

Gamma Radiation Measurements using an Optical Fiber Laser

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Abstract: A fiber ring laser cavity configuration was used to analyze the effect of gamma-irradiation over the performance of different types of erbium doped fibers. Preliminary results validates this method to monitor gamma-radiation in real time.

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1. Introduction

Nowadays gamma irradiation is discovering new applications which are no longer limited to the nuclear industry like medicine, sterilization, food industry, non-destructive testing, recycling or material processing among others [1]. Because of that, the effect of ionizing radiation on different kind of optical fibers is of interest for understanding and predicting device performance in radiation-rich environments [2].

As it is well known, erbium doped fiber (EDF) silica-based are damaged by ionizing radiation, that is the reason why improving their radiation tolerance has been widely investigated. The degradation of these EDFs is generally assessed by the measurement of the radiation-induced attenuation (RIA) [3]. Proof of this are the numerous existing studies showing the radiation-induced power losses in the erbium doped fiber amplifiers (EDFAs) [4].

In this work, a fiber ring laser cavity configuration has been implemented to evaluate the effect of gamma irradiation performance over different types of EDFs when they are used into a fiber ring lasers in terms of output power variation over time. Several pieces of commercial EDFs, were irradiated with different gamma irradiation doses in order to study the output power variations over time.

The obtained results using fiber lasers have been checked against using an Optical Backscatter Reflectometer (OBR) to check the different attenuations of the irradiated fibers. Studies limited to the low-dose region (<100Gy) had been previously carried out [1], however in this work doses up to 1000 Gy were experimentally analyzed. The OBR characterization of the fibers agrees with the measured rise time of the fiber lasers achieved. The OBR measurements shows increasing attenuation slopes depending on the irradiation doses of the fiber samples. Thus, using this laser configuration we can detect in real time the presence of radiation and estimate the irradiation doses applied to EDFs by measuring the slope of the short-term emission power of the achieved laser.

2. Experimental setup

The first analyzed EDF was the M12 (980/125), which is a highly EDF with a high conversion efficiency and designed for small package size C-band amplifiers. The second studied EDF was the type I25 (980/128), and also suitable for C amplifiers with an optimized core composition for high-channel-count DWDM systems' EDFAs. For these fibers, the peak core absorption was between 16 to 20 dB/m at 1531nm for the first fiber, and from 7.7 to 9.4 dB/m at 1531nm of the second one.

The gamma-ray irradiation for these fibers was run at a ⁶⁰Co GC-5000 (BRIT, India) irradiator having a chamber volume of 5,000 cm³. The dose rate was 5.7 kGy/h (±1.8 %), and the doses were from 150 Gy up to 1000 Gy. These irradiated erbium doped fibers (IEDF) were employed as active medium within the cavity while it was pumped with a 976 nm laser through a WDM coupler. A uniform FBG centered on $\lambda=1550.7$ nm with a circulator was used as feedback element to launch the desired wavelengths into the ring cavity, minimizing also the hole burning effect as can be seen in Figure 1. Finally, to extract 10% of the laser output power from the ring, a 90% coupler was used for the laser output, connected to an optical spectrum analyzer (OSA, Anritsu MS9740A) with a resolution of 0.03nm. In order to get a more clear conclusions, all the experiment were carried out under the same conditions, that is, pump power at 980nm of 100mW, the length of the IEDF were 5m for all the analyzed cases and all the tests were performed at room temperature.

As it has been previously pointed out and experimentally demonstrated [1] gamma radiation induced attenuation over all the irradiated fiber, known as radiation-induced attenuation (RIA). In this work, the gamma RIA and its behavior over time of two commercial EDFs have been evaluated as a function of the output power level of the attained fiber laser. Influence of a dose rate from 150Gy to 1000Gy on output power level measurement has been experimentally evaluated in the C band region.

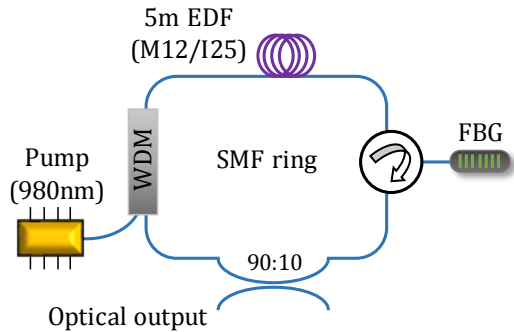


Fig. 1. Fiber ring laser configuration where an IEDF is introduced within the ring cavity.

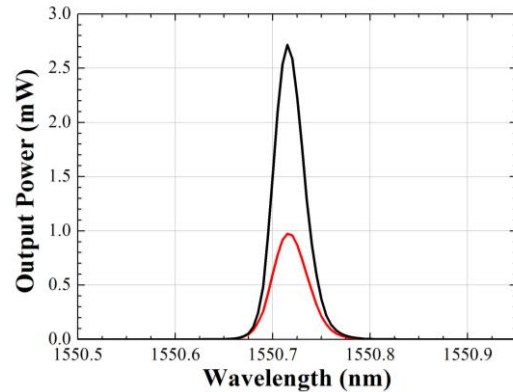


Fig. 2. Output spectra response of the attained laser using 5m of I25 irradiated with 350Gy (red) at the beginning of the experiment and after being pumped for 60 hours (black).

As can be seen in Figure 2, where the output spectrum of the fiber ring laser measured by an OSA is presented, the output power level increases from 1mW up to 2.7mW after being pumped for 60 hours, showing an optical signal to noise ratio (OSNR) of around 55dB and 60dB respectively. It is worth noticing that the central emission wavelength of the laser have remained stable during all the experiments, which means that the FBG central reflected wavelength has not changed because of temperature variations.

3. Results

The aim of this experimental study has been to analyze the effect of gamma irradiation applied to the EDF when they are used into a fiber ring lasers in terms of output power variation and stability over time. By doing that, the attained results show different output power stability levels depending on the type of EDF we use for the fiber ring laser.

The implemented setup showed in Figure 1 was evaluated every 5 seconds for each type of fiber and each gamma doses during the time needed to stabilize its output power level (most of the samples needed at least one to day for pegging this value). A further example of this can be observed in Figure 3, where the output power variation as a function of time when 5m of M12 (black) or I25 (blue) irradiated with 350Gy were measured every 5seconds during 20 hours. As can be seen in that figure, the output power level increases from -7dBm up to 2dBm for the M12 sample and from 0dBm to 3dBm for the I25 after being pumped for a long period of time.

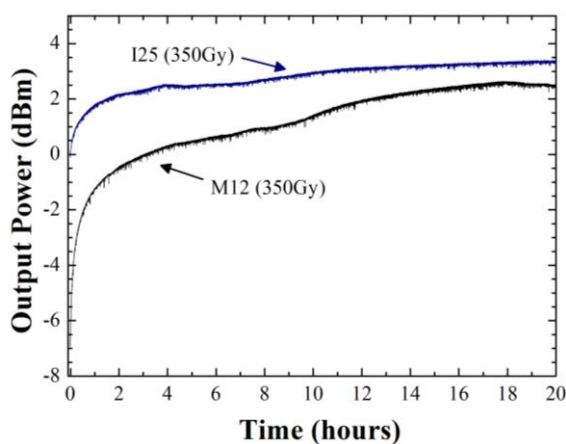


Fig. 3 Output power variation over time when using 5m of an IEDF M12 (black) or I25 (blue) irradiated with 350Gy.

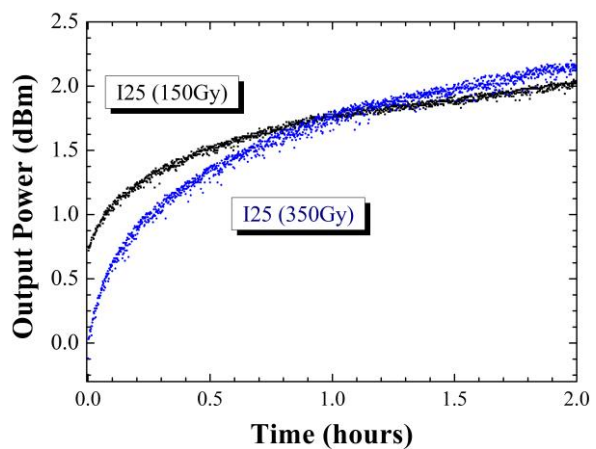


Fig.4 Output power variation using EDF I25 as an active medium with gamma radiation of 150Gy (black) and 350Gy (blue).

For every one of the IEDFs and all the gamma irradiated doses, it is in the first analyzed hours were this output power variation is more relevant. As proof of this, in figure 4 is shown the output power variation of the

laser when the EDF I25 was used as an active medium and for gamma doses of 150Gy (black) and 350Gy (blue) were applied for two hours. In both cases, the best fitting were a 6th order polynomial, however after that period of time the output power behavior's fit corresponds with a lineal adjust with a decreasing slope over the time. Similar results were obtained when the analyzed IEDF was the M12.

As it has been previously pointed out, the more significant rise of the output power level appears during the first hour of pumping. Taking this aspect into consideration, the time required for the output power level to rise from 10% to 90% of its final value after one hour of pumping has been evaluated for both type of IEDFs and for different doses. It is worth noticing that, even if some of these tests were done in different stages, the obtained output power level remained at the higher value once achieved. This effect is currently being studied.

When analyzing the rise time for the IEDF M12, the attained values were 36.41 and 43 minutes for gamma irradiation doses of 150Gy and 350Gy respectively, which means an increase of the rise time of about 18%. Similarly, for the IEDF I25 these values were of 42 and 49 minutes for the same irradiated doses meaning a growth in terms of rise time of around 16%. Those values can be used to discriminate the presence of gamma radiation and to estimate the applied doses.

Finally, it is necessary to point out that when IEDFs irradiated at doses over 500Gy were employed as active medium into the cavity ring laser, no wavelength emission was noticed, so, samples over these doses (e.g. 750Gy and 1000Gy) were not used for these measurements.

After analyzing these IEDFs into lasers with ring cavities, the fibers were extracted from the cavities and characterized by means of an Optical Backscatter Reflectometer (OBR) LUNA OBR 4600, operating in the time domain acquisition mode with a spatial resolution of 4 mm, as it has been done in previous studies [5]. This instrument is used for component testing, enabling ultra-high resolution reflectometry with backscatter level sensitivity. The backscattered light is measured with a spatial resolution as fine as 10 microns and no dead zone.

The gamma irradiated EDFs were connected to the instrument only by means of about 2m pigtail of SMF. Such measurements are used to compare the attenuation of the samples all over their length. Each IEDF sample was spliced to a SMF pigtail with different SMF's lengths in order to discriminate them after connecting to the first pigtail at the beginning of the measurements.

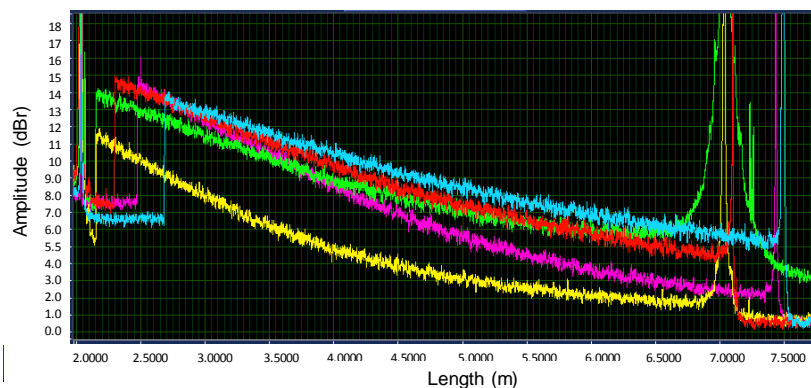


Fig. 5. Backscattered optical power of the IEDF M12 as a function of their length for gamma irradiated doses of: 0 Gy (blue) used as a reference, 150Gy (red), 200Gy (green), 350Gy (pink) and 500Gy (yellow)

Figure 5 shows the reflected backscattered light of the IEDF M12 samples as a function of their length for gamma irradiated doses of: 0Gy (blue) used as a reference, 150Gy (red), 200Gy (green), 350Gy (pink) and 500Gy (yellow). SMF backscattered signals correspond to the almost flat zone before the first jump that indicates the splice with the erbium doped fibers. Afterwards, induced ASE by the wavelength sweeps of the laser source of the OBR dominates the measured optical power. The received power decreases with length depending on the attenuation of the irradiated sample. Finally, last peaks of received power are detected, corresponding with the reflection at the end of the samples. Those results can be seen in Figures 5 and 6 for the M12 and I25 EDF respectively.

Here can be easily seen how the higher the gamma irradiation dose, the greater the slope of the attenuation response. Similar results were obtained when the IEDF I25 was analyzed by means of the LUNA OBR as Figure 6 presents. These measured results are consistent with previous works [1] and here it has been also experimentally demonstrated by evaluating the rise time measured using the ring laser configuration.

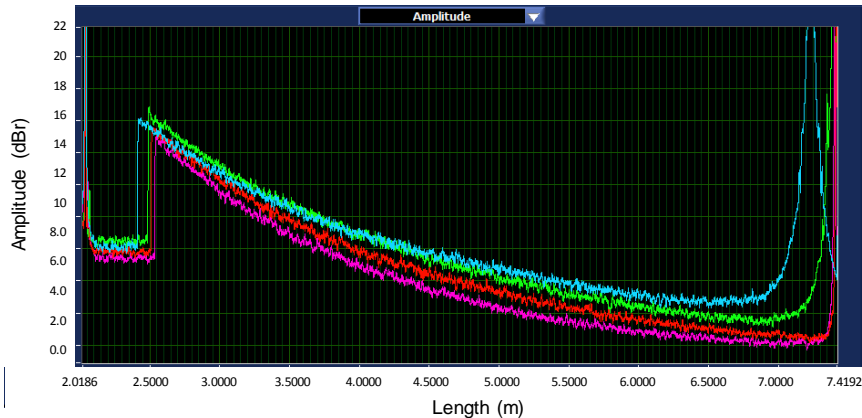


Fig. 6. Backscattered optical power of the IEDF I25 as a function of their length for gamma irradiated doses of: 0 Gy (blue) used as a reference, 200Gy (green), 350Gy (red) and 500Gy (pink) by means of the LUNA OBR.

The last part of this experimental study addresses the output power and central wavelength emission stability. As an example, when 5m IEDF of I25 were used, output power instability from 1 to 1.3 dB were measured for an irradiation dose of 200Gy and 500Gy respectively. On the other hand, when the IEDF employed was 5m of M12, the output power instability were decreasing over time, reaching values as good as 0.8 dB at beginning of the experiment up to 0.4 dB of output power variation over several hours of operation.

Finally, we want to remark that by means of using this laser configuration we can estimate the irradiation doses applied to erbium doped fibers by measuring the slope of the short-term emission power of the achieved laser. This method is considerably cheaper than the utilization of an optical OBR and allows real time monitoring of gamma radiation.

4. Conclusions

In this work, the effect of gamma irradiation over the performance of different types of erbium doped fibers (EDF) has been evaluated using that fibers inside a laser configuration. Several pieces of commercial EDFs, have been irradiated with different gamma irradiation doses and inserted into a ring laser. The generated lasers by pumping the amplifying fibers show a rise time which depends on the irradiation doses. Those fibers have been also characterized by means of an OBR, showing an attenuation profile depending also of the irradiation doses. Both measuring methods agreed on results and are valid for gamma radiation measurements, being the first one considerably cheaper. This ring laser configuration allows also real time measurements. Thus the attained preliminary but promising results offer new possibilities for the field of optical fiber sensors of radiation.

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