Gamma radiation effect of F and Ce doped germano-silicate optical fiber

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1. Introduction

Optical fibers, as shown in Fig.1, are widely used in modern telecommunications because of well known advantages, such as an electromagnetic immunity, large bandwidth, and low transmission loss.

Furthermore, the demand for data transmission under a high radiation environment is expanded in nuclear power plants, nuclear waste treatment facilities, accelerator laboratories, etc. When an optical fiber is exposed to radiation, the attenuation (RIA, Radiation Induced Attenuation) in the optical fiber (OF) is increased because of the color centers which deteriorate the transmission property and generate the absorption loss.

In the research of radiation hardened optical fiber based on silica core, pure silica core fiber, and this fiber with fluorine-codoped cladding were analyzed to show radiation resistant characteristics for steady state environment applications [1]. To improve the radiation hardness of optical fiber above the present technical level, other additives (Cerium, Nitrogen, etc) to a germano-silicate core fiber are considered as the promising candidates for a radiation hardened sensor [2,3].

In this study, the influence of fluorine (F) and Cerium (Ce) dopants to germano silica core optical fibers was investigated under gamma irradiation for the radiation hardness application. This paper describes the optical behavior at 1310 nm of three optical fibers with a different core composition during and after Co-60 irradiation at room temperature.

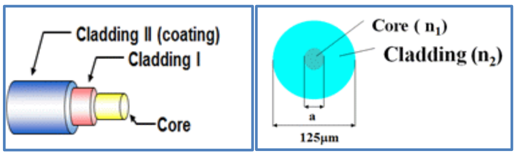


Fig. 1 Structure of Optical Fiber

2. Optical fiber fabrication

An optical fiber preform was fabricated using the MCVD (Modified Chemical Vapor Deposition) process with the solution doping method shown in Fig. 2. F and Ce ions were doped in the core region by soaking the silica glass tube deposited inside with the core layers in the ethanolic solution containing the ions. The glass tube was sintered and sealed to form a preform, then finally drawn into an optical fiber with 125 μm outer diameter using a high-temperature drawing process. The fiber core diameter and cut-off wavelength of this fiber were about 10 μm and 1150 nm, respectively. For a comparison, a reference single mode fiber with a core composition of SiO_2-GeO_2 was also fabricated.

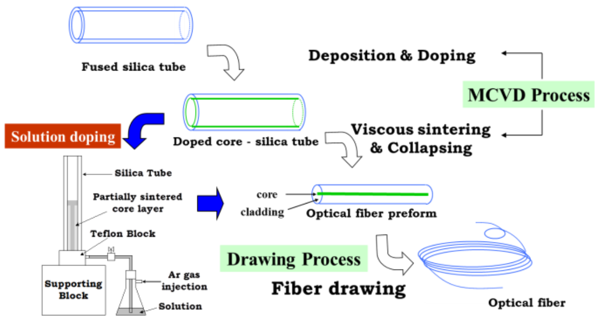


Fig. 2 Fabrication process of the optical fiber

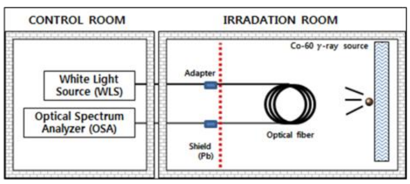
3. Radiation Tests

3.1 Irradiation and measurement

The experimental setup to measure a RIA of the F or Ce co-doped germano-silicate optical fiber is shown in Fig. 3. Gamma rays from a Co-60 isotope was used as a radiation source and a 50 m length of the optical fiber was put inside the irradiation room. The optical fiber ends were connected to the white light source (WLS, YOKOGAWA-AQ4305) and the optical spectrum analyzer (OSA, YOKOGAWA-AQ6370C) for the real-time measurement. Optical components such as adapters and patch cords were protected by the lead block to avoid the radiation exposure, which can cause unexpected radiation induced losses. The gamma irradiation was carried out at a dose rate of 307 Gy/hr for 4 hour. The optical output power at 1310 nm with respect to the radiation dose was measured and RIA was calculated using Eq. (1).

$$RIA\left[\frac{\text{dB}}{\text{km}}\right] = \frac{P_1[\text{dBm}]-P_2[\text{dBm}]}{l[\text{km}]} \qquad (1)$$

where P_1 and P_2 are the optical output powers before and after irradiation, respectively and l is the exposed fiber length.



Irradiation conditions	
Source	Co-60
Dose rate	20 Gy/min
Irradiation time	1 hour
Total dose	1200 Gy
Temperature	24.1 ℃

Fig. 3 Experimental setup for gamma ray irradiation and RIA measurement of optical fiber

3.2 Results and Discussion

The radiation induced attenuation of these different fibers is shown in fig. 4. The reference fiber was found to show a linear trend with respect to the total dose and had a RIA of 35.5dB/km after the irradiation of 1200Gy dose at 1310 nm. The F-doped fiber showed a power-law fit behavior with the total radiation dose at the first half stage, and then became saturated to a loss value of 170dB/km above 700Gy dose. The Ce-doped fiber showed an intermediate behavior between the reference fiber and F-doped fiber

It has been reported that the radiation hardness was generally improved by adding F and Ce elements to the core depending on the weight concentration [1,4]. However, F and Ce additives increase the optical loss in these germane silicate fibers. This unexpected result can be inferred from the different manufacturing process or from the ineffectiveness of F and Ce doping at this concentration.

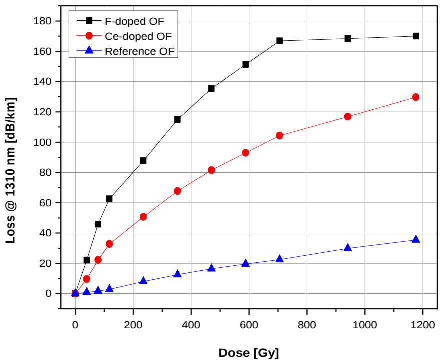


Fig. 4 The optical transmission loss of F-doped optical fiber vs Ce-doped optical fiber under gamma irradiation

Figure 5 shows the optical power spectra of three kinds of fiber before and after irradiation. Before irradiation (dot line), a negative peak of power was found due to OH concentration around 1400 nm which came from the wet condition. After irradiation (solid line), an optical power was decreased in the overall wavelength range. In particular, a gradual power loss was appeared by the effect of infrared absorption edge above the 1500nm band and another gradual loss happened due to drawing defects and other impurities below 1200nm. [4]

From the experimental results, we can estimate that these data were obtained under a wet and contaminated environment. When a germano silica core is exposed to radiation, Ge-related defects are created and are interacted with F or Ce dopant. These associated defects can make an increase of the optical power loss.

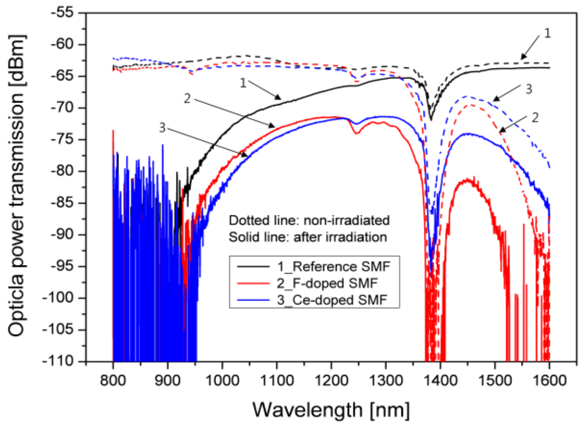


Fig. 5 Optical power spectra of three different fibers before and after irradiation. (1) Reference OF, (2) F-doped OF, and (3) Ce-doped OF.

4. Conclusions

To develop radiation hardened optical fibers, RIA and optical power loss were investigated to a germano-silica core fiber under gamma irradiation. Although a F or Ce additive was effective in radiation hardness for pure silica core fiber, this experiment showed an opposite effect of F or Ce element for germano silica core fiber. To increase the radiation resistance of optical fibers, further investigations are needed, i.e., the optimal contents of different additives, loss recovery characteristics, interaction behavior between Ge-related defects and additives.

Acknowledgements

This work was supported by the National Research Foundation (NRF) grant funded by the Minister of Education, Science and Technology of Korea (No. 2011-0031840).

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