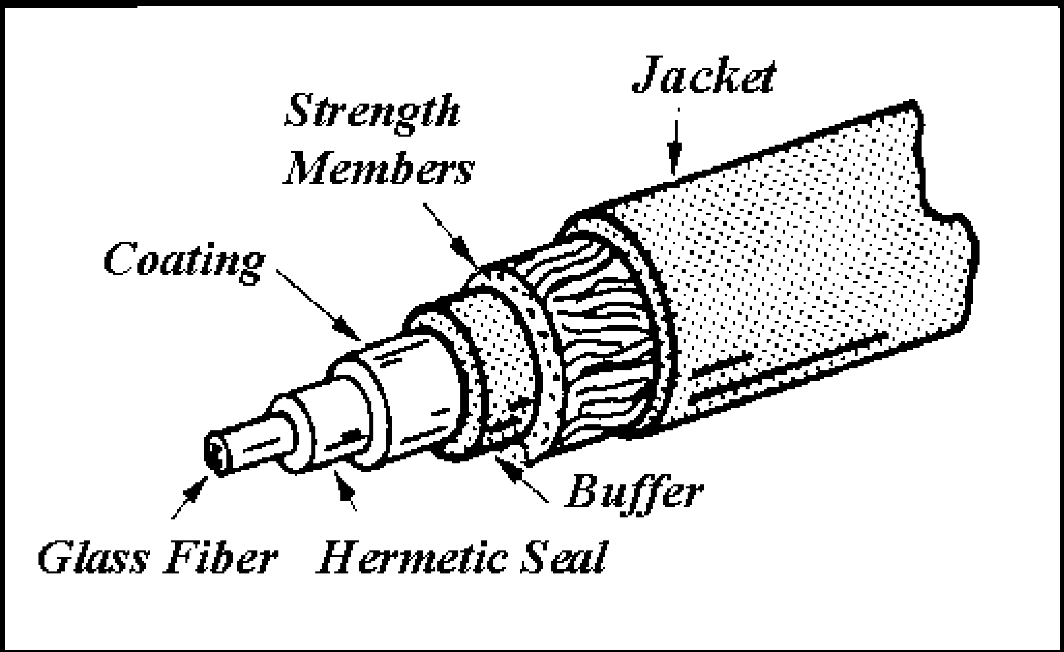
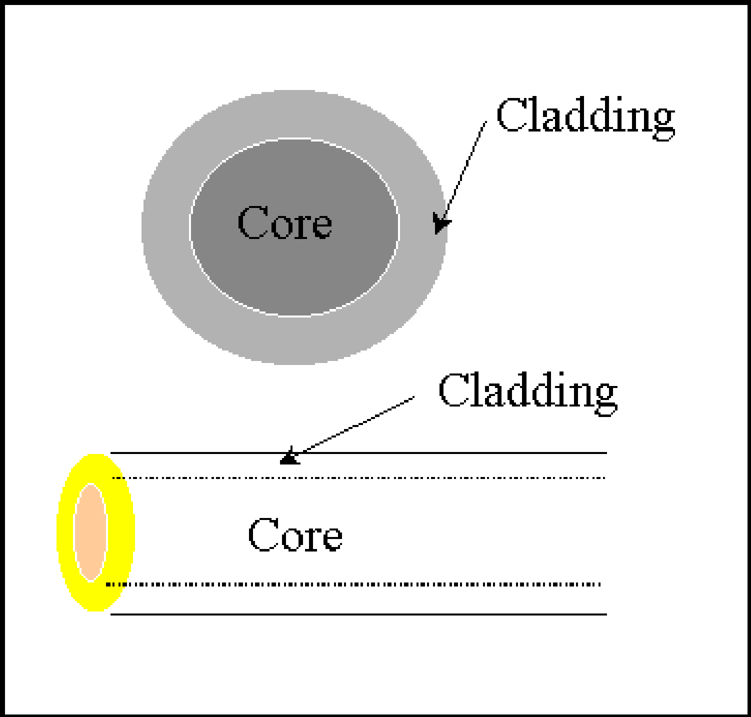
Outline

- Definitions.
- Radiation effects on optical fiber, attenuation.
- Parameters that influence radiation induced effects.
- Mechanisms of recovery.
- Mathematical model for recovery and extrapolation.
- Testing and methods of radiation hardening.

Optical Fiber Definitions





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Optical Fiber Behavior in Radiation Environment

- Attenuation
  - mechanism, peak in UV w/ tails extending to IR.
  - Transient
  - Permanent
  - Dependent on many parameters
- Saturation
- Recovery
- Photobleaching

Why focus on these behaviors?
Attenuation is a significant parameter in communications applications.

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Definition of Color Centers

Areas in materials showing preferential absorption and transmission to certain wavelengths of light due to certain ions having inner-shell electrons that interact with photons of certain wavelengths and do not interact with others.

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Parameters that Affect Attenuation and Recovery of Optical Fiber

- Operating Wavelength
- Materials used as dopants
- Fabrication proceedure
- Fiber Coating Materials
- Temperature of Operation
- Dose Rate
- Total Dose

Wavelength of Light

- In general, more sensitive to smaller wavelengths, peak absorption in UV.
- Less sensitive to longer wavelengths, near IR (1310nm, 1550 nm).
- Incremental loss decreases with increasing wavelength. (not true for P doped fiber)

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Preform Fabrication Materials

$$SiCl_4 + O_2 \longrightarrow SiO_2 + 2Cl_2$$

$$GeCl_4 + O_2 \longrightarrow GeO_2 + 2Cl_2$$

Focus here is on optical fiber for communications in space flight

Dopants are required to fabricate multimode graded index fiber which is commonly used in space communications systems such as the 1773.

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Materials for Doping

- Phosphorus doping of core or clad,
  - used for ease of fabricating preform, for clad.
  - attentuation proportional to wt% content for low dose rate.
  - no saturation.
  - can invert the typical recovery of fiber at high temps and increases absorption at longer wavelengths.
- Fluorine doping of cladding.
- Germanium doping of core and clad
  - high NA fiber can be rad hard when using Ge at an optimal higher wt% in core.
  - reaches saturation, and anneals at higher temperatures.
  - used to reduce intrinsic losses of pure silica and are easier to fab. core.
  - can increase transient response.
- Boron
  - can improve transient response at the expense of the permanent attenuation.
- Germanium, Phosphorus combination
  - Attenuation rises at wavelengths above 1050 nm.

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Fabrication Parameters

- OH content
  - greater density not always more resistant to radiation, dependence on other parameters like temperature and other materials.
  - High absorption at 1390 nm
  - less content is more sensitive in fibers not operating at 1300 nm.
  - low OH more sensitive to rad and temp at low wavelengths.
- Impurities
  - usually make fiber more sensitive to radiation.
  - Cl or H (OH) content
- Drawing Speed, affects initial attenuation, and kinetic order n.
- Drawing Tension, affects initial attenuation.
- Oxygen content
  - used for core fabrication affects final attentuation and recovery time.
- Coating Process
  - Some coating processes such as polyimide cause fiber to go under an annealing from high temp. which removes impurities.

Fiber Coating Materials

- Crosslinking of polymer coating
  - Radiation can cause crosslinking resulting in microbending.
- Polyimide
  - Process of applying polyimide, 400 - 500 C
- Acrylate
  - Requires UV which can have damaging effects.
- Hermetic coating under polymer coating
  - over time can protect from getting further impurities from H.
  - application process.

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Saturation

- Recovery Parameters
- Materials, (ex. Ge vs P)
  - Ge reaches saturation
  - P may not reach saturation.
    (under same dose rate as Ge)
- Photobleaching
  - usually over 10 microwatts
  - Ge responsive to photobleaching
- Annealing
  - Temperature
  - Material dependent
  - real time annealing

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Recovery

- Photobleaching
  - wavelength, power, materials
- Parameter n, kinetic order of recovery.
  - core oxygen content.
  - draw speed
- Parameter, τ half life of incremental loss.
  - materials (more Ge in core can decrease)
- Temperature.
- Oxygen content
  - increasing content along with high draw speed can decrease n
  - increasing content up to an optimal value can decrease the induced final attenuation.

Testing and Using the Extrapolation Method

- What data is necessary?
- What do you calculate?
- What does it tell you?
- What is the real environment?
- What is my testing environment?

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Radiation Induced Loss, following high dose rate exposure, A(t)

(E.J. Friebele, M.E. Gingerich, D. L. Griscom)

Recovery Equation

$$A(t) = (A_o - A_f)\{1 + ct\}^{-1/(n-1)} + A_f$$

$$c = (1/\tau)[\,2^{n-1} - 1\,]$$

A_o initial induced attenuation.

A_f final attenuation.

τ half life of incremental loss.

n kinetic order of recovery.

Extrapolation Method

(E.J. Friebele, M.E. Gingerich, D. L. Griscom)

Radiation induced loss A(D)

$$A(D) = CD^f$$

$$C \propto \Phi^{(1-f)/n}$$

Therefore it is necessary to take loss data at two different dose rates to get f and n and then use equation for A(D) to calculate radiation induced loss at any other dose rate.

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Fiber Optics Systems for Flight

- TRMM, 1773
- XTE, 1773
- MPTB, dual rate
- Lewis, fly-by-light
- Lockheed Martin, Several Projects
- EO-1 1773 dual rate
- MIDEX, 1773
- SAMPEX, 1773
- LDEF
- COBE

Performance and Testing of Available Fiber

- 10 dB/km
- Co^{60} used to characterize damage.
- Primary or secondary electrons can cause displacement damage,
  - 70 KeV to displace oxygen atom.
  - 200 KeV to displace Si atom.
- Best test is simulation of actual environment.
- Doping unavoidable for multimode.
- Pure silica for single mode, impurity content tailored to application.
- Reports of hardening fiber as a result of pre-irradiation.
  - NRL 1996 Ultra high dose (up to 1E8 rads) preirradiation limits peaks in absorption for silica core/fluorine clad fiber.

References

Summary:

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- E. J. Friebele "Photonics in the Space Environment," NSREC 1991.

- P. Marshall, C. Dale, E. J. Friebele, K. LaBel, "Survivable Fiber Based Data Links for Satellite Radiation Environments," SPIE Critical Review Series: CR50 Paper 14 on Fiber Optics Reliability and Testing, 1993.

General:

- D. Griscom, "Radiation Hardening of Pure-Silica-Core Optical Fibers by Ultra-High-Dose Gamma Ray Pre-Irradiation," RADECS 95.

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