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Characteristics of a prototype CdZnTe detector

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Abstract Cadmium zinc telluride (CZT) is a preferred material for X-ray and gamma-ray detector. Thanks to the relatively high atomic number, high density and wide band-gap, CZT detector possesses sharp energy resolution and high detection efficiency without cryogenic cooling. We have developed a CdZnTe detector with an energy resolution of 3.45% (FWHM) at 59.54 keV at room temperature, and it is used for X-ray fluorescence analysis. In this paper, leakage current, energy resolution and long term stability of the CZT detector are discussed.

Key words CdZnTe (CZT) detector, Fabrication, Characteristics, Stability

CLC number TL8

1 Introduction

A number of materials have been studied for making detectors of high stopping power, good spectral performance and imaging capabilities for X- and gamma-ray detection. Silicon or germanium detectors are featured by their excellent energy resolution, but there are drawbacks with them. Silicon offers a low stopping power for high energy photons, limiting its use to low energy. And the small band-gap of germanium (with a higher stopping power) requires the detectors being operated at cryogenic temperatures. On the other hand, inorganic scintillators coupled to photodiodes or photomultiplier tubes offer poor energy resolution, though the materials are of high stopping power. Therefore, compound semiconductors with high atomic number, high density and wide band-gap were explored for X- and γ-ray detection in 1970s.

Cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe) offer an opportunity of achieving excellent spectral and spatial resolution for compact hard X- and γ-ray detection systems operated without cryogenic cooling. CdZnTe is a better choise, because it has a wider band-gap, higher resistivity, lower dislocation density and lower susceptibility to polarization effects. Since the 1990s, progresses in the technology of growing high-quality single crystals of CdZnTe (size, stability and reproducibility) have led to its promising applications in mainly medical imaging and high-energy astronomy[1-3].

CdZnTe compound is based on the well-known material of CdTe, but a fraction of the Cd (Z=48) content is replaced with Zn (Z=30). This increases resistivity of the material, hence a reduction of leakage current in the detectors. Yinnel Tech, Inc. has developed a Modified Vertical Bridgman (MVB) method to grow detector-grade CdZnTe crystal of the best qualities for such an application (Table 1)[4,5]. In the table, $\mu\tau$ is the product of the carrier mobility (μ) and life time(τ), $\mu\tau$(e) is for electrons and $\mu\tau$(h) is for holes . $\mu\tau$ is an important material parameter, which determines a detector's charge collection efficiency, photopeak efficiency and energy resolution[1].

A prototype planar CdZnTe detector of an effective volume of Φ8mm×1.7mm has been developed at SINAP with a Yinnel Tech CdZnTe crystal wafer of 10mm×10mm×2mm. Its leakage current is in nA range at room temperature, its detection energy range is 5~200 keV[6], and can achieve FWHM 2.06% at 59.54 keV. In this paper, further studies on the detector's

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Table 1 Comparison of several typical detectors

Detector material	E_{gap} /eV	Work temperature /K	$\mu\tau$(e) /cm^2·V^{-1}	$\mu\tau$(h) /cm^2·V^{-1}	Equivalent atomic number	Density /g·cm^{-3}	FWHM /keV	Resistivity /Ω·cm
Ge	0.67	77	>1	>1	32	5.35	0.4~2	50
Si	1.12	77	>1	>1	14	2.33	0.2~1	<10^4
CdTe	1.44	300	3.3×10^{-3}	2×10^{-4}	50	5.85	0.2~20	10^9
CdZnTe[1]	1.6	300	1.8×10^{-2}	7×10^{-4}	49	5.81	0.2~20	3×10^{11}

1. Yinnel Tech, Inc.

performance are reported.

2 Fabrication and test of the detector

A 2 mm wafer was sliced form the CdZnTe crystal of a light N-type, The wafer was polished with alumina paste. The layers damaged during incising and polishing were etched for about 2 min with bromine-methanol (BM) solution (3%). The crystal was quenched in pure methanol, rinsed with deionized water, and dried in an infrared oven. It was vacuum evaporated to construct the electrodes, with Al on one surface as the anode and Au on the other side as the cathode. Effective volume of the CdZnTe detector is Φ8 mm×1.7mm[7].

The detector were tested in ambient environment throughout the period of test.

3 Performance of the detector

3.1 Leakage current

Leakage current is a dominant factor that influences a detector's performance. A high resistance amperemeter was used to measure leakage current of the detector biased at -50V to -400V in ambient temperature of -25℃ to 32℃. As shown in Fig.1, the leakage current at 7℃ is 1/10 that at 32℃, and 10 times more than at -25℃.

3.2 Energy resolution

DC coupled configuration is used in the preamplifier. The detector anode is connected to the gate of the input FET and the cathode to the bias. Output signals of the preamplifier go to the main amplifier and shaping amplifier. Much of the noise is filtered and a quickly restored baseline is provided to allow high counting rate detection. An MCA was used to collect the energy spectrum, which is shown on a PC screen[6]. All experiments have been carried out at room temperature.

Measuring an ^{241}Am source with 0.8 μs shaping time and at -300V bias and 12℃ gave the leakage current of I_L=2nA and the energy resolution (FWHM) at 59.54 keV of 2.21 keV (3.71%),the best record is 2.06 keV (3.46%)[7].

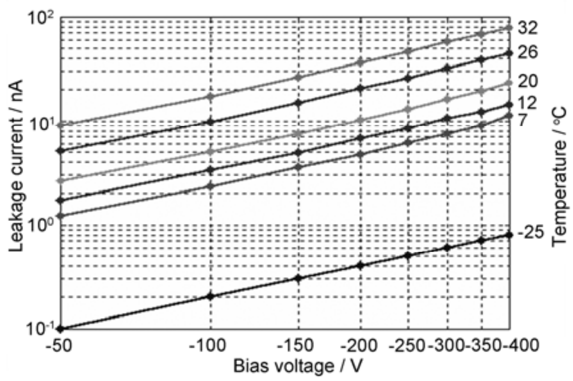

Fig.1 Leakage current of the CdZnTe detector at different bias voltages and ambient temperatures.

3.3 Bias voltage selection

To find the best bias voltage for the detector, different voltages were applied on it, at 17℃ ambient temperature, 0.8μs shaping time, and counting rate of 1800 s^{-1}. FWHM for 59.54 keV at -100, -150, -200 and -300 V was 3.18, 2.17, 2.26 and 2.32 keV, respectively. These show that the detector works better at a bias between –150V and –300V.

3.4 Energy range of detection

The CZT detector has a high detection efficiency in the energy range from several keV to several hundred keV[6]. Fig.2 shows energy spectra of ^{55}Fe and ^{241}Am measured at 12℃ with a 1024 channel MCA. The energy peaks of 59.54 and 17.8 keV of ^{241}Am and 5.9 keV of Fe are at 684.7, 193.0 and 52.9 channel, respectively. The detector's lower limit of detection can be lower than 5.9 keV, and the higher limit of detection can be higher than 88 keV.

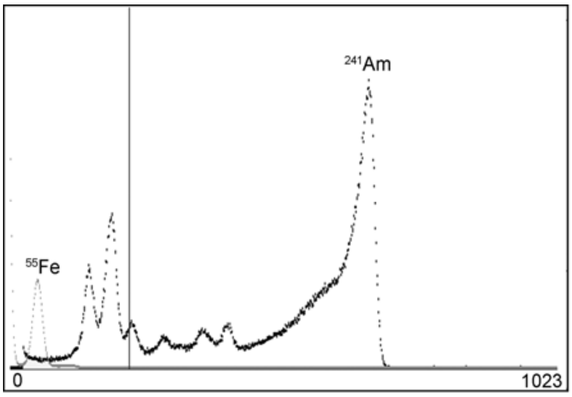

Fig.2 The energy spectra of ^{241}Am and ^{55}Fe acquired by CdZnTe detector.

3.5 Long term stability

Performance of the CZT detector has been investigated ever since its fabrication about 3 years ago. Results of the tests are given in Table 2. The detector has a good resolution in each test at different temperatures and bias voltages. These prove that it works reliably and stably, and the excellent performance can be available without any special conservation methods. In addition, the detector has no polarization effect, as we reported previously[6].

Table 2 Long time stability: change of FWHM at 59.54 keV for ^{241}Am with the conserved time, temperature and bias

Conserved time /month	FWHM /keV	Test temperature /℃	Bias voltage /V
3	2.21	12	-300
7	2.17	17	-150
12	2.06	22	-250
17	2.21	19	-300
23	2.86	27	-100
27	2.21	12	-300
30	2.19	13	-250

3.6 Application

The CZT detector was first applied to a portable energy dispersive analyzer for X-ray fluorescence analysis. Fig.3 shows an XRF spectrum of a Sn-Pb alloy sample.

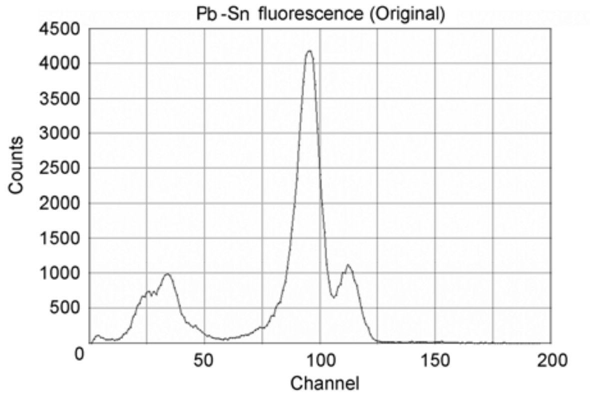

Fig.3 Original energy spectrum of Sn-Pb characteristic fluorescence.

4 Discussion

Performance of the CZT detector has been examined for 32 months. It works with great reliability and long term stability in ambient temperatures, The leakage current keeps in nA range at room temperature, and the energy resolution (FWHM) at 59.54 keV achieves 2.06 keV (3.46%). Similar results of a CZT detector have not been reported. These indicate that the CZT crystal has very good quality with less dislocations and the fabrication process is proper. The detector will be commercially available.

Currently, hole collection is the biggest problem hindering detector application of CZT. Many methods can alleviate the influence of poor ability of hole transportation, including geometry design of the detector's electrodes, such as hemisphere anode and point cathode structure, coplanar grid structure, CAPture, and Frisch grid structure[3]. They may make the device act like a detector of single carrier charge collection, ignoring the hole contribution to the signals. Circuit improvement can also be of help, such as Rise Time Discrimination (RTD) and Charge Compensation (CC). And electric cooling can be applied to reduce leakage current noise further.

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