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Neutron Irradiation Effects on Optical Fibers

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Irradiation effects on optical fibers were observed with 14 MeV fusion neutron and fission neutron. As a result, the following characteristics have become clear. Permanent absorption loss after fission and fusion neutron irradiation, were greater than that of gamma ray irradiation. In case of fission neutron, large absorption loss appeared at wavelength of shorter than 700 nm and loss peak of 600 nm, and absorption loss increased exponentialy to the fluence of 10^{19} n/cm^2. During irradiation, the light emission was observed in the wavelength of 400 to 1700 nm and peak of light at about 1200 nm was appeared. Two kinds of the SiO_2 fibers were survived irradiated up to 3 x 10^{19} n/cm^2.

KEYWORDS : optical fiber, radiation effect, fusion neutron, fission neutron, absorption, fluoescence

1. Introduction

Many intensive studies have been conducted for the effects of radiation on optical fibers(1-3). In these studies, two significant optical effects were pointed out for practical application in high dose and high dose rate of radiation environment. One is, increase of absorption due to the radiation induced defects and the formation of color centers. It is known that the high energies of particle radiation causes ionization and atomic displacements within the molecular bonding network of the optical fiber(1-3). Other is, suprious light emission in the optical fibers through the process of fluorescence phenomena under high dose rates of radiation, arising from the recombination of electron-hole pairs created in their molecular bonding network(4). Therefore, these important issues are commonly addresed to determine the radiation resistance characteristics of optical fibers and their practical application in radiation emvironments.

On the other hand, looking at previous investigations for the radiation effects on various kind of optical fibers, gamma-ray irradiation tests were mainly conducted more than that of other radiation source. From these investigations, while the fiber having pure silica core is known to have the good radiation resistance, and further findings suggest that the content of OH also improve the radiation resistivity. The effect of OH content blocks the formation of defects and there are also methods of adding several hundred of OH to the cores of optical fiber improving its radiation resistivity(5-8).

Since applying to more severe radiation environments in nuclear plants, i.e, in-core measuring systems for fission reactors, diagnostics for fusion reactors, radiation related subjects should be considered by different radiation sources. Owing to this, preliminary studies of irradiation effects on optical fibers are conducted by 14 MeV fusion neutron and fission neutron source.

This paper mainly outlines the radiation resistance characteristics of pure silica core optical fibers, particularly the irradiation effects of different radiation sources.

2. Defects and Radiation Effects of Optical Fiber

During irradiation of solid state substances by ionizing radiation such as X-rays and/or gamma rays, charged particle radiation collides with electrons. In the case of glass, depending on the degree of imperfection in their molecular structure even before irradiation, these collisions which involves charged particles and electrons create new defects of color centers. In optical fibers, these defects cause the increase in transmission loss and is detrimental to optical fibers used for signal propagation.

The imperfection in glass consists of intrinsic defects

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such as oxygen deficient centers, non-bridging oxygen hole centers(NBOHC), oxygen dangling bonds and so on. Multi-component glass with main oxides such as SiO_2 and B_2O_3 usually have the presence of small amount of oxides such as NaO_2, K_2O and CaO; alkaline and alkaline-earth cations thereby causing the imperfection in this glass. Whereas in silica-based glass, the structure which consists of common stable bonding is much more simpler, therefore, the stability of silica-based glass gives it better radiation resistance characteristics.

The better radiation resistivity is dependent on the structure of glass which is determined by the changing of the refractive index of core and clad and the structure of SiO_2 with the dopants. Therefore, the kinds of dopants and the manufacturing methods are also considerations in producing better radiation resistance characteristics. In short, different types, structure and manufacturing conditions of optical fibers produce different degrees of radiation resistivity. The optimum radiation characteristics can only be determined by results based on the experimental post-irradiation effects of all the types of optical fibers.

3. Fibers Used for Experiments

A list of irradiated fibers is shown in Table 1. The fiber No.1, pure silica core with fluorine doped clad single mode(SM) type fiber, was irradiated with 14 MeV fusion neutron. Two kinds of step index(SI) type pure silica core fibers, fiber No. 2 of OH content core and No. 3 of Fluorine doped core, were irradiated with fission neutron. The contents of OH groups in fiber No. 2 was 800 ppm.

Table 1 List of the test fibers with pure silica core, fluorine-doped clad used for experiment.

Irrad. Fiber	Type	Core		Clad	
		Formation	Dia.	Formation	Dia.
No. 1	SM	SiO_2	10 μm	SiO_2-F	125 μm
No. 2	SI	SiO_2 OH:800ppm	100 μm	SiO_2-F F:△=1.0%	125 μm
No. 3	SI	SiO_2-F F:△=0.35%	200 μm	SiO_2-F F:△=1.0%	250 μm

4. 14 MeV Fusion Neutron Irradiation(9)

4.1 Measuring Systems and Irradiation Conditions

Fast Neutron Source (FNS) facility in Japan Atomic Energy Research Institute (JAERI) was used for the experiment as a 14 MeV fusion neutron source. Irradiation condition of the optical fiber is listed Table 2. Figure 1 shows an outline of the measuring systems. The length of fiber No. 1 irradiated was 100 m, and measurement of the optical signal transmission during and after irradiation of the optical fiber was conducted in-situ, while the optical power was monitored through the optical fiber by use of a 1300 nm LED light source and a power meter.

The optical fiber irradiated 8 hours/day under fluence rate of $8.7x10^8$ n/cm^2s, and repeat the irradiation procedure four times. Total fluence of 14 MeV fusion neutron to the SM fiber was up to $1x10^{14}$ n/cm^2.

Table 2 Irradiation condition of 14 MeV fusion neutron for pure silica core SM fiber.

Items	Conditions
Facility	FNS, JAERI
Irrad. Length	100 m
Wavelength	1300 nm, LED Source
Opt. Power	-50 dBm (10nW)
Temperature	Room Temperature
Fluence Rate	8.7×10^8 n/cm^2sec
Irrad. Time	8 (hr/day) × 4 days
Fluence	2.5×10^{13} $n/cm^2/day$ 1.0×10^{14} n/cm^2
Meas. Method	In-situ measurment for Optical Transmission

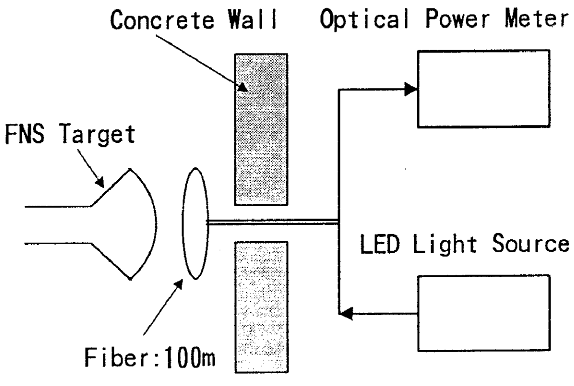

Fig. 1 Schematic diagrm of measuring system for 14 MeV fusion neutron irradiation.

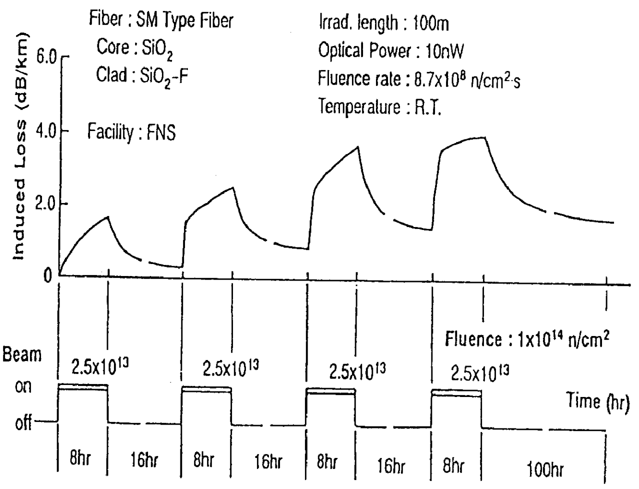

Fig. 2 Increase in transmission loss of SM fiber irradiated by 14 MeV fusion neutron.

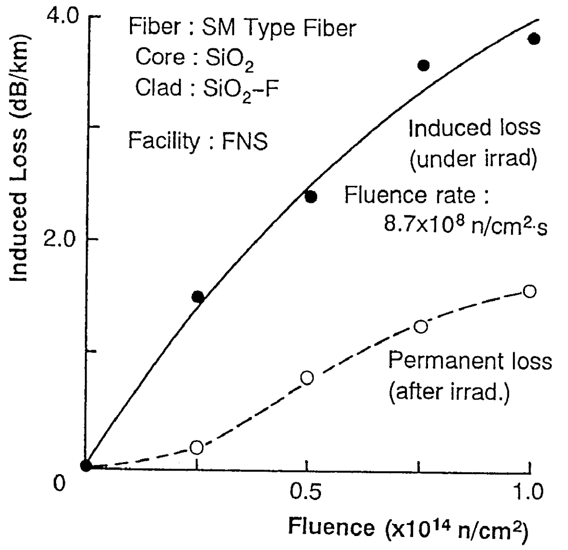

Fig. 3 Permanent loss after fusion neutron irradiation.

4.2 *Results*

Figure 2 shows the increase in transmission loss of fiber No. 1 during and after irradiation by 14 MeV fusion neutron. During irradiation, the transmission loss is increased but after irradiation, there is a sign of recovery in the transmission loss. For the radiation resistant optical fibers, the performance is better with the transmission loss increased slightly and the recovery after irradiation is good.

Fast neutrons penetrate into the optical fiber creating knock-on collisions and hence forming long-lasting defects. This is shown in the recovery period in which the recovery time is much more rapid after gamma irradiation than fusion neutron irradiation. And the permanent absorption loss after fusion neutron irradiation, is shown Fig. 3, were greater than that of gamma ray irradiation.

Table 3 Irradiation condition of fission neutron for OH-doped core and F-doped core fibers.

Items		Conditions
Reactor		JMTR, JAERI
Irrad. Position		J−12
Irrad. Temperature		370K
Irradiated Length		~ 1 m
N_f (E>1MeV)	Flux	8.8×10^{12} n/cm^{2}s
	Fluence	1.6×10^{19} n/cm^2
N_{th}(E<0.68eV)	Flux	9.9×10^{12} n/cm^{2}s
	Fluence	1.7×10^{19} n/cm
γ-ray Dose rate		1.9×10^3 Gy/s
γ-ray Dose		3.3×10^9 Gy

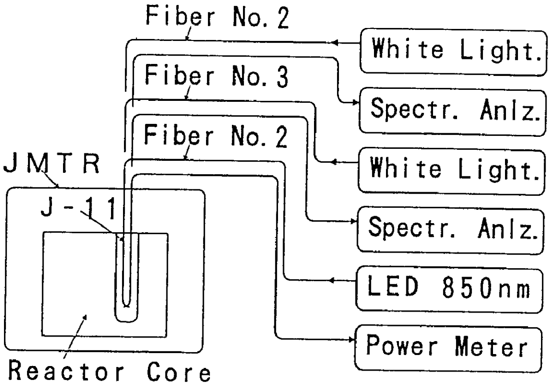

Fig. 4 Outline of measuring procedure for fission neutron irradiation in JMTR.

5. Fission Neutron Irradiation$^{(10,11)}$

5.1 Measuring Systems and Irradiation Conditions

Japan Material Testing Reactor (JMTR) in JAERI was used for the experiment as a fission neutron source. Irradiation conditions of the optical fibers are listed in Table 3. Figure 4 shows an outline of the measuring procedure. The fibers Nos. 2 and 3, OH doped core fiber and Flourine doped core fiber, were irradiated in the reactor core region of JMTR. The irradiated length of both fibers were about 1 m. Both of optical fibers irradiated up to the fast neutron of 1.6×10^{19} n/cm^2(E>1 MeV) and the thermal neutron of 1.7×10^{19} n/cm^2 (E<0.683 eV), under the fluence rate of 8.8×10^{12} n/cm^{2}s and 9.9×10^{12} n/cm^{2}s, concurrent with gamma ray dose of 3.3×10^9 Gy.

The spectral optical properties, radiation induced optical absorption and light emission (fluorescence), were measured by optical spectrum analyzer. And of the monochromatic optical signal transmission during irradiation was monitored by use of a 850 nm LED light sourece and a power meter.

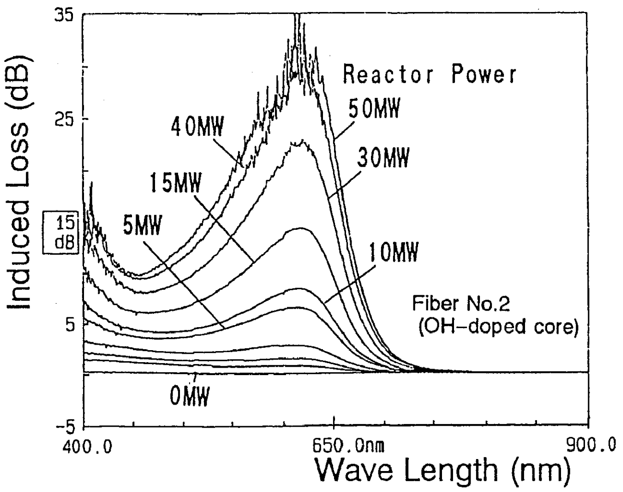

Fig. 5 Spectral absorption loss of OH-doped fiber.

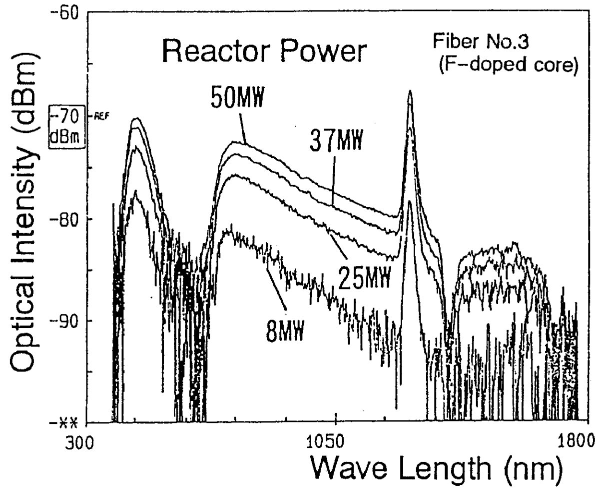

Fig. 7 Spectral light emission of F-doped fiber during fission neutron irradiation.

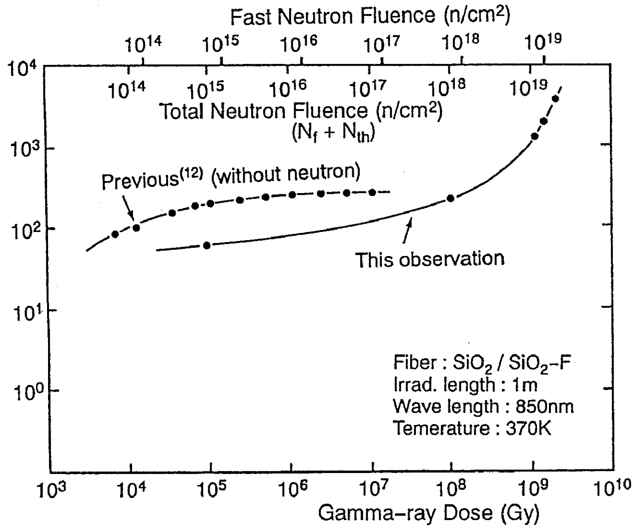

Fig. 6 Increase in transmission loss at 850 nm.

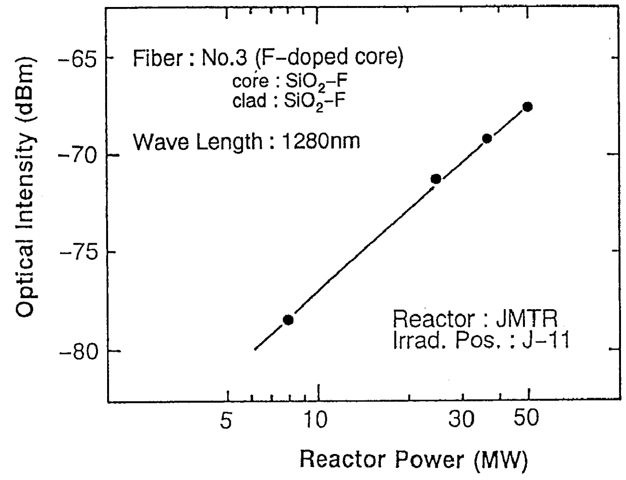

Fig. 8 Relation of reactor power and light emission peak values of F-doped fiber.

5.2 Results

Figure 5 shows the spectral absorption of the fiber No. 2 during fission neutron irradiation. Large absorption loss at wavelength shorter than 700 nm and absorption loss peak of about 600 nm, were appeared. The fiber No. 3 which Fluorine doped core, did not improve the optical transparency at the wavelength 400 to 700 nm, compared with No. 2 of OH content fiber.

Increase in 850 nm monochromatic optical signal transmission loss of the fiber No. 2 during irradiation is shown in Fig. 6. Also figure shows the result of gamma ray irradiation as our previous investigation of pure silica core fiber(12). In case of fiber No. 1, increase in transmission loss at 1 x 10^{19} n/cm^2 of fast neutron and 1 x 10^9 Gy of gamma ray was about 1 x 10^3 dB/km and the loss incresed to 7 x 10^3 dB/km at the end of irradiation. The both SiO_2 fibers were survived irradiated up to about 3 x 10^{19} n/cm^2.

Figure 7 shows the spectral light emission (fluorescence) of the fiber No. 3 during irradiation. Radiation induced light emission was observed at the wavelemgth of 400 to 1700 nm and peak of light at about 1200 nm was appeared. The values of light emission in Fluorine doped fiber is about -65 dBm for length of 1 m at fast neutron fluence rate of 8.8 x 10^{12} n/cm^{2}s and gamma ray dose rate of 1.9 x 10^3 Gy/s. The relation of the reactor power and light emission peak values of 1280 nm are shown in Fig. 8. The peak values of 1280 nm are directly proportinal to reactor power.

6. Conclusion

14 MeV fusion and fission neutron irradiation effects on optical fibers were observed. As a result, the following characteristics have become clear. Permanent absorption loss after fission and fusion neutron irradiation, were greater than that of gamma ray irradiation. In case of

fission neutron irradiation, large absorption loss appeared at wavelength of shorter than 700 nm and loss peak of 600 nm, and absorption loss increased exponentialy to the fluence of 10^{18} n/cm^2. During irradiation, the light emission was observed in the wavelength of 400 to 1700 nm and peak of light at about 1280 nm was appeared. Two kinds of the SiO_2 fibers were survived irradiated up to 3 x 10^{19} n/cm^2.

The experiment of neutron irradiation effects on optical fibers, i.e. knockon collisions and hence cause the formation of E'centers, Si defects, peroxy-radical, dangling oxgen radicals and other defects, are less than that of gamma ray irradiation. Therefore, future basic researches and developments have to be studied and progressed parallel with the nuclear technology.

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