Investigation of CdZnTe Geometrically Weighted Semiconductor Frisch Grid Detectors

D.S. McGregor – Principal Investigator

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The project involves the design and development of the room temperature operated CdZnTe gamma ray spectrometers for field instrumentation. The devices use unique geometric shapes and electrode configurations to increase gamma ray energy resolution. The project was funded through Sandia National Laboratories, Albuquerque NM.

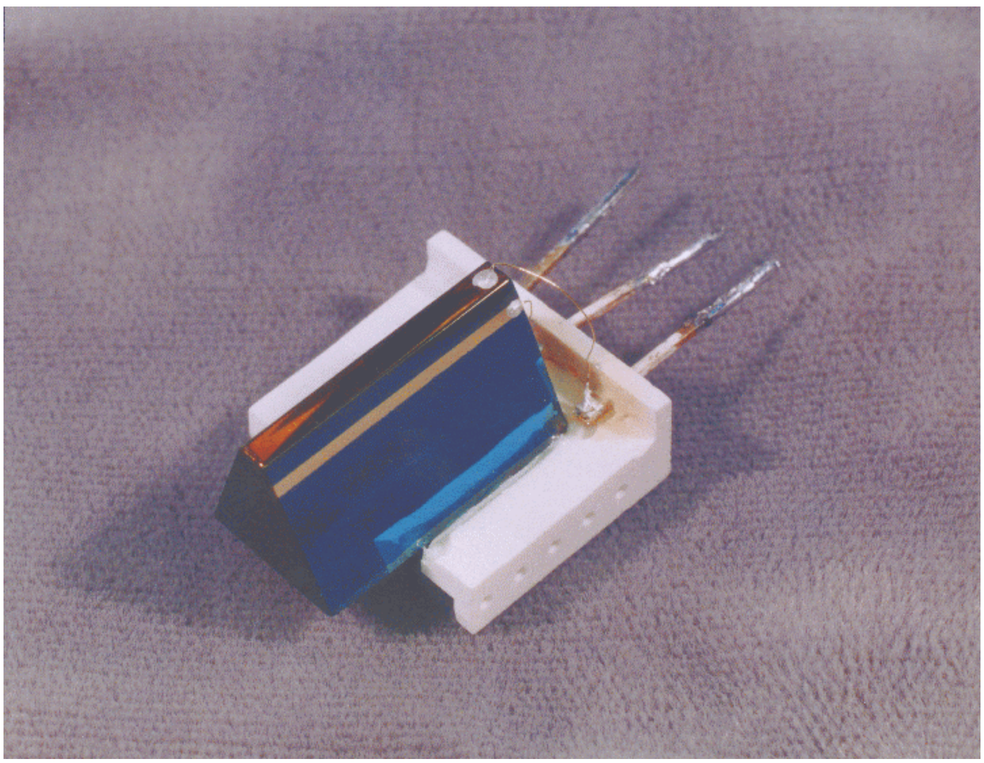

Figure 1: A geometrically-weighted CdZnTe trapezoid frustum detector. The device volume totals one cubic cm and demonstrated energy resolution of 2.68% FWHM at 662 keV.

Gamma rays that interact within a semiconductor detector excite charge carriers. These charge carriers are commonly referred to as electron-hole pairs, and they are usually drifted to the device contacts by an externally applied voltage. The negatively charged electrons are drifted to the anode(s) and the positively charged holes are drifted to the cathode(s). If all (or almost all) of the electrons and holes are "collected" at the device contact terminals, then the detector can function as a spectrometer. Such is true for common high purity Ge detectors (HPGe) and lithium-drifted Si detectors (Si(Li)). Yet, due to intrinsic material problems, large HPGe gamma ray detectors and large Si(Li) detectors do not operate well at room temperature and must be cooled during operation.

There are several compound semiconductor materials that do not require cooling to operate. Unfortunately, the single most difficult problem limiting the widespread use of compound semiconductors for gamma ray spectroscopy are distorted electronic pulses from charge carrier trapping. Charge carrier trapping refers to the removal of charge carriers by local crystal imperfections while in transit, thereby limiting the number of charge carriers (if any) that actually arrive at the terminal contacts. The resulting distorted pulses cause spectral deviations that deteriorate the energy resolution of the detector.

Generally, hole trapping is far worse than electron trapping, and many detector schemes take advantage of the fact. Electronic correction methods and tiny detectors are utilized often in order to reduce the deleterious effects of charge carrier trapping, yet the techniques have limitations. The detector community requires gamma ray detectors that are room temperature operated, large and efficient, and with high gamma ray energy resolution. Such a challenge was presented to the *SMART Laboratory* with the stipulations as follows:

1. *NO electronic correction circuits such as rise time rejection, rise time compensation to be used;*
2. *Simple single preamplifier readout;*
3. *At least 1 cubic cm in volume;*
4. *No electronic or cryogenic cooling;*
5. *Utilize commercially available NIM electronics;*
6. *No custom electronic circuitry, only readily available preamplifiers for NIM components;*

The *SMART Laboratory* researchers met the challenge by producing the novel Geometrically Weighted Semiconductor Frisch Grid Detector. Operating at room temperature, the device utilizes three major effects to accomplish high gamma ray energy resolution, those being the geometrical weighting effect, the small pixel effect, and the Frisch grid effect.

Geometric weighting: Gamma rays are preferentially absorbed in the large base region of the trapezoid for simple geometrical reasons.

Small pixel effect: Charge traveling in the small anode vicinity cause higher charge induction than carriers traveling in the vicinity of the cathode. As a result, electrons traveling towards the anode dominate the charge induction, rather than holes moving towards the cathode.

Frisch grid effect: Based on the famous gridded ion chamber designed and introduced by O. Frisch, the semiconductor device is separated into distinct regions. The large trapezoid base is the measurement region. Conductive strips on the device outside near the anode form the grid. The anode is the small end of the trapezoid prism. Charge carriers moving within the measurement region are effectively screened such that their motion does not induce charge on the anode. Only those charge carriers moving in the tiny region between the grid and the anode induce charge on the anode. As a result, electrons moving from the cathode into the anode vicinity dominate the signal, and holes moving towards the cathode have no effect.

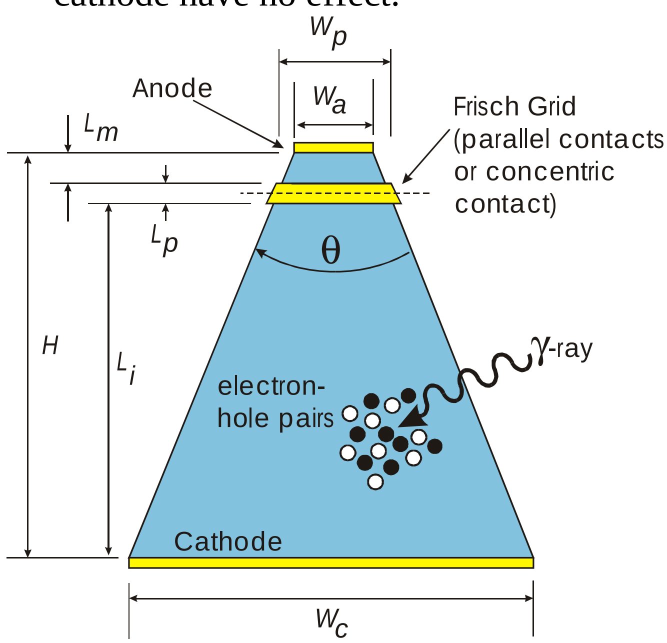

Figure 2: The basic components of a geometrically weighted semiconductor Frisch grid detector, showing the large cathode, the grid, and the small anode. Electrons do not induce charge upon the anode until they arrive within the region between the grid and the anode.

The devices are fabricated from commercially acquired CdZnTe material, and are manufactured completely within the *SMART Laboratory*. The angles and dimensions are ground and polished with precision, allowing for unique packing configurations. Figure 3 shows the results of a room temperature gamma ray measurement from a trapezoid device of 1 cubic cm volume. The outstanding results were obtained from a simple commercial grade Ortec 142A preamplifier attached to the device. No electronic correction was used to enhance the resolution.

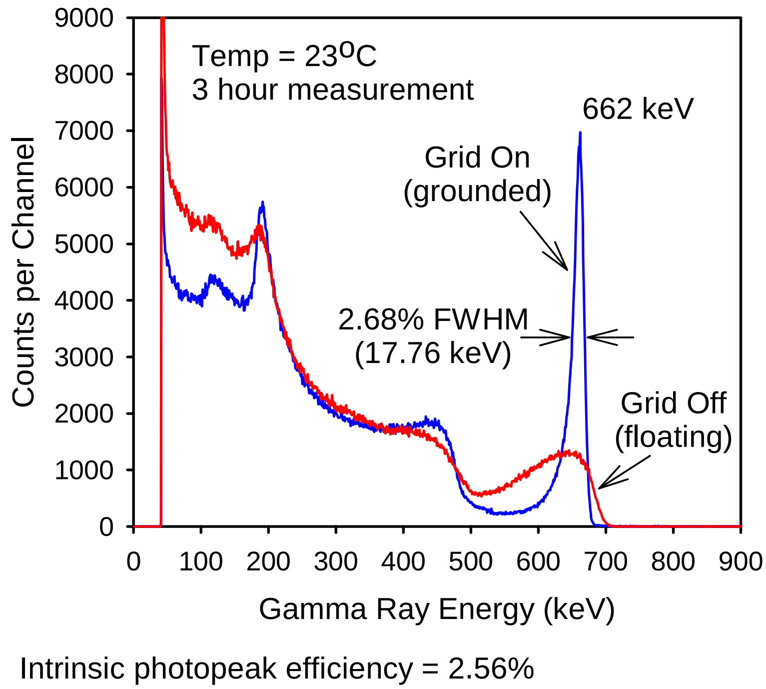

Figure 3: Pulse height spectrum from ^{137}Cs 662 keV gamma rays. The spectrum was taken at room temperature with a 1 cubic cm CdZnTe trapezoid Frisch grid detector. The energy resol-ution is 2.68% FWHM with a photopeak efficiency of 2.56% (at 662 keV).

The exciting results from the unique detector led to the issuance of *US patent 6175120*, in which the device is patented along with a variety of similar permutations. Although the device has shown much promise as a method of overcoming material imperfections, problems still persist with the CdZnTe starting material. Presently, reliable commercial CdZnTe material is still elusive.

Refereed Publications:

1. D.S. McGregor, J.R. Nishanth, and D.K. Wehe, "Low Energy Gamma-Ray Characterization of a Trapezoid-Shaped Geometrically-Weighted Frisch Grid CdZnTe Gamma-Ray Spectrometer," Nuclear Instruments and Methods, A457 (2001) pp. 230-244

2. D.S. McGregor, N.J. Reddy, and D.K. Wehe, “Design Considerations for Trapezoid-Shaped Geometrically-Weighted Frisch-Grid Semiconductor Radiation Detectors,” Proc. SPIE, Vol. 4141 (2000) pp. 281-290.

3. D.S. McGregor and R.A. Rojeski, “Performance of Geometrically Weighted Semiconductor Frisch Grid Radiation Spectrometers,” IEEE Trans. Nuclear Science, 46 (1999) pp. 250-259.

4. D.S. McGregor, R.A. Rojeski, Z. He, D.K. Wehe, M. Driver and M. Blakeley, “Geometrically Weighted Semiconductor Frisch Grid Radiation Spectrometers,” Nuclear Instruments and Methods, A422 (1999) pp. 164-168.

5. D.S McGregor, Z. He, H.A. Seifert, R.A. Rojeski and D.K. Wehe, “CdZnTe Semiconductor Parallel Strip Frisch Grid Radiation Detectors,” IEEE Trans. Nuclear Science, 45 (1998) pp. 443-449.

6. D.S McGregor, Z. He, H.A. Seifert, D.K. Wehe, and R.A. Rojeski, “Single Charge Carrier Type Sensing with a Parallel Strip Pseudo-Frisch-Grid CdZnTe Semiconductor Radiation Detector,” Applied Physics Letters, 72 (1998) pp. 792-794.

Conference Presentations:

1. D.S. McGregor, N.J. Reddy, and D.K. Wehe, “Design Considerations for Trapezoid-Shaped Geometrically-Weighted Frisch-Grid Semiconductor Radiation Detectors,” SPIE-Hard X-Ray, Gamma-Ray, and Neutron Detector Physics II, San Diego, July 31- Aug. 2 (2000).

2. D.S. McGregor and R.A. Rojeski, “Performance of Geometrically Weighted Semiconductor Frisch Grid Radiation Spectrometers,” IEEE Nuclear Science Symposium, Toronto, Ontario, Canada, Nov. 8-14 (1998).

3. D.S. McGregor, R.A. Rojeski, Z. He, D.K. Wehe, M. Driver and M. Blakeley, “Geometrically Weighted Semiconductor Frisch Grid Radiation Spectrometers,” Symposium on Radiation Measurements and Applications, Ann Arbor, May 12-14 (1998).

4. D.S McGregor, Z. He, H.A. Seifert, R.A. Rojeski and D.K. Wehe, “CdZnTe Semiconductor Parallel Frisch Grid Radiation Detectors,” IEEE Nuclear Science Symposium, Albuquerque, New Mexico, Nov. 9-15 (1997).