Evaluation of the optical performance of a Si Solar Cell mechanically stacked under GaAs using Polydimethilsiloxane (PDMS) as an adhesive

Ian Mathews1,3, Donagh O’Mahony5, Brian Corbett5, Alan P. Morrison1,2
1Tyndall National Institute UCC, Lee Maltings, Prospect Row, Cork Ireland
2Department of Electrical and Electronic Engineering, University College Cork, Cork, Ireland

Introduction
Mechanically Stacked Solar Cells (MSSCs) have the potential to improve upon the current state of the art in III-V multi-junction solar cells by removing the current- and lattice-matching constraints of monolithic devices and facilitating the use of bandgap combinations with better spectral matching. However optical losses at the interfaces between dissimilar materials play a significant role in reducing the power output of MSSCs, therefore, it is of interest to consider approaches to minimizing these losses through the use of optically matching adhesives to bond the stacked cells. Polydimethylsiloxane (PDMS) is a widely used low cost polymeric compound that can be used as an optical adhesive due to its low optical absorption and mechanical robustness when cured. We have simulated and compared the performance of a mechanically stacked GaAs-Si tandem cell where the interface comprises an air-gap or PDMS adhesive bond. The thickness of the air-gap or PDMS bond between the two solar cells is also a critical parameter in determining transmission through the GaAs-Si interface. Experimental measurements of the spectral response and 1-Sun short-circuit current density of prototype GaAs-Si tandem cells with an air-gap interface are given.

Motivation/Concept

Motivational image showing the concept of mechanically stacked multi-junction solar cells.

Mechanically Stacked Multi-Junction Solar Cell

• GaAs top junction
• GaAs middle junction
• PDMS interface
• GaAs bottom junction

Monolithic device challenges:
• Crystal lattice mismatch (between optimum cell materials)
• Current matching (current reduction from top junction)
• Reliability (Tunnel Junctions)

Mechanically stacked solar cell challenges:
• Optical losses (high reflection losses at interfaces)
• Cost (Substrate and processing/assembly costs)

PDMS

• High transparency between 850 – 1150 nm [1]
• Low cure temperature (RT → 150 °C)
• High bond strength

<table>
<thead>
<tr>
<th>Material</th>
<th>n @ 880 nm</th>
<th>n @ 1100 nm</th>
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</thead>
<tbody>
<tr>
<td>GaAs [2]</td>
<td>3.66</td>
<td>3.67</td>
</tr>
<tr>
<td>Si [2]</td>
<td>3.44</td>
<td>3.53</td>
</tr>
<tr>
<td>ZnS [3]</td>
<td>2.28</td>
<td>2.26</td>
</tr>
<tr>
<td>PDMS [4]</td>
<td>1.44</td>
<td>1.44</td>
</tr>
</tbody>
</table>

All data for 300 K.

Theoretical GaAs/Si cell performance

Detailed balance limits of efficiency of a dual-junction mechanical stack

Advantages
• Cost-effective alternative to III-V or Ge substrates
• Larger bandgap – reduced thermalisation losses
• Stronger and lighter allowing extra-terrestrial use

Disadvantages
• Thermal mismatch
• Non-optimal bandgap

Potential efficiency of a GaAs-Si mechanical stack

Potential graph showing the efficiency of a GaAs-Si tandem solar cell with PDMS bonding.

Results

The thin film structure considered in the optical model

Modelled Jsc (mA/cm²) of a Si solar cell as a function of interface thickness

Measured External Quantum Efficiency of a GaAs – Si (Air Gap interface) mechanically stacked solar cell

Reflection Model

• GaAs-Si mechanically stacked solar cell structure consists of many optically thin layers
• Transfer Matrix Method used to characterise optical performance
• Complex index of refraction, n = n + k, used i.e. absorption in thin-films accounted for

Conclusion

A concept for the production of GaAs-Si mechanically stacked solar cells has been presented. Simulations show that PDMS provides closer index matching between GaAs and Si which results in a greater transmission through the bonded interface as compared to an Air-Gap, particularly when optimised anti-reflection coatings are used on the back surface of the GaAs solar cell. Initial measurements of short-circuit current density on prototype GaAs-Si mechanically stacked solar cells show good agreement with the simulated performance for an Air-Gap interface while the expected improvement using a PDMS interface has not yet materialised. At present the performance of a GaAs-Si cell with an Air-Gap interface matches that of a PDMS interface. Future work will further investigate the experimental optical performance of PDMS bonding layers utilised in mechanically stacked solar cells.

References
[4] Dow Corning

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