Roll to roll fabrication of thin film silicon solar cells on foil

EU project in the framework of FP7-ENERGY-2009-1

Wim Soppe
Main goals of the project

• Cells on foil, with stable efficiencies > 11%
• Improved light management:
  Design and implementation of textured back contacts.
• Improved silicon absorber material
  Reduction of recombination and a-Si with high Voc
• Improved TCOs
  – reduced collection barrier at p/TCO interface → higher efficiencies
  – reduced indium content → lower costs

Implementation in pilot scale fabrication of thin film silicon cells on foil!

Started on January 1, 2010
<table>
<thead>
<tr>
<th>Partner</th>
<th>Tasks</th>
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</thead>
<tbody>
<tr>
<td>ECN</td>
<td>Management and cell fabrication</td>
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<tr>
<td>EPFL</td>
<td>Cell fabrication</td>
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<tr>
<td>VHF Flexcell</td>
<td>Implementation in production</td>
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<tr>
<td>Technical University of Denmark</td>
<td>Electron microscopy</td>
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<tr>
<td>Nanoptics</td>
<td>Upscaling of nano-imprint technology</td>
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<tr>
<td>University of Ljubjana</td>
<td>Modeling</td>
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<td>Universidad Politécnica de Valencia</td>
<td>Fabrication of masters for texture</td>
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<tr>
<td>Umicore Thin Film Products</td>
<td>New TCO materials</td>
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<tr>
<td>Shanghai Jiatong University</td>
<td>Fabrication of masters for texture</td>
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</tbody>
</table>
Light trapping – main tasks:

**T1** Theoretical determination of **optimal periodic nano-textures**

**T2** Feasibility study of fabrication of surface textures with high aspect ratio

**T3** Fabrication of nano-textured **masters** with optimal periodic textures

**T4** Fabrication of nano-textured **nickel shims** for embossing

**T5** Fabrication of **foil substrates** with embossed optimal nano-textures
2-D simulations of periodic textures
Micromorph tandem solar cell structure:

Can we make textures with that high aspect ratios?
Examples of first masters with very high aspect ratios made by e-beam lithography

P=600 nm, L=250 nm, H=910 nm
Issues with conformal growth on structures with high aspect ratios

Solution: usage of rounded textures

P=800 nm; L=570 nm; H=910 nm
Si absorber layers – Main Tasks:

Prevent crack formation in uc-Si grown on rough substrates.

On V shape valley
(R<5-20 nm)
Located at pinched substrate points
Temperature effect on crack formation in microcrystalline silicon?
TCO layers - Tasks:

Improving band alignment between [p] layer and front ITO
We can manipulate WF of ITO by [O] or by applied power.
High efficiency devices - Main Tasks:

Device fabrication on low T plastic substrates and on metal foils.

Implementation of:
- nanotexture
- improved Si layers
- improved TCO

Target: cells on foil with stable efficiency > 11%
μc-Si nip cells on plastic foil with and without texture

Current gain from 16 to 19.7 mA/cm² (23%)

Close to the theoretical increase of 22%!
a-Si/uc-Si nip tandem cells on random texture:
10% stable efficiency!

$V_{oc} = 1370$ mV
$J_{sc} = 11.4$ mA/cm$^2$
FF = 65%
$\eta = 10.1\%$

$J_{sc} = 11.4$ mA/cm$^2$:
model predicts 14 mA/cm$^2$
for ideal periodic texture
## Device fabrication on metal foils

Present status of nip cells on steel foil with textured back contact

<table>
<thead>
<tr>
<th>Cell type</th>
<th>$V_{oc}$ (mV)</th>
<th>$J_{sc}$ (mA/cm²)</th>
<th>FF (%)</th>
<th>efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-Si</td>
<td>781</td>
<td>18</td>
<td>60</td>
<td>8.4</td>
</tr>
<tr>
<td>uc-Si</td>
<td>411</td>
<td>21</td>
<td>55</td>
<td>5.0</td>
</tr>
<tr>
<td>a-Si/a-Si</td>
<td>1750</td>
<td>7</td>
<td>66</td>
<td>8.0</td>
</tr>
<tr>
<td>a-Si/uc-Si</td>
<td>1125</td>
<td>11</td>
<td>65</td>
<td>8.2</td>
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</tbody>
</table>

**To be improved with dedicated textures for uc-Si**
Integration and Demonstration
Highlights

6-9-2011
Grating periods on different locations on the foil differ no more than 1% from the average.
Feasibility of up-scaling co-sputtering

AZO-ITO chess pattern target, 750x125mm for VHF

Target size: 750 x 125mm
Segment size: 47 x 41mm
48 Segments

Backing Plate: Moly

Goal:
- Co-Sputtering under industrial conditions
- Compare results of co-sputtering in the lab sputtertool at ECN

Higher $V_{oc}$ and FF obtained for a-Si/a-Si tandems
Implementation of textured back contact in pilot production line of a-Si/a-Si tandems

Cell characteristics after 800h of light soaking:

- $V_{oc}$ 1.79 V
- $J_{sc}$ 7.03 mA/cm²
- Fill Factor 63.6 %

- STABLE EFFICIENCY 7.98%
Summary of midterm achievements

• Textures with high aspect ratios are feasible
  → rounded structures

• Taylor made work function of TCO by reactive sputtering
  → implementation in cells

• nip cells on foil: 10% stabilized efficiency on labscale;
  8% in pilot production
  → implementation of ideal periodic textures and improved TCOs
Thank you for your attention
More info at www.silicon-light.eu

Many thanks to: Bas van Aken, Remi Biron, Andrew Burrows, Philippe Couty, Oscar Cubero, Camile Devilee, Marcel Dissel, Martial Duchamp, Rafal Dunin-Borkowski, Diego Fischer, Franz-Jozef Haug, Maurits Heijna, Robert Herrer, Finn Hutterer, Janez Krc, Andras Kovacs, ..., Wilfried Schipper, Hannes Spieker, Haihua Tao, Vanessa Terrazzoni, Marco Topic, Qingkang Wang, Rene Wilde, Yvan Ziegler.

ACKNOWLEDGMENT
This work is financially supported by the EU (FP-7 Energy 2009 – 241477)