Fiber Amplifier Performance in γ-Radiation Environment

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Abstract

Fiber based amplifiers are being considered for use on low earth orbiting (LEO) satellites for next generation communication systems. This paper deals with evaluation of the performance of an Er/Yb based fiber amplifier in γ-radiation environment.

Satellite assisted communication between airborne and ground based assets has already been demonstrated but is currently limited to up and down linking. The next generation communication architecture intends to create a backbone network of satellites transmitting high bit rates of information. One of the key components enabling inter-satellite optical communication is a high power optical amplifier (HPOA) operating in the optical C-band. The power requirement for such a HPOA could be in excess of 1 W with an operational lifetime of 14 years. This in itself is achievable with commercial optical devices. However, an additional and more challenging requirement is survivability in space in the presence of natural and man-made ionizing radiation. The latter in particular requires components like double clad (DC) Er/Yb doped fibers which are now becoming available. In such fibers, the doped glass core carrying the seed and the amplified signal is surrounded by un-doped glass cladding that carries the pump. The glass cladding in turn is surrounded by a low index fluoro-acrylate coating to provide pump guiding structure. In this paper we examine the effects of γ-radiation on the: (i) passive transmission behavior of pump, (ii) mechanical reliability of glass, (iii) passive transmission behavior of signal, and (iv) performance of an optical fiber amplifier based on an existing DC Er/Yb fiber.

DC Er/Yb doped fibers are pumped at 915 nm or 976 nm. To understand the role of fluoro-acrylate coating in affecting the pump transmission behavior, a 125 µm coreless silica fiber was drawn with a fluoro-acrylate primary coating (NA ~0.46) and a regular acrylate secondary coating. Final coating diameter was 250 µm. This fiber was exposed to γ-radiation from a Co^{60} source at dose rates of 19.6 Rad/sec and 33.8 Rad/sec. Radiation induced transmission losses were measured (in-situ) in the 700-1400 nm wavelength range using a broad band source and an OSA. Results for the dose rate of 19.6 Rad/sec are presented in Fig. 1which indicates that absorptive losses increase with increasing total accumulated dose. Results for the dose rate of 33.8 Rad/sec were similar. Absorption peak at ~1190 nm is characteristic of the fluoro-acrylate coating. Radiation induced loss increases rapidly upon exposure to radiation but then levels-off. This is shown more clearly in Fig. 2. The rapid increase in loss followed by almost near saturation of the loss is characteristic of pure silica core fibers and can be represented well by a "sum of saturating exponentials" model.[1] We also measured the absolute attenuation of this fiber using the standard cutback method[2] before and after irradiation. Post exposure measurements were performed on the fiber (exposed at a dose rate of 19.6 Rad/sec to a total accumulated dose of 239.4 kRad) 48 hours after the end of irradiation.

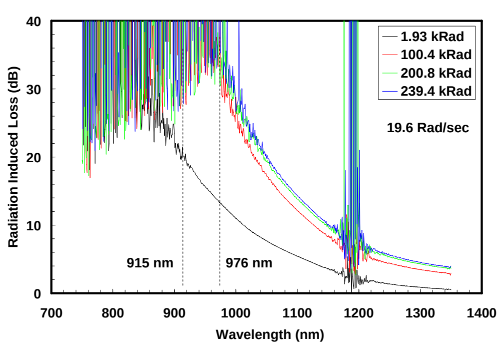

Fig.1 Transmission loss spectra of fluoro-acrylate coated coreless silica fiber at different irradiation levels.

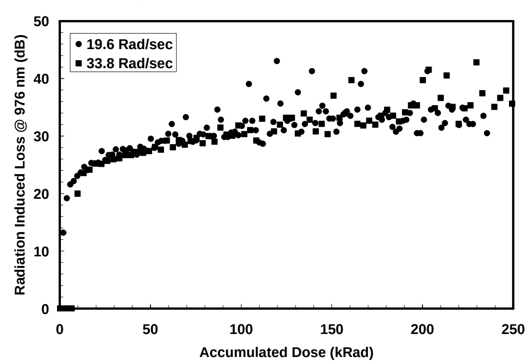

Fig. 2 Radiation induced transmission loss as a function of total accumulated dose.

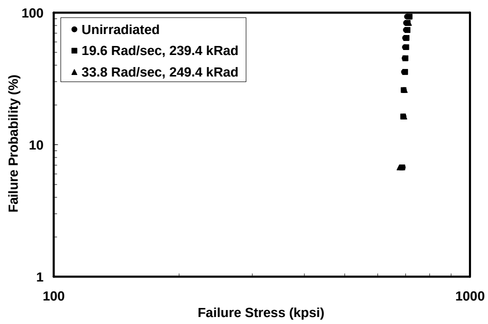

Fig. 3 Tensile strength test results

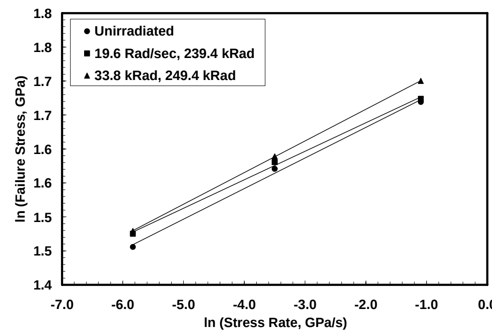

Fig. 4 n-parameter measurement results.

Attenuations at 976 nm before and after irradiation were 5 dB/km and 18 dB/km, respectively. In applications where ~10 m of fiber is used, radiation induced attenuation is of the order of 0.13 dB which is not significant. The results suggest that fluoro-acrylate coating does not have deleterious effects on the pump transmission characteristics with increasing γ-radiation dose up to ~250 kRad.

Tensile pull testing and n-parameter measurements were carried out on un-irradiated and the two irradiated fluoro-acrylate coated coreless silica fibers. Tensile testing was conducted with 0.5 m gauge length and ten specimens were broken per fiber. For n-parameter determination, three stress rates were used for each fiber and ten specimens were tested at each stress rate. Results are presented in Fig. 3 and Fig. 4. Fig. 3 clearly indicates that the tensile strength does not degrade upon exposure to γ-radiation up to a total accumulated dose of ~250 kRad. The corresponding median tensile strength values are 697, 701 and 700 kpsi for un-irradiated, irradiated at 19.6 Rad/sec and irradiated at 33.8 Rad/sec, respectively. Similarly, Fig. 4 indicates that the n-parameter (from slopes of the plots) does not degrade upon exposure to γ-radiation up to a total accumulated dose of ~250 kRad. The corresponding n-parameter values are 19.2, 21.o and 22.6 for un-irradiated, irradiated at 19.6 Rad/sec and irradiated at 33.8 Rad/sec, respectively. The results illustrate that fluoro-acrylate coating has no deleterious effects on short and long-term mechanical reliability of fibers exposed to γ-radiation up to a total dose of ~250 kRad.

To eliminate the effects of fluoro-acrylate coating, measurements were performed on Nufern SM-EYSF fiber (8.3/125/250 µm) that does not have fluoro-acrylate coating. This fiber has peak core Er and Yb absorptions of 19 dB/m at ~1535 nm and 150 dB/m at ~915 nm, respectively. The fiber was exposed to γ-radiation at a dose rate of 4.5 Rad/sec to a total accumulated dose of ~91 kRad. Radiation induced transmission losses were measured (in-situ) in the 900-1040 nm and 1350-1600 nm wavelength ranges using a broad band source and an OSA. A 0.208 m length of fiber was used that was fusion spliced to 5 m long Nufern 980-HP fiber leads. Transmission spectra at various dose levels are presented in Fig. 5 indicating absorptive losses increasing with increasing total accumulated dose. Core Er absorption peaks are visible at 1537 nm. Radiation induced loss and recovery data at 1537 nm are presented in Fig. 6 which indicates that: (i) induced transmission losses are relatively high and loss is far from reaching saturation,

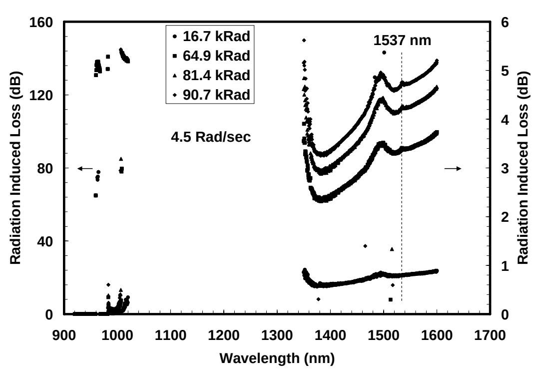

Fig. 5 Transmission of SM-EYSF fiber at different irradiation levels.

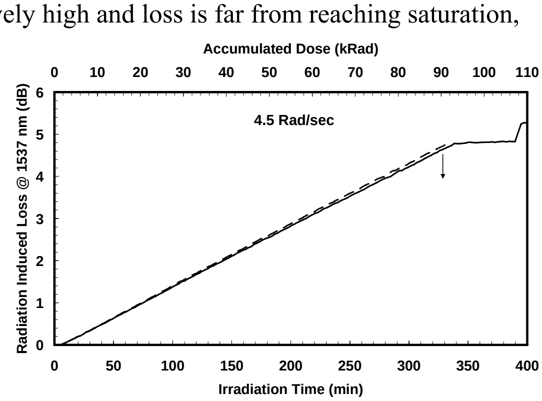

Fig. 6 Radiation induced transmission loss as a function of total accumulated dose.

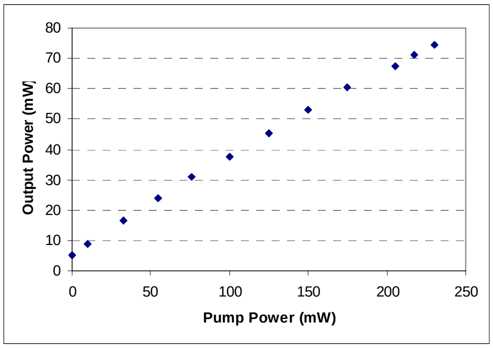

Fig. 7 Amplifier efficiency plot.

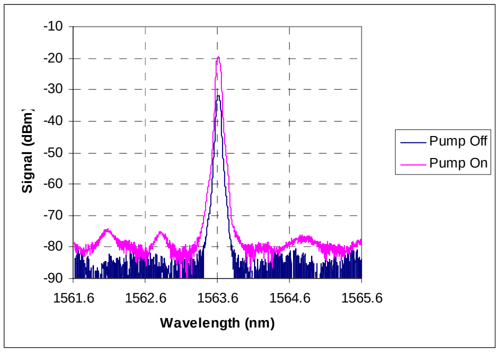

Fig. 8 Amplifier signal with and without pump.

and (ii) fiber does not exhibit recovery for at least one hour after the termination of irradiation.

Two, II-stage amplifiers were built using Nufern SM-EYDF (8.3/123.5/254 μm) that had core Er and cladding Yb absorptions of 32.6 dB/m (@1535 nm) and 0.53 dB/m (@ 915 nm), respectively. Fifteen meters of SM-EYDF was used in each amplifier and pumping was carried out at 980 nm. Performances of one of the un-irradiated amplifiers are shown in Fig. 7-8. Both amplifiers delivered over 1 W of power with signal/noise ratio >50 dB. These amplifiers were exposed to γ-radiation while output power and gain were monitored as a function of accumulated dose. Measurements were carried out at dose rates of 10 and 20 Rad/sec. The results are presented in Fig. 9-10. For both amplifiers, performance in terms of output power and gain degrades significantly upon irradiation with worse performance at higher dose rate. Based on the used fiber design, operation up to 5 kRad total dose is conceivable. Assuming dose rate in the space radiation environment to be of the order of 0.4 Rad/min, SM-EYDF fiber based amplifier service life is projected to be ~3 months.

Clearly, optimization of the fiber amplifier parameters is required to improve the radiation performance. Most important parameter is concentration of the dopants which needs to be increased in order to decrease the amplifier length thereby reducing radiation induced losses. New fibers are currently being designed.

It is concluded that low index fluoro-acrylate coating has very small radiation induced loss and exposure of coating to γ-radiation has no deleterious effects on the mechanical reliability of fiber and its optical performance. Er/Yb doped fibers experience significant losses under radiation that can potentially be reduced by increasing dopant concentration and subsequently lowering amplifier length.

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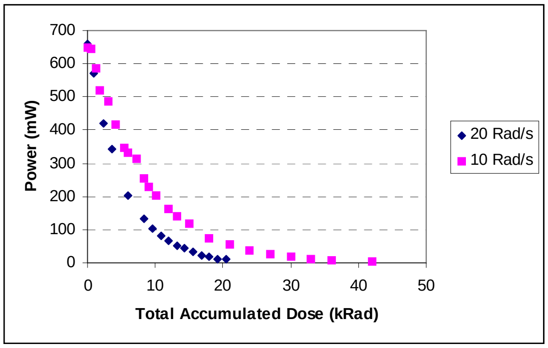

Fig. 7 Output power vs. total dose (SM-EYDF).

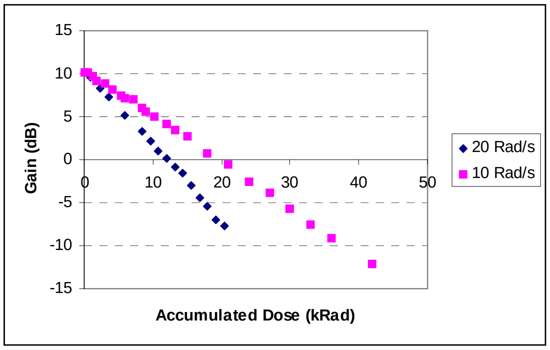

Fig. 8 Gain vs. total dose (SM-EYDF).

1. Y. Morita and W. Kawakami: Dose Rate Effects on Radiation Induced Attenuation of Pure Silica Core Optical Fibers, *IEE Trans. Nucl. Sci.*, Vol. 36, 584-590, 1989
2. EIA/TIA Standard, FOTP-78: Spectral Attenuation Cutback Measurement for Single-Mode Optical Fibers, Electronic Industries Association, Washington, D. C., 1990