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Studying radiation hardness of a cadmium tungstate crystal based radiation detector

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Abstract. The given article considers radiation hardness of an X-ray detector used in production of non-destructive testing instruments and inspection systems. In the course of research, experiments were carried out to estimate radiation hardness of a detector based on cadmium tungstate crystal and its structural components individually. The article describes a layout of an experimental facility that was used for measurements of radiation hardness. The radiation dose dependence of the photodiode current is presented, when it is excited by a light flux of a scintillator or by an external light source. Experiments were carried out to estimate radiation hardness of two types of optical glue used in detector production; they are based on silicon rubber and epoxy. With the help of a spectrophotometer and cobalt gun, each of the glue samples was measured for a relative light transmission factor with different wavelengths, depending on the radiation dose. The obtained data are presented in a comprehensive analysis of the results. It was determined, which of the glue samples is most suitable for production of detectors working under exposure to strong radiation.

1. Introduction

Instrument facilities of customs inspection play an important role in solving tasks of cargo tracking. These facilities normally include systems of X-ray diagnostics, the main part of which is X-ray detectors [1]. One of the main requirements to detectors is stable sensitivity in the process of accumulation of the absorbed radiation dose. That is why studying radiation hardness of detector components and finding the most robust ones is of a particular practical interest. One of the common demands to the detectors is their stable sensitivity, so as sensitivity to time. Temporary instability can be connected with its change of dosage sensitivity during the process of absorbed radiation dose accumulation. That is why the study of the radiation resistance of the detectors components and the selection of more persistent ones have a particular practical interest.

Studies on the radiation resistance of the 16-channel detector based on silicon p-i-n- photodiode and scintillator CsI (Tl)[2,6], in which the radiation resistance of the detector was determined at the level of $5x(10^5-10^6)$ Rad were conducted earlier. However, the contribution of the detectors'(assembly)individual components in the radiation resistance was not considered.

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2. Methodology

2.1. Detector structure

We carried out experiments on evaluation of radiation hardness of a CWO based crystal (fig. 1) both in assembly (crystal-glue-photodiode) and as a single photodiode. The photodiode has a p-i-n structure and made of high-resistivity silicon.

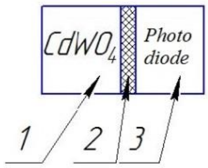

Figure 1. Detector structure, where 1 – cadmium tungstate crystal; 2 – glue; 3 – photodiode.

In the studied detector, cadmium tungstate acts as a scintillator. Optical glue is a bonding element between the scintillator and the photodiode, thus reducing light reflection where they are not tight enough.

2.2. General layout of experiment

Cobalt gun "Radian-2" with radioactive nuclide $^{60}_{27}Co$ (fig. 2) was used as a radiation source in experiments, the measuring circuit was taken outside the beam coverage area. The samples under study (assembled detector first, then photodiode separately) were placed at the output window of the gun collimator.

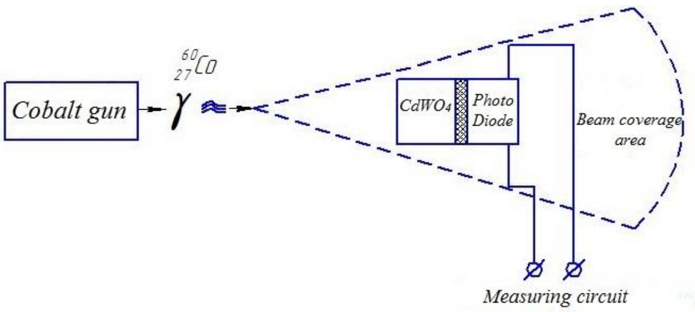

Figure 2. Experiment layout

Measuring circuit is shown in fig. 3. Photodiode current registered by a DC ampere meter Keithley 6485 was measured during experiments. When photodiode only was examined, it was exposed to a light flux from a 24V incandescent lamp, whose voltage was provided by a stabilized power source.

The photodiode efficient current was about three orders more than the dark current when exposed to both scintillator, and lamp. To provide a linearity of the light flux measurement, about 4V of reverse voltage was applied to the photodiode. All data of the photo-electric current measurements are given in relative units reduced to the initial point, where absorbed dose may be considered as zero.

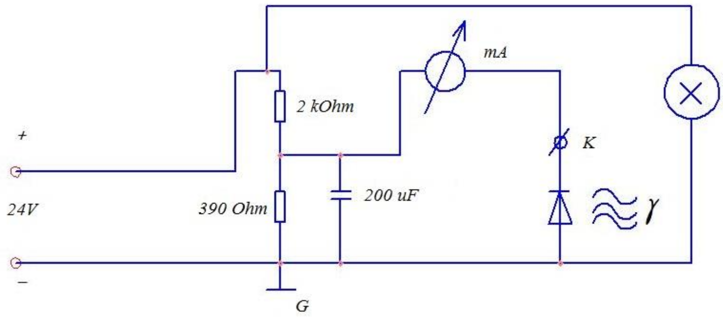

Figure 3. Measuring circuit.

3. Results

When scintillation detector entirely and single photodiode were exposed, the dose rate level was the same and made 5.5 rad/sec. The dose rate was monitored by DKS-101 dosimeter (s/n #71) equipped with ionization chamber BMK-06 (s/n #0871).

3.1. Finding radiation dose dependence of photodiode currents

Fig. 4 shows measurement results of the photodiode both assembled and separately depending on the absorbed radiation dose.

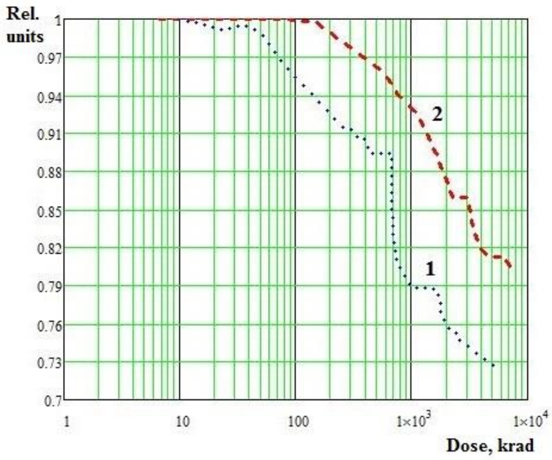

Figure 4. Dose dependence of photodiode currents, where 1 – assembly (scintillator-glue-photodiode); 2 – single photodiode.

The obtained results show that reduction of photo-electric current by 20% in the assembly (scintillator-glue-photodiode) takes place when $8\text{-}9 \cdot 10^5$ rad dose is accumulated, whereas the single photodiode shows the same current reduction at $7\text{-}8 \cdot 10^6$ rad, i.e. is more radiation-proof by about an order.

It is known [3] that oxide crystal based scintillation sensors (including cadmium tungstate) are highly radiation-proof. Together with the above-given experimental results, this fact tells us that the possible reason of the early failure of the assembly (scintillator-glue-photodiode) is low radiation hardness of the used glue.

3.2. Comparative tests for radiation hardness of two types of optical glues

To verify this conclusion we performed comparison tests for radiation hardness of two types of glues: optical silicone rubber based glue (further – SR-glue) and epoxy based glue. Applied on a polyethylene substrate, the SR-glue freezes as a thin uniform layer and is a clear bubble-free gel coat film, which can easily be cut by a scalpel. Epoxy glue freezes unequally, there is a small droplike thickening in the center. Multiple little air bubbles can be seen in it, the sample itself is quite tough and quite difficult to cut by a scalpel.

The core of the tests was as follows. Glues frozen on the polyethylene substrate were used to make samples 5-6 mm in diameter, and were put in special containers integrated in spectrophotometer SF-256 UVI. Then each sample was exposed to gamma-radiation on "Radian-2", the absorbed dose value being 5.5 rad/sec. A tin-lead plate (90% Sn and 10% Pb) 4.5 mm thick was placed in front of the sample. Content and thickness of the plate allowed modelling absorption of the primary and output of the secondary radiation in scintillation crystal of cadmium tungstate. In certain periods of exposure time, the samples in containers were put into spectrophotometer SF-256 UVI where light transmission factor in the range of wavelength from 190 to 1100 nm was measured. The layout and method of measuremetns are described in works [3, 4].

Fig. 5 shows the change of the relative transmission factor as the absorbed dose for epoxy glue increases, for two extreme lines in the visible range of light: curve 1 corresponds to the wavelength of 600 nm ("red"), curve 2 – to 430 nm ("blue"). The results show that for this glue, a significant radiation dose dependence of light transmission (almost linear) is typical, and the dependence becomes more obvious as the wavelength decreases.

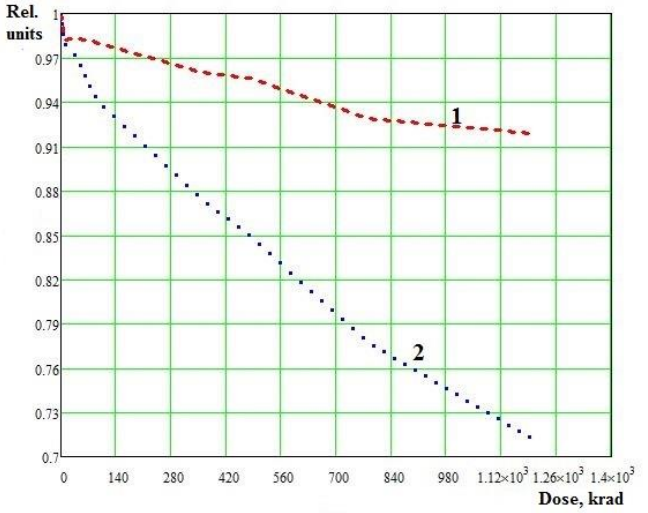

Figure 5. Change of the relative transmission factor as the absorbed dose increases (for epoxy based glue). 1 – 600 nm ("red")' 2 – 430 nm ("blue").

Fig. 6 shows the results of measuring the transmission factor for SR-glue sample. There is a quite weak dose dependence of transmission (up to 3000 krad) for this glue. We observed minor transmission enhancement as compared to the initial one, up to 5-8% ("radiation lucency"), at the initial stage of irradiation (about 20-40 krad in the area of absorbed dose), which is not seen in fig. 6 because of the small scale.

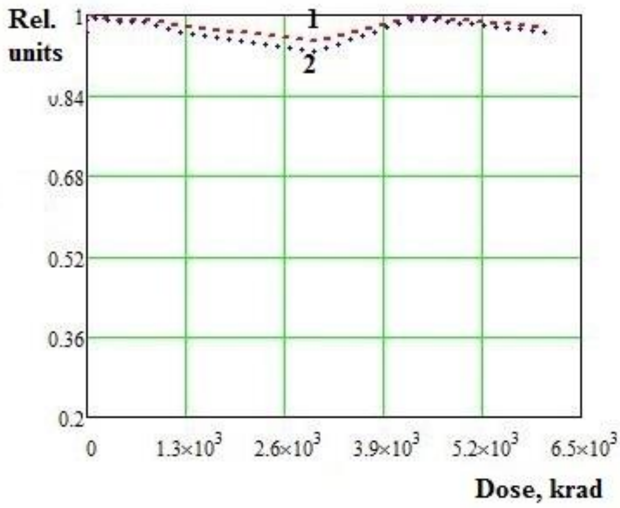

Figure 6. Change of the relative transmission factor for SR-based glue, 1 – 400 nm; 2 – 600 nm.

3.3. Analysis of results

The analysis of radiation degradation results of the assembled detector and measurement results of the transmission factor of SR- and epoxy glues gives an idea that epoxy-based glue was used in manufacture of the examined detector.

Indeed, fig. 7 shows in semi-logarithmic scale the generalized results of current measurements of the exposed assembled photodiode (data from fig. 4), and results of transmission factor measurements for epoxy-based glue (data from fig. 5). Curve 3 of photo current drop in the assembly is between the transmission factors for wavelengths 600 nm (1) and 430 nm (2). One may note that luminescence spectrum of cadmium tungstate lies in the range (380-600) nm with the peak at 480 nm. That is why, absorbed dose dependences of the photocurrent and transmission factor at 430 nm wavelength are almost the same.

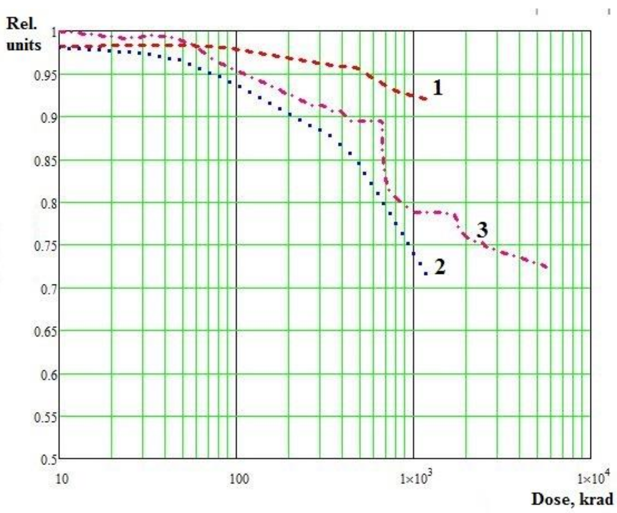

Figure 7. Change of transmission factor for epoxy-based glue (curves 1, 2) and photodiode current for assembly (curve 3).

Therefore, it is found that optical glues on the basis of silicone rubbers are much more radiation-proof (up to radiation dose values of 3000 krad) as compared to epoxy-based glues. The use of epoxy glues explains poor radiation hardness of the examined sample of the detector-assembly (cadmium tungstate – glue – photodiode).

References

[1] S. A. Schetinkin et al. 2011 Equipment for inspection of cars and cargo vehicles *XIX All-Russian scientific and practical conference for non-destructive testing and technical diagnostics*: abstracts, Samara.
[2] E.K.Gelfand.,B.S.Sychev.,T.V.Tkacheva , V.A.Rassylov, L.M. Rodionova. 1999 Radiotional resistance of multichanal detectors on the basis of “scintillation-photodiode” sistems *Theses of the International Conference «STINT-1999»*, Moscow
[3] I. M. Sol'sky 2005 Growing large-size single crystals of cadmium tungstate with high optical homogeneity *Technology and engineering in electronic equipment* **6** 47-52
[4] M. M. Gurevich 1983 *Photometry. Theory, techniques and devices* (Leningrad: Energoatomizdat)
[5] M. I. Epshtein 1990 *Measuring optical radiation in electronics* (Moscow: Energoatomizdat)
[6] Saint Gobain Crystals. Physical Properties of Common Inorganic Scintillators./ – [Electronic resource] URL: http://www.hep.caltech.edu/~zhu/papers/08_tns_crystal.pdf, free. Accessed date: November 13, 2014.