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Effects of Surface Passivation on CdZnTeSe Nuclear Detectors

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Outline

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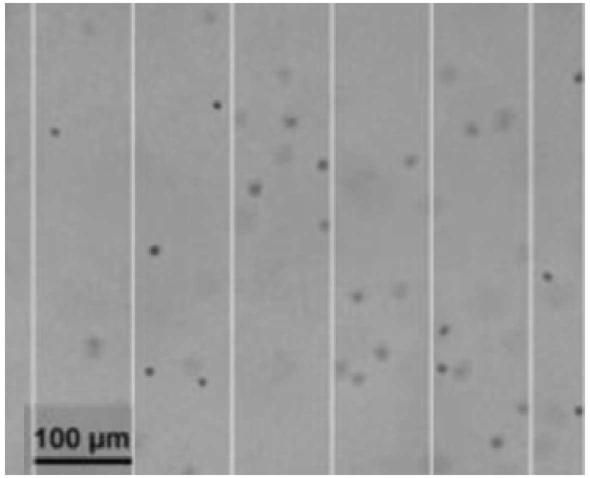
Background and Problems with CdTe-Based Detectors

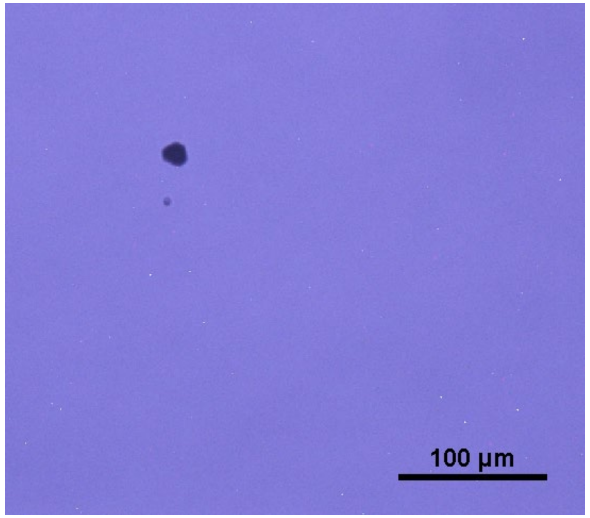
- CdTe-based detectors have the major advantage of operating at room temperature without cryogenic cooling.
- Cadmium zinc telluride selenide (CdZnTeSe) is emerging as a promising material for low-cost production of room-temperature nuclear and radiological detection systems.
- Problems with CdTe-Based Detectors:
  - Defects limits the performance of large-volume CdTe-based crystals for X-rays and gamma-rays detection.
- Defects:
  - Te inclusions, dislocations, sub-grain boundaries, and precipitates.

Advantages of CZTS over CZT

- Better compositional uniformity, which could increase the overall yield of detector-grade material.
- Less Te inclusions and sub-grain boundary network.
- Thus, better uniformity in spatial charge transport properties.
- Hence, increased performance and yield of high-quality detectors.
- Better material hardness.
- Better energy resolutions are being obtained within shorter R&D period.



Infrared Transmission Image of CZT showing high concentration of Te inclusions



Infrared Transmission Image of CZTS showing low concentration of Te inclusions

CZTS Growth by Traveling Heater Method (THM)

- Material composition of $Cd_{1-x}Zn_xTe_{1-y}Se_y$:
  - x = 0.1 and y = 0.04. for Ingot-1 and x = 0.1 and y = 0.02. for Ingot-2.
- It was doped with indium.
- CZTS was synthesized from predetermined stoichiometric amounts of 6N-purity CdZnTe and CdSe.
- The inner walls of the conically-tipped quartz ampoules were carbon coated.
- The CZTS was grown in a Te-rich solution.
- The tellurium and indium were of 6N purity.
- The THM process was carried out in a 3-zone furnace.
- The growth process (THM) described in detail by Roy et al. Scientific Reports volume 9, Article number 7303 (2019). https://www.nature.com/articles/s41598-019-43778-3

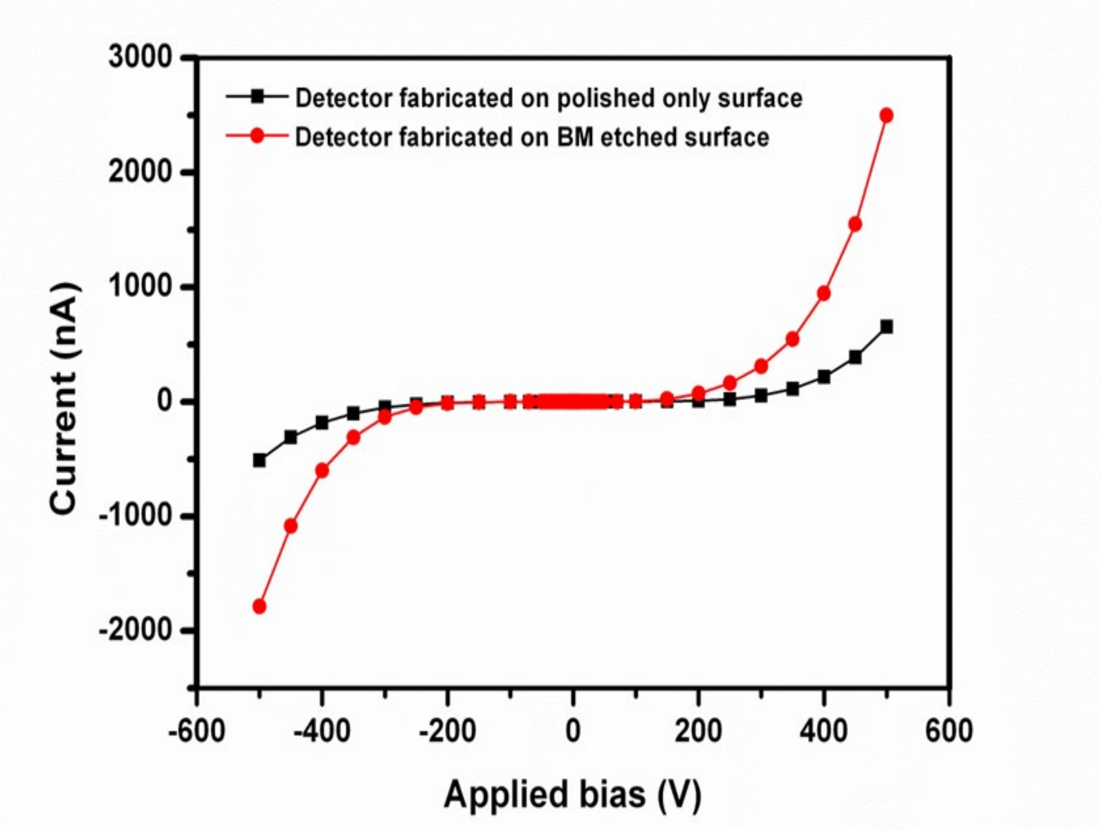
Planar Detectors: Fabrication

- Wafers were cut from as-grown CZTS ingots. Dimensions 6.7 x 5.7 x 1.8 mm^3.
- The wafer was polished successively with 800 grit, 1000 grit and 1200 grit silicon carbide abrasive papers.
- Further smoothed by successively polishing on MultiTex pads with alumina powder of varying sizes (from 3.0 µm to 0.1 µm).
- A mixture of ammonium fluoride and hydrogen peroxide in distilled water ($NH_4F+H_2O_2 + H_2O$) was used to passivate the samples. The process involves dipping a sample in the solution and leaving it for 10 minutes.
- For chemical etching experiments, a 2% bromine methanol solution was used. The sample was immersed in the solution for 2 minutes.
- Gold electrical contacts were deposited on the two opposite sides of the wafer using an electroless deposition technique.

Planar Detectors: I-V Characterization (BM-Etched)

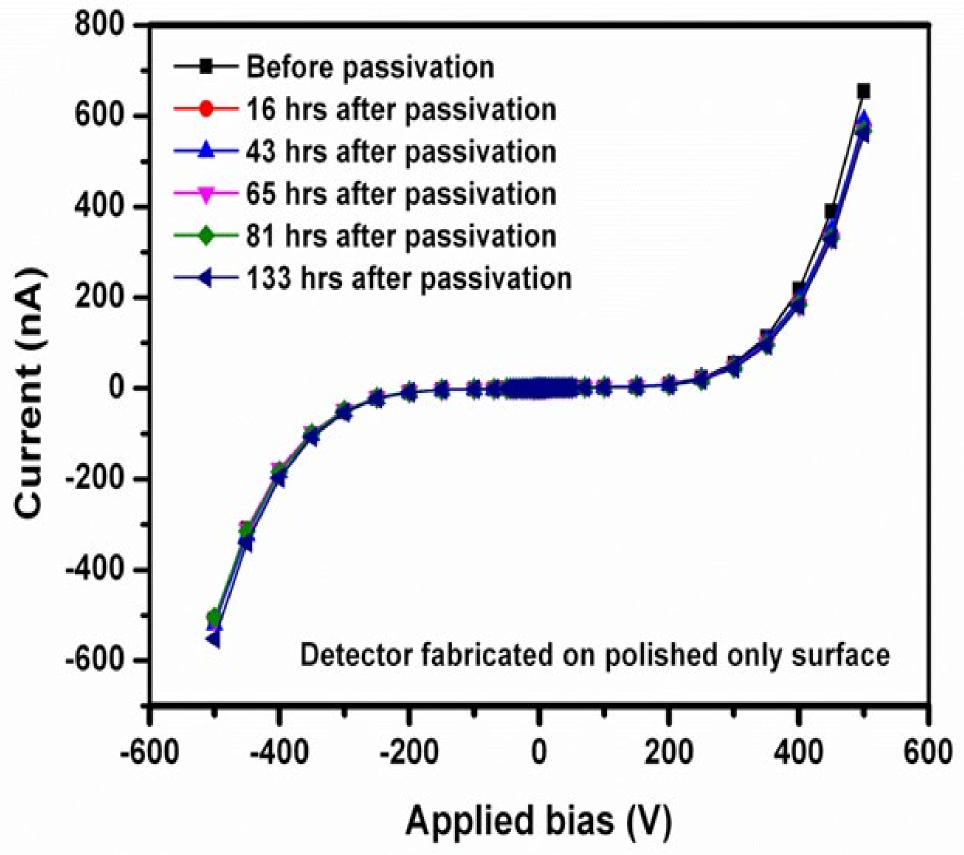
- Current-voltage (I-V) measurements were made in a customized aluminum box equipped with a Keithley Picoammeter and Voltage Source, model number 6487.
- Resistivity is on the order of 10^{10} Ω-cm.

Planar CZTS detector dimensions: 6.7 x 5.7 x 1.8 mm^3

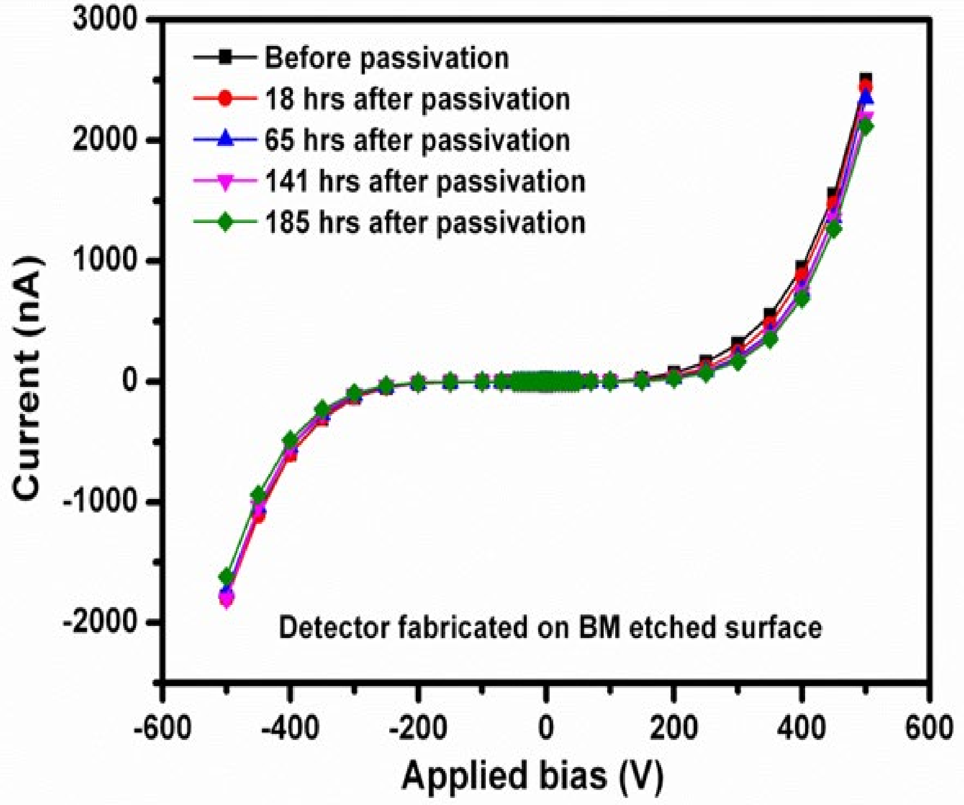


I-V for polished only and Bromine methanol etched surface.

Planar Detectors: I-V Characterization (NH_4F-Pasivated)



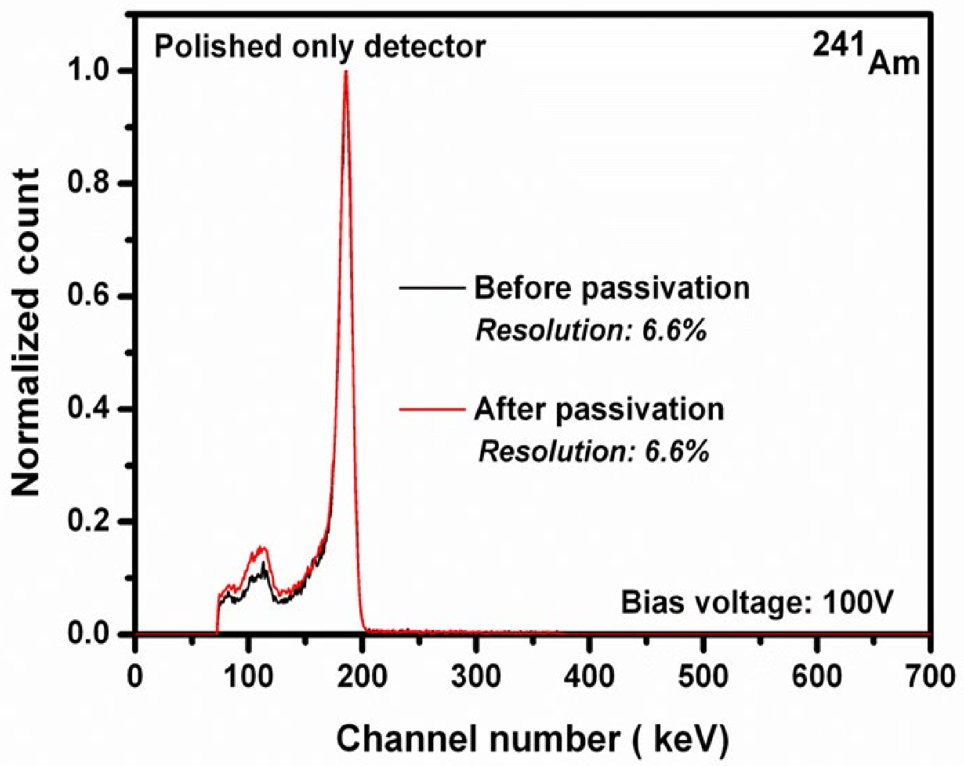
Polished and passivated.



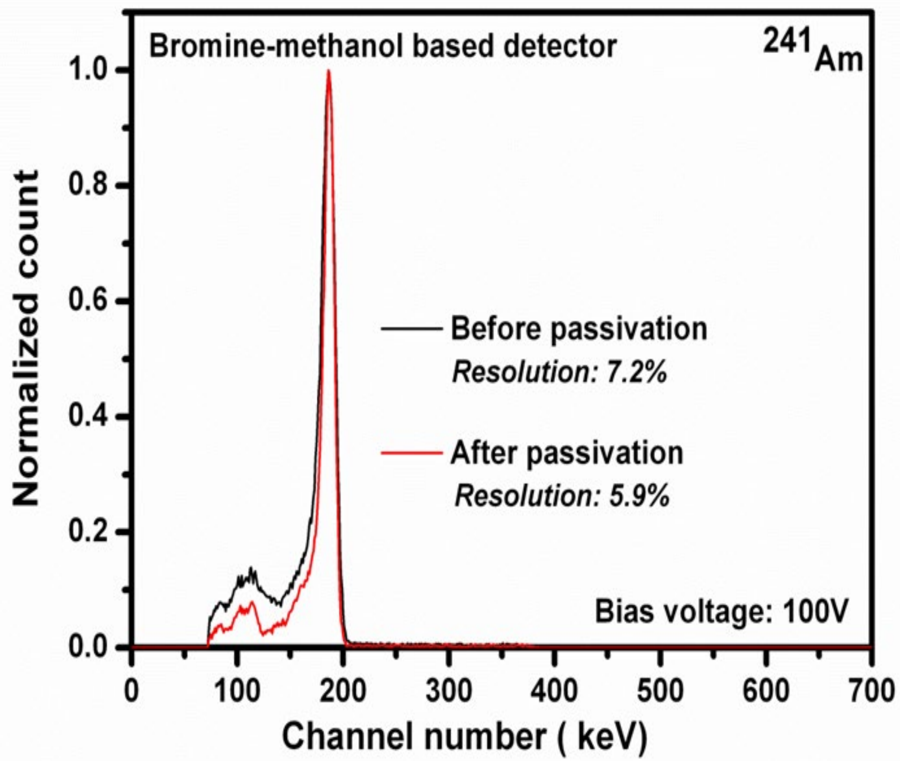
Polished, etched, and passivated.

Planar Detectors: Spectral Characterization

- A special sample holder by eV Products (now Kromek) was used to record the response of the detectors to sealed Am-241 and Cs-137 nuclear radiation sources.
- The signal generated by the ionizing radiation in the detector was passed through a preamplifier, an amplifier, and a multichannel analyzer (MCA) to a computer.

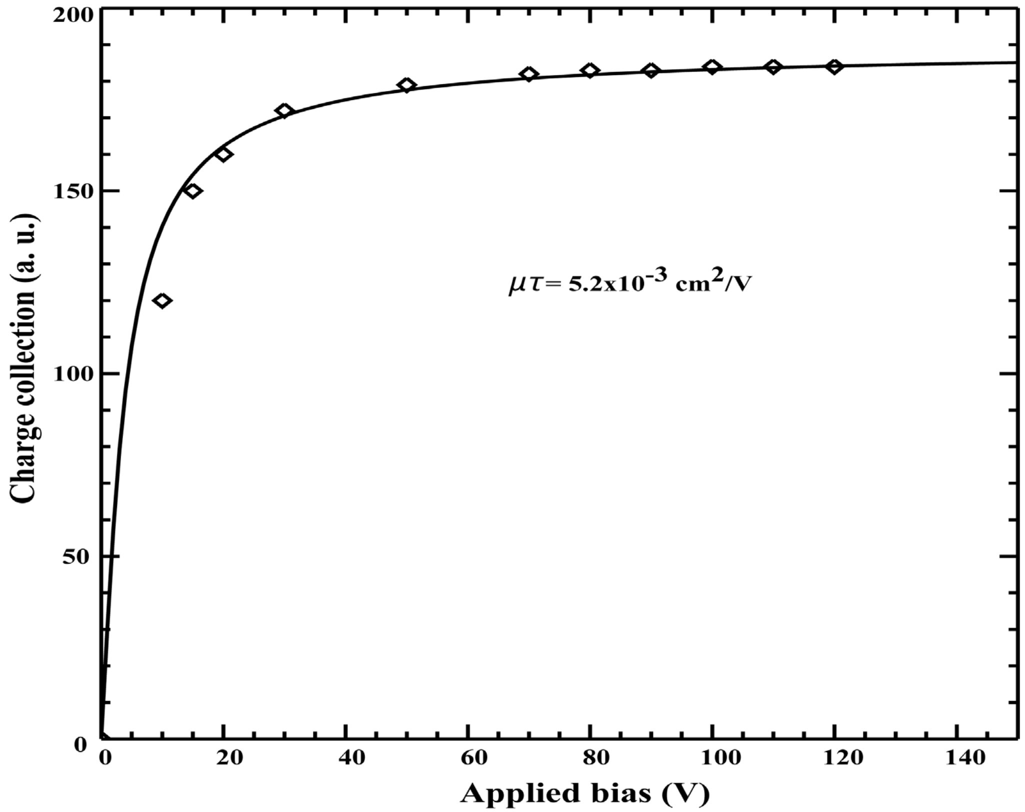


Polished and passivated.



Polished, etched, and passivated.

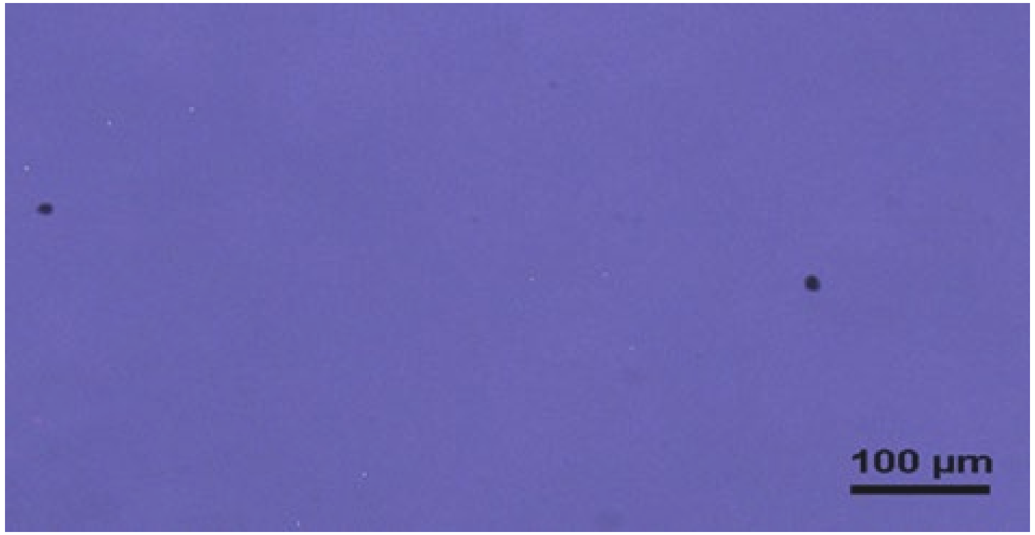
Planar Detectors: Charge-Transport Characterization



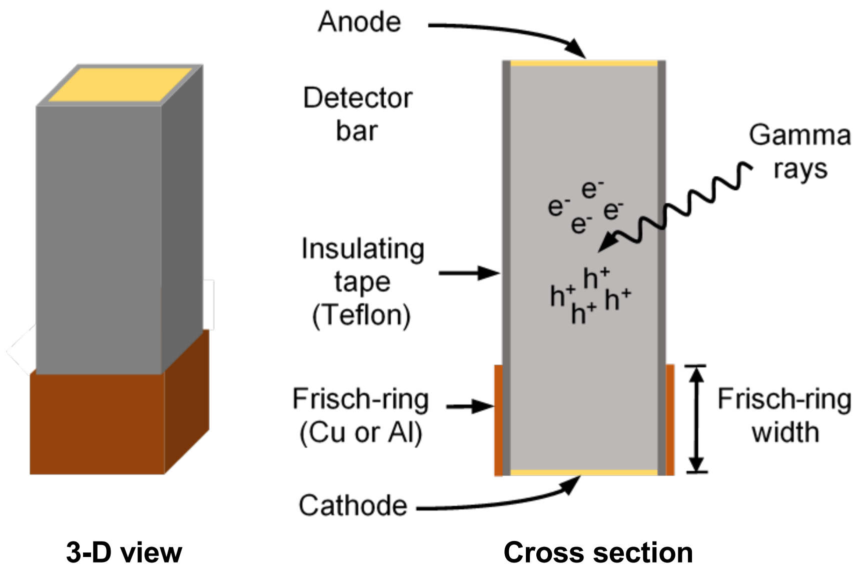
Electron mobility-lifetime product.

Frisch-Grid Detectors: Fabrication and Characterization

- The **4.3 x 4.3 x 10 mm^3** Frisch-grid detector was fabricated from an as-grown CZTS ingot.
- It was grown by THM in a Te-rich solution and with indium doping.
- Gold electrical contacts were deposited on the two opposite sides of the wafer using an electroless deposition technique.



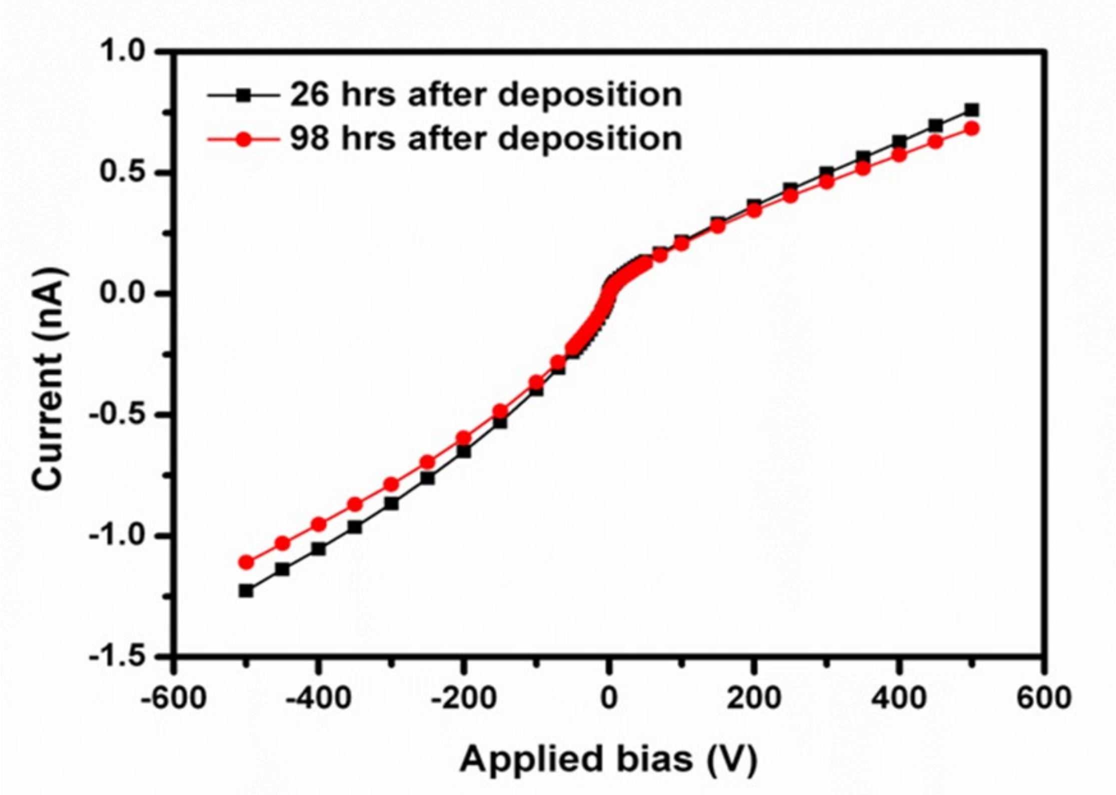
Infrared Transmission Images of CZTS Frisch-grid Detector showing a low concentration of Te Inclusions.



Schematic of virtual Frisch-grid detector configuration. Not drawn to scale. Electrons (e-) drift towards the anode and holes (h+) drift towards the cathode.
From: Egarievwe et al. IEEE Access, Vol. 8, July 2020.
https://ieeexplore.ieee.org/document/9149582

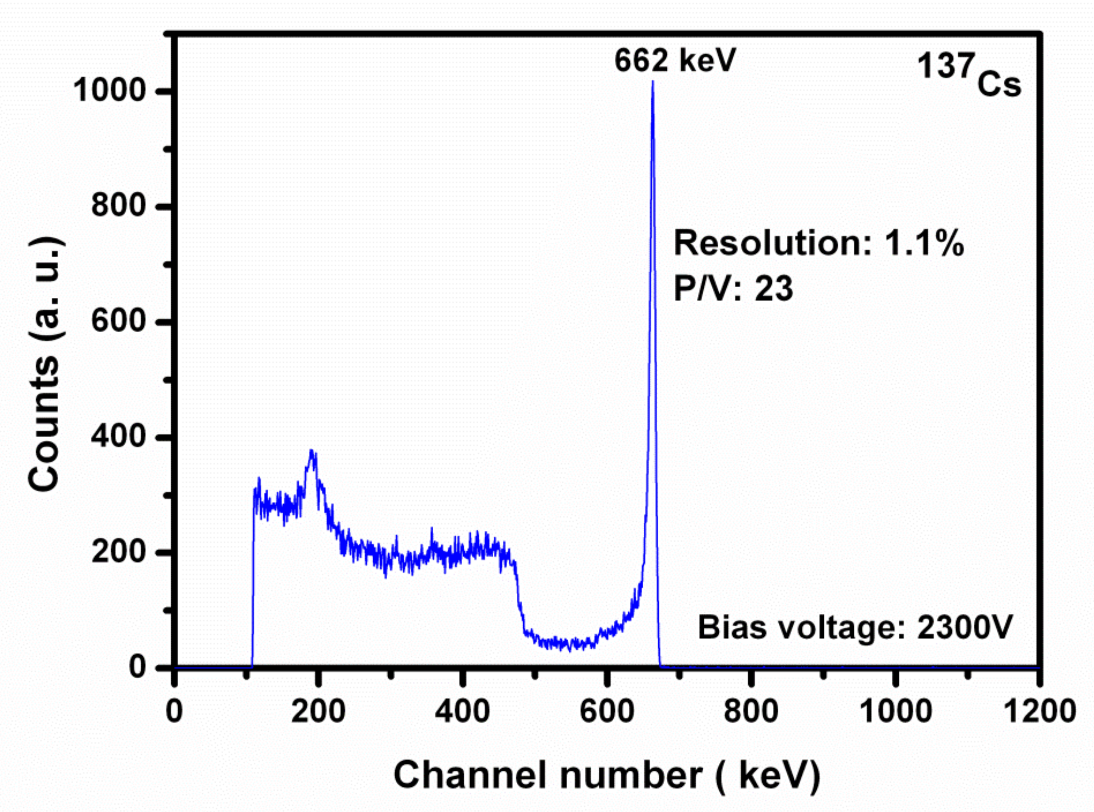
Frisch-Grid Detectors: I-V Plot and Resistivity

- The resistivity of the detector is 4.63 x 10^{10} Ω–cm.



I-V of the CZTS Frisch-grid detector after gold-contact deposition.
Dimensions: 6.7 x 5.7 x 1.8 mm^3

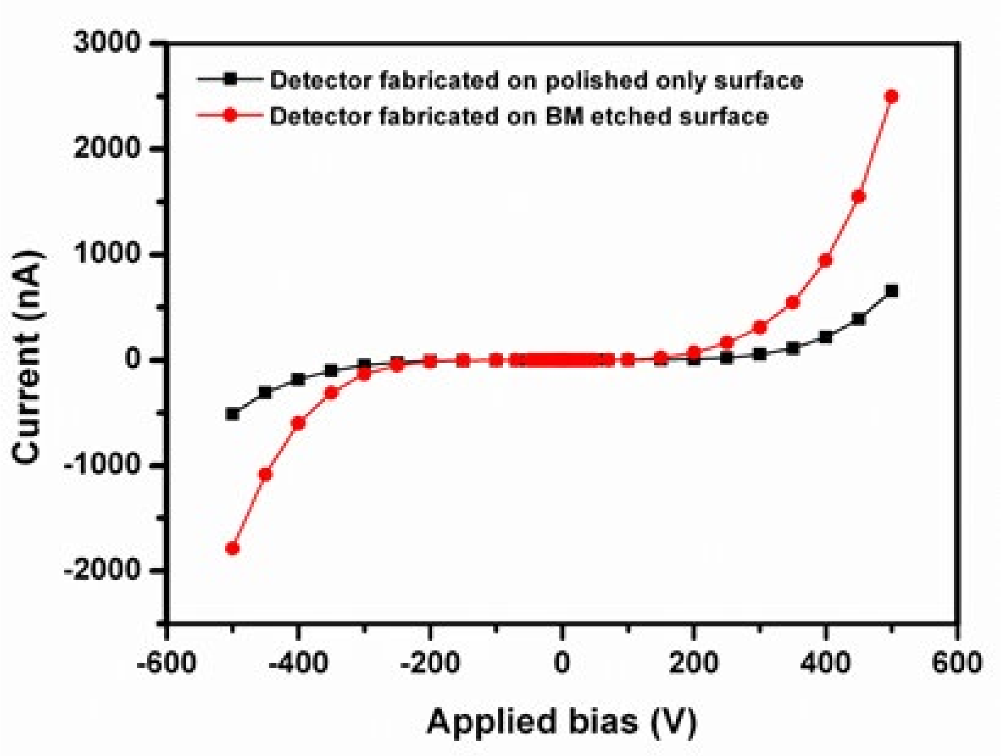
Frisch-Grid Detectors: Energy Resolution and Electron Mobility-Lifetime (μτ) Product



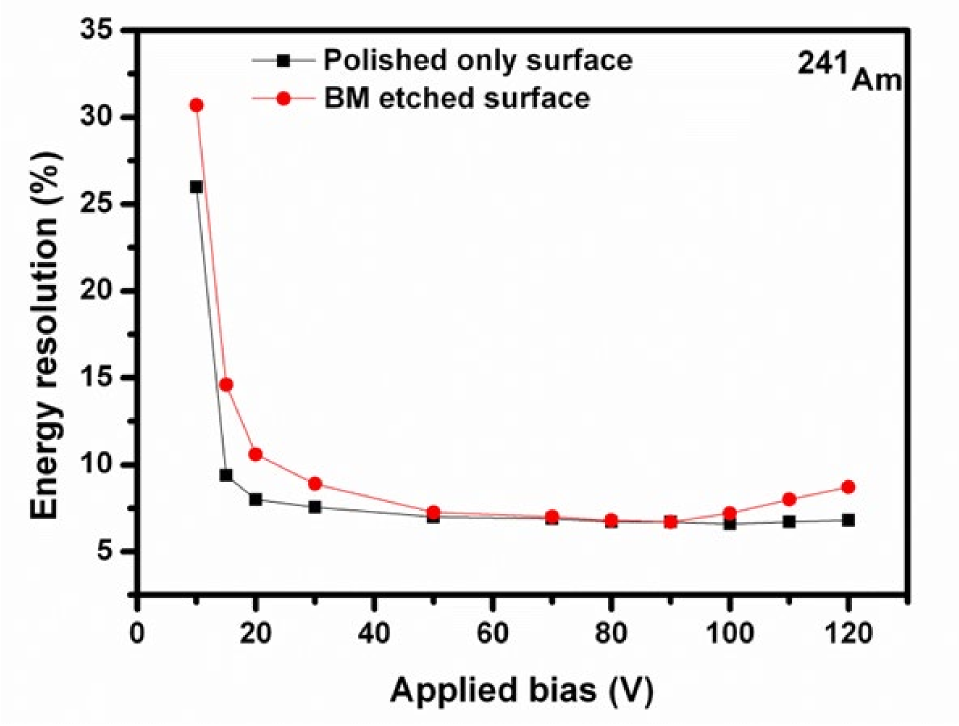
Response of the CZTS Frisch-grid detector to the 662-keV gamma line of ^{137}Cs at 2300 V.

- Resolution (with no correction) for 662-keV gamma line of ^{137}Cs is **1.1%**.
- Mobility-lifetime product of 5 x 10^{-3} cm^2/V.

Effects of Chemical Treatment: Etching in Bromine Methanol (BM)



Current-voltage plot of the 6.7 x 5.7 x 1.8 mm^3 CZTS planar detector.



Energy Resolution on polished only and BM etched surface.

Summary

- CZTS has shown great advantages over CZT.
- The resistivity of the material was on the order of 10^{10} Ω-cm.
- For the planar detector, energy resolution of 6.6% FWHM was obtained for the 59.6-keV gamma line of Am-241.
- CZTS Frisch-grid detector gives energy resolution of 1.1% FWHM for the 662-keV gamma line of Cs-137.
- The leakage currents were observed to be higher for the BM-etched wafer at applied voltages above 150 V. The leakage currents were similar for lower voltages.
- Passivation with ammonium fluoride solution improved energy resolution of BM-etched CZTS wafers.

Thank You