From R&D to Thin Film Silicon PV at Oerlikon Solar

3rd Gen Photovoltaics: CleanTech Day
CSEM Basel / 19th August 2009

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Oerlikon Solar-Lab SA
CH-2000 Neuchâtel
Agenda

1. Why Solar?
2. History IMT - Oerlikon Solar
3. Oerlikon Solar: R&D tasks and results
4. Proven Thin Film Manufacturing Solutions
5. Perspectives & Opportunities
The Need for Renewable Energies

Source: Uppsala Hydrocarbon Depletion Study Group

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Renewable Energy Options

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<th>Energy Source</th>
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<tr>
<td>Geothermal</td>
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<tr>
<td>Wind</td>
<td>3.0</td>
</tr>
<tr>
<td>Tide and ocean currents</td>
<td>2.0</td>
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<tr>
<td>Hydroelectric</td>
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Solar has greatest potential to meet world’s growing electricity needs compared to other renewable energy sources.

Source: Engineering and Science  No. 2 2007
# Two cell technologies

<table>
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<tr>
<th>Technology</th>
<th>Substrate</th>
<th>Cell</th>
<th>Issues</th>
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<tbody>
<tr>
<td>Crystalline Silicon</td>
<td>![image]</td>
<td>![image]</td>
<td>Cost, Silicon Supply</td>
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<tr>
<td>Thin Films</td>
<td>![image]</td>
<td>![image]</td>
<td>Large Scale Efficiency</td>
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</table>

Option: Thin film silicon
A little bit of history….to achieve to

Oerlikon Solar
IMT in the early days.....

Courtesy of IMT-NE
Roots:  Long-term research at IMT Neuchâtel

Very promising concepts (cost reduction & efficiency)

- 1987: Introduction of VHF-GD PECVD deposition
- 1994: Introduction of “Micromorph” concept
- LPCVD ZnO for advanced light-trapping

Courtesy of IMT-NE
Deposition Rates vs. Plasma Excitation Frequency

Deposition rate increase has been reproduced and confirmed by other R&D groups

- no electrical artefact
- hence, real plasma effect
- position of rate maximum due to electrical losses in system

Curtins et al., Elec. Lett 23 (1987) 228
Zedlitz et al., MRS Symp. Proc. 258 (1992) 147

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Micromorph® Process Technology

Amorph Single Junction  Micromorph® Tandem Junction

More Energy Absorbed

The graph shows the quantum efficiency of different solar cells as a function of wavelength. The amorphous silicon (a-Si:H) top cell absorbs energy in the visible spectrum, while the microcrystalline silicon (µc-Si:H) bottom cell absorbs in the near infrared (IR) spectrum. The tandem cell combination allows for a broader spectrum of energy absorption, leading to increased efficiency.
Light-trapping – fundamental for thin film Si solar cells:

Key issue TCO: approach by LPCVD ZnO

Asahi U

LPCVD ZnO
Optical properties:

Enhanced total & diffuse Transmission (Haze)

→ Better quantum efficiency (for a-Si) on ZnO compared to Asahi SnO$_2$
Highest stabilized efficiency for a-Si:H p-i-n on LPCVD ZnO (confirmed)

IMT Neuchâtel 2003:
$\eta = 9.47\%$ stabilized (with ARC)

single-junction a-Si:H p-i-n with “modified” LPCVD ZnO process

(J. Meier et al., WCPEC-3, Osaka 2003)

Our Motivation!
In 2003:

Bottle-necks: up-scaling to 1 m²

• availability of production system
• high investment cost and high risk

Thin film silicon PV technology developed at IMT

search for industrialisation partner
Find Synergies for large-area deposition

In 2003: AM-LCDs: Strong growth

From 22 bn$ to 48 bn$ in 2005
Monitor and TV will be the main driver

Solar cells:
c-Si: $\sim 7 \text{ km}^2$
Thin film: $\sim 0.6 \text{ km}^2$

<table>
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<tr>
<th>Mio Units</th>
<th>2000</th>
<th>2005</th>
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<tr>
<td>Mobile</td>
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<tr>
<td>TVs</td>
<td>0.2</td>
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Source: Nikkei Microdevices FPD 2002 yearbook and Display search 2003 Feb
2003
Oerlikon founds own R&D lab and enters thin film silicon PV

Why Neuchâtel?
Close to IMT and CRPP/EPFL (strategic partners)
Goal: Process Transfer from Lab to Production

Oerlikon Solar-Lab, Puits-Godet 12a, Neuchâtel:
- complete R&D Lab (clean/grey room)
- LPCVD system for ZnO deposition
- PECVD system for silicon deposition
- Laser scribing system
- Cell characterisation
- cleaning, glass cutting, gas delivery systems etc.

Today Oerlikon Solar-Lab SA have 21 employees working in a Lab of about 550 sqm surface
Optimization of devices & deposition processes

a-Si:H p-i-n test cells

9.1 % stabilized a-Si:H p-i-n on ZnO

Update at 24th EU PVSEC Hamburg, September 2009

S. Benaglio et al., 23rd EUPVSEC Valencia (2008)
Up-scaling to 10x10 cm² mini-modules in KAI-M

Characterisation by ESTI of JRC in Ispra

Asahi

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<th>Parameter</th>
<th>Value</th>
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<tr>
<td>$I_{sc}$</td>
<td>66.3 mA</td>
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<tr>
<td>$V_{oc}$</td>
<td>10.39 V</td>
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<tr>
<td>FF</td>
<td>65.1 %</td>
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<tr>
<td>$A_{ap}$</td>
<td>57.18 cm²</td>
</tr>
<tr>
<td>$\eta_{ap}$</td>
<td>7.84 ± 0.19 %</td>
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(aperature area determined at Oerlikon Solar)

LPCVD ZnO

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<tr>
<td>$I_{sc}$</td>
<td>(74.2 ± 1.7) mA</td>
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<tr>
<td>$V_{oc}$</td>
<td>(11.103 ± 0.028) V</td>
</tr>
<tr>
<td>$P_{max}$</td>
<td>(518 ± 12) mW</td>
</tr>
<tr>
<td>$A_{ap}$</td>
<td>57.18 cm²</td>
</tr>
<tr>
<td>$\eta_{ap}$</td>
<td>7.84 ± 0.19 %</td>
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</table>

(aperature area determined at Oerlikon Solar)

$\eta_{ap} = (8.32 ± 0.19) %$

(stabilized)

0.5 % abs. enhanced stabilized efficiency compared to Asahi SnO₂

~1 % abs. compared to commercial TCO

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Best lab Micromorph tandem cell (light-soaked)

SnO$_2$ Asahi glass substrate

Best cell
10.8 % stable efficiency

\[ V_{oc} \quad [\text{mV}] \quad 1376 \]
\[ \text{FF} \quad [%] \quad 69.03 \]
\[ J_{sc} \quad [\text{mA/cm}^2] \quad 11.37 \]
\[ \eta \quad [%] \quad 10.80 \]
Scaling up in R&D Pilot line / Trübbach

a-Si:H p-i-n single-junction R&D module on ZnO: **124.7 W** (ini.)

Confirmed by ESTI of JRC Ispra

>100 W stabilized expected

Still room for further improvements!
Micromorph Module 1.4 m²

R&D Pilot line in Trübbach:

151 W initial 1.4 m² module!

Industrial size 1.1x1.3 m² module on in-house front LPCVD ZnO

Still room for further improvements!
CTI Projects of Oerlikon Solar from start until now

- **CRPP/EPFL: CTI 9675.2** running
  A new low ion energy bombardment PECVD reactor for the deposition of thin film silicon for solar cell applications

- **IMT CTI 8968.3** running
  Development of a novel surface treatment of LP-CVD ZnO layers used as Transparent Conductive Oxide for thin film silicon solar cells.

- **CRPP/EPFL: CTI 6947.1 EBS-IW** finished
  A new large area very high frequency reactor for the high rate deposition of microcrystalline silicon for thin film solar cell applications

- **IMT: Eureka 7253.2 EPRP-IW** finished
  Stability of advanced LP-CVD ZnO within encapsulated thin film silicon solar cells

- **IMT: CTI 6928.1 IWS-IW** finished
  High rate deposition of microcrystalline silicon layers and cells

- **NTB (Neues Technikum Buchs): KTI Nr. 7112.2 EPRP-IW** finished
  Development of QE measuring system
Oerlikon Solar
Segment Overview
Solar key member of the group with global footprint

- Oerlikon Textile
- Oerlikon Coating
- Oerlikon Solar
- Oerlikon Vacuum
- Oerlikon Drive Systems
- Oerlikon Components

800 employees worldwide
280 global support
300 scientists and engineers
20 locations in 11 countries
Over CHF 23m R&D investment in 2007
Over 350 living patents
Over 900,000 modules produced by customers of Oerlikon Solar
Oerlikon Solar

Equipment manufacturer for cost-effective production solutions for thin film silicon solar modules
Oerlikon provides end-to-end (E2E) production solutions...

Front-End
- Clean
- TCO FC
- Laser
- Clean
- PECVD
- Laser
- TCO BC
- Laser
- Voc

Line Automation

Back-End
- Contacted Tested Device
- Encapsulation-Lamination
- Contact
- White Reflector
- Edge Isolation
- Flasher
- Cross Contact
- Lamination
- Junction Box
- Flasher
Oerlikon Solar Manufacturing Systems

TCO 1200
Transparent conductive oxide deposition

KAI 1200
Photovoltaic layer deposition

LSS 1200
Laser scribing

Clean → TCO → Laser → PECVD → Laser → TCO → Laser → Assembly
KAI System Concept - Parallel Processing of 20 reactors

- 2 process towers with 10 reactors in each stack
- 2 load-locks
- 1 transfer chamber
- External robot for glass loading from cassette
- Excitation frequency 40.68 MHz to significantly enhance deposition rate

3.2 m
8.6 m
6 m

Highest productivity on small footprint: 20 MWp / y for a-Si:H
KAI 1200 - Proven Product for PV Layers

KAI 1200 with Plasma Box® reactor
- 40.68 MHz for higher rate & quality
- a-Si:H & μc-Si:H p-i-n layers
- Single-chamber process
- Auto-clean after every run

Result
- High film quality
- High throughput
- High system flexibility & utilization
- Small footprint
Front and back view photo of KAI 20-1200
TCO 1200 - Higher Efficiency and Lower COO

Proprietary LPCVD technology
- High conductivity
- Transparent conductor deposition and texturing in a single step

Integral to Micromorph process
- High transmission in visible and near IR light spectrums
# Project update

<table>
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<th>Customer</th>
<th>Technology</th>
<th>Type</th>
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<th>Move-In On-Time</th>
<th>SOP On-Time</th>
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</table>

Total more than 600 MW
1\textsuperscript{st} Micromorph line in Berlin

Mass production line at Inventux – best Micromorph modules

140 W initial module power (April’09)

\textbf{Graph:}

- \( P = 140 \text{ W} \)
- \( V_{oc} = 131.4 \text{ V} \)
- \( I_{sc} = 1.635 \text{ A} \)
- \( FF = 65.1\% \)
Operational silicon thin film fields

3.4 MWp a-Si installation (Zahna, Germany)
- 39,000 thin film modules & 747 trackers
- Start of operation: 19 February 2009
- System integrator: AC Energy GmbH & Co. KG

1.3 MWp a-Si installation (Zahna, Germany)
Perspectives & Opportunities

Nice example from basic research to mass production

Success recipe:
- Partners with commitments
- Long-term support for basic research (OFEN, CTI)
- Well-trained experts & specialists

Oerlikon Solar:
- Proven solutions for high volume solar module production with more than 900’000 produced panels
- Oerlikon Solar is well-placed for the challenges of the coming PV century
Thank you for your attention.