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Optical characteristics of aluminum coated fused silica core fibers under 14 MeV fusion neutron irradiation

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Abstract

The optical properties of Al-coated fused silica core optical fibers were observed under 14 MeV fast neutrons irradiation with samples pre-annealed at 150 and 300 °C. With the pre-annealing treatment, the optical absorption could be decreased except for the Si–OH (1390 nm). Under fast neutron irradiation, the radiation-induced transmission loss of pre-annealed fiber at 150 °C was over five times larger than that annealed at 300 °C. It is believed that the precursors of optical absorption were decreased by the annealing treatment. Under irradiation, the optical absorption at 1390 nm had characteristic changes. The absorption at 1390 nm was small during the irradiation and became large once the irradiation stopped. This behavior was only observed for the 1390 nm absorption. It is believed that the increase of the transmission loss under irradiation was caused by the atomic displacement by fast neutrons of Si–OHs and that the displaced Si–OHs recovered when the irradiation stopped.

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1. Introduction

In a fusion reactor, it will be necessary to take account of the electromagnetic disturbance caused by the high electrical voltage and the simultaneous high flux of several kinds of radiation. Optical devices are candidate for the signal transmission devices and as dosimeters, because these devices have several advantages over electrical measurements. Advantages include no electrical noises, no transmission of electrical signals, wide optical signal bands, etc. Consequently, the probability of the generation of electrical malfunctions in the reactor is small. Aluminum coated fused silica core fiber was chosen for better compatibility with a vacuum environment. Therefore, it is a candidate for using signal transmission and sensing devices [1–4] in ITER [5].

The fused silica optical fiber has the better radiation resistance by the heat-treatment after drawing the fiber before irradiation [6]. In this paper, pre-annealing effects on the fiber behavior under fusion neutron irradiation are reported.

2. Experiments

The material used in this experiment was fused silica core optical fiber. The main component of the fiber was SiO_2 and the diameter of core/clad was 0.2/0.25 mm. The fiber was coated with aluminum with thickness 0.6 mm. The optical fiber was coiled with diameter 100 mm for the irradiation with 14 MeV fusion neutrons, and the length of the coiled optical fiber was 10 m. The transmission losses in the optical fiber were observed using a white light source (Ando Electric, AQ-4303B) and optical spectrum analyzer (Ando Electric, AQ-6315A). The optical detector can measure optical signals with wavelength range 400–1700 nm. The distance from the irradiation area to the detection was 40 m.

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The irradiation test of the Al-coated optical fiber was performed at a fast neutron irradiation facility of the fusion neutronics source (FNS) in Japan Atomic Energy Research Institute (JAERI). The energy of the neutrons has a sharp peak at 14.1 MeV. The flux of fast neutrons is 3.6×10^9 n/cm^2 s and the gamma-ray dose rate is low. The irradiation was carried out over 4 days, with the irradiation time 7 h/day.

Optical fibers were annealed before irradiation at 150 and 300 °C in the air for 3 h. The heating and cooling rates were not controlled precisely. The optical transmission intensities from 400 to 1700 nm were measured with and without irradiation.

3. Results and discussion

Before the irradiation, the optical absorption of the optical fiber after annealing at 300 °C was measured. It was found that the Al-coated fiber essentially contained OHs. The transmission loss in the wavelength range 400–1700 nm and the annealing time dependence are shown in Figs. 1 and 2, respectively. The transmission loss over the whole wavelength range became large in less than 2 h. It is believed that the microbending loss decreased by the heat-treatment. The transmission loss at 1390 nm attributed to Si–OH [7] became large after 2 h, though the transmission losses in other wavelength ranges were reduced. In other words, the color centers except for Si–OH were decreased with the annealing treatment but the Si–OH was increased.

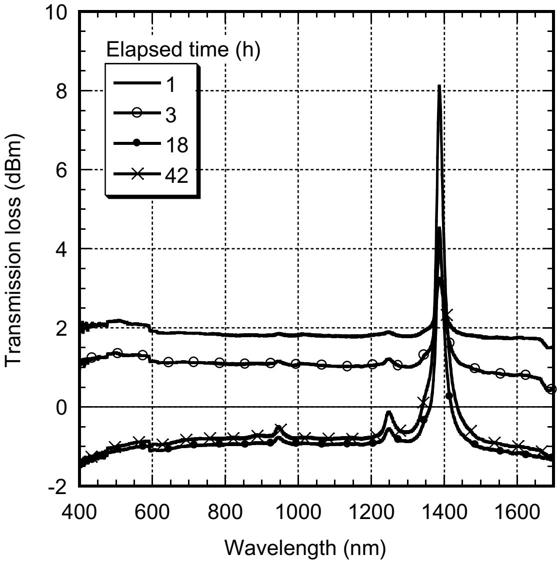

Fig. 1. Transmission loss of fused silica core optical fiber under annealing treatment at 300 °C.

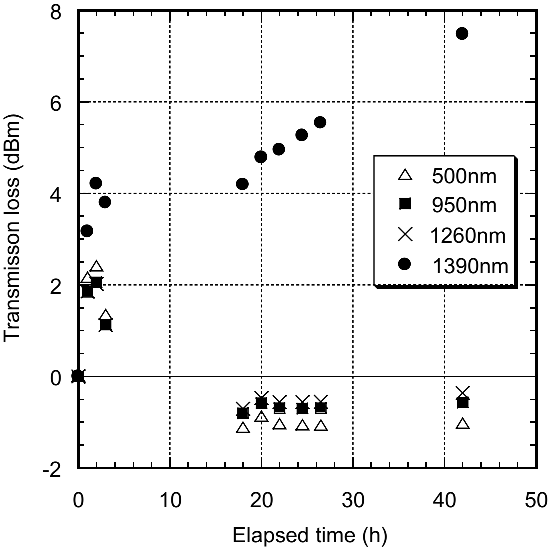

Fig. 2. Annealing time dependence of optical transmission at 500, 950, 1260, and 1390 nm.

The irradiation tests under 14 MeV fast neutrons were carried out over 4 days with 7 h/day operation. An example of the irradiation experimental results, the optical intensities transmitted through the Al-coated optical fiber pre-annealed at 150 °C are shown in Fig. 3. The optical absorption at 1390 nm attributed to Si–OH was measured before irradiation. The changes of the optical intensities were wavelength dependent. The

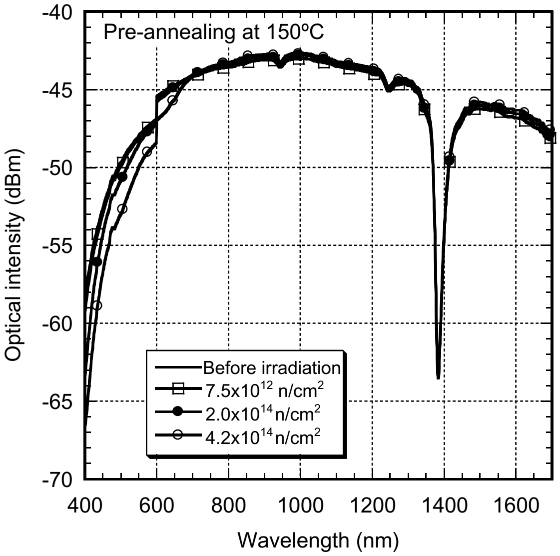

Fig. 3. Observed optical intensity of transmission light through the Al-coated optical fiber pre-annealed at 150 °C under fast neutron irradiation.

radiation-induced transmission losses of Al-coated optical fibers pre-annealed at 150 and 300 °C are shown in Fig. 4(a) and (b), respectively. This shows that the optical transmission loss at wavelength less than 700 nm is much larger than that in the infrared wavelength range. The transmission loss in the visible wavelength range mainly consisted of two components. Optical absorption shorter than 400 nm was ascribed to E′ center and that at 630 nm was ascribed to non-bridging oxygen hole centers (NBOHC). [8,9]. The irradiation time dependence at 400 and 630 nm is shown in Fig. 5. The transmission loss increased under fast neutron irradiation and decreased after the irradiation stopped, though the decreasing rates were different. The transmission loss of E′ center was much larger than that of NBOHC. Moreover, the optical absorptions in fiber pre-annealed at 150 °C were larger than that for 300 °C in the entire wavelength range of our experiments. Therefore, it is believed that the radiation resistance becomes large by the heat-treatment before irradiation, because the concentration of the precursor of the color center reduces by the heat-treatment and the pre-annealing effect at 300 °C is larger than that at 150 °C.

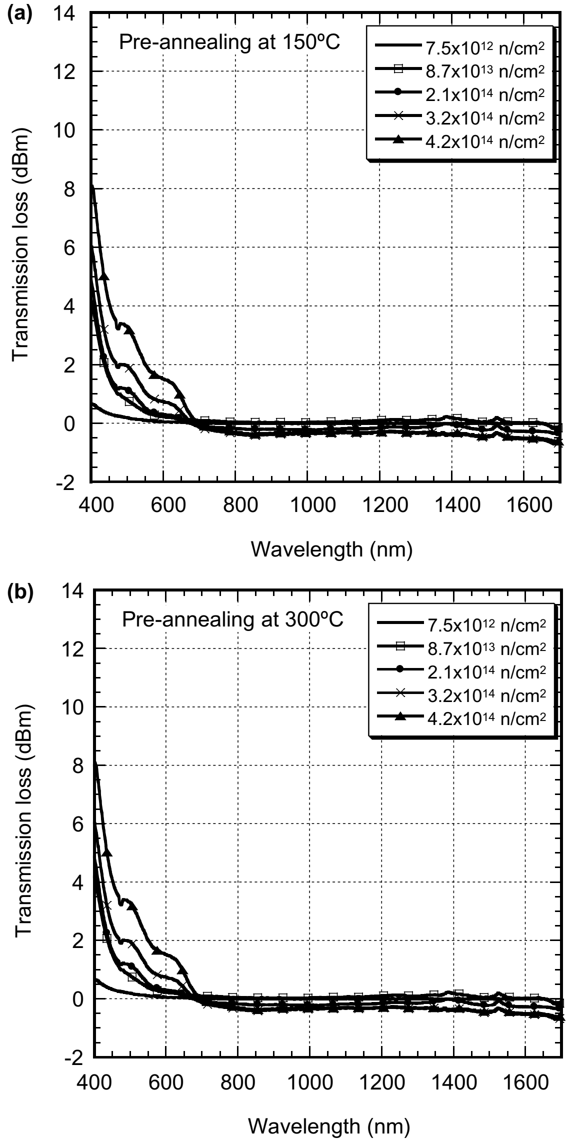

Fig. 4. Radiation-induced transmission loss of the Al-coated optical fiber pre-annealed at (a) 150 °C and (b) 300 °C.

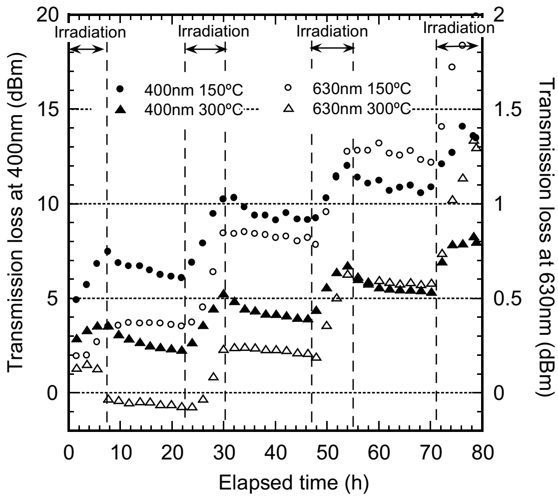

Fig. 5. Time dependence of the transmission loss at 400 and 630 nm pre-annealed at 150 and 300 °C.

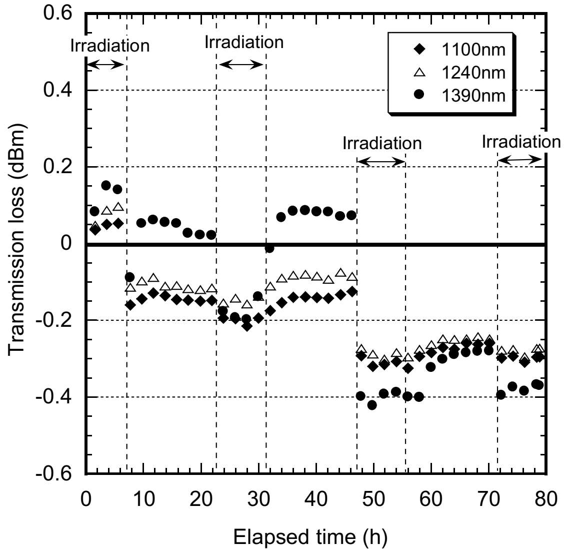

Fig. 6. Time dependence of the transmission loss at 1100, 1240, and 1390 nm pre-annealed at 300 °C.

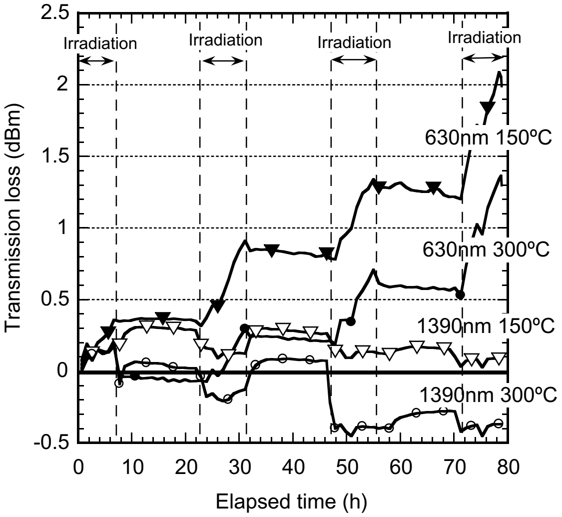

Fig. 7. Time dependence of the transmission loss at 630 and 1390 nm pre-annealed at 150 and 300 °C.

The optical absorption peak at 1390 nm is ascribed to Si–OH contained in the fused silica core fiber. The transmission loss at 1390 nm had a characteristic changes. The radiation-induced transmission loss in near infrared (NIR) wavelength range pre-annealed at 300 °C is shown in Fig. 6. The transmission loss became large in entire NIR range at first day. However, after the second day irradiation, the transmission loss at 1390 nm decreased much more than at other wavelengths under fast neutrons irradiation, and increased in non-irradiation periods. The comparison of the transmission loss at 630 nm with at 1390 nm is shown in Fig. 7. Under fast neutron irradiation, the transmission loss at 630 nm increases though that at 1390 nm decreased. The electron excitation dose rate in this irradiation facility is low. Therefore, it is believed that the characteristic change in the radiation-induced transmission loss at 1390 nm was caused by the atomic displacement of OH. The effect is considered that the concentration of Si–OH decreased because of the atomic displacements under fast neutron irradiation, and displaced OHs were recovered to Si–OH without fast neutron irradiation.

4. Conclusions

The optical transmission of Al-coated fused silica core optical fibers under 14 MeV fast neutrons irradiation was evaluated. The transmission loss in the visible wavelength range was larger than that in the infrared wavelength range under irradiation. After the irradiation stopped, the transmission loss dropped as the optical absorption caused by neutron irradiation was recovered. The transmission loss in fiber pre-annealed at 150 °C was larger than that pre-annealed at 300 °C. Therefore, it was concluded that the precursors of the color centers (optical absorption) were quenched following the annealing treatment, and the quenching rate at 300 °C was larger than that at 150 °C. The transmission loss at 1390 nm attributed to Si–OH had characteristic changes, a significant decrease under irradiation and recovery when the irradiation stopped. It is believed that the atomic displacements of Si–OH were generated by fast neutron irradiation, and the defect recovered when the irradiation stopped.

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