Monitoring of changes in activator's matrix of irradiated Yb-doped optical fibers

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We report on the method for monitoring of the modifications in Yb-doped optical fibers irradiated by γ-rays with the doses corresponding to the space applications. This method is based on the refractive index changes (RIC) effect induced in the tested fibers by square modulated optical pulses at 980 nm with power up to 100 mW. During the experiment the Yb-doped fibers were γ-irradiated with the doses of 1, 2, 4 and 8 kGy. The applied interferometer technique highlighted the key parameters of the RIC effect that changes with the degree of degradation of the irradiated samples.

Introduction

During last decade great attention has been paid to the research of radiation effects in optical fibers. It is well known that optical elements which are placed into the space around the Earth experience radiation environments originated from trapped-particle belts, cosmic rays, and solar events. The study of optical materials affected by the continuous flux of energetic protons, hard x-rays, and gamma photons are of particular interest. These types of radiation exposures lead to the excitation of electrons and the subsequent formation of the color centers in activated glasses. This effect in turn gives rise to changes in optical transmission, loss and luminescent band structure, impacting performance of laser materials. Rare-earth-doped optical fibers, and Yb-doped optical fibers in particular are considered as possible candidates for air and space applications such as optical sensors and optical inter-satellite telecommunication links. The use of Yb-doped optical fibers on the satellite board emerges the challenge of their radiation resistance [1]. The dose of ionizing radiation that such fiber absorbs during 15 years in open spase is estimated to be up to 2 kGy (for SiO_2 based fiber). In a comparison with standard Ge-doped fibers, for Yb-doped fibers co-doped with aluminum or phosphorus such dose causes a significant radiation - induced absorption (RIA) in the near IR spectrum range, which is ~ 10-20 dB/m. Such high RIA and connected with RIA permanent changes in the fiber refractive index (to be estimated as 10^{-5}) have in some extend to affect the dynamics of Yb-ion populations in doped fibers operating the laser radiation. Therefore, independent monitoring of the population inversion dynamics in Yb-doped optical fibers through the electronic refractive index change effect (RIC) [2-6], for an example, has to allow estimating the degree of fiber degradation under γirradiation. In this paper we report an interoferometric method enabling the study of the population inversion dynamics in Yb-doped optical fibers irradiated by γ-rays from a ^{60}Co source. We show some preliminary results on RIC effect in the irradiated Yb-doped optical fibers and discuss the possibility to monitor the degree of fiber degradation under γ-radiation through the RIC effect.

Experimental setup

During the experimental study four single-mode Yb-doped fiber samples of the identical lengths irradiated with different γ-radiation doses were examined. Absorption spectra of the tested fibers are shown in the Figure 1.

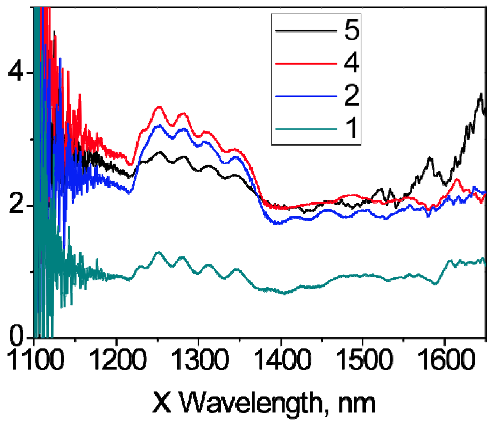

Figure 1. Absorption spectra of the tested fiber samples: 1 – 1 kGy; 2 – 2 kGy; 4 – 4 kGy; 5 – 8kGy

The experimental setup shown in Figure 2 is nearly the same as in [2]. It allows to characterize the refractive index changes in the tested Yb-doped optical fibers induced by square modulated optical pulses at 980 nm. The tested fibers are pumped to the core from a standard laser diode operating at λ_p = 980 nm with the power up to 100 mW. The CW-radiation with a very narrow bandwidth of laser diode "Tunics" with a wavelength λ_t=1550 nm and coherence length ~ 10 m is used as the test wave.

The test wavelength λ_t is tunable within the range from 1460 to 1610 nm. The test signal is detected at the interferometer output by the fast photodiode for the following reconstruction of the induced phase shift $\delta\varphi(t)$.

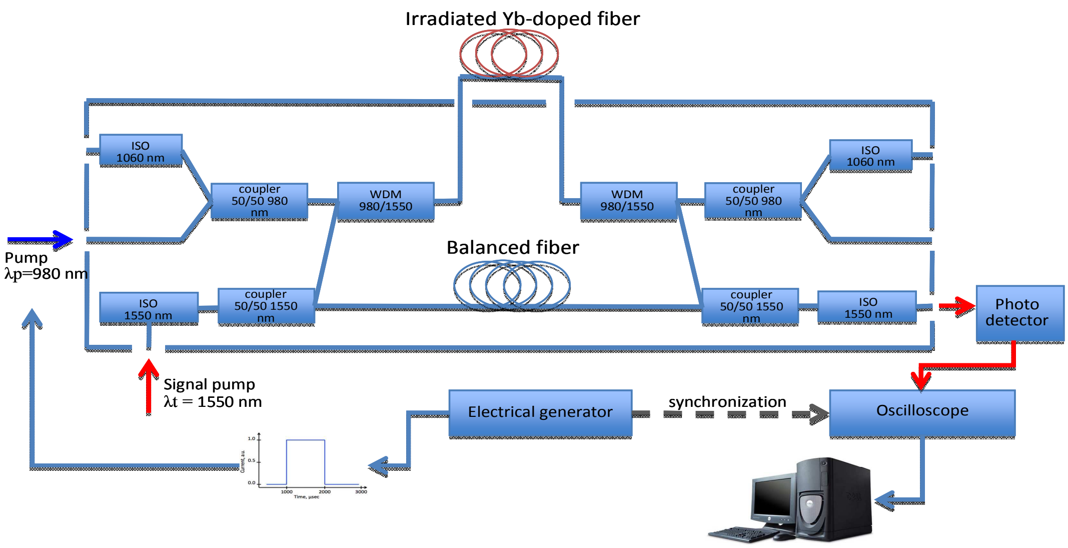

Figure 2. Experimental setup

Experimental results

The RIC signal is measured as the photodiode response to a single rectangular pump pulse with the amplitude of 100 mW and the pulse of 1 ms duration introduced into the fiber under test. The induced phase shifts (Figure 3) reconstructed from the oscilloscope traces recorded at different testing wavelengths are direct results of the electronic refractive index change effect in the investigated fibers described by the equation

$$\delta\varphi(t) = K\tau_{sp}\left[1-\exp\left(-\frac{t}{\tau_{sp}}\right)\right]P_0\,,\; 0<t<\tau_P$$

$$\delta\varphi(t) = K\tau_{sp}\left[\exp\left(\frac{\tau_P}{\tau_{sp}}\right)-1\right]\exp\left(-\frac{t}{\tau_{sp}}\right)P_0\,,\; t>\tau_P$$

where P_0 is the pump pulse amplitude, τ_{sp} is the Yb-ions excited state life time, coefficient K is given in [3, 4].

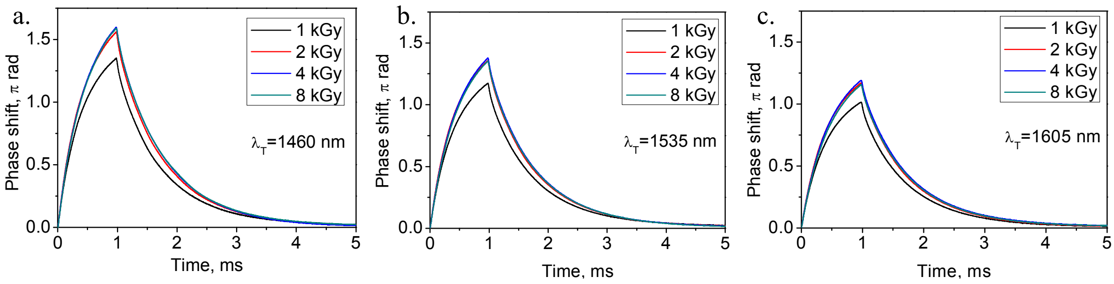

Figure 3. Phase shifts recorded at 1460nm (a), 1535 (b) and 1610nm (c).

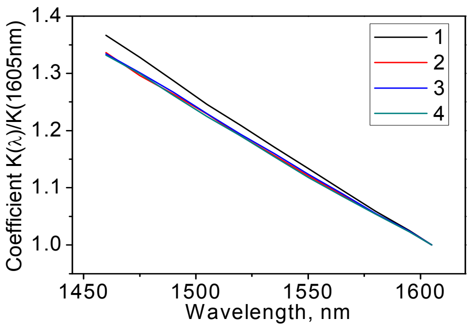

Figure 4. Coefficient $K(\lambda)/K_{1605}$

From the data similar to that shown in Figure 3 the coefficient K has been calculated for the all test samples at the wavelengths range from 1460 nm to 1610 nm. The slope of K(λ) is the most important parameter changing with the radiation dose. Figure 4 presents the dependence of the coefficient K(λ) normalized to the K(1605nm) measured for all fiber samples. One can see that the slope K(λ) for the low-irradiated fiber differs from the slopes of the fibers irradiated with the higher doses. This behavior highlights a kind of the threshold of irradiation influence above which the effect becomes less significant. The threshold behavior is more pronounced for the shorter wavelengths.

The measured phase shifts are governed by the population inversion mechanism in the irradiated fibers and are directly proportional to the total population N_2 of the exited Yb-ions state of the fiber. Therefore the phase traces shown in Figure 3 essentially describe the dynamics of the populations N_2 during and after the excitation of the tested fiber. Importantly, the relaxation of N_2 after exiting pulses occurs exponentially with a typical time τ_{sp} = 770 μs for the all fiber samples. To compare N_2 behaviour related to different fiber samples we could normalize the phase traces in such way that relaxing parts of these traces coincide.

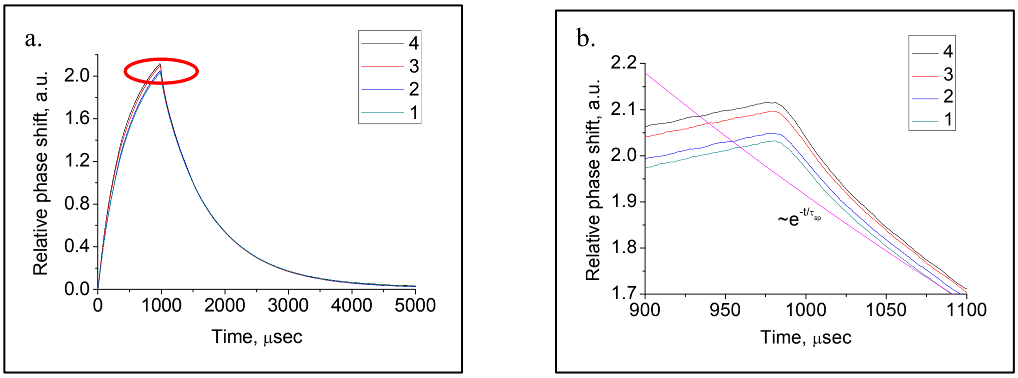

Figure 5. Normalized phase shift traces (a) and its zoom (b)

This procedure shown in Figure 5 highlights the differences in N_2 falling rates just after pulse excitation in different samples. One can see that the most irradiated fiber has the lowest rate of the falling. Therefore recording the value of N_2 falling allows to monitor the degree of the fiber degradation of the fibers under γ-radiation.

Conclusion

We have reported the method of the characterization of the refractive index changes in the γ-radiated optical fibers. The RIC effect is observed in all irradiated samples at different wavelengths. The specific dynamical features of the RIC effect shown in the Figures 3 and 5 demonstrate clear dependence on the radiation doses. In future these results could be we believe to transform into the method of real-time monitoring of the degree of degradation of the irradiated fibers.

Acknowledgements

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