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RADIATION DAMAGE IN SHORT QUARTZ-POLYMER OPTICAL FIBERS

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Abstract

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Short KP-200 quartz-polymer fibers revealed sharp quasiperiodical changes of the light output under γ-irradiation.

Аннотация

Васильченко В.Г., Турчанович Л.К. Радиационные характеристики коротких кварц-полимерных световодных волокон: Препринт ИФВЭ 96-99. – Протвино, 1996. – 5 с., 4 рис., библиогр.: 7.

Под действием γ-облучения в коротких кварц-полимерных световодных волокнах марки КП-200 наблюдались резкие квазипериодические изменения величины прошедшего через них света.

In some monitor systems for hadron calorimeters that are now under construction for high energy physics, optical fibers of high trapping efficiency and radiation hardness are planned to be used. Such quartz-polymer fibers fully meet the above application criteria. Due to that there is a great interest in research and development of radiation resistant quartz-polymer fibers [1-3] in the ultraviolet and visible wavelength regions. In the course of this investigation we found that quartz-polymer fibers of KP-200 trade mark showed sharp decreases of their light output for the visible wavelength region at doses $\geqslant$1 Gy. According to ref.[3] their light outputs in the visible region should not change for doses $10^{-1} < D < 10^6$ Gy. This paper is devoted to the investigation of a possible cause of this phenomenon.

These KP-200[1] quartz-polymer fibers had only one silica-organic cladding based on SIEL[2] with a thickness of about 100 μm. The fibers were drawn of KU-1 high purity amorphous silica with a low level ($< 3-4$ ppm) of OH^- radicals in their cores of $\varnothing =$ 200 μm in diameter. Their initial light attenuation was about 3-6 Db/km at a wavelength of λ=850 nm. Besides we also measured the light attenuation length which was about 60 m at λ_{las}=337 nm. The fibers were curled in circles of $\varnothing \sim 9$ cm in diameter. Note that this procedure did not change the light output from the fibers ends within the accuracy of our measurements. Then the samples were irradiated in a flux of γ-quanta from radioactive sources of ^{137}Cs with a dose rate of about 60 mGy/s in room temperature in air.

The experimental layout for the fibers radiation properties measurements is shown in Fig.1. Light pulses from LGI-21 nitrogen laser (1) (pulse duration 10 ns, frequency $\sim 10-25$ Hz, wavelength 337 nm, intensity ~ 30 μBt/pulse) were 3100 times attenuated with a neutral filter (2) and split into 3 optical channels by a divider (3). The first channel (8) was used for the laser calibration because the stability of the laser light pulses was only $\pm$3%. The electromagnetic background from the working laser during the amplitude measurements was $\leqslant$2%. The second channel (7) was used for the transmission properties measurements of optical fibers in the UV wavelength region. The light that passed through the tested fibers was detected by a photomultiplier (PM) UVP-56 (6). The third channel (6) was used for the transmission properties measurements of optical

[1]The fibers were manufactured at the Glass Plant, Livany, Latvia.
[2]SIEL — silica-organic cladding with the refraction index n_{cl}=1.42.

fibers in the green wavelength region. For that purpose a thin (0.5 mm) scintillator (5) re-emitting light in 4π angle and the green wavelength region with λ_{sci}=530 nm was placed in the third channel before the tested fibers. Signals from the PMs (9,10) with amplitudes not greater than 1.4 B were fed to the ADC and then to our data acquisition system (12). The information was recorded by a personal computer (13). The laser synchroimpulses formed 90 ns gate pulses to trigger the ADC. Pulse light spectra from the tested fibers were measured, pedestals were subtracted and mean values were calculated. These mean values (as a characteristic of the light output) were determined before I_o and not longer than 5-15 min after irradiation I.

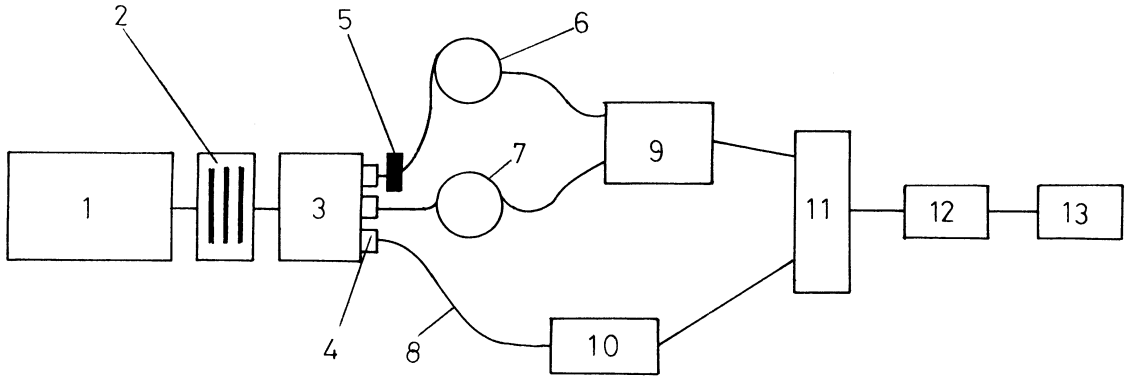

Fig. 1. Experimental layout. 1 — nitrogen laser LGI-21, 2 — neutral filter, 3 — divider, 4 — optical connector, 5 — scintillator, 6,7 — tested optical fibers, 8 — quartz fiber, 9 — PM UVP-56, 10 — PM FEU-84-3 (for calibration), 11 — ADC, 12 — data acquisition system, 13 — personal computer.

A comparative study of the radiation damage in short (l_s=0.26 m) and prolonged (l = 2.6 m) fiber samples was carried out. Some results of the relative light output measurements I/I_o as a function of the dose for a series of KP-200 fibers taken from the same bundle ($\varnothing \sim$ 40 cm) are presented in Fig.2-3. Preliminary measurements showed that all the fibers did not change their I/I_o in a dose region of $1 < D < 100$ mGy.

Fig.2 shows a significant variation of I/I_o from sample to sample for short fibers at λ_{las}=337 nm under γ-irradiation. A theoretical characteristic of I/I_{os} for a short fiber (l_s=0.26 m) with the use of the experimental data measured for the prolonged fiber in (Fig.3) is presented in Fig.2. The calculations were carried out supposing of the homogeneity of optical properties along the fiber calculated with the use of the formula

$$I/I_{os} = (I/I_o)^{l_s/l}. \quad (1)$$

A comparative study of the radiation characteristics of prolonged and short KP-200 fibers for λ_{las}=337 nm and λ_{sci}=530 nm is presented in Fig.3. As is clear from Fig.3, sharp quasiperiodical changes of I/I_o are more significant for λ_{sci} = 530 nm than for λ_{las}=337 nm and there is practically no correlation of I/I_o between these two wavelength regions. At some doses for λ_{sci} = 530 nm, I/I_o of short fibers becomes higher in comparison with their initial values before irradiation I/I_o=1.

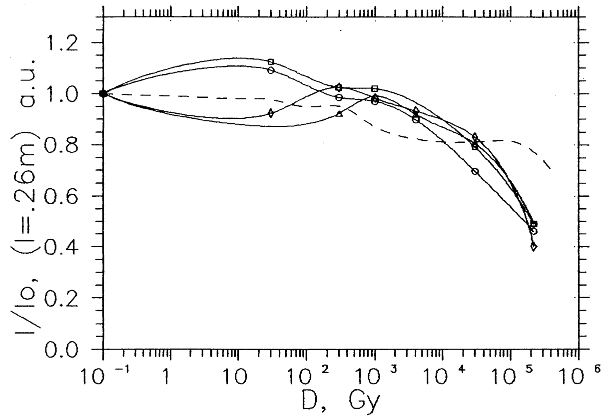

Fig. 2. Four short KP-200 fibers relative transmission in the UV region as a function of the dose (measured just after γ-irradiation). The dashed line is calculated with the use of expression (1). Curves were drawn to guide the eye.

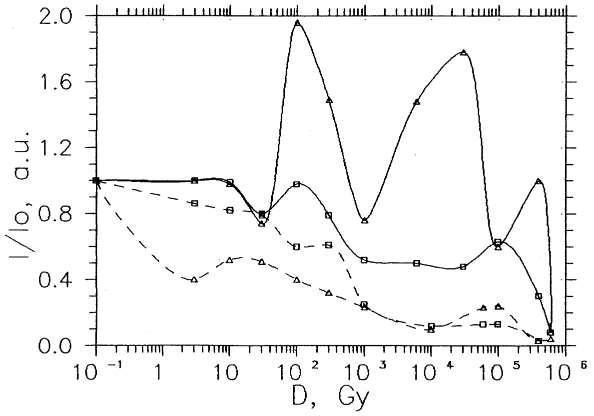

Fig. 3. A short (solid lines) and a prolonged (dashed lines) KP-200 fibers relative transmission in the UV region as a function of the dose (measured just after γ-rradiation): □ — for the UV region; △ — for the green region. Curves were drawn to guide the eye.

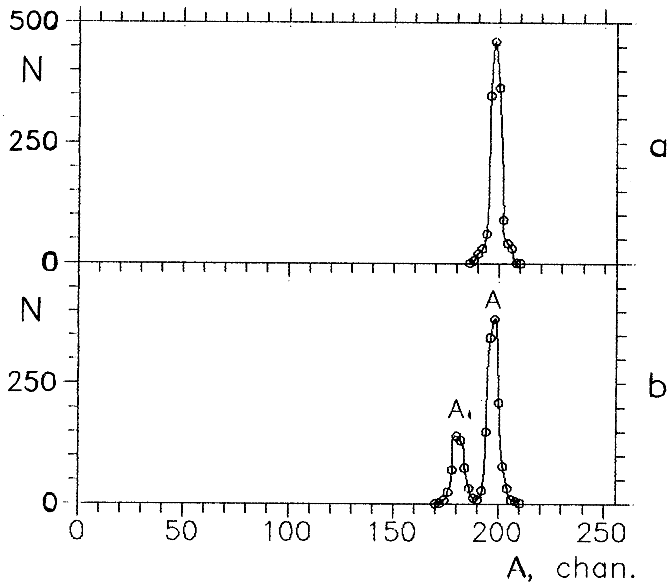

Fig. 4. Short KP-200 fiber pulse height amplitude spectra in the UV region (measured just after γ-irradiation): a — before irradiation; b — after a dose of 10 Gy.

Some time after short fibers irradiation with doses in a region $10^1 \leqslant D < 10^4$ Gy, new additional peaks appeared both for $\lambda_{las} = 337$ nm and $\lambda_{sci} = 530$ nm. After a short fiber irradiation with a dose of 10 Gy, a new additional peak A_1 appeared in the amplitude spectrum for $\lambda_{las} = 337$ nm and $\nu = 10$ Hz (Fig.4, where N is counts/channel). Their relative amplitudes and intensities were $A : A_1 = 1 : 0.91$ and $N : N_1 = 1 : 0.36$, respectively. Two additional peaks A_1 and A_2 appeared in the amplitude spectrum for $\lambda_{las} = 337$ nm and ν=25 Hz (not shown in Fig.4). Their relative amplitudes and intensities were $A : A_1 : A_2 = 1 : 0.91 : 0.74$ and $N : N_1 : N_2 = 1 : 0.3 : 0.2$, respectively. After 5-7 days of recovery at room temperature in air all additional peaks disappeared. We should note that the prolonged fibers have not shown any new additional peaks.

Our experimental data show that the above properties of I/I_o reveal only quartz-polymer fibers without compressing coating (KP-200). This allows us to suppose that the cause of I/I_o sharp changes is a weak and metastable adhesion between the core and the cladding of fibers. It is well known that during the process of reflection light penetrates into the cladding only a few parts of its wavelength deep [5] forming a reflecting layer. Due to the weak adhesion, the reflective index in this layer n may be lower than in the bulk of cladding n_{cl} and its value may change due to the effect of external sources: γ-irradiation, bright light illumination et al. On the one hand, under γ-irradiation the diffusion increases, the adhesion improves and, as a result, n also rises to the value of n_{cl}. On the other hand, under γ-irradiation the radiation annealing of internal strengths between the cladding and core in fibers also takes place. This can create conditions for possible shifts of short parts of the cladding along the core, the decrease of adhesion and, thus further drops of n. Both these processes that occur under irradiation may lead to sharp quasiperiodical changes of the fiber trapping efficiency ε that for λ_{sci}=530 nm is determined by formula [6]

$$\varepsilon = 1/2(1 - n^2/n_{cor}^2). \qquad (2)$$

In accordance with expression (2), large values of I/I_o for $\lambda_{sci} = 530$ nm in Fig.3 can be explained by $\sim 3\%$ changes of n. It is obvious that the more n is close to n_{cor}, the more ε is sensitive to changes of n. Note that noticeable changes of n under irradiation were earlier observed in [7]. Due to a difference in the reflective layers thickness, I/I_o changes for $\lambda_{las} = 337$ nm and $\lambda_{sci} = 530$ nm should not correlate between each other.

Intense laser light illumination of fibers may cause short-term adhesion changes and, as a result, changes of n. When the relaxation time for changes of n is greater than $1/\nu$, then one may expect the appearance of some new structures in the pulse height amplitude spectra similar to those in Fig.4.

The above experimental data and their interpretation allows one to explain the origin of this phenomenon and understand both the great variation of radiation hardness and quasi-periodical changes of I/I_o at doses of $D \sim 10^5$ Gy for some quartz-polymer fibers in [4].

Here we propose using such comparative study of the radiation properties for short and prolonged fibers to control the quality of fibers production.

It is evident that the optical properties of claddings with weak adhesion to the core under irradiation are worth more detailed investigating.

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