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Fused Quartz in the PV Market

Martin Panchula
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

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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

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Momentive Performance Materials:

A global leader in a range of high-technology materials solutions

Silicones	Quartz	Ceramics	Sealants & Adhesives
RTV's, Elastomers	High-purity fused quartz	Ceramic materials	Silicone and acrylic sealants
Silanes, Resins and Specialties			
Specialty Fluids			
Urethane Additives			
Sealants & Adhesives			

Revenues: $2.5B in 2006

Employees: ~5,000

Patents: 2,000+

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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

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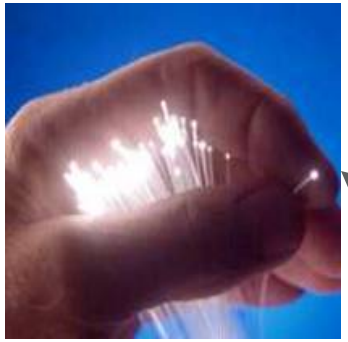
Momentive: Quartz and Ceramics Div.

pBN Crucibles & Sources

BN Powder

Advanced Ceramics



Fiber optics

Core
Lighting
Semiconductor

Photovoltaic

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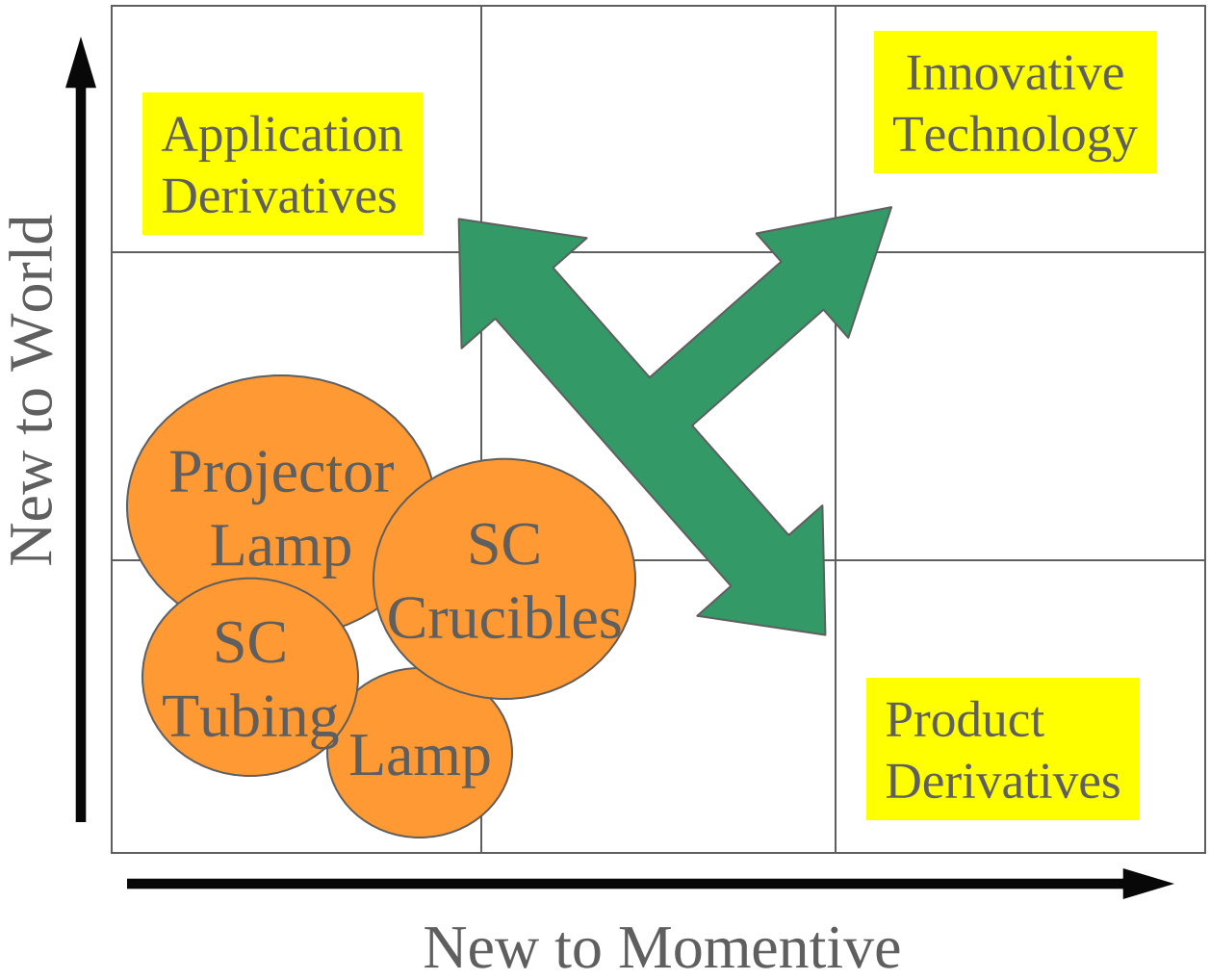
Market Approach



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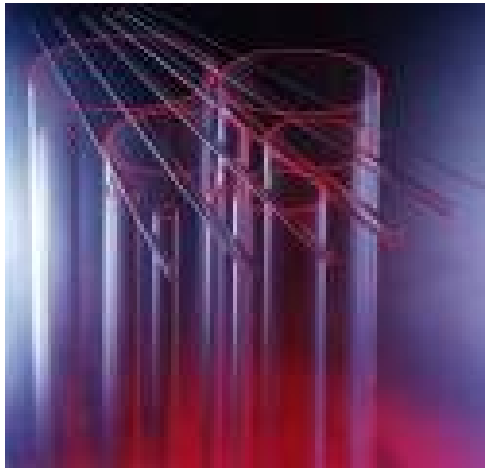
Why Fused Quartz?

- 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



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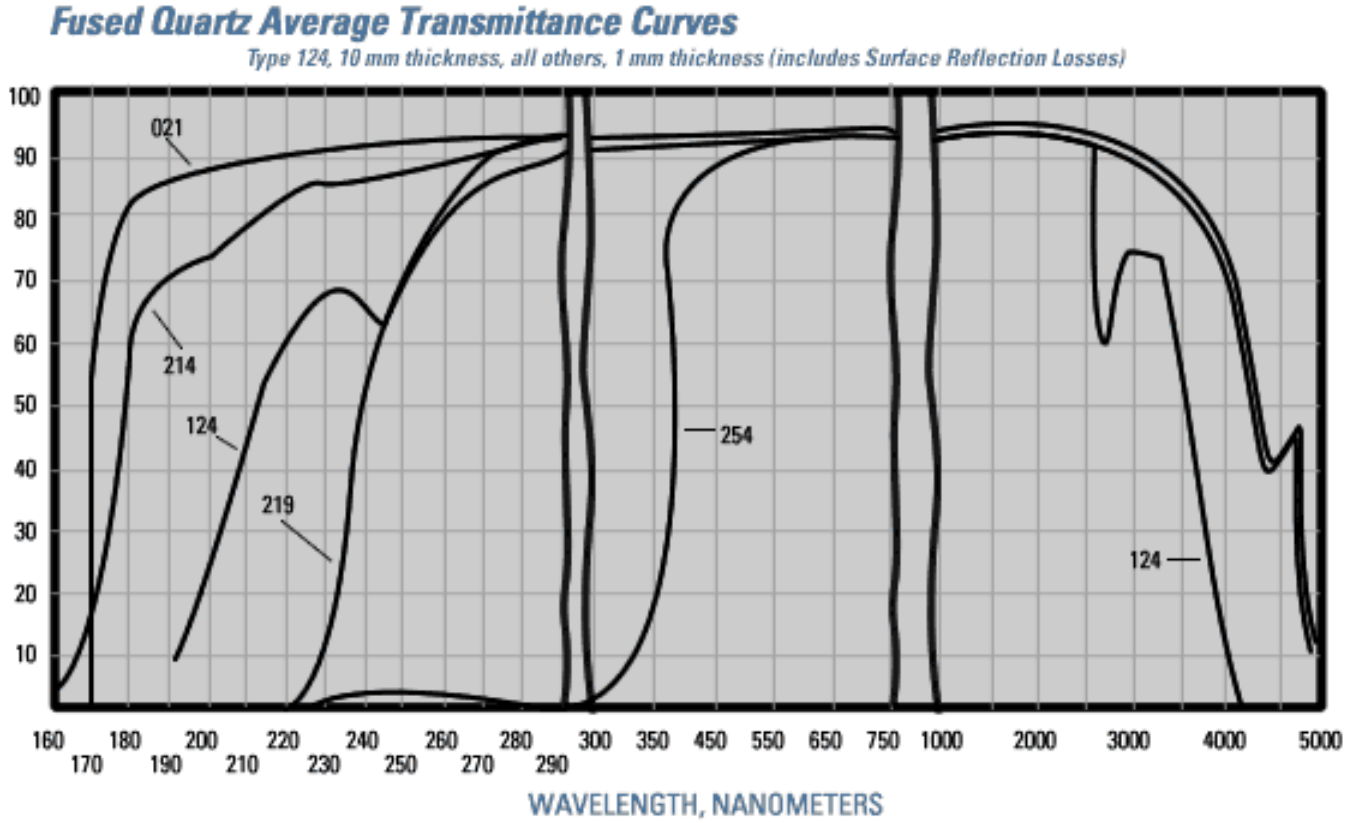
Fused Quartz Transmission



- 214, 124 – fused quartz
- 219, 254 doped quartz for UV blocking
- 021 – synthetic silica

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Typical Sand Purity - ppm

Element	214	021	Element	214	021
Al	14	<0.2	Li	0.6	<0.05
B	<0.2	<0.05	Mg	0.1	<0.05
Ca	0.4	<0.05	Na	0.7	<0.05
Cr	<0.05	<0.05	P	<0.2	<0.05
Fe	0.2	<0.05	Ti	1.1	<0.02
K	0.6	<0.05	Zr	0.8	<0.05

- Internally beneficiate sand to produce higher purity product

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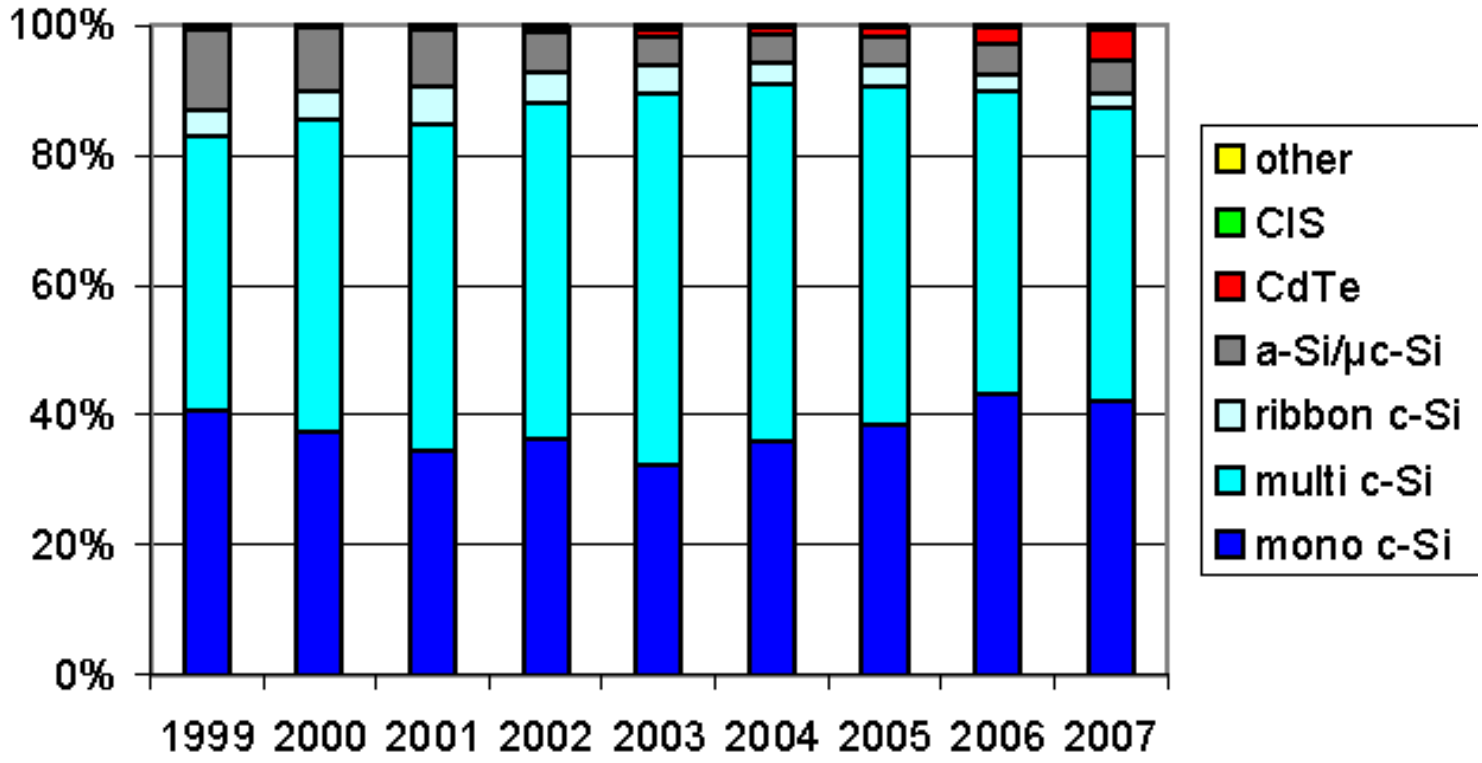
PV Technologies



Source: PHOTON International March 2008

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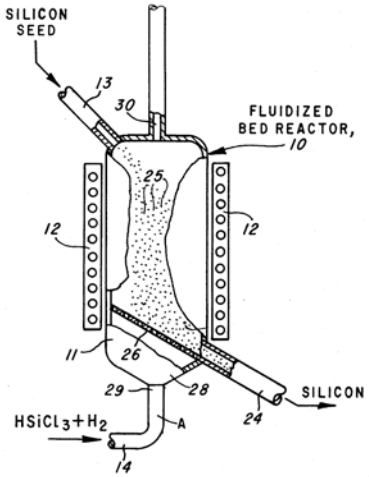
Fused Quartz in PV Industry

Polysilicon Prod.



Monocrystalline Si Crucibles

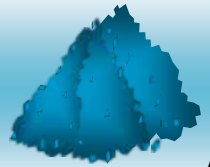
Diffusion Furnaces

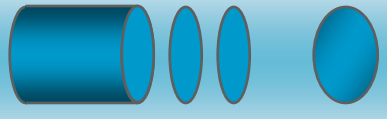
Fabricated Parts

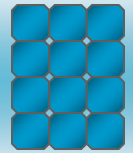
Tubes and Rods

Solids

Raw Material → *INGOT GROWN* → **INGOT** → *INGOT SLICED INTO WAFER* → **WAFER** → *WAFER PROCESSING* → **Cell** → *INTERCONNECTS/ PACKAGING* → **Module**



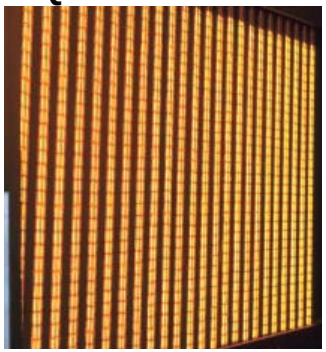




Polycrystalline Silicon Crucibles

Vesuvius web site

Quartz IR heaters



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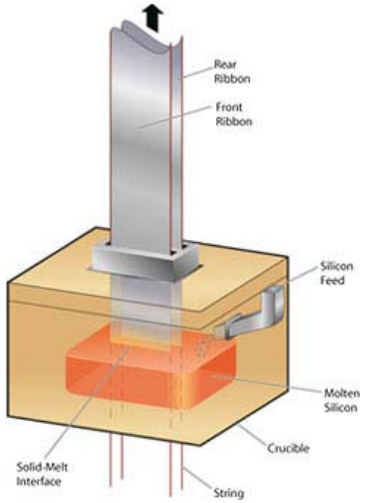
Other applications of fused silica in PV market

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

- Ribbon Si
  - Qtz. Crucibles



Evergreen Solar

String Ribbon - Evergreen

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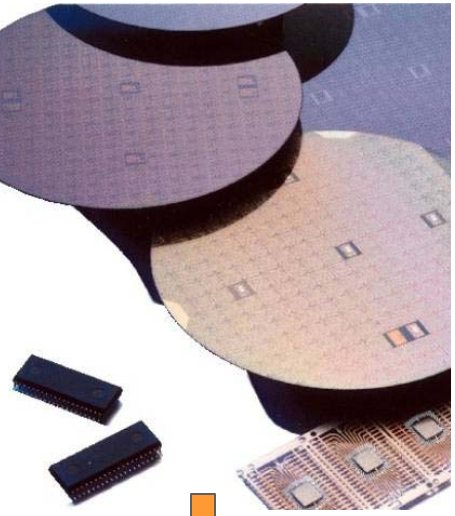
Momentive into PV…

- 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



Suniva

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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

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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.)

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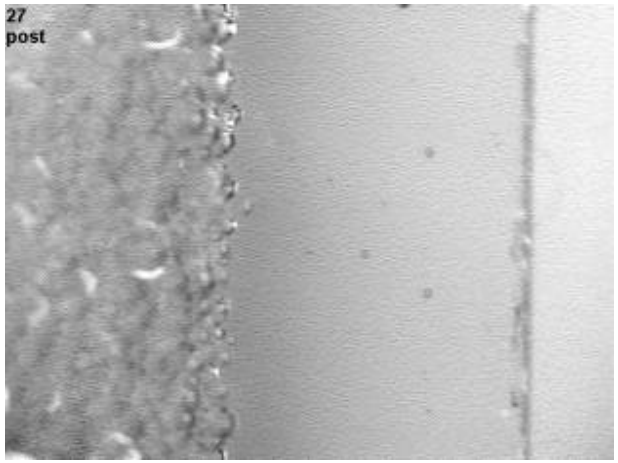
Mono-Si Crucible

Czochralski Growth

Fused Quartz Crucibles

Crucible Wall



Bubble Composite Layer

Bubble Free Layer

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

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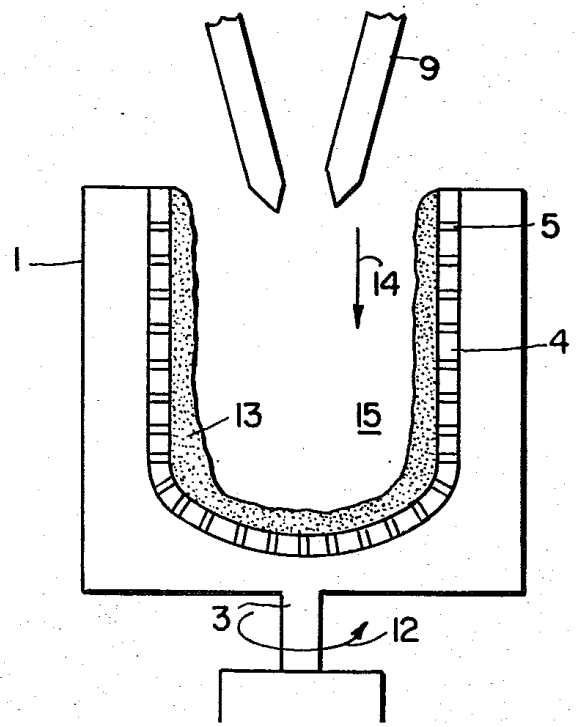
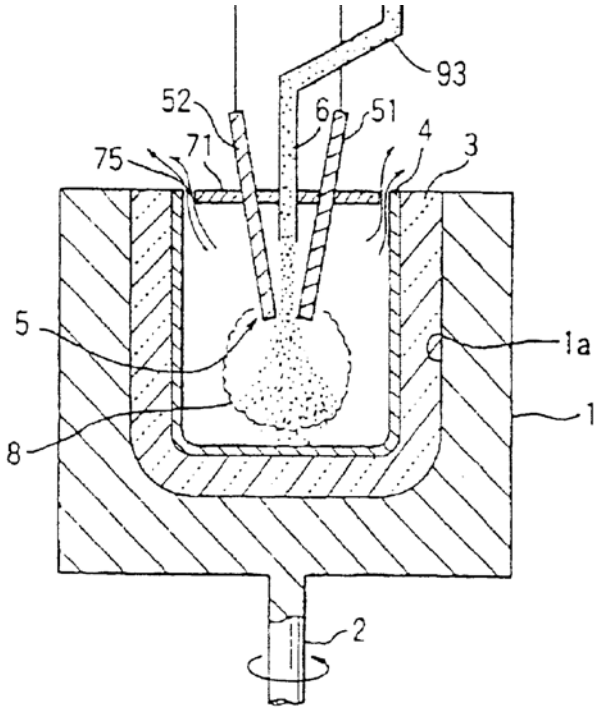
Crucible Manufacture

Arc fusion

"Lighting in a bottle"

Several hundred kW





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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

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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

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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

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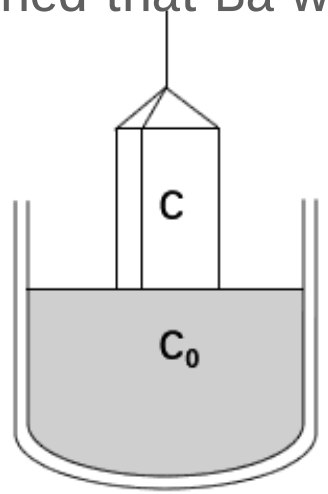
Crucible Improvement – Reduce Slumping

- 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



$C/C0 = k(1-g)(k-1)$

k = segregation coefficient
g = fraction frozen

Element	k
B	0.8
P	0.35
Mo	4.3 x 10-8
Ba	< 10-8

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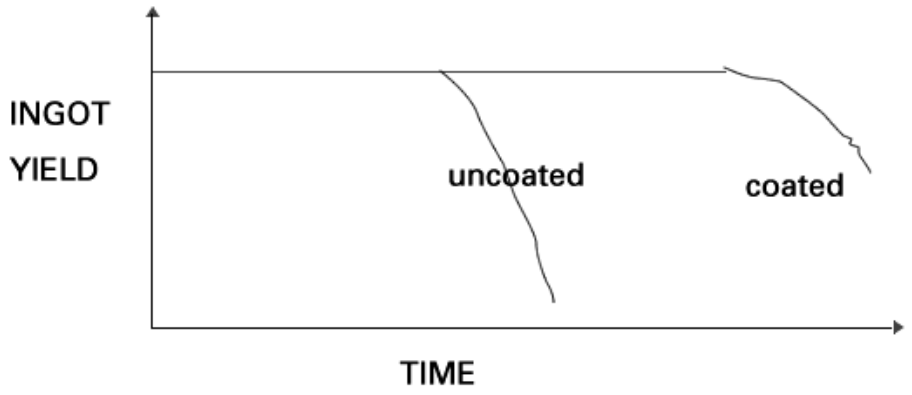
Crucible Improvement – Reduce Slumping

- 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

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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

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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

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How do we provide continued reductions in “Cost of Ownership”

(But it will require customer/supplier partnerships)

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