Cu-PV Project

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www.sustainablepv.eu/cu-pv
Introduction

- Solar photovoltaics (PV) generation capacity grows quickly

- Therefore the demand of PV on natural resources has to be minimized
- E.g., the carbon footprint of solar PV is not negligible, though much less than fossil fuel generated electricity (of order 40 g CO2-eq/kWh)
Sustainability of c-Si PV

- Key sustainability parameters of c-Si PV are:
  1. Energy for production of silicon wafer (cost, CO₂ footprint)
  2. Recyclability of PV modules (recovery of materials, CO₂ footprint)
  3. Use of Ag for metallisation (cost, resource depletion)
Sustainability of c-Si PV

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- To reduce environmental impact, Cu-PV project combined efforts on:
  1. Very thin, high performance solar cells
  2. Module technology designed for recycling
  3. Reduction of Ag consumption for solar cell metallisation
Cu-PV solar cell development

- ultrathin back-contact solar cells of 21-22% efficiency

<table>
<thead>
<tr>
<th>Cell type</th>
<th>Ag-reduction</th>
<th>Thickness</th>
<th>cell efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard industrial cell (ref. ITRPV)</td>
<td>-</td>
<td>160 μm</td>
<td>18-20%</td>
</tr>
<tr>
<td>(2010: 300mg; 2014: 130mg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu-PV cell with evaporated seed layer and Cu plating (Ag-free)</td>
<td>0mg</td>
<td>135 μm</td>
<td>21.5</td>
</tr>
<tr>
<td>Cu-PV cell with printed Ag seed layer and NiCu plating (in progress)</td>
<td>70-94% reduction</td>
<td>120 μm</td>
<td>20.2</td>
</tr>
<tr>
<td>(ref. 300-450mg)</td>
<td></td>
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</tbody>
</table>
Benefit from thin high-performance cells

Carbon footprint
- CFP for thin cells of 22% cell efficiency is ~15-20% lower than standard cell of 18-20% efficiency

Ag resource savings
- at annual production of 100 GWp, every 100mg Ag per cell avoided means 2000 ton/y Ag savings, or ~10% of annual world primary Ag production
Exploitation solar cell technology

- **Meco/Besi**
  - major supplier of plating equipment for PV
  - exploitable results relate to:
    - high yield on thin wafers
    - plate on seed, particular printed seed
    - OSP capping, single side plating, etc.

- **Xjet**
  - developing inkjet metallisation for solar cells since 2007
  - collaboration with several major PV manufacturers, including industrial beta-tools
  - after promising start in Cu-PV, in 2014 due to solar equipment market conditions, board decided to stop solar and focus on 3D printing
  - Xjet is willing to support exploitation by other interested parties

- **Institutes (ECN, Imec)**
  - technology transfer, contract work, joint further development
  - high-efficiency cell technology jointly marketed with process equipment manufacturers
Cu-PV module development

- thin back-contact cells require dedicated module technology
- Backfoil based module technology was improved for application to IBC, cost reduction, and lower environmental impact of backfoil
- Backfoil based module technology was augmented with design for recycling:
  - framing and edge sealing
  - encapsulant

2x2 IBC module
(60-cell module planned Sept 2015)
State-of-the-art Si PV recycling

Collection damaged/end-of-life PV modules

- Removal J-box → electronic waste
- Removal aluminium frame → aluminium smelters

Hammer mill remaining laminate (glass – EVA – solar cell – EVA – backsheet (Fluor))

- clean glass → packaging industry
- contaminated glass → glass wool industry
- metal tabbing → metal industry
- “fluff” (EVA-solar cell-backsheet) → stored in big bags or is disposed off

• Disadvantage: value reduction and loss of valuable material
Why improving recyclability Si PV modules

- Enable cheaper, more cost effective recycling process
- Maximize amount of separated high value material
- Reduce depletion of scarce and expensive resources by increasing re-use
- Reduce carbon footprint of PV modules

<table>
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<tr>
<th>Material</th>
<th>decrease in EPT (%)</th>
<th>decrease in CFP (%)</th>
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<tbody>
<tr>
<td>Al-frame (etch and anodise)</td>
<td>~3</td>
<td>~5</td>
</tr>
<tr>
<td>Glass (option 1 = remelting)</td>
<td>~2</td>
<td>~2</td>
</tr>
<tr>
<td>Glass (option 2 = direct re-use)</td>
<td>~4</td>
<td>~3</td>
</tr>
<tr>
<td>Wafers (option 1 = feedstock)</td>
<td>~30</td>
<td>~26</td>
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<td>Wafers (option 2 = direct re-use)</td>
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EPT = energy payback time  
CFP = carbon footprint
Module recycling

- Technical Plating has developed process and semi-automated line for recycling of currently collected waste PV modules
- separating junction box, aluminium frame, backsheets
- capable of recovering clean unbroken glass sheets
- evaluating recovery of silicon, Ag, encapsulant
- Ag recovery from cell fragments evaluated with noble metal recyclers >> business case appears to be present
Design for recycling applied to module frame

- Module edge sealing was modified, maintaining reliability but improving detachment of frame
- Examples for which improved performance in accelerated degradation tests was demonstrated:
Design for recycling applied to laminate

- Encapsulant can be changed from EVA to thermoplastics, maintaining reliability but allowing recovery of intact cells
- Reliability of modules with (Cu-plated) cells laminated with thermoplastics was demonstrated
- Methods to recover intact wafers were developed

Glass with thermoplastic (mechanical cleaning)

Undamaged solar cell (clean by incineration)

Back-contact foil (Cu-PET-PVF) (cleaning under development)

Glass and solar cell, recovered and recycled, can contribute up to 29% in reduction of carbon footprint.
Environmental benefits from recycling

- Summary of estimates of maximum decrease of EPT of a module, and CFP of kWh generated by PV, for various Cu-PV recycling/re-use scenarios (see D5.4)

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CFP = carbon footprint
Exploitation module and recycling technology

- **Eurotron**
  - major supplier for module production equipment for PV exploitable results:
    - integrated backsheet production system
    - high accuracy IBC cell placement
    - modules with design-for-recycling features
    - recycling know-how

- **Technical Plating**
  - recycling process
    - enhanced recovery of higher value glass, backsheet, frames
    - potential recovery of silicon, silver
    - automation

- **ECN**
  - IBC module technology
  - design for recycling, and subsequent recycling technology
Conclusions

- Cu-PV has demonstrated large reduction of carbon footprint by moving to higher performance and thinner cells
- Large reduction of Ag consumption by modified cell metallisation
- Methods to improve recyclability and recovery of valuable materials from Si PV modules
- Recycling business cases need to be established more firmly
  - Stability and volumes of recycled materials are some of the issues

Which possibilities are there to stimulate manufacturers worldwide to adopt features for more advanced recycling?
- Policies?
- Environmental Footprint Labeling?
- Other?
Extra slides
c-Si PV lifecycle (part 1)

production high-purity Si → crystal growth → cutting wafers → cell production

≈26% of CFP

46% of CFP

soldering into strings

laminate between backsheet and glass

edge sealing, frame and junction box

≈14% of CFP (glass ≈3%)

≈7% of CFP

Note: CFP numbers are approximate for monocrystalline cSi modules.
c-Si PV lifecycle (part 2)

- End of life modules
- Recovery Al frame and junction box
- Shredding
- Recovery copper
- Recovery glass cullet
Forecast mass of end-of-life modules

Waste in t

PV CYCLE 2014
CERES 2013

Karsten Wambach, 2014
Growth of PV

LowE Glass—Float Plant

- Produces 300-1000 tons of glass per day
- Uses 60-200 tons of recycled cullet

Major PV manufacturer

- Uses 300-600 tons glass per day
- 1 - 2 GWp per year
ITR PV and Cu-PV cell type

Fig. 28
Worldwide market shares for different cell technologies.