X-ray irradiation influence on prototype Er^{3+}-optical fibers: confocal luminescence study

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ABSTRACT

The integration of rare-earth doped optical fibers as part of fiber-based systems in space implies the development of waveguides tolerant to the radiation levels associated with the space missions. We report the spatial distribution, the photoluminescence (PL) properties of color centers and the related changes induced by X-rays radiation at different doses (50, 500 and 1000 krad) for two different prototypes of Er-doped optical fibers. Each sample (in the version pristine, X-irradiated and H_2 loaded prior to radiation exposure) was characterized by confocal microscopy luminescence (CML) measurements in Visible range with Visible (488 nm) or UV (325 nm) laser light excitation. The set of tested fibers allowed us to obtain information on the radiation responses of the silica-based host matrix and on the transitions between the energy states of rare-earth ions. Under Vis-excitation, the luminescence spectrum of the core revealed the typical emission pattern of Er^{3+} ions, with an increase of the emission intensity around 520 nm due to the radiation treatment; whereas no spectroscopic change induced by radiation was observed when a particular sensitizing element is added to the core composition or when the fiber was previously H_2-loaded. The PL-core spectra under UV-excitation showed the behavior of the ODC, typical of the silica-based host matrix. For these spectra, addition of the sensitizing element annihilates the depressions that characterize the profile of ODC emission and that are due to the Er^{3+} ions absorption.

Keywords: Rare-Earths, optical fibers, luminescence, X-rays effect, CML, H_2 loading

1. INTRODUCTION

Research interest in the field of rare-earth doped optical fibers is still motivated by practical importance of these specific optical fibers, used as active medium of fiber-lasers and amplifiers designed to operate in radiation environment. Erbium doped fibers for instance, that are suitable for amplification in the 1.5µm window, are very sensitive to ionizing radiations and thus their deployment in numbers of technological applications is at stake. It is therefore crucial to comprehend the mechanisms of material degradation, in order to increase their resistance in radiation environments. The use of a tool combining microscopic and spectroscopic aspects is essential to qualitatively and quantitatively: identify the luminescent centers, attribute them to microscopic structures and to assess the changes induced by radiation in the atomistic scale[1]. In this study, we investigate the role of several chemical elements incorporated in the fiber core composition, also interest in the field of active fibers. These elements can be used structurally to build the waveguide in terms of refractive index profile, to enhance some specific optical properties of the rare earth ions, and in some cases, as sensitizers. Once the core is manufactured, its properties can be modified by the following manufacturing process steps such as fiber drawing, but also in the course of post-treatments on the fiber itself such as hydrogen loading.

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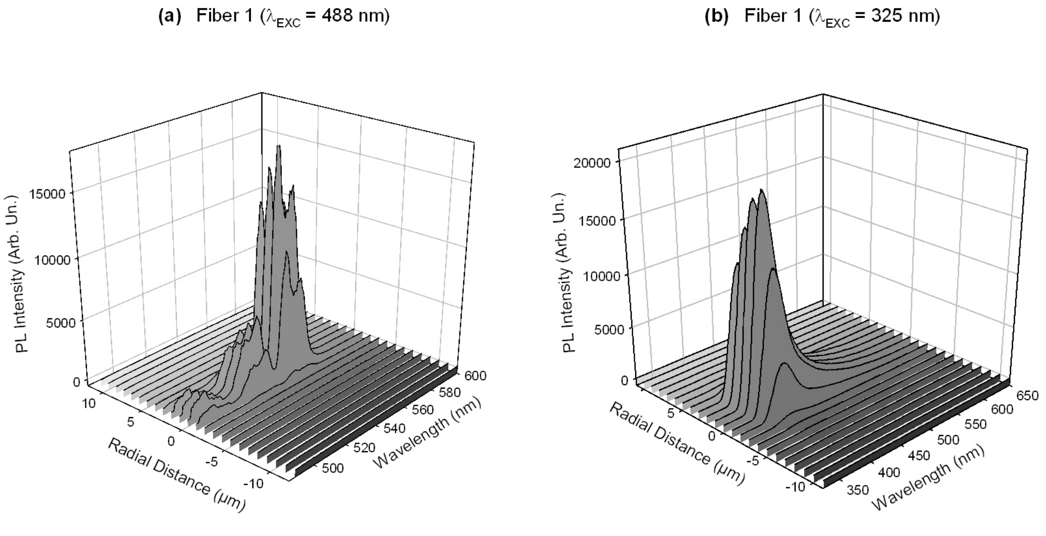
2. EXPERIMENTAL DETAILS

The different prototypes of Er-doped optical fibers have been made by modified chemical vapor deposition (MCVD), process by iXFiber[2]. Short lengths (2 cm) of each fiber have been irradiated with 10 keV X-rays at three different doses (50, 500 and 1000 krad) by using the ARACOR machine of the CEA DIF, France. A copy of the same fibers was loaded with hydrogen for 48 hours at 200 bars and 85°C and then allowed to degas for several weeks prior to radiation exposure at the same three doses. The samples have been studied by confocal microscopy luminescence (CML) at the Hubert Curien laboratory, France. The principle of confocal microscopy[3] consists in focusing the laser source through the microscope objective and carrying out a spatial filtering of the signal coming from the illuminated volume, by using a diaphragm of small diameter placed in the conjugated plane where the magnified image of the sample is formed by the objective. The luminescence spectra of pristine and treated samples have been recorded in visible range with 488 or 325 nm laser light excitation. The CML setup also allows to determine the spatial distribution of the emitting centers in the transverse fiber cross-section through a luminescence mapping with a spatial resolution of about 2 μm.

3. RESULTS/DISCUSSION

The experimental setup allows us to obtain the spatial distribution of emitting centers and thus to verify the homogeneity of the dopants concentration and their repartition. In Fig. 1, we report a typical example of the luminescence distribution, along a fiber diameter. This system is a powerful tool which is used to highlight any modification induced by the radiation both in the core and the cladding zones.


(a) Fiber 1 (λ_{EXC} = 488 nm)

(b) Fiber 1 (λ_{EXC} = 325 nm)

Figure 1. Spatial and spectral distribution of the emitted signal along a fiber diameter under 488 excitation (a) and under 325 nm excitation (b).

Fig. 2 and Fig. 3 show the changes induced by X-ray irradiation in 485-600 nm spectral range for the fibers 1 and 2, that have identical chemical compositions with the notable exception of one sensitizing element. Under 488 nm excitation this spectral domain is dominated by the green Er^{3+}-emission: four main peaks are observed whose relative intensities after irradiation are not affected when the sensitizing element is added to the core composition (Fig. 2). In the Fig. 3, for the X-irradiated fibers the peak, located at 520 nm, increases when the dose is at least 500 krad. The relative amplitude of this peak is not increased in the H_2 treated sample and we get a response quite similar to fiber 1 with the sensitizing element.

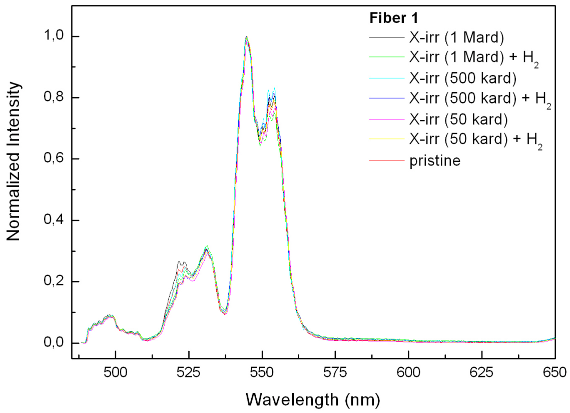


Figure 2. Laser induced emission in the core centre of Er-doped fiber 1(with sensitizing element) before and after several treatment (X-rays radiation and H_2 loading) under a probe signal at 488 nm.

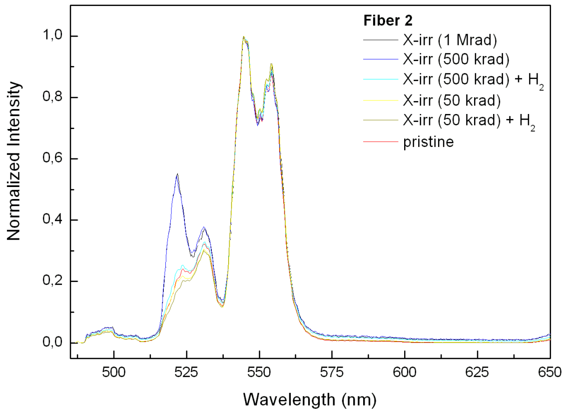


Figure 3. Laser induced emission in the core centre of Er-doped fiber 2(without sensitizing element) before and after several treatment (X-rays radiation and H_2 loading) under a probe signal at 488 nm.

In Fig. 4 and in Fig. 5 are displayed the PL spectra under 325 nm laser excitation: it is evident the band centered at 400 nm, related to the emission of defects of the silica host matrix, the oxygen deficient centers (ODC). When the sensitizing element is not present (Fig.5), the profile of the ODC shows depressions, located at the wavelength of absorption of the Er^{3+} ions[4]. The effect is annihilated with the addition of the sensitizing element (Fig. 4).

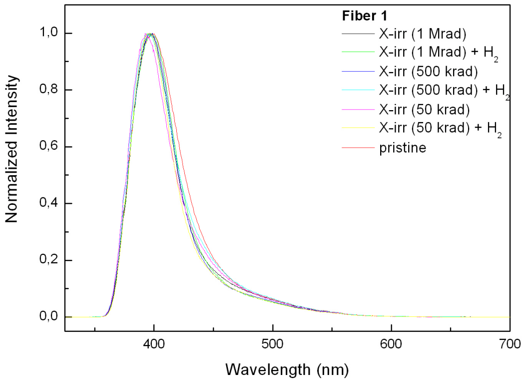


Figure 4. Laser induced emission in the core centre of Er-doped fiber 1 (with sensitizing element) before and after several treatment (X-rays radiation and H_2 loading) under a probe signal at 325 nm.

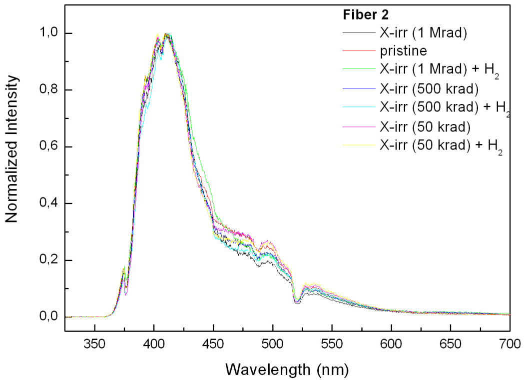


Figure 5. Laser induced emission in the core centre of Er-doped fiber 2 (without sensitizing element) before and after several treatment (X-rays radiation and H_2 loading) under a probe signal at 325 nm.

4. CONCLUSION

We used confocal luminescence microscopy setup to characterize the radiation induced changes in Er-doped fibers, in relation to the presence or absence of a particular sensitizing element. Also, we observed as well that fiber post treatment, such as H_2 loading, can be an effective way to modify the fiber response to radiation exposure. It is evident the positive effect of the addition of the sensitizing element and the H_2 loading on the hardness to the radiation environments.

REFERENCES

[1] Tortech, B., Ouerdane, Y., Girard, S., Meunier, J.-P., Boukenter, A., Robin,T., Cadier,B. and Crochet, P., "Radiation Effects on Yb- and Er/Yb-doped optical fibers: A micro-luminescence study," J. Non-Cryst. Solids, 355, 1085-1088, (2009)

[2] iXFiber website: www.ixfiber.com

[3] Girard, S., Ouerdane, Y., Vincent, B., Baggio, J., Médjahdi, K., Bisutti, J., Brichard, B., Boukenter, A., Boudrioua, A., Meunier, J.-P., "Spectroscopic Study of γ-Ray and Pulsed X-Ray Radiation-Induced Point Defects in Pure-Silica-Core Optical Fibers," IEEE Trans. Nucl. Sci. 54(4), 1136-1142 (2007)

[4] Desurvire, E., [Erbium-doped Fiber Amplifiers], JohnWiley & Sons, INC 215-218 (1994)