Leveraging Glass for Advanced Packaging and IoT

Aric Shorey
Commercial Technology Manager
Semiconductor Glass Products

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Corning Incorporated Overview

**Founded:**
1851

**Headquarters:**
Corning, New York

**Employees:**
35,000 worldwide

**2015 Sales:**
9.8 billion

**Fortune 500 Rank (2015):**
297

- Corning is one of the world’s leading innovators in materials science. For more than 160 years, Corning has applied its unparalleled expertise in specialty glass, ceramics, and optical physics to develop products that have created new industries and transformed people’s lives.

- Corning succeeds through sustained investment in R&D, a unique combination of material and process innovation, and close collaboration with customers to solve tough technology challenges.
We believe the “Glass Age” is here and will help enable a connected world

• Our passion for innovation drives our vision for the future of glass technologies

• Highly engineered glass, with companion technologies, will help shape our world

• We are committed to achieving this vision through our ongoing focus on research and development

• Watch and experience a world enabled by glass...
Corning has a history of delivering keystone technologies through collaboration with our customers.

- 1879: Glass envelope for Thomas Edison’s light bulb
- 1915: Heat-resistant PYREX® glass
- 1934: Processes for mass producing the television bulb
- 1947: Glass ceramics
- 1952: Fusion overflow process
- 1964: First low-loss optical fiber
- 1970: Ceramic substrates for automotive catalytic converters
- 1978: Active matrix liquid crystal display (LCD) glass
- 1982: Thin, lightweight cover glass with exceptional damage resistance
- 2007: Ultra-bendable fiber
- 2006: Environmentally conscious LCD glass
- 2012: Ultra-slim, flexible glass for thin and lightweight applications
- 2013: First EPA-registered antimicrobial cover glass

**Timeline:**
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**Corning Technologies:**
- Dow Corning silicones
- Corning fused silica
- Corning silicones
## Corning Market Segments and Additional Operations

<table>
<thead>
<tr>
<th>Display Technology</th>
<th>Telecom</th>
<th>Environmental Technologies</th>
<th>Life Sciences</th>
<th>Specialty Materials</th>
<th>Other Products and Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCD Glass Substrates</td>
<td>Optical Fiber and Cable</td>
<td>Emissions Control Products</td>
<td>Cell Culture and Bioprocess</td>
<td>Corning® Gorilla® Glass</td>
<td>Emerging Innovations Equity Companies</td>
</tr>
<tr>
<td>Glass Substrates for OLED and high-performance LCD platforms</td>
<td>Optical Connectivity Solutions</td>
<td>Light-duty gasoline vehicles</td>
<td>Drug Discovery</td>
<td>Display Optics and Components</td>
<td>Cormetech, Inc.</td>
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<tr>
<td></td>
<td>Wireless Distributed Antenna Systems</td>
<td>Light-duty and heavy-duty on-road diesel vehicles</td>
<td>ADME/Tox</td>
<td>Optical Materials</td>
<td>Dow Corning Corp.</td>
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<tr>
<td></td>
<td>Optical Cables for Consumer Networks</td>
<td>Heavy-duty non-road diesel vehicles</td>
<td>Genomics</td>
<td>Semiconductor materials</td>
<td>Eurokera, S.N.C.</td>
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<tr>
<td></td>
<td>Copper Connectivity Components</td>
<td>Stationary</td>
<td>Chemistry</td>
<td>Specialty fiber</td>
<td>Samsung Corning Advanced Glass, LLC (SCG)</td>
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<td></td>
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<td></td>
<td>Microbiology</td>
<td>Polarcor™</td>
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<td>General Laboratory Products</td>
<td>Optical Systems</td>
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<td>Aerospace and Defense</td>
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<td>Specialty Glass</td>
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<td>Laser Technologies</td>
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Deep Core Technology Capabilities – Science & Engineering

Corning’s strength is based on a broad portfolio of core technologies… and the ability to integrate them.

- Inorganic Materials and Processes
- Modeling and Simulation
- Organic Materials and Processes
- Biochemical Sciences and Processes
- Engineering: Materials, Optical, Process, Chemical, Electrical, Mechanical
- Optical Physics and Network Technologies
- Materials Characterization and Processes
- Network Integration and Connectivity Research
- Thin Films and Surface Sciences
Industry trends will require new packaging breakthroughs

We want our smart phones to do a lot...all at the same time
- Increased functionality, RF is key (cellular, WiFi, Bluetooth)
  - Talk
  - Text
  - Email
  - Internet
  - Apps
  - Video
  - Music
  - Health and environment monitoring (ie: sensors)

RF bands moving to higher frequency
- Phone roadmap
  - Phone and WiFi simultaneously
  - 5G likely >20 GHz?
  - Interest in other applications at 70 – 100+ GHz

Power consumption
- Increased battery life = less charging = happy consumer

Thinner form factor
Why 3DIC??

3DIC Advantages

*Shorter line length → lower power use; smaller package*

- **Smaller Package Size**: 35%
- **Improved Power Consumption**: 50%
- **Higher Bandwidth**: 8x

**Conventional Package-on-Package Solution** → **Direct chip connection using TGV**

Source: Samsung
Glass is a good fit for the growing RF market

- RFFE market approaching $20B in next few years
- Market growth driven by # bands
- Outlook flat for discrete devices, significant growth in integrated modules

<table>
<thead>
<tr>
<th>CARRIER</th>
<th>NETWORK</th>
<th>3G BANDS</th>
<th>3G FREQUENCIES (MHz)</th>
<th>4G LTE BANDS</th>
<th>4G LTE FREQUENCIES (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERIZON</td>
<td>CDMA</td>
<td>0, 1</td>
<td>650, 1900</td>
<td>2, 4, 13</td>
<td>1900, 1700, 700 c</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>GSM/UMTS/HSPA+</td>
<td>2, 5</td>
<td>1900, 850</td>
<td>2, 4, 17</td>
<td>1900, 1700, 700 abcd, 700 bc</td>
</tr>
<tr>
<td>T-MOBILE</td>
<td>GSM/UMTS/HSPA+</td>
<td>2, 4</td>
<td>1900, 1700/2100</td>
<td>2, 4, 12</td>
<td>1900, 1700, 700, 700 a</td>
</tr>
<tr>
<td>SPRINT</td>
<td>CDMA</td>
<td>10, 1</td>
<td>800, 1900</td>
<td>25, 26, 41</td>
<td>1900 g, 850, 2500</td>
</tr>
<tr>
<td>US CELLULAR</td>
<td>CDMA</td>
<td>0, 1</td>
<td>650, 1900</td>
<td>5, 12</td>
<td>850, 700 ab</td>
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Source: Mobile Experts, Corning Analysis
Corning Semiconductor Glass Products has two complimentary product lines:

<table>
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<tr>
<th>Carrier</th>
<th>Si Thinning</th>
<th>Fan-out (FOWLP)</th>
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<tr>
<th>TGV</th>
<th>Radio Frequency Front End (RF)</th>
<th>Interposer</th>
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<tr>
<td></td>
<td>Filters, antennas, switches in mobile phones, telecom infrastructure, medical equipment</td>
<td>Re-routes connection between layers inside a semiconductor package (ie: chip) using through vias (ie: holes)</td>
</tr>
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Corning Restricted
Glass provides meaningful value for our customers

**Electrical Properties**
- **Low Electrical Loss**
  - Improved signal isolation
  - Lower insertion loss = less power or longer battery life

**CTE Adjustability**
- **Capability to deliver multiple CTEs**
  - Improves reliability
  - Offer range of CTEs from 2.7-12.4

**Surface Quality**
- **Enables fine line spacing**
  - Smaller package size
  - Fewer metal layers, resulting in cost savings

**Stiffness**
- **Glass is stiffer compared to organics**
  - Better flatness enables fine line spacing

**Form Factor**
- **Forming at thickness + panels**
  - Better yield/cost
  - Better quality and efficiency in panels
Corning offers TGV with precision holes; product attributes are a good fit for both RF and interposer applications

<table>
<thead>
<tr>
<th>Glass Size:</th>
<th>Wafers: 100mm → 300mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panels:</td>
<td>&gt; 500x500 mm</td>
</tr>
<tr>
<td>Thickness:</td>
<td>~100µm → 700µm</td>
</tr>
<tr>
<td>Type of Holes:</td>
<td>Blind-Holes, Thru-Holes</td>
</tr>
<tr>
<td>Pattern:</td>
<td>Customer X,Y Location</td>
</tr>
<tr>
<td>Aspect Ratio:</td>
<td>~3-10:1 (in part dictated by metal)</td>
</tr>
<tr>
<td>Pitch:</td>
<td>Minimum 2x Hole Diameter</td>
</tr>
<tr>
<td>Hole Diameter:</td>
<td>100µm → 20µm → 10µm</td>
</tr>
</tbody>
</table>
Our glass maintains strength throughout TGV process

Corning’s advanced hole fabrication process retains the inherent strength of the glass substrate

Ring on ring results for glass samples with and without holes. The strength of glass with holes brackets the strength of glass without holes.

Picture of ROR broken glass sample with 5x5 via array. Note that breakage did not originate at via array.
Demonstrated successful metallization of glass vias with several industry partners and are working on real projects.

**Paste Filling**

- Paste filled TGV 30µm via 100µm thick
- 60µm via void free 300µm thick glass
- 80µm via void free 300µm thick glass

**Panel Processing**

- <3µm L/S 370x470mm (130µm thick) with ~100,000 holes
- Atotech’s double side plating process can fill through holes in panel format with low overburden

**Sample Projects**

- TGV for RF Applications
- Low Cost Glass Interposer
- General Purpose Glass Modules

**TOPPAN**
High Q inductor/capacitor prototypes demonstrated in conjunction with QCOM and DNP

- Completed LC Network
- High Q inductance from 3D Solenoid inductor
- Capacitance achieved through MIM structure
Corning’s ALoT Technology can Provide Substantial Opportunity for Process Simplification and Cost Improvements

**Standard Temporary Bond**

- Blind vias
- Copper fill
- Add carrier
- Backgrind
- De-bond carrier

**Corning’s ALoT**

- Willow with holes on a carrier
- Copper fill
- Peel off thin interposer
Thin Glass Handling – Exciting Performance Demonstration

- Image of a lot after CMP processing to remove the Cu overburden left by TGV filling
- No edge chipping was seen after CMP

OM and SEM image of TGVs after electroplating and Cu overburden removal
< 0.5 um Cu/Glass Planarity after Backside De-bond – Without Polish

• Some small “trench” around perimeter of via
• Recent improvements in bonding will improve
• TGV < 30 um likely

SEM of metallized backside of via
Improvements in bonding will help
Glass helps enable panel-level packaging, which potentially enables significant process savings for our customers.

508 x 508mm glass panel

Targeted CTE of glass improves reliability of package (20x20mm)

Corning has a strong portfolio of emerging innovations

- **Corning® Gorilla® Glass** for new applications
  - Creating new design possibilities for architectural, automotive, and other transportation applications

- **Corning® Willow® Glass**
  - Manufacturing glass at thicknesses that enable the glass to be flexed provides new opportunities for:
    - Architectural and consumer electronic applications
    - A thin and hermetic barrier for solar cells

- **Specialty Surfaces**
  - Developing surfaces such as antimicrobial glass, anti-reflective, and easy-clean coatings

- **Ceramic Adjacencies**
  - Identifying new applications for honeycomb structures for advanced separations, supported catalysis, or high-temperature heat exchange
Flexible Glass Enables High-Quality Optics and Electronics

- Substrate integrates designs, materials, and processes
  - Glass enables improved resolution, registration, performance, and lifetime
    - Thermal and dimensional stability
    - Excellent optical and surface properties
    - Chemical compatibility
- Corning® Willow® Glass is compatible with sheet-fed and R2R processes
  - Thickness ≤200mm
  - Optimized for device substrate and hermetic barrier applications
- Demonstrated solution processes: gravure, screen, ink jet, slot die, gravure-offset
- Flexible glass enables new applications not possible before

Flexible Glass Sheets
Flexible Glass Web

Substrate choice critical for device fabrication and performance
Continuous device fabrication has been demonstrated using flexible glass.
Demonstrated R2R Gravure-Offset Printing on Flexible Glass
Ag-ink metal mesh structures printed on glass web and sheets

- Printing on 500mm-width glass web
- Line-widths <10 μm
- Line thickness ≤ 4 μm
- Printing speed ≤ 100 mm/s
- Linewidth variation ≤ ±20 %

23-inch Touch Sensor Pattern
Gravure-Offset Printed Functional Devices on Flexible Glass
Demonstrated 10GHz antenna and metal-mesh touch sensor performance

- 10GHz Yagi-Uda antenna fabricated
- Print 1-2 μm Cu reduction seed layer
  - UV cure and 180°C thermal treatment
- Electroless plate 5 μm Cu layer

Flexible Glass Antenna  Radiation Pattern (in-plane)

- 7-inch touch sensor fabricated
- Single-layer, single-side device
- Linewidth = 13.6 μm
- Sheet resistance = 55 Ω/sq
- Transmission = 85% (no AR coatings)

Singulated Device

Connectorized Device

Multi-Point Touch Sensor
New process for thin glass with excellent electrical properties

Breakthrough process for thin fused silica sheet
Revolutionary thickness achievement
100 micron thick silica equivalent to thickness of one dollar bill

- 50-300 microns thin (nominal 100 microns today)
- High softening temperature (>1200°C)
- High light transmission (>90% over broad spectral range)
- Low dielectric loss ($2 \times 10^{-4}$ at 10 GHz)
Summary

• IoT is exciting for the proliferation of sensors and devices

• Innovative packaging solutions will help address challenges with incumbent materials, technologies

• Corning has a number of materials such as glass, glass ceramics, ceramics and other processes that will provide these solutions

The best solutions will come through close collaboration
CORNING