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Chicago, IL, October 5-8, 2015

Analysis of Surface Chemistry and Detector Performance of Chemically Processed CdZnTe crystals

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Introduction

- Surface processing plays an important role in controlling many aspects of device operation and is critical for assuring good performance;
- An imperfect surface of a substrate acts as a pathway for the movement of defects. It also acts as a source of trapping centers that distort the pulse height and enhances the surface leakage current in radiation detectors;
- Mechanical polishing followed by chemical etching is the commonly used method to process the surfaces before depositing metals or growing substrates;
- Crystals defects (e.g. dislocations and sub-grains) are present on crystal's surfaces and have an adverse effect on the performance of fabricated devices.

Our goal is to produce non-conductive smooth surfaces for fabricating low-noise and high-efficiency CdZnTe devices.

Sample Preparation and Etching Process

➢ Samples: Methods for growth

CdZnTe: Bridgman Method

➢ Crystal processing

- **Silicon Carbide abrasive papers and alumina powder with decreasing particle size, and a final polishing with 0.1-µm alumina powder against a multi-tex soft pad;**

- **Chemo-mechanical polishing**

  Bromine-methanol solution and ethylene glycol (Etchant A)

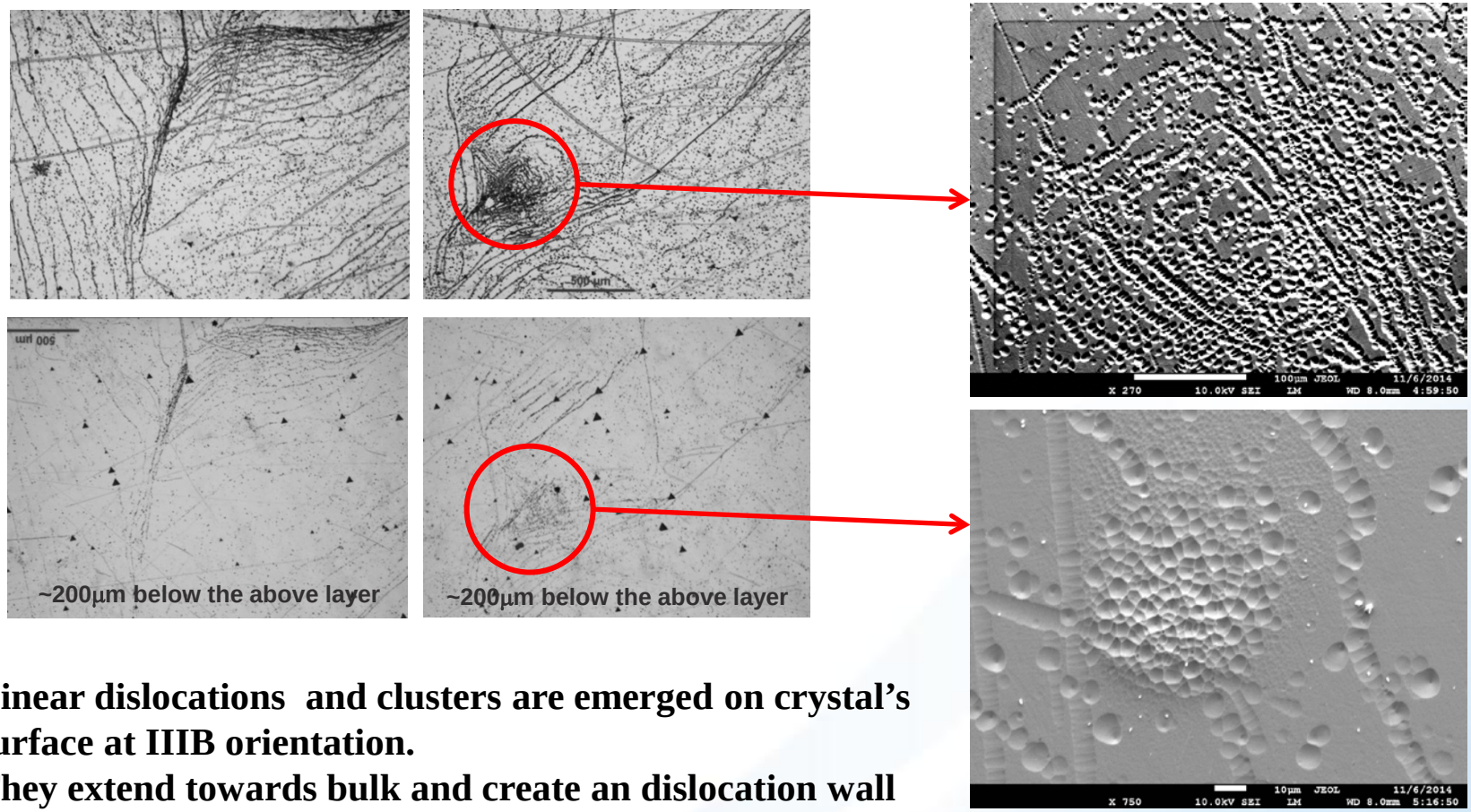
  Bromine-hydrogen peroxide and ethylene glycol (Etchant B)

➢ Chemical etching for revealing EPDs

HF-based solutions were used to show dislocation-related etch pits.

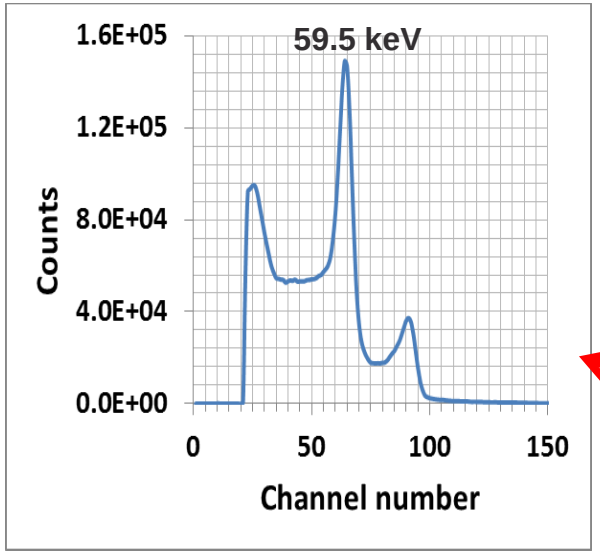
Etch pits were revealed on the crystallographic surfaces (111)A and (111)B.

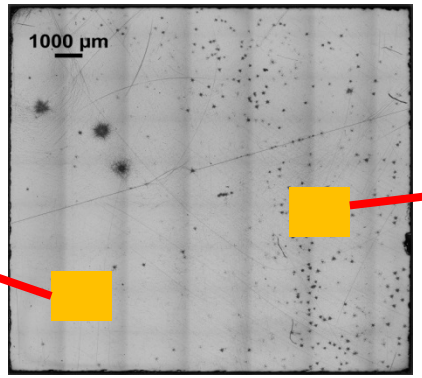
Bulk Defects - Dislocations

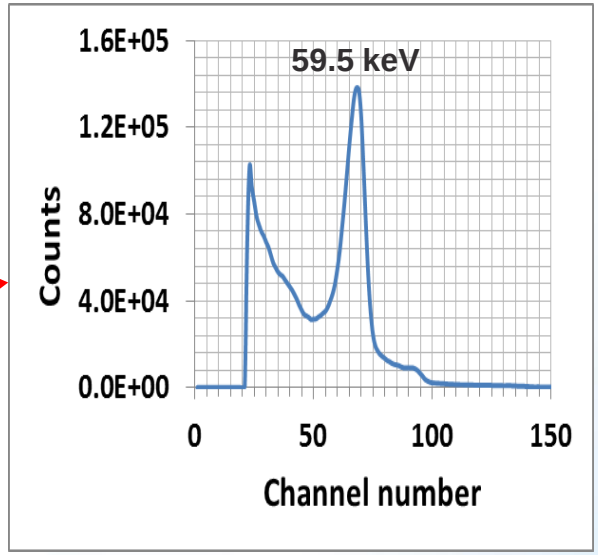


Linear dislocations and clusters are emerged on crystal's surface at IIIB orientation.
They extend towards bulk and create an dislocation wall that hinder the charge carrier transport.
The density of these features at the core was estimated as high as 10^8 cm^{-2}.

Influence of Dislocations on Energy Resolution





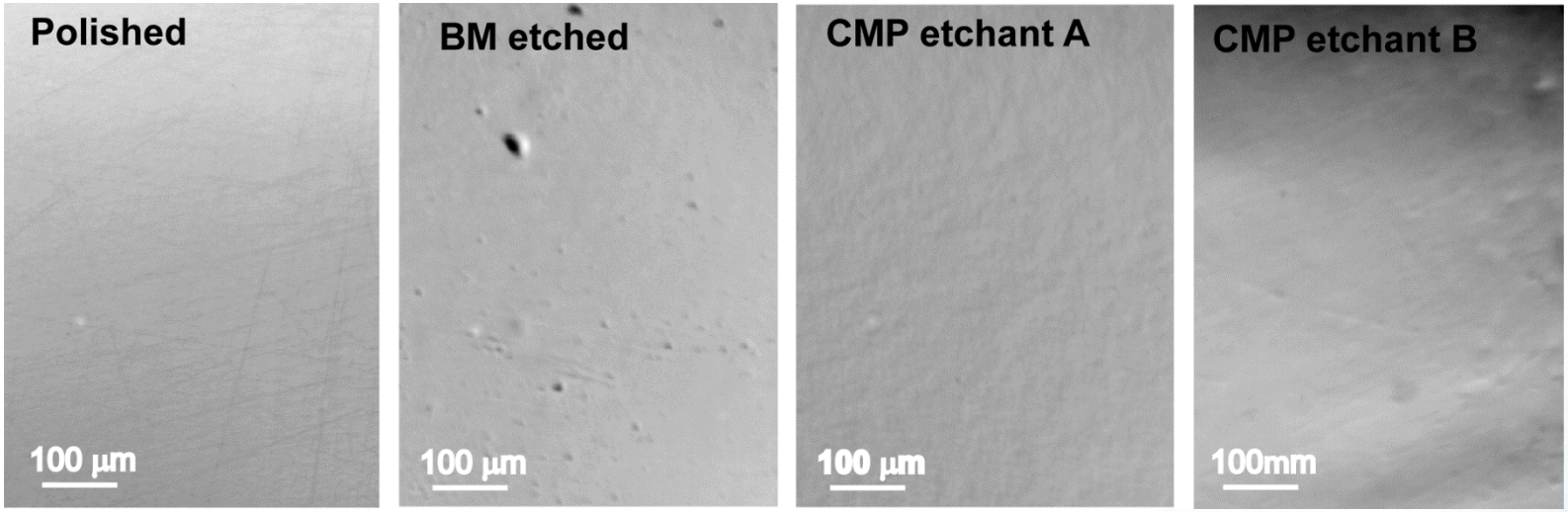


FWHM= 17% of 59 keV

FWHM= 23% of 59 keV

- **High concentration of dislocation defects influence the photopeak efficiency and FWHM.**
- **The tolerance level of such defects has been determined by modeling, but not precisely determined experimentally.**

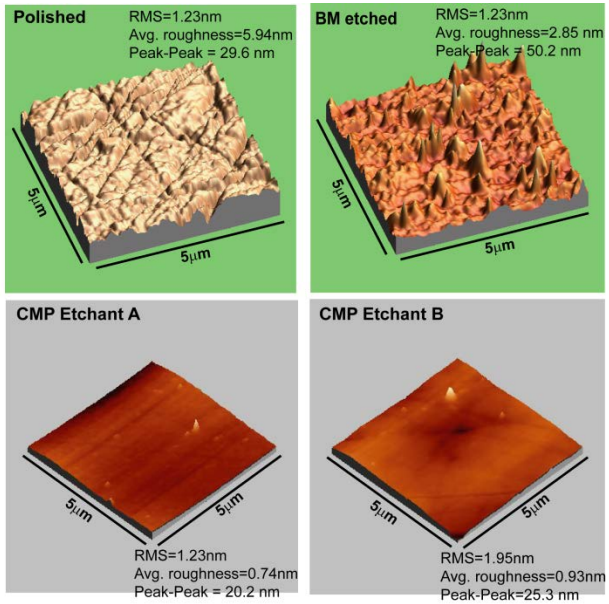
Optical Images of Processed Surfaces



- Mechanical polishing yields visible scratches and damage on the surfaces.
- Chemo-mechanical polishing (CMP) etches off the scratches and leaves smoother surfaces.
- The degree of roughness cannot be determined from the optical images.

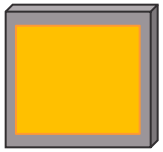
Surface Roughness and Leakage Current

Surface roughness was assessed by AFM measurement

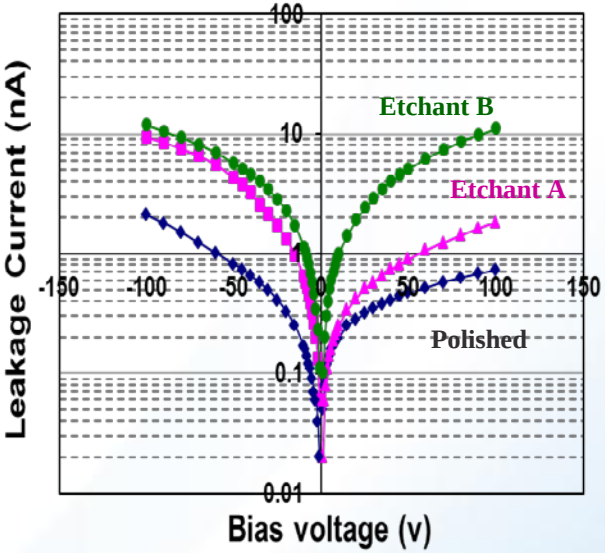


- **Visible damage appears on finely polished surfaces.**
- **BM etching removes damage, but induces some features.**
- **Both CMP etchants yield sub-nanometer roughness.**

Bromine-based solution yields a Te-rich surfaces that causes an increase in the surface leakage current.



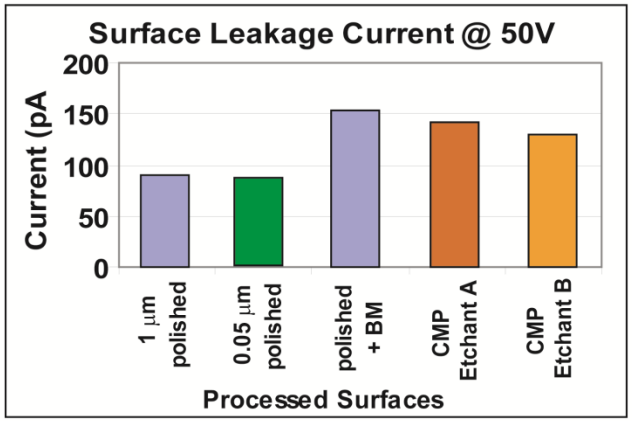
Au-CZT-Au Planar detector



Leakage current increased more than an order of magnitude after CMP for both etchants.

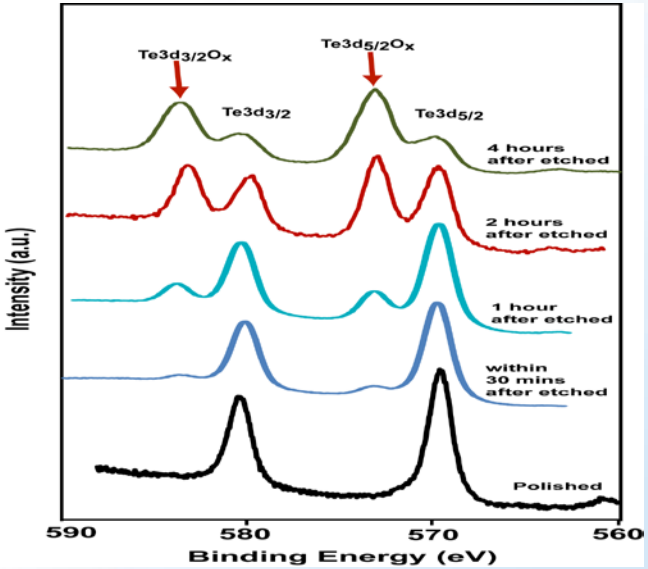
Non-Conductive Nature of Chemically Treated Surfaces

Leakage current was measured for different surface conditions

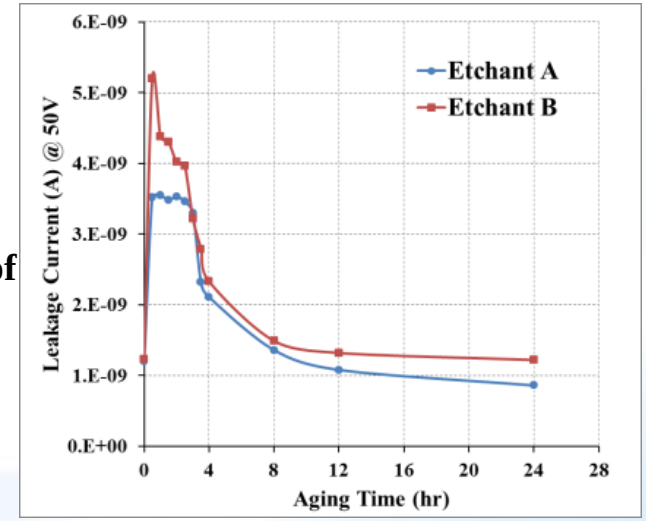


The corresponding TeO_x peaks of the Te doublet gradually appeared as the surfaces oxidized over time, and after a period of two hours, the surfaces were mostly oxidized.

Te doublet peaks



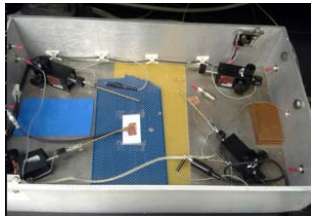
Aging effect



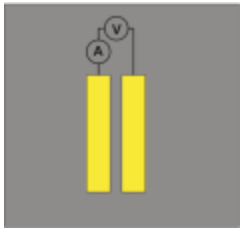
Both bulk and surface leakage current increased immediately after chemical treatment, but gradually decreased and stabilized over the time period of around 4-8 hours.

Surface Current Measurements

Surface leakage current of different chemical treated surfaces were measured by the two-strip method.

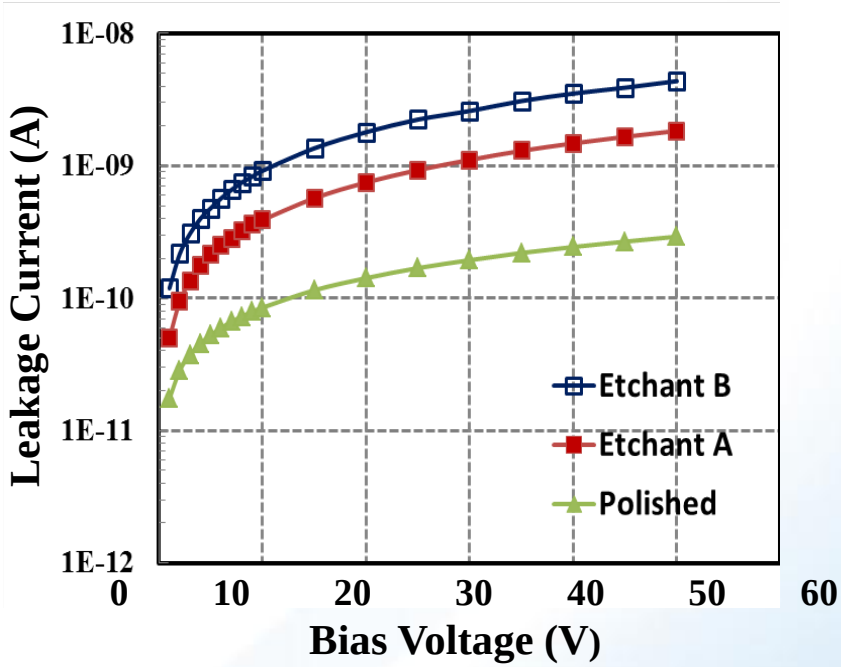


I-V probe



Two-Strip technique

Surface Leakage current @ 100V



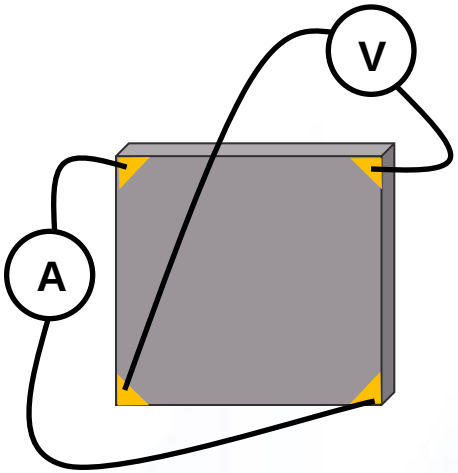
Surface leakage current increased immediately after chemical treatment as bromine creates a Te-rich surface, which is much more conductive.

Sheet Resistivity and Carrier Concentration

Sheet carrier concentration was measured by using a Hall effect measurement setup

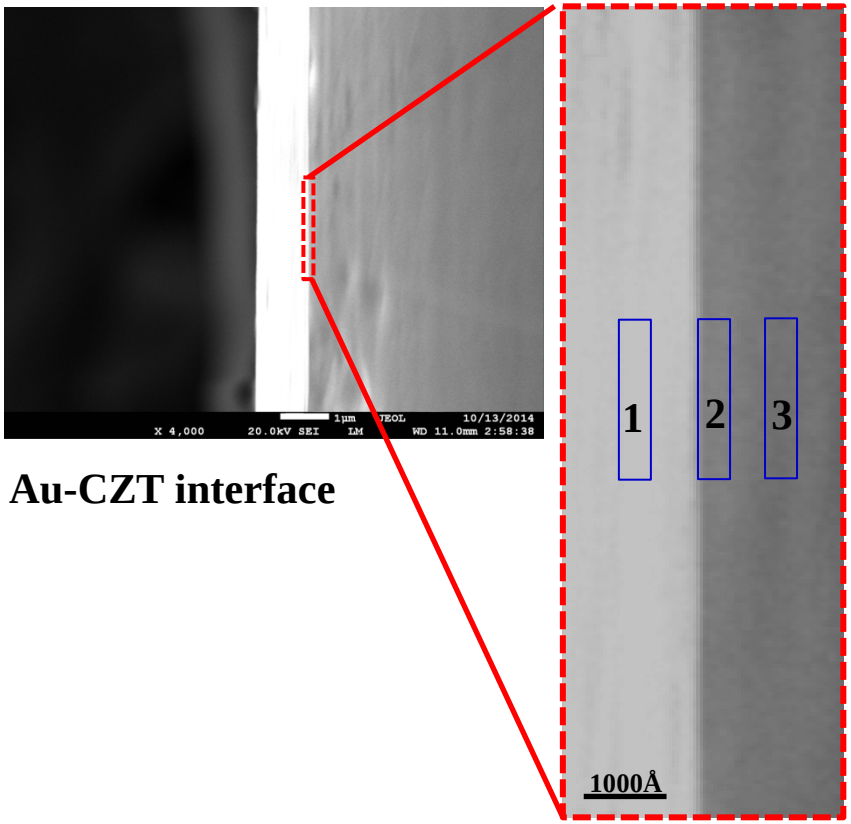
$$n_s = \frac{1}{q \times \mu \times R_s}$$

where
n_s is the sheet carrier concentration,
q is elementary charge,
R_s is the sheet resistivity, and
μ is the Hall mobility.

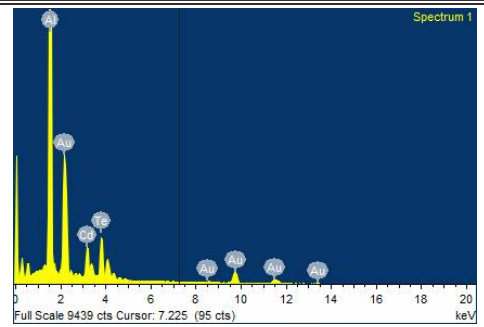


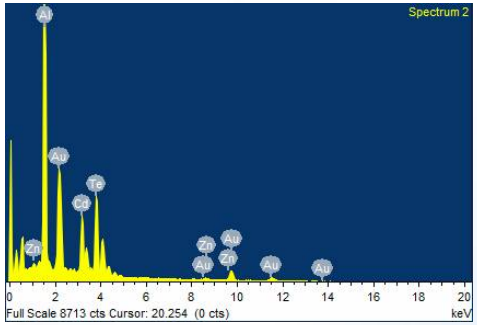
Surface treatment	Sheet Resistivity (Ω/❑)	Sheet carrier concentration (m^{-2})
Polished	$1x10^{11}$	$3.5x10^{11}$
CMP Etchant A	$4x10^{10}$	$1.0x10^{12}$
CMP Etchant B	$3x10^{10}$	$1.3x10^{12}$

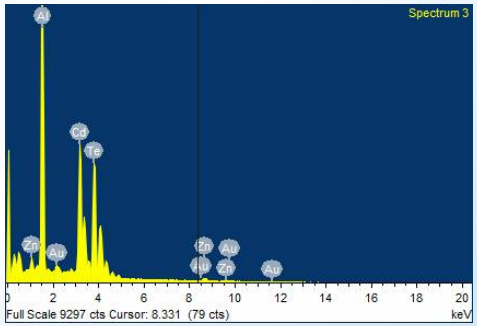
Metal-Semiconductor Interface



Au-CZT interface





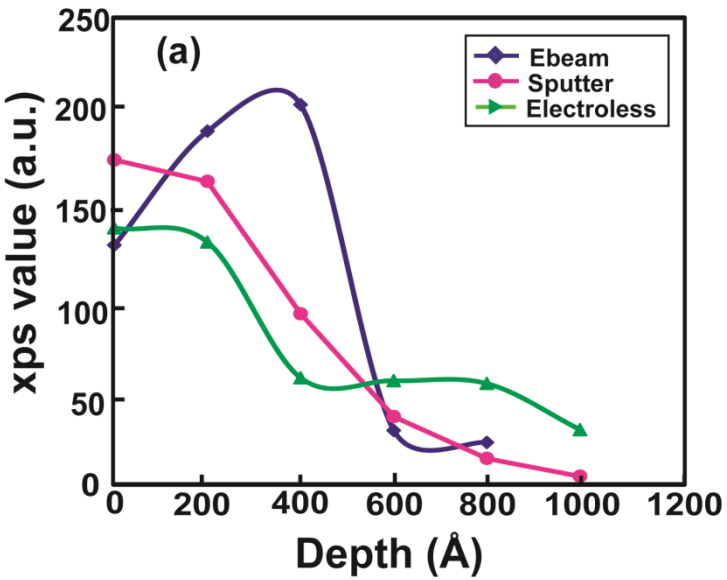


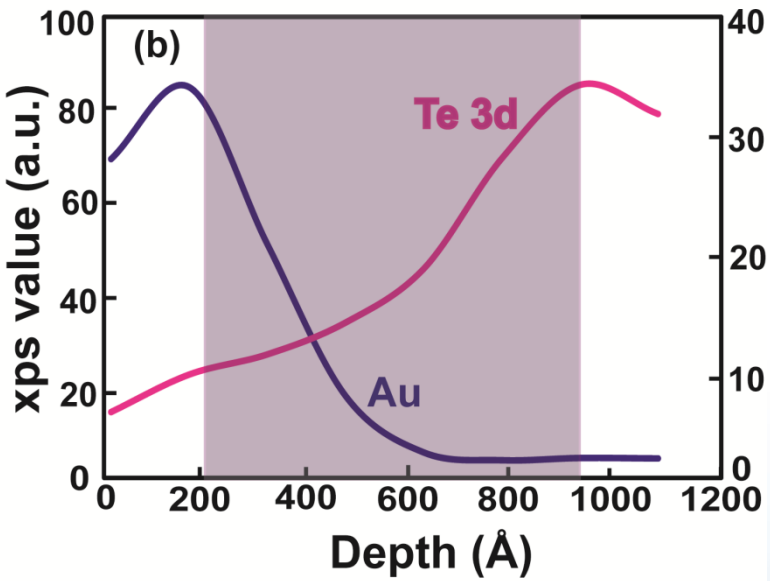
Spectra of EDS measurement around the Au-CZT interface

Achieved smooth interface by optimizing the surface process and metal deposition technique.

EDS spectra show that Au diffused into the bulk.

Diffusion Profile of Metals at Interface





Au diffusion pattern at Au-CZT interface.

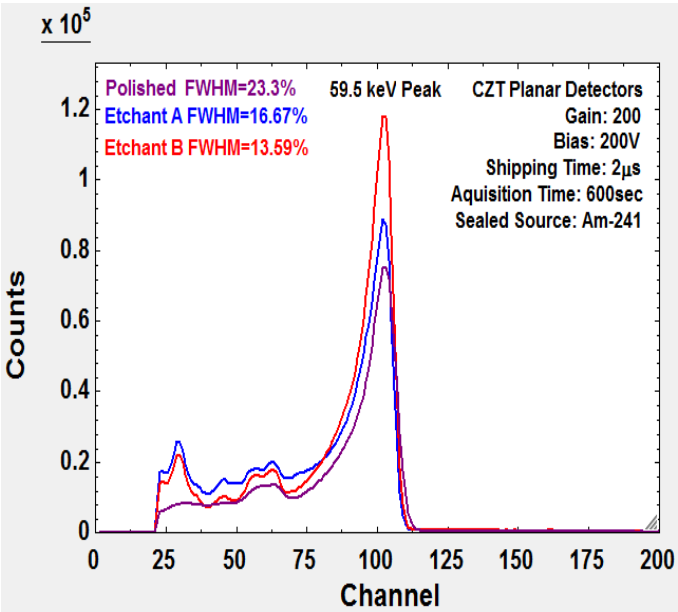
Interface layer was about 600 Å wide.

Au was deposited on identically processed surfaces using electron beam, sputter and electroless methods.

- Diffusion of Au into CZT was found to be lower for electron beam deposition compared to other methods.
- Electroless method seems to generate strong and uniform bonding of Au and CZT.

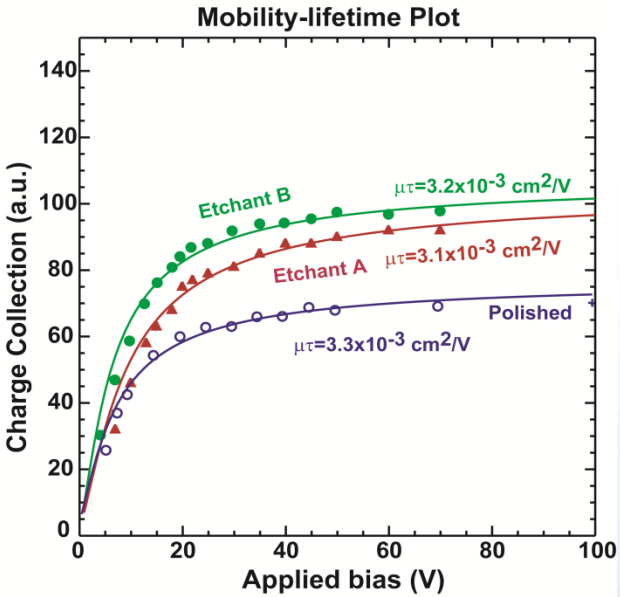
Detector Performance

- Detectors were fabricated after optimizing the surface process.
- Both FWHM and efficiency are improved after chemical treatment.



Am-241 gamma spectral response of a CZT planar detector fabricated at different conditions.

About 6.6% FWHM was improved after treatment with etchant A and about 9.7% FWHM with etchant B.



Mobility-lifetime value was extracted from the best fit of Hecht equation. The estimated value was about $3x10^{-3}$ cm^2/V.

The photon counts (i.e., efficiency) increased significantly after chemical treatment mostly due to reduction of charge-trapping centers.

Summary

- Demonstrated various bulk defects (e.g., dislocations and sub-grain boundaries) and surface defects, and examined their effects on the performance of detectors.

- A comparison study was made between two chemical etchants to produce non-conductive smooth surfaces. A mixture of bromine and hydrogen peroxide (etchant B) showed more effective than conventional bromine etchant (etchant B).

- Both energy resolution and detection efficiency of CZT planar detectors were noticeably increased after processing the detector crystals using improved chemical etchant and processing methods.

Acknowledgement

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~:Thank you:~