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Radiation Effects on Radiation-Hardened KU and KS-4V Optical Fibres

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Previous works on radiation resistance of the optical fibres with KU and KS-4V silicas in the core have been carried out under both gamma irradiation at the doses up to 10^7 Gy [1], [2] and combined neutron + gamma flux of nuclear reactor at the fast neutron fluence and γ dose up to 8×10^{14} n/cm^2 and 0.2 MGy, respectively [3].

Fibres with KU silica core feature a big radiation absorption band of nonbridging oxygen centred at 630 nm [1]. Its amplitude amounts to ~12 dB/m at a dose of ~10 MGy. There is a loss increase (up to 10 dB/m) in the blue spectral region at the wavelength λ < 350 nm, owing to the band of nonbridging oxygen at λ=260 nm. In contrast to KS-4V fibres [2], the KU fibres do not demonstrate saturation of induced absorption with dose. In KS-4V fibres, gamma-radiation induced absorption in the visible spectral region is at saturation at the level of 2-2.5 dB/m in a vast dose range from ~1 to ~10 MGy [1]. At doses below then ~1 MGy, the KS-4V fibres feature a large transient absorption band centred at the wavelength of 670 nm [1], [2]. This band vanishes with dose and does not show up again under subsequent irradiation [4]. The origin of this band has not been established with certainty.

A comparison study of radiation resistance of optical fibres with different core silica including KU and Heraeus F100 has been carried out under combined neutron + gamma flux of nuclear reactor at the fast neutron fluence and γ dose up to 8×10^{14} n/cm^2 and 0.2 MGy, respectively [3]. KU fibre has demonstrated much lower radiation-induced loss than other fibres studied.

It is important to note that the results of the experiments reviewed above were obtained on «as-drawn» (i. e. unpretreated) fibres and were, therefore, of preliminary nature. The next step was to apply hydrogen loading to further harden KU and KS-4V fibres against radiation. This resulted in significant optical loss reduction [5]. It was found that H_2-loading totally suppresses the transient radiation-induced absorption band at the wavelength of λ=260 nm in KS-4V fibre. After gamma-irradiation to 1.7-3.4 MGy, H_2-loaded both KU fibre and KS-4V fibre demonstrate comparable losses (~0.05-0.5 dB/m in the red spectral region and ~0.8-2 dB/m in the blue spectral region), which are far lower than the loss in unpretreated fibres [5].

The aim of this work was to test the as-drawn and hardened (i.e. H_2–loaded and preirradiated) KS-4V and KU optical fibres in the reactor environment by in-situ measurements of both the radiation-induced loss and the luminescence in the visible spectral region.

The two types of the optical fibres based on KU and KS-4V glasses used in the test are described in Ref. 2 in detail. In brief, all fibres have the same cladding diameter, numerical aperture (NA=0.16) and polymer coating, but differ in the principal impurities, the KU fibres core contains 800 ppm hydroxyl and 80 ppm chlorine, and KS-4V fibre core contains 0.25 ppm hydroxyl and 20 ppm chlorine. Both fibres have an undoped silica core and F-doped silica cladding.

The two samples (as-drawn and H_2-loaded & pre-irradiated) of both KU and KS-4V fibres were subjected to simultaneously exposes of reactor irradiation up to a neutron fluence of about $1.2{\times}10^{18}$ n/cm^2. The experimental set-up [3] involved 51 m total length of both sample and reference fibre, coiled inside the reactor active zone (58 cm height) into double and single loops, respectively, of each fibre type studied. The length difference between the homogeneously irradiated parts of the sample and reference fibres was 16 cm. These fibres were illuminated with a spectrometric tungsten lamp that has been calibrated for absolute measurements in terms of J/s/cm^2/Å/sr. Both the radioluminescent and the transmission spectra were in-situ detected during irradiation by charge-coupled-device (CCD) linear detector in the visible spectral region from 400 to 700 nm.

The radiation-induced loss and the luminescence were measured during three successive runs. In the first run the spectroscopic measurement were carried out within each step of neutron flux increasing according with reactor power. In the second stage, after neutron flux reached value of 10^{13} n/cm^2/s the reactor was special shutdown. Thus, in the second irradiation stage we have following tree measurements: the first - at the high neutron flux level, the second - at the zero flux level immediately after shutdown, and the third - at the zero flux level too, but 17 hours after reactor shutdown. In the third stage the tree spectroscopic measurements was carried out at the neutron fluence of $4.5{\times}10^{17}$, $9{\times}10^{17}$, and $1.2{\times}10^{18}$ n/cm^2, respectively, at the constant neutron flux of $1{\times}10^{14}$ n/cm^2/s.

The first stage of irradiation allowed to observe the hardened, H_2-loading and pre-irradiating, effect in the both KU and KS-4V fibres. In Figure 1, the radiation-induced loss spectra observed at the neutron fluence of $2{\times}10^{16}$ n/cm^2 are given for fibres tested. For KU as-drawn fibre, we can see a big radiation absorption band of nonbridging oxygen centred at the wavelength of 630 nm. As for KU hardened fibre, this absorption band is absent and induced loss level for this fibre type is less than 4.5 dB/m in spectral region. It is important to note that the KS-4V hardened fibre have specific point in the loss spectrum in the vicinity of 460 nm. Moreover, the induced loss retain level from 0.2 to 0.5 dB/m at the fluence of up to $3{\times}10^{15}$ n/cm^2.

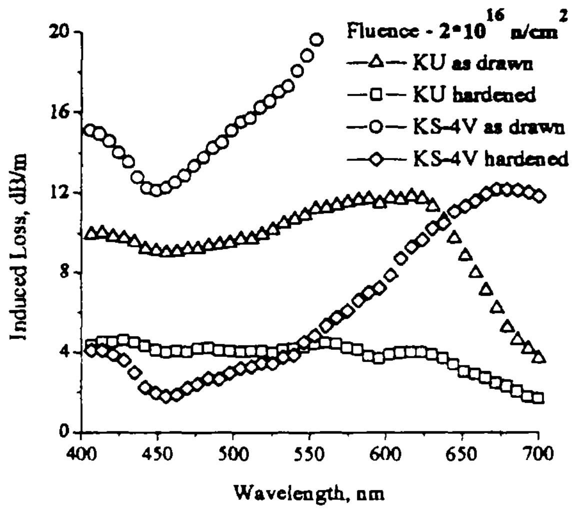

Figure 1: Radiation induced loss spectra of as-drawn and hardened optical fibres observed at the fast neutron fluence of $2{\times}10^{16}$ n/cm^2.

The result of induced loss measurements during the second irradiation stage for KS-4V hardened fibre is shown in Figure 2. The cross symbols correspond to the measurement at the high fluence level of $2{\times}10^{16}$ n/cm^2 before reactor shutdown. The squares and diamonds are immediately and 17 hours after shutdown measurements, respectively. The plus symbols correspond to the first measurement during the first irradiation stage at the minimum fluence level of $5{\times}10^{13}$ n/cm^2. The same measurements were carried out for all fibres types tested.

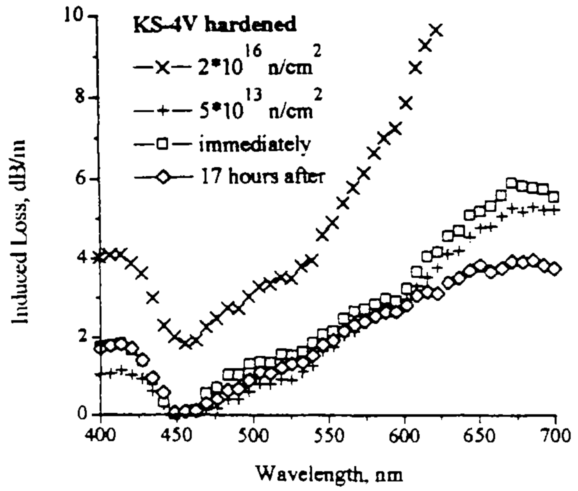

Figure 2: Radiation induced spectra of the KS-4V hardened fibre as the result of time measurements at the reactor shutdown.

It is to be drawn attention that the immediately measured induced loss for KS-4V hardened fibre (Figure 2) have the same level as at the fluence of 5×10^{13} n/cm^2. This kind of behaviour of the loss could be explained with gamma radiation annealing.

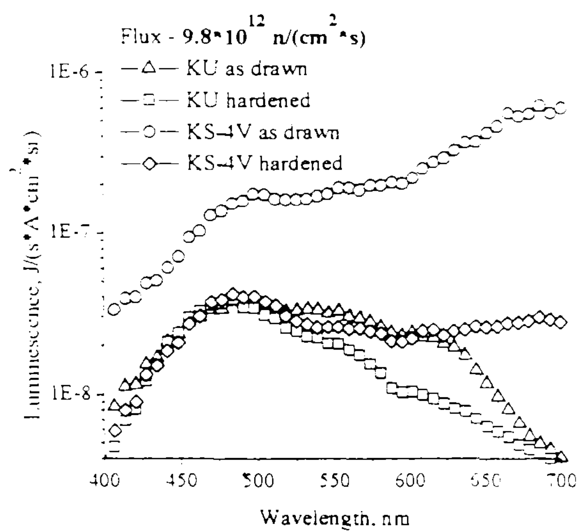

Figure 3: Radioluminescence spectra of optical fibres tested at the fast neutron flux level of 9.8× 10^{12} n/cm^2/s, corrected for fibre trans-mission.

As for radiation induced loss, the luminescence was absolutely measured in terms of J/s/A/cm^2/sr according with neutron fluence. Luminescence spectra for both KU and KS-4V fibres (as-drawn and hardened) at the neutron flux of 9.8×10^{12} n/cm^2/s are shown in Figure 3. The spectra are corrected for fibre transmission. All fibres demonstrate much the same luminescence level, except for KS-4V as drawn fibre (circle symbols). Moreover, the luminescence of all fibres increases approximately linearly with neutron flux, at least at flux of up to 10^{13} n/cm^2/s.

In the third irradiation stage, at the constant neutron flux level of 1×10^{14} n/cm^2/s, the spectroscopic measurements were carried out at the neutron fluences of 4.5× 10^{17}, 9×10^{17}, and 1.2×10^{18} n/cm^2, respectively. The induced loss increases according with neutron fluence, but the effect of reduction of induced loss was observed for KS-4V fibre.

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