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Characterization of CdZnTe Ambient Temperature Detectors

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Characterization of CdZnTe Ambient Temperature Detectors

Purpose

A great deal of interest has been generated in the use of cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe) detectors for ambient temperature detection of radionuclides. The addition of zinc to CdTe provides several benefits that enhance the materials operational characteristics at ambient temperature.

Recent movement in the industry is to produce larger volume detectors using CdZnTe without much known about the effects of larger geometry on performance. The purpose of this study is to get an idea of the relationship of detector performance to both area and thickness variations.

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Method

The procedure used to determine the performance of the detectors was to irradiate several detectors of various geometries with a collimated, 2 mCi ^{57}Co source.

Equipment:

Pulser -- Berkeley Nucleonics Corp., model BH-1

Preamplifier -- Ortec, model 142PC¹

Spectroscopy Amplifier -- Ortec model 572

Multichannel Analyzer -- Ortec 916A, 2048 channels

High Voltage Power Supply -- Power Designs Inc. model 3K10B

Oscilloscope -- Tektronix TDS644A

Capacitance Meter -- Tektronix Type 130

Detectors -- See Table 1 below:

Table 1 Detectors

Number	Size (HxWxT mm)	Material	Zinc Content (% molecular)	Capacitance (pF)	Bias (volts)
1	2X2X2	CdTe	0	2.2	120
2	2X2X2	CdZnTe	20	4.75	800
3	5X5X1.5	CdZnTe	20	2.8	410
4	5X5X5	CdZnTe	10	3.0	1000
5	5X5X10	CdZnTe	10	11.5	1000
6	5X10X5	CdZnTe	20	4.3	2900

¹The 142PC preamp was modified for operation with CdZnTe detectors.

A diagram of the test setup is shown in Figure 1 below:

Figure 1 Experiment Configuration

Source Location

The source was placed approximately 2 inches from the detector crystal. The actual detector crystal location within the detector package was determined by moving the source around the housing and finding the position at which the count rate dropped off. Though not precise, this was an attempt to reduce the source-detector distance variations due to unknown packaging techniques. This distance was selected in order to obtain the largest photon flux without a large dead time, regardless of the detector used. The dead time on the largest efficiency detector was kept to less than 10%. This reduced the effects of pulse pileup but did result in unusually long acquisition times for the smaller detectors.

FWHM Determination Method

Since there is no currently used standard for determining the performance of these detectors, the FWHM measurements made in this report are determined by absolute counts. The absolute full width at half maximum peak count is used without correction for background events or low energy tailing.

Procedure

All equipment was turned on and allowed to stabilize over night.

Pulsar resolution spectra were then taken for each possible configuration of the test setup (Appendix A). Two spectra were then taken for each detector using the ^{57}Co source (Appendix B). The first spectra integrated from channels 100 and 1850 (inclusive) for a total of 5,000,000 counts to get an idea of relative detector efficiency. The second spectra acquired data until the 122.06 keV peak reached a count of 10,000. This spectra was taken to give a relative

comparison of detector performance and peak efficiency. All spectra were taken with a shaping time of 0.5 usec. Neither pulse pileup rejection nor baseline restoration was used. Table 2 lists the results.

Table 2 Spectral Data

Configuration	Detector	Bias (volts)	Resolution (keV)	Spectra Number (Appendix A)
Preamp Pulser	None	0	1.33	P1
Preamp Pulser Bias Supply	None	0	1.33	P2
	None	120	1.32	P3
	None	250	1.33	P4
	None	410	1.34	P5
	None	500	1.35	P6
	None	800	1.34	P7
	None	1000	1.36	P8
	None	2900	1.48	P9
Preamp Pulser Bias Supply Detector	1	0	1.77	P10
	1	120	2.23	P11
	2	0	1.85	P12
	2	800	2.14	P13
	3	0	1.60	P14
	3	410	2.37	P15
	4	0	1.94	P16
	4	1000	2.23	P17
	5	0	2.29	P18
	5	1000	3.77	P19
	6	0	1.74	P20
	6	2900	3.82	P21

Results

While examining the spectra from the detectors, the absence of the 14.48 keV peak should be noted. This is due to the source packaging. The ^{57}Co source was energetic enough to require a metal housing that was unfortunately sufficiently thick enough to absorb all low energy photons.

The CdTe (Detector #1) and LEPS detectors were used as comparisons. The spectrum of the CdTe device shows a relatively constant background level at all low energies, as compared to the CdZnTe detectors that demonstrate an increasing background with energy. It should also be noted that Detector #5 had a large capacitance (11.5 pF) and may have been outside the optimization range of the electronics. A preamp designed for higher capacitance detectors may have resulted in better performance results for this detector.

The effects on resolution and efficiency can easily be seen in the spectra. As the area increased, the resolution decreased with a corresponding increase in efficiency. The efficiency also increased, in proportions larger than expected, for increases in detector thickness. The following graph shows the results of a COG² simulation to determine material absorption.

CdZnTe Absorption (Co-57 122.06 keV Gamma-ray)

The formula used to determine the absorption is as follows:

$$\text{Absorption} = 1 - e^{-(\text{material cross section} \times \text{detector thickness})}$$

Where the material cross section for CdZnTe was determined to be approximately 550 m^{-1}

By examining the spectra taken for peak counts of 10,000, the data shows more of a correlation between thickness and efficiency than area and efficiency. This can be seen by comparing the acquisition times for detectors 4, 5, and 6. The acquisition time for detectors 4 and 6 are the same despite the fact that the areas differ by a factor of two. Comparing detectors 4 and 5 show a sharp decrease in acquisition time with respect to thickness, which does not correspond to the theoretical data from the COG simulation that indicates less than a 10% increase in absorption.

²COG is a monte carlo neutron, photon, and electron transport code developed at Livermore.

Knowing the pulser resolution data allows the detector contribution to the FWHM measurement to be determined. Table 3 shows these results.

Table 3 Noise Contributions

Detector	FWHM	Pulser Resolution	Detector Contribution
1	3.95	2.23	3.26
2	3.97	2.14	3.34
3	4.41	2.37	3.72
4	4.24	2.23	3.61
5	8.90	3.77	8.06
6	6.78	3.82	5.60

As can be seen by the table, the detector remains the dominant contributor to the system noise even though the electronics was not optimized for each detector.

Charge collection was compared for the CdTe and CdZnTe detectors by looking at the output waveforms of the preamp. The following 2 waveforms are typical charge collection representations from the preamp. Each waveform is an average of 1000 charge collections.

Figure 2 CdTe Charge Collection

Figure 3 CdZnTe Charge Collection

The rise time of CdTe is roughly 3 times the average rise time of CdZnTe. Much of the slow charge collection of CdTe can be attributed to the low resistivity of the material (about $10^8 \Omega\text{-cm}$). The low resistivity dictates a lower bias voltage, as seen in Table 1, such that shot noise from leakage currents do not become an appreciable part of the detector signal. This, in turn, results in a lower electric field across the crystal adversely affecting charge collection. This may also account for the rather constant low energy noise observed in CdTe spectra.

Conclusions

The relationship of thickness to detector efficiency as the dominant geometry rather than area was unexpected. A cursory examination of other experimental data tends to support this result. The COG simulation data was revisited and it was found that COG does not transport electrons, rather it deposits the electron energy at the location that it was generated. Software exists that will work with COG to process electrons in a more appropriate fashion and will be used in further studies. Also, other Monte carlo photon transport codes will be used to verify modeled results.

It appears that any geometric increase in the size of a CdZnTe detector will result in a reduction of performance. The low energy tailing tends to increase with volume, which is no surprise to those involved in the field. As there is not an appreciable percentage of slow components in the charge collection in CdZnTe material, most of this degradation in performance is most likely due to charge trapping.

The fact that CdZnTe does not have a high percentage of slow charge collection phenomena supports the fact that the application of PSD (pulse shape discrimination) techniques that discriminate against this type of problem have little or no effect on the resolution of these detectors. PSD techniques do show significant improvements in the spectra from CdTe. To use this technique though, one must be able to live with an efficiency reduction in excess of 50%.

Appendix A

Pulser Spectra

Pulser Resolution P1

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	Not Connected
FWHM	1.33 keV

Pulser Resolution P2

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	0 VDC
FWHM	1.33 keV

Pulser Resolution P3

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	120 VDC
FWHM	1.32 keV

Pulser Resolution P4

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	250 VDC
FWHM	1.33 keV

Pulser Resolution P5

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	410 VDC
FWHM	1.34 keV

Pulser Resolution P6

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	500 VDC
FWHM	1.35 keV

Pulser Resolution P7

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	800 VDC
FWHM	1.34 keV

Pulser Resolution P8

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	1000 VDC
FWHM	1.36 keV

Pulser Resolution P9

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	Not Installed
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	2900 VDC
FWHM	1.48 keV

Pulser Resolution P10

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	1
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	0 VDC
FWHM	1.77 keV

Pulser Resolution P11

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	1
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	120 VDC
FWHM	2.23 keV

Pulser Resolution P12

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	2
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	0 VDC
FWHM	1.85 keV

Pulser Resolution P13

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	2
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	800 VDC
FWHM	2.14 keV

Pulser Resolution P14

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	3
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	0 VDC
FWHM	1.6 keV

Pulser Resolution P15

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	3
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	410 VDC
FWHM	2.37 keV

Pulser Resolution P16

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	4
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	0 VDC
FWHM	1.94 keV

Pulser Resolution P17

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	4
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	1000 VDC
FWHM	2.23 keV

Pulser Resolution P18

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	5
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	0 VDC
FWHM	2.29 keV

Pulser Resolution P19

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	5
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	1000 VDC
FWHM	3.77 keV

Pulser Resolution P20

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	6
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	0 VDC
FWHM	1.74 keV

Pulser Resolution P21

Peak counts = 10,000

Spectra Information

Date	April 21, 1994
Detector	6
Source	BH-1 Pulser
Shaping Time	0.5 uSec
Bias Voltage	2900 VDC
FWHM	3.82 keV

Appendix B

^{57}Co Spectra

Detector #1 (2X2X2 mm)

5.0e6 counts integrated from channels 100 to 1850

Spectra Information

Date	April 25, 1994
Detector	CdTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	120 VDC
FWHM	4.02 keV
Acquisition Time	5.5 Hours

Detector #1 (2X2X2 mm)

Peak counts at 122.06 keV = 10,000

Spectra Information

Date	April 26, 1994
Detector	CdTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	120 VDC
FWHM	3.95 keV
Acquisition Time	4 Hours

Detector #2 (2X2X2 mm)

5.0e6 counts integrated from channels 100 to 1850

Spectra Information

Date	April 22, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	800 VDC
FWHM	3.86 keV
Acquisition Time	4.8 Hours

Detector #2 (2X2X2 mm)

Peak counts at 122.06 keV = 10,000

Spectra Information

Date	April 25, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	800 VDC
FWHM	3.97 keV
Acquisition Time	4 Hours

Detector #3 (5X5X1.5 mm)

5.0e6 counts integrated from channels 100 to 1850

Spectra Information

Date	April 25, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	410 VDC
FWHM	4.41 keV
Acquisition Time	1.2 Hours

Detector #3 (5X5X1.5 mm)

Peak counts at 122.06 keV = 10,000

Spectra Information

Date	April 25, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	410 VDC
FWHM	4.41 keV
Acquisition Time	0.7 Hours

Detector #4 (5X5X5 mm)

5.0e6 counts integrated from channels 100 to 1850

Spectra Information

Date	April 25, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	1000 VDC
FWHM	4.33 keV
Acquisition Time	0.6 Hours

Detector #4 (5X5X5 mm)

Peak counts at 122.06 keV = 10,000

Spectra Information

Date	April 25, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	1000 VDC
FWHM	4.24 keV
Acquisition Time	0.25 Hours

Detector #5 (5X5X10 mm)

5.0e6 counts integrated from channels 100 to 1850

Spectra Information

Date	April 26, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	1000 VDC
FWHM	8.66 keV
Acquisition Time	0.12 Hours

Detector #5 (5X5X10 mm)

Peak counts at 122.06 keV = 10,000

Spectra Information

Date	April 26, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	1000 VDC
FWHM	8.9 keV
Acquisition Time	0.09 Hours

Detector #6 (5X10X5 mm)

5.0e6 counts integrated from channels 100 to 1850

Spectra Information

Date	April 27, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	2900 VDC
FWHM	7.17 keV
Acquisition Time	0.44 Hours

Detector #6 (5X10X5 mm)

Peak counts at 122.06 keV = 10,000

Spectra Information

Date	April 27, 1994
Detector	CdZnTe
Source	Co-57
Shaping Time	0.5 uSec
Bias Voltage	2900 VDC
FWHM	6.78 keV
Acquisition Time	0.25 Hours

16 mm Dia X 13 mm LEPS Detector

5.0e6 counts integrated from channels 100 to 1850

Spectra Information

Date	April 27, 1994
Detector	HPGe LEPS
Source	Co-57
Shaping Time	6.0 uSec
Bias Voltage	1000 VDC
FWHM	0.52 keV
Acquisition Time	0.18 Hours

16 mm Dia X 13 mm LEPS Detector

Peak counts at 122.06 keV = 10,000

Spectra Information

Date	April 27, 1994
Detector	HPGe LEPS
Source	Co-57
Shaping Time	6.0 uSec
Bias Voltage	1000 VDC
FWHM	0.52 keV
Acquisition Time	0.004 Hours