Effect of high-temperature high-intensity nuclear reactor radiation on transmission in rad-hard silica fibers

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In-situ multi-point low-invasive measurements are the key requirements for the modern nuclear material research programs. An example of such program is the study of the dimensional stability of fuel elements. Optical Fibre Sensors feature intrinsic properties that allow to accomplish this task. In the mentioned program optical fibres will be exposed to high temperatures up to 400°C simultaneously with nuclear radiation. Optical fibres are sensitive to ionizing radiation and the assessment of radiation induced transmission degradation is necessary to predict the feasibility of the system. We present results of the reactor irradiation of several commercial rad-hard fibres up to a total dose of 0.1 dpa at elevated temperatures in a range from 200 to 390°C. Transmission degradation was measured in situ. The results showed that, although all the studied fibres were rated as radiation-hard, the actual transmission degradation may vary significantly from one fiber to another. A fiber suitable for the above application was identified.

Introduction

The possibility of in-situ measurements is a key requirement for advanced nuclear experiments. Optical Fibre Sensors can provide the necessary functionality allowing for multi-point or distributed on-line sensing. It is also important that several different parameters can be measured with one fibre. In situ monitoring of dimension changes of nuclear fuel elements as well as dimension variations of structural material samples is an important requirement for advanced irradiation programs in Material Testing Reactors. Different techniques already exist to perform such measurements but they come with a number of drawbacks. Development of an extrinsic Fabry-Perot optical sensor capable accurately measuring radiation-induced elongation of material under radiation is intended to overcome most of those problems [1]. Specifically, the compactness and the passive operation should allow a low intrusiveness, which is important not only because of a limited space available but also because a small sensor will not disturb the temperature and radiation profiles on the tested samples.
This sensor will have to withstand an extremely harsh environment: high temperature, high pressure, vibrations, in addition to a very high level of reactor gamma-neutron radiation. Radiation affects performance characteristics of optical fibres by creating point defects of different nature (see, for example, [2] for a review). In particular the Radiation Induced Attenuation (RIA) is an adverse effect, which can significantly decrease the performance or even result in a failure. This issue has been widely considered, especially by R&D program for thermonuclear fusion. In-core reactor

experiments have been conducted in order to assess the RIA under high neutron and gamma flux [3-7].
In the present work we investigate transmission degradation of several radiation hard metal coated fibres exposed to nuclear reactor radiation at temperatures up to 390°C considering their use in the Fabry-Perot optical sensors. The results show that optical fibres can survive this harsh environment.

Fiber irradiation

The fibre chemical composition is a key parameter affecting the radiation resistance. High purity silica core fibres are the most radiation hard. Several such fibres with a high-temperature compatible coating were selected for the test, Tab. 1.

Fiber Code	**Comments**	**T_{max}, °C**
AFS50/125G	MMF, low OH silica core, Au coating	700
SRH-MMF	GI-MMF, high-temperature polyimide coating	300
SMPS1000-125CB	SMF, pure silica core, CuBall (Copper Alloy) coating	600
SMPS1000-125Al	SMF, pure silica core, Al coating	550
ASI9.0/125/175A	SMF, pure silica core, Al coating	400

Tab. 1 Tested fibres. MMF – multi-mode fiber, SMF – single-mode fiber; GI – graded index

The irradiation experiment was performed in the BR2 material testing reactor, Mol, Belgium in the Smirnof rig [8]. The experiment setup is shown in Fig.1. It includes a broad-band photonic source, which allows measurements in a spectral range from 600 to 1700 nm. A reference fiber was used to compensate for the source instabilities.

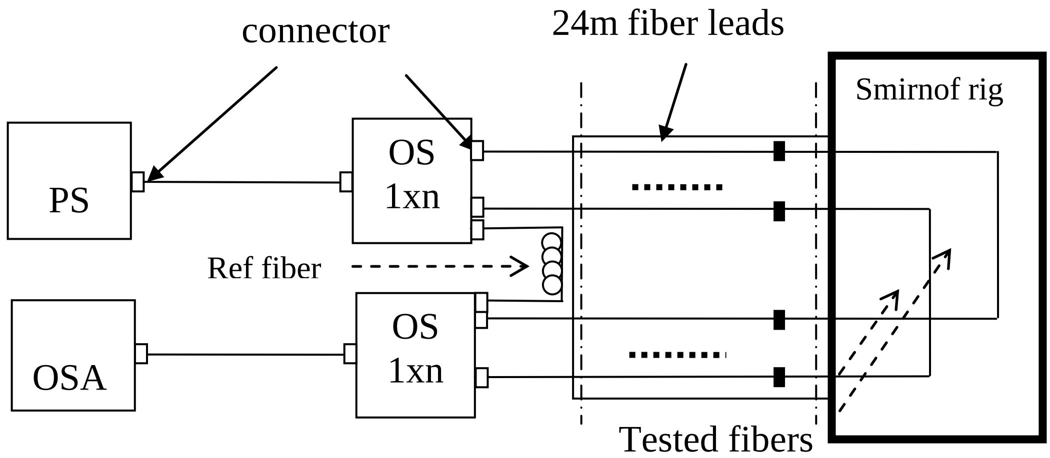


Fig.1 Schematics of the experimental set-up. PS – broad-band photonic source; OSA – Anritsu optical spectrum analyser, OS – optical switch.

Protected with a stainless steel tube the fibres went down the reactor core and back, making a U-turn with the bend radius of ~3 cm, Fig.2. The total length under a high flux was ~1 m. The fiber length outside the reactor core received a negligible dose. The thermal (E<0.5eV)/fast (E>1Mev) neutron flux was $1.7\cdot10^{14}$ / $2.0\cdot10^{13}$ n/cm²·s at the 56 MW power. The flux scales linearly with the power. The total irradiation duration was 686 h corresponding to 0.01 dpa fast fluence. The temperature during irradiation was measured with three thermocouples placed in the high flux zone.

An important feature of the Smirnof rig is the possibility of active temperature control using air circulation. Using this option a major part of the irradiation was performed at the a temperature of 200°C. At the end of the reactor cycle the temperature was increased up to 395°C for a one day period, Fig. 3.

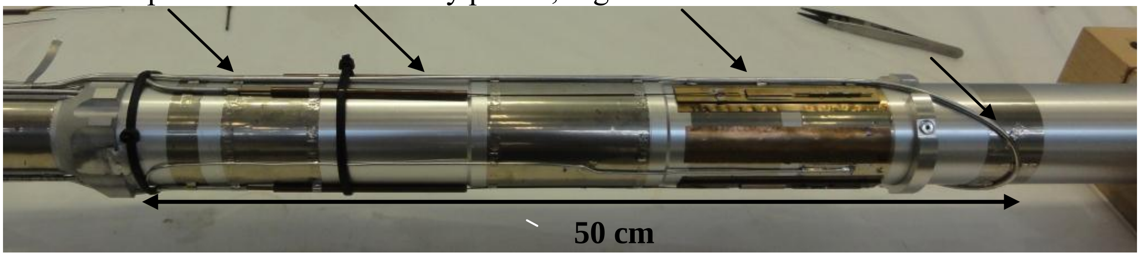


Fig.2 Part of the Smirnof rig placed inside the reactor core. The arrows indicate the tube with the fibres.

Fig. 4 shows correlation between the reactor power increase, i.e. the radiation level, and the induced absorption. At 654 nm the effect is obvious while in the IR changes are hardly detectable.

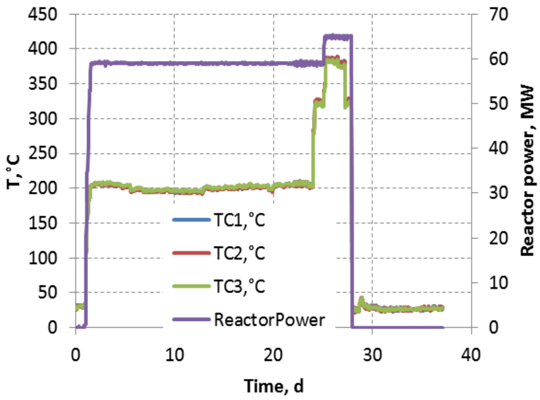


Fig. 3 Variation of the temperature of the fibres and the reactor power during the experiment.

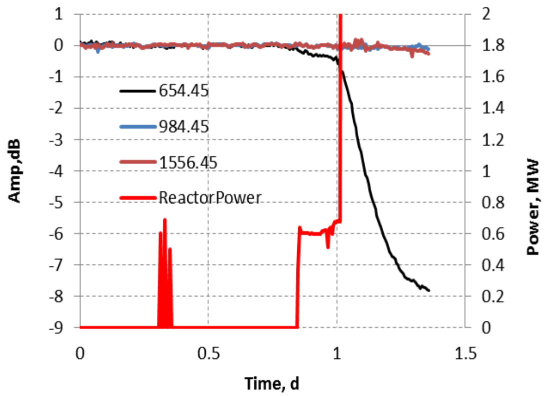
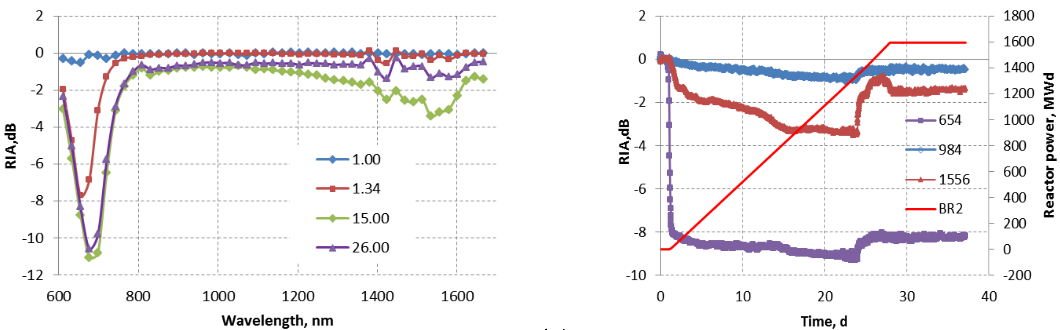


Fig.4 Correlation between RIA and the reactor power for fiber SMPS1000-125Al at the start of the irradiation.

Fig. 5a shows spectral RIA transmission changes. Two absorption bands can be seen: one in the visible range and the other in the IR. Similarly to the previous results of the exposure of the metal-coated fibers to reactor radiation published in [3] no OH-related peak is observed in the current experiment.



(a) (b)

Fig. 5 RIA spectral evolution for fiber SMPS1000-125Al. The insets indicate (a) - times after the start of the experiment, (b) – wavelengths.

The initial absorption spectrum of SMPS1000-125Al contains a very strong OH-related absorption band, Fig. 6, which is surprisingly not changed by radiation. Another interesting observation is that absorption band in the visible range is moving toward longer wavelengths. Usually this absorption band is attributed to the contributions from several different radiation defects. Therefore, the change of the peak position is explained by differences in the growth of different defects.

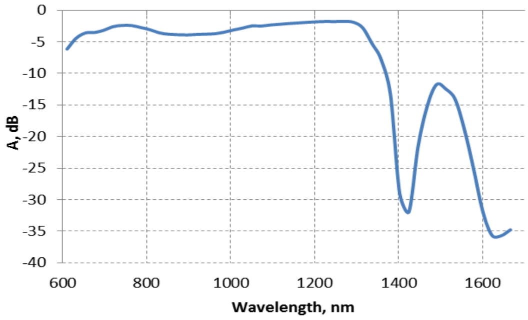


Fig. 6 Initial transmission spectrum of SMPS1000-125Al.

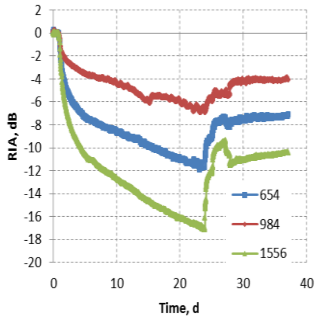


Fig. 7 RIA for ASI9.0/125/175A.

The absorption level after 26 days of irradiation is lower than after 15 days, Fig.5. This effect is clearly related to the temperature increase, cf. Fig. 3 and Fig. 5b. The temperature increase from 200 to 325°C lowers the level of the RIA at 1556 nm by 2 dB, and further temperature raise up to 395°C decreases the RIA by ~1 dB. When temperature was decreased back to 325°C the absorption raised again.

The RIA level for SMPS1000-125Al can be compared with that of ASI9.0/125/175A. Both fibres are single-mode Al-coated pure silica core but the RIA for the second fiber is much stronger. The induced absorption level of the first one allows reliable operation of the Fabry-Perot optical sensor at 980 nm.

Conclusion

We performed reactor irradiation of several commercial rad-hard fibres up to a total dose of 0.1 dpa at temperatures in a range from 200 to 390°C. Transmission degradation was measured *in situ*. The results show that the actual absorption level may vary significantly from one fiber to another. A fiber suitable for the target Fabry-Perot optical sensor application was identified.

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