Ionizing radiation-induced attenuation of light in single-mode optical fibers in the near IR-region

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INTRODUCTION

Optical fibers (OFs) have currently found wide application in various fields of science and technology from high-speed information transmission to fiber lasers and precision sensors of various physical quantities. Nevertheless, the use of OFs in nuclear and fusion installations, including the international experimental fusion reactor ITER, leads to degradation of their optical properties due to the appearance of additional radiation-induced attenuation (RIA) of light [1-4]. This phenomenon considerably limits the use of OF in conditions of increased radiation levels and, therefore, there is an urgent need to reduce RIA to an acceptable level for a particular application.

It is known [5] that OFs will be used in the ITER diagnostic systems as transport from fiber-optic sensors operating at a wavelength of λ=1550 nm. When exposed to ionizing radiation, the optical transmittance at this wavelength is significantly reduced due to the long-wavelength (LWL) RIA with a maximum at wavelengths λ>1600 nm. Unfortunately, the physical nature and basic properties of this RIA remain questionable. It is worth noting that it is the LWL RIA that limits the radiation resistance of OF in applications in intense gamma-neutron fields and is a limiting factor for a wider implementation of OF in diagnostic and control systems in nuclear and fusion facilities. Therefore, the study of the mechanisms of occurrence and properties of long- wavelength RIA is an important and urgent task for OF applications at increased levels of ionizing radiation, especially in strong radiation fields.

This work is devoted to a study of the behavior of LWL RIA in pure-silica-core OF during and after gamma irradiation in the near-infrared range.

EXPERIMENTAL DETAILS

In ICHPS of RAS a preform with a pure-silica-core and a F-doped cladding with refractive index difference Δn~0.0095 (Figure 1) was made by MCVD (Modified Chemical Vapor Deposition). The reflective cladding (2 in Figure 1) contained about 2 wt% fluorine appearance).

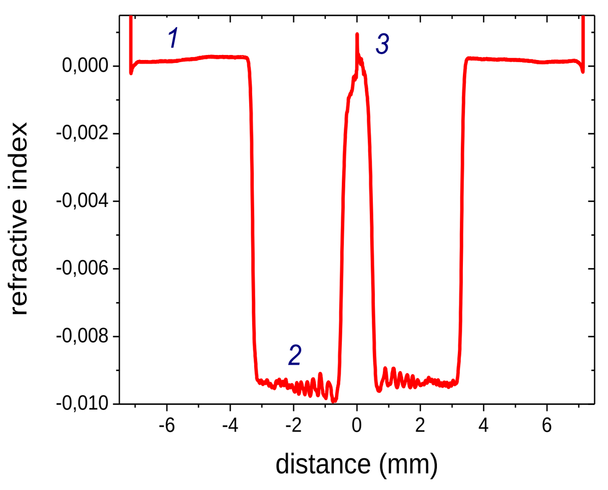

Fig 1. Fiber refractive-index profile: 1- substrate tube 2- F-doped reflective cladding, 3- pure silica core

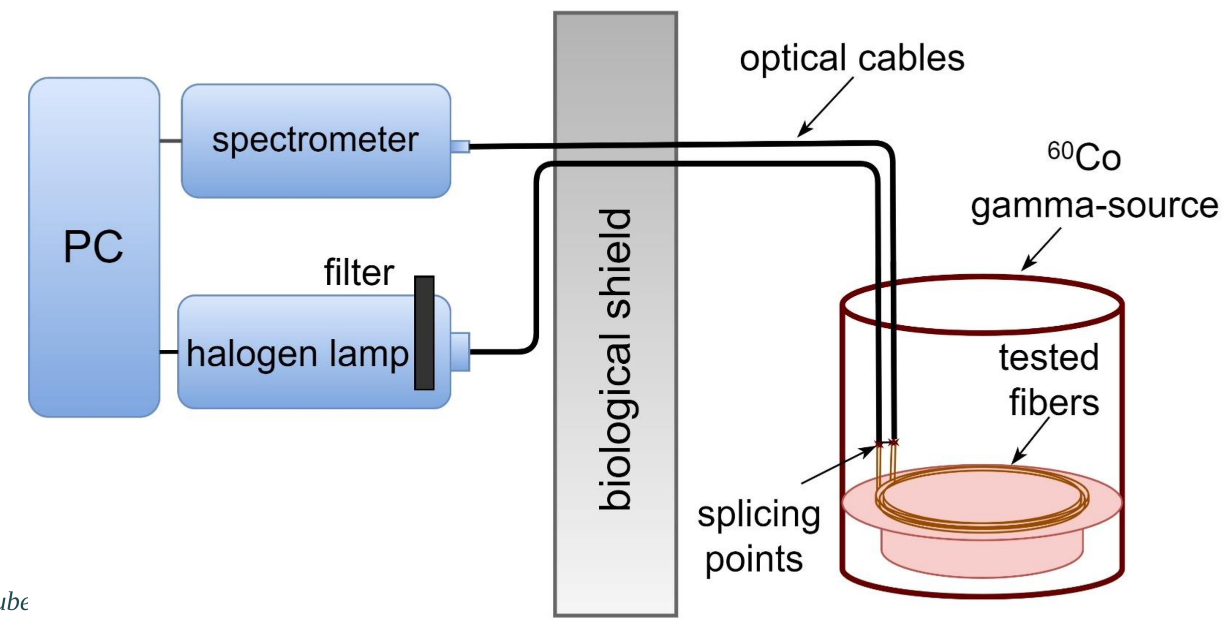

Fig 2. Experimental set-up

To study the RIA spectra, 100 m of OF was wound on a plastic coil 160 mm in diameter and 100 mm in height. The OF was irradiated with a 60Co γ-source with an average gamma-quantum energy of 1.25 MeV at a dose rate of 7.6 Gy/s. The entire irradiation process can be divided into two stages. In the first one, the OF was irradiated for 180 min followed by relaxation for 30 min. In the second one, the OF was irradiated for 1112 min followed by relaxation for 15 min. The irradiation was conducted at +25°C until the time of 1082 min, after which the temperature increased to +40°C when the ventilation was switched off.

RESULTS

RIA dependence on dose

Figure 3 shows the dependence of RIA during irradiation and relaxation at wavelengths of 1310 nm and 1550 nm. At the first stage of irradiation RIA (up to 180 min) at wavelength 1310 nm is greater than at 1550 nm. At the very beginning of gamma exposure there is a sharp increase in RIA up to absorbed dose ~3.7 kGy (point 1 on Figure 2), after that RIA begins to decrease, herewith so-called transient absorption is greater at 1310 nm, at maximum it reaches 17.5 dB/km

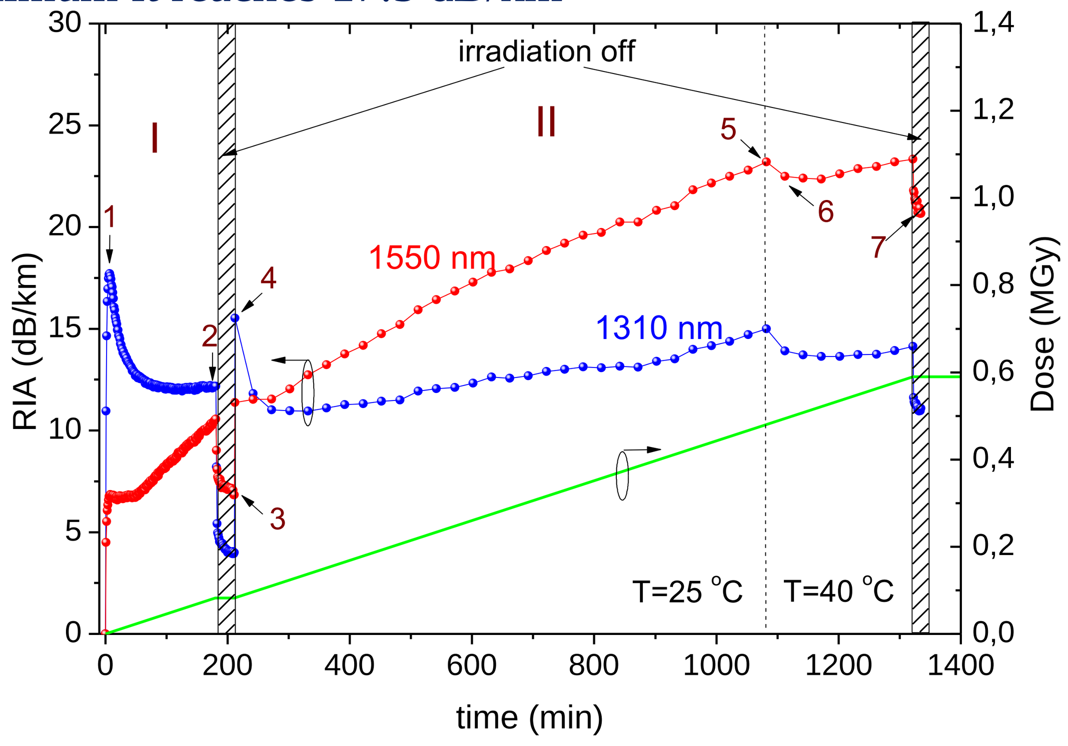

Fig 3. RIA and dose (green curve) evolution with time of irradiation and post-irradiation recovery at wavelengths 1310 nm (red curve), 1550 nm (blue curve).

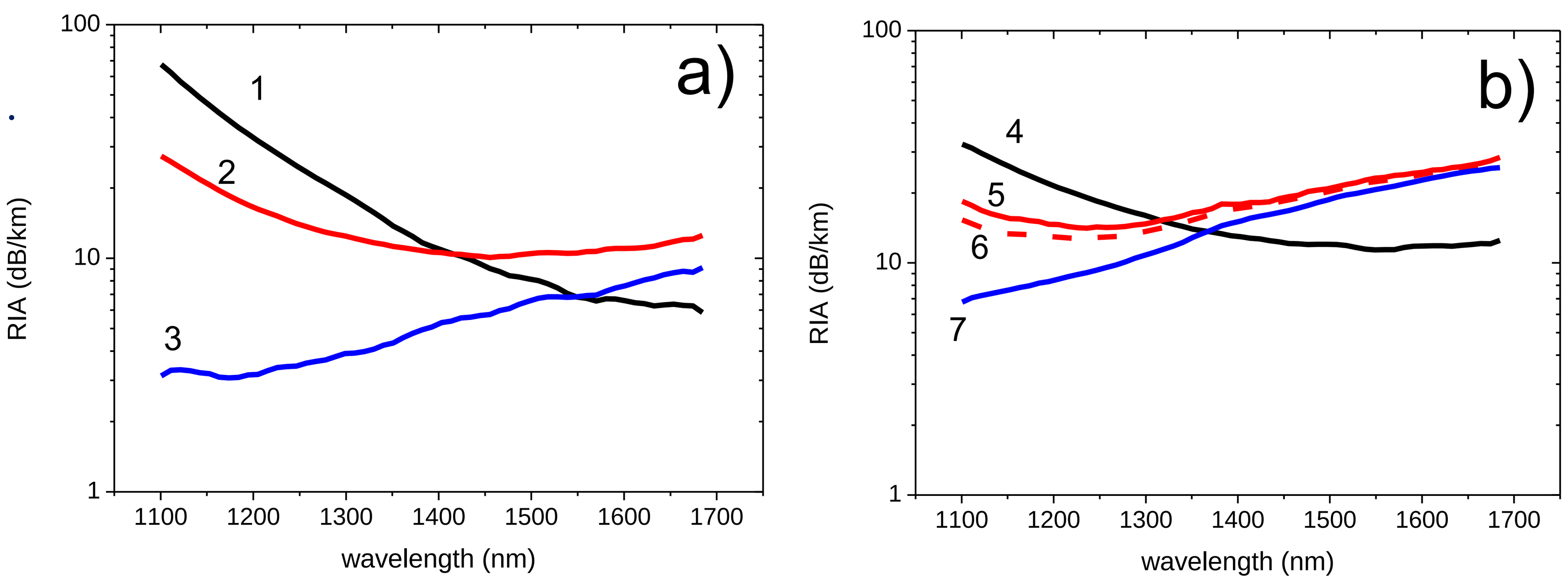

Fig 4. a) RIA spectra during irradiation and relaxation at I stage of irradiation (points 1 - 3.7 kGy, 2 - 82 kGy, 3 - 30 min of relaxation after 82 kGy,), b) - at II stage of irradiation 4 - 82.5 kGy, 5- 479.7 kGy, 6 - 480.2 kGy, 7 - 15 min of relaxation after 590 kGy). Temperature T=25 °C for spectra 1-5 and T=40 °C for -6-7

The RIA dependence on relaxation time

Figure 5 shows the spectra of total and radiation-induced optical loss. From the spectra of total optical loss for the initial OF and irradiated to a dose of 590 kGy it is clear that in the LWL region starting from 2000 nm the spectra coincide. From the difference in the spectra of total loss of the irradiated and initial OF, we find the RIA spectrum, from which it is clear that an asymmetric band with a maximum at a wavelength near 1800 nm with a gentle SWL part and a steep decline in the LWL part is responsible for the LWL absorption. Therefore, in this study, we observed the absorption band responsible for the LWL RIA in its full form for the first time

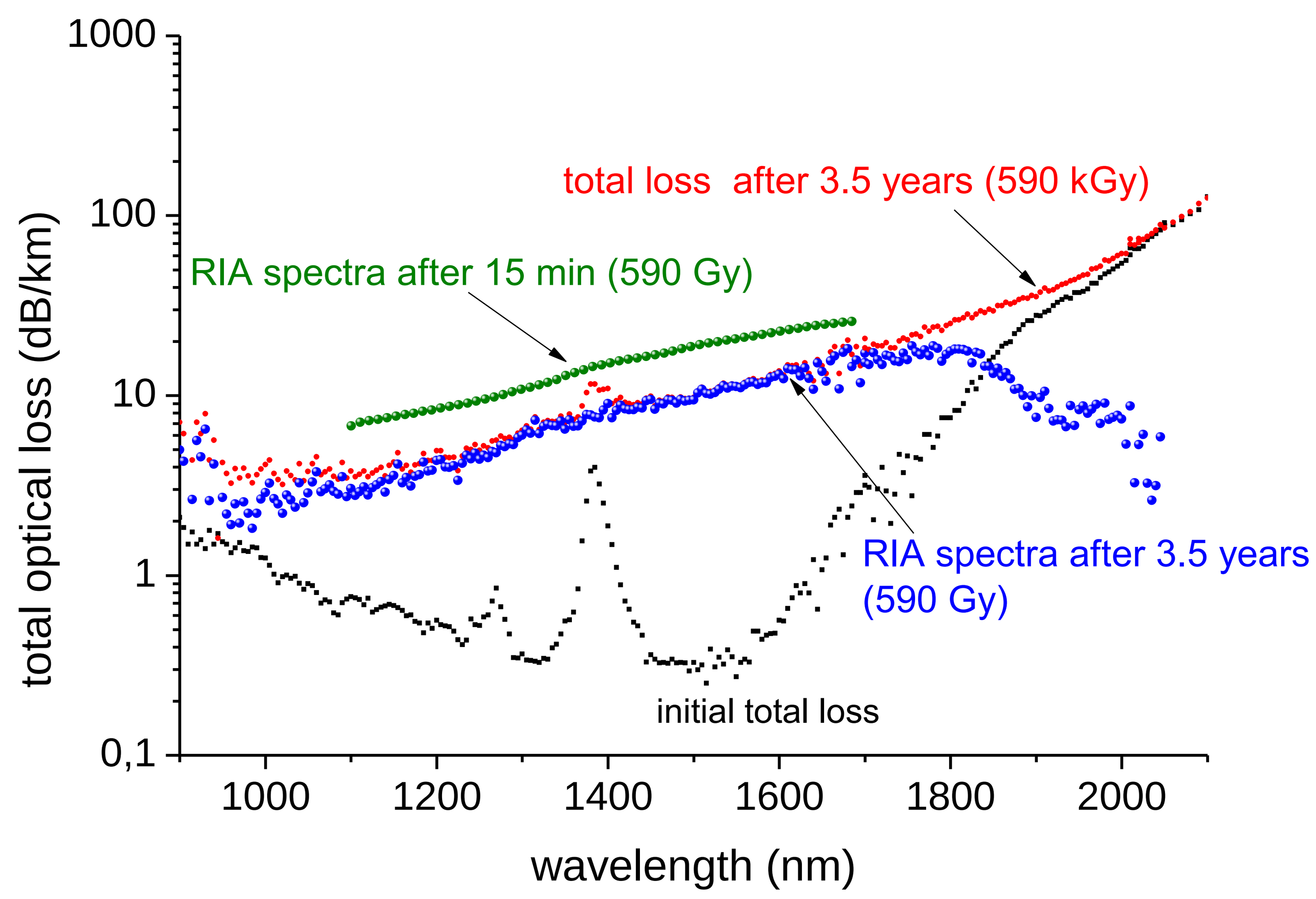

Fig 5. Spectrum of optical loss. Initial loss (black dots), loss 3.5 years after irradiation with a dose of 590 kGy (red dots), RIA spectrum after 15 min (green dots) and 3.5 years (blue dots) after irradiation

CONCLUSIONS

The dependence of RIA in the PSC OF during and after gamma-irradiation up to 590 kGy at a dose rate of 7.6 Gy/s in the near-IR range has been investigated. The mechanisms affecting RIA in the near-infrared range have been established: absorption of STHs having bands with maximums at 660 and 760 nm and LWL absorption.

It was shown that starting with an absorbed dose of ~100 kGy, the RIA at 1550 nm becomes larger than at 1310 nm because of the prevalence of LWL RIA over STH absorption. For the first time, the absorption band, with a maximum at wavelength around 1800 nm, responsible for the LWL RIA is fully defined. At an absorbed dose of 590 kGy at wavelengths of 1310 and 1550 nm, the RIA is 14.1 and 23.3 dB/km, respectively. During 3.5 years of annealing of the OF at room temperature the RIA in the entire spectral range of 1100-1700 nm decreases by 40-50%.

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