Fused Quartz in the PV Market

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Materials Group Manager, Technology
Quartz and Ceramics
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Agenda

• Introduction to Momentive Performance Materials
• Quartz Properties
• Fused Quartz within PV value chain
  – Fused Quartz Crucibles
• Development Example
• PV market challenges for fused Quartz
Acquisition Announcement:
Apollo Management, L.P. acquires GE’s Advanced Materials business unit on December 4, 2006

GE Advanced Materials

Silicones
Quartz & Ceramics
Sealants & Adhesives
GE Toshiba Silicones
GE Bayer Silicones
Momentive Performance Materials:
A global leader in a range of high-technology materials solutions

<table>
<thead>
<tr>
<th>Silicons</th>
<th>Quartz</th>
<th>Ceramics</th>
<th>Sealants &amp; Adhesives</th>
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</thead>
<tbody>
<tr>
<td>RTV’s, Elastomers</td>
<td>High-purity fused quartz</td>
<td>Ceramic materials</td>
<td>Silicone and acrylic sealants</td>
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<tr>
<td>Silanes, Resins and Specialties</td>
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<td>Specialty Fluids</td>
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<tr>
<td>Urethane Additives</td>
<td></td>
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<tr>
<td>Sealants &amp; Adhesives</td>
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**Revenues:** $2.5B in 2006

**Employees:** ~5,000

**Patents:** 2,000+
Major Worldwide operations:

**Europe**
- Belgium
  - Antwerp

- Germany
  - Geesthacht
  - *Leverkusen – EMEA HQ*

- Italy
  - Termoli

- The Netherlands
  - Bergen op Zoom

- U.K.
  - Lostock

- Switzerland
  - Geneva

**Asia**
- China
  - Shanghai
  - Shen Zhen
  - Songjiang
  - Wuxi

- India
  - Bangalore

- Japan
  - Kobe
  - Kozuki
  - Ohta
  - *Tokyo – Asia Pacific HQ Gotemba*

- Singapore
  - Singapore

- Thailand
  - Rayong

**Americas**
- Canada
  - Pickering, ON

- United States
  - Chino, CA
  - Euless , TX
  - *Charlotte, NC- Sealants & Adhesives HQ Garrett, IN*
  - **Newark, OH**
    - New Smyrna Beach , FL
  - **Richmond Heights, OH**
    - Sistersville, WV
    - *Strongsville, OH - Quartz HQ*
    - South Charleston WV
    - Tarrytown, NY
    - *Waterford, NY – Americas HQ Willoughy, OH*
    - *Wilton, CT – WHQ*

- Brazil
  - Itatiba
**Market Approach**

- **New to Momentive**
  - Projector Lamp
  - SC Crucibles
  - SC Tubing
  - Lamp

- **Application Derivatives**
- **Innovative Technology**
- **Product Derivatives**
Why Fused Quartz?

• Unique material
  - Purity – typically >99.995%
  - High Temperature
    • Softening – 1683 C
    • Annealing – 1220 C
    • Strain – 1120 C
  - Low CTE – 0.55 ppm/C
  - Chemically stable
    • Stable against most acids and bases
    • Slow dissolution into Si melt
  - Versatile
    • Accepts dopants, secondary phases
    • Ground, polished, welded
    • Stable glass
Fused Quartz Transmission

- 214, 124 - fused quartz
- 219, 254 doped quartz for UV blocking
- 021 - synthetic silica
Typical Sand Purity - ppm

<table>
<thead>
<tr>
<th>Element</th>
<th>214</th>
<th>021</th>
<th>Element</th>
<th>214</th>
<th>021</th>
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<tbody>
<tr>
<td>Al</td>
<td>14</td>
<td>&lt;0.2</td>
<td>Li</td>
<td>0.6</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>B</td>
<td>&lt;0.2</td>
<td>&lt;0.05</td>
<td>Mg</td>
<td>0.1</td>
<td>&lt;0.05</td>
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<tr>
<td>Ca</td>
<td>0.4</td>
<td>&lt;0.05</td>
<td>Na</td>
<td>0.7</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>P</td>
<td>&lt;0.2</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Fe</td>
<td>0.2</td>
<td>&lt;0.05</td>
<td>Ti</td>
<td>1.1</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>K</td>
<td>0.6</td>
<td>&lt;0.05</td>
<td>Zr</td>
<td>0.8</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

- Internally beneficiate sand to produce higher purity product
PV Technologies

Source: PHOTON International March 2008
Fused Quartz in PV Industry

Polysilicon Prod.

Monocrystalline Si Crucibles

Diffusion Furnaces

Fabricated Parts

Tubes and Rods

Solids

Raw Material

INGOT

WAFER

Cell

Module

INGOT GROWN

INGOT SLICED INTO WAFFER

WAFFER PROCESSING

INTERCONNECTS/PACKAGING

Polycrystalline Silicon Crucibles

Quartz IR heaters

Vesuvius web site

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Other applications of fused silica in PV market

• Thin Film Processes
  – Qtz rollers
    • Substrate handling, annealing
    • Preserve flatness and purity

• Ribbon Si
  – Qtz. Crucibles

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Momentive into PV...

- Momentive historical leader in Semiconductor Quartz Market
- Monocrystalline PV market largely adopted SC process, equipment
- Momentive has grown to be the #1 supplier to monocrystalline crucible market
Momentive Growth with PV

• Rapid growth of PV market driven by
  – Environmental concerns
  – Government feed-in tariff

• Our ability to capitalize and grow
  – Well known to many SC grade Silicon wafer producers
  – PV processes compatible with Semi processes and distribution channels
  – Capacity within our manufacturing system
  – Commercial team that recognized potential
PV Market Challenges

• Polysilicon supply and cost implications
  – Tight supply increases price driving manufacturers to more efficient Si processes
    • Drive to thin-film PV (up to 12% of production 2007)
  – Drives price-performance equation for crucibles from price towards performance – higher yield per lb of Si melted
    • Pushes customers to value high quality crucibles that give good attempts, yield, low defects, etc.

• Demand
  – Feed-in tariff by various governments as social/environmental
  – Investment Tax credit
  – Alternatives (Wind, solar-thermal, C-sequestration, Oil&NG etc.)
Mono-Si Crucible

- Fused Crucible is complex “composite” structure
- Dimensions, purity, bubble structure, defects all must be controlled even after many 10’s of hours at >1420C
Crucible Manufacture

Arc fusion
“Lighting in a bottle”
Several hundred kW
**Crucible Customer Needs**

- **Purity**
  - ~1-2 mm of SiO$_2$ will dissolve into Silicon melt during crystal draw
  - Impurities act as electronic defects, dopants
  - Oxygen incorporation impacts silicon wafer properties

- **Bubbles/inclusions**
  - Release particles into the melt that end up in the crystal affecting single crystal and zd yield

- **Geometry**
  - unique dimensions for heaters, graphite assemblies, thermal loads, etc. defined by customer

- **Material Properties**
  - Viscosity of base quartz (OH, impurities)
  - Devitrification and crystal growth of quartz on heating

- **Value – Cost of Ownership**
Product Development Example

• Cost of Ownership
  – Price of Crucible
  – Quality of resulting crystal
  – Amount of silicon that can be pulled
    • Larger, longer crystals
    • Recharge hot crucible
      – Requires recharge method and materials
      – Very long life, stable crucible - slumping
Crucible Improvement - Reduce Slumping

• Potential approaches
  – Reduce Temperature
    • Fixed at melting point of silicon
  – Raise viscosity of bulk glass
    • Difficult to do for pure silica
  – Crystallize quartz
    • Increase nucleation and growth of cristobalite
    • Form a glass-ceramic in-situ
Crucible Improvement – Reduce Slumping

• Constraints
  – Cannot impact crystal quality
    • High segregation coefficient in solid/melt
    • Minimal donor/acceptor impact
    • Shouldn’t form insoluble silicide, other phase that could impact crystal structure
  – Cannot reduce viscosity of quartz – melt leaks

• Small list of candidate elements
  – Trials with customers determined that Ba was nearly ideal candidate

• Application method?
  – ID or OD surface
  – Bulk glass
  – Within Si melt

\[
\frac{C}{C_0} = k(1-g)(k-1)
\]

\[k = \text{segregation coefficient}\]
\[g = \text{fraction frozen}\]

<table>
<thead>
<tr>
<th>Element</th>
<th>(k)</th>
</tr>
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<tbody>
<tr>
<td>B</td>
<td>0.8</td>
</tr>
<tr>
<td>P</td>
<td>0.35</td>
</tr>
<tr>
<td>Mo</td>
<td>4.3 \times 10^{-8}</td>
</tr>
<tr>
<td>Ba</td>
<td>&lt; 10^{-8}</td>
</tr>
</tbody>
</table>
Crucible Improvement - Reduce Slumping

- Selected method was a Ba coating applied to crucible surfaces
  - Used for many years in SC crystal growth
  - Adopted very well by PV industry
- Helped enable multi crystal production

Reduced “Cost of ownership” only obtained by strong supplier and customer interactions
Threats to Fused Quartz in PV

• Alternate Technologies
  – Thin Film PV
  – Polysilicon production method
    • Lower temp polysilicon bead chemistry
    • Newer metallurgical to solar grade process

• Alternate Materials
  – Crucibles
    • Graphite – edge defined film growth, ribbon
  – Furnace Boats
    • SiC or Si for wafer boats, furnace components
Additional Demands by PV market

• Price
  – Continued pressure on Crucible price ($/W)

• Performance
  – Longer life, higher yields, fewer defects

• Dimensions
  – Larger crucibles
  – Heavier wall
  – Unique shapes
How do we provide continued reductions in “Cost of Ownership”

(But it will require customer/supplier partnerships)
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