SIM: SoPPoM
SBO3: PhyCIGS

21 October 2013

GEBRUIKERS COMMISSIE MEETING
OUTLINE

▸ Goals and activities of SBO3: PhyCIGS
  - Objectives, partners and their role
  - Description of a CIGS solar cell

▸ Case: collaborative approach in SBO3 to determine the influence of carbon on CIGS solar cell performance
  - Imec: cell processing
  - KUL/MTM: absorber formation
    ▪ Precursors: KUL-MTM, Ugent (SBO1), Umicore-Agfa (ICON2)
  - U Hasselt: X-SEM EDX analysis
  - KUL/FYS: ESR analysis
  - U Antwerp: X-TEM ESD analysis
  - U Gent: electrical influence of carbon in CIGS
SBO3: PHYCIGS – CELL PROCESSING/CHARACTERIZATION

PROJECT LEAD: DR. MARC MEURIS AND PROF. JEF POORTMANS

• Focus:
  ▶ Understanding the physics of CIGS PV cell stack: electro-optical properties
  ▶ Only study CIGS and TCO layers, not hybrid OPV (done in O-Line)

• Objective:
  ▶ Develop a baseline process for a CIGS solar cell stack to provide SBO1&2 with feedback about performance
  ▶ Build technological understanding, to allow an investment in cell integration capability (feedback to ICON2)

• Challenges:
  ▶ Study the interactions between the different layers and annealing conditions on the basis of printing technology for CIGS and TCO layers
  ▶ Development of working cells to provide SBO1&2 with feedback
  ▶ Unravel link between material synthesis, ink/paste formulation and post deposition treatment as to obtain the maximal efficient CIGS module and to understand the up scaling issues
WHAT IS A CIGS TF-PV CELL

CIGS ≈ ZnS

- Cu In Se Ga
- II-VI
- Glass or flex substrate
- Mo backside contact
- Direct band gap
- p-type semiconductor absorber layer
- Transparent conductive oxide
- n-type heterojunction

• CIGS lab efficiency largest in TF PV: 20.4% (ZSW)
• Industrial module efficiency: 14-15%
PARTNERS / CONTACT PERSONS

• WP1: Solar cell stack process development
  • Imec: M. Buffiere (solar cell processing steps and device)
  • KULeuven/MTM: J. Vleugels (Selenization process/TCO anneal)

• WP2: electrical and physico-chemical analysis
  • UHasselt: J. Manca (SPM/AFM, EBIC, C-AFM,...)
  • Kuleuven/FYS: A. Stesmans (ESR, band alignment,...)
  • UA: J. Hadermann (TEM, HR-TEM,...)

• WP3: Solar cell characterization and modeling
  • UGent: S. Khelifi (advanced analysis and modeling)
SBO3: WORK STRATEGY

WP1: CIGS processing

- Qualify baseline process (with HZB)
- printed CiGS & baseline TCO
- baseline CIGS & printed TCO
- printed CIGS & printed TCO
- Solar cell characterization

WP2: Analysis
- Physico-chem
- Electrical

WP3: Solar cell modeling
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Grid design reduces impact of series resistance

<table>
<thead>
<tr>
<th>Best Cell (on TNO absorber)</th>
<th>Voc</th>
<th>Jsc (EQE)</th>
<th>FF</th>
<th>Eff.</th>
<th>Rsh</th>
<th>Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>HZB process</td>
<td>602 mV</td>
<td>29.2 mA/cm²</td>
<td>53.7 %</td>
<td>9.45 %</td>
<td>347.1 Ω.cm²</td>
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<tr>
<td>solliance process</td>
<td>582 mV</td>
<td>27.8 mA/cm²</td>
<td>58.9 %</td>
<td>9.53 %</td>
<td>572.1 Ω.cm²</td>
<td>2.6 Ω.cm²</td>
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Imec (solliance) process = HZB process
**ABSORBER FORMATION**

Q: Why adding a binder?
A: to form a smooth crack-free layer after deposition

After selenization (formation of CIGS): Extra layer formed between ‘top-CIGS’ layer and bottom Mo-contact layer
X-SEM EDX ANALYSIS

Bottom layer: carbon-rich CIGS

Larger carbon signal

Smaller carbon signal

MoSe

Mo
X-TEM EDS ANALYSIS

CIGSe (I): thick layer with C/O amorphous clusters/shell and nanograins (ternary, binary, intermetallic)

Note: not the same sample as SEM-EDX but similar preparation
**ESR ANALYSIS**

No carbon detected before selenization

<table>
<thead>
<tr>
<th>Sample</th>
<th>Center</th>
<th>g-value</th>
<th>Density ($g^{-1}$)</th>
<th>Error ($g^{-1}$)</th>
<th>Processing</th>
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<tbody>
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<td>12Q2</td>
<td>C</td>
<td>2.0029</td>
<td>1.1E+17</td>
<td>3E+16</td>
<td>Selenized 500°C</td>
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<tr>
<td>12G061</td>
<td>No C</td>
<td>g</td>
<td></td>
<td>= 2.41; g⊥ ≤ 1.0E+13</td>
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</tr>
</tbody>
</table>

**Main conclusions**

- Carbon impurity depends on precursor
- Slight decrease in carbon with higher temperature
- No carbon detected in co-evaporated reference
ELECTRICAL CHARACTERIZATION

DLCP: Deep Level Capacitance Probe
CV: Capacitance-Voltage

EQE: External Quantum efficiency

Main Conclusions:
DLCP shows smaller space charge region with increased carbon content
EQE shows best current collection for lowest carbon content

Note: ESR quantification of these samples are planned
SOLAR CELL RESULTS

Best cell results for precursors developed in soppom:

- Ugent nano-particle based: 2.4%
- KUL-MTM nanopowder based: 4.8%

Ugent precursor

KUL-MTM precursor

A = 0.25 cm²; J_{sc} = 15 mA/cm²; V_{oc} = 372 mV; FF = 44%; η = 2.38%