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Influence of temperature, dose rate and optical power on the radiation-induced attenuation of a commercial rad-hard optical fiber

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Abstract

The literature offers numerous studies on the Radiation-Induced Attenuation (RIA) of various fibers as a function of irradiation parameters (dose and dose rate). However, RIA also depends on temperature and on the optical power guided by the fiber. Rarer are the studies that take into account the latter two parameters. This work focuses on the joint influence of temperature, dose rate and optical power on the RIA of a commercial rad-hard optical fiber. Experiments involve two values for each parameter: 22 and -62 °C, 25 and 250 Gy/h, 10 nW and 3 mW. Measurements have been carried out at a wavelength of 1540 nm or 1542 nm. Results show that at low optical power, the RIA difference observed when irradiating at two different dose rates is almost constant as a function of dose. Moreover, when the optical power and the temperature are high, dose rate effect almost cancels out.

I. INTRODUCTION

For decades, it is a well-known fact that when ionizing radiation pass through silica, the light transmission properties of the glass get altered [1]. Within silica-based optical fibers, this phenomenon is expressed as an increased attenuation of the waveguide, so-called the Radiation-Induced Attenuation (RIA). The literature offers numerous studies on the RIA of various fibers as a function of irradiation parameters (dose and dose rate) [2] [3] [4]. However, RIA also depends on temperature [5] and on the optical power guided by the fiber [6]. Rarer are the studies that take into account the latter two parameters. This work focuses on the influence of temperature, dose rate and optical power on the RIA of a commercial rad-hard optical fiber, the

Prysmian-Draka Super Rad-Hard Monomode fiber. Experiments involve two values for each parameter: 22 and -62 °C, 25 and 250 Gy/h, 10 nW and 3 mW. In the remainder of this document, each value of a parameter is referred to as the low one or the high one. Presented measurements have been carried out at a wavelength of 1540 nm or 1542 nm. For a RIA measurement in this wavelength domain, this 2 nm difference is not significant and data obtained at each wavelength can be compared confidently. Two test benches have been used to measure the RIA of several optical fiber samples. Both benches, described hereafter, got their name from their light source type.

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II. EXPERIMENTAL SETUP

1. The DFB test bench

The DFB bench allows measuring the fiber RIA at a wavelength of 1542 nm with an optical power of several tens of mW. Its structure and operation are detailed by Fig. 1 and its caption. During the irradiation, RIA is calculated by computing the ratio between the optical power going out of the fiber and the same power before the irradiation start.

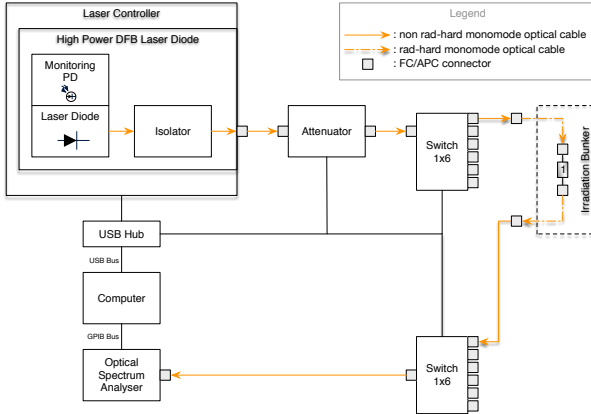


Fig. 1. DFB Bench Diagram. The laser diode, whose optical power fluctuations are monitored, can output up to 100 mW at 1542 nm. An optical attenuator allows adjusting the power injected into the DUT (Device Under Test). A pair of optical switches measures sequentially several samples; for clarity reasons, only one optical path is drawn between the switches. For each dose rate, one optical path is used without DUT as a reference in order to take into account the RIA of the cables on either side of the DUT. An optical spectrum analyzer records the optical power going out of the DUT. The optical power injected in the DUT can vary from sample to sample. For each switch position, it has been measured, with an optical power meter, right after the rad-hard optical cable (before the DUT) and adjusted to 30 mW by setting the optical attenuator.

2. The halogen test bench

The halogen bench allows measuring the fiber RIA with a low optical power (about 10 nW) at wavelengths ranging from 400 to 1550 nm. Its structure and operation are detailed by Fig. 2 and its caption. For each wavelength, RIA, expressed in dB, is calculated using Eq. (1) in which PD_{ref} and PD_{att} are the voltages measured on the photodiodes named the same way.

$$RIA(t) = 10 \text{ Log} \frac{\left(\frac{PD_{att}(t)}{PD_{ref}(t)} \right)}{\left(\frac{PD_{att}(0)}{PD_{ref}(0)} \right)} \quad (1)$$

Each photodiode is a “two-color” detector with a wide spectral response range from UV to IR. This device is composed of two stacked layers: the top one is made of silicon, the bottom one of InGaAs. Transimpedance circuits have been developed to convert and amplify the photocurrent. Selected gain values allow using the silicon sensor from the lowest wavelengths up to 1170 nm and the InGaAs one operates from 1000 nm up to the highest wavelengths. Voltages from each “half”-photodiode are acquired independently and both measurements are then joined

up during a post-processing step with a transition chosen at 1020 nm.

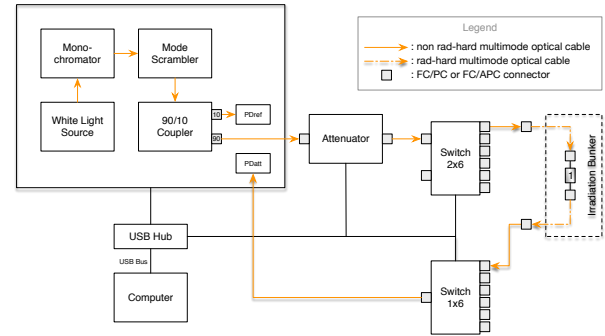


Fig. 2. Halogen Bench Diagram. Operation is mostly similar to the DFB bench described in Fig. 1. The white light source is filtered through a monochromator. The 90/10 coupler is used to keep 10% of the optical power as a reference and to inject the remaining 90% into the DUT. Optical powers are monitored using the 2 photodiodes, called PD_{ref} and PD_{att} .

3. Fiber samples and irradiation conditions

Fibers are prepared as unstressed spools hung on a T-shaped stand (see Fig. 3) and placed in front of the gamma-ray source. Their geometry is adapted to minimize the dosimetry error while respecting a minimum curvature radius. Spool thickness is about 1 cm, inner diameter 10 cm and outer diameter about 13 cm. For all samples, fiber length is 600 m and irradiation duration is 16 h. Table 1 shows the experimental conditions of each sample. Eight samples have been irradiated and one reference optical line (named Rf-XX-XX) has been used on each test bench for each dose rate. The RIA measured on the reference line has subsequently been subtracted from the RIA measured on the optical lines containing the samples. The lowest temperature, - 62 °C, has been obtained by placing the sample inside a cubic box made from polystyrene and filled with blocks of carbon dioxide snow. Wall thickness is 6 cm ; the attenuation caused by the polystyrene box on the gamma rays coming from the ^{60}Co source is about 0.07%, which remains negligible compared to the dosimetry uncertainty.

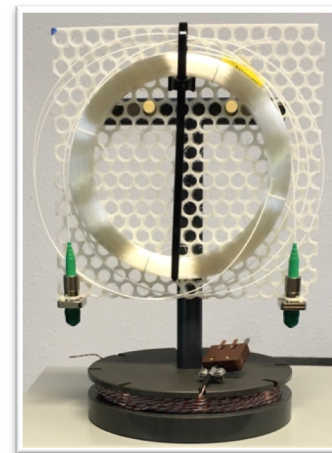


Fig. 3. A photograph of a 600 m fiber sample prepared as an unstressed spool.

TABLE 1. SAMPLE EXPERIMENTAL CONDITIONS.

Designation	Dose (Gy[Si])	Dose rate (Gy[Si]/h)	Temp. (°C)	Optical Power (mW)
<i>Halogen Bench (400-1550 nm)</i>				
1	4000	250	22	1E-5
2	4000	250	-62	1E-5
Rf-Ha-Hi	4000	250	22	1E-5
3	400	25	22	1E-5
4	400	25	-62	1E-5
Rf-Ha-Lo	400	25	22	1E-5
<i>DFB Bench (1542 nm)</i>				
5	4000	250	22	30
6	4000	250	-62	30
Rf-DF-Hi	4000	250	22	30
7	400	25	22	30
8	400	25	-62	30
Rf-DF-Lo	400	25	22	30

III. RESULTS

Fig. 1 to Fig. 4 show the RIA of each sample, whose experimental conditions are described in Table 1. On each figure, the two curves correspond to the two different dose rates, optical power and temperature being constant. Looking at the figures separately allows inferring the following features.

- Independently of the temperature, at low optical power, dose rate effect barely changes with dose (Fig. 1 or Fig. 2).

- At high optical power and low temperature, dose rate effect increases with dose (Fig. 3).

- When the optical power and the temperature are high, dose rate effect is almost zero (Fig. 4).

Moreover, analyzing these figures collectively permits to investigate how the effect of a dose rate change is influenced by a variation of optical power and/or temperature. The next features can then be deduced.

- Independently of the optical power, switching from low to high temperature strongly reduces the dose rate effect (Fig. 1→Fig. 2 or Fig. 3→Fig. 4).

- Independently of the temperature, switching from low to high optical power strongly reduces the dose rate effect (Fig. 1→Fig. 3 or Fig. 2→Fig. 4).

- Switching from low to high temperature and optical power almost cancel the dose rate effect (Fig. 1→Fig. 2→Fig. 4 or Fig. 1→Fig. 3→Fig. 4).

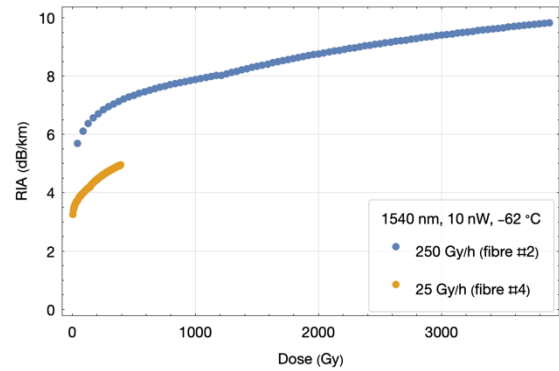


Fig. 1: RIA as a function of dose at low optical power and low temperature.

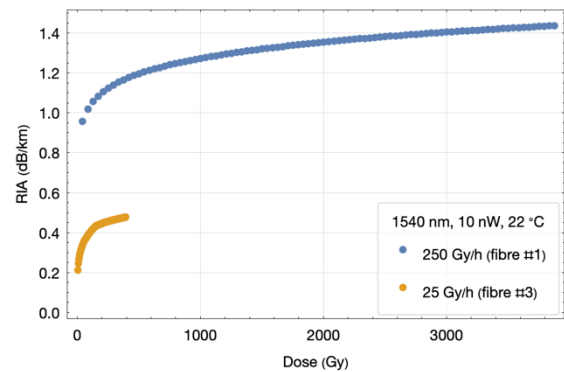


Fig. 2: RIA as a function of dose at low optical power and high temperature.

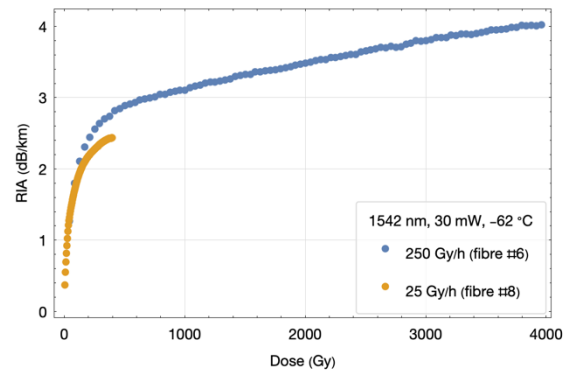


Fig. 3: RIA as a function of dose at high optical power and low temperature.

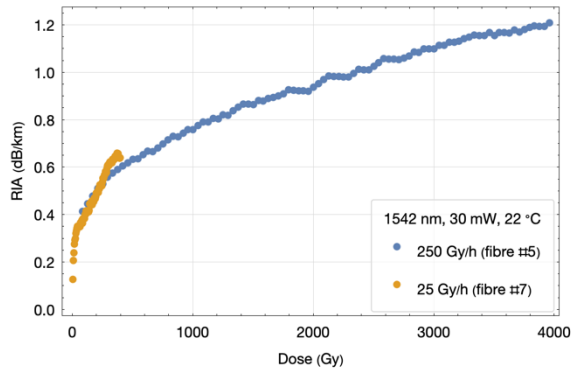


Fig. 4: RIA as a function of dose at high optical power and high temperature.

IV. CONCLUSION

Since the radiation-induced attenuation (RIA) of optical fibers depends on several parameters, an experiment has been designed to investigate the coupled effects of dose rate, temperature and optical power on the radiation response of a commercial rad-hard fiber. Results have been presented in order to highlight how irradiating a fiber with two different dose rates can yield different RIAs depending on the values of the temperature and the optical power guided by the fiber. At low optical power, the RIA difference observed when irradiating at two different dose rates is almost constant as a function of dose. At high power and temperature, the dose rate effect is almost zero. These observations are, of course, limited to the tested fiber reference and cannot be generalized to other fibers.

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