Invited Paper

Cadmium Zinc Telluride High Resolution Detector Technology

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ABSTRACT

Electrode contacting on semiconductor radiation detectors has been a topic of active interest in many recent investigations. Research activities have focused on the morphology and chemistry of modified surfaces using sophisticated preparation techniques and employing characterization methods that are able to discriminate between surface and bulk effects. From an applied point of view, the detector fabrication technology involves a series of fabrication steps which can be optimized. Results of an ongoing effort to improve the performance of high resolution $Cd_xZn_{1-x}Te$ (CZT) spectrometers by addressing wafer surface preparation, electrode deposition and contact passivation are described..

Keywords: Cadmium zinc telluride, detector fabrication, contacts, surface preparation

1. INTRODUCTION

There is presently a widespread need for room temperature gamma and X-ray imaging capability for both medical and industrial applications. Solid state CZT arrays offer the possibility of reducing the weight of existing nuclear medicine cameras based on scintillators and photomultiplier. CZT combines the room temperature operation with the energy resolution that approaches that of the cryogenically cooled Ge and Si detectors. However, CZT detectors are still in very limited use, mainly due to the limited availability of low price and defect free material. Recently, studies aimed at a better understanding of the electric contact formation process were performed and it was shown that in many cases, in particular when high resolution, low active volume detectors, the performance of the detectors is limited by surface preparation, contacting and device passivation.

Two typical problems associated with detector fabrication are encountered during the detector fabrication process: the formation of conductive layers on the surface of the detector and injecting contacts. They can seriously degrade detector performance via large dark leakage current which acts as an important source of noise in the detector spectral response. In addition, the internal electric field profile, recombination centers in the near surface regions may be introduced during surface preparation and metallization processes. All these factors affect the charge collection efficiency and the dark leakage current which in turn significantly affect the performance of the device.

In this paper, we review the progress made in the implementation new detector fabrication processing steps resulting in a significant lowering of the dark leakage current and an improvement in the detector performance. The development of metallic contacts to CZT which are stable, reliable and laterally uniform is an essential step in the production of pixel and strip based imaging devices, as well as planar spectrometers.

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2. WAFER PREPARATION

The fabrication process starts with the selection of the wafer, the crystals are usually examined under an optical microscope equipped with a CCD camera sensitive in the near IR range. Crystal inhomogeneities (pipes, precipitates, voids, cracks) are identified and unfortunately are common to most CZT crystals grown by HPB technique. Their presence will usually reflect in an increased leakage current or even electrical breakdown at a voltage below the voltage needed for full efficiency, high resolution performance. Although the correlation between the presence of grain boundaries and detector performance is yet to be established, they may affect the device performance in an indirect manner by providing a likely path for the accumulation of precipitates and voids with a distortion in the electric field to follow. For best performance single crystalline, oriented wafers free of macrodefects would be preferable.

The removal of the damaged layer is typically done by Br-methanol (2-10%) solution etching, which is performed at room temperature for 2-4 minutes, with or without stirring the solution. Rinsing the detector from the etching solution should be done gradually by diluting the solution with the final rinse in pure methanol. The introduction of a second step after the Br-methanol etching, involving a solution of 2% Br-20% lactic acid in ethylene glycol was shown to reduce the mean surface roughness and lead to lower leakage current devices. The wafer is dried and introduced immediately in the contact deposition system to prevent surface oxidation.

3. METAL CONTACTING

Four different ways of metallization were used : (i) thermal Au evaporation which is a convenient thin film deposition method, (ii) electroless method (from $AuCl_3$ aqueous solution) (iii) sputtered Pt deposition and (iv) sputtered Au deposition.

The thermal evaporation and sputtering deposition were performed in a vacuum chamber (from Kurt J. Lesker Inc.) containing a substrate holder, gas feedthrough, a magnetron sputtering head and a thermal evaporation boat. The chamber is evacuated to a 10^{-6} Torr background pressure by a turbomolecular pump. Typical sputtering conditions are 50 W of RF power delivered to the Au (Pt) target. The Ar gas pressure was kept constant at 5×10^{-2} Torr. The sputtering deposition time was 5 minutes. The thermal evaporation was carried out at 10^{-6} Torr and the deposition time was 2 minutes. The film thickness was typically a few hundreds Angstroms.

Due to the inertness and easiness of the deposition Au is the preferred material for contacting. Au contacts on both sides of the wafer are normally used with undoped High Pressure Bridman material, which is believed to be p-type. Recent published data [11] on dark noise spectra as function of the applied bias acquired with CZT detectors having contacts made of gold, indium, zinc, aluminum, titanium or platinum confirmed that gold is the material producing the least injecting contact.

4. PASSIVATION OF THE LATERAL SURFACES

It is common to anneal metal contacts after their deposition and contact improvements have been observed by heating to around 100 °C [5]. At the present status of development, HPB grown CZT material tends to degrade at temperatures above about 150 °C [9].

A few recent reports mention the benefits of passivation. In one report the surface was passivated with an insulator and the measured 1/f noise at 1 Hz and 100 V was smaller by one order of magnitude compared to unpassivated CZT detectors [8]. An increased interstrip resistance by three orders of magnitude was measured following passivation [5].

Finally, surface passivation was achieved after an oxidation treatment in aqueous H_2O_2 solution [12] or by atomic oxygen bombardment [13]. Based on the equilibrium phase diagram of the Cd-Te-O system, a high resistivity layer of $CdTeO_3$ was proposed [14] as the probable stable phase forming during the oxidation of CZT. For reasons mentioned above, a low temperature process would always be preferable.

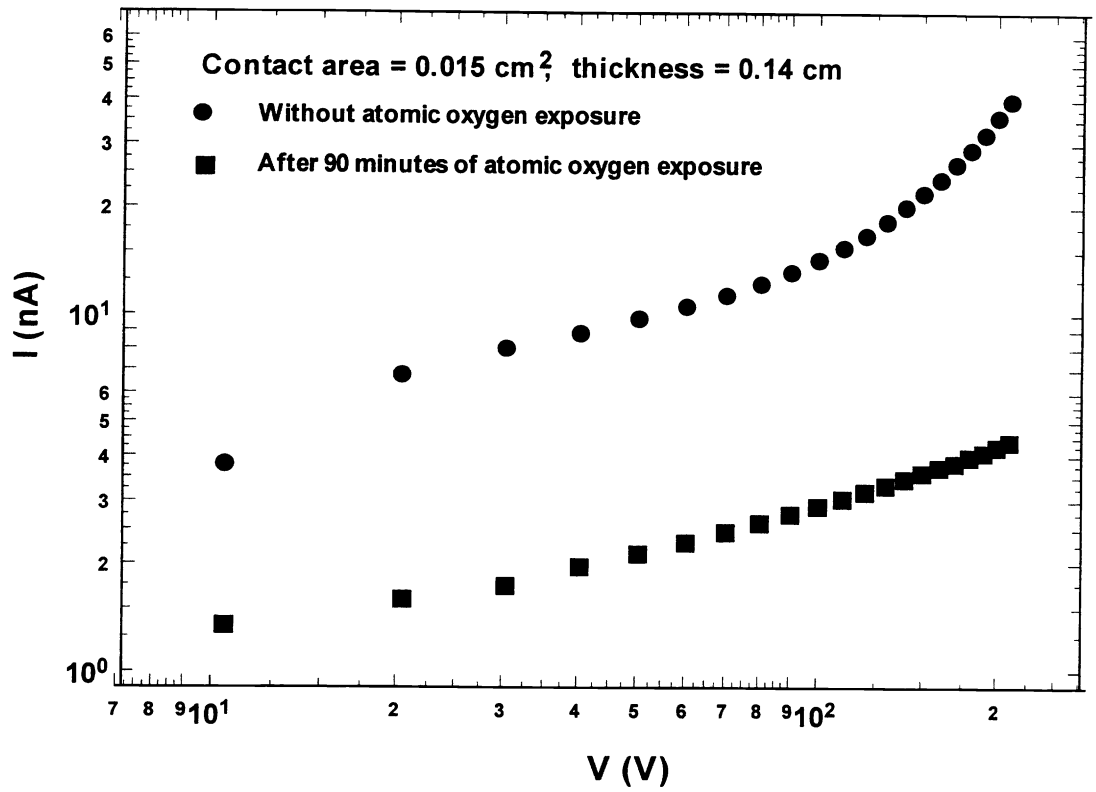

Figure 1. The reduction in the leakage current of a CZT detector following 90 minutes of atomic oxygen exposure

The hydrogen peroxide (H_2O_2) solution forms a oxide layer with a thickness in the range of 21 - 44 nm, and a saturation stage was reached after 5 minutes etching.[13] A recent [15] micro-spectroscopic study identified TeO_3^{2-} as the dominant surface species formed during oxidation of CdTe. The observed improvements probably result from the conversion of the electrically conductive residual tellurium film into a higher resistive species. After several minutes of H_2O_2 treatment a saturation level is reached beyond which there are indications that leakage current starts increasing again. The possibility of the formation of nonstoichiometric oxides exists, although we do not have any evidence so far, based on X-ray photoelectron spectroscopy data obtained so far.

A reduction in leakage current leads to a significant improvement in detector performance for the low energy range of 5 - 70 KeV. This is shown in Figure 2 where the energy resolution of the ^{241}Am 59.6 keV gamma peak is reduced from 6.9% FWHM to 4.7% FWHM after a treatment of 90 minutes of atomic oxygen exposure [13]. The noise and threshold level is also significantly reduced near the 14 keV, 18 keV and 21 keV x-ray peaks.

5. FUTURE STUDIES

The study of the stability of the oxide at ambient conditions is underway and preliminary results show a deterioration of the insulating property of the oxide after several months. A full encapsulation of the detector (after the oxidation) may be required.

The improvements we obtained so far were obtained by lowering the surface leakage current through oxidation of the lateral areas of the detector. A brand new study may go into the subject of the role played by inadvertent oxidation of the region under the contact. A basic understanding of the way the oxide affects the metal/semiconductor interface is needed as most past reports show no dependance of the metal barrier height with the choice of the metal.

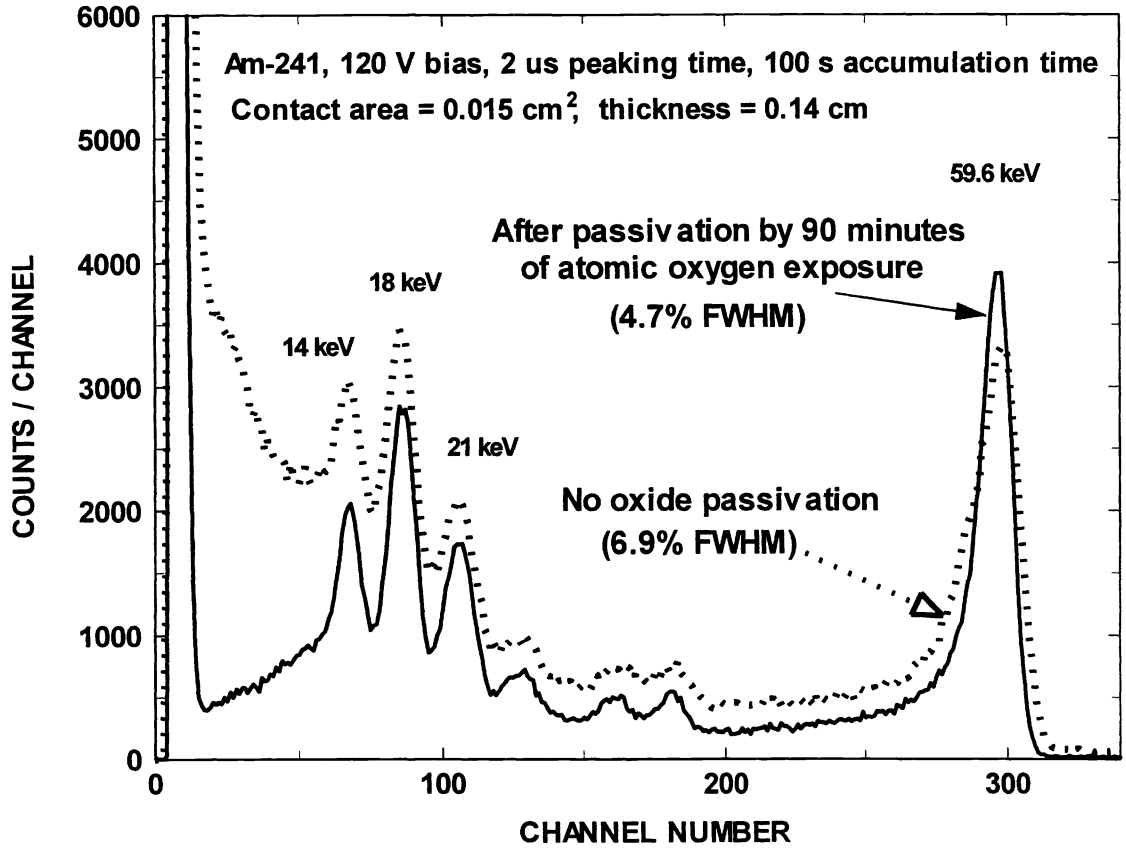

Figure 2. The improvement in the resolution of CZT detectors following 90 minutes of atomic oxygen exposure.

6. CONCLUSIONS

This review paper summarizes the CZT detector fabrication process aimed at obtaining the lowest leakage current and best energy resolution. While major advances have been made, it is expected that additional improvements in detector performance will be achieved through further development and refinement of current technology via novel designs, through implementation of p-i-n structures, for example.

7. ACKNOWLEDGMENTS

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