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Temperature dependence of radiation induced optical transmission loss in fused silica core optical fibers

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Abstract

The radiation induced optical transmission loss of heat-treated fused silica core optical fibers has been investigated under gamma-ray irradiation. Observed radiation induced transmission loss indicated temperature dependence, which suggests that the behavior of radiation induced defects responsible for the transmission loss depend on heat-treatment temperatures before irradiation. As a result, the optical fibers heat-treated at 200 °C had the most radiation resistance among those investigated. We propose that an optimum temperature for developing radiation resistance should exist and might be near 200 °C.

1. Introduction

Optical fibers have a lot of advantages, such as lightweight, insulating character, non-inductivity to electromagnetic noise, wide bandwidth and low loss of transmitting signals. Much research for using optical fibers as new devices to replace conventional electrical devices has been performed [1–7]. It is very useful for control and maintenance of fusion reactors to adapt the optical fiber device.

However, when optical fibers are used under radiation environments, they have the disadvantage that an increase of the radiation induced transmission loss is caused by the formation of color centers generated in the silica glass. This radiation induced transmission loss varies in a complicated way with the optical fiber's composition, temperature, dose rate, total absorbed dose, and wavelength of transmitted light. This increase of the radiation induced transmission loss leads measurement errors for using the optical devices as the signal transmission tool or as the sensor itself. These problems have been pointed out since about 1990 [8]. For example, Ramsey et al. reported that dynamic optical transmission loss decreased by a few orders of magnitude with increase of the temperature from room temperature to about 600 K in plasma diagnostics in TFTR in Princeton Plasma Physics Laboratory (PPPL) [9]. Therefore, we considered that the response of the optical transmissibility of fused silica core fiber would have the temperature dependence.

In this paper, we investigated the variation of the radiation induced transmission loss under gamma-ray irradiation after optical fibers were heat-treated at 140, 160, 180, 200, 220 and 300 °C.

2. Experimental

In this experiment, the temperature dependence of radiation induced optical transmission loss in fused silica core optical fibers was observed in the Co-60 gamma-ray irradiation facility in Tohoku University. The intensity of the gamma-ray source is 4.07 TBq and the absorbed dose rate is 7.2×10^{-3} Gy/s. The mother rod of the optical

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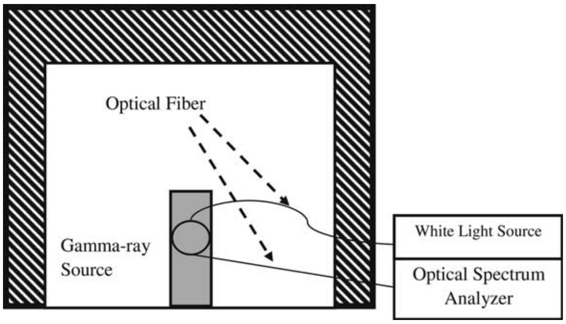

Fig. 1. Irradiation setup in Co-60 gamma-ray irradiation facility.

fiber used in this paper was KS-4V fabricated by the Fibre Optic Research Centre (FORC-Troisk) and the rod was drawn by Fujikura Corp. in Japan. The fiber consists of pure SiO_2 core, fluorine doped clad, low-OH, and low-Cl materials. The diameter of the clad and the core were 0.25 and 0.20 mm, respectively. Irradiated length of the optical fiber was 5 m and it was coiled with a diameter of 100 mm. The coiled optical fibers were annealed in the air for 3 h at 140, 160, 180, 200, 220 and 300 °C before irradiation. Fig. 1 shows the overview of this experiment. One end of the optical fiber was connected to the white light source (Ando Electric, AQ-4304B), and the other end of the optical fiber was connected to an optical spectrum analyzer (Ando Electric, AQ-6315A). The optical transmissibility was measured from 400 to 1700 nm through the irradiated optical fiber.

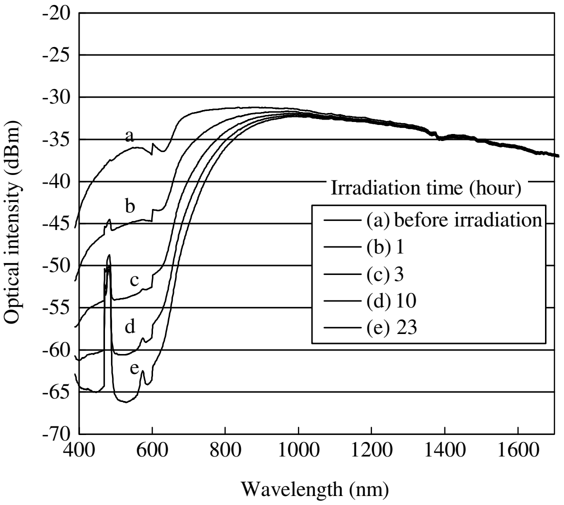

Fig. 2. Radiation induced optical transmissibility of the optical fiber heat-treated at 180 °C.

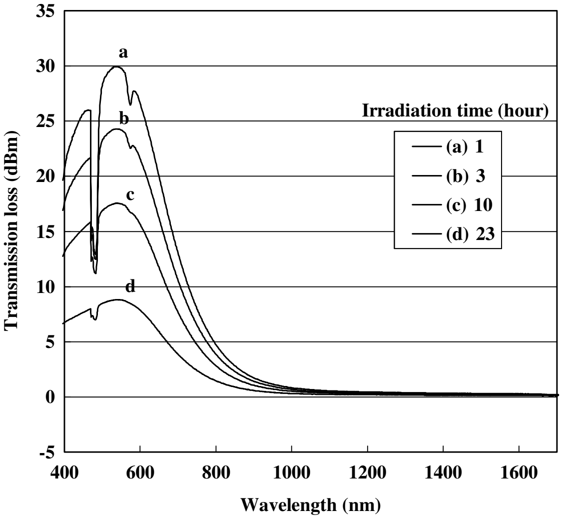

Fig. 3. Radiation induced optical transmission loss of the optical fiber heat-treated at 180 °C.

3. Results and discussion

A example of the results of irradiation experiments the radiation induced optical transmissibility of the optical fiber annealed at 180 °C is shown in Fig. 2. The radiation induced optical transmission loss of the same optical fiber is shown in Fig. 3. One can see from Fig. 2 that the optical transmissibility of the optical fiber was decreased by gamma-ray irradiation, and the optical transmission loss in the visible wavelength range was much larger than that in the infrared wavelength range. Moreover, it was found that the transmission loss increased as the irradiation time increased. The increase of the transmission loss in the fused silica optical fiber was caused by the generation of several color centers in silica. The fused silica core optical fibers have the absorption peak at 630 nm. The absorption peak is caused by the color center in SiO_2 called the non-bridging oxygen hole center (NBOHC). However the optical absorption peak at 630 nm was not found in Fig. 2, because the optical absorption of E' center is much larger than that of NBOHC. Fig. 2 shows that there were the peaks at 450, 570 and 600 nm. The optical spectrum analyzer used in this experiment scans the incident light by an optical grating. The analyzer uses first and second order diffractive light, because the analyzer observes wide wavelength range from 400 to 1700 nm. It is difficult to optimize the matching with the switching of first and second order diffractive light, and the cut off filters for attenuating the needless order light. Therefore these peaks were not real optical peaks but optical noises, depending on the optical spectrum analyzer.

Figs. 4 and 5 show the irradiation time dependence of the optical transmission loss at 630 and 1390 nm, respectively, and Figs. 6 and 7 show the optical trans-

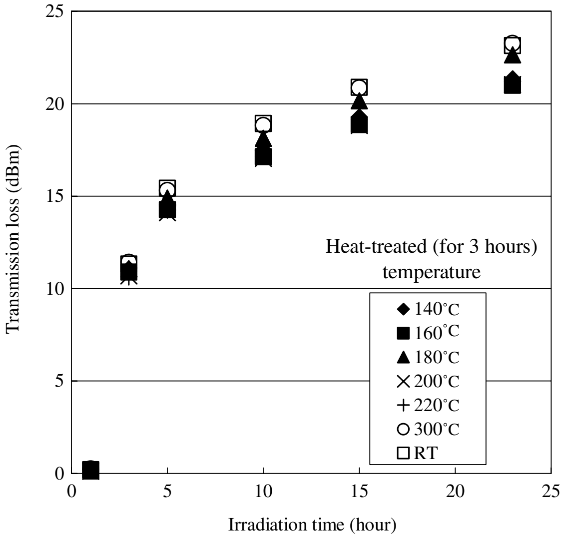

Fig. 4. Irradiation time dependence of the optical transmission loss at 630 nm.

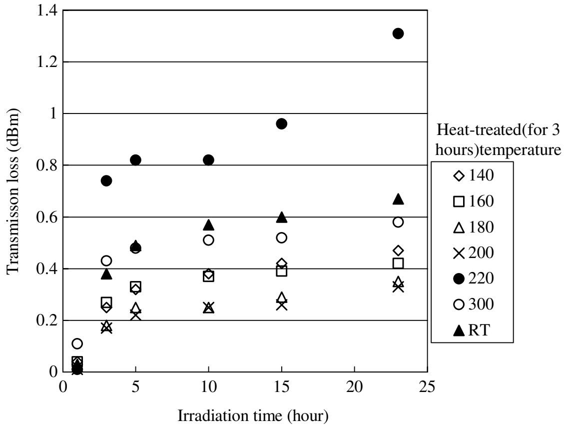

Fig. 5. Irradiation time dependence of the optical transmission loss at 1390 nm.

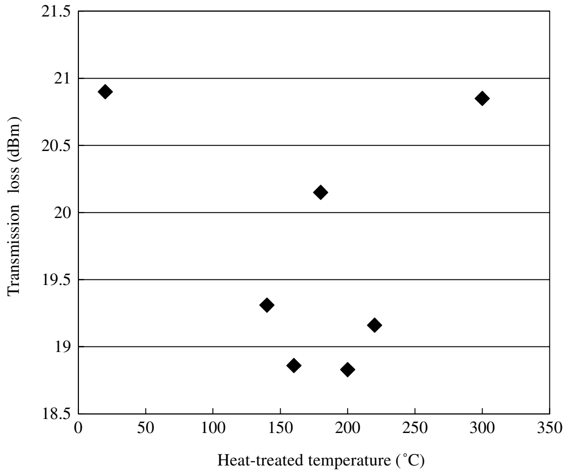

Fig. 6. Optical transmission loss as a function of heat-treatment temperature at 630 nm.

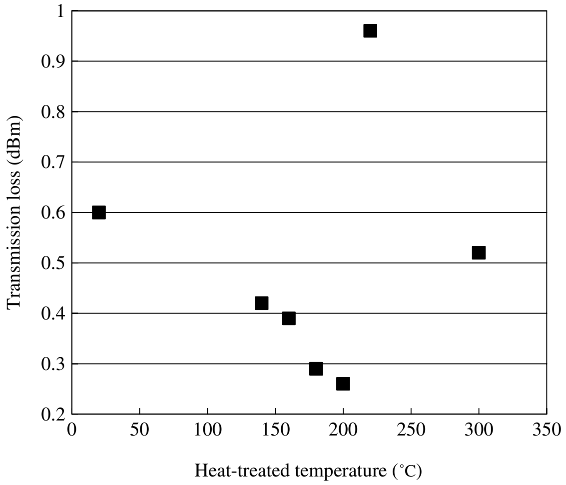

Fig. 7. Optical transmission loss as a function of heat-treatment temperature at 1390 nm.

mission loss as a function of the heat-treatment temperature at 630 and 1390 nm, respectively. It was found from Figs. 4 and 5 that the optical transmission loss increased just after the start of the irradiation and the rate of loss decreased after about 5 h except for 220 °C annealing. It was obvious from Figs. 6 and 7 that the transmission loss could be decreased by the annealing treatment before irradiation. The transmission losses increase under irradiation by the generation of color centers in the fused silica core optical fiber. Therefore, it was considered that the heat-treating could decrease the generation of the color centers under Co-60 gamma-ray irradiation. Comparison of all temperature conditions, we estimate that there was an optimum heat-treated temperature to minimize the radiation induced transmission loss, and the optimum temperature might be near 200 °C. Its mechanism is very complicated. I consider that the defects which generate during the production process are improved by heat-treatment before irradiation, but in more than 200 °C the polymer coating covered the core and cladding is spoiled and the optical transmission loss of the fiber increases with heat-treatment temperature. However, we still observe irregular optical transmission losses of the fiber in Figs. 6 and 7. Therefore, an experiment to determine in detail the effect of pre-irradiation annealing temperature is necessary.

4. Conclusions

Annealing temperature dependence of radiation induced optical transmission loss was investigated using the Co-60 gamma-ray irradiation facility. Under Co-60 gamma-ray irradiation, the transmission losses in the visible wavelength range were much larger than in the infrared wavelength range. Moreover, we could see the heat-treatment effect to decrease the transmission loss, and the losses in the whole wavelength range had a heat-treatment temperature dependence. It was estimated that an optimum temperature to minimize the transmission loss (radiation damage) exists and that the optimum temperature might be near 200 °C.

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