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RADIATION HARDENING COMMERCIAL OFF-THE-SHELF ERBIUM DOPED FIBERS BY OPTIMAL PHOTO-ANNEALING SOURCE

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I.INTRODUCTION

Erbium doped fibers (EDFs) based devices are widely employed in space for optical communication [1], remote sensing [2], and navigation applications, e.g. interferometric fiber optic gyroscope (IFOG). However, the EDF suffers severely radiation induced attenuation (RIA) in radiation environments, e.g. space applications and nuclear reactors [3]. To decrease the RIA, several radiation-hardening methods have been proposed, e.g. hydrogen pre-loading [4, 5], thermal annealing [6, 7], and photo-annealing [8, 9, 10-17]. For thermal annealing, it needs to take up to 300°C to decrease RIA. Such a high temperature could damage many other devices; therefore, this method could not be employed practically. The hydrogen pre-loading method needs a hermetic coating to avoid out-diffusion of hydrogen. Among them, the unique photo-annealing (PA) method provides excellent annealing effect of diminishing EDF's RIA for commercial off-the-shelf (COTS) EDFs [4-5]. Recently, photo-annealing of using 980-nm continuous light on Ge-doped [6] and Al-doped [6, 10] EDFs, 532-nm continuous light on both Ge- and Al-doped EDFs [6, 10], and 800-nm pulsed light on Al-doped EDF [11-13] has been performed. The 980-nm photo-annealing light showed only partial RIA recovery, but the 532-nm photo-annealing light showed nearly total RIA recovery in the spectral range between 900 nm and 1750 nm [10]. These results showed possibility of employing photo-annealing to realize radiation-hard EDF-based devices. In this paper, we will report our experimental results for optimizing PA source's annealing efficiency by using a wavelength-tunable femto-second (fs) pulsed laser, and the PA effect of a γ-irradiated fiber light source (FLS) by using a 425-nm continuous wave (CW) laser diode.

II. EXPERIMENT

A Ti:Sapphire wavelength tunable laser, a 976-nm CW laser diode and a 532-nm Nd:YAG SHG CW laser were used as the photo-annealing light source to study the spectral dependence of the photo-annealing effects. The schematic diagram of experimental setup is shown in Fig. 1, and the measurement procedure is described as follows for a specific laser wavelength: (1) for photo-annealing step, the laser light was coupled into the γ-irradiated EDF through a conventional single mode fiber; (2) for RIA measurement step, the RIA of the photo-annealed EDF was measured by using an optical spectrum analyzer (OSA); (3) (1) and (2) were repeatedly carried out until the RIA change of the EDF was too small to be analyzed due to the resolution limit of the OSA. Then the whole process started again for another laser wavelength. The irradiation test was performed at room temperature.

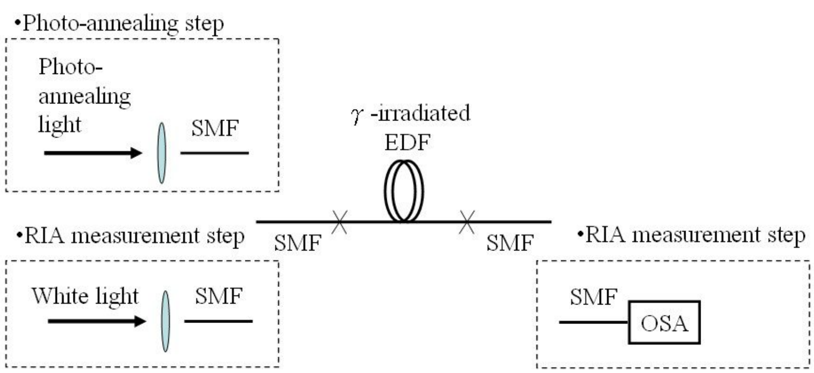

Fig.1. Schematic diagram of experimental setup for measuring photo-annealing induced RIA decreases.

The parameters of the photo-annealing light sources are listed in the Table I. The 976-nm and 532-nm photo-annealing light sources were continuous wave, and the 885.7-nm, and 427-nm ones were pulsed. The incident powers were the maximum powers of the corresponding wavelengths. The tested EDF lengths were chosen either 15 cm or 30 cm according to (1) the available power of the photo-annealing light, (2) the initial RIA at the wavelength of photo-annealing light, and (3) the magnitude of the spectral change due to photo-annealing. To better resolve RIA changes, the γ-irradiated EDF should be longer; however, longer EDF incurred larger initial RIA which in turn caused noisy results.

TABLE I
OPTICAL PARAMETERS OF THE PHOTO-ANNEALING LIGHT SOURCES

Wavelength (nm)	976.0	885.7	532.0	427.0
EDF length (cm)	30	15	30	15
Incident power (mW)	290	15	10	3
Light source	Diode laser	Ti:Sapphire fs-mode	Nd:YAG+ SHG	Ti:Sapphire+ SHG

III. RESULTS AND DISCUSSION

Fig.2 shows the annealing efficiencies of the fs laser with different wavelengths. These wavelengths were chosen excluding the erbium ion's absorption bands for avoiding excess loss of PA light, such as 427 nm, 469 nm, 504 nm, 590 nm, 735 nm, 775 nm, and 885 nm. Therefore, by using the PA lights with these wavelengths, their annealing effect of EDF's RIA can work for several meters in EDF's length. Our experimental result shows the 427-nm pulsed laser of 3-mW optical power has the best annealing efficiency among the tests. The PA 427-nm light nearly eliminated the RIA of the 200-krad (24 rad/s) γ-irradiated EDF (30 cm, ER20, nLight) in a wavelength range from 460 nm to 1700 nm, as shown in Fig. 3. The Co^{60} radiation test was performed in the Radioisotope Laboratory of National Tsing Hua University.

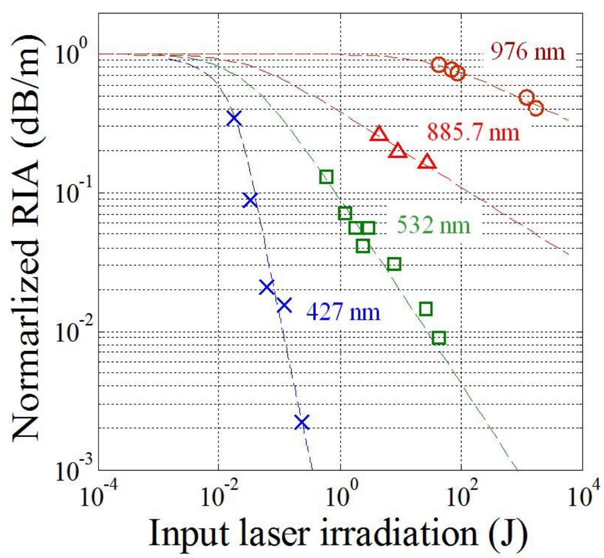

Fig. 2 the annealing efficiencies of the PA sources with different wavelengths.

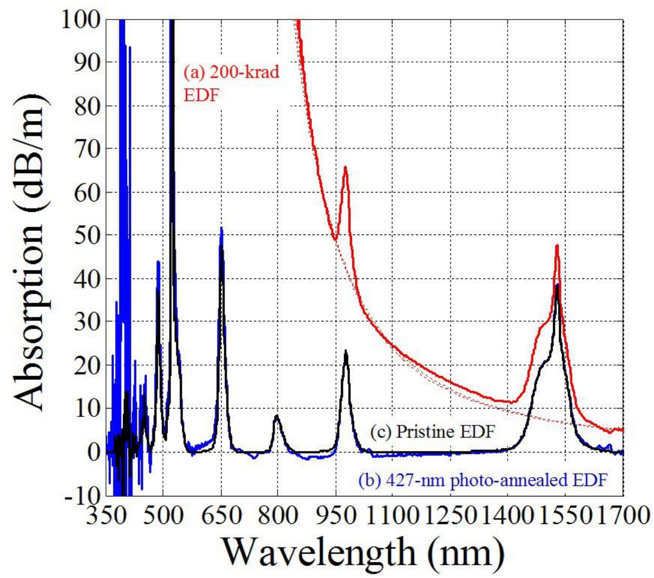

Fig. 3 RIA spectra of (a) 200-krad γ-irradiated EDF, (b) 427-nm photo-annealed EDF, and (c) the pristine EDF.

In the second phase, for more realistic demonstration ,and for minimizing the package size and the power consumption, we used a 425-nm CW laser diode (RLT425-50CMG, Roithner LaserTechnik GmbH) and an EDF-based (3 meter, I-25, Fibercore) FLS to demonstrate the radiation hardening effect. The results (Fig. 4) showed that the output power loss of the 108-krad (5 rad/s) γ-irradiated FLS after 425-nm PA (4 mW, 6 hr) was as small as 0.047 dB.

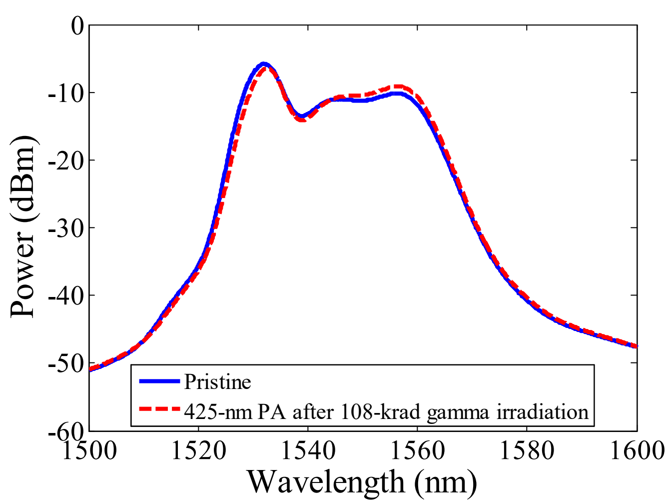

Fig. 4 Optical spectra of the FLS using (1) the pristine EDF (blue solid curve) and (2) the 425-nm photo-annealed EDF after 108-krad gamma irradiation (red dashed curve)

IV. CONCLUSION

The photo-annealing is an efficient radiation-hardening technique for EDF-based devices. Based on our experimental data, the photo-annealing efficiency was inversely proportional to the wavelength of the photo-annealing light. Our best photo-annealing efficiency was to use a 427-nm pulsed laser. For more realistic demonstration, we assemble a 3-meter EDF-based FLS. After 108-krad γ-irradiation, it showed the output power loss of the FLS after 425-nm PA (4 mW, 6 hr) was only 0.047 dB. The PA method showed excellent annealing effect of diminishing EDF's RIA. The further analysis is ongoing and will be presented in the future.

REFERENCES

[1] D. M. Boroson, et al., "The Lunar Laser Communications Demonstration (LLCD)," Space Mission Challenges for Information Technology, 2009. SMC-IT 2009. Third IEEE International Conference on, Pasadena, CA, 2009, pp. 23-28.
[2] Mike Krainak, "Applications of Fiber Amplifiers for Space: Laser Altimetry and Mapping", presented in ESA-NASA Working Meeting on Optoelectronics, 2005.
[3] G. M. Williams, et al., "Space radiation effects on erbium-doped fiber devices: Sources, amplifiers, and passive measurements," IEEE T Nucl Sci, vol. 45, pp. 1531-1536, 1998.
[4] T. S. Peng, et al., "Radiation-Tolerant Superfluorescent Fiber Sources for High Performance Fiber Optic Gyroscopes Working Under Gamma Irradiation Higher than 200 krad," IEEE Photon. Technol. Lett., vol. pp, no. 99, pp. 1, Jun., 2012.
[5] US patent no. 9077143 B2
[6] K. V. Zotov, M. E. Likhachev, A. L. Tomashuk, M. M. Bubnov, M. V. Yashkov, and A. N. Guryanov, "Radiation-resistant erbium-doped silica fibre," Quantum Electron, vol. 37, pp. 946-949, 2007.
[7] K. V. Zotov, M. E. Likhachev, A. L. Tomashuk, A. F. Kosolapov, M. M. Bubnov, M. V. Yashkov, A. N. Guryanov, and E. M. Dianov, "Radiation Resistant Er-Doped Fibers: Optimization of Pump Wavelength," IEEE Photonic Tech L, vol. 20, pp. 1476-1478, 2008.
[8] P. Borgermans and B. Brichard, "Kinetic models and spectral dependencies of the radiation-induced attenuation in pure silica fibers," IEEE T Nucl Sci, vol. 49, pp. 1439-1445, 2002.
[9] H. H. J. Kuhnhenn, O. Köhn, and U. Weinand, "Thermal annealing of radiation dosimetry fibres," in Proc. Euro Conf Radiation Effects on Components and Systems, Madrid, Spain, 2004, pp. 39-42.
[10] T. S. Peng, Y. W. Huang, Lon A. Wang, R. Y. Liu, and F. I. Chou, "Photo-annealing effects on gamma radiation induced attenuation in erbium doped fibers and the source using 532-nm and 976-nm lasers," IEEE Transca. Nuc. Sci., vol. 57, pp. 2327-2331, 2010
[11] S. H. Chang, C. Y. Tai, R. Y. Liu, and C. C. Chen, "Anti-irraidation Superfluorescent Fiber Soucre Pumped by 800nm Band," Annual Meeting of the Physical Society of Republic of China, D05-2.00003, Chiayi, Taiwan, 17-19 Jan, 2012.
[12] S. H. Chang, R. Y. Liu, C. E. Lin, F. I. Chou, C. Y. Tai, and C. C. Chen, "Photo-annealing effect of gamma-irradiated erbium doped fiber by femtosecond pulsed laser,", Journal of Physics: D Applied Physics, vol. 46, pp. 495113-495118, 2013.
[13] S. H. Chang, R. Y. Liu, C. E. Lin, C. Y. Tai, and C. C. Chen, "1550-nm Fluorescence Efficiency and Heat Generation of Erbium-Doped Fiber Pumped by Pulsed and Quasi-Continuous-Wave Lasers," Aerospace Science and Technology, vol. 39, pp. 187–189, 2014.
[14] E. J. Friebele, C. G. Askins, C. M. Shaw, M. E. Gingerich, C. C. Harrington, D. L. Griscom, T. E. Tsai, U. C. Paek, and W. H. Schmidt, "Correlation of Single-Mode Fiber Radiation Response and Fabrication Parameters," Appl Optics, vol. 30, pp. 1944-1957, 1991.
[15] Y. L. Han, W. Xiao, X. S. Yi, and Y. C. Zhang, "Research on the active recovery technology of optical fiber radiation effect - art. no. 627965," 27th International Congress on High Speed Photography and Photonics, Prts 1-3, vol. 6279, pp. 27965-27965, 2007.
[16] H. Henschel, O. Kohn, and H. U. Schmidt, "Radiation hardening of optical fibre links by photobleaching with light of shorter wavelength," IEEE T Nucl Sci, vol. 43, pp. 1050-1056, 1996.
[17] G. H. Sigel, E. J. Friebele, M. J. Marrone, and M. E. Gingerich, "An Analysis of Photobleaching Techniques for the Radiation Hardening of Fiber Optic Data Links," IEEE T Nucl Sci, vol. 28, pp. 4095-4101, 1981.