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MEASUREMENT OF RADIATION EFFECTS ON ACTIVE AND PASSIVE OPTICAL FIBER COMPONENTS

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Abstract − The present contribution is focused on the measurement of the degradation induced in the case of two splitters and two attenuators used in optical fiber communication systems, under gamma and neutron irradiation. The measurements were carried out at specific wavelengths (λ = 1310 nm and λ = 1550 nm) or over a spectral band (λ = 1510 – 1620 nm), in order to evaluate the wavelength dependence of the phenomena. These components were also tested as it concerns the changes of the polarization state of optical radiation they guide. A second investigation was performed on the degradation of the operational parameters for a laser diode driving circuit and a Peltier TEC (thermoelectric cooler), under gamma-ray, neutron and electron beam irradiation. No significant changes were noticed in the spectral transmission of the two passive components, but the degradation of the light polarization parameters was a significant one under gamma-ray irradiation. In the case of the laser diode drivers a drop of 80 % of the laser diode optical power and the embedded photodiode responsivity was observed under gamma-ray and neutron irradiation.

Keywords: irradiation induced degradation, passive and active optical fiber components

1. INTRODUCTION

Optical fibers are expected to play an important role in plasma diagnostics, distributed sensing and communication systems within the ITER (International Thermonuclear Experimental Reactor) infrastructure, as different types of signals have to be transmitted in radiation environments, under high temperatures and high electromagnetic noise [1-5]. Apart from the optical fiber itself, such optical signal transmission systems include various types of passive components (i.e. splitters, couplers, connectors, attenuators, etc.), and active components (emitters, detectors, modulators). In the last few years, research was carried out on the evaluation of irradiation effects (gamma-ray, neutron, proton, electron beam) on various optical fibers for communications and plasma diagnostics [6-10], and on different types of active components (heterojunction, index-guided, quantum well laser diodes, Si and InGaAs photodiodes) [11-16].

2. EXPERIMENTAL SET-UP

Our present investigation is focused on two subjects:

A. the irradiation induced degradation for the optical transmission of two 1x2 optical fiber splitters and for two on-line fixed attenuators, as they were subjected to gamma-ray and neutron irradiation;
B. the irradiation induced degradation of the operating characteristics of three laser diode driving circuit boards and three Peltier TECs (thermoelectric cooler) irradiated by gamma-rays, neutron and electron beam.

The investigated passive components were:

a) two 1 x 2 beam splitters/ combiners 50%/50% (denoted by OFS-1 and OFS-2), with the common path - a SM, 2 m long having FC/APC connector, and the separate arms - SM, 2 m long patch cords, equipped with FC/PC connectors;
b) two on-line fixed attenuator patch-cords (denoted by OFA-1 and OFA-2), with a 2 dB fixed attenuation, and equipped with 2 m long SM patch cords, having FC/APC & FC/PC connectors.

The measurements were carried out on the following active components:

a) three compact, circuit boards laser diodes current driver (denoted by LDC-g; LDC-n; LDC-e), softstart, maximum driving current 200 mA, photodiode current monitor included with a maximum photodiode current of 1,2 A, having common laser diode anode/ photodiode cathode;
b) three TEC modules (denoted by TEC-g; TEC-n; TEC-e) composed of one stage cooler, with 7 couplers, I_{max} = 5A; V = 0,85 V; P_{max} = 2,8 W; ΔT_{max} = 67 ^{O}C.

In the case of the four passive components, measurements before and after the irradiation were done at two fixed wavelength of interest for optical communications (λ = 1310 nm, λ = 1550 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/ 1550 nm, and a calibrated power meter. The stability of the optical power (0.5 %) and the wavelength (±1 pm) of the emitted radiation for the sources used are illustrated in Fig. 1.

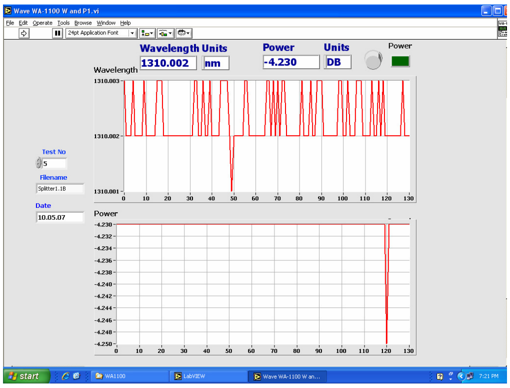


Fig. 1. The stability of the wavelength (upper graph) and optical power (lower graph) emitted by the 1310 nm DFB laser.

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

For the spectral band 1510 nm – 1620 nm we used a calibrated wavelength meter having also power measurement capabilities and a tunable laser diode (1 pm spectral resolution). The laser source was tuned automatically over the entire spectrum, while data are acquired by the calibrated wavelength meter, using a LabVIEW application 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 wide spectral band measurements were performed with an optical spectrum analyzer (OSA), having a spectral resolution of about 15, corresponding to the input optical fiber core diameter of 9 µm. In this set-up the tested passive components were connected to a very stable broad band source and to the OSA.

These components were also tested as it concerns the degree of polarization for the optical radiation they guide. For all the measurements we performed tests for several laser wavelengths from 1510 nm to 1620 nm, in 10 nm increments.

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

Irradiated component/ 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 total irradiation dose per the irradiation step, for the electron beam irradiation

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

Table 3. The fluence per the irradiation step, for the neutron irradiation.

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

The laser radiation from the tunable laser source was coupled at the input of a polarization controller, while the polarization controller output radiation was connected to the passive optical element under test (splitter or fixed attenuator). The output radiation from this device is measured by a polarization analyzer. The changes in the azimuth, ellipticity of the exiting optical radiation, as well as the three normalized Stokes parameters were simultaneously recorded [17-19].

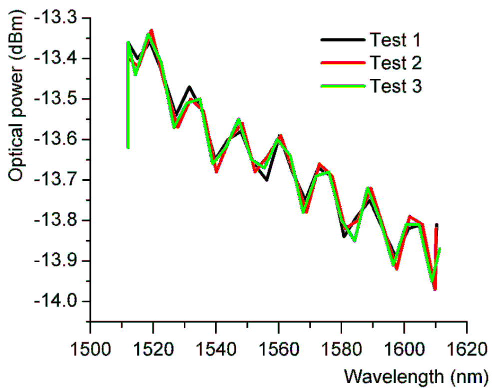
In the case of the circuit board laser divers the set-up included: a laser diode emitting at λ = 670 nm; a calibrated laser power meter; a regulated voltage supply (5V); a digital voltmeter and a digital multi-meter; and a Si detector embedded into an integrating sphere, operating in the visible – NIR 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 each circuit board was adjusted to provide a 20–40 mA direct current, and its setting was kept the same during the entire experiment.

For the evaluation of the irradiation induced changes in TEC module a compact set-up was designed, which includes: a constant current/ variable voltage source and a thermocouple connected for data acquisition to a National Instruments USB-controlled data logger. We changed manually the electrical power applied to the TEC and we measured the temperature changes and stability, in both operating modes, on the hot and the cold side, as well as the Delta-T parameter [20-22].

3. RESULTS

The spectral attenuation measured for both passive components presents no major changes in the case of gamma-ray and neutron irradiation, for fixed wavelengths and over a spectral band.

Examples of the measured data for the two arms of the first splitter (just before the gamma-ray irradiation) are given in Fig. 2. The collected data are saved in Excel-like files for further processing. A good stability and reproducibility of the measurements can be noticed.



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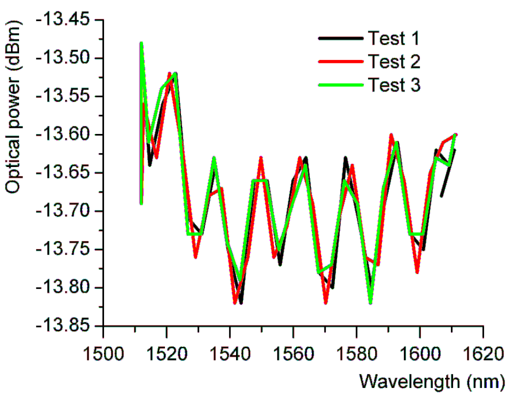
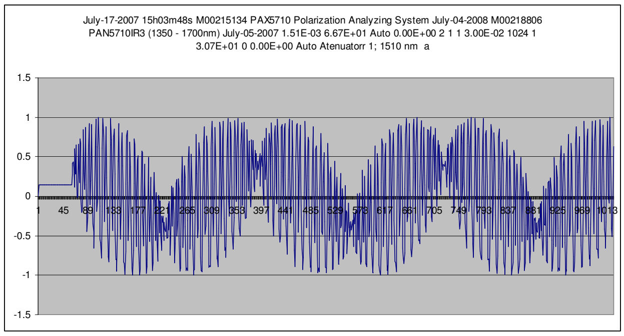


b

Fig.2. The optical power transmitted by the two arms of the splitter subjected to gamma-ray irradiation, over the spectral range λ = 1510 nm - 1620 nm, for three consecutive up scanning: a - splitter 1.1; b - splitter 1.2.

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. These modifications of the DOP (degree of polarization) are probably due to the change of the refractive index of the optical fiber core in the exposed zone [23]. In this way, gamma-rays irradiation induces locally a random variation of the optical fiber birefringence characteristics.

In Figs. 3-7 this phenomenon can be noticed at different wavelengths, 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 (Fig. 8). The horizontal axis designates the measurement elapsed time, as all the possible polarization states are scanned periodically, every two minutes.



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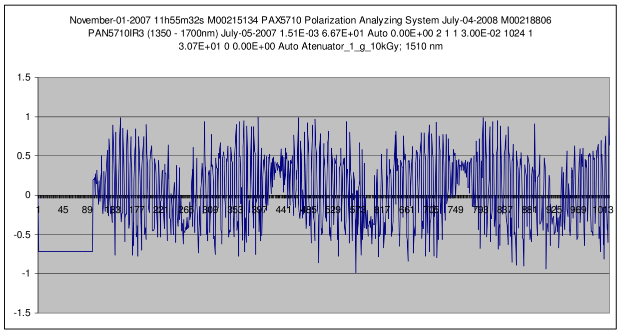
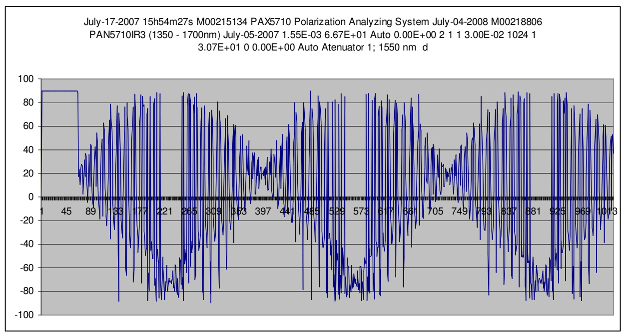


b

Fig. 3. 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.

Laser diodes used 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 TEC (thermo-electric cooler), under gamma-ray, neutron and electron beam irradiation.



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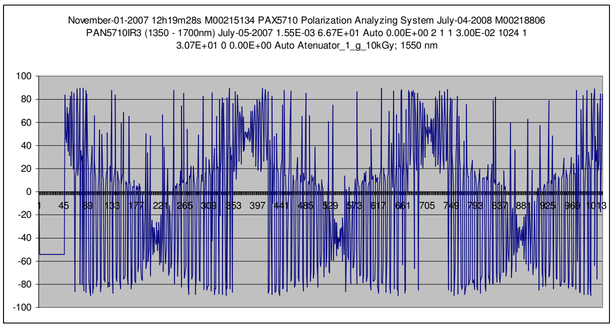

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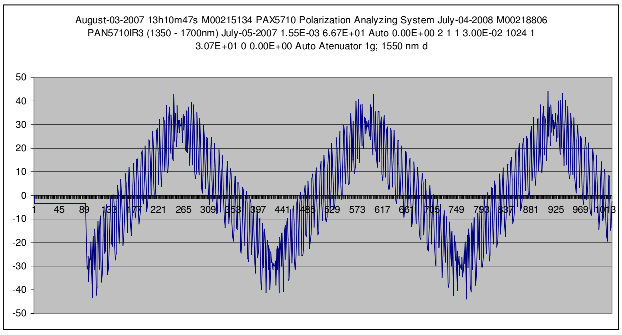
Fig. 4. The change of the azimuth, in the case of the optical fiber attenuator OFA-1: a – before the irradiation; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1550 nm.



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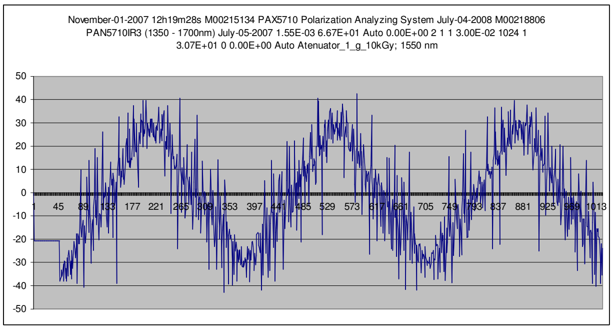

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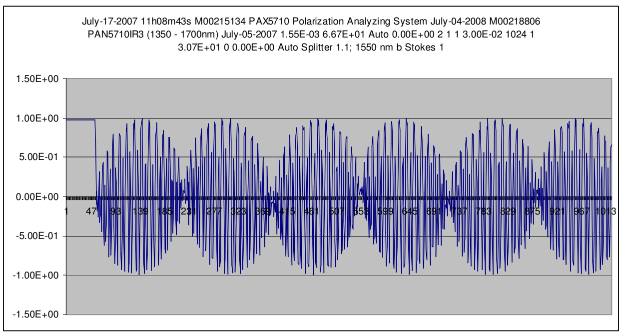
Fig. 5. The change of the ellipticity, in the case of the optical fiber attenuator OFA-1: a – after the gamma-ray irradiation at a total dose of 100 Gy; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1550 nm.



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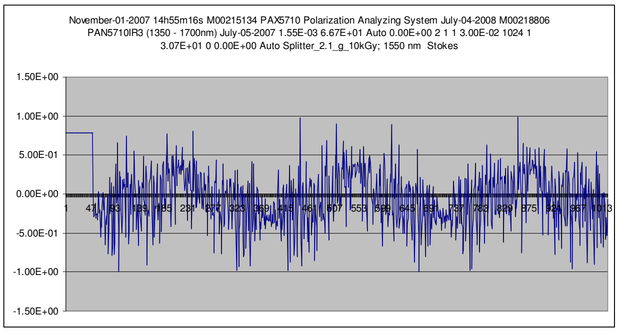
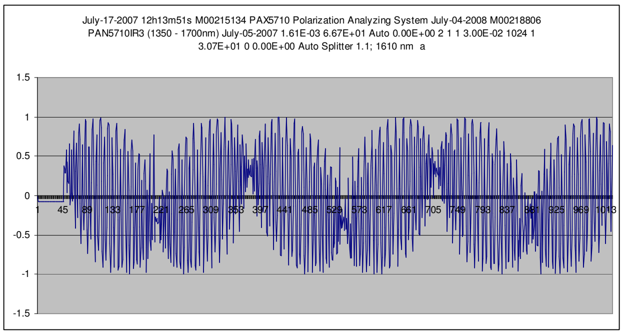


b

Fig. 6. The change of the first Stokes' parameter, in the case of the optical fiber splitter OFS-1.1: a – before the irradiation; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1550 nm.



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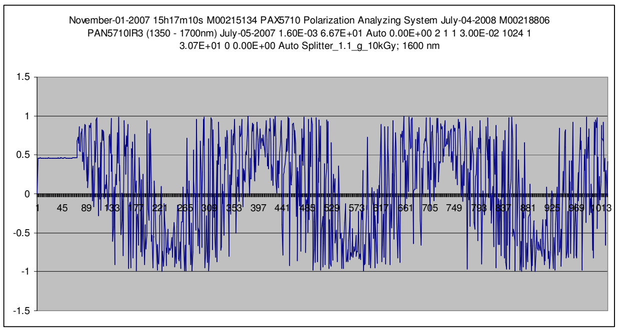

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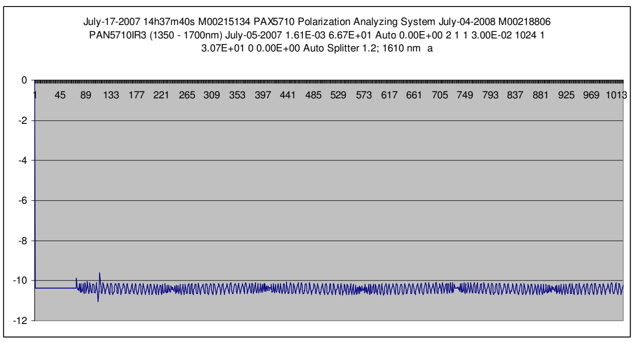
Fig. 7. The change of the second Stokes' parameter, in the case of the optical fiber splitter OFS-1.1: a – before the irradiation; b – after the gamma-ray irradiation at a total dose of 10 kGy, at λ = 1610 nm.



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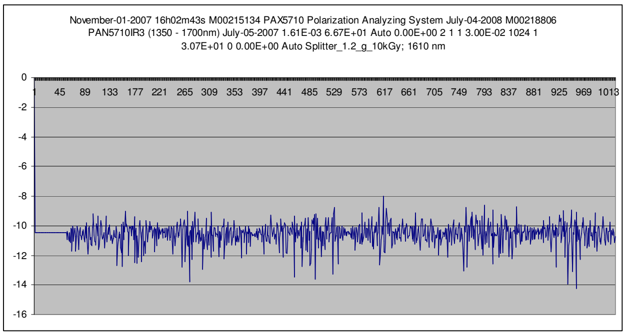

b

Fig. 8. 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 = 1620 nm.

For the laser diode driving boards the most affected was that subjected to electron beam irradiation case when the standard deviation for the optical power measurements reached 2.68 μW as compared to 1.76 μW for gamma irradiation, at the same total irradiation dose. A drop by 80 % of the laser diode optical power and the embedded photodiode responsivity was observed under gamma-ray and neutron irradiation (Figures 9- 11). For such a driving circuit board subjected to irradiation it is not easy to locate precisely the component which suffers the most severe degradation as far as the electronic circuit per se is a close-loop system (the photodiode current is used to regulate the laser diode driving current). For this reason, additional investigations are required to separate the irradiation effects upon individual electronic components (i.e. the voltage regulator, the photodiode current amplifier, the output current driver for the laser).

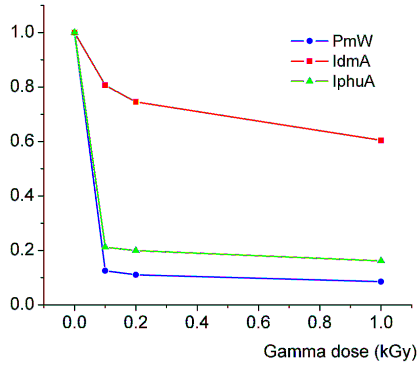

Fig. 9. The change of the laser diode optical power, direct current and the embedded photodiode current as it was subjected to gamma-ray irradiation.

In the case of the thermoelectric cooler irradiated by an electron beam (for the total irradiation dose of 10,6 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. In the same time, the electron beam irradiation produced an increase of about 8 ^{O}C for the Delta-T (the difference in temperature of the two facets of the device - ΔT_{max}). Such changes can be explained by the modification induced by the ionizing radiation into the number of available charge carriers present in the thermoelectric materials composing the Peltier element.

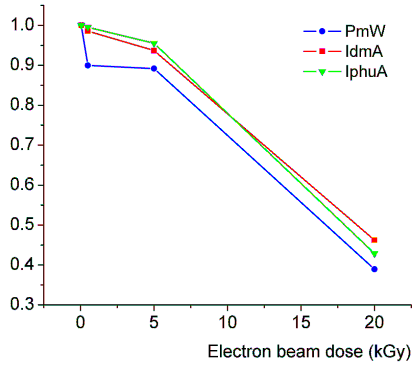

Fig. 10. The change of the laser diode optical power, direct current and the embedded photodiode current as it was subjected to electron beam irradiation.

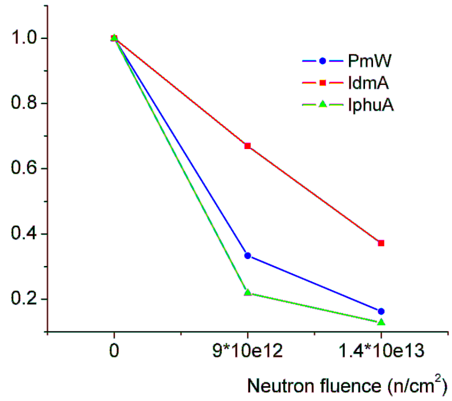

Fig. 11. The change of the laser diode optical power, direct current and the embedded photodiode current as it was subjected to neutron irradiation.

4. CONCLUSIONS

Passive and active components for optical fiber communication systems were evaluated under gamma, neutron and electron beam irradiation. According to our knowledge, the investigations we done in relation to irradiation effect on the Peltier TEC, on the driving board for laser diode control and on the modification of laser radiation polarization transmitted by exposed optical fibers are premieres. For the passive optical components (beam splitters and on-line fixed attenuators), the spectral transmission and the polarization characteristics of the transmitted optical irradiation were measured over the 1510 nm - 1620 nm spectral range. For neutron and gamma irradiation no changes of the optical spectral attenuation were observed. Under high total gamma irradiation dose (100 kGy) significant modification of the Stocks parameters and of the transmitted optical power was noticed.

In order to assess the possibility to use laser diode control systems under irradiation conditions, several driving boards and Peltier coulers were investigated off line as they were subjected to gamma, neutron and electron-beam irradiation. The optical power, the driving current and the embedded photodiode current were measured for a standard laser diode emitting at 670 nm. The major degradation was identified for the laser diode current driver as the board was subjected to total gamma dose of 1 kGy and for a total neutron fluence of about $9x10^{12}$ n/cm^2. Additional investigations are planned on the change of the polarization characteristics of optical fibers under different irradiation conditions, as well as on the on-line measurements of active components to be used in controlling the operating parameters of laser diodes.

ACKNOWLEDGMENTS

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