APPLICATION OF CdZnTe QUASI-HEMISPHERICAL DETECTORS IN STRONG GAMMA-RADIATION FIELDS

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***Abstract*—The results of a study of some ways to improve spectroscopy characteristics of the CdZnTe quasi-hemispherical detectors when working in high gamma radiation fluxes are presented. It was shown that the use of IR illumination with a wavelength of 1050 nm or 1200 nm or at slight warm-up of the detector to +30°C … +40°C can significantly improve spectroscopy performance of the CdZnTe detectors of size 3.5 mm × 3.5 mm × 1.75 mm when operating in a tested gamma-radiation field with a dose rate up to 590 mGy/h.**

Keywords*—CdZnTe (CZT), gamma-radiation detectors, semiconductor radiation detectors, room temperature semiconductor detectors, infra-red (IR) illumination, IR LED, high flux gamma-radiation, leakage current, voltage-current characteristic

I. INTRODUCTION

Presently room temperature CdZnTe (CZT) nuclear radiation detectors of various designs and sizes are widely used for spectrometric measurements of X- and gamma-radiations. In most cases, the spectrometric detectors with highest efficiency are required. However, there are tasks where good spectroscopic CZT detectors with a low efficiency should be used. These tasks are connected with spectrometric measurements in high gamma-radiation fluxes. Small size quasi-hemispherical CZT detectors [1–6] are already successfully used to control nuclear spent fuel or/and high-level radiation waste. Recently a new system for verification of nuclear spent fuel assemblies using Passive Gamma-Emission Tomography (PGET) [7] was developed and tested. The system contains about 200 detector modules with CZT quasi-hemispherical detectors of size 3.5 mm × 3.5 mm × 1.75 mm. More than 1000 such detectors were tested. Approximately, only half of the measured detectors successfully passed tests under high gamma-radiation fluxes and were found suitable for subsequent use in the PGET system. Therefore, study of causes of the detectors' characteristics deterioration in high gamma-radiation fluxes and search for ways to eliminate these causes is an urgent task. It was previously shown [8] that IR illumination with infrared light with wavelengths close to the absorption edge of the CdZnTe can significantly improve the performance of the quasi-hemispherical detectors operating at room and low temperatures. In this work, we studied the effects of IR illumination and heating of the quasi-hemispherical detectors operating in high gamma-radiation fluxes from the ^{137}Cs.

II. RESULTS AND DISCUSSION

For measurements, experimental setup based on application of a calibrated measurement bench with a high activity gamma-radiation source ^{137}Cs was used. The stand allows changing distance between the source and the detector. The maximum achievable dose rate at the measurement point with the minimal distance between the source and the detector (R=28 cm) was about 590 mGy/h. Detector fixture allowing installation and quick change of the detectors and IR LED. CZT quasi-hemispherical detectors of size 3.5 mm × 3.5 mm × 1.75 mm fabricated of different raw CdZnTe crystals were tested. Changeable IR LED with wavelengths 940 nm, 1050 nm and 1200 nm were used at measurements. Used heater allows heating the detector up to the +50°C. During the measurements LED forward current, heater consumption currents and operation temperature were controlled. Detector's leakage currents and spectra of ^{137}Cs were recorded. Schematic experimental setup is shown on Fig. 1.

Intense gamma irradiation significantly affects leakage currents and spectrometric characteristics of the CZT detectors. Fig. 2 show typical voltage-current characteristics of CZT quasi-hemispherical detectors measured at room

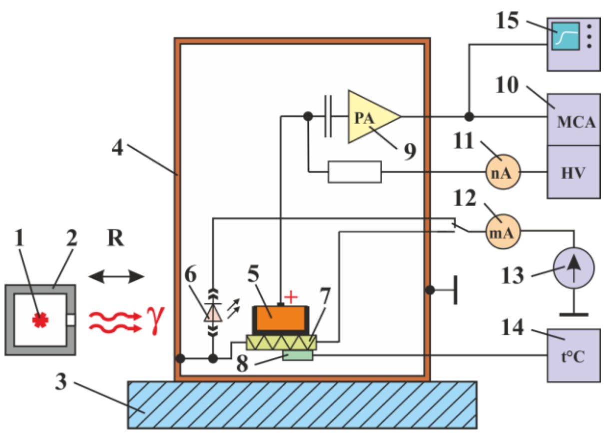

Fig. 1. Schematic experimental setup.

1-highly active radiation source ^{137}Cs; 2-lead container/collimator; 3-movable stand; 4-detector fixture; 5-CZT detector; 6-IR LED; 7-heater; 8-temperature sensor; 9-charge sensitive preamplifier; 10-digital multichannel analyzer type MCA527 with high voltage power supply; 11-detector leakage current meter (resolution 1 nA); 12-LED forward current or heater consumption current meter; 13-stabilized current source for IR LED or heater; 14-temperature monitor; 15-digital oscilloscope.

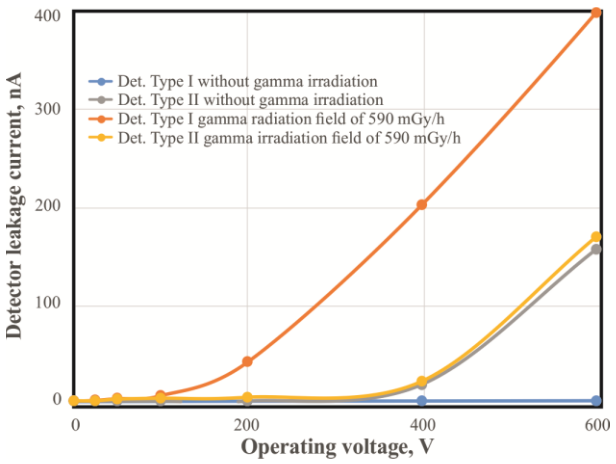

Fig. 2. Voltage-current characteristics of CZT quasi-hemispherical detectors measured at room temperature without and under influence of high gamma-radiation fluxes.

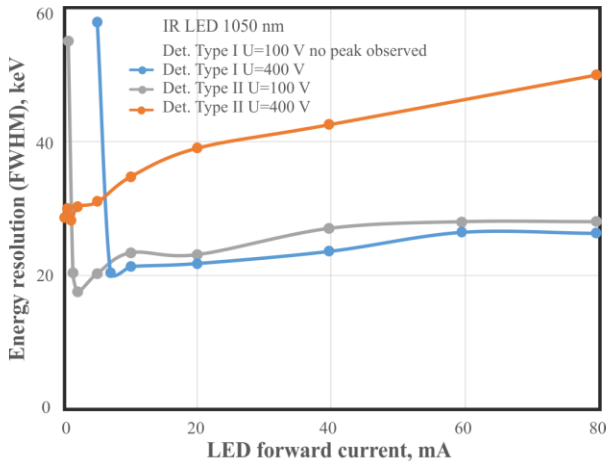

Fig. 4. Energy resolution (FWHM) at 662 keV versus IR LED forward current at different operating voltages measured in gamma-radiation field of 590 mGv/h.

temperature without and in high gamma-radiation flux. Processing of measurement results allows distinguishing two types of detectors differing in a behavior of leakage currents under gamma irradiation. Type I – are detectors that have a significant (20 … 100 times) increase in leakage current under influence of strong gamma irradiation. Large increasing of the leakage currents were accompanied by a significant deterioration or even complete disappearance of the spectrometric capabilities of such detectors. These detectors, as a rule, had insignificant leakage currents < 5 nA at room temperature at 400 V without exposure to intense gamma irradiation. Type II – are detectors that did not have or had a slight increase in leakage current under to influence of gamma irradiation. These detectors, as a rule, had significant leakage currents 20 … 300 nA at 400 V without exposure to intense irradiation and did not allow increasing the operating high voltage to acceptable values due to a significant increase in the noise level with increasing voltages.

For detectors of the first type, operating in high gamma-radiation fluxes, complex dependencies of the leakage currents on IR illumination intensity with IR LED wavelength of 1050 nm were obtained, Fig. 3 in the range of the LED operating currents (⩽ 100 mA), the LED relative radiant intensity is approximately directly proportional to the LED forward current. With increasing of the LED forward current,

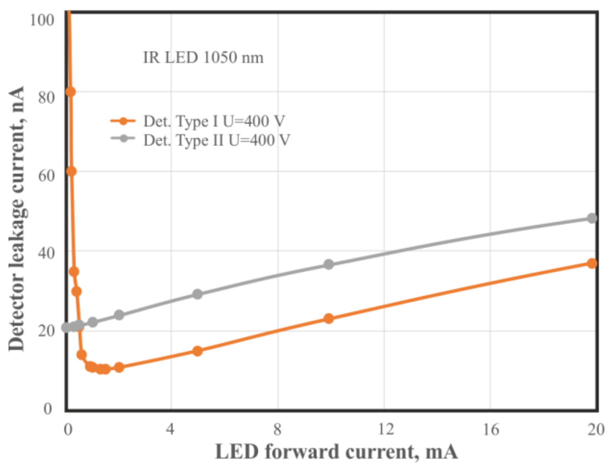

Fig. 3. Detectors leakage currents versus IR LED (1050 nm) forward current measured in gamma-radiation field of 590 mGy/h.

the leakage currents of such detectors first decreases, then reaches the minimum, and then begins to rise slowly. The leakage current of the second type detectors increases with rising of the LED forward current.

The behavior of the energy resolution of the detectors of both types under IR illumination also had own peculiarities, Fig. 4. First, it improves noticeably with increasing of IR LED forward current and then starts to deteriorate. Moreover, such a dependence of energy resolution on values of the LED direct current for detectors of the second-type was observed only at relatively low operating voltages < 200 V. At higher operating voltages, the energy resolution of the second-type detectors deteriorated with increasing of IR illumination intensity.

Illumination by IR light with wavelengths of 1050 nm or 1200 nm as well was found to greatly improve spectrometric characteristics of the quasi-hemispherical CZT detectors operating in high gamma-radiation fluxes. This allows expanding the range of count rates in which the normal operation of the detectors is observed. Fig. 5 demonstrates dependence of energy resolution versus count rate obtained with different levels of IR illumination. Count rate was varied by changing the distance between radioactive source and tested detector. Illumination by IR light with wavelengths of 940 nm did not produce positive effect.

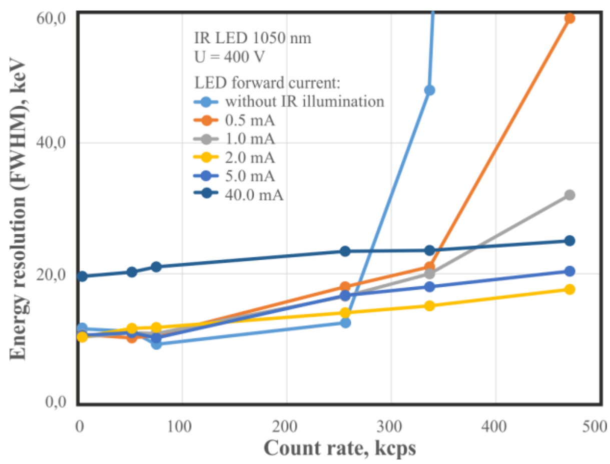

Fig. 5. Energy resolution (FWHM) at 662 keV versus recorded count rate measured without and with IR LED illumination with different LED forward currents.

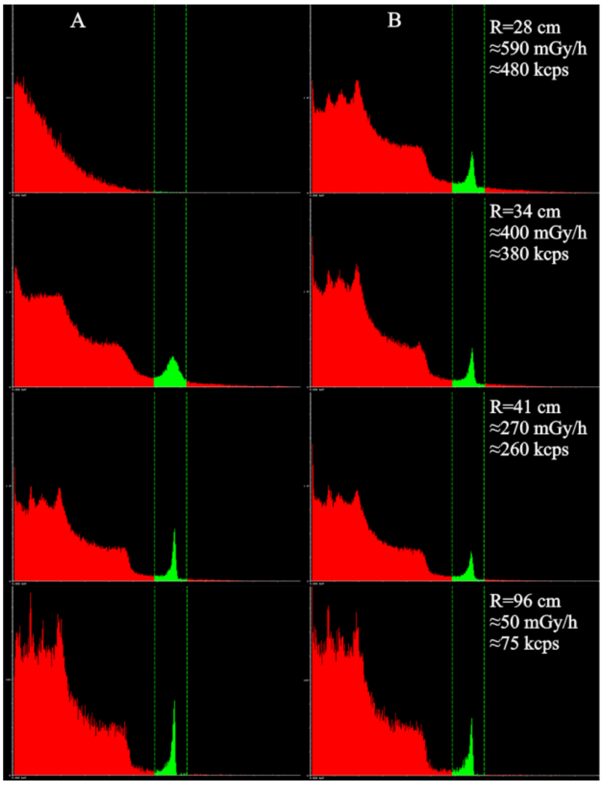

Fig. 6. Spectra of ^{137}Cs measured without (A) and with (B) IR illumination at different distances between radiation source and detector.

Fig. 6 illustrates changes in the shape of ^{137}Cs spectra measured at different distances between the radiation source and the detector without and with IR illumination (1050 nm) The LED forward current 2 mA and detector operating voltage 400 V were applied.

A study of temperature dependence of the detector's leakage currents and energy resolutions of the detectors operating in a high gamma radiation fluxes was carried out. A decrease (quenching) of the detector's leakage currents and energy resolution improvement with a slight increase in the operating temperature by + 5°C … + 10°C were found, Fig. 7 dependences were measured in gamma-radiation field of 590 mGy/h without IR illumination.

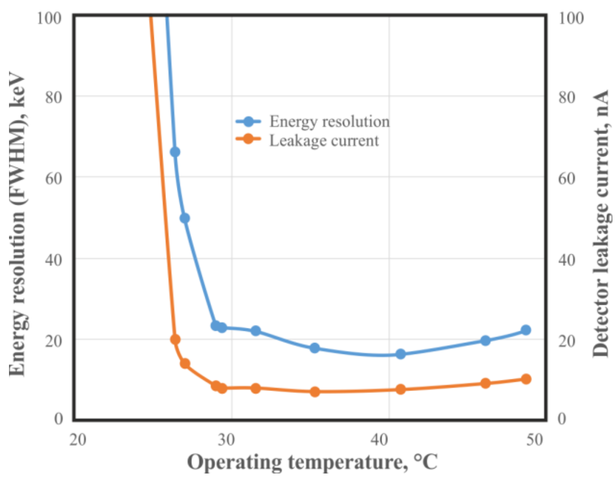

Fig. 7. Temperature dependencies of energy resolution (FWHM) at 662 keV and leakage current at 400 V.

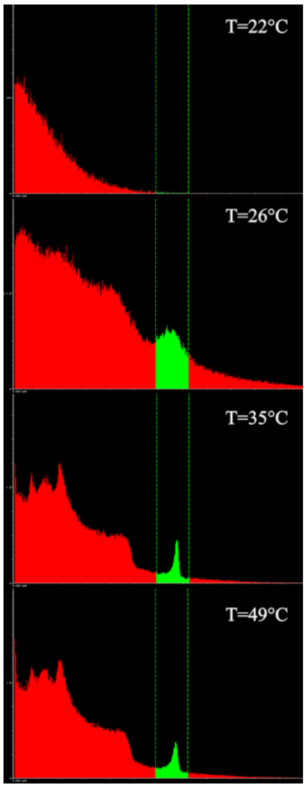

Fig. 8. Spectra of ^{137}Cs measured without IR illumination at different operating temperatures in radiation field of 590 mGy/h. Operating voltage 400 V.

The Table I shows the measurement results of energy resolutions of two types CZT quasi-hemispherical detectors of 3.5 mm × 3.5 mm × 1.75 mm without and with IR illumination measured in a weak and in a high gamma-radiation flux.

TABLE I.

Detector type	**Operating voltage, V**	**Energy resolution (FWHM) at 662 keV, keV**			
		Count rate <5 kcps	***Count rate ≈ 500 kcps***		
		room temperature, without IR illumination	***room temperature, without IR illumination***	***room temperature, with IR illumination***	***increased temperature (+30°C … +50°C), without IR illumination***
I	50	19	no peak	no peak	58
	100	15	no peak	no peak	15
	200	13	no peak	14	13
	400	12	no peak	18	16
	600	10	no peak	24	17
II	50	16	no peak	26	24
	100	15	no peak	24	28
	200	13	28	25	23
	400	16	44	37	52
	600	29	62	57	61

III. Main Results

Operating in high gamma-radiation fluxes can significantly worsen spectroscopy performance of the tested quasi-hemispherical detectors.

Tested detectors can be divided into two groups. The first are detectors with rather low leakage currents < 5 nA at 400 V without gamma-irradiation but with strongly increasing leakage currents (to 20 … 100 times) under influence of the high intensity gamma-radiation flux. In second group are detectors with leakage currents of about 20 … 300 nA at 400 V without gamma-irradiation, which only slightly increasing in high gamma-radiation flux.

Illumination by IR light with wavelengths of 1050 nm or 1200 nm as well as heating up to + 30°C … + 40°C was found to greatly improve spectrometric characteristics of the quasi-hemispherical CZT detectors operating in high gamma-radiation fluxes.

For detectors of the first type, complex dependencies of the leakage currents and the energy resolutions on forward currents of the IR LED and operating temperatures were obtained. With increasing IR illumination intensity or with increasing operating temperature, the leakage current of such detectors first decreases, reaches the minimum, and then begins to rise slowly. The behavior of the energy resolution is similar – first it improves noticeably and then starts to deteriorate.

Such complex behavior of leakage currents and energy resolution under the influence of high gamma-radiation fluxes and IR illumination can be associated with a change in an electric field distribution in the detector caused by formation of a space charge due to trapping of photo generated holes at deep levels and their detrapping under the influence of IR illumination [9]. A detailed explanation of the effects found requires additional research.

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