Silicon heterojunction solar cells using aluminum doped zinc oxide as back contact: sputtering and ALD

G. Christmann¹, D. Sacchetto¹, L. Sansonnens¹, L. A. A. Duval², M. Creatore², W. M. M. Kessels², G. Wahli³, L. Barraud¹, A. Descoedres¹, B. Paviet-Salomon¹, N. Badel¹, B. Strahm³, M. Despeisse¹, S. Nicolay¹, and C. Ballif¹,⁴

¹ Centre Suisse d’Électronique et de Microtechnique (CSEM), PV-center, Neuchâtel, Switzerland
² Eindhoven University of Technology, Eindhoven, The Netherlands
³ Meyer Burger Research, Hauterive, Switzerland
⁴ École Polytechnique Fédérale de Lausanne (EPFL), Institute of Microengineering (IMT), Photovoltaics and Thin Film Electronics Laboratory, Neuchâtel, Switzerland
Motivation

- Heterojunction technology (HJT) solar cells requires transparent conducting oxides for contacts, generally ITO is used
- Indium is a high cost strategic resource with limited supplies

It is highly desirable to replace ITO with indium free alternatives
ZnO is a good candidate thanks to its high bandgap and ability to be doped

AZO by thermal Atomic Layer Deposition: properties

ALD supercycle:

- 23 cycles DEZ and H\textsubscript{2}O
- 1 cycle TMA and H\textsubscript{2}O

<table>
<thead>
<tr>
<th>t (nm)</th>
<th>Mobility (cm\textsuperscript{2}/(V.s))</th>
<th>Carrier concentration (cm\textsuperscript{-3})</th>
<th>R\textsubscript{sheet} (\Ohm/\square)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>23</td>
<td>$1.7 \cdot 10^{20}$</td>
<td>278</td>
</tr>
<tr>
<td>105</td>
<td>7</td>
<td>$6.1 \cdot 10^{20}$</td>
<td>187</td>
</tr>
<tr>
<td>201</td>
<td>10</td>
<td>$5.2 \cdot 10^{20}$</td>
<td>76</td>
</tr>
</tbody>
</table>

AZO by sputtering: properties (~100 nm thick)

Advantage: Easily tunable electrical and optical properties
Semiconductor heterojunction solar cell process flow

Front emitter solar cell

- c-Si wafer \( n \) → Cleaning
- Texturing
- c-Si wafer \( n \) → PECVD
- a-Si:H \( p \)
- a-Si:H \( i \)
- a-Si:H \( n \)
- Silver fingers
- Silver printing
- c-Si wafer \( n \) → TCO deposition
- TCOf
- a-Si:H \( p \)
- a-Si:H \( i \)
- a-Si:H \( n \)
- Silver deposition
- TCOf
- a-Si:H \( p \)
- a-Si:H \( i \)
- a-Si:H \( n \)
- Silver
AZO by Atomic Layer Deposition: results

Underdeposition from back deposition but no shunts

η of cells with ALD AZO is 0.7% below reference value
AZO by sputtering: Results

Slightly better efficiency with AZO back contact compared to reference.
Higher $V_{OC}$ and fill factor.

<table>
<thead>
<tr>
<th>Material</th>
<th>$d$ (nm)</th>
<th>$R_s$ ($\Omega/\square$)</th>
<th>$\mu$ (cm$^2$/V.s)</th>
<th>$n$ (cm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITO</td>
<td>103</td>
<td>421.6</td>
<td>16.76</td>
<td>8.58E+19</td>
</tr>
<tr>
<td>AZO</td>
<td>109</td>
<td>3712</td>
<td>2.204</td>
<td>7.00E+19</td>
</tr>
</tbody>
</table>
Transfer on industrial scale device: ALD underdeposition

Large wafers tend to bend leading to significant underdeposition

Metal blocks were used to flatten the wafers

Shunts are then manually removed with HCl
ALD and PVD: large scale cell results

Best efficiency is achieved with PVD AZO back contact

ALD AZO efficiencies are below the ones of ITO references
Transfer to Meyer Burger PVD process

Replacement of ITO back contact via AZO leads to an efficiency gain of 0.45%.

AZO is a very promising alternative to ITO for SHJ solar cell contacts.
Conclusions and perspectives

Conclusions

• Sputtered AZO provides an excellent alternative for the replacement of ITO as back contact for HJT solar cells

• ALD AZO has been used as back contact for HJT solar cells, but PCE is still lower than ITO

• The sputtering process has been successfully transferred on Meyer Burger platform showing higher efficiencies than ITO references

Perspectives

• Improve the results with the ALD process

• Explore the replacement of the front ITO contact with AZO
Develop and deploy valid and robust alternatives to indium based transparent conductive electrode materials as electrodes.