Radiation-induced transmission degradation in metal-coated silica fibres

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The increasing demand for the improved safety operation of nuclear installation stimulates a growing interest for the use of optical fiber technologies. Our intension is to use optical fiber to address the dimensional stability of fuel elements based on low coherence interferometry with an Extrinsic Fabry Perot fiber cavity. In such experiments optical fibres will be exposed to high temperatures up to 400°C, which call for the use of metal-coated fibres. We have irradiated such fibres up to a 2.65 MGy dose. Transmission degradation was measured in-situ. The results show that the use of metal coating may slightly increase the transmission degradation.

Introduction

Real-time in-situ measurement of various parameters is a key requirement for the safe operation of advanced nuclear installations. Optical Fibre Sensors (OFS) have many attractive features, like the possibility of multiplexing many sensors on one fiber or performing distributed measurements, small dimensions, passive operation, a low sensitivity to electromagnetic interference. All those features give OFS a leading edge over electro-mechanical sensors, but it is also know OFS are sensitive to ionizing radiation. Radiation affects transmission of optical fibres by creating point defects of different nature which absorb light at specific wavelengths (see, for example, [1] for a review). This Radiation Induced Attenuation (RIA) is particularly strong in the UV region and can significantly decrease the performance of even result in a failure of an OFS.

Besides radiation level and temperature *in situ* monitoring of dimension changes of nuclear fuel rods as well as those of structural material samples is an important issue for future irradiation programs in Material Testing Reactors. Different techniques already exist to carry out such measurements but they all come with a number of drawbacks. Development of an optical sensor capable accurately measuring radiation-induced elongation of material placed in the core of a nuclear reactor is intended to overcome those problems. Specifically, the compact size and the passive operation should allow a low intrusiveness, which is important not only because of limited space available but also because small sensors will not disturb the temperature and radiation profile on the material samples. This sensor will have to withstand an extremely harsh environment: high temperature, possibly high pressure, vibrations, in addition to a very high level of reactor gamma-neutron radiation.

Irradiation testing demonstrated that modern radiation hard optical fibres can withstand extremely high level of radiation without critical transmission degradation. The RIA can

remain limited to few dB/m in the 800-1100 nm even after intense irradiation up to very high dose levels [2, 3].
However, in many cases temperatures of ~400°C expected at the sensor location and fibres with standard polymer coatings are not useable. Instead fibres with metal coatings need to be applied. In the present work we investigate the effect of replacement of a polymer coating on a metallic one on the transmission degradation of fibres exposed to intense ionizing radiation. The results show that the use of metal coating may slightly increase the level of RIA.

Experiment Setup

The irradiation experiment was performed at the BRIGITTE ^{60}Co under-water gamma-irradiation facility at SCK•CEN, Mol, Belgium at 10 kGy/h dose rate. This dose-rate was measured with Red Perpex dosimeters before irradiation with a standard accuracy ±5%. The total irradiation dose was ~2.65 MGy. The experiment setup is shown in Fig.1. The radiation source is placed at the bottom of a 6 m deep pool, and to connect the irradiated fibres and the measurement equipment a 8 m long fiber bundle terminated with FC/PC connectors with ceramic ferrule, placed in additional flexible house, was used. Inside the container the tested fibres were coiled with a diameter of ~20 cm without support and connected to the bundle using stainless steel threaded mating sleeves.

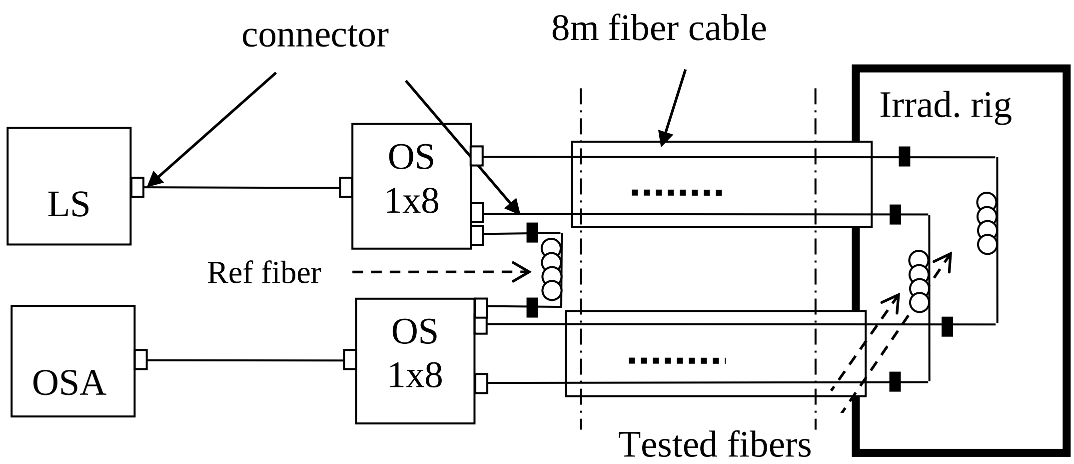


Fig. 1 Schematics of the experimental set-up. LS – broad-band source with emission maximum at 980 nm; OSA – Anritsu optical spectrum analyser.

Irradiation rig is instrumented with thermocouples. Fig. 2 shows temperature variation during the test as measured with a thermocouple at the fibres location. No active temperature regulation was applied. The temperature increase during irradiation is related with gamma-radiation heating.
Fig. 2 also shows transmission variation through the reference fiber. This fiber was a 3 m long patch-cord placed near the spectrophotometer. Both the long- ans short-term light source stability is quite good. Small steps at the moment of insertion/removal of the rig in the irradiation position can be seen on the transmission variation. The changes are small but look well correlated with the temperature increase and decrease. We have no sure explanation to this observation. Normally, no such effect should be observed. We can guess that during manipulations at the start of irradiation the reference fiber was occasionally stretched and the stress was removed during the rig unloading.

In the experiment we compared radiation-induced transmission changes of pure silica core fibres from Fiberguide ASI 633 with polyimide and aluminium coatings, from Oxford electronics with aluminium and CuBall coatings, and Sumitomo Z-fiber with polyimide coating. Rated operation temperature range for Al-coated fibres is up to 400°C and for CuBall up to 500°C. The length of all fibers was ~20 m.

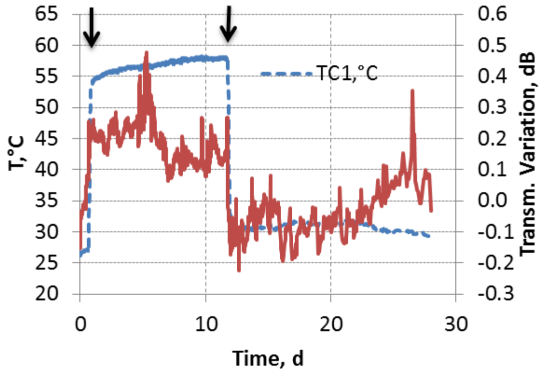


Fig. 2 Temperature at the fiber location and reference fibre transmission variation during the experiment. The arrows indicate the start and the end of irradiation.

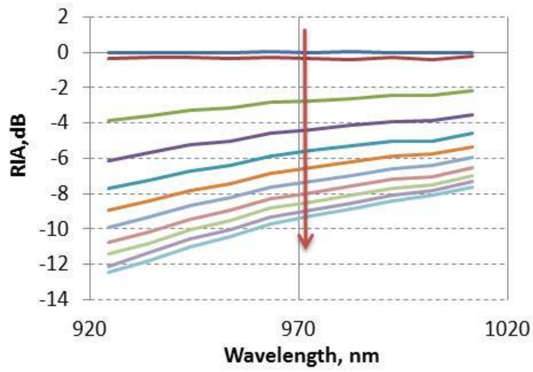


Fig. 3 Spectral transmission changes during several first hours of irradiation. The arrow indicates the dose increase.

In order to exclude the effect of the source spectral and temporal variations on the RIA measurements, the double reference subtraction method was used. The intensity of light transmitted through the system is defined as:

$$I_{out}(\lambda, t) = I_{src}(\lambda, t)T(\lambda)R(\lambda, t)$$

where I_{out} is the spectrum measured by the OSA, T are transmission losses in the fibers, connectors, and the optical switch, which are considered to be constant and R is the radiation-dependent transmission coefficient, $R(t=0) = 1$ and it remains unchanged for the reference arm fiber. Therefore in log-units for the reference arm

$$F_{ref}(\lambda, t) = Lg\big(I_{out}(\lambda, t)\big) - Lg\big(I_{out}(\lambda, t = 0)\big) = Lg\big(I_{src}(\lambda, t)\big) - Lg\big(I_{src}(\lambda, t)\big).$$

For a fiber under irradiation

$$F_{irr}(\lambda, t) = Lg\big(I_{out}(\lambda, t)\big) - Lg\big(I_{out}(\lambda, t = 0)\big)$$
$$= Lg\big(I_{src}(\lambda, t)\big) - Lg\big(I_{src}(\lambda, t)\big) + Lg\big(R(\lambda, t)\big)$$

Therefore

$$F_{irr}(\lambda, t) - F_{ref}(\lambda, t) = Lg\big(R(\lambda, t)\big)$$

This means that the effects of spectral-dependent losses in the optical components, spectral and temporal variations of the source intensity are all eliminated. This conclusion remains valid until the source is stable on the time scale corresponding to the measurement of both reference and the irradiated arms.

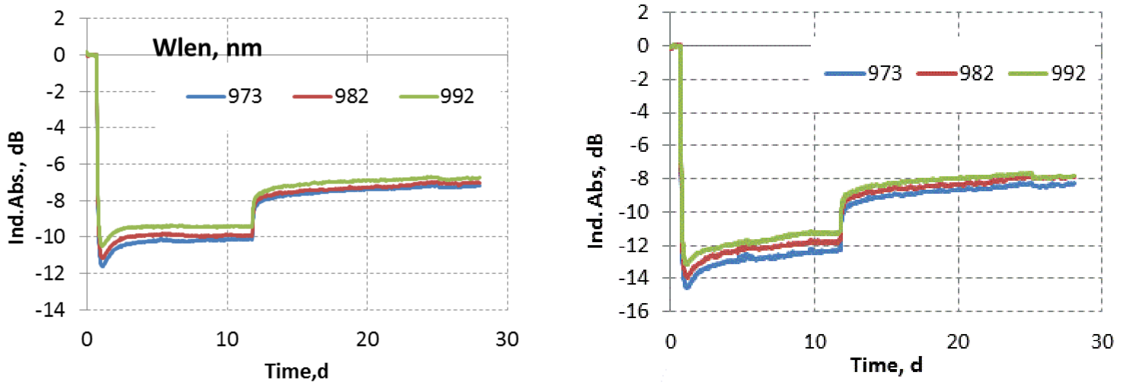
Results

Fig. 3 shows spectral transmission changes Fiberguide polyimide coated fiber during several first hours of irradiation. The changes are monotonous with a stronger absorption increase at shorter wavelengths. This indicates that the observed RIA is related to absorption bands in the Visible and UV range.

The temporal behaviour of the transmission at several wavelengths is shown in Fig. 4a. An interesting feature is a maximum in the spectra: at the initial stage of irradiation the absorption grows very quickly, but then it starts to decrease. In is known that in pure silica core fibres strong transient absorption can occur in the 660-760 nm region [4].

Such a peculiar phenomenon is usually observed in very dry silica prepared with a sol-gel technique or other types of glasses. Self-trapped holes are believed to be responsible for this transient RIA [5]. These defects are meta-stable and are bleached by radiation. Fig. 4b shows results for Fibreguide fibre with aluminium coating. The responses shown in Fig. 4a and b are very similar, but the absorption of the Al-coated fibre is slightly higher.

It may be noted that in a separate experiment we studied the effect of temperature changes in the range from 25 to 70°C on the fibre transmission with the same set-up as that used in the irradiation. The transmission changes were within the measurement error, which means that the behaviour observed in Fig. 4 is not influenced by temperature variations.



(a) (b)

Fig. 4 The temporal behaviour of the RIA for Fiberguide pure silica core fibre at 973, 982 and 992 nm wavelengths with polyimide (a) and aluminium (b) coatings.

Conclusion

We have examined the influence of fibre coating on its radiation sensitivity. It was found that Al-coated fiber has a slightly higher level of absorption as compared to the same but polyimide fiber. We explain this effect assuming that metal coating induces additional stresses in the fiber and those stresses make fibre more sensitive to ionizing radiation.

References

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