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Journal of Nuclear Materials 307–311 (2002) 1277–1281

journal of nuclear materials

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Round-robin irradiation test of radiation resistant optical fibers for ITER diagnostic application

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Abstract

Fused silica core optical fibers are expected to play crucial roles especially in the size-reduced International Thermonuclear Experimental Reactor (ITER-FEAT). Several radiation resistant optical fibers have been developed in Japan and the Russian Federation. The task force on radiation effects in diagnostic components in the ITER-EDA (engineering and design activity) promoted international round-robin irradiation experiments on the developed optical fibers. Ten different optical fibers were tested in a cobalt-60 gamma-ray irradiation facility and in the Japan Materials Testing Reactor. The paper reports results obtained on five different optical fibers, which include purified, hydrogen loaded, and fluorine doped ones. Results show that the developed optical fibers could be deployed in remote handling and out-of-vessel applications. But, for the in-vessel diagnostics in the visible range optical spectroscopy, further improvement of the radiation resistance of optical fibers will be needed.

1. Introduction

Optical diagnostics are expected to play crucial roles in the International Thermonuclear Experimental Reactor (ITER). At the beginning of the ITER-EDA (engineering and design activity) in 1991, the general consensus among international diagnostic groups was that silica (SiO_2)-core optical fibers were too vulnerable against radiation damages to be deployed inside the reactor vessel [1]. Since then, substantial efforts have been devoted to improve radiation resistance of the silica core optical fibers, mainly in the Russian Federation (RF) and Japan (JA), under the auspices of ITER-task T-246 chaired by Yamamoto of the ITER Joint Work Site at Garching, Germany [2]. Recently, several radiation resistant optical fibers were developed and preliminary irradiation tests yielded promising results for their applications even in-vessel in ITER.

Optical diagnostic systems utilizing optical fibers have some advantages over other optical systems such as periscope systems. Optical fibers would not need large space to be accommodated and they will be far less expensive. These advantages are especially attractive for the recent modification of the ITER-design (ITER-FEAT). The ITER-EDA has recommended carrying out round-robin irradiation tests of optical fibers developed in Japan and Russia, to establish a reliable data base for their application in the ITER plasma diagnostics [2]. Detailed procedures for the round-robin irradiation tests in gamma irradiation facilities and in fission reactors

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PII: S0022-3115(02)01277-1

were settled in the related ITER-EDA specialist workshops [3].

Ten different optical fibers were selected as round-robin optical fibers and were provided to three parties in the ITER-EDA, namely, European Union (EU), RF and Japan. Each party will carry out irradiation tests following procedures recommended by the ITER-EDA specialist group [3]. The present paper describes results of irradiation tests performed in Japan on some of the round-robin optical fibers.

2. Experimental procedures

Ten kinds of silica core optical fibers developed for application in environments of high irradiation were irradiation tested in a cobalt-60 gamma cell at room temperature and in Japan Materials Testing Reactor (JMTR) at about 135 °C. Irradiation-tested optical fibers included two Japanese fluorine doped fibers and one Japanese standard fiber (pure silica core), as well as three Russian fibers. Some of Russian fibers were drawn by Japanese manufactures from Russian made mother rods to study effects of manufacturing procedures to radiation resistant properties. In the present paper, results on five optical fibers, which are tabulated in Table 1, will be reported.

The RF home team is recommending fibers drawn from fused silica mother rods of KU-1 and KS-4V, whose irradiation resistance was reported to be excellent [4]. Furthermore, the RF-home team is applying a technique called hydrogen-discharge loading to improve radiation resistance much more as in the optical fiber of KU-H2G. In the meantime, the JA-home team is working on fluorine doped fused silica core optical fibers, whose radiation resistance revealed to be excellent [5].

The scheme of the experimental setup for the Co-60 gamma-ray irradiation tests is shown in Fig. 1. Here, the electronic excitation dose rate is 3.3 Gy/s and length of the irradiated part is 20 m. A similar setup was used for a reactor irradiation in the JMTR with a length of irradiated part of 0.5 m. Detailed experimental procedures for the JMTR irradiation can be found elsewhere [6,7]. The fast ($E > 1$ MeV) and thermal ($E < 0.68$ eV) neutron fluxes were 2.4×10^{17} and 1.9×10^{18} n/m^2 s, respectively, with an electronic excitation dose rate of 1.4 kGy/s.

3. Experimental results and discussions

Fig. 2 shows initial optical transmission properties of five optical fibers tabulated in Table 1, before the irradiation. The fluorine doped fibers, MF and FF, and KS-4V had only small amount of OH (oxyhydrate) absorption, whose strongest absorption peak can be seen at about 1390 nm. In the meantime, KU-1 and KU-H2G had strong OH absorption peaks as they have an OH concentration of about 800 ppm. In the meantime, the OH doping improved the optical transmissivity in the visible wavelength range.

Fig. 3 shows the growth behavior of optical absorption under the Co-60 gamma-ray irradiation in KS-4V as a function of the electronic excitation dose. Fig. 4 compares the optical absorption in five optical fibers, induced by the Co-60 gamma-ray irradiation at an electronic excitation dose of 1.9×10^6 Gy. A strong absorption peak centered at 600–650 nm, non-bridging the oxygen hole center (NBOHC) peak, was clearly observed in KU-1, KU-H2G, MF, but it was not clear in KS-4V and FF. Optical absorption intensities at about 600–650 nm were 30, >50, 16, 18, and 5 dB/20 m, for KS-4V, KU-1, KU-H2G, FF, and MF at the electronic excitation dose of 1.9×10^6 Gy. Thus, the hydrogen-discharge loading (hereafter denoted as hydrogen loading) was effective in improving the radiation resistance and KS-4V showed better radiation resistance than KU-1 under pure electronic excitation irradiation. Also, the fluorine doping was effective in improving the radiation resistance. In the meantime, the absorption profile in the visible wavelength range is different among different fibers, which may be important for optical spectroscopy using the optical fibers.

Table 1
Five radiation resistant optical fibers round-robin irradiation tested and reported in the present paper

Team	Fiber type	Supplier	Diameter (μm)		Remarks
			Core	Clad.	
RF	KS-4V	FORC	200	250	Pure silica core, OH- and Cl-free
	KU-1	FORC	200	250	Original, OH: 800 ppm
	KU-H2G	FORC	200	250	Improved, hydrogen treated OH: 800 ppm
JA	FF	Fujikura Ltd.	200	250	Fluorine-doped silica core, OH-free
	MF	Mitsubishi Cable	200	250	Fluorine-doped silica core, OH-free

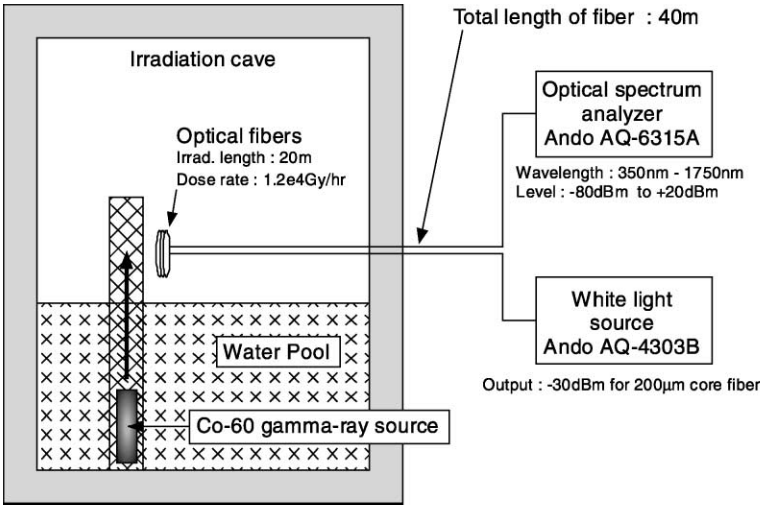

Fig. 1. Schema of irradiation setup in cobalt-60 gamma-ray irradiation facility.

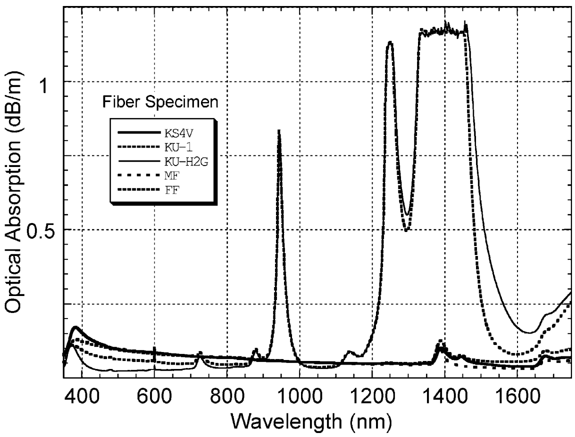

Fig. 2. Initial optical transmissivity of five optical fibers before irradiation.

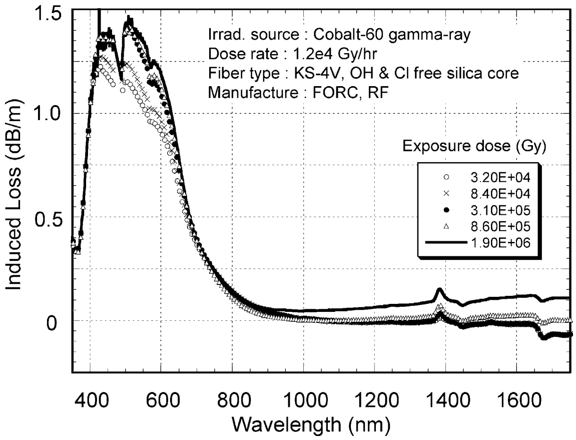

Fig. 3. Growth of optical transmission loss under gamma-ray irradiation in RF-made KS-4V.

In general, the expected electronic excitation dose in remote handling systems and out-of-vessel components will be in the range of MGy [2] and the total length which will be exposed to intense gamma rays will be less than 10 m. Under these conditions, the present optical fibers will work properly as an optical guide from the visible to the infrared wavelength range. Especially, the fluorine doped MF fiber will be applicable even to spectroscopy.

Fig. 5 shows the growth of optical absorption in FF under the JMTR irradiation. Up to a neutron fluence of 5.7×10^{20} n/m^2, it showed good radiation resistance, however, the optical absorption intensity was above 40 dB/m at a neutron fluence of 5.1×10^{23} n/m^2, being worse than previously developed F-doped optical fiber [5]. KS-4V and KU-H2G also showed good radiation resistance up to the neutron fluence of 5.7×10^{20} n/m^2, where the maximum absorption intensity was about 10 dB/m, however, they had absorption intensity larger than 40 dB/m at the neutron fluence of 5.1×10^{23} n/m^2.

Fig. 6 shows the optical absorption induced in the F-doped MF in the JMTR irradiation. MF also showed good radiation resistance up to the neutron fluence of 5.7×10^{20} n/m^2, but then it lost the optical transparency suddenly. A broad absorption band extending from 400 to 1800 nm grew as shown in Fig. 6. Causes of this broad and strong absorption peak in MF have not yet been understood, but, a similar behavior was also observed in previous JMTR experiments, where optical fibers heavily doped with fluorine were irradiated. The doping of fused silica core with fluorine will decrease the optical

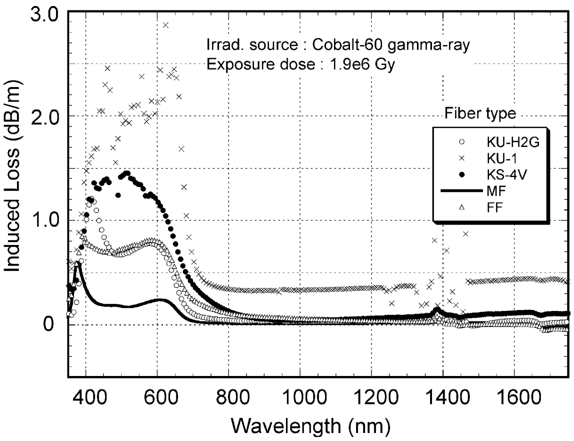

Fig. 4. Comparison of optical absorption in five round-robin optical fibers after gamma-ray irradiation dose of 1.9e6 Gy.

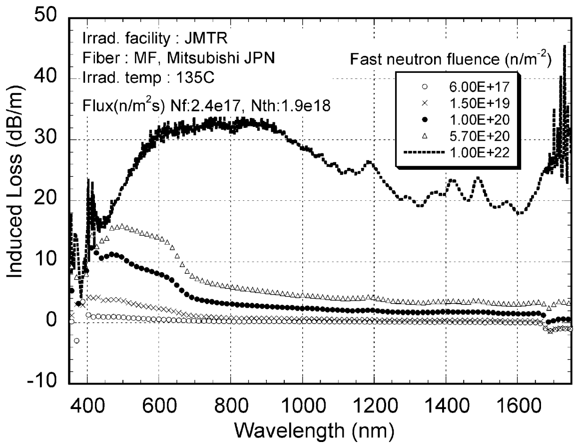

Fig. 6. Growth of optical transmission loss under JMTR irradiation in JA-made MF.

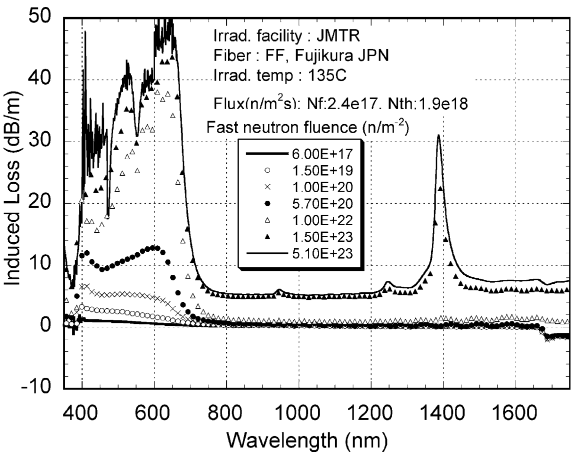

Fig. 5. Growth of optical transmission loss under JMTR irradiation in JA-made FF.

reflection index of the core material and the optical fibers will be susceptible to the micro-bending loss. The optical fibers were bent with a curvature of 1/5 cm^{-1} inside the JMTR core, which would assist the micro-bending loss under irradiation.

The OH absorption peaks grew as the irradiation proceeded, for KS-4V, KU-1, KU-H2G, and FF optical fibers as seen in Fig. 5 at about 1390 nm. However, this growth was not observed in MF. This peculiar behavior may be related to the introduction of a broad absorption band in MF.

KU-H2G showed better radiation resistance at neutron fluences lower than 5.7×10^{20} n/m^2 than KU-1, but they behaved similar after they received a neutron fluence of 1×10^{22} n/m^2. With the results obtained in the Co-60 gamma-ray irradiation, it could be suggested that the hydrogen-loading would be effective to the pure electronic excitation irradiation and to the neutron associated irradiation only up to a moderate irradiation dose. For the application of optical fibers to in-vessel diagnostics, the hydrogen-loading may not be effective. In the meantime, the fluorine doping will be effective even to the neutron associated irradiation expected in invessel of the ITER. However, it will enhance micro-bending loss, when optical fibers were bent with small a curvature.

4. Summary

Round-robin irradiation tests of developed radiation-resistant fused silica core optical fibers were carried out in a Co-60 gamma-cell and JMTR. The round-robin optical fibers were supplied by the RF- and the JA-home teams. All the round-robin optical fibers showed good radiation resistance under gamma-ray irradiation, indicating that they could be deployed for the remote handling systems and out-of-vessel components.

The strong absorption of about 40 dB/m was introduced under JMTR irradiation, which will cause troubles in in-vessel deployment of these optical fibers in ITER. Further improvement of the radiation resistance will be needed for their reliable application in ITER.

The EU- and the RF-home teams are also carrying out the round-robin irradiation experiments. All these results will be reported by the end of 2001. Possibility of further international collaboration after the ITER-EDA is surveyed by the three parties, to develop the ITER relevant radiation resistant optical fibers.

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