A multi-technique characterization of electroless gold contacts on single crystal CdZnTe radiation detectors

S J Bell1,2, M A Baker2, H Chen3, P Marthandam3, V Perumal2, A Schneider1, P Seller1, P J Sellin2, M C Veale1 and M D Wilson1

1 Rutherford Appleton Laboratory, Didcot, Oxfordshire, OX11 0QX, UK
2 Faculty of Engineering and Physical Sciences, University of Surrey, Guildford, Surrey, GU2 7XH, UK
3 Redlen Technologies, 123–1763 Sean Heights, Saanichton, British Columbia, V8M 0A5, Canada

E-mail: steven.bell@stfc.ac.uk

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Abstract
Cadmium zinc telluride (CdZnTe) is now established as a popular choice of sensor for the detection of γ-rays and hard x-rays, leading to its adoption in security, medical and scientific applications. There are still many technical challenges involving the deposition of high-quality, uniform metal contacts on CdZnTe. A detailed understanding of the interface between the bulk CdZnTe and the metal contacts is required for improvements to be made. To understand these complex interfaces, a range of complementary materials characterization techniques have been employed, including x-ray photoelectron spectroscopy depth profiling, focused ion beam cross section imaging and energy dispersive x-ray spectroscopy. In this paper a number of Redlen CdZnTe detectors with asymmetric anode/cathode contacts have been investigated. The structures of the contacts were imaged and their compositions identified. It was found that the two stage electroless indium/electroless gold deposition process on ‘polished only’ surfaces formed a complex heterojunction on the cathode, incorporating compounds of gold, gold–tellurium, tellurium oxide (of varying stoichiometry) and cadmium chloride up to depths of several 100 nm. Trace amounts of indium were found, in the form of an indium–gold compound, or possibly indium oxide. At the surface of the CdZnTe bulk, a thin Cd depleted layer was observed. The anode heterojunction, formed by a single stage electroless gold deposition, was thinner and exhibited a simpler structure of gold and tellurium oxide. The differing (asymmetric) nature of the anode/cathode contacts gave rise to asymmetric current–voltage (I–V) behaviour and spectroscopy.

(Some figures may appear in colour only in the online journal)

1. Introduction
The ternary compound of cadmium zinc telluride (CdZnTe) is a semiconductor with properties that are well suited to the application of x/γ-ray radiation detection. The high atomic numbers of cadmium and tellurium ensure superior stopping power compared with silicon, gallium arsenide or germanium. In addition, the wide bandgap of CdZnTe provides the ability to operate at room temperature whilst maintaining spectroscopic performance. The binary compound of cadmium telluride (CdTe) offers the same advantages, however due to the polarization effects associated with their Schottky contacts [1, 2] these detectors are limited to a practical thickness of ∼1 mm. Many applications require good detection efficiency at high energies and this simply cannot be achieved with a 1 mm device. As CdZnTe does not suffer from the same polarization effects as Schottky CdTe detectors, CdZnTe detectors can be fabricated with a thicker active volume. In recent years Redlen Technologies have delivered significant improvements in the quality of travelling-heating method (THM) grown CdZnTe
2.1. Sample preparation

material, and detectors with a thickness of 15 mm have been successfully demonstrated [3]. For these reasons, there is interest in using CdZnTe to make spectroscopic x-ray imagers in the medical, security and scientific sectors [4–10].

2.2. Current–voltage measurements

A probe station andKeithley pico-ammeter were used to measure the I–V behaviour in the low voltage (−1 V to +1 V) and high voltage ranges (−1 kV to +1 kV), with the cathode biased and the current read out from the shorted anode pixel array. The bulk resistivity of a sample can be extracted from a low voltage I–V measurement (as band bending should be minimal at low biases) [18, 19]. The resistivity, \( \rho \), was calculated by fitting equation (1) to the low voltage range of the I–V data, where \( V \) was the applied bias, \( A \) the contact area, \( I \) the leakage current and \( d \) the detector depth

\[
\rho = \frac{VA}{td}. \tag{1}
\]

The high voltage range provided a measurement of the leakage current at typical operating voltages and an idea of the nature of the device (i.e. Ohmic or blocking). These properties are often observed to have a greater dependency on the contacts than on the bulk.

2.3. X-ray spectroscopy

The detectors investigated in the current study were fabricated with different electrode structures on the two (1 1 1) faces of the CdZnTe crystal. To investigate what affect this asymmetry had on the operation of the detector, the detectors were operated both in standard and reverse configuration (see figure 1). This involved testing two detectors, with the first detector configured as standard; the planar electrode on the (1 1 1)B face negatively biased (−250 V) and the measurement readout from the pixellated electrode on the (1 1 1)A face (all pixels shorted together). The second detector was operated in reverse, with the pixellated electrode on the (1 1 1)A face negatively biased (−250 V, again all pixels shorted) and the measurement made from the planar electrode on the (1 1 1)B face. In both instances the radiation, from a variable energy x-ray source, was incident on the detector being biased. An Amptek CoolFET discrete preamplifier connected to an Ortec 570 amplifier and Canberra Multiport II MCA were used to record the measured spectra.

2. Experimental procedure

2.1. Sample preparation

The Cd\(_{0.9}\)Zn\(_{0.1}\)Te detectors investigated in the current study were grown by THM. Each detector measured 19.3 \( \times \) 19.3 \( \times \) 5 mm\(^3\) in size and were configured with a planar contact deposited by a two stage electroless indium/electroless gold process on the (1 1 1)B Te-face (cathode) and an 8 \( \times \) 8 pixel array of contacts deposited by an electroless gold process on the (1 1 1)A Cd-face (anode) [17]. Both surfaces were polished before contact deposition (SiC lapping followed by 0.3 then 0.05 \( \mu \)m alumina slurry polishing). Neither surface was chemically etched nor chemo-mechanically polished with bromine methanol or other such agents.

Electroless gold contacts on Cd(Zn)Te have been extensively investigated before, with characterization methods such as Rutherford backscattering spectroscopy (RBS) [12–14], x-ray photoelectron spectroscopy (XPS) [15] and Auger electron spectroscopy (AES) [16] used to probe the MS interface formed during the deposition process. The current work aims to build on these previous studies by introducing a range of complementary materials characterization techniques, which when applied together, provide electrical, structural and detailed chemical information over a range of length scales. These techniques included current–voltage measurements (I–V), XPS depth profiling, focused ion beam (FIB) cross section imaging, transmission electron microscopy (TEM) imaging and energy dispersive x-ray spectroscopy (EDS). This complementary approach has been used to investigate the asymmetric MS interfaces formed on the anode and cathode contacts of CdZnTe following Redlen’s past electroless deposition process on ‘polished only’ surfaces.

Figure 1. Detector configurations for spectroscopy measurements. (a) Standard configuration and (b) reverse configuration. Radiation (broken red arrows) was incident on the biased contact.
2.4. FIB cross section imaging

A Carl Zeiss XB1540 cross-beam FIB was used to mill and image the MS interface. To preserve the gold surface and protect from ion beam damage during alignment, a coating of ion beam platinum, or a dual layer of ion beam tungsten and sputtered carbon was deposited onto the surface prior to milling. An ion current of 200 pA was used to mill the main trench, with a reduced current of 50 pA used to fine polish the interface for imaging.

Efforts were made to ensure that the results reported were representative of the entire contact area by investigating several locations across each sample, with each exposed interface re-milled at least once to obtain multiple, parallel interface profiles several micrometres apart.

2.5. TEM and EDS

An FEI 2500 FIB was used to prepare thin (∼100 nm thick) cross section foils for analysis with a JOEL TEM. The TEM was used to image the foils in bright and high-angle annular dark field (HAADF) modes to provide complementary views of the interface. Each mode produces contrast in a different manner. An Oxford Instruments EDS module provided chemical information from line and area scans.

2.6. X-ray photoelectron spectroscopy

XPS analysis and depth profiling was performed using a Thermo Scientific Theta Probe spectrometer, employing a monochromated Al Kα characteristic X-ray source with an energy of 1486.7 eV and a take-off angle (relative to the surface normal) of 37°. The binding energies were calibrated with respect to the aliphatic carbon contamination peak at 285.0 eV and an analyser pass-energy of 50 eV was employed for elemental peak analysis. The depth profiles were obtained by sequentially etching layers of material with a 1 µA current of 3 keV Ar⁺ ions rastered over an area of 2.5 mm² followed by XPS analysis. The XPS binding energies of the elemental peaks considered in the current study are presented in table 1. The shift in peak positions of tellurium and oxygen upon oxidation (compared with bulk CdZnTe or OH−/H2O contamination, respectively) are well known [20, 22] and these have also been considered.

The atomic composition as a function of etch time was calculated by applying instrument-modified Wagner sensitivity factors to the intensity of the measured peaks, following a Shirley background subtraction. Details of this method can be found in [22]. A minor variation in the Ar⁺ ion etch current was noted during sputtering and to ensure consistency between measurements, the depth profiles were normalized to the same etch current of 1 µA (with the assumption that the sputter rate was linearly proportional to etch time [23]). No attempt was made to convert etch time to depth because of the variation in etch rate between the different materials in the surface layers.

Principal component analysis (PCA) is a mathematical method used to identify patterns within large data sets, such as XPS depth profile data. When applied to XPS data, it is possible to identify different regions within the depth profile where a particular photoelectron peak has shifted or broadened. This can be related to a variation in the chemical bonding or state of the element of interest. If a number of principal components are identified for a particular element, it can indicate multiple chemical states of that element through the depth profile. The PCA method was used to identify the principal components associated with the elements listed in table 1 and the intensity of these components plotted as a function of etch time. It was then possible to assign these components either to a different element, thus suggesting the presence of a chemical compound of these two elements in this region. Further information regarding the PCA method can be found in the literature [22, 24].

The x-ray spot used during the experiment had a radius of ∼400 µm; this defined the analysis area and the resulting profile was an average over this area. While XPS results are more likely to be representative of the contact interface as a whole, techniques such as FIB/TEM provide information on small scale structure.

3. Results and discussion

3.1. Current–voltage measurements

The high voltage I–V measurements, with current density plotted as a function of field strength, are displayed in figure 2 for two of the detectors investigated. Details of the resistivity and the measured leakage current at 1500 V cm−1 (typical operating field strength) for each detector are presented in table 2.

Both detectors produced a diode-like response, with high leakage in the forward direction and blocking behaviour in the reverse direction. Many Redlen detectors were tested during the current study and such I–V behaviour was representative of the majority of these detectors. This asymmetry was related to the significantly different contacts formed on the (1 1 1) faces. These detectors were configured for the (1 1 1)B Te-face to be operated as the cathode and the (1 1 1)A Cd-face operated as the anode (i.e. reverse biasing of Te-face), as illustrated by figure 1(a). For a Au/CdZnTe/Au detector, it has been suggested that this configuration creates a blocking cathode (restricting electron injection from the...
Table 2. The resistivity and leakage current for detectors A and B. Leakage current measured at $-1500 \text{ V cm}^{-1}$ and normalized for a single 2.5 mm pitch pixel.

| Detector | Resistivity ($\times 10^{11} \text{ } \Omega \text{ cm}$) | Leakage current (nA per 2.5 mm pixel) |
|----------|-------------------------------------------------|---------------------------------------|
| A        | $6 \pm 1$                                      | 0.25                                  |
| B        | $2.4 \pm 0.4$                                  | 0.15                                  |

contact into the bulk) and Ohmic anode (improving electron collection following an interaction) [17]. This configuration has a disadvantage when the poor hole transport of CdZnTe is considered, due to positive charge build up at the cathode. An injection of electrons at the cathode is required to neutralize this build-up of positive charge and this is achieved by introducing an intermediate layer of indium between the bulk and gold cathode contact. The work function of indium ($\Phi_{\text{In}} = 4.1 \text{ eV}$ [25]) is lower than gold ($\Phi_{\text{Au}} = 5.1 \text{ eV}$ [26]) and high resistivity CdZnTe (which is approximately the same as gold). This asymmetric Au/In/CdZnTe/Au configuration produces an imbalance between the heights of the Schottky barriers formed at each contact and so current will flow preferentially in one direction across the device.

The leakage current reported was normalized to represent a single 2.5 mm pitch anode pixel (the pitch of Redlen’s standard medical imaging module). Measurements were not made of individual pixels, so it was not possible to comment on uniformity across the array. The values measured were considered to be very low. The resistivities of the two samples were all measured to be in the order of $10^{11} \text{ } \Omega \text{ cm}$, which is very high for CdZnTe.

3.2. X-ray spectroscopy

The energy spectra measured with detectors A and B following irradiation by a Ba x-ray source and a Tb x-ray source are presented in figure 3. Detector A was configured as standard, with the planar contact negatively biased and readout from the shorted pixellated contact and detector B was configured in reverse, as illustrated in figure 1. The full-width at half-maximum (FWHM) of the 32.2 keV Ba $K_{\alpha}$ peak was measured to be 2.2 keV (7.0% energy resolution) for detector A and 2.8 keV (8.5%) for detector B. The FWHM of the 44.5 keV Tb $K_{\alpha}$ peak was measured to be 1.4 keV (3.2%) for detector A and 2.1 keV (4.7%) for detector B. These results confirmed the superior spectroscopic performance of the standard configuration over the reverse configuration and were related to the asymmetric $I-V$ behaviour reported in figure 2.

3.3. FIB and TEM analysis

Cross sectional FIB and bright field TEM images taken of the Au/In cathode contact are presented in figure 4. Regions of differing contrast were observed below the gold layer indicating a complicated structure. Small ‘specks’ of bright contrast were observed in the FIB image within an extended region ($\sim 400–700 \text{ nm}$ thick) below the gold layer. Following this, two further layers were observed before the bulk CdZnTe was reached. The total interface depth was measured to vary from $\sim 400$ to $700 \text{ nm}$ over several micrometres. It has previously been reported such variation in interface depth was related to polishing damage and associated sub-surface strain [27], however this variation has also been observed in chemo-mechanically polished surfaces following electroless deposition but not following sputter deposition [28]. Chemical or chemo-mechanical etching, with agents such as bromine methanol, has been demonstrated to remove polishing induced surface damage [29–31]. It was concluded that the variation

Figure 2. High voltage range $I-V$ measurements for detectors A and B. Current density plotted as a function of field strength.

Figure 3. Energy spectra measured by detectors A and B following irradiation by (a) Ba x-ray source and (b) Tb x-ray source.

Figure 4. Cross sectional FIB and bright field TEM images of the Au/In cathode contact.
observed in the present study was the result of a localized difference in the rate of reaction of the electroless process.

The EDS area maps presented in figure 5 show a mixture of gold and oxygen within the extended region below the gold surface layer of the cathode contact and an aggregation of chlorine close to the CdZnTe interface. The profile measured was characteristic of an electroless deposition process involving gold chloride in deionized water; the CdZnTe surface was oxidized during the deposition process with gold forming on top and throughout the oxide region [14, 32]. A layer of cadmium depletion and tellurium enrichment towards the bulk was observed. This was attributed to the preferential removal of cadmium by the gold chloride solution and subsequent precipitation of cadmium chloride due to supersaturation of the Cd\(^{2+}\) and Cl\(^{-}\) containing solution. The precipitation of CdCl\(_2\) will reduce the crystal quality and increase voiding [33–36] due to the solubility of chloride salts and sub-surface stress from lattice mismatches causing strain and local deformations. The bright regions observed in the bright field image of figure 4 were consistent with porosity or voiding. The presence of voiding, and modification of the material stoichiometry, makes it highly likely that the region may contain vacancies, interstitials and defect complexes. It has previously been reported that an increase in the concentration of cadmium vacancies occurs during electroless deposition [13] while other authors have proposed that the presence of chlorine is correlated with an increase in the concentration of cadmium interstitials (\(E_C \sim 0.56\) eV) [37]. It is also well known that chlorine compensates cadmium vacancies in CdZnTe forming an A-centre (\(E_V + 0.12\) eV) with the shallow chlorine donor, Cl\(_{TE}\) (\(E_C = -0.14\) eV) [38–40].

Bright and dark field TEM images and an EDS line scan of the anode contact are presented in figure 6. A thin gold surface layer of \(\sim 15\) nm was observed, with a shallow region of oxygen and chlorine below. Gold had also penetrated this sub-surface region. Compared with the earlier cathode interface, the anode interface was much simpler. The observed difference between the cathode and anode was in agreement with the asymmetric \(I–V\) and spectroscopic response of the detectors.

3.4. XPS depth profiles

The XPS depth profile taken through the cathode interface is presented in figure 7. In agreement with the earlier EDS chemical maps, the cathode was found to be a complicated heterojunction interface of gold/mixed gold, oxide and tellurium/mixed oxide and chloride/bulk CdZnTe, with this heterojunction superimposed, or penetrating into the Cd(Zn)Te bulk. The bulk ratio of Cd(Zn): Te was found to be 0.99 ± 0.02, consistent with what would be expected from detector grade CdZnTe. The measured composition of the cathode interface is different from bulk CdZnTe and will not contribute towards the active volume of the detector. As has previously been observed [41], any extended inactive area below the cathode is potentially significant, especially when radiation is incident on the cathode and of low energy which would result in a shallow interaction.

Low levels of indium were measured throughout the interface of the cathode contact of detector B. The signal was measured to peak at only 0.9 atomic%, between an etch time of 5000–10 000 s. This peak concentration compared with a background (or noise) measurement of \(\sim 0.6\) at% at an etch time of 18 000 s (in the bulk). The indium photopeak spectrum, formed by summing all measurements between 5000 and 10 000 s is shown in figure 8; the 3d\(_{5/2}\) and 3d\(_{3/2}\) photoelectron peaks were measured at binding energies of 444.8 eV and 452.2 eV, respectively. These binding energies represent a shift of \(\sim 0.9\) eV from the expected elemental values (as given in table 1) and puts the 3d\(_{5/2}\) peak close to the reported 444.5 eV position of In\(_2\)Te\(_3\) and In\(_2\)O\(_3\) [20]. Compounds of indium with gold have been reported at slightly lower 3d\(_{5/2}\) binding energies; \(\sim 444.1–441.2\) eV [42]. The electroless deposition of indium is a relatively weak process, especially when compared with the electroless deposition of gold, and the subsequent deposition of gold on top of the indium layer has caused dispersion of indium through the interface region resulting in the observed low concentration and diffuse distribution of indium. Despite the low concentration and diffuse distribution, it has been demonstrated that the presence of indium does have a beneficial effect on the performance of CdZnTe radiation detectors [17].

The photoelectron peaks of oxygen, tellurium, gold and cadmium were observed to shift at different regions within the profile. The observed shifts were considered to represent a change in chemical state. Examples of the gold and cadmium photoelectron peaks measured within the interface of the cathode contact on detector B are given in figure 9. Rather than attempt to peak fit each individual spectrum acquired at every depth level, it was decided to apply PCA to the gold and
cadmium datasets in order to identify any spectral patterns that may relate to the peak shifts identified in figure 9.

Two PCA components were found within the gold spectra dataset, the second component represented a slight shift and broadening of the Au 4f photoelectron peaks to higher energies (84.2 eV). The relative intensities of the two components were quantified and plotted as a function of etch time, and this is shown in figure 10. The intensity and distribution of the second gold component (Au_{PCA2}) was found to track that of the tellurium 3d_{5/2} photoelectron peak (Te_{3d5/2}) with good agreement up to an etch time of 10 000 s, strongly indicating the formation of a AuTe phase in this region. The tellurium 3d_{5/2} elemental peak was also observed to shift in this region, from a bulk value of 572.4 eV (measured after 22 000 s) to 572.9 eV (measured after 6000 s); this is shown in figure 11. Within the surface layer of gold (after etching for 600 s), the binding energy of the 4f_{5/2} gold peak was measured to be 84.0 eV, which was consistent with elemental gold (see figure 9(a)). The first gold PCA component (Au_{PCA1}), located at 84.0 eV, was related to this elemental gold and the distribution of this PCA component through the depth profile was an indication that elemental gold was distributed throughout the extended interface, and mixed with the AuTe phase. It was shown in figure 4 that the gold was present as particulates in this region; it is proposed that these particulates had an internal bulk composition of elemental gold and a surface composition of AuTe. The two PCA components of gold are displayed in the inset of figure 10.

Two cadmium components were identified using PCA. The first component (Cd_{PCA1}) corresponded to bulk CdZnTe and the second component (Cd_{PCA2}) was associated with a shift to higher binding energies (405.6 eV), compared with the bulk CdZnTe. The second cadmium component was found to be co-distributed with chlorine, which was distributed throughout the mixed gold-oxide region and had a peak concentration of 8–9 at% (∼10^{21} \text{ cm}^{-3}) after an etch time of ∼13 000 s, at the interface with the bulk. This concentration was above the solubility limit of 10^{19} \text{ cm}^{-3} in CdTe [36]. The distributions of chlorine and cadmium are shown in figure 12, along with an insert showing the two primary components identified by PCA. The similarity of the Cd_{PCA2} and Cl distributions was an indication of the presence of a compound between the two elements. The chlorine 2p_{3/2} peak had a binding energy of 198.5 eV, typical of a metal chloride compound. The cadmium 3d_{5/2} peak had a binding energy of 405.0 eV in the CdZnTe bulk but the peak energy was measured to increase by ∼0.2 eV and also to broaden by ∼0.2 eV (FWHM) between an etch time of ∼2000–15 500 s (see figure 9(b)). The cadmium peak is known to shift to higher binding energies when bound with Cl [20, 43]. The ratio of the second cadmium PCA component (Cd_{PCA2}) to chlorine (Cl_{2p}) was found to be ∼1:1 throughout the profile suggesting a phase of CdCl, although CdCl_{2} could have formed [33–36] with the ratio distorted by preferential etching. The position (405.0 eV) and distribution of the first cadmium component (Cd_{PCA1}) was consistent with cadmium bound as CdZnTe. A contribution from cadmium oxide (CdO or CdTeO_{3}) to the two PCA components was also possible.

The ratio of oxygen to tellurium (both in an oxide form) was calculated from the atomic percentage values measured during the XPS analysis. If it is assumed that the interfacial oxide was a phase of tellurium oxide, then this ratio would be an indication of the value of n in TeO_{n} (e.g. a ratio of 2.5 would suggest a mixed layer of TeO_{2} and TeO_{3}). Figure 13 shows how this ratio evolved through the interface for the cathode contact. The ratio increased from ∼1–2 close to the surface,
Figure 6. (a) Bright field and (b) dark field TEM images showing the interface region of the anode contact. (c) EDS line scan through the interface of the anode contact. Location of the line scan indicated by the broken line.

to ∼4–5 nearer the bulk. The majority of the interfacial oxide content existed in regions with ratios of ∼2–3. It was unlikely that a phase of TeO$_2$–5 was present; instead it is suggested that the oxide phase evolved through the interface from a phase of TeO$_2$ near the surface, to CdTeO$_3$ nearer the bulk (CdTeO$_3$ has been reported as the most stable oxide to form in the Cd–Te–O system [44]). The highest ratios were a result of the reduced signal to noise ratio of the increasingly weak oxide signals, but there could be a contribution from CdO or ZnO.

The XPS depth profile taken through the interface of the anode contact is given in figure 14. The profile agreed with the corresponding TEM and EDS results (see figure 6), with a weak gold surface layer, consistent with the semi-transparent appearance of the contact, and a weak interfacial oxide signal. It was not possible to determine if the oxygen content was present as a ‘discrete’ oxide layer, or simply a result of contamination and diffusion through the very thin gold layer. The bulk ratio of Cd(Zn):Te was found to be 1.04 ± 0.02, consistent with what would be expected from detector grade CdZnTe.

4. Conclusions and summary

The quality and yield of CdZnTe material has steadily increased in recent years and the limit in performance is now due to the quality of the metal contacts. Uniform metal pixels on CdZnTe radiation detectors must be further developed before these detectors can realize their potential. A better understanding of the MS interface formed during the deposition of metal contacts onto bulk CdZnTe will lead to improvements in detector performance.

The work presented has contributed to this development by introducing how a range of complementary characterization techniques, such as $I–V$ analysis, XPS depth profiling, FIB
Figure 9. (a) The 4f7/2 and 4f5/2 gold photoelectron peaks. The 4f7/2 peak was measured to have a binding energy of 84.0 eV after etching for 600 s (solid line) and 84.1 eV after etching for 6,200 s (dashed line). (b) The 3d5/2 and 3d3/2 cadmium photoelectron peaks. The 3d5/2 peak was measured to have a binding energy of 405.2 eV after etching for 12,400 s (dashed line) and 405.0 eV after etching for 22,800 s (solid line).

Figure 10. XPS Depth profile through the cathode contact showing the concentration of tellurium and two PCA components of gold, indicative of elemental Au and AuTe. Insert: The two primary components identified within the gold spectra dataset using PCA. The Au_PCA1 component was measured to have a 4f7/2 binding energy of 84.0 eV and the Au_PCA1 component was measured to have a 4f7/2 binding energy of 84.2 eV.

cross section imaging, TEM imaging and EDS mapping, can be used to investigate the MS interface.

The asymmetric construction of Redlen’s detectors, via the direct electroless deposition on ‘polished only’ surfaces, produced a diode-like response and superior spectral performance with the (1 1 1)B contact reverse biased. Cross section images taken with a FIB and TEM revealed a complicated, multi-layer structure to the cathode interface. Chemical depth profiling with XPS and EDS mapping complemented these images by confirming the presence of a diffuse gold/oxide region, on a layer of oxide and metal chloride. The tellurium based oxide phase was seen to evolve through the interface. It was found that TeO2 dominated near the surface, but phases of TeO3, CdTeO3 or other Cd or Zn based oxides increased towards the bulk. The Au was present as a surface layer, but was also distributed within the extended oxide layer as particulates. The composition of these particulates was proposed to be elemental Au in the particulate bulk and AuTe at the particulate surface. Indium was present at trace/dopant levels throughout the interfacial region. The structure of the anode contact was simple, with a thin layer
deposition.

between metal contacts and CdZnTe following electroless phase is an insufficient description of the MS interfaces found quoting only the metal work function and oxide depth and a single sample. A simple metal–oxide–semiconductor model significantly from sample to sample, and from site to site within Facilities Council).

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