Nuclear Technology & Radiation Protection: Year 2017, Vol. 32, No. 3, pp. 256-260

STUDY ON TEMPERATURE COEFFICIENT OF CdTe DETECTOR USED FOR X-RAYS DETECTION

by

Siming GUO[1*], Jinjie WU[1], Haiyan DU[1], Jian ZHANG[1], Xufang LI[2], Congzhan LIU[2], Shuai ZHANG[1], Chengze LI[1], Binbin HUO[1], Zhenyu LIAO[1], and Ying LIU[1]

[1] National Institute of Metrology, Beijing, China
[2] Institute of High Energy Physics, Beijing, China

Scientific paper
http://doi.org/10.2298/NTRP1703256G

The temperature of the working environment is one of the key factors in determining the properties of semiconductor detectors, and it affects the absolute accuracy and stability of the standard detector. In order to determine the temperature coefficient of CdTe detector used for X-rays detection, a precise temperature control system was designed. In this experiment, detectors and radiographic source were set inside a thermostat with temperature of 0 40 °C, so that the temperature can be regulated for the test of the temperature coefficient of CdTe detector. Studies had shown that, with the increase of the temperature, the energy resolution and detection efficiency of the CdTe detector would deteriorate, and under 10 °C the detectors have better performance with the 8 keV X-rays.

Key words: CdTe detector, temperature coefficient, X-ray, detection efficiency, energy resolution

INTRODUCTION

The basic principle of semiconductor detector is that the high voltage electric field is generated in the semiconductor by a thin layer of metal electrodes on the surface of semiconductor. Ionizing rays generate electron-hole pairs in the detector when the rays get inside the semiconductor, the number of the electron-hole pairs is proportional to the energy of the incident particle. Electrons and holes move to different electrodes, and are collected by the electrodes. The electrical pulse signal is thus formed. Cadmium telluride (CdTe) is a type of compound semiconductor materials [1]. Compared with Si and Ge, CdTe has a larger atomic number and higher density (ρ = 5.83 gcm^{-3}), hence it has better ability to prevent and absorb the X-rays and gamma rays, so it has higher intrinsic detection efficiency. Besides, CdTe detector also has the advantage of small size and high resolution ratio. The most remarkable characteristic of the CdTe detector is that it can work at room temperature [2].Thanks to these characteristics, CdTe detector has broad application, including medical diagnosis [3].

Performance of the detector can be various at different temperatures. Temperature characteristic is a key factor that influences the absolute accuracy and stability of a standard detector. CdTe detectors can be operated at room temperature. But the temperature is changing, so the performance of the detector can also be affected [4]. Thus, it is a significant work to carry out the study on temperature characteristics of CdTe detector within 0-40 °C and understand the influence of temperature on CdTe detector's detection efficiency and energy resolution.

* Corresponding author; e-mail: gsm@nim.ac.cn

EXPERIMENTAL FACILITY

Temperature control system

Temperature control system is thermostat designed for the experiment. The thermostat uses the technology of compressor refrigeration, as well as stable and reliable control technology. The control system is independently researched and developed. Equipped with a high resolution ratio true color touch screen, it is user-friendly, convenient to operate and has high control accuracy. Therefore, it can provide a stable, accurate temperature environment, which meets the needs of the experiment. As shown in fig. 1, the thermostat temperature control system has a separated structure, the thermostat and operation screen occupy upper part, and supporting frame in the lower part. The refrigerating compressor set is separately placed behind the test chamber and connected by refrigeration pipe line. The system structure is compact and takes up a small space.

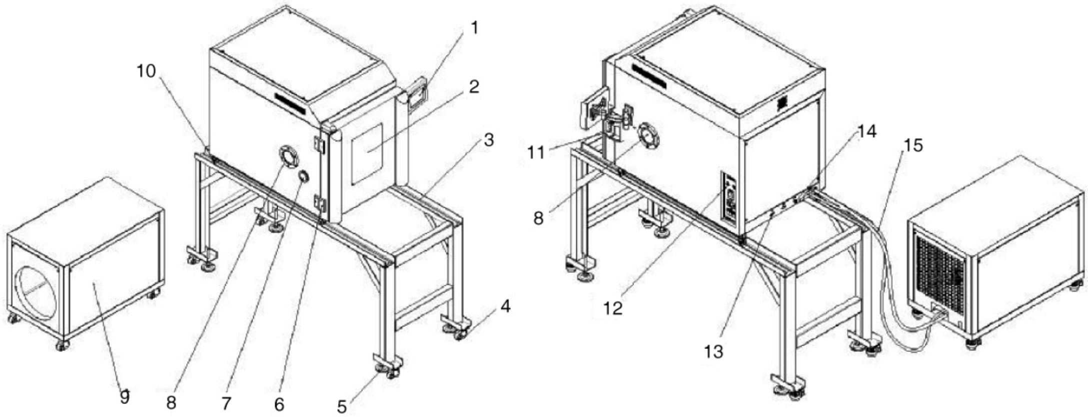

Figure 1. Diagram of the thermostat
(1) Touch screen, (2) viewing window, (3) supporting frame, (4) wheels, (5) angular glass, (6) hinge, (7) wire hole, (8) rays hole, (9) refrigeration and heating set, (10) wheel of thermostat, (11) handle, (12) control panel, (13) power wire, (14) inflator nozzle, (15) refrigeration tubes

The thermostat has a nominal capacity for 216 L, controllable temperature range –20 °C C fluctuation of temperature 0.5 °C, uniformity of temperature 2 °C, temperature deviation 2 °C, cooling rate 1 °C min^{-1}, (+70 °C –20 °C, zero load, tested according to GB/T 5170.2-2008), warming rate 3 °C min^{-1} (–20 °C +70 °C, zero load, tested according to GB/T 5170.2-2008), using low-noise high efficiency scroll refrigeration compressor for refrigeration with an air-cooled engine for cooling, using high-efficient stainless steel finned tube heater for heating. The cycle air cooled machine for cooling is highly reliable noise-proof motor and stainless steel centrifugal impeller. In addition, temperature control system has security control device for electric leakage protection, phase sequence protection, incorrect operation protection, overpressure protection, overheating (overload) protection, working fluid leakage alarm, fan overheating (overload) protection, heater overheating protection, multiple temperature excess protection, program operation protection, and temperature warning. The thermostat has high stability, can precisely adjust and control the experimental environment temperature to meet experimental requirements.

X-rays generation system

In the experiment an X-rays apparatus is used to produce X-rays. X-rays apparatus consists of X-rays tube, power supply and control circuit. High voltage provides high pressure field, makes active electrons on filament accelerated flow to anode, electron current bombards the anode target, most of the power is converted to heat, a small part of the power produces X-rays by bremsstrahlung [5]. Figure 2 shows the principle of X-rays apparatus. In the experiment, a micro X-rays apparatus is used, its maximum tube voltage is 50 kV, maximum tube current is 1.0 mA, and the peak-power is 50 W.

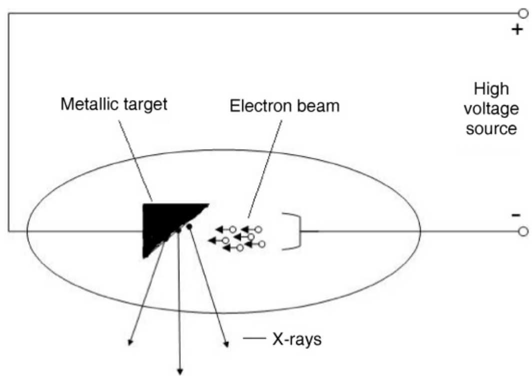

Figure 2. Principle of X-rays apparatus diagram

In the X-rays tube, the cathode launches out two different X-rays spectra, produced from accelerated electrons bombardment of the anode target, under high voltage. One is continuous spectrum, uncorrelated with the target material, the other one is linear characteristic X-rays spectrum, which is uncorrelated with accelerated voltage, but correlated with the target material. Characteristic X-rays spectrum is produced by inner shell electronic transitions of atoms. Inner shell electrons are ionized when high-speed electrons bombard the target atoms, holes are produced in the inner shell, electrons from the outer shell transit to holes in the inner shell where electromagnetic radiation spectrum, namely characteristic X-rays spectrum, is generated. Usually K, L, M, N... are used to represent principal quantum number (number of electron shells in chemistry), n = 1, 2, 3, 4 ... represents energy level. When the electron at n = 2 shell transits to the hole at n = 1 shell, this radiation is known as the K_α type. When the electron at n = 3 shell transits to the hole at n = 1 shell, this radiation is known as the K_β type so, n = 3 jump to n = 2 shell is called L_α type, n = 4 jump to n = 2 is called L_β type *etc*. It is more intuitive to understand mechanism of producing X-rays using XOP software simulation of the spectrum of X-rays apparatus. Figure 3 shows X-rays spectrum of tungsten target

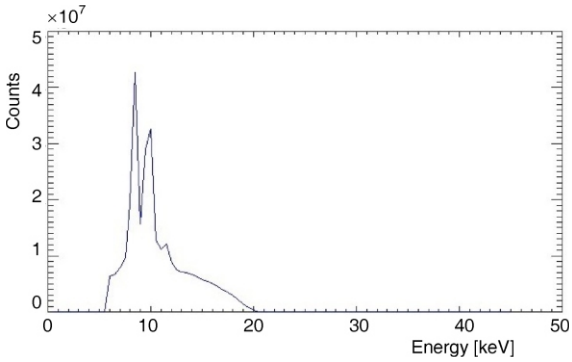

Figure 3. X-rays spectrum of tungsten target at 20 kV by XOP simulation

at 20 kV by XOP software simulation. In the figure, the two peaks respectively correspond to K_α and K_β characteristic peak of tungsten target [6].

Control software of the X-rays apparatus displays temperature of the X-rays tube in real time. Temperature of the X-rays apparatus is almost invariant when changing the temperature in the thermostat during the experiment, it always remains around 40 °C. The effects of temperature change on X-rays apparatus could be omitted in the experiment.

CdTe DETECTOR TEMPERATURE CHARACTERISTIC EXPERIMENT

To study the detection efficiency of the detector one should determine the absolute photon number of detector's location first. In the experiment, a standard HPGe Detector is used for absolute photon number measurement. The detection efficiency of the HPGe detector has been calculated by Monte Carlo simulation program. The photon number deposited in HPGe Crystal can be recorded in different energy interval with a defined parallel X-rays source, so the detection efficiency in each energy interval can be calculated. The results of simulation displayed that the maximum energy that can be detected by the HPGe detector is 350.00 keV, the detection efficiency is high between 14.84 keV and 96.23 keV energy interval, can reach to more than 90 %. Figure 4 shows the detection efficiency in 2-18 keV energy interval. At about 11.00keV, the detection efficiency decreased obviously because Ge elements are activated, photons cannot be documented owing to the occurrence of K_α and K_β characteristic X-rays escape [7, 8].

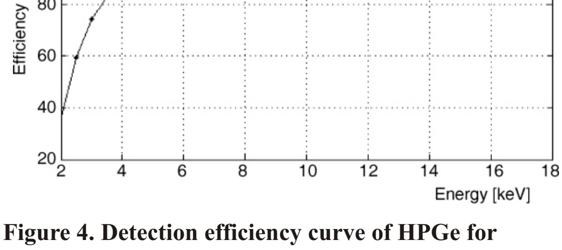

Figure 4. Detection efficiency curve of HPGe for (2-18) keV photons

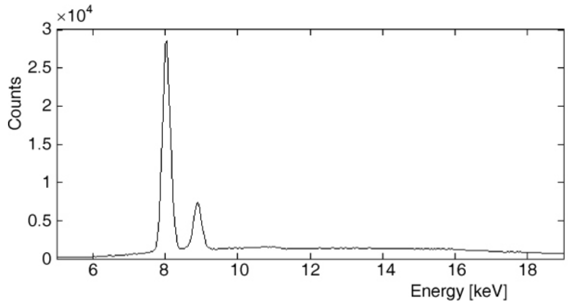

Figure 5. Measured spectrum of X-rays tube by HPGe

Set the X-rays tube voltage at 20 kV, the energy spectrum is measured with standard HPGe detectors, as shown in fig. 5. Contrast with fig. 3, fig. 5 shows that the characteristic peak appears around 8 keV with 20 kV X-rays tube voltage. There are two peaks apparent in the experiment.

The temperature characteristics is studied by using a CdTe semiconductor detector, the outermost of the probe is a covering layer of beryllium window, underside are CdTe crystals, electronics system, cooling module and power system. A layer of platinum is attached to upper surface of CdTe crystal, lower surface is ceramic material for supporting, the whole detector is wrapped up by stainless steel. X-rays apparatus and CdTe detector are placed in the thermostat and it is made sure the CdTe crystal faces directly to exit portal of X-rays apparatus. Experiment device schematic is shown in fig. 6. In order to guarantee the temperature of the detector is same as environment temperature, counting should begin after the thermostat has reached the target temperature and it stayed stable for one hour.

When the temperature of thermostat is adjusted from 0 °C to 40 °C with each interval of 10 °C, the measured spectrum of the experiment is shown in fig. 7. The bimodal spectrum, shown in fig. 5 and fig. 3, appears when the temperature is 0 °C. There is only one L characteristic peak when the temperature is above 10 °C, meanwhile the energy resolution reduces. As

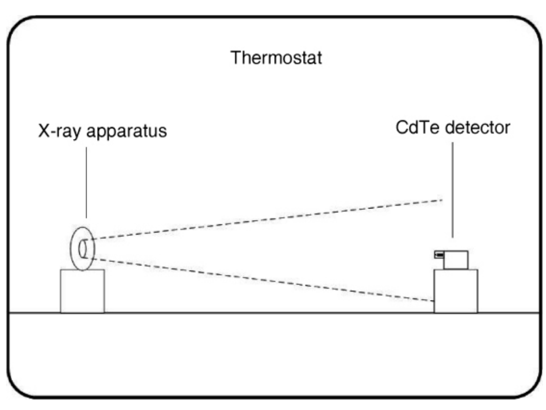

Figure 6. Diagram of CdTe temperature characteristics experiment

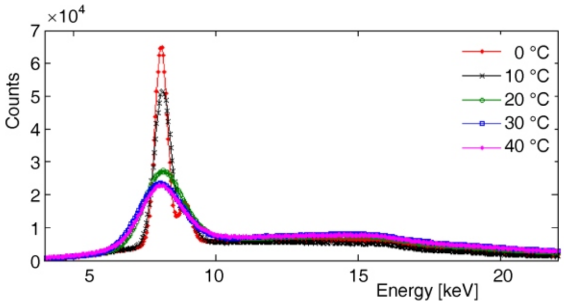

Figure 7. Spectra of X-rays tube at different temperatures by CdTe detector

Table 1. Result statistics

Temperature [°C]	Counts at the peak	Counts in the area	Detection efficiency at the peak [%]	Detection efficiency [%]	Energy resolution [%]
0	64 751	857 879	61.32	80.96	6.95
10	51 605	811 334	48.88	76.57	9.89
20	27 350	615 983	25.90	58.13	23.07
30	22 944	529 171	21.73	49.94	25.27
40	21 910	511 700	20.75	48.29	31.15

the temperature increases the energy resolution becomes worse, while the detection efficiency decreases.

The total count of the detector at the characteristic peak of L is shown in tab. 1. The absolute number of photons at the energy level can be measured by standard HPGe detector, which can determine the detection efficiency of CdTe detector, and understand the effect of temperature on the detection efficiency of the detector. The counts of the peak of HPGe detection is 456 336, and counts of the peak area is 4 579 680. As the detection efficiency at the energy point is 98 %, the total photon number at the peak is 465 649, and the total number of photons getting into the HPGe detector is 4 673 143. The effective detection area of this HPGe detector is 104.04 mm^2 [9], and the effective detection area of the CdTe detector is 23.59 mm^2 [10], so the number of mono-energetic photons getting into CdTe is $23.59/104.04 \times 465649 = 105581$, and the total detected photons number of the CdTe detector is 1 059 587, hence the detection efficiency of CdTe detection could be deduced, the result is shown in tab. 1.

The principle of the semiconductor detector is that the photons hit the crystal atoms and the atoms are activated to generate electron-hole pairs finally, collecting electron-hole pairs, current signal is generated [11]. The noise becomes larger with the increase of temperature, so the energy resolution and detection efficiency of the detector will obviously decrease. The experimental results show that the detection efficiency and energy resolution of CdTe detector will decrease with the temperature rising. At 0 °C, the detection efficiency is highest and peak detection efficiency is 61.32 %, the total detection efficiency reaches 80.96 %, energy resolution is the best, two characteristic peaks could be separated perfectly. The performance is significantly reduced with the temperature increasing. The detection efficiency and energy resolution of the detector is poor for low energy X-rays of 8 keV at 20 °C or higher. There is a peak shift to the right with the increase of temperature which is consistent with the reference [12, 13].

CONCLUSION

Seen from the experimental results, the environment temperature has a great influence on the detection efficiency of CdTe detector. As the temperature increases, the peak count reduces accordingly. The count decreased about 66 % with the temperature changing from 0 °C to 40 °C. The lower the temperature, the higher the detection efficiency. When the temperature is above 10 °C, the detection efficiency is getting lower and lower as the temperature increases above 10 °C. Within 10 °C, the efficiency is acceptable and the results of the experiment are basically consistent with the theory.

The energy resolution of the detector acts well below 10 °C, which can remain below 10 %; while as the temperature rises above 20 °C, the energy resolution becomes poor, and it cannot reflect the actual condition of the radioactive source.

The experimental results show that this type of CdTe detector is reliable for use in X-rays detection. The detection efficiency is very high especially under temperature below 20 °C. On the basis of this experiment, we could conclude that it is necessary to use air conditioning to control the environment temperature when we measure the radiation with CdTe detectors. The results are especially ideal when the ambient temperature is below 10 °C. In addition, according to the influence of temperature on the detection efficiency, some corrections should be made to reduce the uncertainty of the study.

ACKNOWLEDGEMENT

This work was supported by National Natural Science Foundation of China under Grant No. 11505178, Research Fund for the Study on the Measurement Method of (10-100) keV Monoenergetic X-ray Source Flux.

AUTHORS' CONTRIBUTIONS

The experiment was carried out by S. Guo with the assistance of C. Liu, B. Huo, and S. Zhang, under guidelines of J. Wu and J. Zhang. The thermostat was designed by X. Li and C. Liu. All authors performed literature research, theoretical analysis, and discussion of the presented results. The manuscript was written by all the authors.

REFERENCES

[1] Arlt, R., *et al*., Room Temperature Semiconductor Detectors for Safeguards Measurements, *Nucl. Instrum Methods, 380* (1996), 1-2, pp. 455-461

[2] Eisen, Y., Current State-of-the-Art Industrial and Research Applications Using Room-Temperature CdTe and CdZnTe Solid State Detectors, *Nucl. Instrum Methods, 380* (1996), 1-2, pp. 431-439

[3] Mori, I., *et al*., The CdTe Detector Module and its Imaging Performance, *Nucl. Med. A., 15* (2001), 6, pp. 487-94

[4] Suzuki, K., *et al*., Temperature-Dependent Measurements of Time-of-Flight Current Waveforms in Schottky CdTe Detectors, *IEEE T. Nucl. Sci., 60* (2013), 60, pp. 2840-2844

[5] Hill, D. R., Principles of Diagnostic X-Ray Apparatus, Macmillan Education, UK, 1975, pp. 5-9

[6] Unsworth, M. H., Greening, J. R., Theoretical Continuous and L-Characteristic X-Ray Spectra for Tungsten Target Tubes Operated at 10 to 50 kV, *Phys. Med. Biol., 15* (1970), 4, pp. 621-30

[7] S. Pašić, M., *et al*., Experimental Determination of Absolute-Scale Compton Cross Sections Using the K X-Ray Escape and a Comparison with Three Versions of the Impulse Approximation, Bodily Integrity and the Politics of Circumcision, Springer, The Netherlands, 2006, pp. 303-310

[8] Kumar, S., *et al*., Measurement of Germanium Escape Peaks in PIXE Spectra Recorded Using High Purity Ge (HPGe) Detector, *International Journal of Pixe, 19* (2009), 1-2, pp. 67-76

[9] Jiang, W., The Measurement and Research of Personal Dose Equivalent for Protection Level X-Rays, Chengdu University of Technology, Chengdu, China, 2014, pp. 46-50

[10] Chen, C., *et al*., CT Technology Combined with MC Simulation Efficiency of Detector Calibration Curve, *Nucl. Electronics Detection, 35* (2015), 5, pp. 490-494

[11] Matsumoto, C., *et al*., Performance of a New Schottky CdTe Detector for Hard X-Ray Spectroscopy, *IEEE T NUCL SCI, 45* (1997), 3, pp. 428-432

[12] Shoji, T., *et al*., Temperature Characteristics of the Radiation Detector Using the TlBr Crystals, *IEEE T Nucl. Sci., 46* (2000), 6, pp. 1934-1937

[13] Dusi, W., *et al*., A Study of Temperature Dependence of Some Relevant Parameters Performed on a Set of CdTe Detectors, *IEEE T. Nucl. Sci., 42* (1994), 4, pp. 143-146

Received on May 31, 2017
Accepted on August 18, 2017

**Симинг ГУО, Ђинђе ВУ, Хајен ДУ, Ђен ЦАНГ, Сјуфанг ЛИ,
Цунгцан ЉУ, Шуај ЦАНГ, Ченгце ЛИ, Бинбин ХУО, Ценју ЉАО, Јинг ЉУ**

ИСПИТИВАЊЕ ОСОБИНЕ ТЕМПЕРАТУРНОГ КОЕФИЦИЈЕНТА CdTe ДЕТЕКТОРА ЗА ДЕТЕКЦИЈУ Х-ЗРАЧЕЊА

Температура радне средине је један од кључних фактора при одређивању особина полупроводничких детектора, која такође утиче и на апсолутну тачност и стабилност стандардног детектора. Ради одређивања температурног коефицијента CdTe детектора за детекцију Х-зрачења, дизајнирали смо прецизан систем контроле температуре. За потребе експеримента, детектор и извор Х-зрачења постављени су унутар термостата са температуром од 0 40 °C, како би се температура могла регулисати током испитивања температурног коефицијента CdTe детектора. Резултат експеримента показује да са порастом температуре долази до пада енергетске резолуције и ефикасности детекције CdTe детектора, а при температурама мањим од 10 °C детектор испољава боље перформансе за Х-зрачење од 8 keV.

Кључне речи: CdTe детектор, температурни коефицијент, Х-зрачење, ефикасност детектора, енергетска резолуција