Equipment to enable GW-scale production of highly efficient CIGS Modules
History SINGULUS TECHNOLOGIES

Ernst Leybold started his business in Cologne Company building 1860

1851

1860

1851

1960

1966

1967

1995

LEYBOLD HERAEUS
Vacuum Technology, Metallurgy and Coating

Foundation
SINGULUS TECHNOLOGIES

1995

LEYBOLD / BALZERS

Merger

Unicorn Pharmacy was founded 1600 in Hanau W.C. Heraeus took over business in 1851 and started with platinum

1851

1866

Heraeus Hochvakuum

1851

1860

E. Leybold (Successor)
Worldwide Connected, Close to the Markets,
Close to the Customer Base

Singulus Inc.
Headquarter US, Hartford

Singulus Inc.
Sales and Service West Coast

Singulus Latin America
Sales and Service South America

SINGULUS Technologies AG
Branch FFB
Fürstenfeldbruck (near Munich), Germany

SINGULUS Technologies AG
Headquarter Kahl am Main, Germany

Singulus Asia
Sales and Service

Singulus Taiwan
Sales and Service

Optical Disc
over 8550 systems installed

Semiconductor
over 180 systems installed

Photovoltaic
over 4,000 MW production capacity installed

Over 180 systems installed

Over 4,000 MW production capacity installed

Over 8,550 systems installed

---

Semiconductor
Photovoltaic
Optical Disc
Main Characteristics CIGS Thin Film Technology

- Excellent stability
- Good low light performance
- Light soaking effect
- Reduced sensitivity to overheating
- Tolerance to shading & low intensity
- Low production cost at high volume production
Projected CIGS Production Costs using Available Technology and Leveraging Cost Reduction Potential

For achieving this projected OPEX cost we need mass production system with stable processes with high Yield and Uptime

Source: www.cigs-pv.net

<table>
<thead>
<tr>
<th></th>
<th>Present fab</th>
<th>Next gen fab</th>
<th>Upgrade &amp; scale next gen fab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>150 MWp/a</td>
<td>250–500 MWp/a</td>
<td>500–1000 MWp/a</td>
</tr>
<tr>
<td>Average efficiency</td>
<td>14.3%</td>
<td>16%</td>
<td>18%</td>
</tr>
<tr>
<td>Reductions versus present fab</td>
<td>material -20% capex -20%</td>
<td>material -30% capex -30% t&amp;m -20%</td>
<td></td>
</tr>
</tbody>
</table>
CIGS Thin Film Cells – Full PV Value Chain in one Production Flow – From Glass to Module

SINGULUS TECHNOLOGIES

Core Process
Deposition & thermal treatment of absorber layers → optimized chalcopyrite
CIGS Core Process Variations

**With H$_2$Se Precursor**

- Bosch
- Solar Frontier
- Stion
- PTIP

**With Se Precursor**

- CNBM/Avancis

**With Co evaporator**

- Hanergy/Solibro
- Manz

**Copper Indium Gallium**

**H$_2$Se & H$_2$S**

**Sputtered Cu, In, Ga Precursors**

**INLINE RTP H$_2$Se & H$_2$S Gas Form**

**CdS**

**CBD**

**CdS Buffer Layer Deposition**

**Copper Indium Gallium Selenium**

**Se Evaporation**

**INLINE RTP H$_2$S Gas Form**

**InS & iZnO**

**Combination Evap & Sputtering InS & iZnO**

**Co-Evaporation Cu, In, Ga, Se**

**CBD**

**CBD Buffer Layer Deposition**
VISTARIS - Inline Sputtering System for CIGS Modules with fully vertical substrate transport

- Modular concept
- Adaptable throughput (up to 150MW)
- Flexible cycle time
- R&D to GW
VISTARIS - Inline Sputtering System for CIGS Modules with fully vertical substrate transport

Inline Sputtersystem for CIGS Solarcells

approx 32 m

approx 12 m
Uniformity CIG Layer: Layer Thickness measurement with XRF for CIG

Normalised CIG Uniformity profile

Excellent Long term stability

+/- 1.5%
SELENIUS – Se Evaporation

- Modular concept
- Adaptable throughput (up to 150MW)
- Flexible cycle time
- R&D to GW
INLINE Selenization/ Sulphurization - Innovative Production Equipment for CIGS Manufacturing (CISARIS)

- Modular concept
- Flexible cycle time
- Adaptable throughput
- R&D to GW
INLINE Selenization/ Sulphurization - Innovative Production Equipment for CIGS Manufacturing (CISARIS)

Inline Diffusion Oven for CIGS Solarcells

Return Section

- Cooling units
- SD1
- New conveyor system
- Handling Station
- Loading Chamber (2 pcs)
- Exit Chamber
- 5x Heating chamber
- 2x Cooling chamber
- Substrate Exchange station
- Up to 600°C substrate temperature

Process Section
Heating Chamber configuration

IR Heating – Temperature measurements with 2D-IR-Scanner

Individual controlled special IR Heaters
Heating Chamber performance

Temperature homogeneity

Temperature cross section over glass sheet with IR-camera

Sigma 4.7°C
INLINE Selenization/ Sulphurization - Innovative Production Equipment for CIGS Manufacturing (CISARIS)

Inline Diffusion Oven for CIGS Solarcells

- Product launch in 2010
- 19 Machines sold
- Ongoing optimization programs
- Proven concept
- Proven process performance
New Batch/Inline Three-Chamber Forced Convection System O3* for CIGS Formation in GW-Scale Mass Production

- Hot wall reactor for best process control
- Heating, reaction and cooling by strong forced convection of processing gases
- Homogeneous gas flow & temperature distribution
- Gas flow adjustable from laminar to turbulent
- High heating and cooling rates
- Max process temp > 600°C
- Gas recirculation for minimized reactor
- Very beneficial combination of batch type and inline processing

*O3: 3rd Oven Generation Forced Convection
O3 for CIGS Formation in GW-Scale Mass Production: Cross Section

- Carrier load: up to 320 substrates
- One system for up to 200 MW/year
- Compact design, low floor space
- Low energy consumption
- Absolutely corrosion resistant, long lasting
- **Significant Reduction of Capex and Opex**

IP by Dr. Volker Probst
TENUIS – Chemical Bath Deposition of CdS Buffer Layer for CIGS Modules

- Standard reference process: highest efficiencies and low risk
- More than 150 process modules in production
- Minimized chemical consumption
- Single side deposition incl. protection against backside contamination
- Modular system (easy upgrade for higher throughput)
- Reproducible process results
- Automatic dosage and mixing system
- Deposition systems for cadmium-free buffer layers available
Layout Tenuis Gen2

150 MW Example Layout

- Central Pumps stations for disposal
- RTB-Boiler station
- 9 Process Modules
- HMI Control Station
- Central Dosage tank system
- Feed IN
- Feed OUT
- VITRUM Final Rinse
- Unloading-Conveyor
- Loading-Conveyor
- Robot system on linear handling system
## Comparsion Batch Dipping vs. Tenuis Gen 2

### Advantages TENUIS Gen 2 Single Side CBD vs. Batch Applications

<table>
<thead>
<tr>
<th></th>
<th>Batch</th>
<th>Tenuis GEN 2</th>
</tr>
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<tbody>
<tr>
<td>Deposition Side</td>
<td>Double sided</td>
<td>Single sided</td>
</tr>
<tr>
<td>Chemical Consumption</td>
<td>20 l/m2</td>
<td>4,16 l/m2 (3,5 l/m2)</td>
</tr>
<tr>
<td>Temperature Uniformity</td>
<td>+/- 2°C</td>
<td>+/- 2°C</td>
</tr>
<tr>
<td>Layer uniformity</td>
<td>+/- 5%</td>
<td>+/- 3%</td>
</tr>
<tr>
<td>Uptime</td>
<td>appr. 85%</td>
<td>&gt; 97%</td>
</tr>
<tr>
<td>OPEX incl. WWT per watt *</td>
<td>0,05 €</td>
<td>0,013 €</td>
</tr>
<tr>
<td>Efficiency Increase **</td>
<td>No</td>
<td>up to 0.2-0.4% abs</td>
</tr>
<tr>
<td>add. Equipment Cost for BSR ***</td>
<td>appr. 750.000 €</td>
<td>w/o</td>
</tr>
<tr>
<td>OPEX of BSR per watt *</td>
<td>0,01 €</td>
<td>w/o</td>
</tr>
<tr>
<td>Temperature Profiles</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Subsequent dosing steps</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Alternative Buffer</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* OPEX based on European Cost | ** according RTB system | *** BSR = Back Side Removal
Amortization Total Cost of ownership for 100 MW/a

Amortization of higher capex within less than 70 MW output (9 month) due to lower running costs

Cost saving more than 5 Mio € per 100MW output (OPEX)
CdS or Alternative Buffer Layer Deposition - Comparison of RTB-Profiles

<table>
<thead>
<tr>
<th>RTB</th>
<th>Process Time</th>
<th>Deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>w/o – (24KW)</td>
<td>360 seconds</td>
</tr>
<tr>
<td>II</td>
<td>75% - (32KW)</td>
<td>360 seconds</td>
</tr>
<tr>
<td>III</td>
<td>85% - (36KW)</td>
<td>360 seconds</td>
</tr>
<tr>
<td>IV</td>
<td>100% - (42KW)</td>
<td>240 seconds</td>
</tr>
</tbody>
</table>
Conclusion

- Core competence in all major process steps
- Systems for core processes designed, built and in production
- Systems available from R&D scale to GW production
- Strict modular concepts for cost optimization and minimized failures
- Synergies in ThinFilm technology for continuous improvement
Forward-Looking Statements

This presentation contains forward-looking statements based on current expectations, assumptions and forecasts of the executive board and on currently available information. Various known and unknown risks, unpredictable developments, changes in the economic and political environment and other presently not yet identifiable effects could result in the fact that the actual future results, financial situation or the outlook for the company differ from the estimates given here. We are not obligated to update the forward-looking statements made in this presentation unless there is a legal obligation.