NCCAVS: Thin Film Applications and Equipment Solutions for Photovoltaic Applications

February 23, 2011
Discussion Overview

- Overview / Introduction Roth & Rau
- Product Introduction
- Applications & Cell Performance Benefits
- Process Discussion
- Conclusions / Questions
<table>
<thead>
<tr>
<th>Segment</th>
<th>Leading supplier of equipment and technology for the photovoltaic industry and supplier of process systems based on plasma and ion beam technology for other sectors like the semiconductor and optical industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological expertise</td>
<td>Comprehensive know how in development and application of plasma process equipment for surface treatment in various industrial sectors 10 years of experience with plasma technology in solar cell manufacturing</td>
</tr>
<tr>
<td>Founding year</td>
<td>1990</td>
</tr>
<tr>
<td>Management</td>
<td>Dr. Dietmar Roth (CEO, co-founder), Thomas Hengst (CSO), Paul Breddels (COO)</td>
</tr>
<tr>
<td>Location</td>
<td>Hohenstein-Ernstthal (headquarters)</td>
</tr>
<tr>
<td>Employees</td>
<td>1134 as of June 30, 2010</td>
</tr>
<tr>
<td>Listing</td>
<td>listed on Frankfurt Stock Exchange since May 2006, listed in TecDAX since June 2008</td>
</tr>
<tr>
<td>Shareholders</td>
<td>11,35% founders, 6,34% OTB Group B.V., 82,31% free float</td>
</tr>
</tbody>
</table>
International footprint

Roth & Rau AG
Roth & Rau Dünnschicht Solar
AIS Automation Dresden
SLS Solarline Saxony
Muegge Electronic
Roth & Rau MicroSystems
CTF Solar
R³T
OTB Solar

Roth & Rau Ortner
Roth & Rau Italy
Roth & Rau Korea
Roth & Rau Shanghai
Roth & Rau Hong Kong
Roth & Rau Australia

Roth & Rau Switzerland
Roth & Rau USA
Roth & Rau Ortner USA
Roth & Rau Software Automation
Cober Muegge
Roth & Rau India
Roth & Rau Singapore
Roth & Rau Ortner Malaysia

production  sales / service  R & D

Trade partners
Strong customer base in the PV industry

... and many others
Installed Base SiNA® / DEPx / MAiA

Total:

- > 500 SiNA/DEPx/MAiA-Tools
- 129 PV Solar cell makers in 21 Countries on 4 continents
- > 17 GW delivered theoretical PV power (70% already installed)

Confidential
Products and technology for photovoltaics' solar modules

Value chain crystalline silicon solar module manufacturing

New business field from 2010

Focus of Roth & Rau
Products and technology for photovoltaic’s

**Single equipment**
- In-line PECVD/PVD equipment
- Diffusion and firing furnace
- mc-Si crystallisation furnace

**Turnkey solutions**
- Crystalline Si solar cells
- CdTe thin film solar modules
- mc- silicon wafers
AR coating equipment for c-Si solar cells

Key products of the Roth & Rau group

- **SiNA®** / **MAiA®** by Roth & Rau AG
  - Leading product in the market
  - Equipment with the highest throughput in combination with excellent layer quality and low running costs
  - From 2010 launch of new model with further cost advantages and possible applications for the production of new types of solar cell (e.g. with rear side passivation)

- **DEPx** by OTB
  - Most compact in-line equipment with high deposition speed
  - Well suited for small to mid-scale production

Next generation:

- Development has already started
- Goal: modular equipment for several application combining the advantages of both systems
Products and technology for photovoltaics

Standard crystalline silicon solar cell production process

- saw damage etch texturing
- emitter diffusion
- PSG etch
- AR coating
- print front and back contacts
- firing and drying contacts
- wafer handling automation
- test and sort

Over the whole production process:
- technology know how
- manufacturing control (MES software)

Market position of the Roth & Rau group:
- dark blue: market leader
- blue: among TOP 3
- light blue: market presence (new products)
- gray: no products
Products and technology for photovoltaic's

Heterojunction solar cell production process

- Test/sort
- Edge isolation
- Screen print front contact
- PVD TCO front-/backside back contact

Roth & Rau PRiMELiNE\textsubscript{HJT}
- Target capacity of 80 MWp
- Floor space approx. 140 x 10 m$^2$
What is the meaning of the product name?

SiNA®

Silicon Nitride Deposition (DE) = Deposition (EN)

Modular Design offers HIGHEST Flexibility
Heterojunction Cell Format
What are the product applications? C-Si

**SiNA® & DEPx**
- Plasma deposition processes
  - Si$_x$N$_y$
  - Si$_x$O$_y$- DEPx

**MAiA®**
- Plasma etch processes
  - Texturing
  - Saw damage etch (depends on further process requirements)
  - Pre-cleaning
- Plasma deposition processes
  - a-Si
  - Si$_x$O$_y$
  - Si$_x$O$_y$/Si$_x$N$_y$
  - Si$_x$C$_y$N$_y$
  - Al$_x$O$_y$
  - Al$_x$O$_y$/Si$_x$N$_y$
  - Al$_x$O$_y$/Si$_x$O$_y$/Si$_x$N$_y$/Si$_x$O$_y$N$_z$
What are the product applications? Heterojunction

**HELiA PECVD/PVD**

**PECVD deposition processes**
- a-Si un Doped (intrinsic)
- a-Si Doped

**PVD deposition processes**
- TCO (ITO)
- Metal (e.g. Al, Ag)
Best Cell

**EFF.: 17,3%**

could be successfully proven in Roth & Rau R&D pilot line (Technology Centre)

<table>
<thead>
<tr>
<th>Efficiency [%]</th>
<th>Uoc [mV]</th>
<th>Isc [A]</th>
<th>FF [%]</th>
<th>Rs [Ω]</th>
<th>Rsh [Ω]</th>
</tr>
</thead>
<tbody>
<tr>
<td>17,29</td>
<td>627</td>
<td>8,63</td>
<td>77,7</td>
<td>0,0039</td>
<td>52,2</td>
</tr>
</tbody>
</table>

**Fig1:**
Top Efficiency LoBaCo Cell

**Fig2 (right):**
View into the Roth & Rau R&D pilot line
Applications for c-Si wafer processing

- Back side passivation on p-type
- Passivation of B-emitter on n-type
- Front side optical coating
Applications for c-Si wafer processing

- Front contact (Ag)
- SiOx
- SiNx
- P-emitter (n+)
- p-type Si
- Rear contact (Al)

Graph showing absolute efficiency gain with SiNx/SiOx stack:
- SiOx layer as front side optical coating
- Process improvement by changing to N2O
- Significant gain on cell level both on multi and mono wafers
Heterojunction Technology Baseline

- Roth&Rau-research-center in Neuchatel, Switzerland
- Team of 10 physicists and technicians
- Fully equipped research-lab including all manufacturing steps on lab scale
- Close collaboration with EPF Lausanne

<table>
<thead>
<tr>
<th>Area (cm²)</th>
<th>Efficiency (%)</th>
<th>V_{oc} (mV)</th>
<th>FF (%)</th>
<th>I_{sc} (mA/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>21.0</td>
<td>729</td>
<td>77.9</td>
<td>37.0</td>
</tr>
<tr>
<td>148</td>
<td>19.3</td>
<td>726</td>
<td>76.6</td>
<td>34.7</td>
</tr>
</tbody>
</table>

Results published in September 2010
Heterojunction Technology Baseline
HJT Technology status

Proven carrier-lifetime of >6 ms
Demonstrated cell performance of 21% (4cm²)
Demonstrated cell performance of 19.3% (wafer)
(EU PVSEC 2010 Valencia)

(2x2 cm², VOC 7.29mV, FF 77.9%)
1. Evacuate
2. Fast heat up
3. Transfer

1. Pre-heat
2. Transfer

1. Cool down
2. Transfer
3. Transfer

1. Vent
2. Cool down
3. Transfer

SiNA General Design

- **Evacuate**
- **Fast heat up**
- **Transfer**

- Pre-heat
- **Transfer**

- Cool down
- **Transfer**
- **Transfer**

- Vent
- **Cool down**
- **Transfer**

GUI
(Graphic User Interface)

Chamber Valve
(Atmospheric Gate)

Unload Module
(Cooling Zone)

Chamber Valve
(Vacuum Gate)

Buffer Module OUT
(Cooling Zone)

Process Module
(Plasma Zone)

Buffer Module IN
(Pre-heating Zone)

Chamber Valve
(Vacuum Gate)

Load Module
(Pre-heating)

Chamber Valve
(Atmospheric Gate)

Modular Design
offers

HIGHEST Flexibility
## SiNA Modular Construction System

<table>
<thead>
<tr>
<th>Modular Construction System</th>
<th>SiNA®</th>
<th>SiNA®</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carrier 1000 x 1000 mm 25 - 6“ – wafer</td>
<td>Carrier 1860 x 1000 mm 50 - 6“ – wafer</td>
</tr>
<tr>
<td>30-80 MWp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-120 MWp</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Basic Design
- Selection based on technology requirements
- Selection of single modules requirements

### Main Function

<table>
<thead>
<tr>
<th>Sub Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Lock Module</td>
</tr>
<tr>
<td>Buffer Module (BM)</td>
</tr>
<tr>
<td>Process Module (PM)</td>
</tr>
</tbody>
</table>

### Sub Function
- Load Module
- Unload Module
- Transfer Module
- + Pre-heat
- + Cool down

- with 4 Plasma Sources
- with 6 Plasma Sources
# Overview – Product Types & Sizes

## Capacity

<table>
<thead>
<tr>
<th></th>
<th><strong>SiNA®1000</strong></th>
<th><strong>SiNA®1600</strong></th>
<th><strong>SiNA®2000</strong></th>
<th><strong>SiNA®2400</strong></th>
<th><strong>SiNA®2800</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GROSS wafer TpT</strong></td>
<td>1061</td>
<td>1542</td>
<td>1996</td>
<td>2426</td>
<td>2831</td>
</tr>
<tr>
<td><strong>NET wafer TpT</strong></td>
<td>1014</td>
<td>1472</td>
<td>1900</td>
<td>2302</td>
<td>2683</td>
</tr>
<tr>
<td><strong>Wafer size</strong></td>
<td>125/156/200</td>
<td>125/156/200</td>
<td>125/156/200</td>
<td>125/156/200</td>
<td>125/156/200</td>
</tr>
<tr>
<td><strong>Wafer thickness</strong></td>
<td>100…300</td>
<td>100…300</td>
<td>100…300</td>
<td>100…300</td>
<td>100…300</td>
</tr>
<tr>
<td><strong>MTBF</strong></td>
<td>450</td>
<td>430</td>
<td>390</td>
<td>350</td>
<td>340</td>
</tr>
<tr>
<td><strong>MTTR</strong></td>
<td>2,1</td>
<td>2,5</td>
<td>3,3</td>
<td>4,1</td>
<td>4,3</td>
</tr>
<tr>
<td><strong>Uptime</strong></td>
<td>&gt; 95</td>
<td>&gt; 95</td>
<td>&gt; 94</td>
<td>&gt; 93</td>
<td>&gt; 93</td>
</tr>
<tr>
<td><strong>Foot print (LxW)</strong></td>
<td>7,6 x 3,7</td>
<td>7,6 x 3,7</td>
<td>9,6 x 3,7</td>
<td>10,9 x 3,7</td>
<td>10,9 x 3,7</td>
</tr>
</tbody>
</table>

1) TpT calculated for 6 inch wafers @Tk.=85nm R.I.=2,05 measured on cz-wafer
2) Calculations based on RR field data
3) Excluded scheduled preventive maintenance time.
4) Excluded pump units

Overview – Product Types & Sizes

<table>
<thead>
<tr>
<th>Capacity</th>
<th>SINA®2200+</th>
<th>SINA®2600+</th>
<th>SINA®3200+</th>
<th>SINA®3600+</th>
<th>SINA®4000+</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROSS wafer TpT(1):</td>
<td>2201</td>
<td>2687</td>
<td>3153</td>
<td>3593</td>
<td>4018</td>
</tr>
<tr>
<td>NET wafer TpT(1):</td>
<td>2101</td>
<td>2563</td>
<td>3001</td>
<td>3413</td>
<td>3801</td>
</tr>
<tr>
<td>Wafer size:</td>
<td>125/156/200</td>
<td>125/156/200</td>
<td>125/156/200</td>
<td>125/156/200</td>
<td>125/156/200</td>
</tr>
<tr>
<td>Wafer thickness:</td>
<td>100…300</td>
<td>100…300</td>
<td>100…300</td>
<td>100…300</td>
<td>100…300</td>
</tr>
<tr>
<td>MTBF(2):</td>
<td>440</td>
<td>430</td>
<td>390</td>
<td>370</td>
<td>330</td>
</tr>
<tr>
<td>MTTR(2):</td>
<td>2,1</td>
<td>2,5</td>
<td>3,3</td>
<td>4,1</td>
<td>4,3</td>
</tr>
<tr>
<td>Uptime(2):</td>
<td>&gt;95</td>
<td>&gt;95</td>
<td>&gt;94</td>
<td>&gt;94</td>
<td>&gt;93</td>
</tr>
<tr>
<td>Foot print (LxW)(4):</td>
<td>11,0 x 3,7</td>
<td>11,6 x 3,7</td>
<td>13,8 x 3,7</td>
<td>14,7 x 3,7</td>
<td>16,9 x 3,7</td>
</tr>
</tbody>
</table>

1) TpT calculated for 6 inch wafers @T+.=85nm R.I.=2,05 measured on cz-wafer
2) Calculations based on RR field data
3) Excluded scheduled preventive maintenance time.
4) Excluded pump units

Carrier Capacity: 50 wafers @6”-wafers

Highest PECVD Throughput in the PV market
### General Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer thickness (1)</td>
<td>20 ... 200 [nm]</td>
</tr>
<tr>
<td>Index of refraction (2)</td>
<td>1.9 ... 2.3</td>
</tr>
<tr>
<td>Layer uniformity (3)</td>
<td>((\text{Max}-\text{Min})/(\text{Max}+\text{Min}) \times 100%)</td>
</tr>
<tr>
<td>Tk (p-t-p) spec./typical</td>
<td>(&lt; \pm 3.0 / \pm 2.5 %)</td>
</tr>
<tr>
<td>Tk (w-t-w) spec./typical</td>
<td>(&lt; \pm 3.0 / \pm 2.5 %)</td>
</tr>
<tr>
<td>Tk (r-t-r) spec./typical</td>
<td>(&lt; \pm 3.0 / \pm 2.5 %)</td>
</tr>
<tr>
<td>R.I. (p-t-p)</td>
<td>(&lt; \pm 1.5 %)</td>
</tr>
<tr>
<td>R.I. (w-t-w)</td>
<td>(&lt; \pm 1.5 %)</td>
</tr>
<tr>
<td>R.I. (r-t-r)</td>
<td>(&lt; \pm 1.5 %)</td>
</tr>
</tbody>
</table>

#### Process gases:

- **SiH₄/NH₃**
- **Process gases total flow (4)**: 1.0 ... 4.0 [slm]
- **Gas ratio \(Q_{\text{NH}_3}/Q_{\text{SiH}_4}\)**: 2.0 ... 3.5 [\%]
- **T<sub>process</sub>**: 350 ... 550 [°C]
- **P<sub>process</sub>** (5): 0.1 ... 0.3 [mbar]
- **No. of vacuum chambers**: 5 ... 8
- **Base pressure**: \(< 1 \times 10^{-3}\) [mbar]
- **No. of plasma sources**: 2 ... 8
- **MW Peak power**: 2 ... 5 [kW]

1) Impact on TpT (typical: tk=85nm).
2) Impact on TpT (typical: R.I.=2.05).
3) Depends on measurement layout. The measurement layout ist attached in RR-Process-Spec.
4) Depends on No. of plasma sources
5) Impact on TpT.
Automation

Features

- RR own automation for all SiNA® & MAiA® applications (“all from one single source”) → defined system with defined interfaces
- Non robot solution → Less stress on wafer through belt drives → back side handling for face up deposition
- Configuration as single or double end solution according customer requirements based on a modular concept
- Compact design (small footprint)…

Benefits

LESS wafer stress

LESS wafer breakage

Fig. 1: single end automation, i.e. loader (footprint ~2m² + 5m² carrier handling)

Fig. 2: single end automation

Fig. 3: double end automation
Summary Benefits New SiNA®

- Highest flexibility in terms of throughput and process by modular design
- Highest throughput (4000wph and more)
- Excellent layer uniformity (+/-3%)
- High Uptime (>95%)
- High Yield (>99%)
- Higher process temperature (up to 550 °C) and good thermal uniformity (+/-4%)
- 40% smaller total footprint compared with the forerunner model
- Low Operating Cost
- Low CoO (0,008€/Wp)
- Best Safety, Quality & Design
What is the meaning of the product name?

MAiA®

Multi
pplication
mple
line
pperatus (Latin) = Equipment (EN)

Modular Design offers HIGHEST Flexibility
Double Side MAiA® Plasma Process

3 PROCESS STEPS ONE SYSTEM ONLY!

Front End:
- Wafer Inspection
- Saw Damage Etching & Texturing
- Phosphorus Doping
- Emitter Diffusion
- Phosphor Glass (PSG) Etching
- Emitter Isolation

Back End:
- Cell Sorter, Transfer & Storage
- Firing
- Drying
- Screen Printing
- Laser
- Aneal (~500°C)

Rear Side Passivation Layer No.1 (AlxOy)

Rear Side Passivation Layer No.2 (SiN:H)

Front Side Passivation Layer (SiN:H)
Al₂O₃–PE CVD for backside passivation

PERC cell Passivation -> Front ARC + RS AlOₓ/SiN Stack
as “all in one” low cost solution for 3x dielectric coatings in just 1x pass through on MAiA inline tool with upto 3600 wph.

Fig1: 
PERC-type solar cell structure used to demonstrate the applicability of an Al₂O₃ rear surface passivation to high-efficiency solar cells. 
Source: 
23rd European Photovoltaic Solar Energy Conference

- Surface field passivation to high negative fix charges in Al₂O₃ after anneal + firing
- Improved IQE for red photons with optimized SiN cap layer

expected Efficiency gain up to + 1%
Double Side MAiA® Deposition Concepts

1st Generation

MAiA Front - Front Concept:

- separate tools for front side and for backside processing,
- only use of top down plasma processes (good layer uniformity),
- Atmospheric wafer flipping between both tools

MAiA®1600

1st ARC-System
Back Side SiOx and Back Side SiNx
(as Face Up Deposition)

2nd ARC-System
Front Side SiN
(as Face Up Deposition)
Double Side MAiA® Deposition Concepts

2nd Generation

MAiA Front - Front Concept:
- separate tools for front side and for backside processing, but without vacuum and thermal disruption
- Vacuum wafer flipping between both tools
- Less chambers

MAiA R2.2

MAiA®1600

1st ARC-System
Back Side SiOx and Back Side SiNx
(as Face Up Deposition)

2nd ARC-System
Front Side SiN
(as Face Up Deposition)
3rd Generation

MAiA Front - Back Concept:
- **ONE** tool for front side and for backside processing,
- **NO** vacuum and thermal disruption → less chambers
- **NO** wafer flipping necessary → **NO** mechanical stress on wafer material

MAiA®1600

ONE ARC-System
Back Side SiOx and Back Side SiNx (as Face Down Deposition) & Front Side SiN (as Face Up Deposition)

BEST CoO
Double Side MAiA® Plasma Process

ALL IN ONE
The new generation of MAiA® - Summary

- High performed modular plasma equipment system based on SiNA platform with:
  - HIGHEST Flexibility
  - BEST Throughput
  - BEST CoO

- MAiA’s combines PE-CVD for SiN-front and dielectric layer systems for backside (SiOx/SiNx or AlOx/SiNx) in one tool as the unique PV supplier

- 3 process steps ONE system only!

- SiOx/SiN process for backside passivation successfully placed on the market,

- Front & Back Side ARC in ONE Step

- new AlOx-process for high efficient solar cell concepts as stand-alone or in combination with cap layer available with superior results,

Comparable or better to SEMI proven ALD process in Cell Efficiency at higher throughput and lower costs
PRiME-LiNExHJT
HELiA PECVD Tool Layout
PRiME-LiNE\textsubscript{HJT} HELiA PECVD Deposition System

- Superior patented S-Cube Reactor for high quality a-Si:H deposition
  - Low contamination with Box-in-box reactor
  - Isothermal heating for good uniformity
  - Narrow gap electrode, symmetrical
- Carrier-less wafer handling for contamination-free processing
- High throughput of 2400 wph for i/p or i/n
  - Flexible design to accommodate 1000 – 2400 wph
- Deposition of intrinsic, p-doped or n-doped a-Si:H possible

Excellent passivation quality of a-Si – layers (carrier lifetime > 6ms)
PRiME-LiNE_{HJT} HELiA PECVD Production System

- Patented S-Cube™ PECVD process system for high performance a-Si:H deposition
- Advanced, carrier-less wafer handling system for contamination-free transfer of substrates

- Isothermal heating for excellent film uniformity
- Homogenous gas distribution
- Symmetrical parallel plate PECVD reactor for excellent film stoichiometry
- Differential pumping for low contamination (process at 1 mbar, outside chamber <1E-2 mbar)
PRiME-LiNE\textsubscript{HJT}
HELiA PVD Production Tool configuration
PRiME-LiNE HJT
HELiA PVD Production System

High-performance PVD Solution with rotary magnetrons:

- Proven high quality TCO and metal deposition in R&D line and pilot tool
- Lowest COO: Low material cost with rotary magnetrons (>90% Target util.)
- Tact time of PECVD tool – simple handling interface
- Capability of front and back deposition in same tool (2400 wph)
- Excellent uniformity with rotary linear magnetrons
- Long MTBM with multiple magnetrons for front and back side deposition
Benefits HELiA PECVD/PVD

- Competence in HJT – Full R&D line and Commercially Available Deposition Systems
- Superior PECVD Solution with S-Cube, carrier-less wafer handling
  - Superior passivation quality
  - Flexible design for throughput up to 2400 gross WPH
- PVD: Excellent process conditions and CoO advantage with rotary magnetron sources
  - Option for 2 or 3 back metal deposition sources and processes
- Access to R&D line, full qualification of PECVD and PVD tools in pilot line format at Roth & Rau HQ, Hohenstein Germany
Conclusions

- Market Leader in PECVD, PVD Deposition Equipment and Process Technology
- Large Process base
- Single and multi process application
- Multi cell format base
- Focus on enhanced Cell efficiency process and equipment solutions
- Positioned for short term and long term success

*How can we help?*
Thank you for your attention.