GAMMA IRRADIATION EFFECTS IN OPTICAL FIBRES, SPLITTERS, AND CONNECTORS

by

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The paper presents a brief overview of contemporary ELION techniques with stress on their use for material modification and dosimetry. In the attempt to avoid some common misjudges of irradiation effects, special attention is paid to exact definition of irradiation geometry and careful adjustment of dose rates, which enable a proper elaboration of experimental results. In particular, effects of γ-rays irradiation on properties of commercial optical fibres, splitters, connectors, and fibre joints are examined, which enables monitoring of irradiation effects in complex configurations made of materials with different radiation hardness (resistance). It has been established that γ-rays irradiation of the investigated elements influences, in different ways, the transmission of laser beam signals of various wavelengths, under different modulation regimes. After irradiation, the signal attenuation is noticeably larger, both in optical connectors and optical splitter, than before it, and the effect increases in time. The effects are more pronounced at the 99 % than at the 1 % Y-splitter output at both measured wavelengths, and are more pronounced at 1310 nm than at 1550 nm.

Key words: γ-irradiation, fibre, optical connector, material property, laser signal propagation, dosimetry, hardness

INTRODUCTION

The scope of applications of ELION (electron, laser, ion, neutron) techniques in modern civilization is large, and still increases. New, models of accelerators and spallation sources, but also the devices using particular chemical reactions, have been developed to produce well-defined beams of electromagnetic (EM) radiation, nuclear particles, and ions in large diapasons of energies and intensities. In that sense, the extension of present future ELION applications will depend mostly on capabilities of technical systems planed for their implementation [1-11].

Plasma processes providing electron, laser, ion, and neutron beams may also be classified as ELION techniques with strong acoustical processes. Powerful laser beams interaction with selected targets can generate high harmonics of EM radiation reaching X, and gamma rays energies, but also fast ionized particles, including isotopes. Applications of beam, or ELION techniques can be extended to production of shock and acoustic waves, as well [1-15].

In the presented paper several issues, which for years have been used in studies of irradiations effects on various materials, and assessment of principal material changes induced by them [16-28], are discussed. The attention is paid, also, to dosimetric aspects of the performed experiments, and to proper assessment of the results avoiding some common misinterpretations. This dosimetric approach could be also extended to effects of laser irradiation, pointing out the differences and common features of nuclear and laser dosimetry (irradiation), and necessity of a cooperative approach, if both types of irradiation are present simultaneously.

Nowadays, we are witnesses of extensive usage of optical fibres in many applications, like in sensors, communications, and computer nets. The earliest optical fibre sensors that rely on optical reflection were built in various forms, as multi fibres, twin-fibres, or single-fibres with a directional Y coupler [29-46]. Measuring uncertainty interpretation in new concept in all measured results should be another point of view [46, 47].

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Selection of materials for optical fibres production is essential for realization of sensor systems with ultimate performances in terms of sensitivity, selectivity, cost benefit and the working durability in the operating conditions. The most frequently used materials are glasses and plastics (polymers). Glasses have superior optical properties, but are more expensive than plastics. As attenuation in an optical fibre strongly depends on the fibre core material and the wavelength of operation, the glass based fibre devices are used for high data rates, and the long distance transmission. For lower data rates over short distances, plastic fibres are more economical. A compromise is a fibre with the core made of high quality glass with an inexpensive plastic cladding [39, 41, 42].

The effects of γ-ray irradiation at carefully monitored dose rates in fibres, connectors (including solid connections), fibre joints and fibre splitters are studied in this work, with principle aim to relate them with laser beam signal losses at various wavelengths and under different modulation regimes. The clear difference between the properties of fibre material, and materials used for permanent and temporary connectors, opens the possibility to investigate the γ-ray irradiation effects in devices with complex configurations made of materials with different irradiation hardness (resistance) [17-24, 37].

EXPERIMENTS

In principle, the connector loss can be caused by a number of factors. Loss is minimal when two fibre cores are identical and perfectly aligned, if the connectors are properly finished and no imperfection is present. Only the signal coupled to the receiving fibre's core will propagate, and all the rest of it can be considered as the connector loss.

The gap at the end of a fibre causes the insertion loss, and the return loss. The cone of light emerging from the connector spills over the core of the receiving fibre, and diminishes. In addition, due to the change of the refractive index n in the gap between the fibres, the Fresnel reflection of about 5 % for typical flat polished connectors occurs, which means that any connector with the air gap must have losses of at least 0.3 dB. This reflection is referred to as the back reflection or the optical return loss, and imposes serious problems in the laser based systems. A number of polishing techniques have been used to insure good physical contact of the fibres in connectors, and minimize the back reflection. Some of the commonly used solutions are presented in fig. 1.

Back reflection for these physical contacts is:
– PC (Physical contact), ORL: –30, –35 dB,
– UPC (Ultra-polish physical contact), ORL: –35, –55 dB, and
– APC (Angle physical contact), ORL: –55, –70 dB.

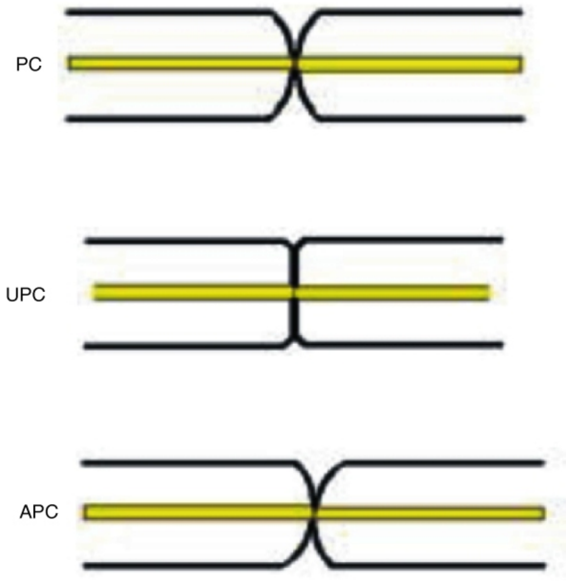

Figure 1. Some of the contacts commonly used for prevention of the back reflection (ORL) in fibres

Single mode and multimode connectors are different in performances, and require the proper fibres to be used. FC/PC has been one of the most popular single mode connectors for many years.

The effects of γ-ray irradiation were studied in optical fibres with a FC/PC connector, fig. 2(a), and a Y-splitter, fig. 2(b).

The insertion losses in optical connectors before, and after the γ-ray irradiation were measured by the EXPO FOT-900 single mode Fibre Optic Test Sys-

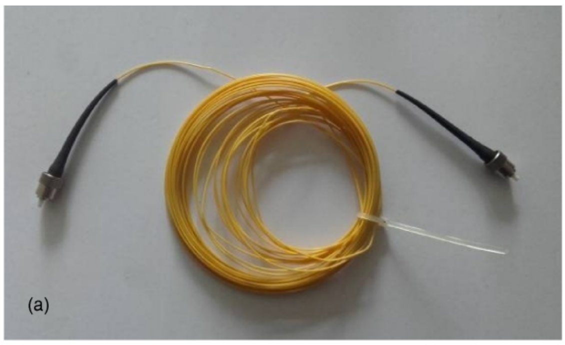

Figure 2. (a) Optical fibres with FC/PC connectors, and (b) Y-splitter used in experiments

tem instrument with a 1310 nm and 1550 nm coherent source wavelengths. The coherent source (1310 nm) wavelength is for FOT 50 devices. Test cable is single mode with red coating with a diameter of 250 m. The test cable which is tested, *i. e*. hardness to gamma ray, is presented in fig. 2(a).

The test cable, presented in fig. 2(a), was single mode, operating at 1310 nm and 1550 nm wavelengths.

The principle scheme of these measurements is presented in fig. 3.

The insertion loss in the Y-splitter, produced by Gould Fibre Optics was measured before and after the γ-ray irradiation by the GN Nettest instrument (OTDR – Optical time Domain Reflektometer) operating at 1310 nm and 1550 nm.

The OTDR procedure was applied for backscattering (directly proportional to the test pulse) and reflections measurements (fig. 4).

The connectors and the Y-splitters were exposed to the well-defined gamma-ray field generated by the radiation unit IRPIK-B at the Metrology Dosimetry Laboratory (Secondary Standard Dosimetry Laboratory) of the Vinča Institute of Nuclear Sciences. The radiation unit is equipped with a ^{60}Co source having activity of 238.438 TBq on reference date 01.09.1999, at energies of 1,173 MeV, and 1,332 MeV. The irradiation was performed in atmospheric conditions, with sequences which lasted from several minutes up to 21.5 hours, and the dose rate varying from 16.8 to 72.8 Gyh^{-1}. The maximal absorbed dose of 1026 Gy was deposited in a sample under the dose rate of 14.25

Figure 3. The principle scheme of insertion loss measurements in optical connectors by the EXPO FOT-900 single mode Fibre Optic Test System instrument

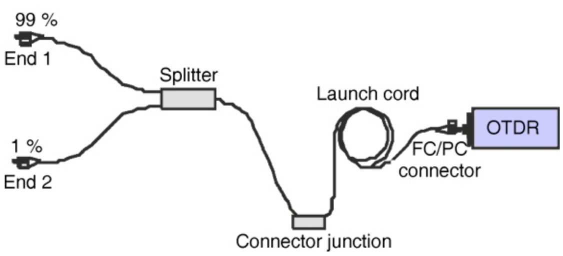

Figure 4. The OTDR measuring scheme of the insertion losses in the Y-splitter

Figure 5. The radiation unit IRPIK-B at the Metrology Dosimetry Laboratory of the Vinča Institute of Nuclear Sciences, used for γ-irradiation of the samples

Gyh^{-1}, after 21.5 hours of irradiation. The radiation unit is presented in fig. 5.

The radiation unit IRPIK-B produces the gamma-ray field that has a characteristic quadratic shape with the characteristic dimension H in the plane orthogonal to the axis, defining the distance from the ^{60}Co radiation source to the dosimetric center of the object (FCD). Values of the FCD and H parameters are given in tab. 1. This means that radiation field has the sample holder geometry that can be adjusted to the sample size.

A Y-splitter with two output optical fibres enables precise optical power splitting. For the performed experiments a single mode Y splitter 9/125 m, was used at λ = 1310 nm with power splitting of 1:99.

RESULTS AND DISCUSSION

Gamma irradiation effects in optical fibres

The performances of optical connectors were measured before, immediately after, and 15 days after the γ-irradiation at different dose rates. The results of the insertion losses measured in optical connectors are presented in tab. 2.

Table 1. The *FCD* and *H* parameters of the gamma-ray field generated by the irradiation unit IRPIK-B

Object position	Distance from the ^{60}Co source to the dosimetric center of the object *FCD* [cm]	Characteristic dimension – the square edge *H* [cm] in the radiation field plane
1	70	25
2	100	35.7
3	150	53.6
4	200	71.4
5	250	89.3
6	300	107.1
7	350	125
8	400	142.9

Table 2. The results of the insertion losses measured in optical connectors before$^{(1)}$, immediately after$^{(2)}$, and 15 days$^{(3)}$ after the γ-irradiation

Dose rate	Fibre [m]	Optical connectors	Insertion losses [dB]	
			1310 nm	1550 nm
16.8 Gyh^{-1}	9/125/250	FC/PC left	–0.28$^{(1)}$ –0.37$^{(2)}$ –0.030$^{(3)}$	–0.31$^{(1)}$ –0.42$^{(2)}$ –0.31$^{(3)}$
72.8 Gyh^{-1}	9/125/250	FC/PC right	–0.10$^{(1)}$ –0.23$^{(2)}$ –0.11$^{(3)}$	–0.18$^{(1)}$ –0.29$^{(2)}$ –0.20$^{(3)}$

Gamma irradiation effects in Y-splitter

The results of the Y-splitter OTDR measurements are presented in tab. 3, together with the data provided by the producer.

Signal attenuation (losses) in irradiated samples is noticeably increased than before irradiation, and the effect increases in time.

The effects are more pronounced at the 99 % than at the 1 % output at both measured wavelengths, and more pronounced at 1310 nm than at 1550 nm.

The results of the Y-splitter OTDR measurements before, and 15 days after the γ-irradiation are presented in figs. 6(a) and (b).

Assuming a linear dependence of degradation on a time, degradation rate (Θ) in a 15 days period is found to be as shown in tab. 4.

CONCLUSIONS

The paper presents a brief overview of contemporary ELION techniques with stress on their use for material modification and dosimetry. In particular, the effects of γ-rays irradiation on properties of commercial optical fibres, splitters, connectors, and fibre junction are examined, enabling investigation of irradiation effects in complex configurations made of materials with different radiation hardness (resistance). The effects of γ-ray irradiation were monitored for the well-defined irradiation geometry and at carefully controlled dose rates, which enable proper elaboration of experimental results and avoiding some common mistakes in irradiation effects interpretation. The results are related to laser beam signal losses at various wavelengths and under various modulation regimes. It is established that after irradiation signal attenuation (losses) is noticeably larger, both in irradiated connectors and splitters, than before irradiation, and that the effect increases in time. The effects are more pronounced at the 99 % than at the 1 % Y-splitter output at both measured wavelengths, and more pronounced at 1310 nm than at 1550 nm.

Table 3. The results of the Y-splitter OTDR measurements before$^{(1)}$, immediately after$^{(2)}$, and 15 days$^{(3)}$ after the γ-irradiation. The manufacturer results are denoted by *

Y-splitter losses [dB] (GOULD, single mode fiber 9/125 mm)		
Wavelength	1310 nm	1550 nm
Referent signal	–5.71	–13.30
Output 1: 99%	–0.50* –0.47$^{(1)}$ –0.51$^{(2)}$ –0.63$^{(3)}$	–0.40$^{(1)}$ –0.43$^{(2)}$ –0.50$^{(3)}$
Output 2: 1%	–22.85* –23.70$^{(1)}$ –24.10$^{(2)}$ –25.70$^{(3)}$	–21.08$^{(1)}$ –23.65$^{(2)}$ –24.98$^{(3)}$

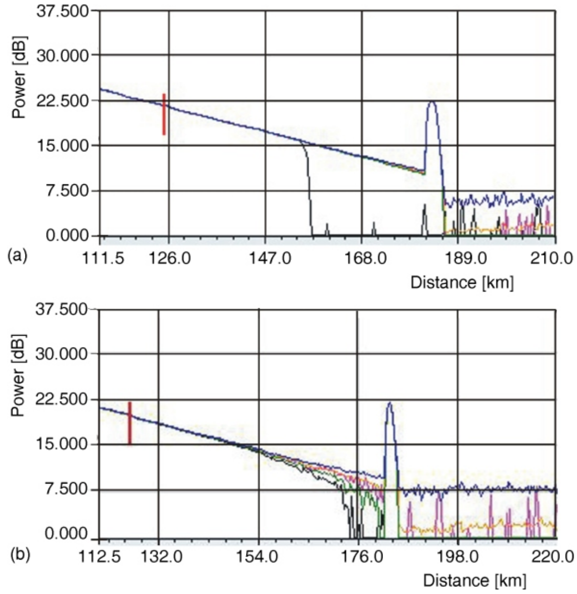

Figure 6. The display of the OTDR measurements of the Y-splitter: (a) before, and (b) 15 days after the γ-irradiation

Table 4. Degradation rate of investigated fibres at *vs.* wavelengths and outputs

λ [nm]	1310		1550	
Output [%]	99	1	99	1
Θ [dB/day]	0.0098	0.1251	0.0059	0.1888

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AUTHORS' CONTRIBUTIONS

The idea for the presented work came from all the authors, which have also equally contributed to data analysis and discussion. In addition, S. J. Stanković performed the samples irradiation, and S. N. Pantelić has done the insertion loss measurements.

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ЕФЕКТИ ГАМА ЗРАЧЕЊА НА ОПТИЧКА ВЛАКНА, РАЧВЕ И КОНЕКТОРЕ

Рад представља кратак осврт на елионске технике са акцентом на њиховој употреби за модификацију материјала и дозиметрију. У покушају да се избегну нека уобичајена, погрешна мишљења о ефектима зрачења, посебна пажња је посвећена тачној дефиницији геометрије зрачења и пажљивом прилагођавању јачине дозе, који омогућавају правилну обраду експерименталних резултата. Посебно су испитивани ефекти озрачивања гама зрацима комерцијалних оптичких влакана, оптичких рачви, конектора и спојева фибера, што омогућује праћење ефекта озрачивања на комплексне конфигурације уређаја од материјала са различитом радијационом отпорношћу. Нађено је да озрачивање испитиваних елемената гама зрацима на разне начине утиче на трансмисију сигнала – ласерских снопова различитих таласних дужина и под разним ефектима модулације. После озрачивања, слабљење сигнала је знатно веће и код оптичких конектора и код оптичке рачве, него пре њега, а ефекат расте са временом. Ефекти су много израженији код 99 %, него код 1 % излаза Y рачве на обе мерене таласне дужине, и више су изражени на 1310 nm, него на 1550 nm.

Кључне речи: гама озрачивање, влакно, оптички конектор, особина материјала, пролаз ласерских снопова-сигнала, дозиметрија, радијациона отпорност