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New Room Temperature High Resolution Solid-state Detector (CdZnTe) for Hard X-rays and Gamma-rays

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AmyElizabeth C. Stewart
University of Maryland
College Park, MD 20740-3328

Upendra D. Desai
Goddard Space Flight Center - Code 682
Greenbelt, MD 20771

Abstract

The new CdZnTe high "Z" material represents a significant improvement in detectors for high energy photons. With the thicknesses available, photons up to 100 keV can be efficiently detected. This material has a wide band gap of 1.5 - 2.2 eV which allows it to operate at room temperature while providing high spectral resolution. Results of resolution evaluations are presented. This detector can be used for high resolution spectral measurements of photons in x-ray and gamma-ray astronomy, offering a significant reduction in the weight, power, and volume of the detector system compared to more conventional detector types such as scintillation counters. In addition, the detector will have the simplicity and reliability of solid-state construction. The CdZnTe detector, as a new development, has not yet been evaluated in space. The Get Away Special program can provide this opportunity.

Semiconductor Detectors

The most commonly used materials for semiconductor detectors are silicon (Si), germanium (Ge), mercury-iodide (HgI_2) and cadmium-telluride (CdTe). The energy resolution of these detectors is dependent on the number of electron-hole pairs generated and the loss of charge during collection. The resolution can be improved by "doping" the detector material with the appropriate elements so that resistivity and the product of mobility and lifetime (μT) of the carriers will both be increased. Increasing resistivity will decrease the reversed bias leakage current which is the most significant cause of noise. Although silicon has the best mobility-lifetime product of any material currently studied, its low atomic number and small band gap result in relatively poor detection efficiency for energies above 20keV. Germanium provides good resolution with good detection efficiency, but cannot be used at room temperature due to its very small band gap. CdTe is a useful combination of elements because it combines relatively high atomic numbers (Z) with higher density and large band gap energy (E_g). The high Z and high density give the detector a higher efficiency of absorption than Si or Ge while the wide band gap allows the CdTe detector to be operated at room temperature with decreased probability of thermal excitation. A comparison of these three materials is provided in Table 1.

material	z	$\rho(g/cm^3)$	$E_g(eV)$
Si(300K)	14	2.33	1.12
Ge(77K)	32	5.32	0.74
CdTe(300K)	48/52	6.06	1.47

Table 1

The electronic properties of CdTe can be further improved, which has led to the development of ternary materials such as the new CdZnTe . The high resistivity (~10^{11} Ω-cm) of this material results from the increased band gap, thereby improving resolution through lower leakage currents. The CdZnTe detector has good collection efficiency for energies up to 100 keV and has good energy resolution without cooling. While the CdZnTe detector's energy range is not as large as that of the APD/scintillator combination, its solid-state construction gives it the advantages of reliability, reduced weight and reduced volume. A comparison of CdZnTe to some other commonly studied binary and ternary materials is presented in Table 2.

material	atomic #	$\rho(g/cm^3)$	$E_g(eV)$	resistivity(Ω-cm)	$\mu T(cm^2/V)$ (electrons)
CdZnTe	48/30/52	~6	1.5 - 2.2	10^{11}	$1X10^{-3}$
CdTe	48/52	6.2	1.44	10^{9}	$3.5X10^{-3}$
ZnTe	30/52	5.72	2.26	10^{10}	$1.4X10^{-6}$
HgI_2	80/53	6.4	2.13	10^{13}	$1X10^{-4}$
HgBrI	80/35/53	6.2	2.4 - 3.4	$5X10^{13}$	$2X10^{-7}$

Table 2

Results

We are currently evaluating four 4 mm X 4 mm and four 8 mm X 8 mm CdZnTe detectors manufactured by Aurora Technologies Corporation. All of these detectors are 1.5 mm thick. Results achieved with these detectors are summarized in Table 3.

detector #	bias voltage (V)	FWHM resolution (@59.6 keV)
732 (4mm)	250	7.0%
328 (4mm)	250	8.1%
736 (4mm)	350	8.0%
739 (4mm)	300	8.1%
540 (8mm)	350	9.8%
181 (8mm)	250	7.6%
788 (8mm)	280	9.0%
431 (8mm)	350	9.1%

Table 3

The average energy resolution of the smaller set of detectors at 59.6 keV is ~7.8%. For the 8 mm detectors, the average resolution goes up to ~8.9%. Figure 1 shows an energy spectrum for a 8 mm X 8 mm CdZnTe detector at room temperature with a ^{241}Am source. Figure 2 is a comparison of the spectra generated by a silicon avalanche photodiode(APD) and a CdZnTe detector, both 4 mm X 4 mm . In the CdZnTe spectrum, the 59.6 keV line and the lower energies are detected with comparable efficiency. In the APD spectrum, however, the 59.6 keV line is noticeably weaker than the low energy lines (logarithmic scale).

Conclusion

CdZnTe detectors offer great potential for the future of x-ray and γ-ray detection. Their low leakage current and good collection efficiency make them superior to the semiconductor detectors currently in use. We hope that the evaluation of CdZnTe detectors in space will demonstrate their reliability and usefulness.

CdZnTe Detector #700431

Length: 8mm

Width: 8mm

Thickness: 1.5mm

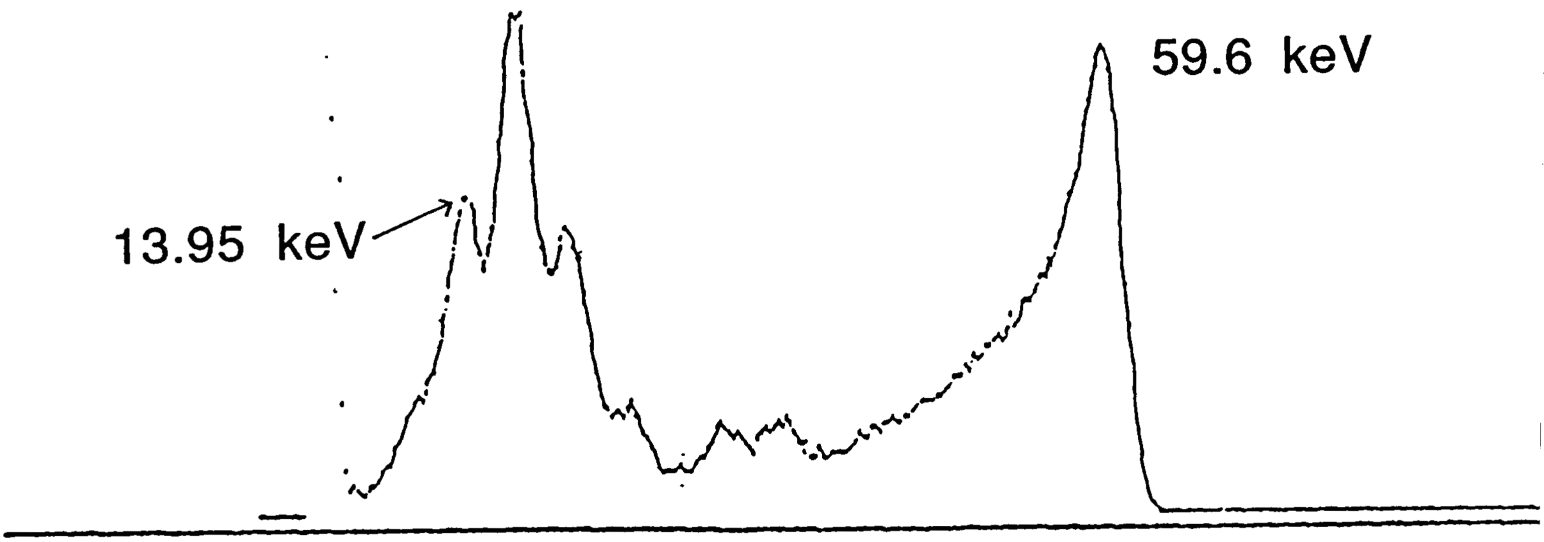
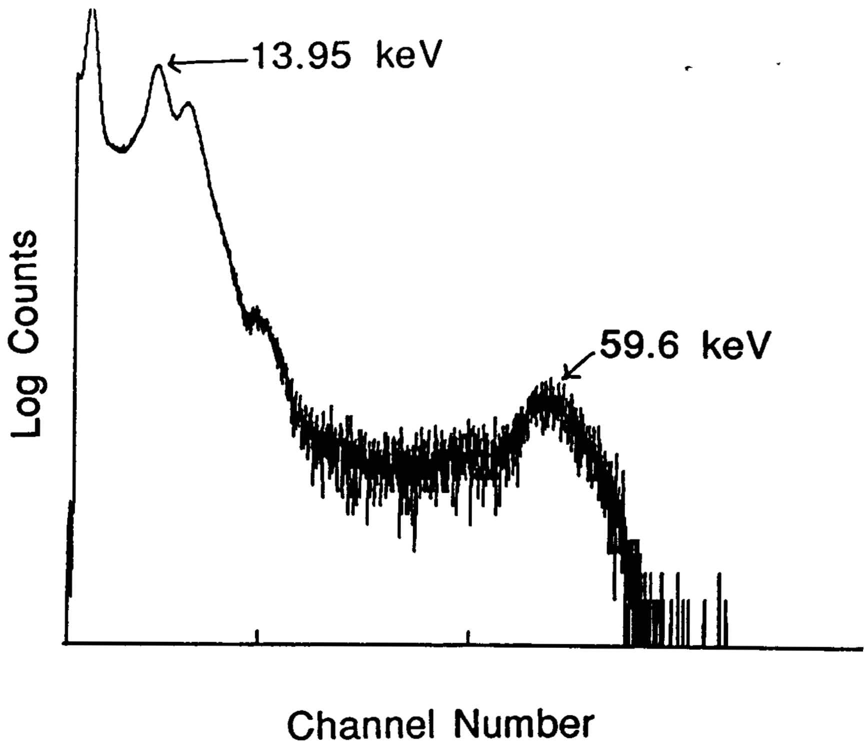


Figure 1

Taken at room temperature with ^{241}Am source and bias voltage at 350V.

CdZnTe Detector #700732
Length: 4mm
Width: 4mm
Bias Voltage: 250 V



Silicon APD #ND1231-3
Length: 4mm
Width: 4mm
Bias Voltage: 1.18 kV

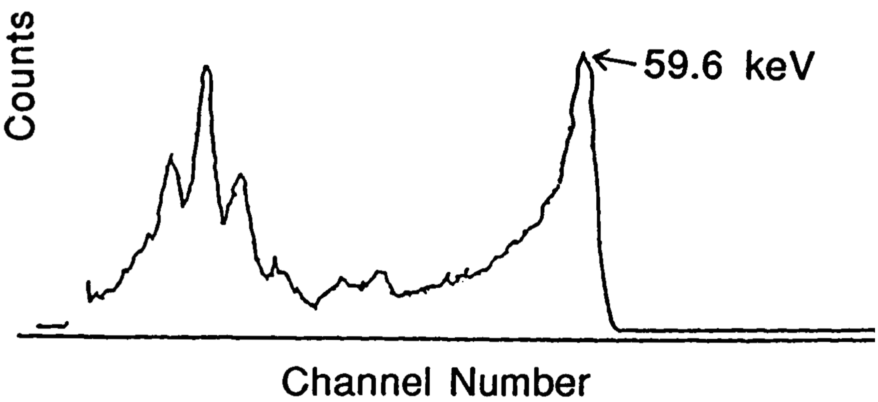


Figure 2: A Si avalanche photodiode (APD) and a CdZnTe detector of the same dimensions. Both spectra were taken at room temperature with a ^{241}Am source. (The APD also used a ^{55}Fe source.) The APD spectrum is logarithmic. As shown by the figure, the detection efficiency of the APD is poor at the 59.6 keV line, which cannot be seen in a linear plot. The CdZnTe spectrum is a linear plot.

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