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Characterization of CdZnTeSe Planar and Frisch-Grid Nuclear Detectors

Stephen U. Egarievwe,[1,2,3] Utpal N. Roy,[3,4] Parion L. Alexander,[5] Mordecai B. Israel,[2] Amir H. Davis,[6] Ezekiel O. Agbalagba,[7] and Ralph B. James[4]

[1]Nuclear Engineering and Radiological Science Center, Alabama A&M University, Huntsville, Alabama, USA
[2]Electrical Engineering and Computer Science, Alabama A&M University, Huntsville, Alabama, USA
[3]Nonproliferation and National Security, Brookhaven National Laboratory, Upton, New York, USA
[4]Science and Technology, Savannah River National Laboratory, Aiken, South Carolina, USA
[5]Biological and Environmental Sciences Department, Alabama A&M University, Huntsville, Alabama, USA
[6]Brooklyn Technical High School, Brooklyn, New York, USA
[7]Physics Department, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria

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Outline

- Background and Problems with CdTe-Based Detectors
- Advantages of CZTS over CZT
- CZTS Growth by Traveling Heater Method (THM)
- Planar Detectors: Fabrication and Characterization
- Frisch-Grid Detectors: Fabrication and Characterization
- Effects of Chemical Treatment
- Summary

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 resolution are being obtained within shorter R&D period.

CZTS Growth by Traveling Heater Method (THM)

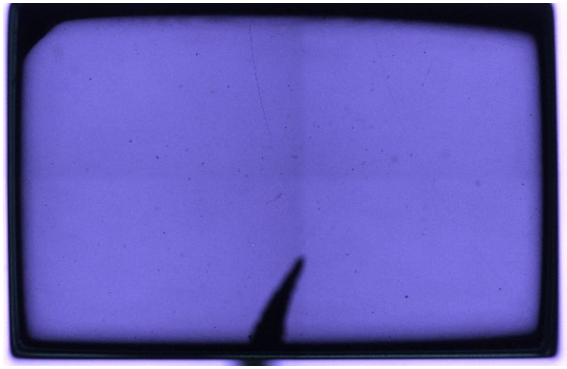
- Material composition of $Cd_{1-x}Zn_xTe_{1-y}Se_y$:
  - x = 0.1 and y = 0.04. for Ingot-1 and x = 0.1 and y = 0.02. for Ingot-2.
- It was doped with indium.
- CZTS was synthesized from predetermined stoichiometric amounts of 6N-purity CdZnTe and CdSe.
- The inner walls of the conically-tipped quartz 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 and Characterization

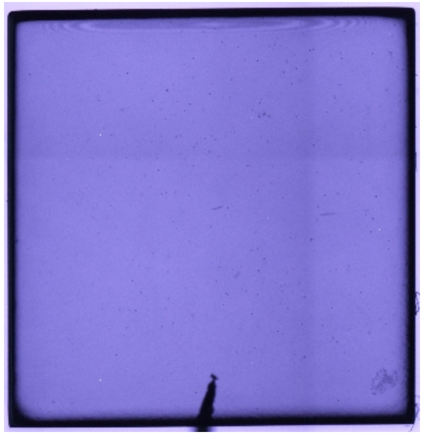
- Wafers were cut from as-grown CZTS ingots.
- The wafer was polished successively 800 grit, 1000 grit and 1200 grit silicon carbide abrasive papers.
- Further smoothed by successively polishing on MultiTex pads with alumina powder of varying sizes (from 3.0 μm to 0.1 μm).
- The wafer was rinsed in distilled water and dried using compressed air.
- Gold electrical contacts where deposited on the two opposite sides of the wafer using an electroless deposition technique.

Sample 1 Size: 7.0 x 4.7 x 2.7 mm^3 (from Ingot-1)
Sample 2 Size: 5.9 x 6.0 x 1.6 mm^3 (from Ingot-2)

Infrared transmission images:



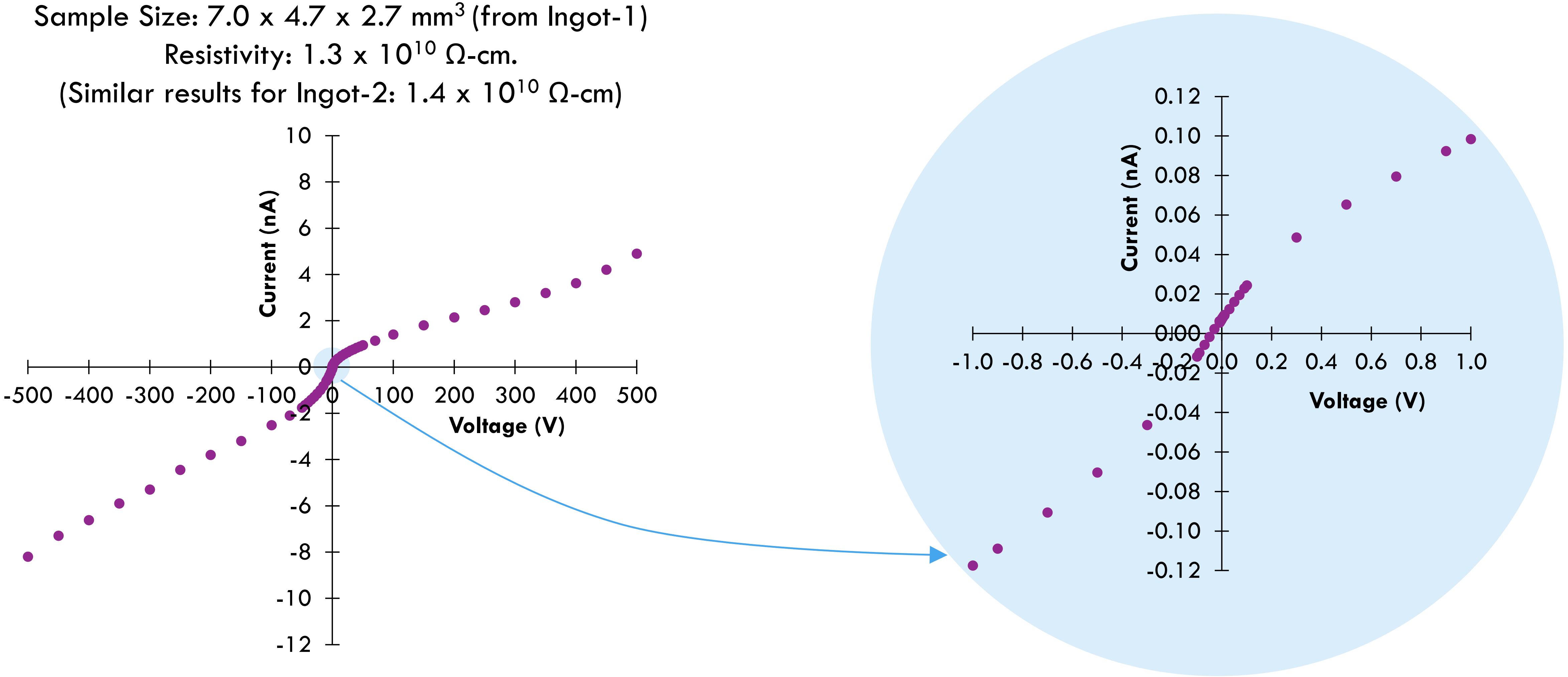
Wafer from ingot-1 (7.0 mm × 4.7 mm).



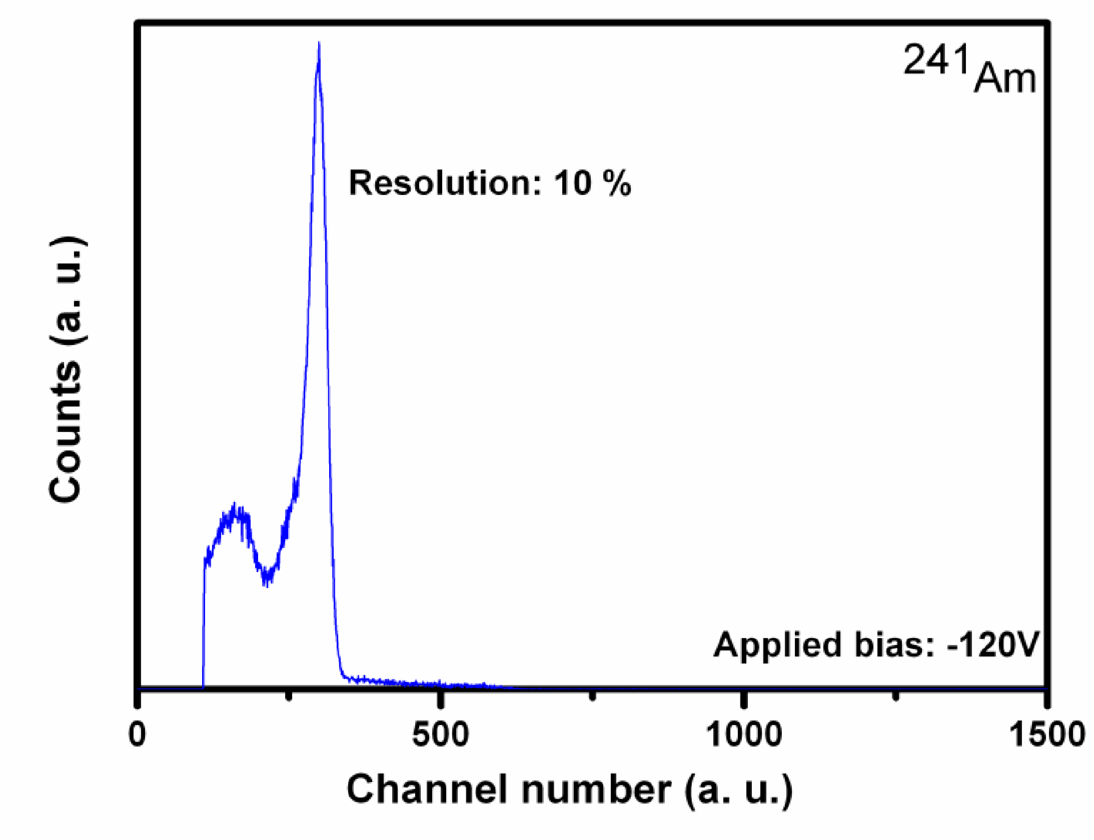
Wafer from ingot-2 (5.9 mm × 6.0 mm).

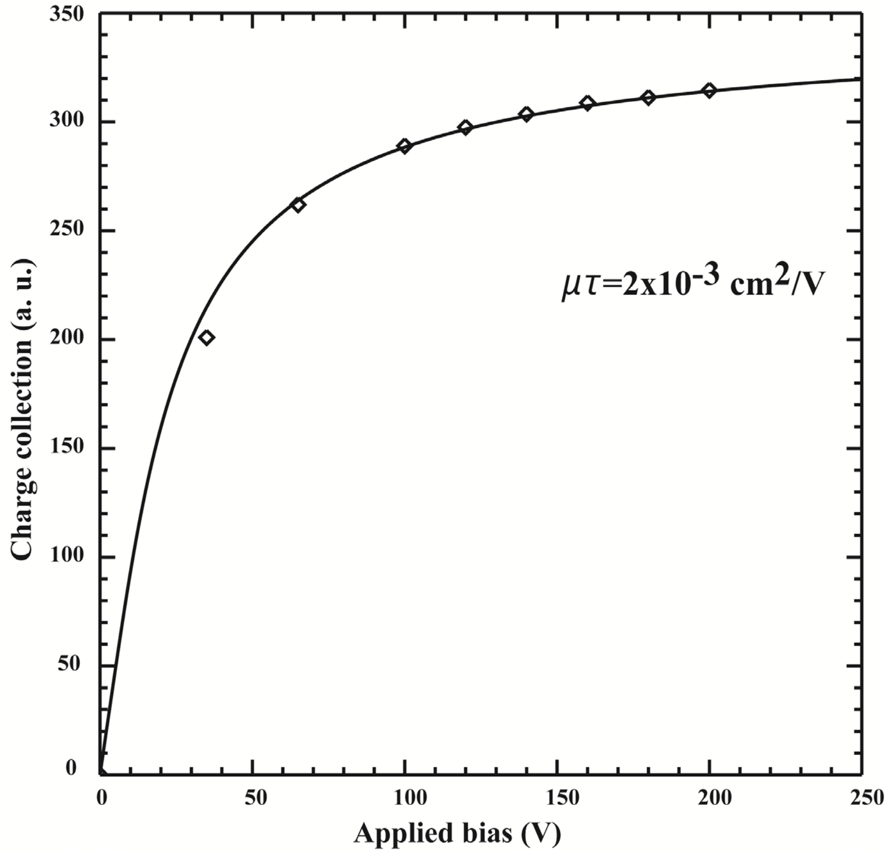
Planar Detectors: I-V Plot and Resistivity

Sample Size: 7.0 x 4.7 x 2.7 mm^3 (from Ingot-1)
Resistivity: 1.3 x 10^{10} Ω-cm.
(Similar results for Ingot-2: 1.4 x 10^{10} Ω-cm)

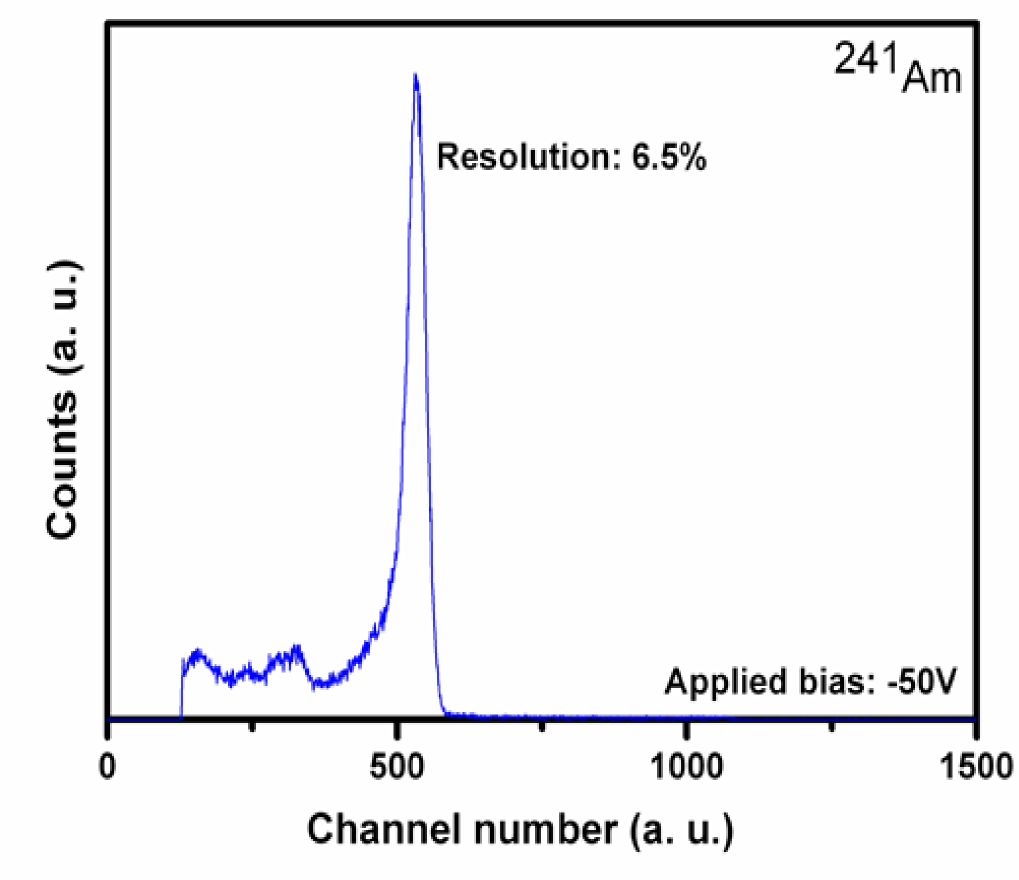


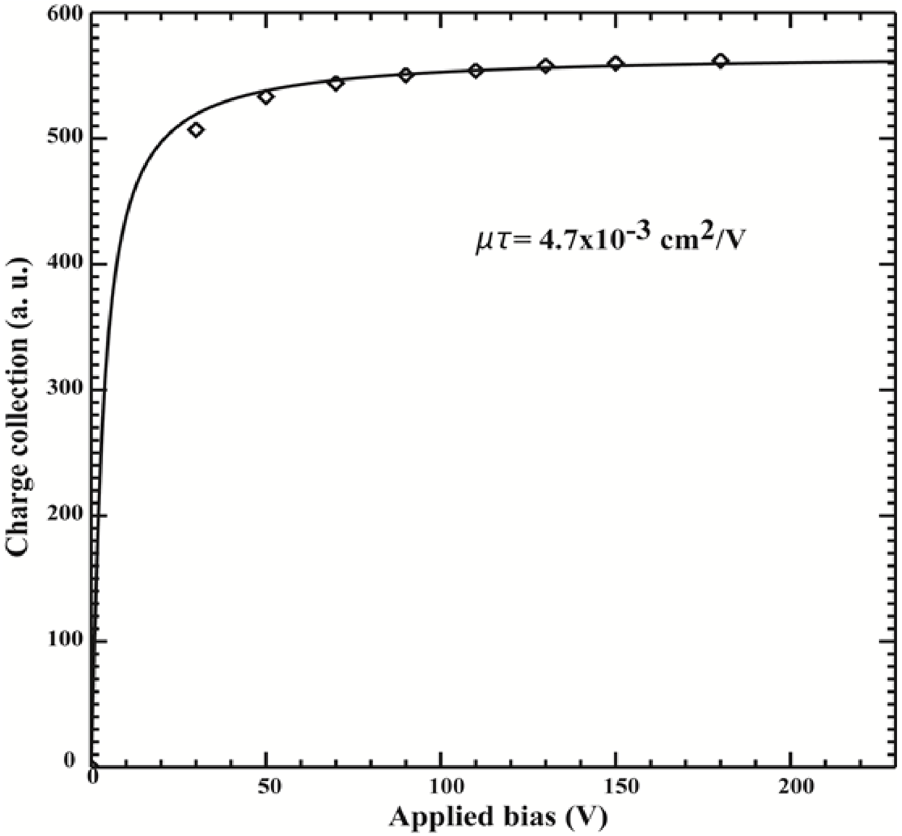
Planar Detectors: Energy Resolution and Electron Mobility-Lifetime (μτ) Product of Sample 1





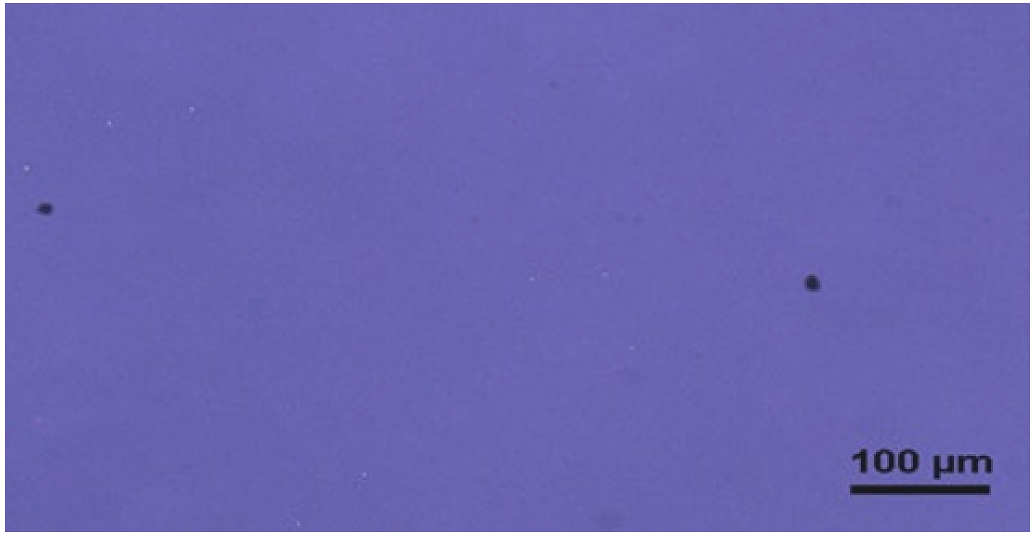
Planar Detectors: Energy Resolution and Electron Mobility-Lifetime (μτ) Product of Sample 2



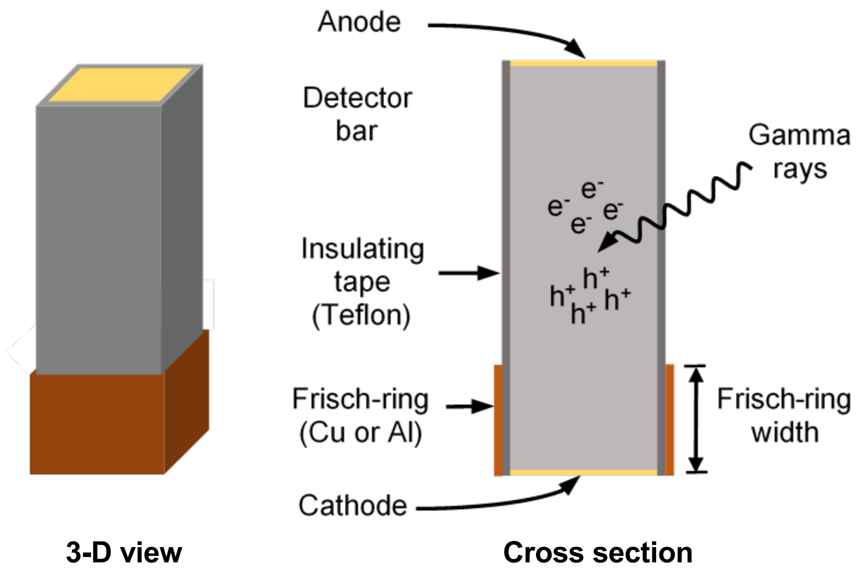


Frisch-Grid Detectors: Fabrication and Characterization

- 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 where deposited on the two opposite sides of the wafer using an electroless deposition technique.



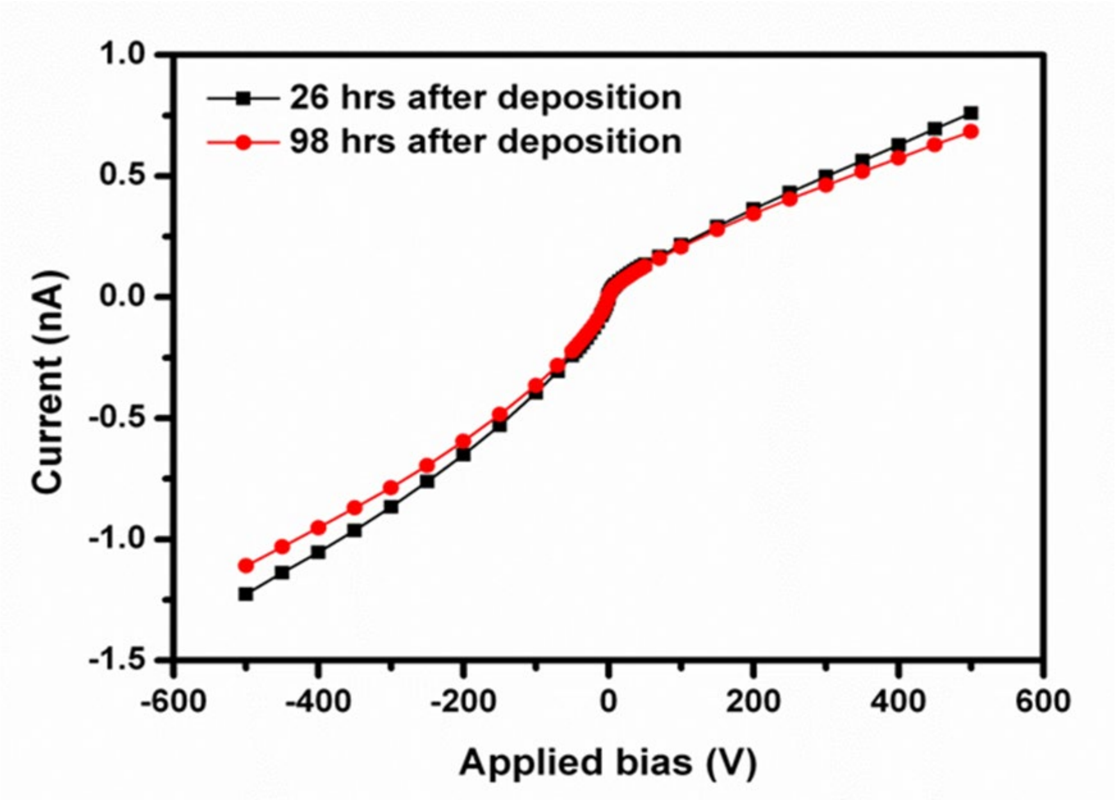
Infrared Transmission Images of CZTS Frisch-grid Detector showing a low concentration of Te Inclusions.



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

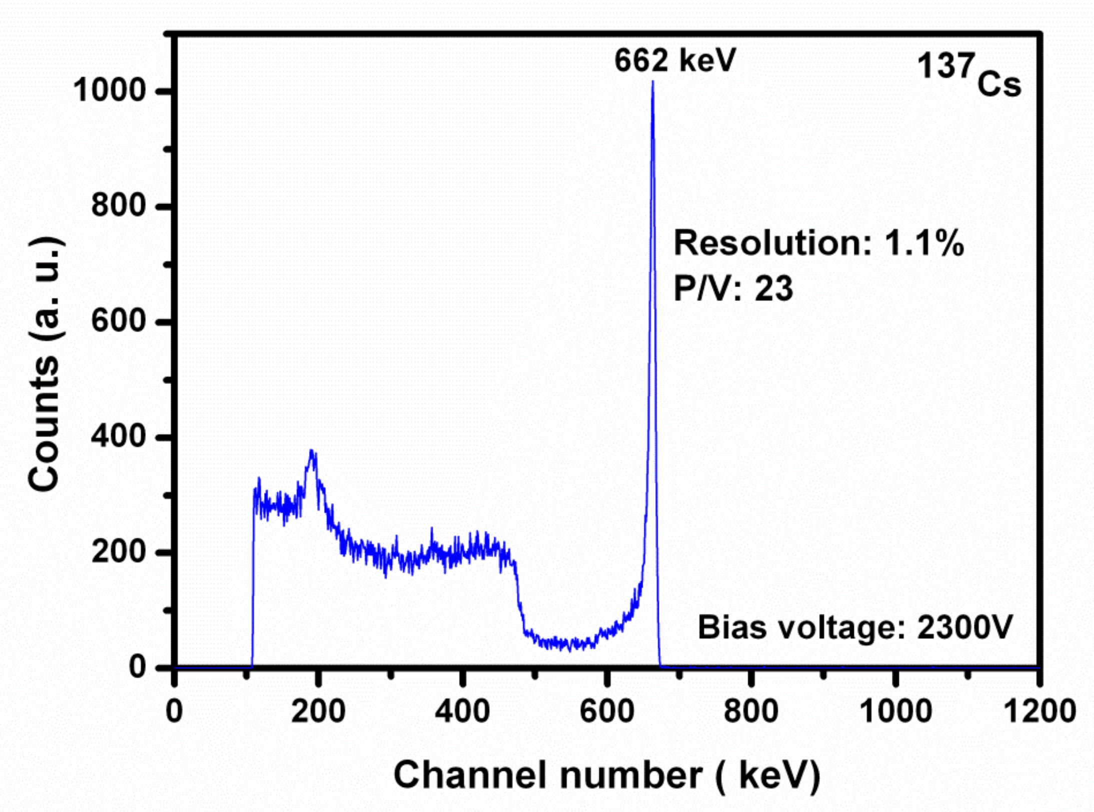
Frisch-Grid Detectors: I-V Plot and Resistivity

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



I-V of Frisch- grid detector after gold-contact deposition.

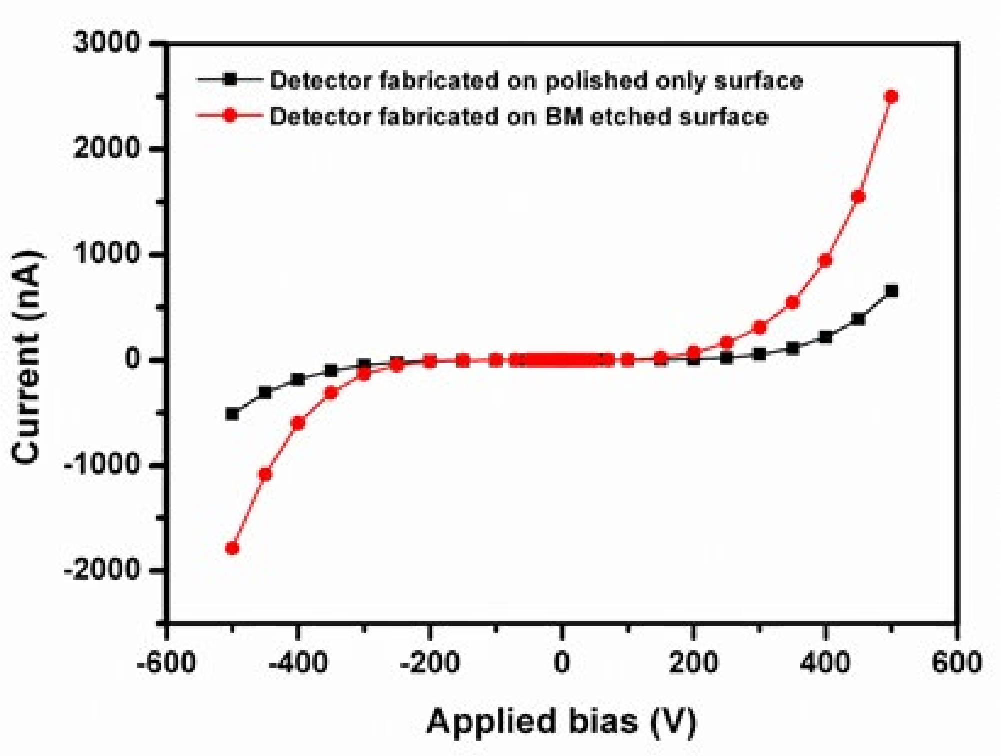
Frisch-Grid Detectors: Energy Resolution and Electron Mobility-Lifetime (μτ) Product



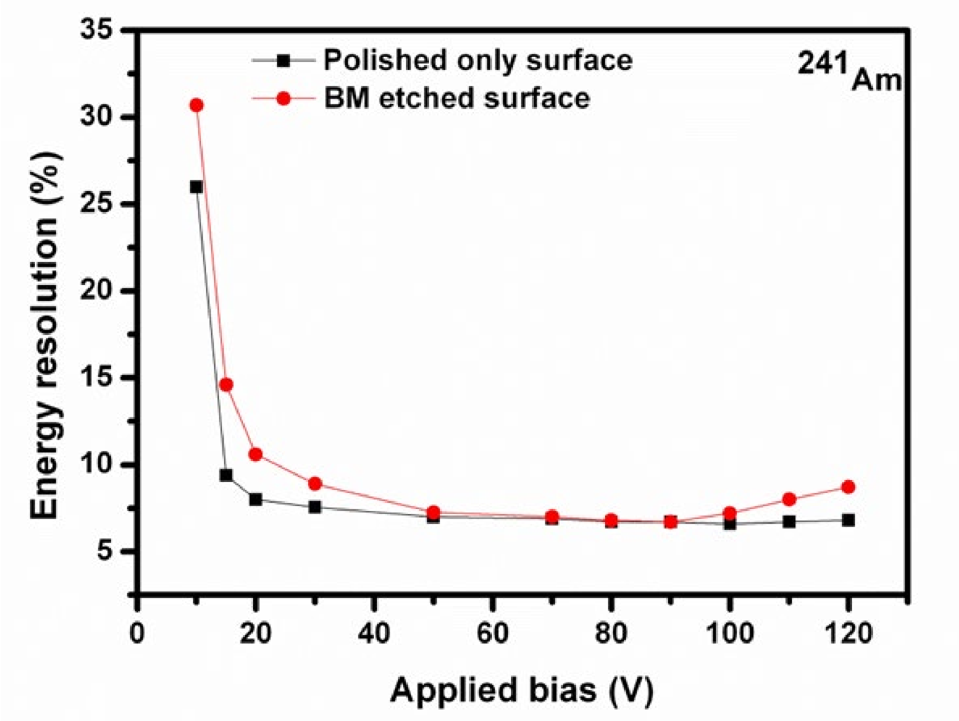
Response of the CZTS Frisch-grid detector to the 662-keV gamma line of ^{137}Cs at 2300 V.

- 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.

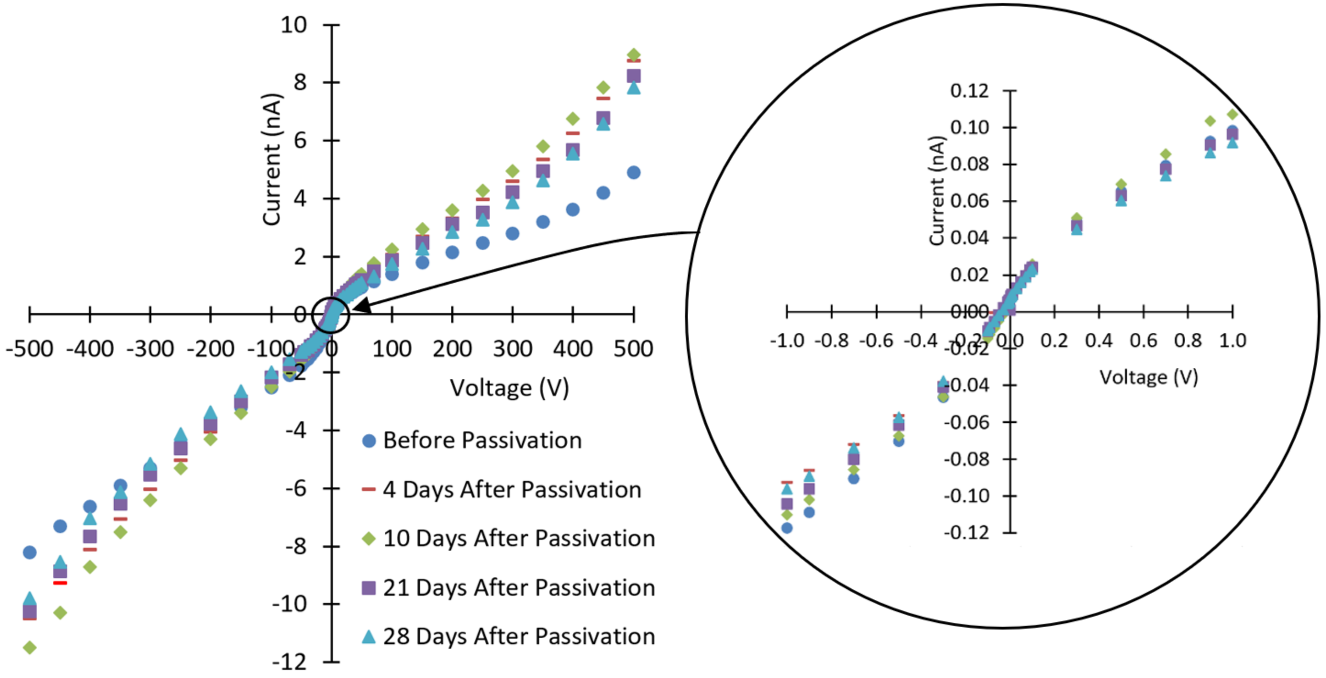


Energy Resolution on polished only and BM etched surface.

Effects of Chemical Treatment: Passivation in NH_4F

Our recent work: *Egarievwe et al. Sensors 2019.*
https://www.mdpi.com/1424-8220/19/15/3271

- Sample from Ingot-1.
- The passivation process was accomplished by dipping the wafer in a 10% by weight of aqueous solution of NH_4F in three consecutive dips for five minutes.
- The sample was then dried, and gold contacts applied by electroless method.



Effects of Chemical Treatment: Passivation in NH_4F

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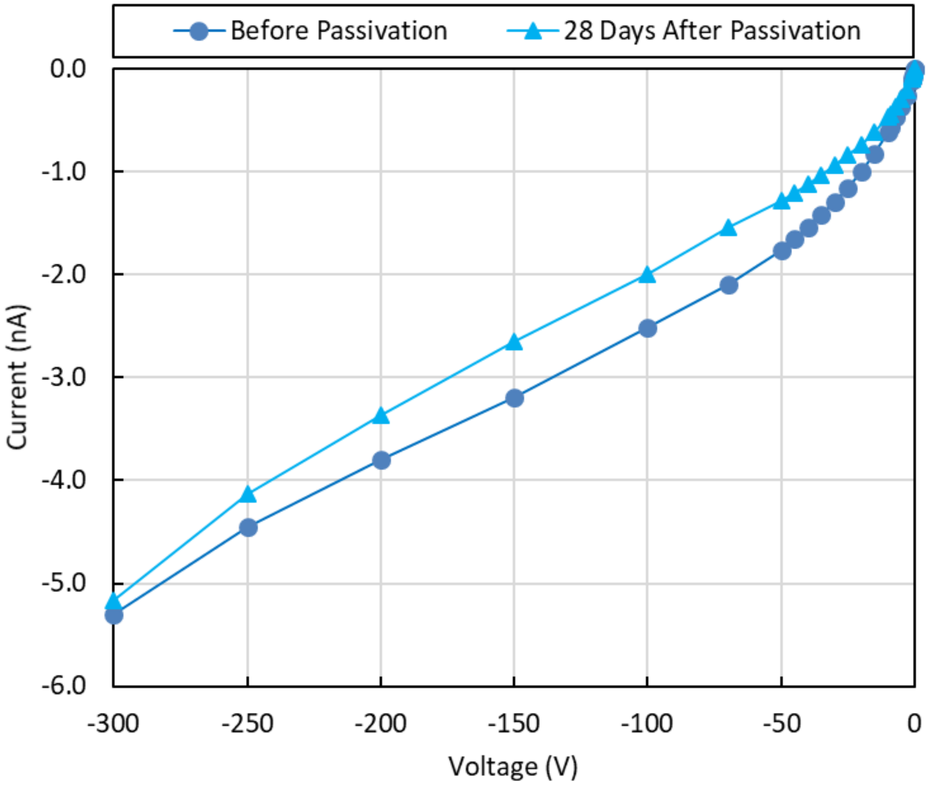

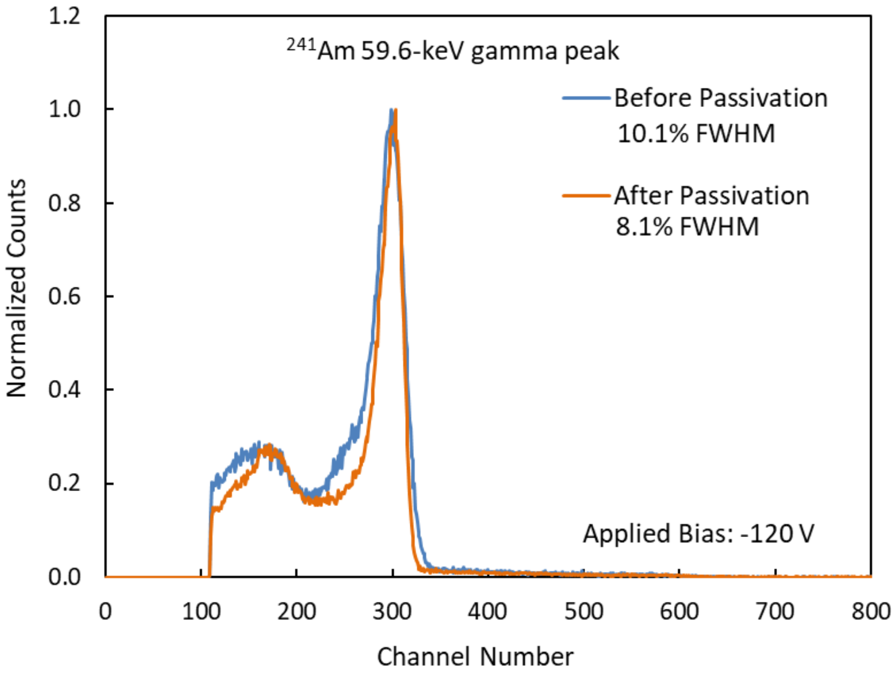

Applied Voltage (V)	FWHM before Passivation (%)	FWHM after Passivation (%)	Improvement in Energy Resolution
−35	17.9	12.0	33%
−65	12.9	10.0	22%
−100	9.9	8.0	19%
−120	10.1	8.1	20%
−140	10.0	7.2	28%
−160	9.3	6.9	26%
−180	8.9	6.4	28%
−200	8.7	6.7	23%

Summary

- CZTS has shown great advantages over CZT.
- The resistivity of the material was in 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 give 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 CZTS.

Minority Training and Workforce Development

- **Research, Teaching and Curriculum**
- **Training and Hands-On**
- **Building Capabilities and Facilities**

Thank You