EVALUATION OF IRRADIATION EFFECTS ON PASSIVE/ACTIVE COMPONENTS OF OPTICAL FIBER SYSTEMS FOR CONTROL AND SENSING

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Our research subject within the subtask is to evaluate:

The objective of this investigation was the study of gamma-rays and neutron irradiation on passive components for optical fibers systems, and on active components for laser diodes control.

1. Introduction

Optical fibers are expected to play an important role in plasma diagnostics, distributed sensing and communication systems within the ***ITER infrastructure***, as different types of signals have to be transmitted in radiation environments, under high temperatures and high electromagnetic noise. Apart from the optical fiber itself, such optical signal transmission systems include various types of passive components (i.e. splitters, couplers, connectors, attenuators, etc.). Our investigation is focused on the degradation of two splitters and two attenuators, under gamma and neutron irradiation, either at specific wavelengths of interest or over a spectral band, in order to evaluate the wavelength dependence of the phenomena. These components are also tested to determine the change of the polarization state of optical radiation they guide. On the other hand, laser diodes applied in sensing/ communication systems have to be controlled both in current and temperature. For this reason, we investigated the degradation of the operational parameters for a laser diode driving circuit and a Peltier cooling structure (TEC – thermo-electric cooler), under gamma-ray, neutron irradiation and electron beam irradiation.

2. Experimental set-up

2.1 Tested components

The investigated components are:

a) two 1 x 2 beam splitters/ combiners 50% / 50% (denoted by OFS-1 and OFS-2), with the common path - SM, 2 m long, FC/APC connector, and the separate arms - SM, 2 m long, FC/PC connectors;

b) two on-line attenuator patch-cords (denoted by OFA-1 and OFA-2), 2 dB, 2 m long, SM, FC/APC & FC/PC connectors;

c) three compact, circuit boards for laser diodes current driving (denoted by LDC-g; LDC-n; LDC-e), softstart, max. driving current 200 mA, photodiode current monitor included with a max. photodiode current of 1.2 A, common laser diode anode and photodiode cathode;
d) three TEC modules (denoted by TEC-g; TEC-n; TEC-e), 1 stage cooler, 7 couplers, I_{max} = 5A, V = 0.85 V, P_{max} = 2.8 W, $\Delta T_{max} = 67^{O}C$.

2.2 The measuring set-up

In the case of the two splitters/ combiners, the measurements before the irradiation were done at a fixed wavelength of 1310 nm, over a narrow spectral band (1510 nm - 1620 nm), and over a wider spectral band (700 nm - 1700 nm). The set-up for the fixed wavelength measurements includes a high stability, narrow-bandwidth DFB laser diode emitting at 1310 nm and a calibrated power meter. For the spectral band 1510 nm – 1620 nm we used a calibrated wavelength meter having also power measurement capabilities and a tunable laser diode. The laser source was tuned automatically over the entire spectrum, while data are acquired by a calibrated wavelength meter, both for optical power and wavelength, using a software program developed in the Laboratory. Each branch of the optical fiber splitter and the fixed attenuator were tested separately, and for the evaluation of the set-up stability and reproducibility three full runs were performed. The collected data are saved in Excel-like files for further processing. For the measurements over the spectral band 700 nm – 170 nm we used a high stability broad-band light source and an optical spectrum analyzer. Before any irradiation, all the passive components were also tested to determine the change of polarization for single wavelength laser radiation, as the polarization state of the input optical radiation is scrambled for almost all polarization states. The laser radiation from the tunable laser source is coupled at the input of a polarization controller, while the polarization controller output radiation is connected to the passive optical element under test (splitter or fix attenuator). The output radiation from this device is measured by a polarization analyzer. For all the performed measurements we used several laser wavelengths from 1510 nm to 1620 nm, in 10 nm increments. At each wavelength we set the initial polarization state at point “H” on the Poincaré sphere, and the azimuth and the ellipticity for this starting point were recorded. The measurement was run by arbitrarily scanning of the polarization states, over the Poincaré sphere in 5^{O} increments.

The changes in the azimuth, ellipticity of the exiting optical radiation, as well as the three normalized Stokes parameters were simultaneously recorded.

For the evaluation of the irradiation induced changes in the TEC module a compact set-up was designed, which includes: a constant current, variable source and a thermocouple connected for data acquisition to a National Instruments USB-controlled module. We changed manually the electrical power applied to the TEC and we measured the temperature changes and stability, in both operating modes (heating and cooling facet).

In the case of the circuit board laser drivers the set-up included: a laser diode emitting at λ = 670 nm; a calibrated laser power meter; a regulated voltage supply (5V); a digital voltmeter and a digital multimeter; and a Si detector embedded into an integrating sphere, operating in the visible – near-IR range. During the measurements, the background optical radiation was about 0.2 μW. The measurements were performed on the following quantities: emitted optical power; the laser diode driving current; the embedded monitoring photodiode current. Data acquisition lasted for about 30 min in each case, and the sampling interval was of 2.5 min. The variable resistor on the circuit board was set to provide a 19 – 40 mA direct current and its setting was kept the same during all the experiment.

2.3 Irradiation conditions

Table 1 details the total doses for the gamma-ray irradiation. In Table 2 is given the same information for the neutron irradiation, while the doses for the electron beam irradiation are presented in Table 3.

Table 1. The total irradiation dose per irradiation step, for the gamma-ray irradiation

Irradiated part/ irradiation step	1	2	3	4
OFS-1	100 Gy	1 kGy	10 kGy	100 kGy
OFA-1	100 Gy	1 kGy	10 kGy	100 kGy
LDC-g	100 Gy	200 Gy	1 kGy	-
TEC-g	100 Gy	1 kGy	20 kGy	-

Table 2. The fluence per irradiation step, for the neutron irradiation

Irradiated part/ irradiation step	1	2
OFS-2	9×10^{12} n/cm^2	$1{,}4 \times 10^{13}$ n/cm^2
OFA-2	9×10^{12} n/cm^2	$1{,}4 \times 10^{13}$ n/cm^2
LDC-n	9×10^{12} n/cm^2	$1{,}4 \times 10^{13}$ n/cm^2
TEC-n	9×10^{12} n/cm^2	$1{,}4 \times 10^{13}$ n/cm^2

Table 3. The total irradiation dose per irradiation step, for the electron beam irradiation

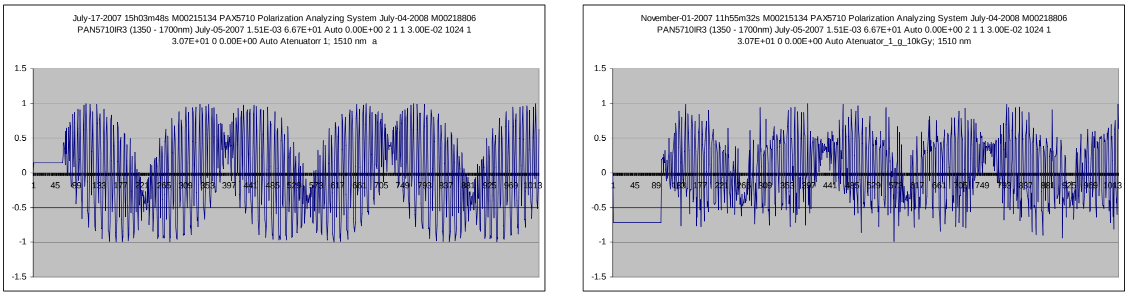
Irradiated part/ irradiation step	1	2	3	4
LDC-e	50 Gy	500 Gy	5 kGy	20 kGy
TEC-e	50 Gy	500 Gy	10 kGy	-

3. Results

The degradation of the circuit board parameters subjected to gamma-ray irradiation made impossible the proper operation of the optical power control loop as the driving current increased dramatically and produced a thermal stress in the laser diode, hence its destruction. Following this situation, the driving current delivered by the circuit was set to a low value and the laser diode was replaced with a new one. After the irradiation a decrease of the driver capability to maintain a constant value of the output optical power was observed, as it is indicated by the higher values of the standard deviation for the diode current and the monitoring photodiode current.

In the case of the thermoelectric cooler irradiated by an electron beam (for the total irradiation dose of 10.550 kGy) there is an increase, as compared to the same device before any irradiation, of about 10 ^{O}C of the highest temperature level reached by the device for the same input electrical power level. At the same time the electron beam irradiation produced an increase by about 8 ^{O}C of the temperature differences existing between the two facets of the device (the parameter ΔT_{max}). A similar module irradiated by gamma-rays exhibits an increase of about 6 ^{O}C of the highest temperature level as compared with the non-irradiated device, and a slight decrease of the difference between the two facets (about 2 ^{O}C), at a total irradiation dose of 21.1 kGy. The measurements were done at the same electrical power levels injected to the device. In the case of neutron irradiation, the lower temperature level increased by 11 ^{O}C for a fluence of 9 x 10^{12} n/cm^2.

For the gamma and neutron irradiations carried out on the passive optical components for optical fiber systems we did not notice a significant change for the optical transmission in the 700 nm – 1700 nm spectral range, for both the attenuators and the optical fiber splitters. In the case of the optical fiber splitters and attenuators irradiated with gamma-rays a perturbation of the polarization state of the transmitted optical radiation was observed, as the input optical radiation polarization state is scanned over the entire Poincaré sphere. In Figures 1-3 can be noticed this phenomenon, as it appears from the investigated parameters (i.e. the azimuth, the ellipticity or the Stokes parameters). Changes appear also in the variation of the transmitted optical power (Figures 4 and 5).



a b

Figure 1. The change of the first Stokes' parameter, in the case of the optical fiber attenuator OFA-1: a – before the irradiation; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1510 nm.

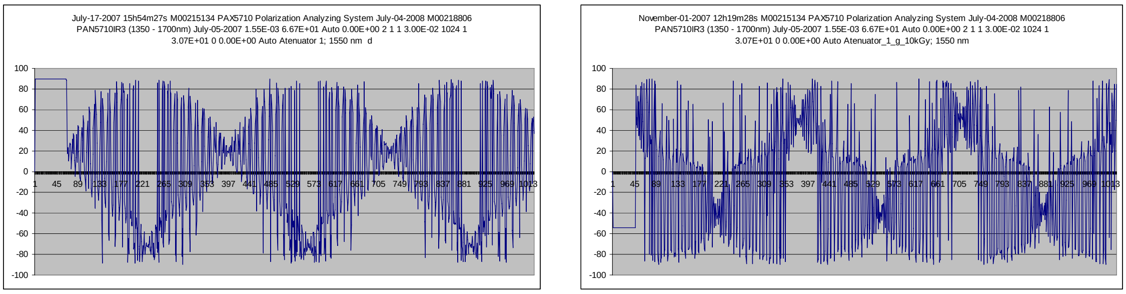


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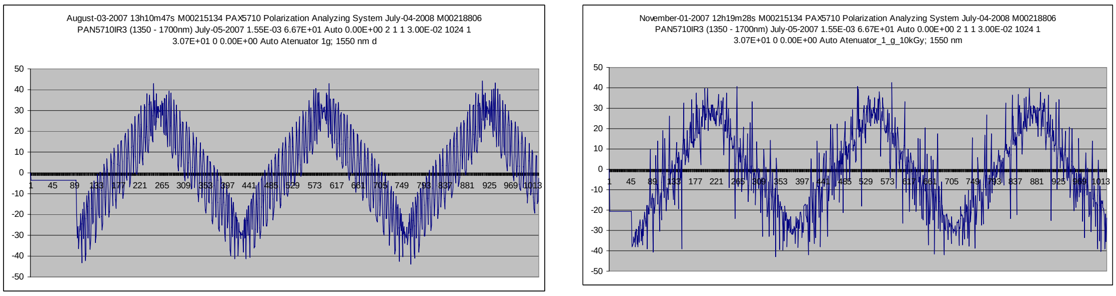
Figure 2. The change of the azimuth, in the case of the optical fiber attenuator OFA-1: a – before the irradiation; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1550 nm.



a b

Figure 3. The change of the ellipticity, in the case of the optical fiber attenuator OFA-1: a – after the gamma-ray irradiation at a total dose of 100 Gy; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1550 nm.

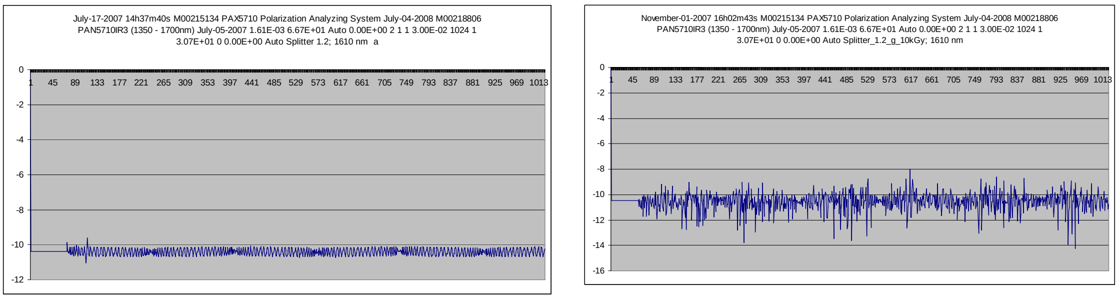


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Figure 4. The change of the transmitted optical power, in the case of the optical fiber splitter OFS-1.2: a – before the irradiation; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1610 nm.

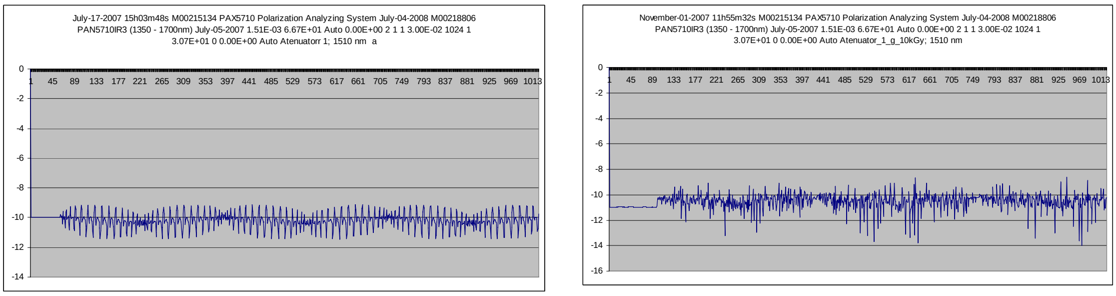

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Figure 5. The change of the transmitted optical power, in the case of the optical fiber attenuator OFA-1.2: a – before the irradiation; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1610 nm.

Conference papers

[1] **Dan Sporea, Adelina Sporea, Ion Vata**, "*Comparative study of gamma-ray and neutron irradiated laser diodes*", Proceedings of Photonics North, Ottawa, Canada, June 2007.

[2] **Dan Sporea, Adelina Sporea, Constantin Oproiu, Ion Vata**, "*Evaluation of irradiation effects on semiconductor lasers subjected to gamma-ray, electron beam and neutron irradiation*", International workshop on ITER-LMJ-NIF components in harsh environments, Cadarache, France, June 2007.

[3] **Dan Sporea, Adelina Sporea, Benoit Brichard,** "*Irradiation-induced UV optical attenuation in optical fibers for plasma diagnostics*" International workshop on ITER-LMJ_NIF components in harsh environments, Cadarache, France, June 2007.

[4] **Dan Sporea, Adelina Sporea, Constantin Oproiu**, "*On-line evaluation of gamma-ray irradiated large diameter optical fibers for plasma diagnostics*", Proceedings of ICONE 15, 15th International Conference on Nuclear Engineering, Nagoya, Japan, April 2007.

[5] **Dan Sporea**, "*Update on the radiation effects in optical fibers and optoelectronic components for fusion installations*", 4 th Association Days Meeting, Ramnicu-Valcea, Romania, October 2007.

Published papers

[1] **Dan Sporea, Adelina Sporea**, "*Radiation effects in sapphire optical fibers*", Physica Status Solidi (c) 4, No.3 (2007) Wiley-VCH Verlag GmbH & Co. KgaA, Weinheim.

[2] **Dan Sporea, Adelina Sporea**, "*Dynamics of the radiation induced color centers in optical fibers for plasma diagnostics*", Fusion Engineering and Design, vol 82, issues 5-14, 2007, 1372-1378, DOI information: 10.1016/j.fusengdes.2007.05.053