Optimization of Surface Passivation for InAs-GaSb Infrared Photodetectors

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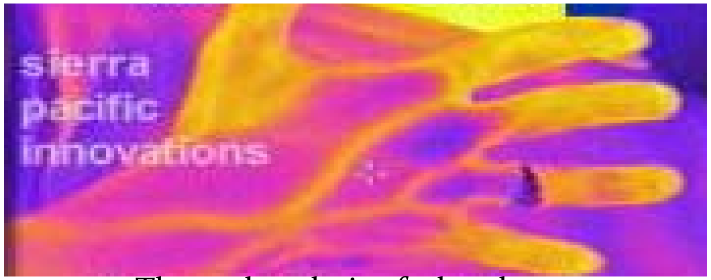
Overview

- Introduction
- Theory & Principles
- Apparatus & Experimental
- Results & Discussion
- Conclusion
- Acknowledgements

Introduction: Infrared Imaging

Medical:
- Temperature measurements that is non-invasive
- Diagnosis early on of health threats

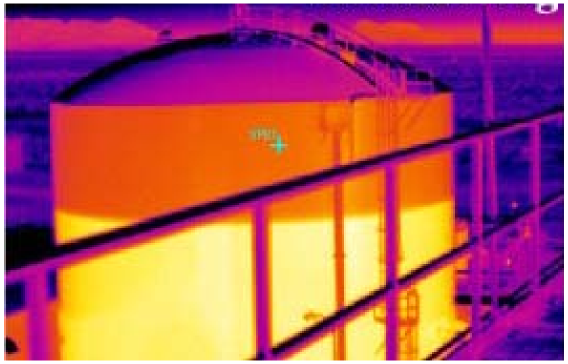


Thermal analysis of a hand

Night vision:
- Police
- Military
- Driving

Thermal analysis of a suspected marijuana grow house

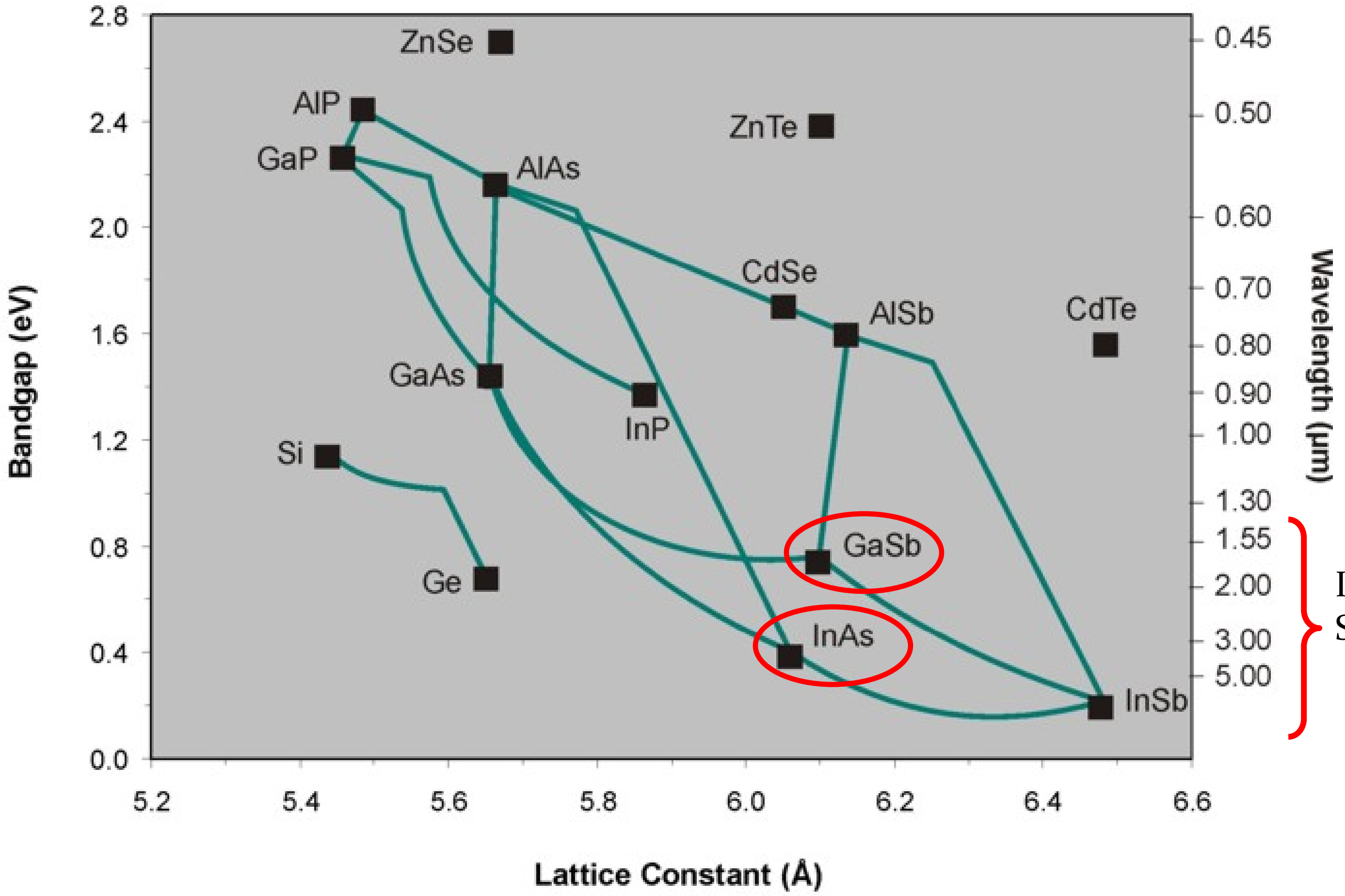
Manufacturing:
- Maintenance through thermal identification
- Detecting general temperature uniformity



Thermal analysis of a fluid tank level detection

Images courtesy of www.x20.org

Introduction: Semiconductor Material

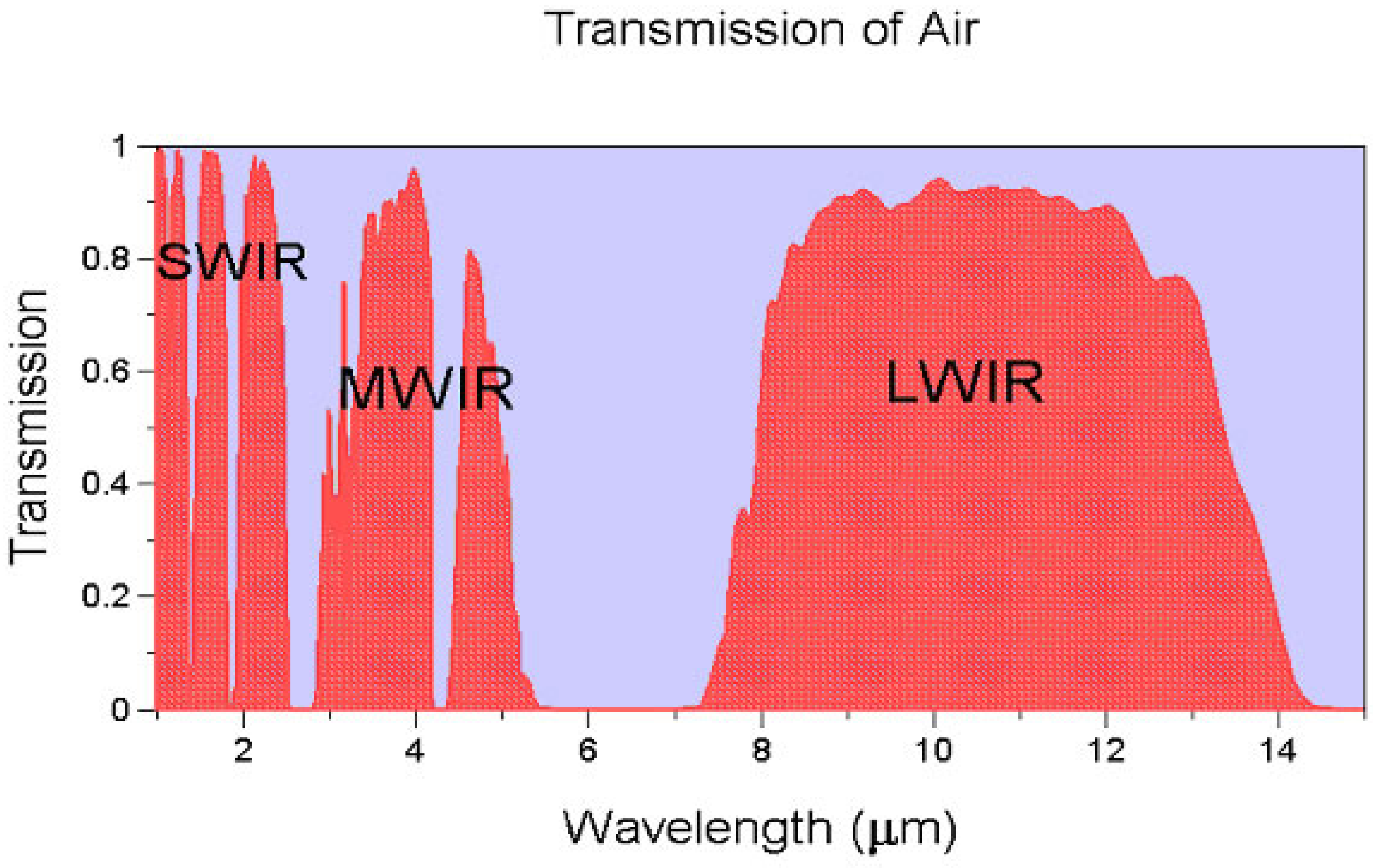


Visible
Spectrum

Infrared
Spectrum

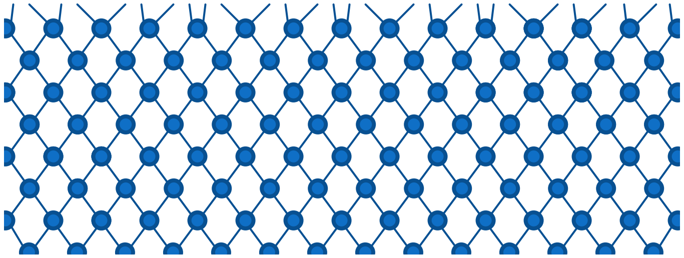
The above image has been used with the permission of Dr. Ghosh

Introduction: Long Wavelength Infrared (LWIR)

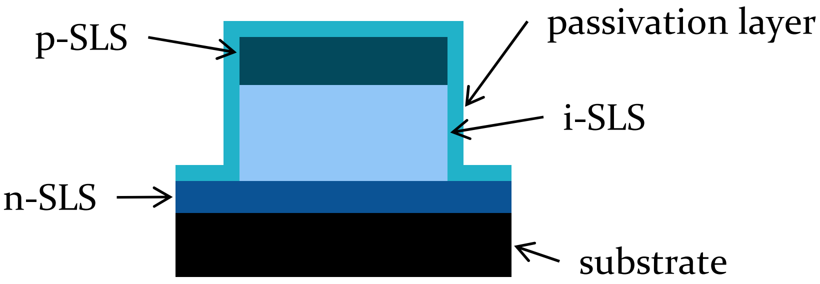


Theory & Principles: Passivation

- Dangling bonds at the edges of the broken crystal structure leave the semiconductor open to contaminants

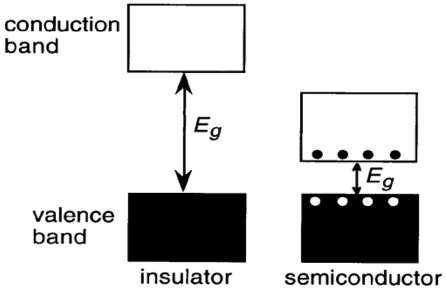


- To reduce the effects of contamination such as increased dark current and noise, a thin film passivation layer is applied to the semiconductor



Potential Passivants: Qualities of Passivants

- Must be a good insulator so must have higher bandgap and resistivity



- To avoid stress at the interface of the passivant and semiconductor, they should have similar linear thermal expansion coefficients
- To minimize the electric field that is produced in the passivation layer materials with high dielectric constants are considered
- Desire a material with a refractive index that is not too large nor too small

image courtesy of http://icn2.umeche.maine.edu/genchemlabs/lecmaterials2.htm

Potential Passivants: Parameters

Parameters	Si_3N_4	SiO_2	ZnS	InAs-GaSb
Bandgap (eV)	~ 5	9	3.68	<0.31
DC Resistivity Index @ 25°C (Ω - cm)	~ 10^{14}	10^{14}-10^{16}	10^{14}	Dependent on Doping
Linear coefficient of thermal expansion (10^{-6}-°C^{-1})	3.3	50	7.089	5.24-8.87
Dielectric Constant	7.5	3.9	8.9	15.15-15.69
Refractive Index	2.05	1.46	2.368	3.65-4.05

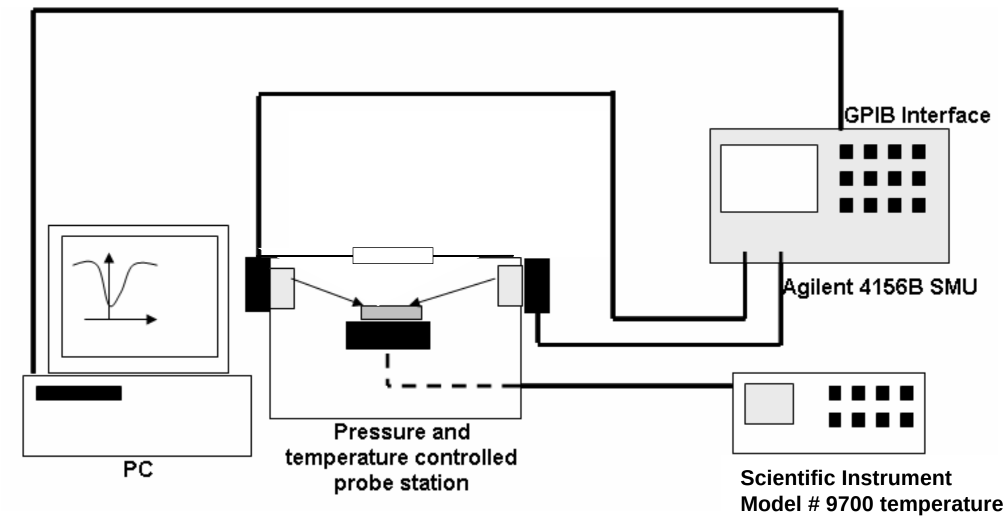
data found in S. Mallick's thesis paper, at http://www.siliconfareast.com/sio2si3n4.htm

Apparatus & Experimental: Deposition Techniques

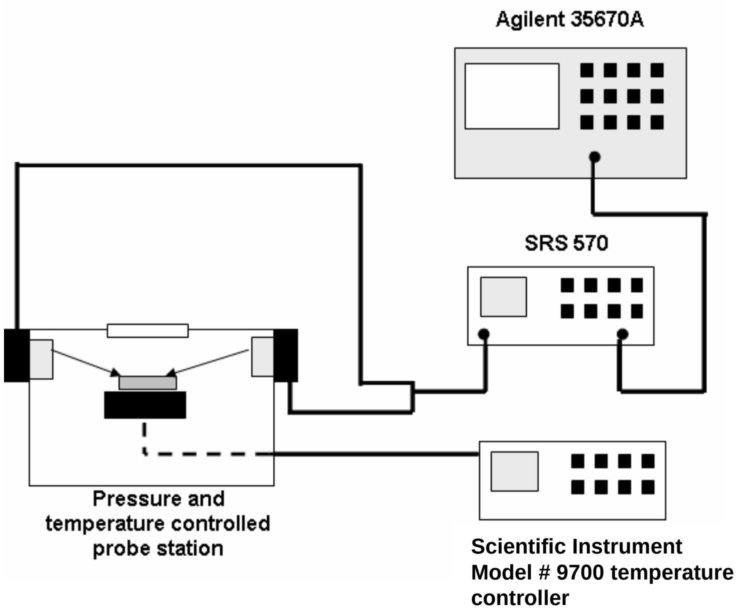
Passivation Materials	Si_xN_y	SiO_2	ZnS
Deposition technique	RF Magnetron sputtering	PECVD (Plasma Enhanced Chemical Vapor Deposition)	E-Beam
Temperature (°C)	Room Temperature	300	Room Temperature
Deposition time (minutes)	90	10	~ 90
Thickness (Å)	~3000-3500	3200	3000

- With the ZnS an aqueous layer of $(NH_4)_2S$ is applied to the semiconductor before the ZnS layer is applied to reduce surface leakage current.
  - Device soaked in 20-24% aqueous $(NH_4)_2S$ for 15 minutes

Apparatus & Experimental: Schematic



I-V Characterization Setup



1/f Noise Setup

images courtesy of S. Mallick's thesis paper

Apparatus & Experimental: Measurements

Material Characterization
- 1/f Noise
- Current

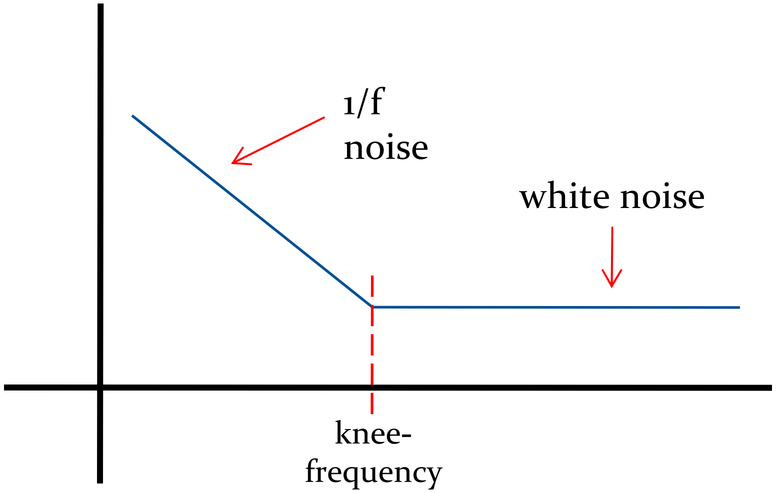
Device Characterization
- Dark Current
- Dynamic Resistance Multiplied by Area (R_dA)

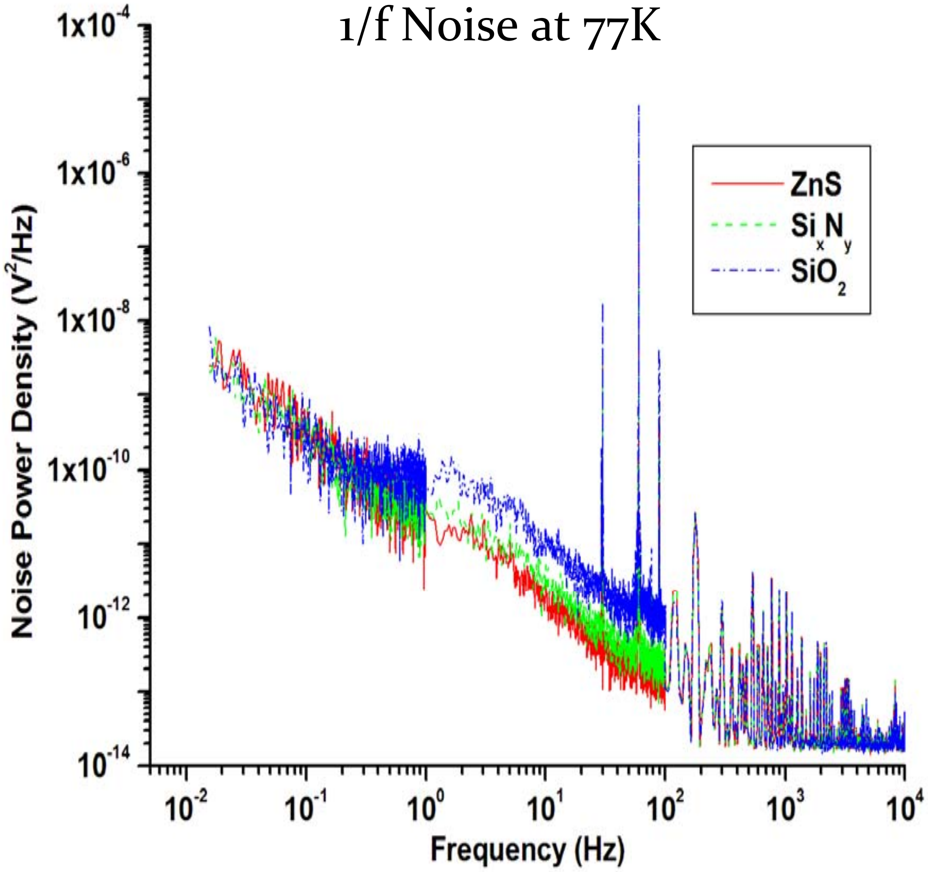
Results: Material Characteristic

1/f Noise

Knee frequencies determined to be:

- ZnS: 406 Hz
- Si_xN_y: 789 Hz
- SiO_2: 3100 Hz





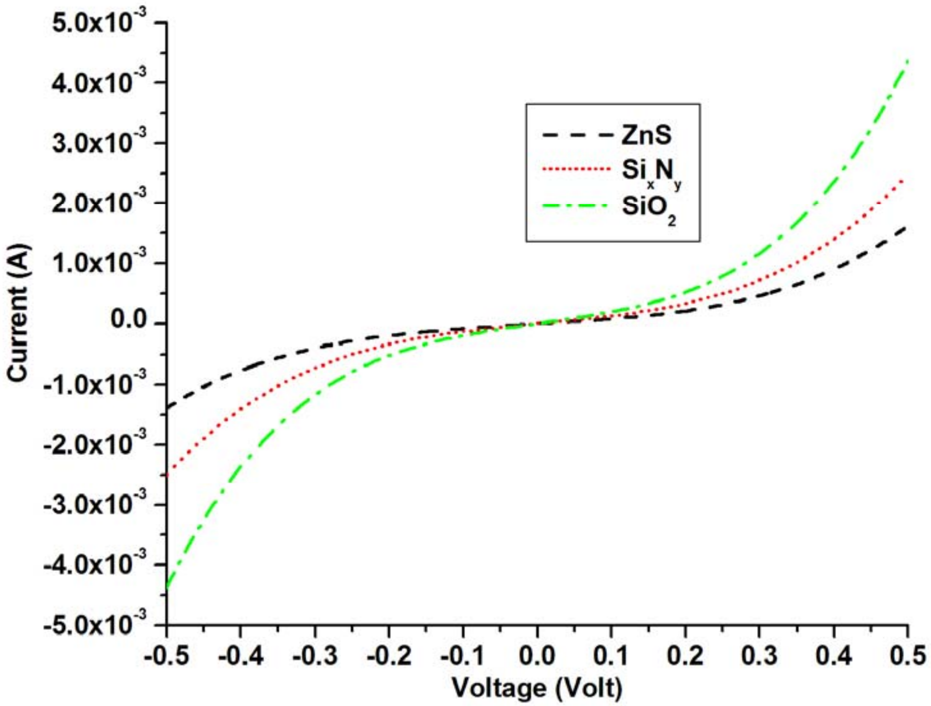
Results: Material Characteristic

Surface Current

Based on relationship of
V = IR, the lower the current the higher the surface resistance.

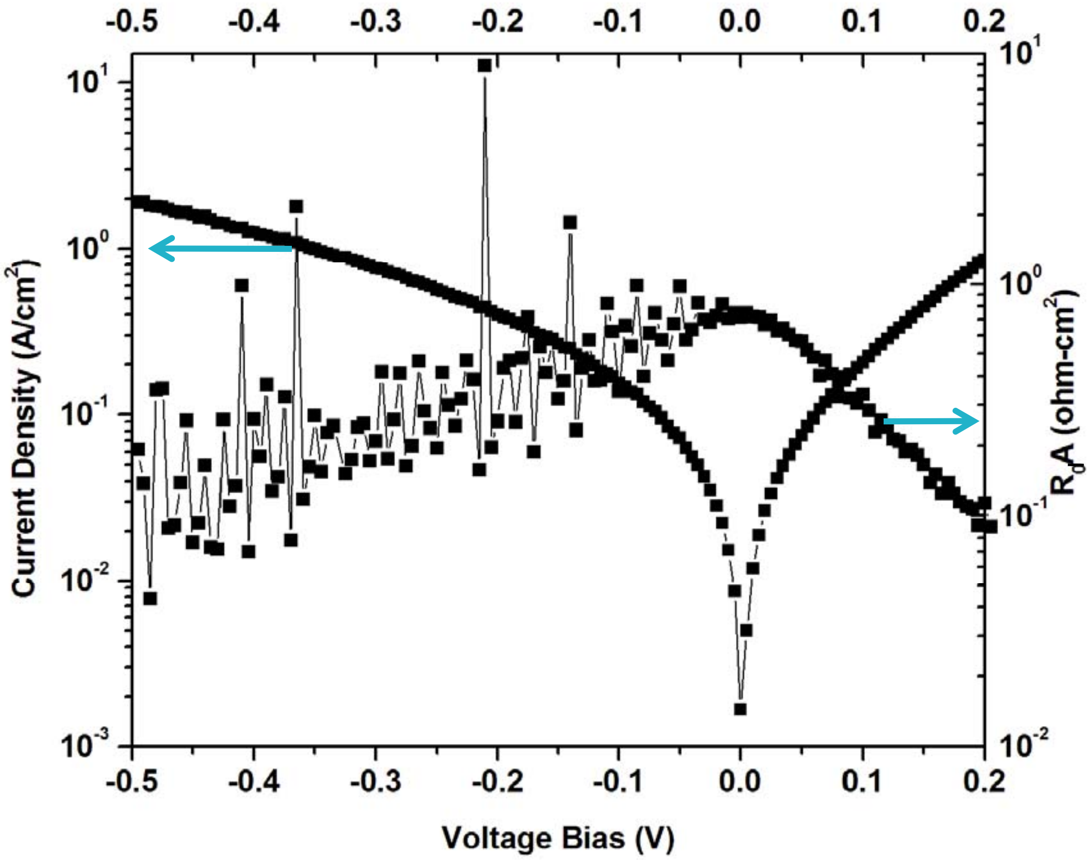
Higher surface resistance will result in the majority of the current to be carried through the bulk of the material and therefore loose less current to surface leakage.

Current at 77 K



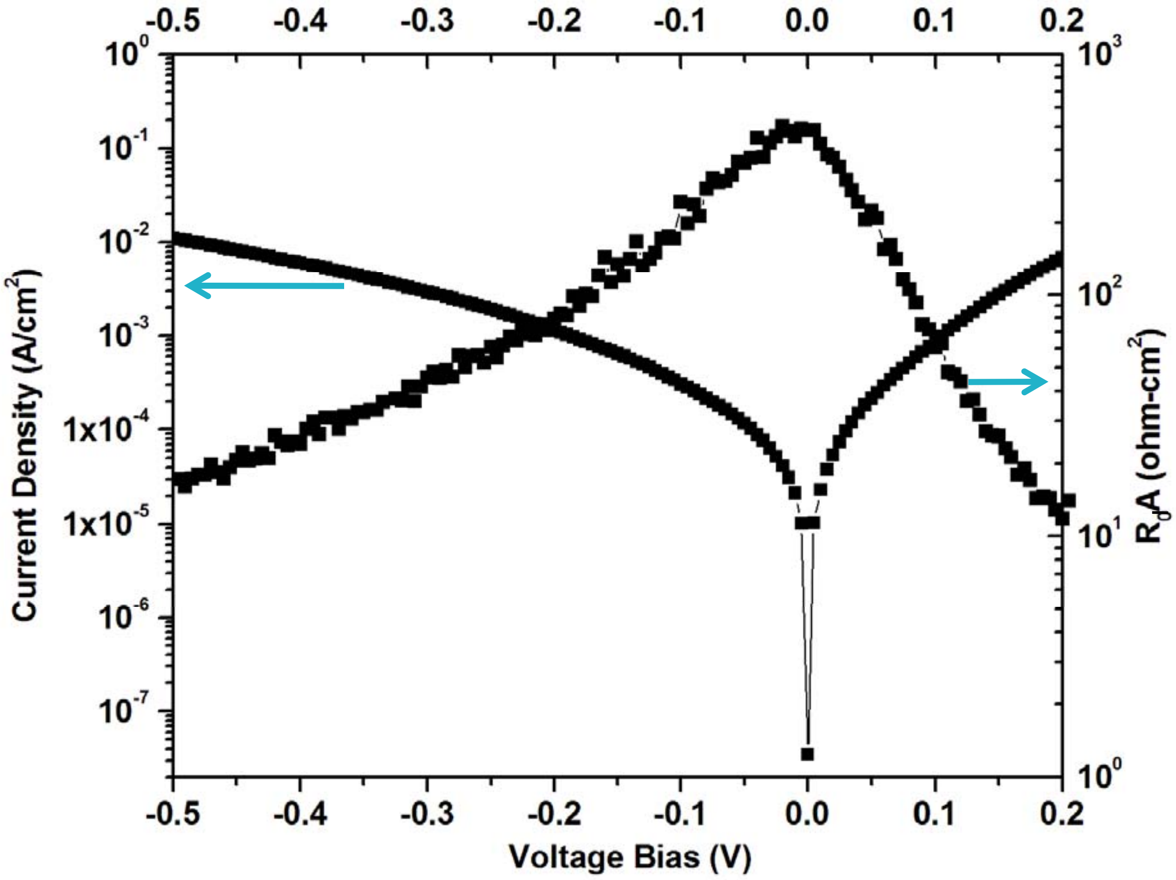
Results: Device Characteristic

Unpassivated at 77K



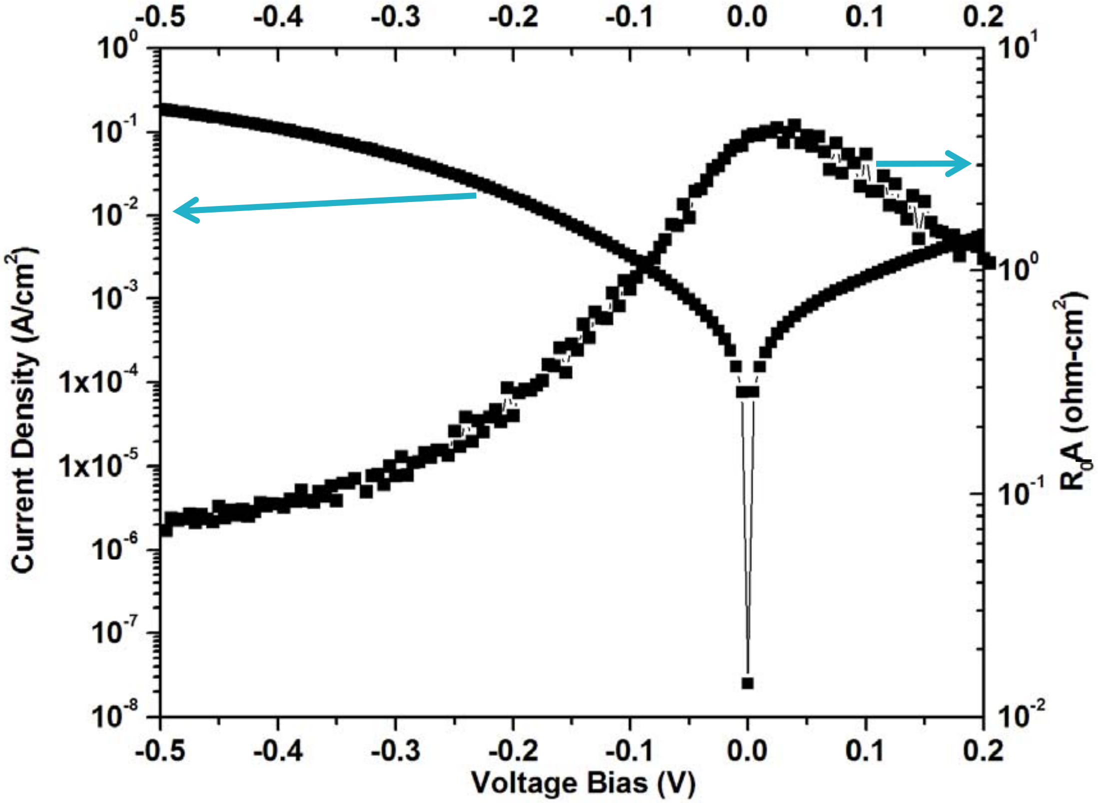
Results: Device Characteristic

ZnS Passivated at 77K



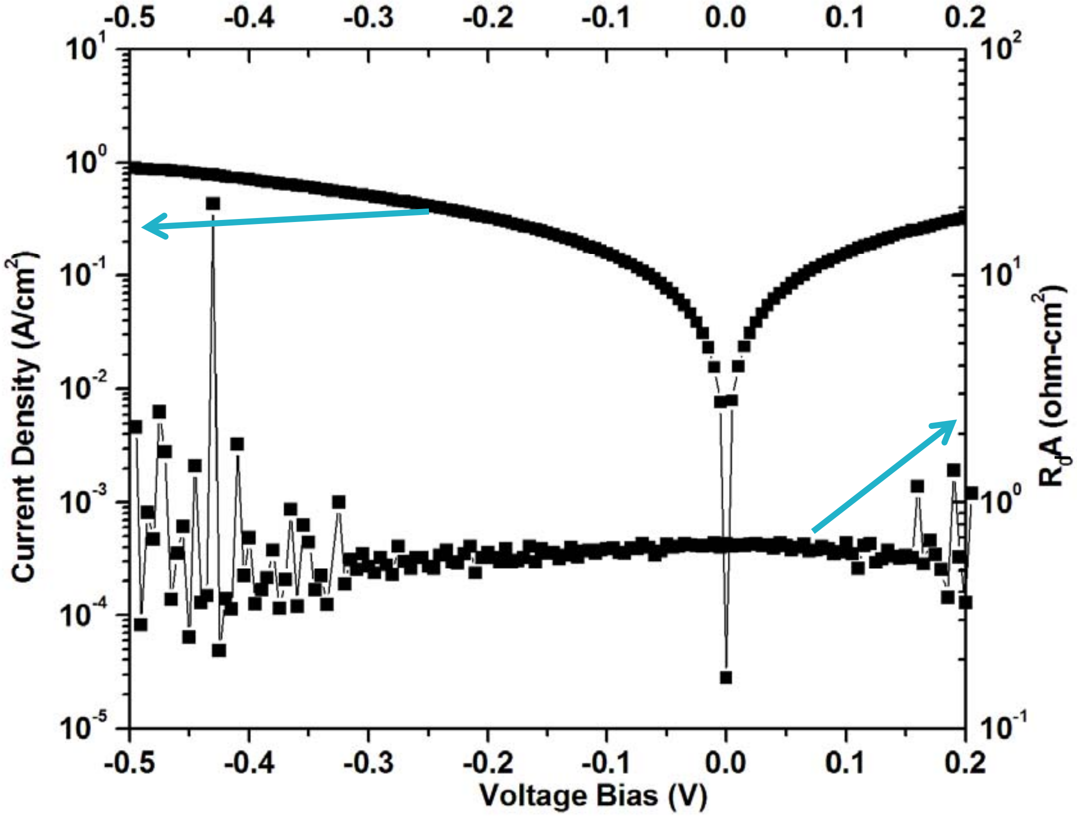
Results: Device Characteristic

Si_xN_y Passivated at 77K



Results: Device Characteristic

SiO$_2$ Passivated at 77K



Results: Device Characteristic

	Unpassivated	ZnS	Si_xN_y	SiO_2
Dark current density at -0.5 V ($A\text{-}cm^{-2}$)	1.93	1.11×10^{-2}	1.87×10^{-1}	9.02×10^{-1}
R_oA ($ohm\text{-}cm^2$)	7.21×10^{-1}	4.92×10^{2}	4.1	6.58×10^{-1}

Conclusion

- ZnS performed the best out of the three passivants both in terms of material and device characterization.

- Si_xN_y showed some improvement across the device in terms of R_oA but not as significantly as the ZnS.

- SiO_2 showed little improvement from the unpassivated device nor did it perform the best out of the three in material characterization.

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