LA-UR- 98-2008

Approved for public release; distribution is unlimited.

Title: **PERFORMANCE OF CdZnTe DETECTORS PASSIVATED WITH ENERGETIC OXYGEN ATOMS**

CONF-980545--

Author(s): **T. H. Prettyman, M. A. Hoffbauer, J. Rennie, S. Cook, J. Gregory, M. George, P. N. Luke, M. Amman, J. Earnhart, and S. Soldner**

Submitted to: **1998 Symposium on Radiation Measurements and Applications**
Ann Arbor, MI USA
May 11-14, 1998
(FULL PAPER)

Los Alamos
NATIONAL LABORATORY

Form No. 836 R6
ST 2629 8/96

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LA-UR-98-2008

PERFORMANCE OF CdZnTe DETECTORS PASSIVATED WITH ENERGETIC OXYGEN ATOMS

T. H. Prettyman,[1] M. A. Hoffbauer,[1] J. Rennie,[1] S. Cook,[1] J. Gregory,[2] M. George,[2]
P. N. Luke,[3] M. Amman,[3] S. Soldner,[4] and J. Earnhart[1]
[1]Los Alamos National Laboratory
[2]University of Alabama, Huntsville
[3]Lawrence Berkeley National Laboratory
[4]eV Products, Inc.

1998 Symposium on Radiation Measurements and Applications
Ann Arbor, Michigan
May 11-14, 1998

Los Alamos National Laboratory document LA-UR-98-2008

Performance of CdZnTe Detectors Passivated with Energetic Oxygen Atoms

T. H. Prettyman,[1] M. A. Hoffbauer,[1] J. Rennie,[1] S. Cook,[1] J. Gregory,[2] M. George,[2]
P. N. Luke,[3] M. Amman,[3] S. Soldner,[4] and J. Earnhart[1]
[1]Los Alamos National Laboratory
[2]University of Alabama, Huntsville
[3]Lawrence Berkeley National Laboratory
[4]eV Products, Inc.

Corresponding author:
T. H. Prettyman
Mail Stop E540
Safeguards Science and Technology group, NIS-5
Los Alamos National Laboratory
Los Alamos, NM 87545
E-Mail: thp@lanl.gov
Phone: (505) 667-6449
Fax: (505) 665-5910

ABSTRACT

Noise caused by surface-leakage current can degrade the performance of CdZnTe spectrometers, particularly devices with closely spaced contacts such as coplanar grid detectors. In order to reduce surface leakage, we are treating CdZnTe detector surfaces with energetic, neutral oxygen atoms. Energetic oxygen atoms react with the surface to form a resistive oxide layer. Because the reaction is effective at room temperature, deleterious heating of the substrate is avoided. In most cases, leakage current and noise are shown to decrease significantly after treatment. The effect of the treatment on the performance of coplanar grid detectors is presented.

INTRODUCTION

Noise due to surface leakage can limit the performance of CdZnTe detectors. The magnitude of leakage noise depends on electrode design and surface-processing methods. Coplanar-grid detectors are particularly susceptible to leakage noise. Fine grid spacing (100–500 μm) is often used to obtain uniform charge measurement efficiency, which results in excellent energy resolution at high energy (e.g., 662 keV). However, application of differential bias across fine electrode structures can produce large electric

fields on the surface. Consequently, leakage between electrodes usually dominates the dark current. The magnitude of the leakage current is expected to depend on the condition of the surface (e.g., roughness and surface conductivity). For coplanar-grid detectors, noise caused by leakage current can dominate pulse-height resolution at low energy (<200 keV).

A variety of wet chemical treatment methods are used by researchers and manufacturers to reduce surface leakage currents. Detectors are often treated with etchants, such as bromine/methanol, to remove damage caused by polishing and to increase the planarity (smoothness) of CZT crystals (Chen, 1996 and Chen, 1997). Oxidizing agents, such as lactic acid and hydrogen peroxide, are sometimes used to reduce surface conductivity. Reduction in leakage current by ~37% has been demonstrated using this approach, but only small improvements in resolution have been achieved (Burger, 1997). Detectors are also routinely coated with a protective paint to ensure long-term stability by protecting the surface from damage or accidental contamination. However, these treatments generally produce only minor reductions in leakage and noise. Very recently, an attempt was made to treat the surface with thermal atomic oxygen with low kinetic energy (<0.2 eV). A very thin oxide passivation layer was produced and reductions in leakage current were reported (Burger, 1998).

At Los Alamos National Laboratory (LANL), energetic oxygen atoms are being used to passivate the surfaces of CdZnTe detectors (Prettyman, 1997). Energetic, neutral oxygen atoms are produced at a unique facility where a high-power CO_2 laser is used to generate a high-temperature, high-density oxygen plasma (Hoffbauer, 1990). A supersonic expansion of the plasma through a nozzle produces an intense, high-purity,

collimated beam of neutral atomic oxygen. The oxygen source can be used to irradiate large-area samples (> 4 cm^2), and can deliver up to 100 monolayers/s of atomic oxygen with a kinetic energy in excess of 2 eV.

Comparisons of energetic (hyperthermal) oxidation to several other related oxidation processes are given in Table 1. Surface oxidation processes that use thermal, plasma, and reactive gas sources usually produce species with low kinetic energy (<0.5 eV). To initiate complete surface oxidation would typically require high substrate temperatures. However, low-temperature surface oxidation is critical for CdZnTe detectors because the material is known to deteriorate at temperatures above ~120°C. Ion-beam and plasma sources that produce higher energies (>20 eV), do not require detector heating for surface oxidation; however, bombardment with their high-energy species introduces defects, causes surface roughness, and can severely damage the surface. By contrast, neutral oxygen atoms produced using the LANL source are energetic enough to efficiently induce surface oxidation but are not energetic enough to inflict surface damage.

SUMMARY OF SURFACE ANALYSIS FOR TREATED MATERIAL

CdZnTe samples provided by eV Products, Inc., were treated with energetic oxygen atoms and were provided to the Laboratory for Materials and Surface Science (LaMSS) at the University of Alabama, Huntsville, for analysis. At eV Products, the material underwent all processing steps (e.g., polish and etch) including electrode deposition. Several witness samples were used for comparison. A variety of analytical methods were applied to study the surfaces of treated and untreated samples, including x-ray

photoelectron spectroscopy (XPS), sputter depth profiling, and atomic force microscopy (AFM).

Results of XPS shown in Fig. 1 clearly indicate the formation of TeO_2 on the surface after passivation. The absence of the Te substrate peaks after passivation indicates that the oxide layer is thicker than the electron escape depth (~6 nm). Results of sputter depth profiling reveal that the oxide layer is thicker than 20 nm. This is at least an order of magnitude thicker than any competing process reported in the literature. These results indicate that the oxidation process is very complete, and that the suspected Te precipitates left on the surface following polishing and etching have been totally reacted to form a uniform TeO_2 surface layer. This surface layer could also contain CdO. Atomic-force microscopy (AFM) measurements on the energetic oxygen-atom treated surface show a more uniform and smoother surface layer following the passivation treatment. The properties of the passivating surface layer revealed by the surface analysis demonstrate the uniqueness of the results that can be obtained using energetic O-atoms rather than by other surface oxidation methods (see Table 1).

PASSIVATION OF COPLANAR GRID DETECTORS

Four coplanar-grid detectors were treated with energetic oxygen atoms at the Los Alamos Neutral Beam Facility. The characteristics of the detectors are given in Table 2. A general description of coplanar-grid detectors can be found elsewhere (Luke, 1994). The detectors were treated at room temperature. Individual detectors were mounted on a manipulator and inserted through a load-lock into the atomic oxygen beam path. The manipulator could be rotated to enable exposure of the grid surface as well as the sides of

the detector. Provisions were made to monitor intergrid leakage current *in situ*. To enable precise exposure times, a flag was used to shutter the beam on and off. Leakage current was measured (usually at a grid bias of 20 V) with the beam flagged to eliminate photo-induced currents caused by light from the plasma source.

The procedure for irradiation involved exposing the surfaces of the detector for fixed time intervals. This process was continued until the change in leakage between exposures was negligible. The time interval for exposure ranged from 2 min to 20 min with a maximum total exposure time of approximately 1 h. Most of the reduction in leakage current was realized after the first exposure, even at the shortest exposure times.

The performance of the detectors for gamma-ray spectroscopy was characterized before and after passivation. Characterization measurements included at a minimum: leakage current measurements (e.g., intergrid and bulk I-V curves), pulse-height spectra for ^{137}Cs, and noise measurements with a precision pulse generator. Additional measurements were made in some cases to further quantify detector noise characteristics, including noise spectrum measurements, the variation of noise with amplifier shaping time, the variation of noise with grid-bias and bulk-bias settings, and pulse-height spectra for lower energy sources (e.g., ^{241}Am and ^{57}Co). Detectors 1, 2, and 4 were characterized at LANL. Detector 3 was characterized before and after passivation at Lawrence Berkeley National Laboratory (LBNL). At LANL, the grid bias and bias settings that produced the best resolution at 662 keV were determined systematically before and after passivation. Before passivation, noise and pulse-height resolution were measured for a wide range of bias settings. Optimal post-passivation settings were selected within this

range. For LBNL, the same bias settings were used before and after passivation. Optimal settings were not determined.

Results of the characterization are shown in Table 3. For all of the detectors, leakage current was significantly reduced, in one case by a factor of 6 (detector 3). For the three detectors characterized at LANL, optimal bias settings were found to differ significantly before and after passivation. Resolution at 662 keV was improved except for detector 3, for which no attempt was made to determine optimal bias settings. Comparisons of noise were made for the same bias settings before and after passivation, as well as for the optimal settings. In all but one case (detector 2), noise measured at the same bias settings was reduced. For detector 2, the noise determined before passivation (at -550 V bulk bias and -30 V grid bias) was approximately four percent lower than the value measured after passivation (13.8 keV before passivation vs 14.4 keV afterwards). Nevertheless, for this detector, the optimal pulse-height resolution improved by ~10%.

The most dramatic overall change in performance was observed for Detector 1. Intergrid current-voltage and noise-voltage curves are shown in Fig. 2 for the optimal bias settings before and after passivation. Note that the shape of the I-V curve after passivation is nonlinear. In addition, following passivation the efficiency of the collecting circuit was found to saturate at a lower grid bias. At the optimal bias settings, the noise was reduced by 25% as measured by the pulser. A 25% improvement in the pulse-height resolution at 662 keV was also realized (Fig. 3).

SUMMARY

A systematic improvement in the performance of CdZnTe detectors treated with energetic oxygen atoms has been observed: treatment of coplanar-grid detectors with energetic oxygen atoms significantly reduces surface leakage current, and the associated reduction in noise consistently leads to an overall improvement in pulse-height resolution. Treatment with energetic oxygen atoms has a number of advantages over competing methods: a thick, uniform, resistive oxide layer is formed, and no heating of the substrate is required to initiate surface chemistry. The treatment method is fast, in principle, taking no more than 10 min per sample. Commercially implemented, the passivation method could be applied as a final processing step to improve the production yield of grid or pixellated detectors. For example, application of this method to large-volume coplanar-grid detectors could enable the detectors to function effectively at both low and high energies.

Additional research is needed to fully develop the passivation method. The link between surface chemistry, surface electronic properties, and device performance needs to be better understood. For example, it is unclear how passivation affects surface electronic properties other than resistivity. The dramatic change in optimal bias settings before and after passivation and the change in the shape of the I-V curve suggest that the passivation process influences charge collection. This behavior may be caused by the formation of an oxide layer underneath the contacts. The effect of passivation on contact chemistry and physics is being investigated.

From the standpoint of device engineering, the effect of treatment parameters on detector performance needs to be studied systematically. For example, the optimal

thickness of the oxide layer is unknown. The optimal exposure time for leakage reduction appears to be less than 10 min. However, the oxide layer could increase intergrid capacitance, resulting in a lower optimal irradiation time needed to minimize noise. The addition of an apparatus to monitor noise and capacitance *in situ* is needed to determine optimal irradiation time.

ACKNOWLEDGEMENTS

This work was conducted with funding from Laboratory Directed Research and Development through the Department of Energy under contract W-7405-ENG-36.

REFERENCES

A. Burger, et al., "Oxidation of CdZnTe Materials," Scientific Symposium on Room Temperature X-Ray, Gamma-Ray, and Neutron Detectors, Livermore, California, March 11–12, 1997.

A. Burger, et al., JVST, in press (1998).

H. Chen, "Low Temperature Photoluminescence of Detector Grade $Cd_{1-x}Zn_xTe$ Crystal Treated by Different Chemical Etchants," *J. App. Phys.* 80, 1 (1996).

K.T.Chen, D.T. Shi, B. Granderson, M.A. George, W.E. Collins, A. Burger, and R.B. James, "Study Of Oxidized Cadmium Zinc Telluride Surfaces," *J. Vac. Sci. & Technol.* A15, 850 (1997).

M. A. Hoffbauer, J.B. Cross, and V.M. Bermudez, "Growth of Oxide Layers on Gallium Arsenide with a High Kinetic Energy Atomic Oxygen Beam," *Appl. Phys. Lett.* 57, 2193 (1990) and references therein.

P. N. Luke, "Single-Polarity Charge Sensing in Ionization Detectors Using Coplanar Electrodes," *Appl. Phys. Lett.* 65, 2884 (1994).

T. H. Prettyman, M. A. Hoffbauer, M. R. Sweet, P. A. Russo, P. N. Luke, and S. A. Soldner, "Optimization of CdZnTe Detectors for Safeguards," *Proc. INMM* (1997).

Table 1. Comparisons of various surface oxidation processes.

Source Kinetic Energy	Sources Used	Oxidation Process	Process Induced Effects
<0.5 eV (thermal)	Thermal, Plasma, and Reactive Gas Sources	Surface heating required to initiate chemistry	Low damage but problems due to high substrate temperatures
1.0 to 10 eV (hyperthermal)	LANL Atomic Oxygen Beam Source	Kinetic energy initiates *unique* surface chemistry	*No* process induced damage to surface or substrate
>20 eV	Ion-beam and Plasma Sources	Kinetic energy or physical sputtering drives chemistry	Heavy damage to oxide films and substrates from high energy species

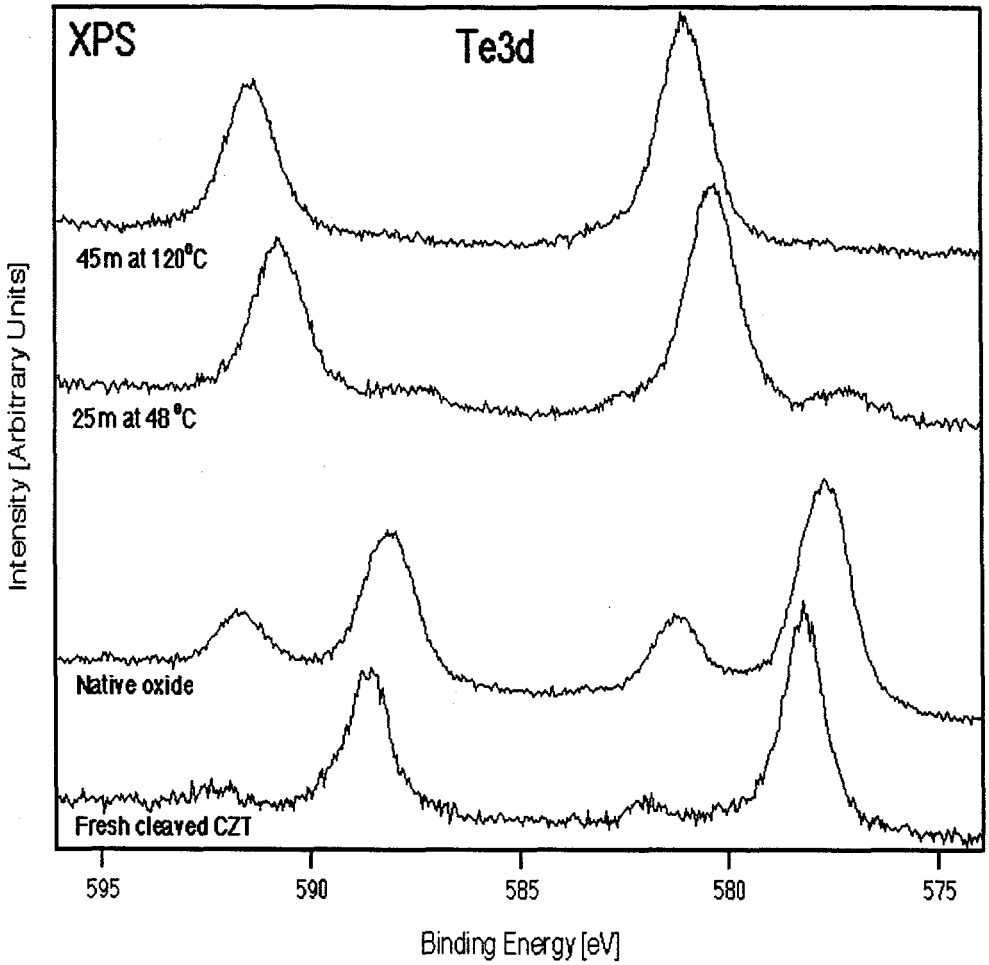

Figure 1. Results of XPS for surfaces exposed to energetic oxygen at 48°C and 128°C for 25 min and 45 min, respectively, are shown. Note that the Te substrate peaks near 578 eV and 588 eV are prominent for freshly cleaved CdZnTe and CdZnTe exposed to ambient oxygen. These peaks disappear after treatment with energetic oxygen and show a chemical shift corresponding to TeO_2.

Table 2. Description of CdZnTe detectors exposed to energetic oxygen atoms.

ID	Manufacturer	Substrate dimensions (mm)	Grid pitch (μm)
1	eV Products	7 x 7 x 3	250
2	LBNL	10 x 10 x 5	500
3	LBNL	10 x 10 x 5	500
4	eV Products	15x 15x10	200

Note that the pitch is defined as the distance between the electrodes (center-to-center). The electrodes and gaps are the same width.

Table 3. Performance of CdZnTe detectors before and after passivation. The full width at half maximum (FWHM) measurements were made at the bias settings quoted in the table.

	Before Passivation					After Passivation				
ID	Bias (V)	Grid bias (V)	Grid current (nA)[b]	FWHM 662 keV (keV)	FWHM Pulser (keV)	Bias (V)	Grid bias (V)	Grid current (nA)[b]	FWHM 662 keV (keV)	FWHM Pulser (keV)
1	-700	40	300	34.5	20.7	-850	30	60	26.7	15.7
2	-700	40	132	35.1	17.2	-550	30	51	32.8	14.4
3	-500[a]	25[a]	116	27.3	11.8	-500[a]	25[a]	19	31.2	11.6
4	-1300	-10	273	43.5	29.6	-1200	-15	53	40.0	27.9

[a]Optimal bias and grid bias settings were not determined for this detector.
[b]All leakage quantities are for ~20V grid bias.

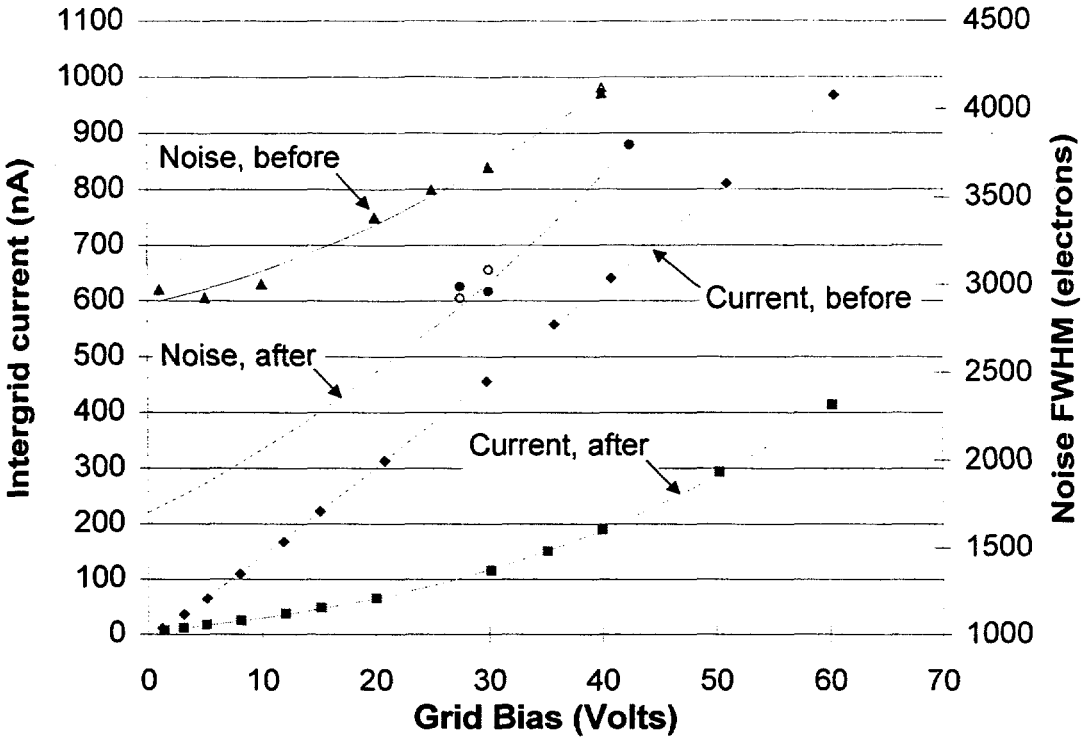

Figure 2. Intergrid I-V curves at optimal bulk bias settings for Detector 1 (eV Products). The open symbols represent measurements taken at slightly different bulk bias settings, within ± 100V of the optimal setting.

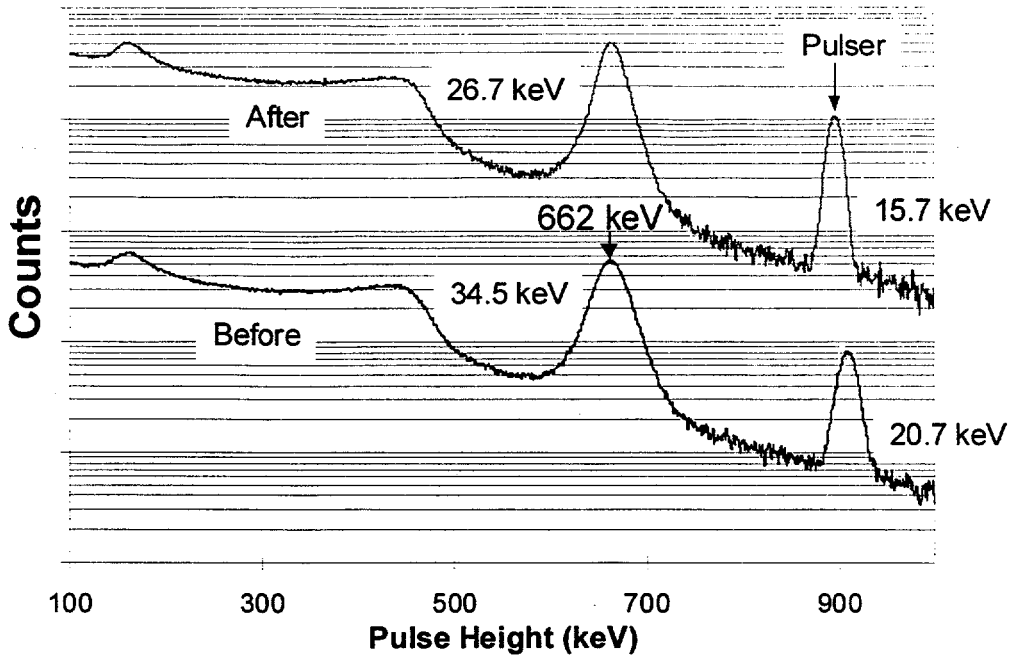

Figure 3. The ^{137}Cs spectra before and after passivation (Detector 1, eV Products). The FWHM of the pulser and gamma-ray peaks are indicated in the figure.