INFLUENCE OF NUCLEAR RADIATION AND LASER BEAMS ON OPTICAL FIBERS AND COMPONENTS

by

***Sladjana N. PANTELIĆ* [1], *Nadežda V. BORNA* [2], *Milesa Ž. SREĆKOVIĆ* [1*], *Aleksander G. KOVAČEVIĆ* [3], *Aleksandar R. BUGARINOVIĆ* [4], *Milojko S. KOVAČEVIĆ* [5], *and Djordje R. LAZAREVIĆ* [5]**

[1] Faculty of Electrical Engineering, University of Belgrade, Belgrade, Serbia
[2] Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia
[3] Institute of Physics, Belgrade, Serbia
[4] "Telekom", Bijeljina, Republic of Srpska, B&H
[5] Vinča Institute of Nuclear Sciences, Belgrade, Serbia

Scientific paper
UDC: 004.085:620.193.6:544.032.65
DOI: 10.2298/NTRP1101032P

The influence of nuclear radiation and particles has been the object of investigation for a long time. For new materials and systems the research should be continued. Human activities in various environments, including space, call for more detailed research. The role of fibers in contemporary communications, medicine, and industry increases. Fibers, their connections and fused optics components have one type of tasks – the transmission of information and power. The other type of tasks is reserved for fiber lasers: quantum generators and amplifiers. The third type of tasks is for fiber sensors, including high energy nuclear physics. In this paper we present some chosen topics in the mentioned areas as well as our experiments with nuclear radiation and laser beams to fiber and bulk materials of various nature (glass, polymer, metallic, *etc*.).

Key words: fiber optics, radiation effects, electron irradiation, environmental effects, gamma and X irradiation

INTRODUCTION

The contemporary striving directions of the mankind – travel to space, communication, medicine and others – are full of demands for the consumption of various energy types. Technical solutions concerning the issues of fulfilling the demands offer many energy couplings, the transformations of one kind of energy into another, including trends which are – in "philosophical" sense – positive, or negative. On the scale where energies operate with the term "coherence", coherent energy (ASER effects – the amplification of stimulated emission by radiation [1]), is ranked highly, while the transformation of nuclear energy into thermal would be considered as a "degradation of energy". These issues might be a topic of many discussions but the reality is full of both positive and negative examples of energy transformations of these kinds, where one is considered to have the lower quality than the nuclear energy [2-4].

On the other hand, communication demands the transformation of electromagnetic radiation from optical frequencies to microwave and *vice versa*, due to various reasons.

Medical applications use many various ELION (electron, laser, ion, and neutron beams) techniques, gamma and X radiation for following purposes: medical treatment, medical diagnostics, *etc*. [5-7].

The fibers express their roles in: fiber lasers, fibers for information transmission, optical sensors as the parts of other devices (fiber sensors), and also in (optical) energy supply (fiber powered sensors). Indirect roles cover tools for facility maintenance, with fiber laser for material processing (welding of individual components in the facility) as an example.

The topics which cover the influence of various types of radiation to materials have been naturally present for a long time, due to the changeability of the environmental operating conditions: the bottom of mine pits, outer space, power plants (nuclear, thermal, hydroelectric, *etc*.) [8-11].

The influence of optical radiation on the mechanical performances of optical fibers is expressed

* Corresponding author; e-mail: esreckov@etf.rs

by the process of fiber drawing, and the influence of CO_2 laser heating is strong.

The process of fiber drawing and influence of CO_2 laser heating is analyzed. It can be seen that elasticity modulus extremely change, *i. e.*, 1.5 times. The process can be discussed from the point of view of uncertainty taking into account that the scattering data are large. It means that the coherent radiation of 10.6   m of wavelength strongly changes the mechanical performances by drawing process.

The influence of various kinds of radiation (electromagnetic, electron beams, lasers, *etc.*) on living beings, biological tissues, bio- and inorganic materials is the subject of many research groups. In this work, we shall present some results of exposing various materials – some being used in optical componets – to ELION beams. The irradiated components are of bulk and fiber types. In the numerous applications of contemporary fiber technologies, connectors, integral and fused optics play the great role. For connectors, it is important to have different materials with the same function: metals, ceramics, plastics, glass. Therefore, in spite of the fact that the effects of the exposure of pure and compound materials to the nuclear radiation (gamma, *etc.*) from various sources are investigated and mutually compared, a main question always arises – where will the attenuation appear? In accordance to the answer of this question, another question emerges: how to plan the number of the connections on one line? This is particularly important for non-standard telecommunication long-term solutions, which are present in – for instance – medical, military, mining technology applications and in working environment where some of ELION techniques exist in processing or process control [12-14].

In modern material processing, there is another point of view: the comparison of ELION beam techniques, where plasma, laser, water beams have competing roles. The techniques of welding and soldering processes based on some of ELION techniques including plasma and other processes are especially of interest for welding processes where hybrid techniques play a large role. The laser welding of dielectrics, polymers, *etc.* has been present for a long time in both the industry and many practical situations.

The properties of fibers can be tailored to a wide variety of applications. Adjusting the fibers to measurement techniques requires many novel connectors with broader possibilities of opening variables, particularly for devices of various types. Difficulties commonly emerge in complex cases, which oppose everyday routine applications – communications, medicine, *etc.*

There are defined working conditions in the professional welding of steel. In regulation documents for fiber testing, there are some administrative demands concerning the radiation hardness to specific types of radiation. In nuclear facilities, the implementation of optical components in the control units displays growth nowadays, which stimulates some research groups to investigate the hardness of various materials to nuclear radiation.

PSD techniques, developed since 1970s, which serve simultaneously for both the measurement and distinguishing of different kinds of radiation, apply a crystal (or plastic) as a key element, whose characteristics might be improved by the exposure to laser beams – achieved in the case of polymers in nuclear radiation or fibers drawing.

It has been shown that the target temperature is dependent on the pulse regime of the incoming beam. For instance, after the exposure to ps pulses, the temperature of the dental tissue remains the same, but it rises after the exposure to fs pulses. Note that enamel is known as one of the materials with the highest hardness and is hard to process for common "non-laser" techniques.

Ion implantation conditions on the depth dependent refractive index profile $n(z)$ for some material defining optical wavelength deserves discussion. Many theories exist and nowadays there are many hypotheses that need to be confirmed and to solve the question of the doses and the question of the optical and other characteristics of the materials.

EXPERIMENTAL PROCEDURE

Optical connectors exposure to gamma radiation

In order to estimate the radiation hardness of some optical components – standard optical connectors, standard and modified optical fibers, components made of fused optical materials – several laboratory and commercial samples have been exposed to gamma and other kinds of radiation.

In this paper, some of the used samples had been exposed to gamma radiation prior to the experiments, while others had not been exposed. The purpose was to compare the transmission characteristics of optical fibers and connectors before and after the irradiation.

The samples were chosen from "Alcatel" modified single-mode optical fibers (MOF) as well as from "Molex" and "Diamond" optical connectors of the FC/PC, DIN, and SC types for single-mode optical fibers. The attenuations of optical connectors were less than 0.4 dB/km and backscattering greater than –30 dB/km, and fibers 9/125/3000   m [15, 16].

For this purpose, single-mode fibers ("Molex" and "Diamond") have been used in the optical windows of 1300 and 1550 nm (II and III windows).

According to the manufacturer specification, MOF (by "Alcatel"), have the following losses: single-mode 9/125   m 0.34 dB/km (II window) and 0.21 dB/km (III window). MOF have been obtained by coating optical fibers with composite materials. Composite coating has been formed in the various concentrations of Ba-ferrites and $SmCo_5$ powders dispersed in the solution of poly-ethylen-co-vynil-acetate RVA in toluene [15-18]. The MOF length varied in the 1-10 m range. The MOF and connectors have been irradiated with beams from the linear accelerator 10 MeV of X-rays. The dose rate has been adjusted in two steps up to the level of 4.7 Gy/min for the two energies, 10 Gy and 30 Gy, measured in the field of 30 cm 30 cm. Before and after the exposure to the nuclear radiation, the fiber-optical tester EXFO FOT 900 has been used for the measurements and control of the characteristics of modified fibers and optical connectors. The measurements have been performed by a *cut-back* method.

The losses have been measured before the exposure of the chosen type of radiation and after the fibers and the connectors have been exposed to the radiation [15-18]. The main characteristics of the samples of optical fiber 9/125/3000 are presented in tab. 1.

Table 1. Main characteristics of the irradiated samples

N°	Type of optical fiber	Irradiation [Gy]
1	FC/PC	10
2	FC/PC	10
3	DIN	10
4	SC	10
5	FC/PC	30
6	FC/PC	30
7	DIN	30
8	SC	30

Some of the results are presented in figs. 1(a) and (b).

The results represent the mean values of the attenuations on both ends of the samples (fiber-connector compounds). According to figs. 1(a) and (b), the attenuation deterioration depends on the connector type, so it seems that the influence of the connector is important. Greater deterioration is present for FC/PC connector types and fibers at 1300 nm.

Fiber exposure to laser beams

Laser beam damages represent a large area of investigation. We applied different optical components including scintillator materials, fibers, as well as non-linear crystals invented for modulations components *etc*. [19, 20]. Some of the exposures to Nd^{3+}:YAG laser beam of fiber, ferrulas and three-layered structures [21, 22] are presented in figs. 2(a)-(d).

Fiber exposure to electron beams

The exposure of materials to electron beams induce changes of optical and other material performances and is frequently compared to the influence of other ELION beams with gamma and X radiation in-

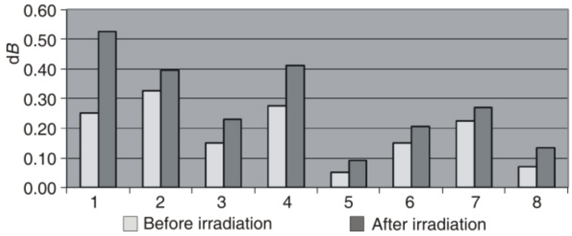

Figure 1(a). Attenuation before and after the exposure to nuclear radiation, 1300 nm, average

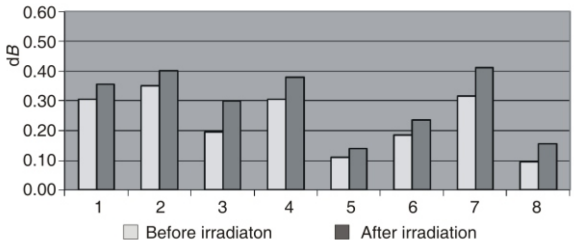

Figure 1(b). Attenuation before and after the exposure to nuclear radiation, 1550 nm, average

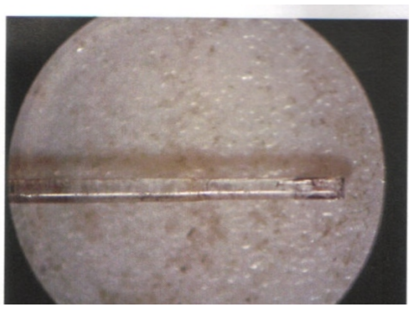

Figure 2(a). Multimode optical fiber (core diameter 100 μm) damaged by several Nd^{3+}: YAG pulses (11 J, 4834 J/cm^2)

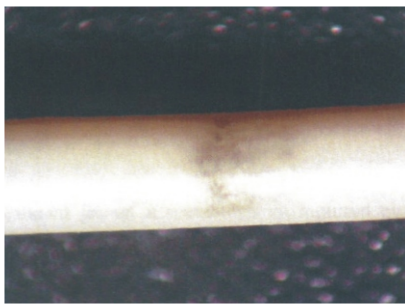

Figure 2(b). Optical connector ferrule damaged by Nd^{3+}: YAG laser pulse (13 J)

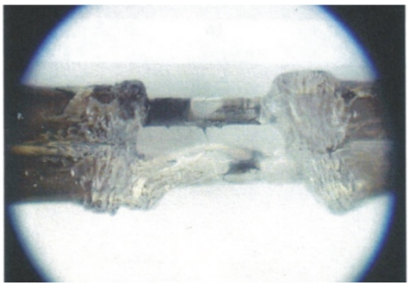

Figure 2(c). Duplex optical cable (core diameter 100 mm) damaged by several Nd^{3+}: YAG pulses

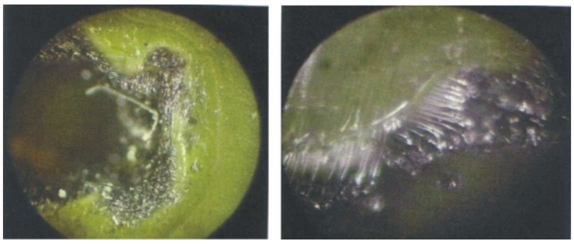

Figure 2(d). Macro (left) and micro (right) transversal damages of optical fiber bundles after exposure to Nd^{3+}: YAG laser, analyzed by SEM

cluded. Though many facts about exposures of well-known materials are known, the exposure of optical systems, novel materials and components needs much more research effort. This is particularly valid if the combinations of different beams simultaneously or consecutively appear with various temporal dynamics. In these cases, the situations leading to annealing should be chosen, or others, where damage is augmented. In figs. 3(a) and (b), the optical fibers of telecommunication types are exposed to gamma radiation and after a long time to electron beams which completely cut the fiber. For the comparison, the bulk material of metallic type can be welded with the same electron beams figs. 3(c) and (d).

In figs. 4(a) and (b), the transmission spectra in visible range before and after the exposure to gamma (^{60}Co) radiation are presented. The results are the part of the work presented in [22, 23].

Influence of optical radiation in femtosecond range to PMMA-based material

The interaction of femtosecond laser beam to targets of various materials has been covered by literature for more than 30 years [22, 24-27].

The interaction of fs laser (Coherent Mira 900) beam (pulse repetition rate 76 MHz, wavelength 400 nm, average power 230 mW) to samples of PMMA doped with dyes or modern magnetic materials [28-31] is presented in figs. 5(a) and (b).

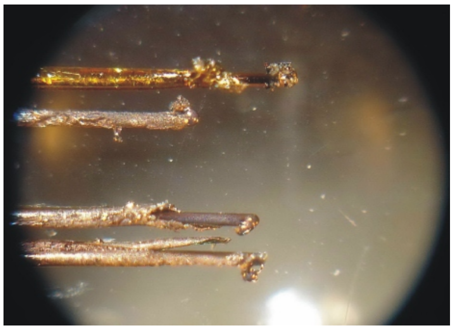

Figure 3(a). Communication optical fibers irradiated by electron beams. In the past, the sample were irradiated by nuclear radiation [19]

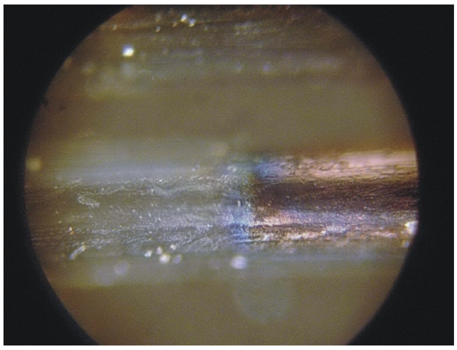

Figure 3(b). The detail of fig. 3(a)

Figure 3(c). Bulk steel material welded by electron beam

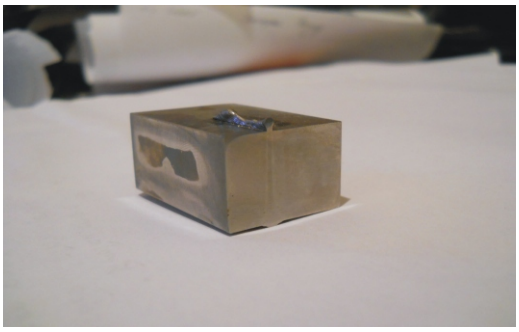

Figure 3(d). Another angle of view of the specimen from fig. 3(c)

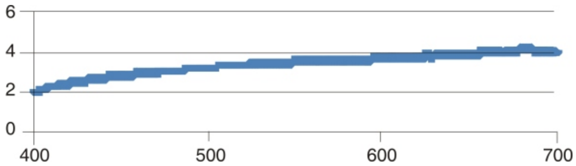

Figure 4(a). Attenuation spectrum (arbitrary units) of PM95 before the exposure to gamma radiation (range 400-700 nm)

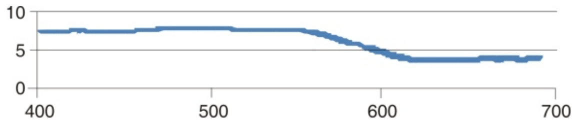

Figure 4(b). Attenuation spectrum (arbitrary units) of PM95 after the exposure to gamma radiation (range 400-700 nm)

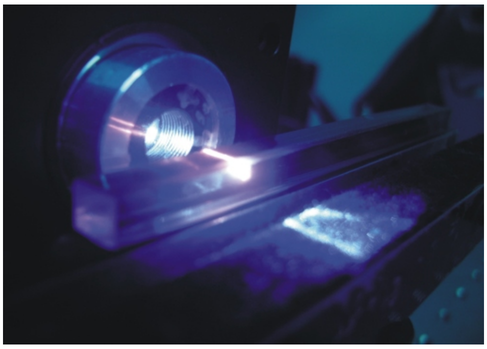

Figure 5(a). Interaction of fs laser beam with transparent doped PMMA sample

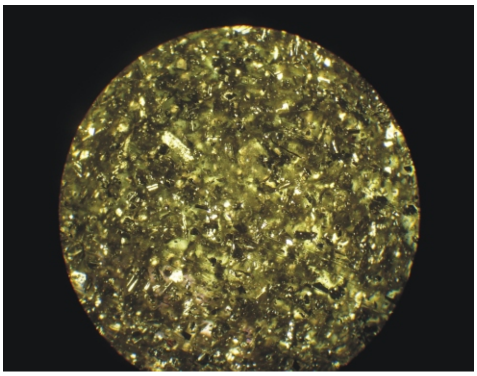

Figure 5(b). Light microscope view of the fs beam damage at the surface of PMMA samle doped with NdFeB

CONCLUSIONS

In this paper we present the interaction issues of some optical materials (fiber, PMMA doped or not, metallic) exposed to nuclear radiation, electron and laser beams or combined beams. In the chosen power density ranges several situations occurred: from minimal damages (localized craters, *etc*.) and welding to total destruction and burning.

In spite of the fact that the number of published papers dealing with the combined influence of various beams (gamma, electron) to some materials is rather small, the interest for the influence of electron beams (alone) to those materials is large. The experimental facts of chosen materials and kinds of radiation could be of interest to complete the picture.

Considering the results given for the mean values of attenuations, the attenuation deterioration depends on the connector type, manufacturer and exposure dose with the conclusion that the deterioration is greater for 1300 nm and FC types. We think that both multiple experiments and greater number of samples would be preferred for further investigation.

ACKNOWLEDGEMENT

This work is supported by the Ministry of Science and Environmental Protection of the Republic of Serbia under contract numbers 141009, 141003, and 171007. The authors would like to thank to the employees of the company "Orao" (Bijeljina).

REFERENCES

[1] Siegman, A. E., Lasers, University Science Books, Stanford, 1986

[2] Dunskaya, Y. M., Laser and Chemistry (in Russian), Nauka, Moscow, 1978

[3] Srećković, M., Dinulović, M., Fotev, V., Constructions and Calculations Related to Non-Conventional Ecological Approaches for Earth and Space, Machine Design, Monograph, 2010, pp. 193-198

[4] Srećković, M., Quantum Electronics, Lasers and Macromolecules (in Serbian), *Proceedings*, Yu Polymers 2002, May 27-29, 2002, Čačak, Serbia, 2002, pp. 32-43

[5] Srećković, M., Kutin, M., Hribšek, M., Pavlović, M., Polić-Radovanović, S., Zarubica, V., The Implementation of ELION Techniques in Measurement, Control and Processing of Materials, and Processes, Society for Technical Diagnostics of Serbia, Belgrade, 2009

[6] Srećković, M., Osmokrović, P., Konstantinović, Lj., Arsoski, V., Chosen Laser Implementations in Medicine (in Serbian), Institute for Physics of Technical Faculties of the University of Belgrade, Belgrade, 2010

[7] Živković, M. M., Stantić, T. J., Ciraj-Bjelac, O. F., Technical Aspects of Quality Assurance in Mammography: Preliminary Results from Serbia, *Nuclear Technology & Radiation Protection, 25* (2010), 1, pp. 55-61

[8] Vujisić, M., Stanković, K., Marjanović, N., Osmokrović, P., Simulated Effects of Proton and Ion Beam Irradiation on Titanium Dioxide Memristors, *IEEE Transactions on Nuclear Science, 57* (2010), 4, pp. 1798-1804

[9] Osmokrović, P., Jurošević, M., Stanković, K., Vujisić, M., Radiation Hardness of Gas Discharge Tubes and

Avalanche Diodes used for Transient Voltage Suppression, *Radiation Effects and Defects in Solids, 164* (2009), 12, pp. 800-808

[10] Vujisić, M., Stanković, K., Dolićanin, E., Jovanović, B., Radiation Effects In Polycarbonate Capacitors, *Nuclear Technology & Radiation Protection, 24* (2009), 3, pp. 209-211

[11] Vujisić, M., Osmokrović, P., Lončar, B., Gamma Irradiation Effects in Programmable Read only Memories, *Journal of Physics D: Applied Physics, 40* (2007), 18, pp. 5785-5789

[12] Mix, P. E., Introduction to Non-Destructive Testing, John Wiley and Sons, New York, USA, 2005

[13] ***, Research Techniques in Non-Destructive Testings (in Russian), (Ed. R. S. Sharpe), Mir, Moscow, 1972

[14] Christie, B., White, S., Gorodetzky, P., Lazić, D., Calorimetry at 0º in RHIC, Some Issues in the Choice of Detector Technology, March 1994, RHIC/Det, Note 6

[15] Srećković, M., Marinović, A., Šijački-Žeravčić, V., Ristić, S., Krasnjuk, V., Milutinović-Nikolić, A., Pantelić, S., Tomić, Ž., Optical and Radiation Resistance of Some Optical Components and Fibers and Interaction with Some Laser Beams, *Proceedings* (Eds. V. J. Corcoran, T. A. Corcoran), Conference Lasers 2001, STS Press, McLean, Tucson, Ariz., USA, 2002, pp. 367-375

[16] Milutinović-Nikolić, A., Ph. D. thesis, Faculty of Technology and Metallurgy, Belgrade, 2002

[17] Milutinović-Nikolić, A., Srećković, M., Marinović, A., Aleksić, R., Mechanical Properties and Mechanical Reliability of Polymer Coated Silica (pCS), *Proceedings*, (Eds. V. J. Corcoran, T. A. Corcoran), Conference Lasers 2001, STS Press, McLean, Tucson, Ariz., USA, 2002, pp. 359-366

[18] Srećković, M., Ivanović, N., Šijački-Žeravčić, V., Ostojić, S., Vedlin, B., Vujković Cvijin, P., Boreli, F., Stepić, R., Some Laser Damage of Glass, Scintilator and Optical Materials, *Optics and Laser Technology, 23* (1991), 3, pp. 169-174

[19] Srećković, M., Bugarinović, A., Latinović, Z., Janićijević, A., Nikolić, D., Djokić, B., Dinulović, M., Fidanovski, Z., Contemporary Problems in the Interpretation and Estimation of the Laser-Material Interaction (in Serbian), *Proceedings*, Contemporary Materials Conference , Banja Luka, July 3-4, 2009, Academy of Sciences and Arts of the Republic of Srpska, Bosnia and Herzegovinia, pp. 367-392

[20] Borna, N., Ćosović, V., Grujić, A., Aleksić, R., The Influence of Rheological Properties of Glass on the Structure of a Three Layer Optical Fiber Sintered Block, *Science of Sintering, 504* (2003), Special editions, pp. 307-311

[21] Borna, N., Pantelić, S., Aleksić, R., Grujić, A., Optical Fibers, Techniques of Connection and the Levels of Laser Damages (in Serbian), *Proceedings* (Ed. A. Kovačević), Photonics 2010 Conference, Belgrade, April 21-23, 2010, p. 13

[22] Kovačević, A. G., Srećković, M., Karastojković, Z., Grujić, A., Zarubica, V., Jovanić, P., Jelenković, B. M., 3rd Medinano Conference Nanophotonica, *Book of Abstracts*, Belgrade, 2010, p. 90

[23] Zarubica, V., Optical Characteristics of Materials and their Metrological Assurances (in Serbian), Ph. D. thesis, Technical Faculty of Čačak, Serbia, 2008

[24] Ahmanov, A., Vysloukh, A. V., Chirkin, A. S., Optics on Femtosecond Laser Pulses, American Institute of Physics, New York, USA, 1992

[25] Milosavljević, A., Petronić, S., Srećković, M., Kovačević, A., Krmpot, A., Kovačević, K., Fine-Scale Structure Investigation of Nimonic 263 Superalloy Surface Damaged by Femtosecond Laser Beam, *Acta Physica Polonica A, 116* (2009), 4, pp. 553-556

[26] Srećković, M., Ilić, J., Kovačević, A., Pantelić, S., Latinović, Z., Borna, N., Ćosović, V., Models of Interactions of Laser Beams with Materials of Interest for Optical Components and Provoked Damages, *Acta Physica Polonica A, 112* (2007), 5, pp. 935-940

[27] Srećković, M., Kovačević, A., Rajković, V., Tomić, Ž., Dukić, M., Bugarinović, A., Jovanić, P., Laser Damage in Thin Film and Bulk Materials, *Proceedings*, 4th Serbian Congress for Microscopy, 2010, pp. 101-102

[28] Radojević, V., Nedeljković, D., Grujić, A., Talijan, N., Ćosović, V., Aleksić, R., Influence of Composition of the Magnetic Composite Coating on the Performance of the Optical Fiber Magnetic Field Sensing Element, *Journal of Optoelectronics and Advanced Materials, 9* (2007), 9, pp. 2873-2878

[29] Grujić, A., Ćosović, V., Stajić-Trošić, J., Talijan, N., Spasojević, V., Lazić, N., Aleksić, R., Dynamic Mechanical Properties of Polymer Bonded Magnetic Materials with Different Nd-Fe-B Content, *Proceedings* (Eds. S. Kobe, P. McGuiness), 21st Workshop on Rare-Earth Permanent Magnets and their Applications, August 29 – September 2, 2010, Bled, Slovenia,

[30] Grujić, A. S., Lazić, N. L., Talijan, N. M., Spasojević, V., Stajić-Trošić, J. T., Ćosović, V. R., Aleksić, R., Polymer-Bonded Magnetic Materials with Various Nd-Fe-B Filler Content, *Acta Physica Polonica A, 117* (2010), 5, pp. 859-863

[31] Radojević, V., Talijan, N., Grujić, A., Ćosović, V., Aleksić, R., Influence of Composition of the Magnetic Composite Coating on the Performance of the Optical Fiber Magnetic Field Sensing Element, *Journal of Optoelectronics and Advanced Materials, 9* (2007), 8, pp. 2424-2429

Received on November 14, 2010
Accepted on January 27, 2011

**Слађана Н. ПАНТЕЛИЋ, Надежда В. БОРНА, Милеса Ж. СРЕЋКОВИЋ,
Александер Г. КОВАЧЕВИЋ, Александар Р. БУГАРИНОВИЋ,
Милојко С. КОВАЧЕВИЋ, Ђорђе Р. ЛАЗАРЕВИЋ**

УТИЦАЈ НУКЛЕАРНОГ ЗРАЧЕЊА И ЛАСЕРСКИХ СНОПОВА НА ОПТИЧКЕ ФИБЕРЕ И КОМПОНЕНТЕ

Утицај нуклеарног зрачења и нуклеарних честица већ дуго времена је предмет научног испитивања. За нове материјале и активности у разним областима, укључујући и Космос, потребна су детаљнија истраживања. Посебно, улога оптичких влакана у савременим комуникацијама, медицини и индустрији, стално расте. Влакна и њихове везе, и компоненте на бази стопљене оптике имају једну врсту задатака – да преносе информације и енергију. Други тип задатака односи се на фибер ласере, то јест, квантне генераторе и појачаваче. Трећи тип задатака везан је за сензоре на бази оптичких влакана, који укључују нуклеарну физику високих енергија. У овом раду се приказују изабране теме из ове области, као и наши експерименти са нуклеарним зрачењима и ласерским сноповима на материјалима влакнастог и балк типа различите природе (стакло, полимер, метали, итд).

Кључне речи: оптичка влакна, ефекти зрачења, електронски снопови, ефекти околине, гама и озрачавање