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ORIGINAL PAPER

Efficient reading of thermoluminescent dosimeter signals using semiconductor detectors

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Abstract. The aim of this experimental work was to examine whether semiconductor photodetectors may be applied for the efficient reading of thermoluminescent dosimeter (TLD) signals. For this purpose, a series of experiments have been performed at the Department of Physics, Warsaw University of Technology, in cooperation with the Central Laboratory for Radiological Protection (CLOR). Specifically, the measurement system proposed here has been designed to detect a signal from TLDs that use a semiconductor detector operating in conditions analogous to those met when using commercial devices equipped with a classic photomultiplier. For the experimental tests, the TLDs were irradiated with a beam of ^{137}Cs radiation in the accredited Laboratory for Calibration of Dosimetric and Radon Instruments. Eventually, a comparison of the results obtained with a semiconductor detector (ID120) and a commercial TLD reader with a photomultiplier tube (RADOS) were made.

Keywords: TLD • TLD reader • Semiconductor detector

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Introduction

Thermoluminescent dosimeters and dosimetric measurement

Thermoluminescent dosimeters (TLDs) are passive dosimeters that measure the cumulative dose of ionizing radiation throughout the exposure by measuring the intensity of light emitted by a suitable material placed inside the detector. The measurement takes place in a special reader in which dosimeters are heated up to a specific temperature. The temperature needed for readout depends, among others, on the thermoluminescent (TL) material used for the detectors. During readout, stored energy is released in the form of light. The energy of the emitted light is proportional to the radiation energy absorbed by the TL material. By measuring the emitted light intensity, one can get information about the absorbed dose of ionizing radiation. After the measurements are performed, the assessment about the ionizing dose is lost, and the dosimeter cannot be read out again [1].

More than a dozen among the available TL substances are used as components of ionizing radiation detectors. The most widely used substances in TLDs are (1) lithium fluoride activated with magnesium and titanium (LiF:Mg,Ti) and (2) lithium fluoride activated with magnesium, copper, and phosphorus (LiF:Mg,Cu,P), which are much more sensitive. Additionally, $Li_2B_4O_7$:Mn, $Li_2B_4O_7$:Cu, CaF_2:Mn, CaF_2:Dy, $CaSO_4$:Tm, Mg_2SiO_4:Tb, BeO,

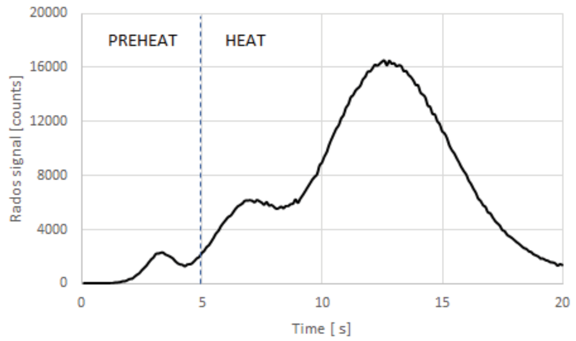

Fig. 1. Typical glow curve of the TLD readout obtained with a commercial RADOS detector. Two phases of the measurement, namely, preheat and heat, are indicated.

MgO, MgB_4O_7:Dy, and MgB_4O_7:Tm are also used. When selecting the material for TLD, it is necessary to ensure balance between sensitivity to radiation and tissue equivalence.

The result of a typical TLD readout, showing the dependency of the intensity of the TL signal on measurement time, is presented in Fig. 1.

As shown in Fig. 1, the glow curve from the TLDs is composed of several peaks, each of them corresponding to the different types of trapping state present in the TL material (lattice). The peaks appearing in the preheat stage of the measurement correspond to the trapping states shallow enough to be emptied thermally at room temperature, and these disappear within a few days of irradiation [2]. The peaks in the second set of the glow curve, corresponding to the heat section, are called the dosimetric peaks. The latter form the basis of the measurement procedure facilitating assessment of the dosimetric properties of a TL dosimeter. The shape of the glow curve depends on the concentration of the dopants in the TL material used in the dosimeter [3], the thermal treatment during fabrication, the time and temperature of annealing, and finally, the reading from the dosimetric pellets [4]. The simplest method to analyse the curve is to integrate the whole TL signal.

The detectors used for measurements in this work are TL-type commercial MCP-N detectors. These detectors are in the form of round pellets, with a diameter of 4.5 mm, made of LiF:Mg,Cu,P. These are popular detectors used to routinely monitor personal and environmental doses from ionizing radiation. According to the readout procedure applied in the Central Laboratory for Radiological Protection (CLOR) for MCP-N detectors, the preheating phase takes 5 seconds, heating takes 15 s, and TL signal sampling takes 0.1 s. MCP-N detectors are read out at a temperature of 250°C.

Photomultipliers

Photodetectors used for thermoluminescence tests and measurements in TLDs are the most important elements of this type of dosimetric devices when used to evaluate doses stored in detectors. The most commonly used are high-voltage photomultipliers made of a vacuum tube and a system of signal-amplifying electrodes [5]. Use of a photomultiplier is a good and proven solution, but its application is associated with several restrictions. First of all, photomultiplier lamps require a voltage of >1 kV [5], which is in opposition to most of the other elements in the TLD system operating in the voltage range of 5–12 V. In addition, photomultipliers are sensitive to (1) possible mechanical damage due to their construction based on a vacuum lamp and (2) eventual harm of the photocathode caused by interaction with light of very high intensity.

Even if the main aim of this paper is not intended to suggest that photomultipliers should be completely eliminated from applications in TLD readers, it allows the conclusion that the dynamically developing technology of semiconductor detectors allows achieving similar results in TLD dosimetry. The latter is possible owing to the progressively increasing number of new semiconductor materials allowing the measurement of the entire spectrum of visible light, as well as the increasingly developed methods for amplifying signals from active photosensitive elements. Such reasoning allows one to believe that in the future, in some applications, photomultipliers may be successfully replaced by photosensitive semiconductor elements.

Currently, the best solution when using semiconducting elements to detect weak optical signals is to apply avalanche photodiodes and their matrices [6–10]. This solution, with appropriate temperature stabilization, allows achieving similar results in TL dosimetry as with photomultipliers but without the restrictions described earlier. Such a measuring system, made of a temperature-stabilized avalanche photodiode, has been applied in this work, as described in the next section.

Experiment

The measurement system presented in this paper has been specifically designed to read the TLDs using a semiconductor detector in conditions analogous to those prevailing in commercial devices equipped with a classic photomultiplier (e.g., RADOS). The measuring system consists of two basic blocks (Fig. 2), the first of which is applied to the heat-analysed pellets made of TL material; and the second one that allows to register the light emitted by the pellets during their heating.

The first part of the system allows to heat the TLDs using heated nitrogen and to feed the signal from the dosimeter to the photodetector by means of an optical fiber. The second part of the system is formed by an avalanche photodiode combined with a cooling system for measurement of light signals of significantly low intensities.

Specifically, the system applied in the measurement experiment is a photon counter built from the ID120 visible single-photon detector (IDQ, Switzerland), based on reliable silicon avalanche photodiodes sensitive in the visible spectral range with a high quantum efficiency up to 80% and a large active area and adjustable settings. Such a de-

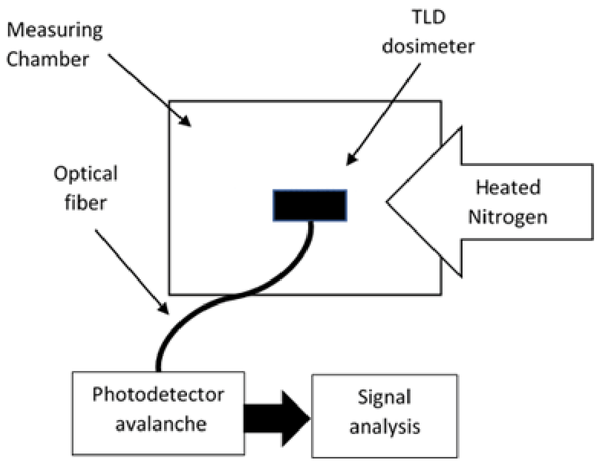

Fig. 2. Measurement setup composed of two main blocks – one related to the heating system, and the other responsible for optical system detection and analyses.

vice allows for the precise setting of the photodiode working temperature and registration of the signal by means of the embedded software. The photodiode is tightly connected with a fiber optic cable, so that the measured signal of thermoluminescence is not disturbed by external light.

The only disadvantage of the ID120 device is its maximal spectral sensitivity, which is observed at the wavelength of 750 nm, when the spectrum of TLD pellet radiation is within the range of 350–450 nm. Although <10% of photodetector effectiveness is applied in this case, it still allows the registration of the characteristics of the TLD pellets' response.

Results

The results obtained with the system based on a semiconductor photodetector for dosimeters irradiated with doses of 4.13, 8.26, 12.40, 520.66, and 826.45 mGy are shown with a solid gray line in Fig. 3A–E, respectively. The graphs for the measurements obtained using a commercial TLD reading device RADOS are also shown using black solid lines. The final comparison of the results obtained with the two measurement systems is presented in Fig. 4.

The obtained results clearly show that despite the use of a photodetector whose spectral characteristics are not matched to the wavelength of light emitted by the TLD, the compliance of the measurements performed with the proposed system is satisfactory.

As one can notice from Fig. 3A–E, the shape of the signal obtained by the semiconductor photodetector is close enough to the shape of the curve obtained by a commercial reader. The quality of the glow curve is related to the operating frequency (5 Hz) of the ID120 photodetector. By increasing the frequency, one can obtain a smoother characteristic.

The graphs obtained with the tested detector allow for the clear identification of the "preheat" stage, as well as measurement of the corresponding thermoluminescence, the value of which is proportional to the dose measured by the TLD.

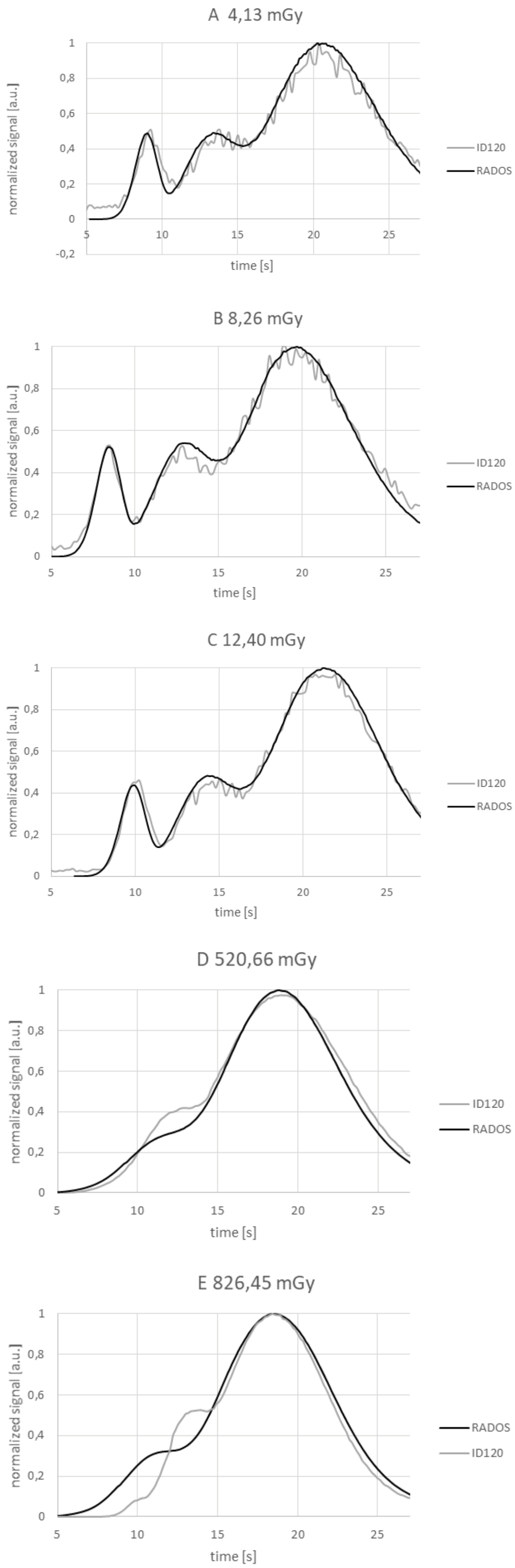

Fig. 3. Results obtained with a semiconductor detector (ID120) and a commercial reader with a photomultiplier tube (RADOS) for five different irradiation doses.

Table 1. Combined measurement results for the RADOS reader and the tested ID120, for various doses recorded in TL dosimeters

Radiation dose [mGy]	4.13	8.26	12.40	520.66	826.45
RADOS signal [counts]	5 740 914	11 561 294	17 685 898	690 597 534	1 097 703 281
ID120 signal [counts]	28 721	53 532	74 975	1 959 558	2 687 246

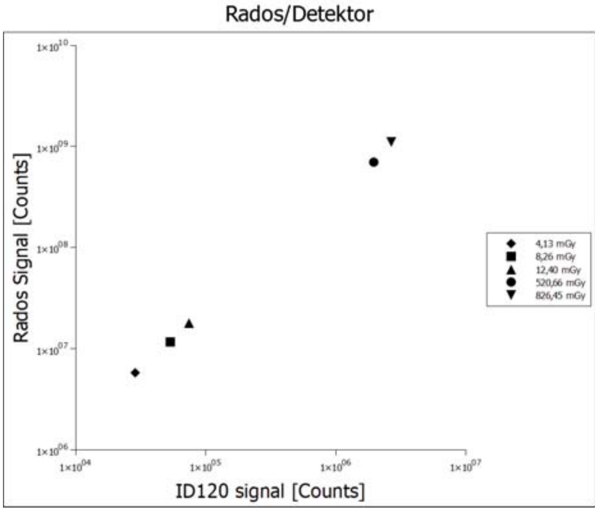

Fig. 4. Comparison of the signal intensities obtained with the commercial RADOS device and the tested ID120 semiconductor detector.

Each measurement was performed repeatedly to make sure that the results obtained do not contain errors. At the same time, before each measurement, a test light pulse was generated, which had the same shape and size each time.

We did not estimate the detection threshold of the light detector because this publication is a preliminary work. The article shows that the detector can work properly for dosimeters irradiated with doses from 5 mSv (4.13 mGy) to 1 Sv (826.45 mGy). The measurement range obtained during the work allows us to conclude that further development will enable the use of semiconductor photodetectors to measure the entire dose range used by TLDs.

The difference in signal shapes for high doses (520.66 mGy and 826.45 mGy) is related to the delay between irradiation and readout. The preheat part of the glow curve, which does not participate in dose estimation, ends at the 10th second. Readouts for 4.13, 8.26, and 12.40 mGy were made within a few days from irradiation, while readouts for 520.66 mGy and 826.45 mGy were made with greater delay (about two weeks). Therefore, the preheat peek in the readouts of 520.66 mGy and 826.45 mGy faded. Additionally, the shape of a glow curve may vary for different TL pellets.

Figure 4 shows that there is almost a linear dependence between the data obtained for the professional photodetector and the semiconductor photodetector. Deviations of the measurement data from a straight line are caused by the fact that a photodetector with spectral characteristics not matched to the spectrum emitted by the TL dosimeters has been used for testing. This may cause the measurements for low-dose values (i.e., 4.13, 8.26, and 12.40 mGy) to be subject to high uncertainty while the detector works at the limit of its resolution.

Table 1 shows the actual counts for the semiconductor detector and professional detector tested.

The use of avalanche diodes instead of traditional high-voltage photomultipliers seems to be a good solution. Of course, the results presented in the article consist of preliminary work, but ultimately, such a solution can be much cheaper than when using photomultipliers. Avalanche diodes are much more resistant to mechanical damage and require lower levels of supply voltage than glass photomultipliers used so far in TL dosimeter readers.

The limitations seem to be that avalanche diode cooling needs to be performed, and the working threshold for small doses is currently higher than that for the traditional solution. The development of technologies based on avalanche diodes suggests that in the near future, we will achieve sensitivity at a similar level.

Conclusion

The results presented in this paper show that it is reasonable to use semiconductor photodetectors to read TL dosimeters, instead of the commercially available dosimeters based on photomultipliers.

The results presented in the graphs (Fig. 3) are similar in shape to those obtained with a commercial detector, which suggests that they can be calibrated and used to read TLD detectors. A very important result is that in the case of small doses of about 5 mSv, the shape of the signal is similar to the signal from a commercial reader. It is important because for semiconductor photodetectors, measuring the very weak light signals is the biggest problem.

In further work on the development of the proposed and designed measurement system, an avalanche photodetector with a spectral sensitivity matching that of the measured signal will be used, thus enabling us to achieve even better results.

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