Industrial BBr3 Boron Furnace Doping for High-Efficiency N-type Cells

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Outline

• Introduction of Amtech Systems and Subsidiaries
• Overview of High-Efficiency N-type Cell (N-Panda)
• BBr3 Boron-Emitter Process for N-type Cell
• Dry HF Etcher for PSG/BSG Removal and Clean Surface Passivation
Amtech Group:

Nasdaq: ASYS
Amtech History *(Diffusion Experts)*
(Founded 1981)

1983  ➔  Acquired Intel Corp invention: **Diffusion** processing tool (ATMOSCAN).


1997  ➔  Acquired P.R. Hoffman®, silicon polishing consumable business.

2004  ➔  Acquired Bruce Technologies® from Hitachi Kokusai; **Diffusion** furnace business.
Became No. 1 Semi horizontal **Diffusion** company in the world.

2006  ➔  Entered into Joint Development Agreement with ECN for N-type **Diffusion** Technology.

2007  ➔  Acquired R2D™ Ingenierie SAS; **Solar Diffusion Automation**.

2008  ➔  Entered into 3-party Collaboration Agreement: Tempress, Yingli, and ECN for N-type technology.

2009  ➔  Introduced Solar Dry Etch (PSG removal) product, in addition to Solar PECVD.
Amtech Products, Brands & Applications

- Diffusion Furnace, PSG & PECVD
- Furnace Automation & Wafer Handling Systems
- Wafer Carriers
- Solar Cells & Semiconductor Chips
- Silicon Wafers

*Manufacturer of Semiconductor and Solar Equipment*
About Tempress as the preferred furnace supplier

- Proven track record since 1968 in Semiconductor and Solar industry

- One company supplying both furnace systems and wafer automation equipment (one contact point for service and support)

- Worldwide service organisation with local service offices in Europe, USA, China Taiwan and Singapore

- Close cooperation with ECN (Energy Centre Netherlands) on POCL3, BBr3, Oxidation and PECVD process development for higher efficiency mono-Si cells

- Tempress POCl3 furnace market share in China > 35%
- Tempress POCl3 furnace market share in Taiwan > 40%
- Tempress POCl3 installed cell capacity in Asia > 10 GWatt

- Tempress BBr3 boron emitter is a well production-proven technology demonstrated by volume production of bi-facial n-type cell at Yingli (n-Panda) with high-efficiency.
N-type: the road to higher efficiencies

- N-type cells lead to higher efficiency:
  - No light-induced degradation
  - Less sensitive to metal contamination.

- Boron-emitter formation and passivation are key technologies for n-type cells

- Temppress provides industrial BBr3 diffusion for boron-emitter and POCl3 for BSF (Back Surface Field).
N-type Bifacial Cell (N-Panda)

Self aligned selective emitter

Front Contact (Ag/Al)  ARC: SiO$_2$/SiN$_x$

Front and Rear Ag

PSG / BSG Glass Removal

POCl$_3$ BSF and BBr$_3$ Emitter

SiO$_2$/SiN$_x$ Passivation/ARC

Co-Firing

(p$^+$) Boron Emitter

N-Type substrate

(n$^+$) Phosphorous BSF

Back Contact (Ag)

SiN$_x$
Breakthrough in boron-emitter passivation

Simple chemical oxide passivation (ECN Patent)

![Graph showing IQE vs Wavelength (µm) for different boron emitter passivations: none, SiNx, SiO2+SiN x](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$I_{sc}$</td>
<td>9.0 A</td>
</tr>
<tr>
<td>$U_{oc}$</td>
<td>636 V</td>
</tr>
<tr>
<td>FF</td>
<td>78.14%</td>
</tr>
<tr>
<td>Area</td>
<td>239.8 cm²</td>
</tr>
<tr>
<td>$J_{sc}$</td>
<td>37.5 mA/cm²</td>
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<tr>
<td>Eff.</td>
<td>18.71%</td>
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</table>
p+ emitter: materials choice & technique

Possible dopants for p+ emitters on the front side of n-type solar cells:

- **Gallium**: Low solid solubility, very fast Ga diffusion in SiO₂
- **Aluminum**: No proper high temperature treatment for high-doping level
- **Boron**: Various methods available:
  - **Deposition**: CVD print, spin
    - B₂H₆ (doped poly)
    - BSG paste, H₃BO₃
    - not for uniform front side (HIT, IBC)
    - Ferro, Filmtronics, Honeywell
  - **Implant**: Solar implanter
    - B, BF₃
    - Tempress, Varian
  - **Diffusion**: Solid-source
    - BN
    - semiconductor industry
  - **Liquid source**: BBr₃
    - Tempress: solar PV industry
  - **Gas source**: BCl₃
    - semiconductor R&D

A major disadvantage of the first two categories is that they require a separate drive-in and/or oxidation process step. Amongst the single-step diffusion methods, there is only one industrial process to form a front p+ emitter for n-type cells:
Standard BBr₃ diffusion processing

Schematic drawing:

A standard process sequence of the diffusion can consist of several steps, shown schematically here:
P+ emitter: BBr$_3$ optimization

Optimized the BBr$_3$ conversion rate to achieve a uniform load size of 400 wafers/run and are still working on further improvement:

$\sigma$(within wafer) <2%

$\sigma$(wafer-to-wafer) <2%

$\sigma$(run-to-run) <3%

(2-10 randomly selected wafers/run)

uniformity within load  
run-to-run stability
**Current status & future outlook**

- Tempress is the largest & most experienced company supplying BBr₃ systems used industrially. Yingli Solar uses these for mass-production of high-efficient n-type Panda cells (average η=18.7% in mass production).

- Further n-type cell efficiency improvement is on-going using new available technologies including HF dry etching for high quality surface passivation.
Dry HF Etcher: BSG removal & clean surface

Dry HF etching is a stable glass removal process providing a very clean surface which is critical for high-quality surface passivation.

- p⁺ diffusion (B)
- BSG removal
- ARC & passivation

Dry HF etching:
- Closed vacuum system
- Fresh HF vapour, no plasma!
- For PSG, BSG, SiO₂, SiNx removal
Dry HF Etcher

Key Attributes:

- **Compact Footprint:**
  - 1/3 of wet bench

- **Large Batch Size:**
  - 500 wafers per load

- **High Throughput:**
  - 3000 WPH

- **Easy Maintenance:**
  - Wall residue prevention

- **Wide Temperature Range:**
  - RT to 200°C
Lifetime Test Results
(FZ Wafers + POCl3 Doping)

Before Firing

After Firing

<table>
<thead>
<tr>
<th>Wet No OX</th>
<th>Wet PE OX</th>
<th>Wet Furn OX</th>
<th>Wet Ch OX</th>
<th>Dry No OX</th>
<th>Dry PE OX</th>
<th>Dry Furn OX</th>
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<tr>
<td>73.3</td>
<td>69.8</td>
<td>69.8</td>
<td>82.2</td>
<td>282</td>
<td>247</td>
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<tr>
<td>103.7</td>
<td>98.5</td>
<td>101</td>
<td>113.8</td>
<td>400.8</td>
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Lifetime (µs)
Summary

- We have successfully developed industrial BBr3 diffusion technology for high-efficiency n-type cells.

- BBr3 diffusion is in volume production as a proven industrial process (η~19.0% in mass production at Yingli).

- Further efficiency improvement is underway using some new techniques including HF dry etching for high-quality surface passivation.
Special thanks to our co-workers:

Peter Venema, Henri Geerman, Malcolm Harris, Ronald Naber
(Tempress Systems, Solar Process Development Group)

Bart Geerligs, Yuji Komatsu, Teun Burgers, Nicolas Guillevin
(ECN, Silicon Photovoltaics)

Cindy Hu, Faye Li, Mark Song, Zhang Wei
(Yingli Solar, Technology Team)
Thank you for your attention!