Combined Temperature and Photobleaching Effects on P-doped Optical Fibers

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Abstract

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In this paper we focus on the combined temperature (-80∘C to +80∘C) and the photobleaching process on the radiation induced attenuation (RIA) of multimode P-doped fibers. In particular, we investigated the behavior of the optical absorption spectra in the visible range (of 450-800 nm) after irradiation and laser injection in the fiber.

1 Introduction

Phosphorous-doped silica is known to play a key role in various domains. For instance, it can be incorporate in telecom fibers to increase the refractive index of the silica or as a co-dopant to avoid clustering of rare earths in amplifier fibers. In addition, Phosphorous in silica induces a higher radiation sensitivity compared to the other fiber composition (Ge, F, PSC...). As a consequence, using P dopant enables to design dosimeters based on optical reflectometry (OTDR) providing spatially-resolved dose mapping (1).

Nowadays, P-doping is then widely used for the production of specialty radiation sensitive optical fibers, optimized to measure the dose of radiation through the radiation induced attenuation (RIA) phenomenon. So, a great deal of research has been carried out on their radiative response, particularly in the near infrared (NIR) and visible region. This research on P doped OFs has resulted in a reliable dosimetry tool operating in NIR. In fact, thanks to these researches this material can provide linear dose response up to 500Gy. For a reliable dosimeter, RIA needs to be independent of the dose, dose rate (lower than < 10Gy/s for nIR region), the temperature range (-80 to 120∘C) and with different type of particle (X, ,

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sciencesconf.org:sio2-2025:645695

e-...) (2). For this reason these systems are widely used in large facilities such as CERN (1) and in harsh environments such as nuclear or space, which are subject to extreme conditions of radiations. As for all the silica types, even for P doped silica, ionizing radiation causes the degradation of the optical properties, mainly due to point defects generation and drive the RIA. While in the IR the optical features and dosimetry applications are many due to the P1 defects (1,2,3), in the visible range the main point defect investigated seems to be the phosphorus oxygen hole center (POHC) (3,4). In ref. (4) it was suggested that there are two types of POHC, the stable POHC (constituted by an unpaired electron located on a non-bridging oxygen atom) and the metastable POHC (in which the unpaired electron is shared by two non-bridging oxygen atoms) (4). Both are responsible for the high radiation sensitivity (over 100 dBkm-1Gy-1) (5) where P-doped fibers exhibit linear response and could serve as dosimeter. One limitation is that at a certain point, the RIA overcomes the dynamic of the acquisition chain and it is becoming necessary to change the fiber or to regenerate it in order to reset the sensor. This second option is available, in fact, the injection of a well-adapted laser light allows to reset the transmission capacity of the fiber through the photobleaching mechanism while maintaining its dosimetry properties at room temperature (2). So, studying the evolution of the RIA signal under laser illumination can provide further information on the PB mechanism allowing to optimize the regeneration procedure. However, despite different investigation on the PB, the effect of temperature on this mechanism is still not sufficiently unexplored.

2 Methods

We studied a multimode P-doped optical fiber manufactured by Exail with two levels of phosphorous doping in its core, for each experiments we used samples with lengths of 3 meters. For radiation test we use the X-ray irradiation facility named LabhX from Hubert Curien Laboratory in St-Etienne. This irradiator is an X-ray tube operated at 100kV (with a mean photon energy of 40 keV) allowing homogeneous irradiation from low dose rates (500μGy) to high dose rates (> 6Gy/s). This facility is equipped with a temperature controlled plate (Instec HCP204SC) which allows the control of irradiation temperature in the range of -120∘C to +400∘C. To ensure maximum dose homogeneity, samples are prepared in monolayer spiral. To measure the visible RIA, the set-up is equipped with a halogen-deuterium white light source (DH2000 from Ocean Optics), a visible spectrometer (Ocean Optics) and a 408nm laser of 4mW. Samples are spliced to radiation hardened transport fibers (doped with fluorine) which are used to connect the sample under test to the instrumentation outside the LabHX. In the first experiments, each sample was irradiated at the total ionizing dose (the energy deposited per unit mass by ionizing radiation) of 5Gy(SiO2) with a dose rate of 10 mGy/s. Several irradiation temperatures (Tirr) within the range of (-80 to 80∘C) have been studied. Before to inject the laser we studied a recovery of 20 minutes at the irradiation temperature. After this stage we performed 1 hour of PB at the same irradiation temperature. The laser injection was performed with the same experimental set-up reported in ref (2) which allows avoiding to move the fiber, but that does not allow to record the transmission spectrum during the laser injection. Then, the transmission was monitored during two recovery-step. The first takes place at the irradiation temperature (1 h) while the second one occurs at room temperature (25∘C). An example is shown in **Fig1**. During a second set of irradiations we highlight the effect of the PB duration by varying it (1, 10, 20 and 60 minutes) at room temperature (25∘C).

3 Results

Fig1 illustrates as example the experiment time sequence with an example of the run performed at T=-40∘C. Fig2, is an example of experimental results performed at Tirr (+80, 0, -80∘C). These data allow to study the influence of temperature on the PB mechanism monitoring by the RIA signal. Above 600 nm, there is almost no recovery while below 600 nm, higher the Tirr, the more is reduced the RIA after 5 Gy dose. In fact, Fig2A shows that 1) higher is the irradiation temperature lower is the RIA, 2) a recovery of the signal takes place at all the temperature and 3) higher is the temperature higher is the recovery after the irradiation. In all the fibers the RIA after PB is very similar in shape and intensity. The residual RIA has the shape of a band peaked at about 550 nm, which remains very stable for the combination of PB and temperature investigated. As a consequence, we can guess that the stable POHC are still present in the fiber, while the strong bleaching at shorter wavelength suggest the destruction/conversion of metastable POHC and of another defect called P2, which can affect the investigated spectral range with the tails of their absorption bands in the UV. Fig2B shows that, after the end of the laser injection minor, but detectable, processes take place both at the Tirr and at room temperature. In fact, all the RIA feature a slow re-increase. Small differences are observed that can be explained either by small defect kinetics or by some changes in attenuation related to the effect of varying the temperature on the light guiding properties in our multimode optical fibers. A second type of experiments was performed as a function of the PB duration (1, 10, 20, 60 min). This experiment illustrates the efficiency of PB mechanism by changing the duration of PB to see the effect on the RIA signal recovery. Basing on a preliminary analysis the most of the recovery occurs during the first 10 minutes of PB, which is consistent with the work of Martin Roche in (5).

Figure 1: Set-up of the different steps of experiments

Figure 2: a) RIA spectra at different temperature, irradiated up to 5 Gy, after recovery and after PB; b) RIA spectra recorded during the last two recovery steps.

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Keywords: Photobleaching phenomenon (PB), Radiation Induced Attenuation (RIA), Phosphosilicate optical fiber, Phosphorous point defects, Dosimeter.