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Neutron degradation of UV enhanced optical fibers for fusion installation plasma diagnostics

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Abstract

The remote diagnostics of plasmas in fusion installations requires adequate connection links to transfer the measured signals in media subjected to high electromagnetic disturbances. We evaluated the neutron irradiation induced optical absorption in several commercially available optical fibers, as they were assessed for their possible use in fusion installations. Optical fiber samples were subjected to subsequent irradiation with fluences from 6×10^{11} to 6×10^{13} n/cm^2. Significant radiation induced absorption was observed in the 220–260 nm spectral band, mainly for small core diameter optical fibers (200/220 μm), independent of the cladding material used.

1. Introduction

The ITER and the future DEMO will require high-temperature, high-neutron flux resistant materials to be used in plasma diagnostics, subjected to ITER requirements [1]. A solution for remote plasma diagnostics implies the operation of various optical instruments placed apart from the critical temperature-neutron zones, with the optical signal transmitted over optical channels, for a reduction of radiation effects on the equipment, and a higher immunity to electromagnetic disturbances. Generally, data are available on the radiation effects (gamma-ray and neutron) on optical fibers used in communication applications or for transmission in the visible range [2–4]. A special problem arises when optical signals have to be transmitted in the UV region (200–450 nm), where attenuation over distance is quite high, and the UV radiation by itself produces an increase in the attenuation upon several hours of exposure.

In the frame of the EU funded Fusion Programme, we focused on the evaluation of radiation induced changes in the optical transmission for different commercially available optical fibers, for possible use in optical light guides.

2. Experiment

Pure silica optical fibers with an UV enhanced response, and core diameters of 200 and 400 μm were evaluated, as they are subjected to neutron irradiation. The optical fiber core was of a high hydroxyl content type, and the coating was either polymide or aluminium. Optical fibers with low (150 °C) and high (350 °C) temperature jacket materials were investigated. Table 1 specifies the optical fibers investigated, their characteristics and the total fluences used. Samples OFS1 and OFS2 are from the same producer, while samples OFS3–OFS7 originate from another producer. We were interested both on the dose dependence and total dose effects, as well as on the reproducibility of radiation induced degradation of the optical transmission. For this reasons, the same optical fibers samples were irradiated in three steps and similar samples were irradiated under comparable conditions.

The optical fiber samples were irradiated at IFIN-HH U-120 Cyclotron facility (schematic drawing of the

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Table 1
The characteristics of the optical fibers samples and the neutron fluences used for the irradiation

Characteristics					Fluence (n/cm^2)		
Optical fiber sample	Core diameter (μm)	Cladding diameter (μm)	Buffer/jacket material	Maximum operating temperature (°C)	Irradiation 1	Irradiation 2	Irradiation 3
OFS1	200	240	Plastic	125	6×10^{11}	6×10^{12}	6×10^{13}
OFS2	400	425	plastic	125	6×10^{11}	6×10^{12}	6×10^{13}
OFS3	200	220	Al	400	6×10^{11}	6×10^{12}	6×10^{13}
OFS4	200	220	Polymide	350	6×10^{11}	6×10^{12}	6×10^{13}
OFS5	400	440	Tefzel	150	6×10^{11}	6×10^{12}	6×10^{13}
OFS6	400	440	Polymide	350	6×10^{11}	6×10^{12}	6×10^{13}
OFS7	400	480	Tefzel	150	6×10^{11}	6×10^{12}	6×10^{13}

specimen chamber is shown in Fig. 1), which produces neutrons based on the reaction $^{9}\mathrm{Be}+\mathrm{d}\rightarrow\mathrm{n}+\mathrm{X}$, using a deuteron beam (13 MeV) and a thick beryllium target (165 mg/cm^2) [5]. To obtain the desired neutron fluences the samples are located downstream at the distances from 10 to 40 cm of the Be target. The fast neutrons facility is provided with a biological shield build from borated paraffin bricks of 20 cm thickness, leaving a free volume ($100\times50\times50$ cm), for neutron irradiation.

The absolute neutron flux was measured using the activation detectors presented in Table 2. From the induced activity of the metallic foils, using an unfolding procedure [5], we obtain the neutron energy spectrum. The spectrum has a bell shape distribution around a mean energy of 5.2 MeV. The higher part of the energy spectrum was derived from the time of flight (TOF) measurements. The neutrons flux above 1 MeV is estimated with a relative error of about 20%. The measured production yield, at 10 cm distance from the Be target, is 2.13×10^{8} n/cm^2 s μA. The maximum neutron flux achievable in our set-up, at a distance of 10 cm from the target, is 2×10^{9} n/cm^2 s μA, corresponding to a deuteron beam intensity of 10 A. The neutron and gamma components of the mixed radiation dose are 138 and 2.38 Gy/C respectively, at 30 cm distance from the Be target. The unit Gy/C is for the yields (η) for the neutron and respectively gamma production. From this yields can be evaluated for example the neutron dose rate, which, for a current of 5 μA, is: $\mathrm{d}D/\mathrm{d}t = 138$ Gy/C $*$ 5 μC/s ≈ 700 μGy/s $= 2.52$ Gy/h. In practice, a neutron fluence up to 10^{13} n/cm^2 can be obtained in about 1–6 days of irradiation, depending on the position of the samples. The heat (≈100 W) released in the Be target is removed by a flow of distilled cooling water. At maximum beam power, the highest temperature of the target does not exceed 50 °C. The Be target is electrically insulated, allowing on-line monitoring of the beam current.

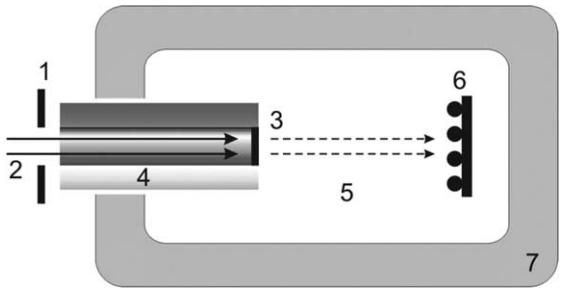

Fig. 1. The setup for the neutron irradiation of optical fibers: collimator (1); 13 MeV deuterons (2); Be target (3); transport tube (4); neutron flux (5); samples and detectors base-plate (6); shield (7).

Table 2
Fast neutron activation detectors used for the characterization of the neutron field

Reaction	Neutron energy range of sensitivity (MeV)	Half-life $T_{1/2}$
$^{115}\mathrm{In(n,\gamma)^{116}In}$	Thermal	54.15 min
$^{115}\mathrm{In(n,n\gamma)^{115m}In}$	1–14	4.49 h
$^{27}\mathrm{Al(n,\alpha)^{24}Na}$	7–18	14.96 h
$^{58}\mathrm{Ni(n,p)^{58}Co}$	2–18	70.916 d
$^{58}\mathrm{Ni(n,2n)^{57}Ni}$	12–18	1.5 d
$^{59}\mathrm{Co(n,p)^{59}Fe}$	4–18	44.5 d
$^{197}\mathrm{Au(n,\gamma)^{198}Au}$	0–18	2.704 d

During the reported irradiation the neutron fluences were measured by activated foil detectors ($^{58}\mathrm{Ni(n,p)^{58}Co}$ reaction) and mica track detectors [6]. The Ni detectors were chosen because of appropriate sensitivity, for long irradiation time (2.5×10^{9} n/cm^2 Bq). The accuracy of the measurements is 20%, due mainly to uncertainty in activation cross-sections, but results are typically reproducible within a few percent accuracy. The optical fibers were placed perpendicular to the beam axis and therefore some non-uniformity of the neutron fluences along the fiber occur; a check with Ni activation and tracks detectors has shown that this non-uniformity is less than 25%, in our experimental conditions.

The optical transmission of the optical fibers samples was evaluated off-line: pre- and post-irradiation measurements were carried out at room temperature. The laboratory set-up we developed enables the investigation of optical transmission of UV hardened optical fibers, in the spectral range 200–650 nm, with spectral resolution of 1.5 nm, and 12 bits amplitude resolution of the transmission readings. The set-up is based on a CW operating deuterium source, and a miniature, multichannel optical fiber spectrometer coupled to a PC via the USB link (Fig. 2). Additionally, optical fiber heating can be done, in order to introduce a temperature stress.

As the assessment of the optical transmission in optical fiber for the UV region (190–300 nm) is very difficult to carry out (source efficiency is very low, UV solarization effects in sampling probes are quite high, and the detection noise is significant in the CCD array) signal averaging and box-car smoothing are used for data processing. In order to obtain the best sensitivity for the detected signal at the optical fiber sample output we divided the spectral range of the investigation into several spectral bands (200–220; 220–240; 240–260; 260–470 and 470–650 nm). In this way, for each interval, the optimum measuring conditions were established (integrating time, number of averaged measurements), enabling the optimization of the data acquisition process. The integration time varied from 15 to 350 ms.

All the optical fiber samples were of 24 cm long, and were irradiated over a 3 cm length, at their middle point. For the absorption measurements, temporal SMA 905 connectors were mounted to each optical fiber. Each sample was coupled to the deuterium source and the spectrometer channel through two 1.5 m solarization resistant, 400 m core diameter patchcords. As the SMA connectors were not exactly tailored for each optical fiber core diameter and because of their inherent mechanical misalignment a variable absorption offset is present in our measurements. To reduce as much as possible this inconvenience, several measurements were carried out on each sample, at each irradiation step, over all spectral bands.

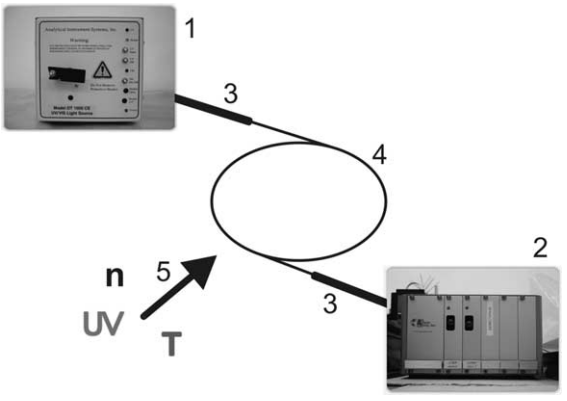

Fig. 2. The setup for the evaluation of optical fiber absorption: deuterium lamp (1); optical fiber multi-channels spectrometer (2); probe patch cords (3); optical fiber sample (4); external stress (UV radiation; neutron flux; heating) (5).

2.1. Results and conclusion

Figs. 3 and 4 illustrate, as examples, the radiation induced degradation of the optical absorption for the optical fibers mentioned in Table 1, for the fluence of 6×10^{11} n/cm^2.

Our investigation on commercially available, enhanced UV transmission optical fibers indicated that:

- all the optical fibers can be used without any restriction for light guides construction, to operate under neutron flux with fluences up to 10^{13} n/cm^2 in fusion installations, for wavelengths higher than 300 nm;
- if we consider the bias line, imposed by the connectors losses, to have a value of 0.4 units for a non-irradiated optical fiber, the best performing optical fibers of 400 m core diameter exhibit a peak of the optical absorbance of 06. units for a fluence of 10^{12} n/cm^2, and a peak of 1.1 units for a fluence of 10^{13} n/cm^2. The absorbance is represented in a logarithmic scale.
- the absorbance peak for the 400 m core diameter fibers occurs at 220–230 nm;
- smaller core diameter optical fibers have a high degradation of their optical transmission even for a lower fluence level (10^{11} n/cm^2);
- as the measurements were done off-line as compared to the irradiation it is difficult to assess the influence of the optical transmission recovery at room temperatures;
- for the same optical fiber core diameter the bandwidth of the absorption peak differences from manufacturer to manufacturer, meaning that the fabrication conditions and ingredients used play a

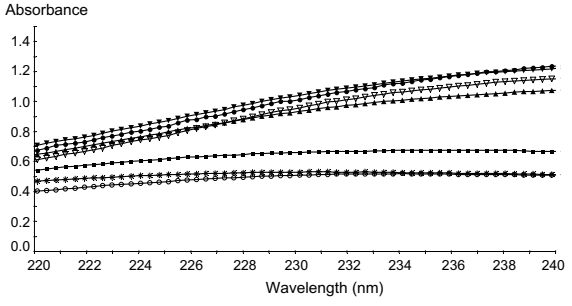

Fig. 3. The absorption spectrum in the 220–240 nm spectral band: ▼ – OFS1; ● – OFS2; ▽ – OFS3; ▲ – OFS4; ○ – OFS5; ∗ – OFS6; ■ – OFS7; fluence = 6×10^{11} n/cm^2.

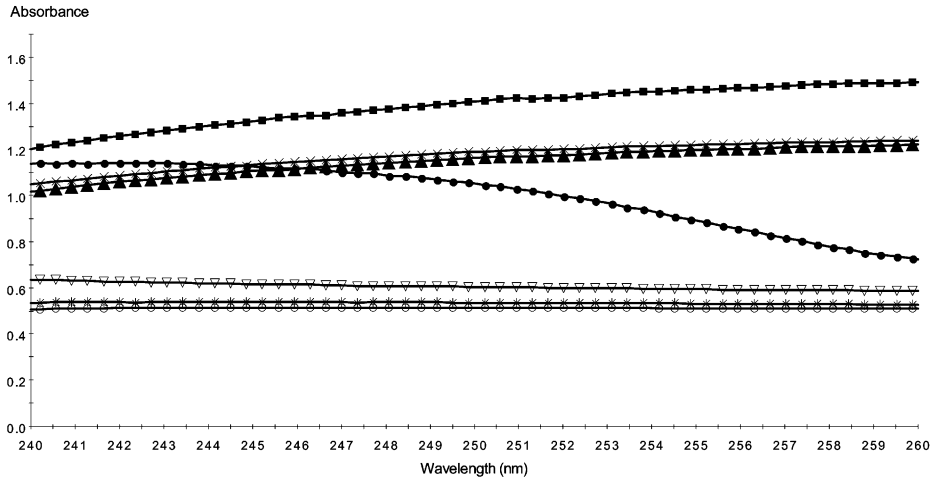

Fig. 4. The absorption spectrum in the 240–260 nm spectral band: ▼ – OFS1; ● – OFS2; ▽ – OFS3; ▲ – OFS4; ○ – OFS5; ∗ – OFS6; ■ – OFS7; fluence $= 6\times10^{11}$ n/cm^2.

significant role in the fiber behavior under neutron irradiation.

Considering these first results, we shall focus in the next step of our investigations on:

- the influence of the combined neutron and UV exposure on the optical absorption of irradiated optical fibers;
- recovery phenomena at high temperatures (150–250 °C).

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