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

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

**Night vision:**
- Police
- Military
- Driving

Thermal analysis of a hand
Thermal analysis of a fluid tank level detection
Thermal analysis of a suspected marijuana grow house

Images courtesy of www.x20.org
Introduction: Semiconductor Material

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.main.edu/genchemlabs/lecmaterials2.htm
## Potential Passivants: Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Si₃N₄</th>
<th>SiO₂</th>
<th>ZnS</th>
<th>InAs-GaSb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandgap (eV)</td>
<td>~ 5</td>
<td>9</td>
<td>3.68</td>
<td>&lt;0.31</td>
</tr>
<tr>
<td>DC Resistivity Index @ 25°C (Ω - cm)</td>
<td>~ 10¹⁴</td>
<td>10¹⁴-10¹⁶</td>
<td>10¹⁴</td>
<td>Dependent on Doping</td>
</tr>
<tr>
<td>Linear coefficient of thermal expansion (10⁻⁶-°C⁻¹)</td>
<td>3.3</td>
<td>50</td>
<td>7.089</td>
<td>5.24-8.87</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>7.5</td>
<td>3.9</td>
<td>8.9</td>
<td>15.15-15.69</td>
</tr>
<tr>
<td>Refractive Index</td>
<td>2.05</td>
<td>1.46</td>
<td>2.368</td>
<td>3.65-4.05</td>
</tr>
</tbody>
</table>

Data found in S. Mallick's thesis paper, at http://www.siliconfareast.com/sio2si3n4.htm
**Apparatus & Experimental: Deposition Techniques**

<table>
<thead>
<tr>
<th>Passivation Materials</th>
<th>Si$_x$N$_y$</th>
<th>SiO$_2$</th>
<th>ZnS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition technique</td>
<td>RF Magnetron sputtering</td>
<td>PECVD (Plasma Enhanced Chemical Vapor Deposition)</td>
<td>E-Beam</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>Room Temperature</td>
<td>300</td>
<td>Room Temperature</td>
</tr>
<tr>
<td>Deposition time (minutes)</td>
<td>90</td>
<td>10</td>
<td>~ 90</td>
</tr>
<tr>
<td>Thickness (Å)</td>
<td>~3000-3500</td>
<td>3200</td>
<td>3000</td>
</tr>
</tbody>
</table>

• With the ZnS an aqueous layer of (NH$_4$)$_2$S is applied to the semiconductor before the ZnS layer is applied to reduce surface leakage current.
  • Device soaked in 20-24% aqueous (NH$_4$)$_2$S 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 (RdA)
Results: Material Characteristic

1/f Noise

Knee frequencies determined to be:

• ZnS: 406 Hz
• Si$_x$N$_y$: 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.
Results: Device Characteristic

Unpassivated at 77K
Results: Device Characteristic

ZnS Passivated at 77K

![Graph showing current density vs voltage bias with R_0 (ohm-cm²) on the right y-axis.](image)
Results: Device Characteristic

$\text{Si}_x\text{N}_y$ Passivated at 77K
Results: Device Characteristic

SiO$_2$ Passivated at 77K
Results: Device Characteristic

<table>
<thead>
<tr>
<th></th>
<th>Unpassivated</th>
<th>ZnS</th>
<th>Si$_x$N$_y$</th>
<th>SiO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark current density at -0.5 V (A·cm$^{-2}$)</td>
<td>1.93</td>
<td>1.11×10$^{-2}$</td>
<td>1.87×10$^{-1}$</td>
<td>9.02×10$^{-1}$</td>
</tr>
<tr>
<td>$R_0A$ (ohm·cm$^2$)</td>
<td>7.21×10$^{-1}$</td>
<td>4.92×10$^2$</td>
<td>4.1</td>
<td>6.58×10$^{-1}$</td>
</tr>
</tbody>
</table>
Conclusion

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

• $\text{Si}_x\text{N}_y$ 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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