CORNING

Leveraging Glass for Advanced Packaging and IoT

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Semiconductor Glass Products

21 April 2016

Corning Incorporated Overview

Founded:
1851

Headquarters:
Corning, New York

Employees:
35,000 worldwide

2015 Sales:
9.8 billion

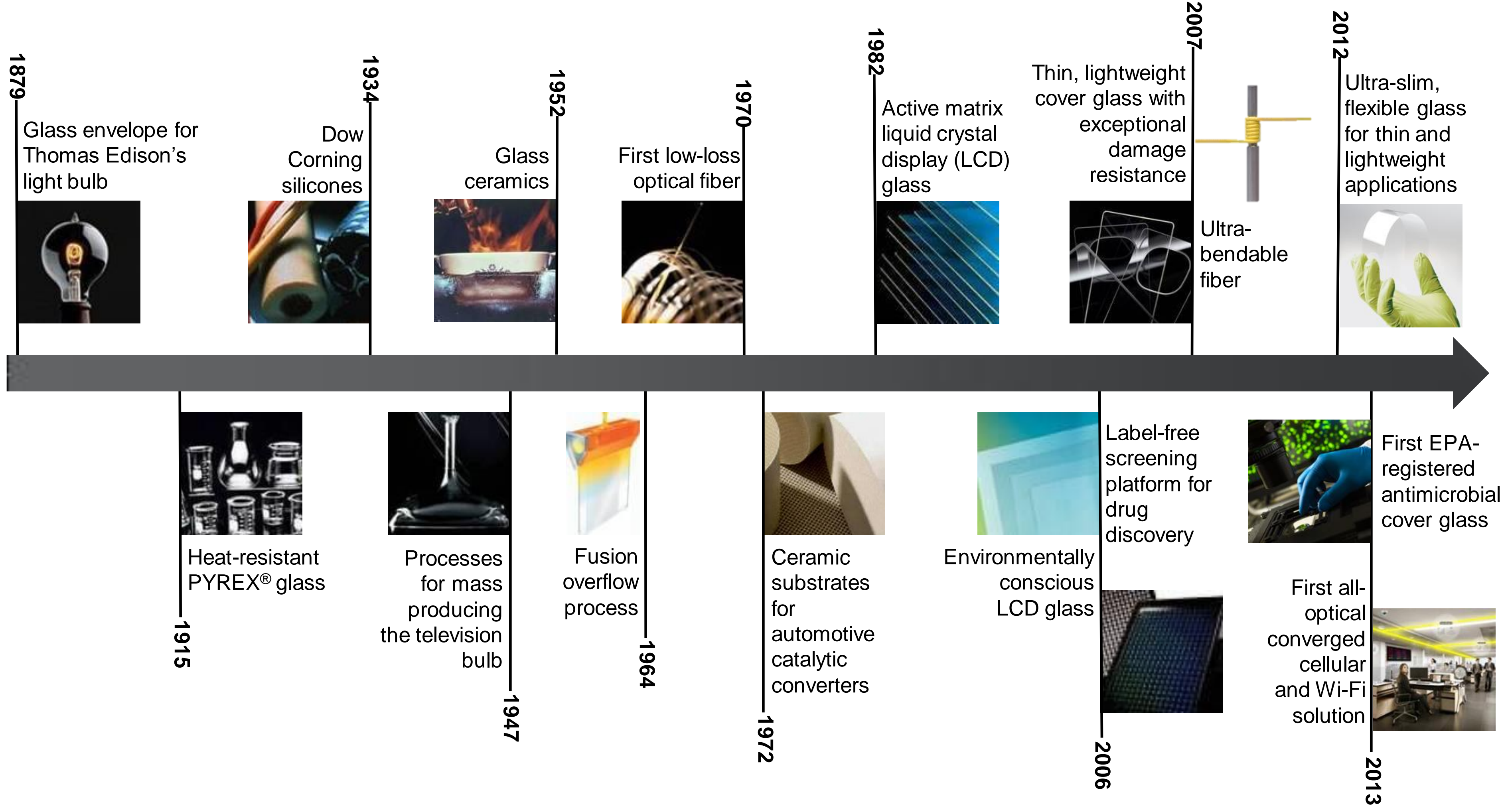
Fortune 500 Rank (2015):
297

- Corning is one of the world's leading innovators in materials science. For more than160 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.

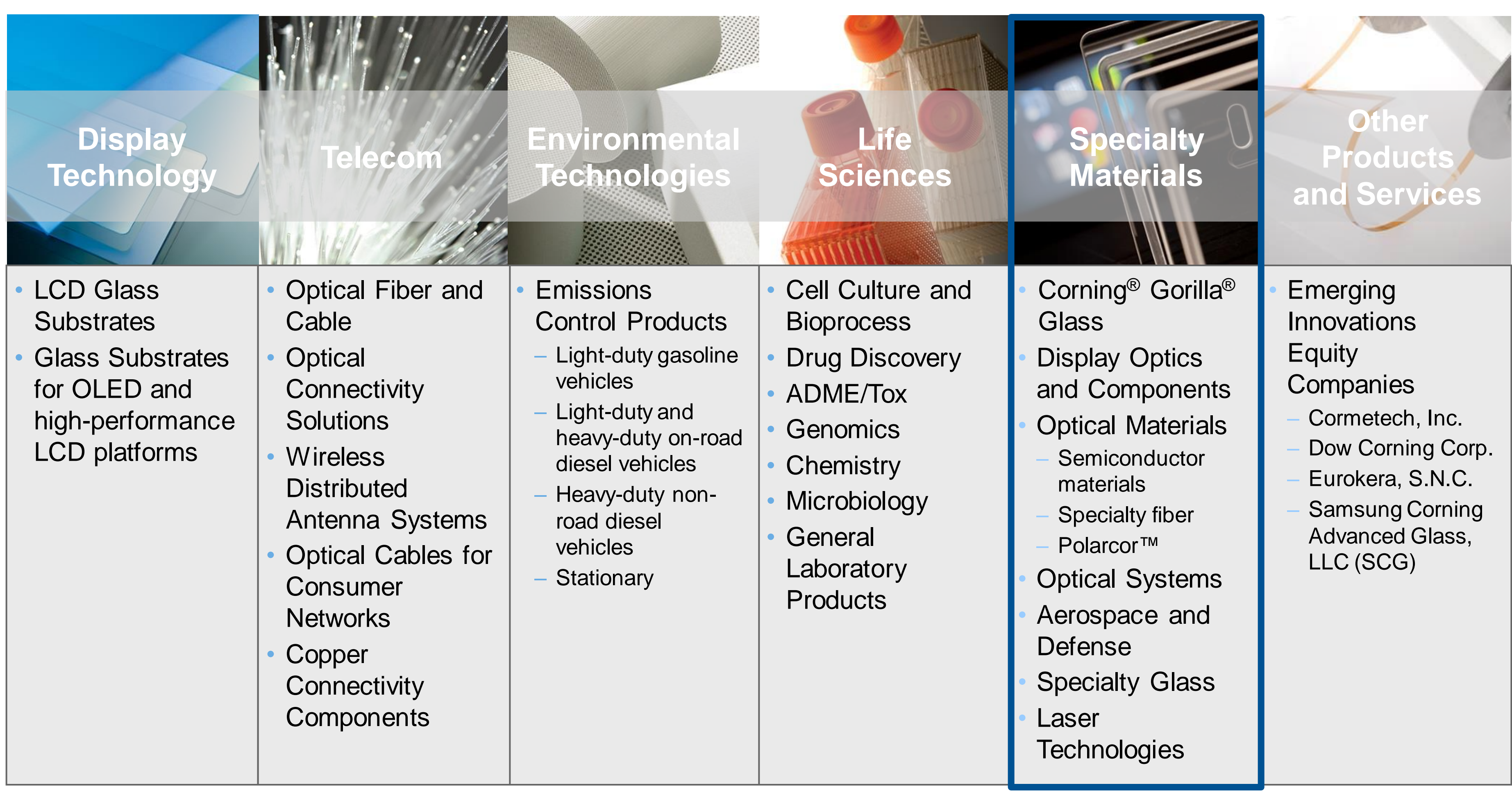
We believe the “Glass Age” is here and will help enable a connected world

- 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



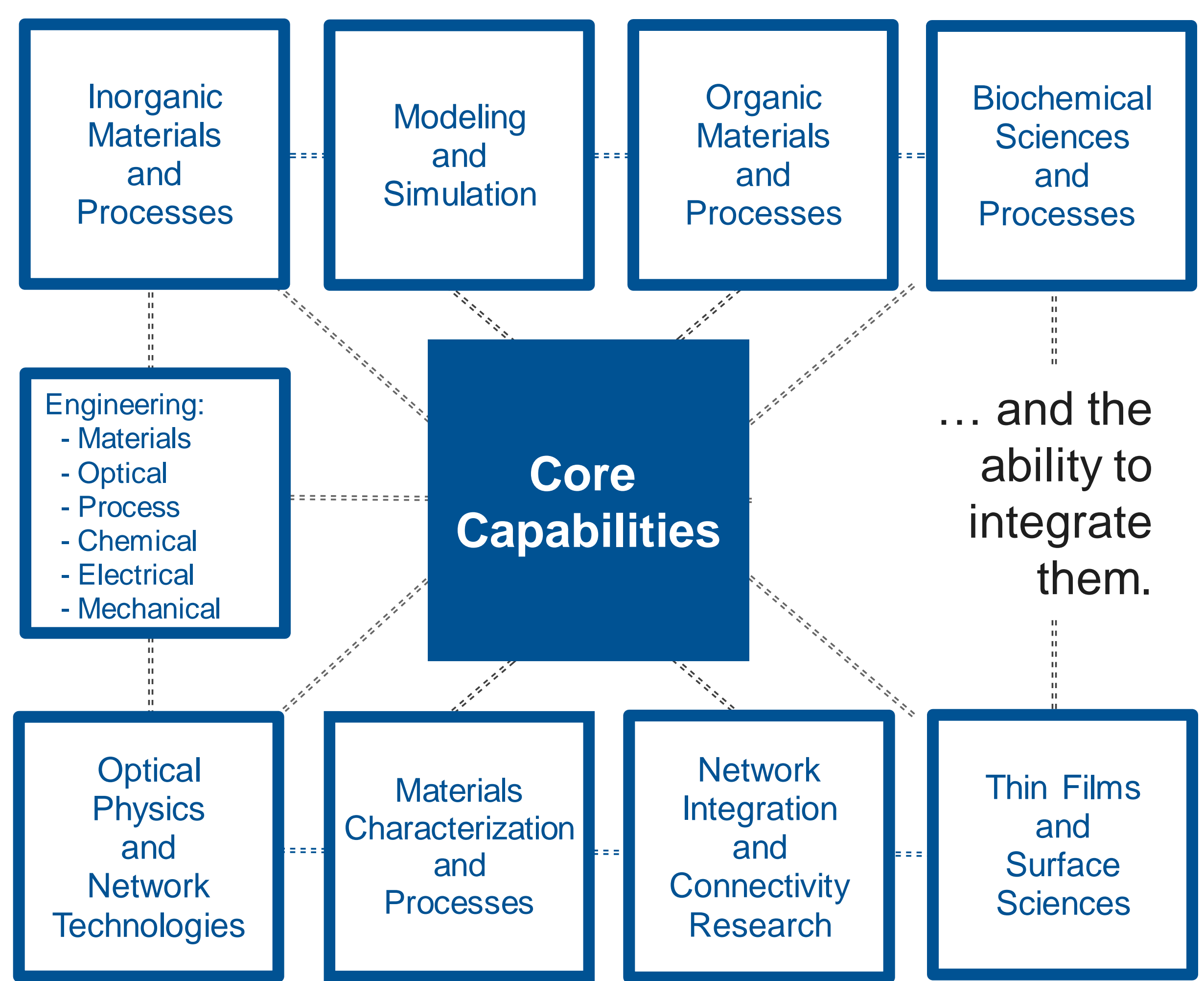
Corning Market Segments and Additional Operations



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

Deep Core Technology Capabilities – Science & Engineering

Corning's strength is based on a broad portfolio of core technologies…



… and the ability to integrate them.

Industry trends will require new packaging breakthroughs

We want our smart phones to do a lot…all at the same time

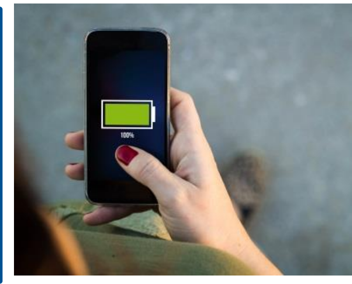
- Increased functionality, RF is key (cellular, WiFi, Bluetooth)
  - Talk
  - Text
  - Email
  - Internet
  - Apps
  - Video
  - Music
  - Health and environment monitoring (ie: sensors)

RF bands moving to higher frequency

- Phone roadmap
  - Phone and WiFi simultaneously
  - 5G likely >20 GHz?
  - Interest in other applications at 70 – 100+ GHz

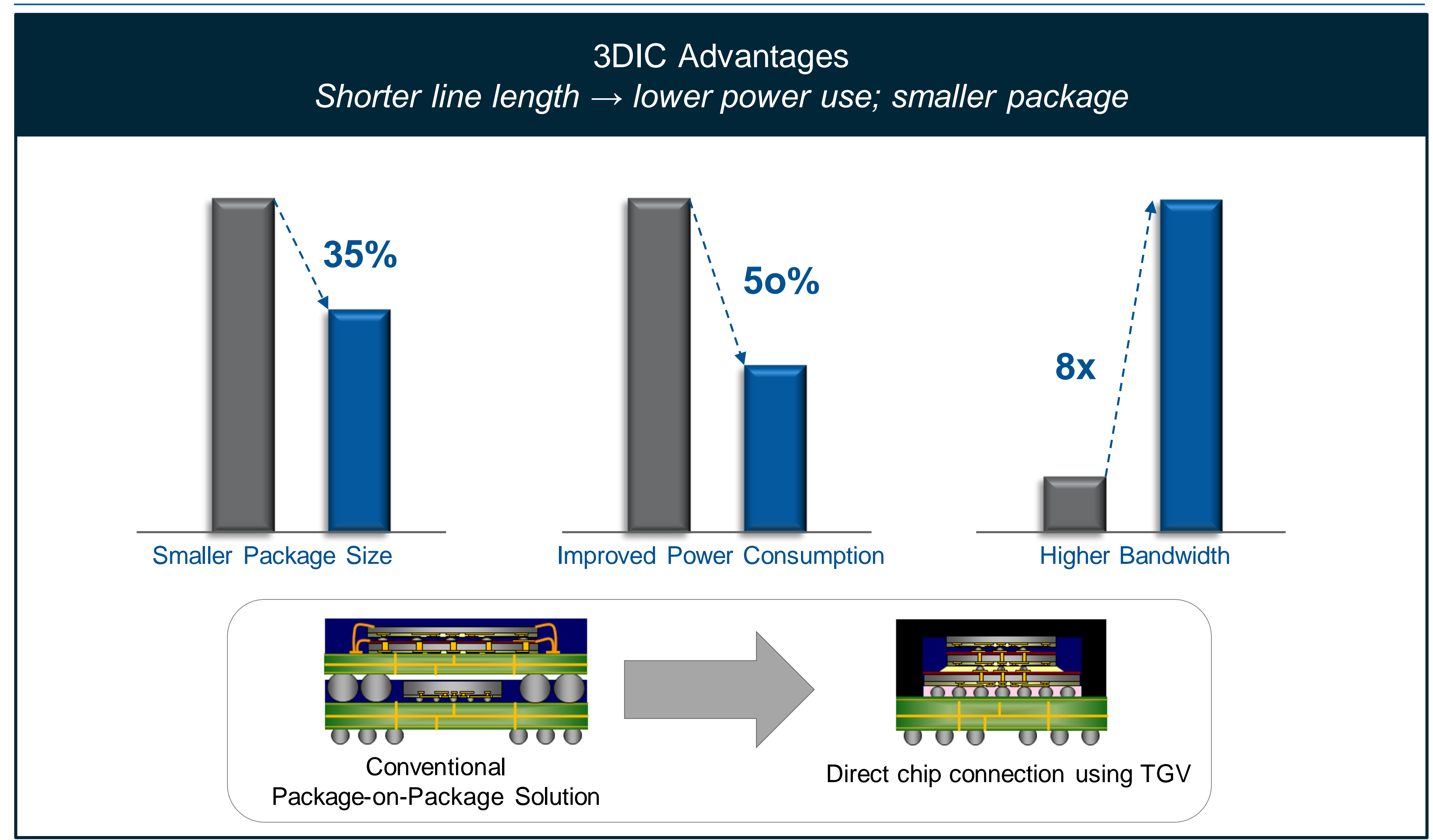
Power consumption

Increased battery life = less charging = happy consumer



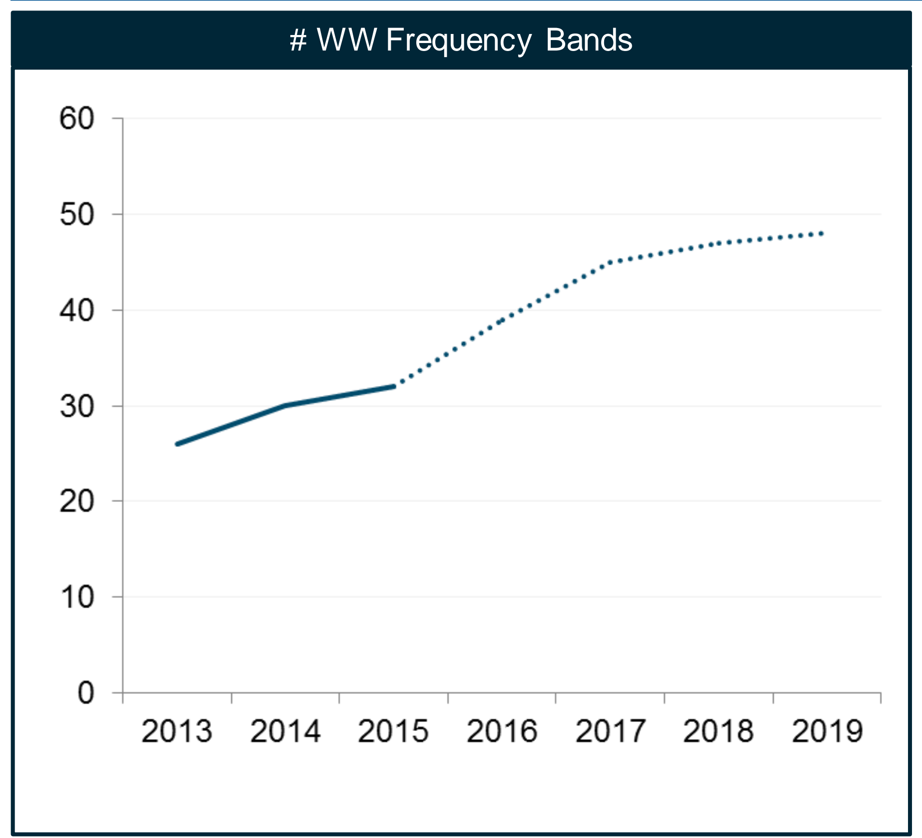
Thinner form factor

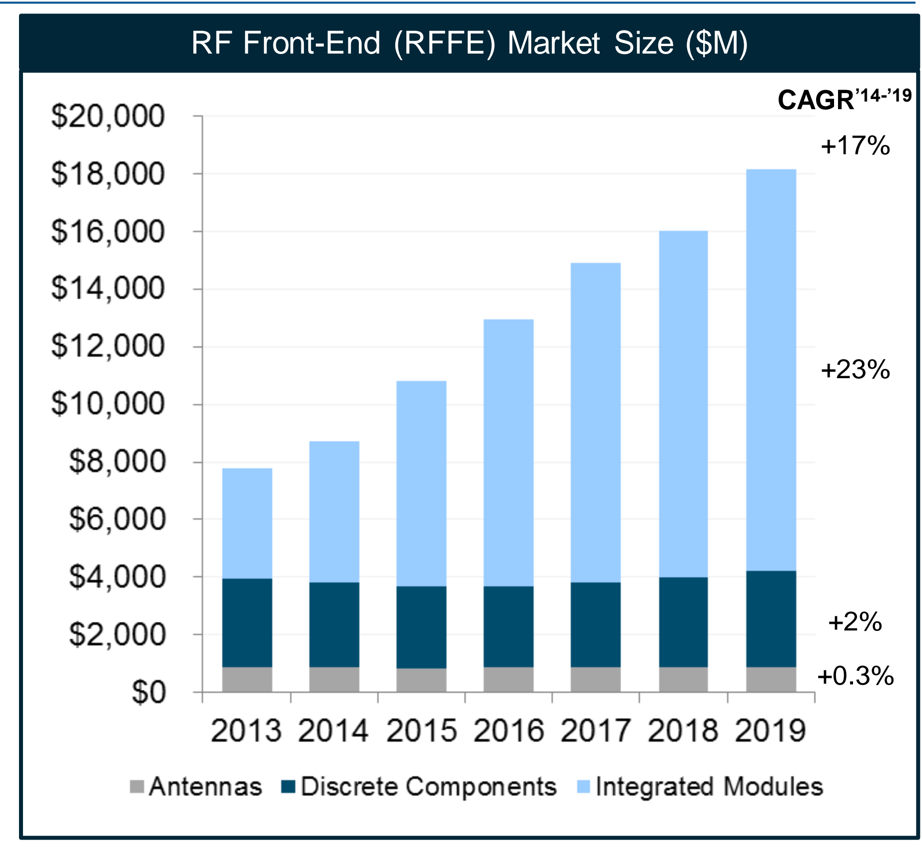
Why 3DIC??



Source: Samsung

Glass is a good fit for the growing RF market



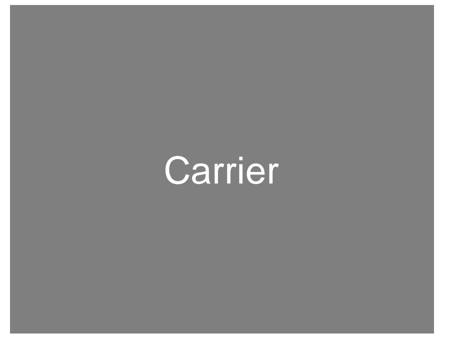


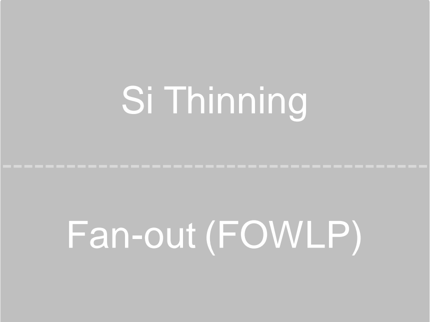
CARRIER	3G			4G LTE	
	NETWORK	BANDS	FREQUENCIES (MHz)	BANDS	FREQUENCIES (MHz)
VERIZON	CDMA	0, 1	850, 1900	2, 4, 13	1900, 1700 f, 700 c
AT&T	GSM/UMTS/HSPA+	2, 5	1900, 850	2, 4, 17	1900, 1700 abcde, 700 bc
T-MOBILE	GSM/UMTS/HSPA+	2, 4	1900, 1700/2100	2, 4, 12	1900, 1700 def, 700 a
SPRINT	CDMA	10, 1	800, 1900	25, 26, 41	1900 g, 850, 2500
US CELLULAR	CDMA	0, 1	850, 1900	5, 12	850, 700 ab

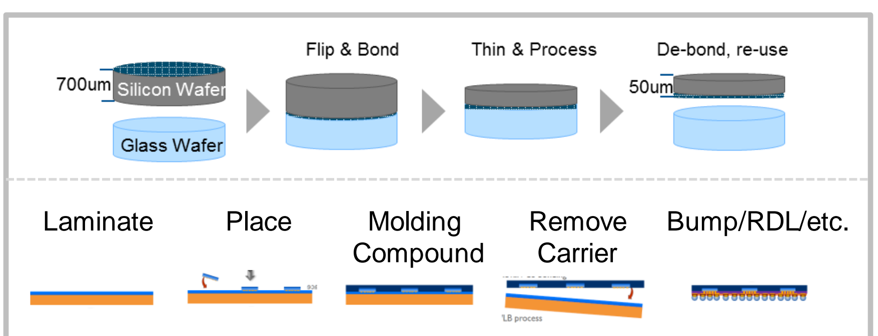
- RFFE market approaching $20B in next few years
- Market growth driven by # bands
- Outlook flat for discrete devices, significant growth in integrated modules

Source: Mobile Experts, Corning Analysis

Corning Semiconductor Glass Products has two complimentary product lines



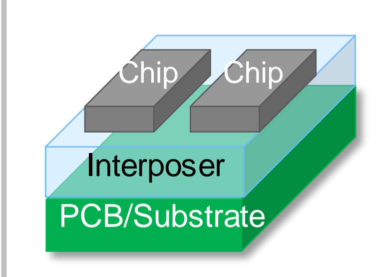




Radio Frequency Front End (RF)

Filters, antennas, switches in mobile phones, telecom infrastructure, medical equipment

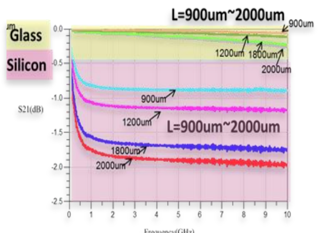
Interposer



Re-routes connection between layers inside a semiconductor package (ie: chip) using through vias (ie: holes)

Glass provides meaningful value for our customers

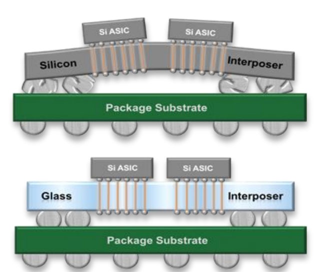
Electrical Properties



Low Electrical Loss

- Improved signal isolation
- Lower insertion loss = less power or longer battery life

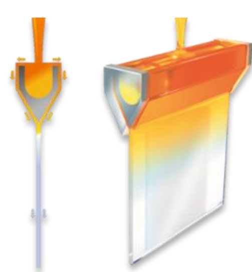
CTE Adjustability



Capability to deliver multiple CTEs

- Improves reliability
- Offer range of CTEs from 2.7-12.4

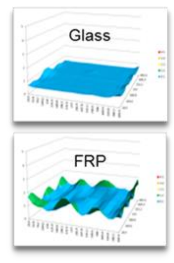
Surface Quality



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

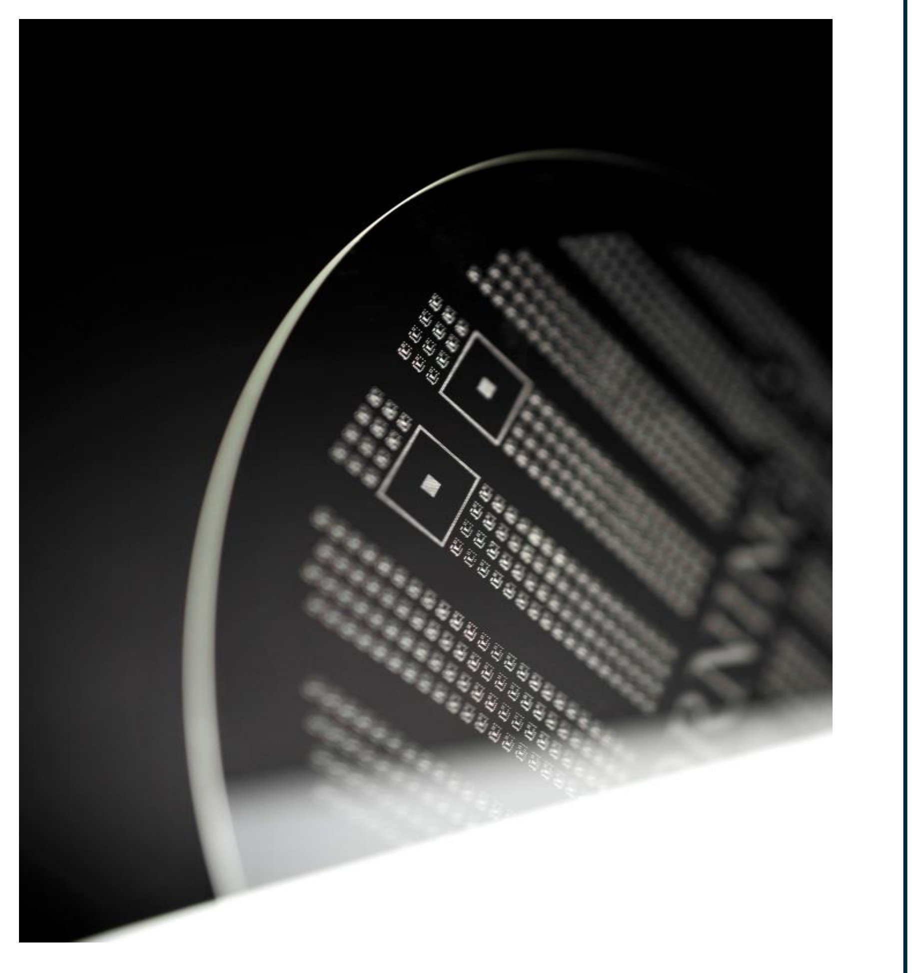
Forming at thickness + panels

- 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

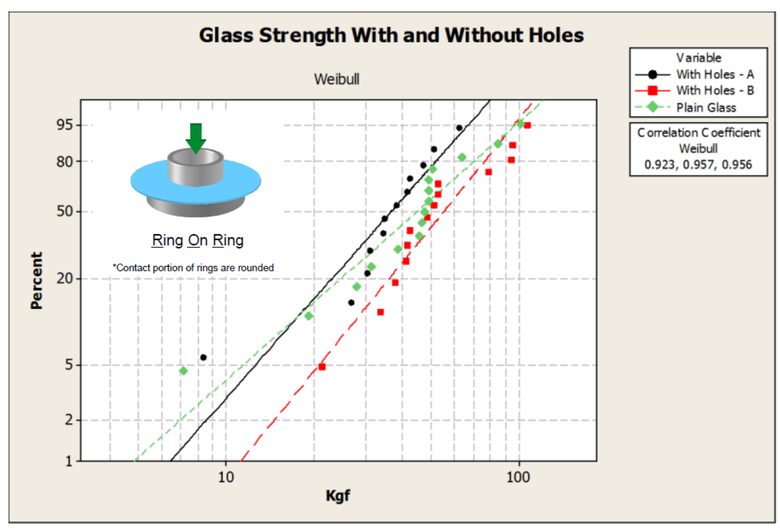
Precision Holes

Glass Size:		
	Wafers:	100mm → 300mm
	Panels:	> 500x500 mm
Thickness:		~100µm → 700µm
Type of Holes:		Blind-Holes, Thru-Holes
Pattern:		Customer X,Y Location
Aspect Ratio:		~3-10:1 (in part dictated by metal)
Pitch:		Minimum 2x Hole Diameter
Hole Diameter:		100µm → 20µm → 10µm

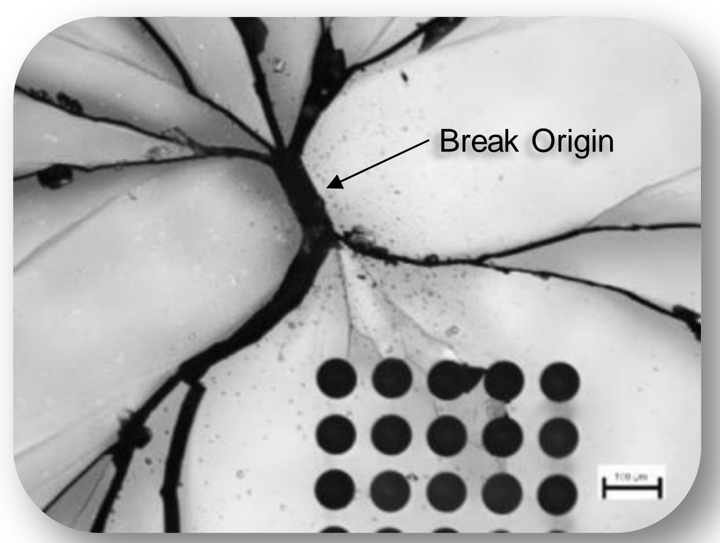


Our glass maintains strength throughout TGV process

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

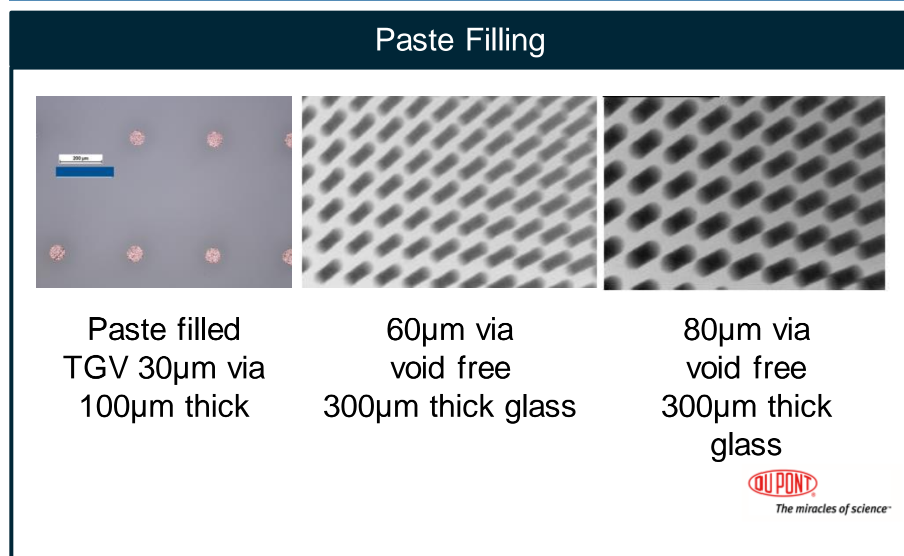


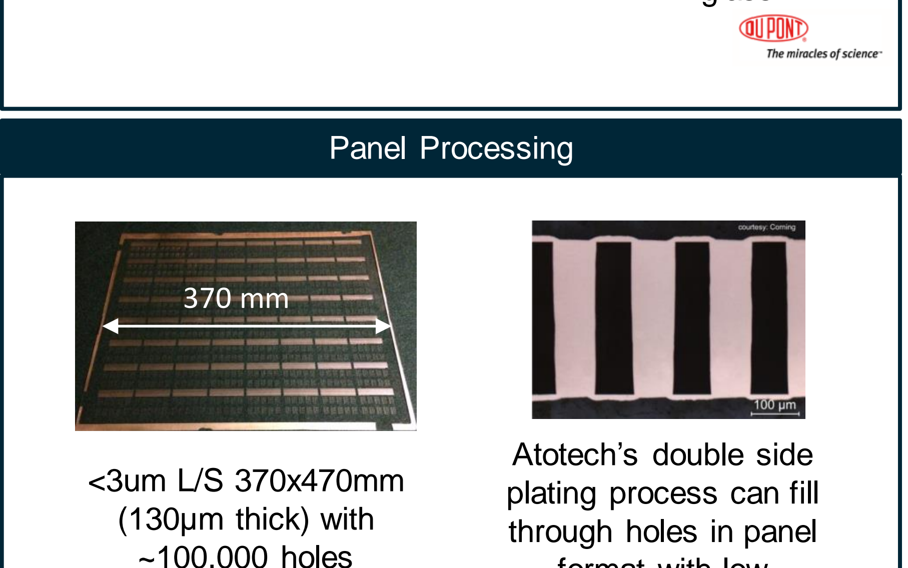
Ring on ring results for glass samples with and without holes. The strength of glass with holes brackets the strength of glass without holes.

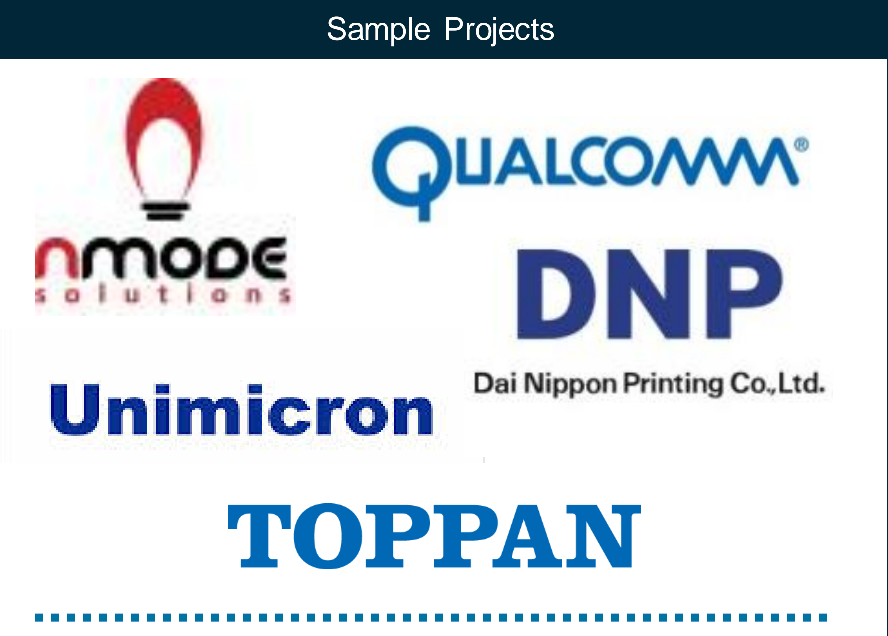


Picture of ROR broken glass sample with 5x5 via array. Note that breakage did not originate at via array.

Demonstrated successful metallization of glass vias with several industry partners and are working on real projects

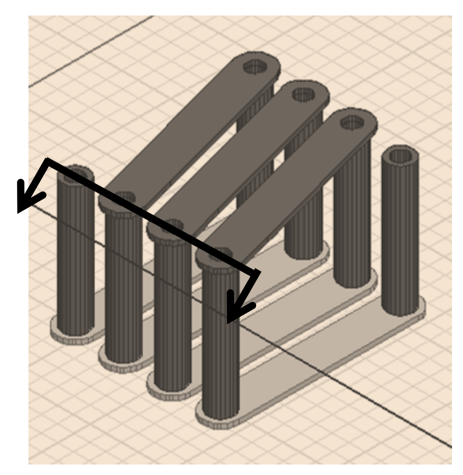


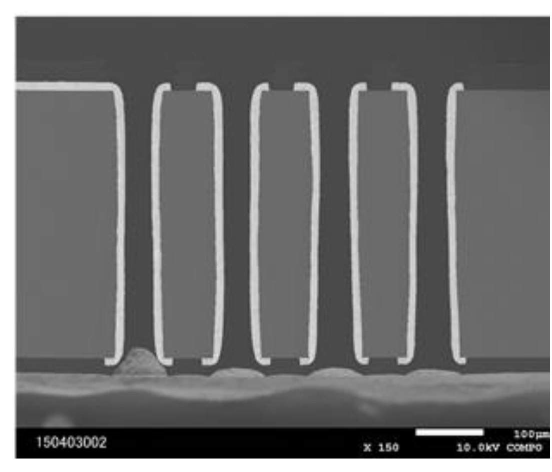




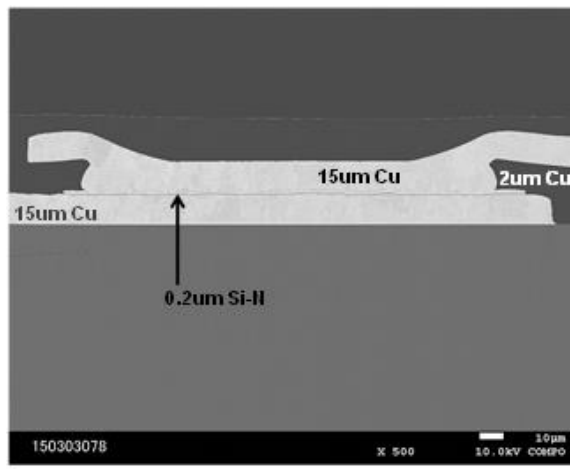
- TGV for RF Applications
- Low Cost Glass Interposer
- General Purpose Glass Modules

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

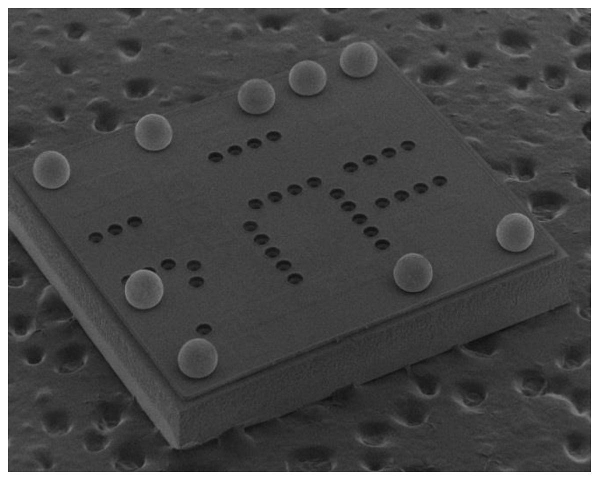

3D rendering of inductor structure, top-down view



Cross-sectional SEM of a fabricated 3D inductor

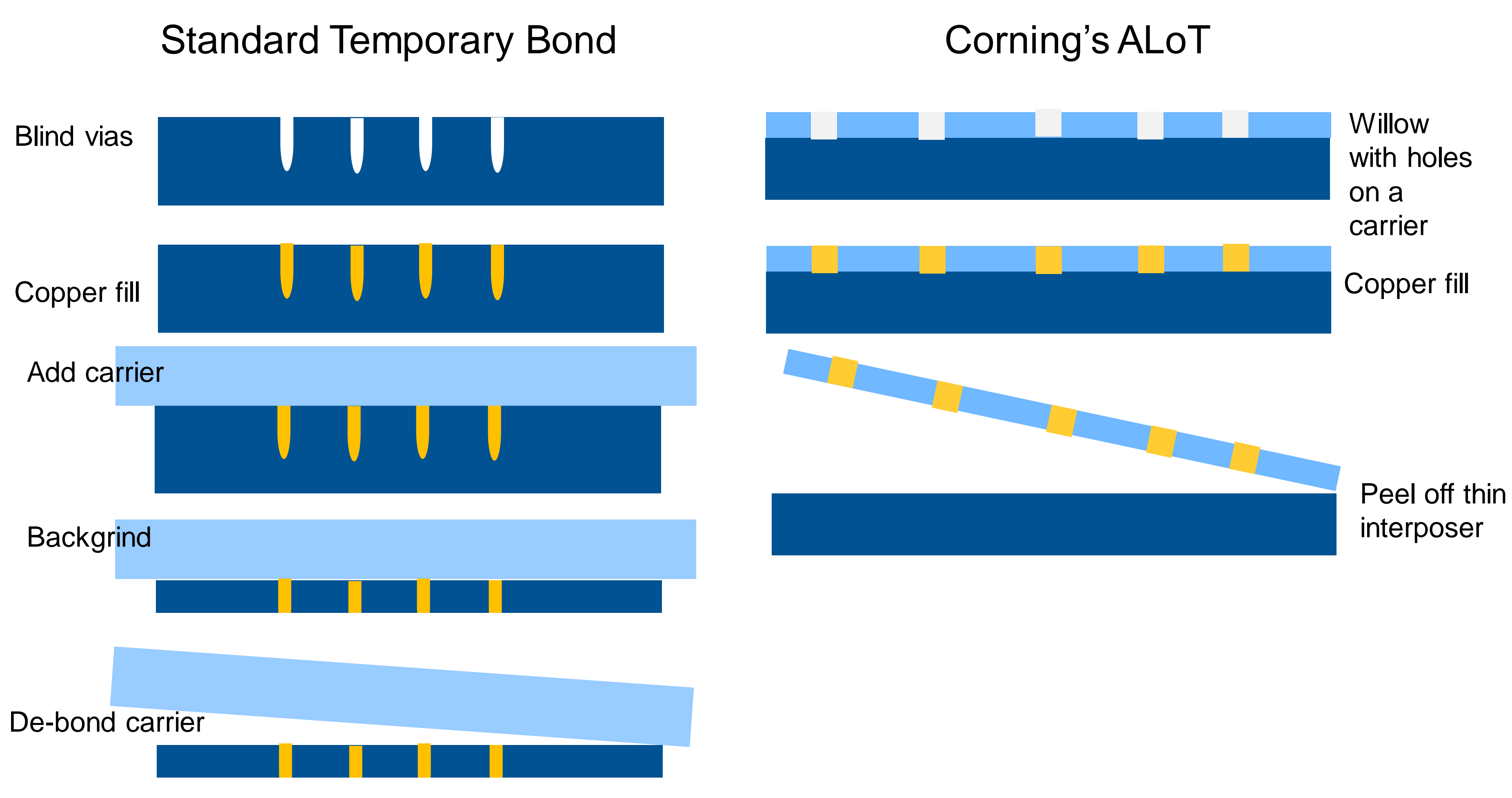


Cross-Sectional SEM of Cu-Silicon Nitride-Cu MIM structure

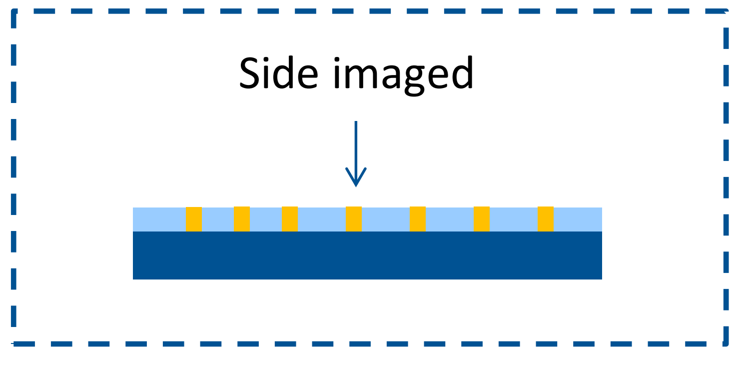


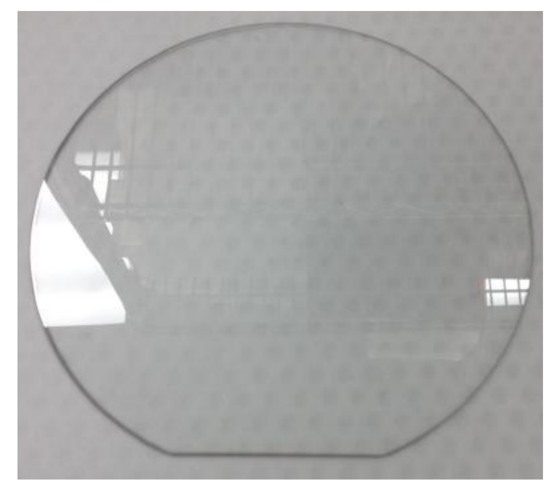
- Completed LC Network
- High Q inductance from 3D Solenoid inductor
- Capacitance achieved through MIM structure

Corning's ALoT Technology can Provide Substantial Opportunity for Process Simplification and Cost Improvements



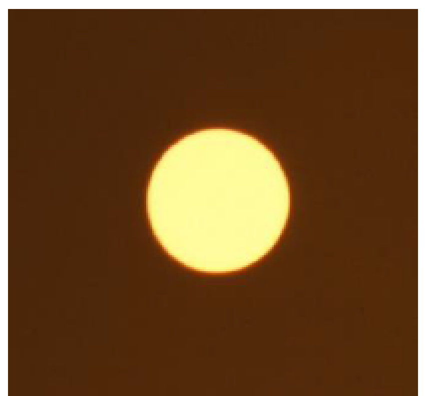
Thin Glass Handling – Exciting Performance Demonstration

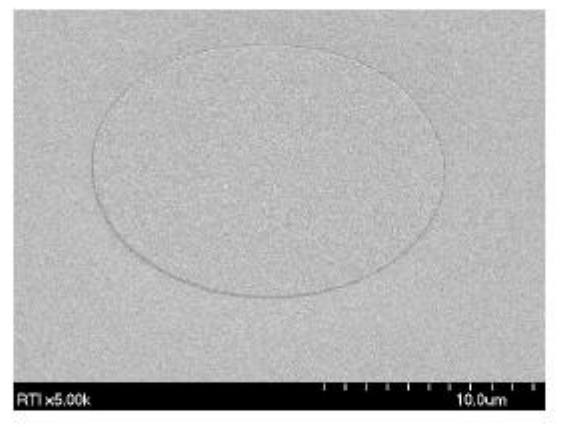


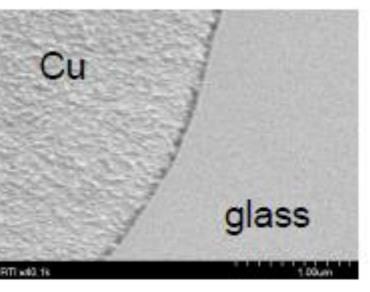


- Image of A lot after CMP processing to remove the Cu overburden left by TGV filling
- No edge chipping was seen after CMP

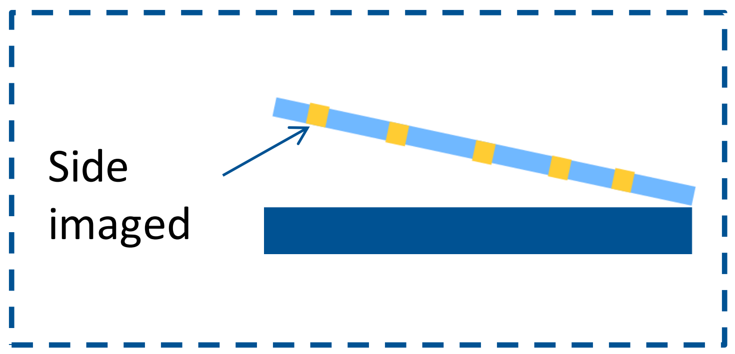
OM and SEM image of TGVs after electroplating and Cu overburden remova

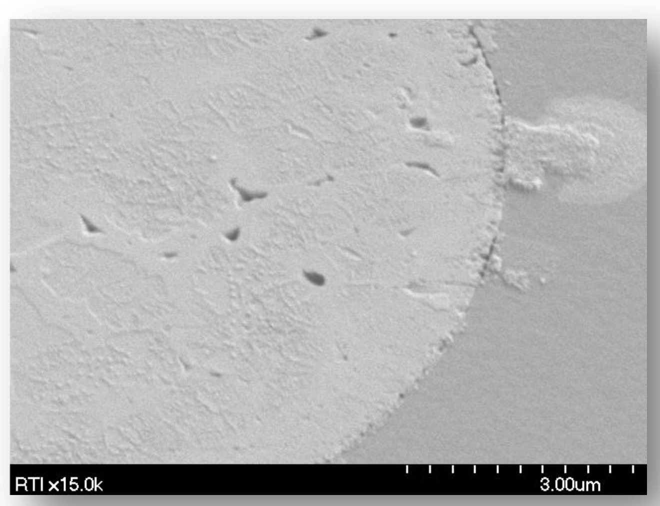




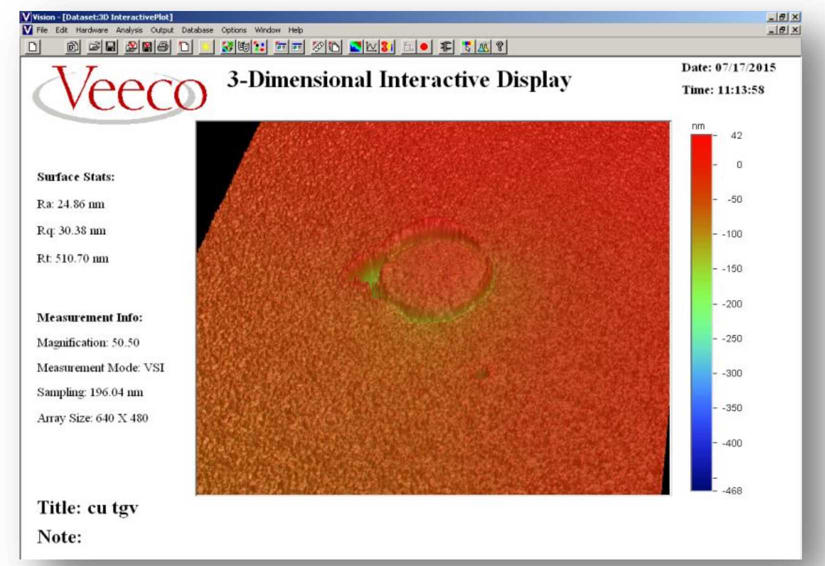


< 0.5 um Cu/Glass Planarity after Backside De-bond – Without Polish



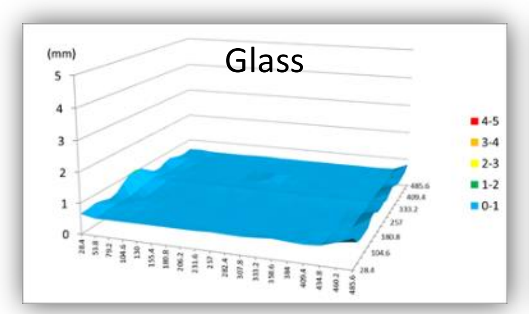


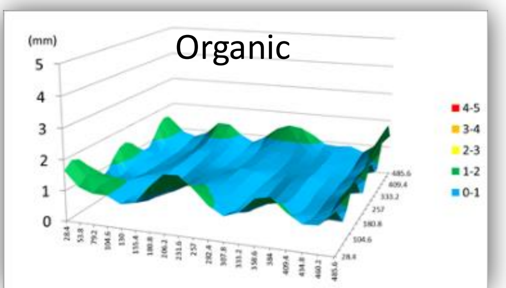
- SEM of metallized backside of via
- Improvements in bonding will help



- Some small "trench" around perimeter of via
- Recent improvements in bonding will improve
- TGV < 30 um likely

Glass helps enable panel-level packaging, which potentially enables significant process savings for our customers

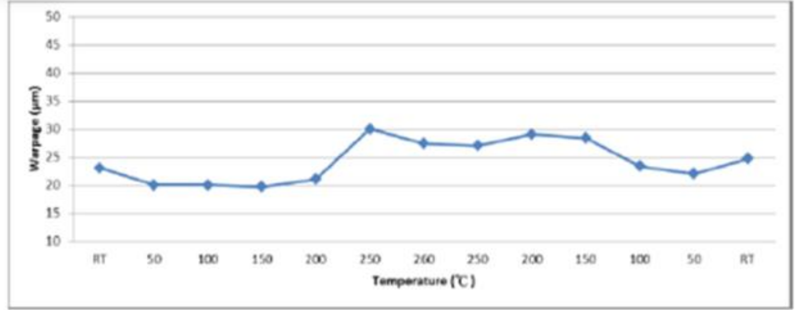


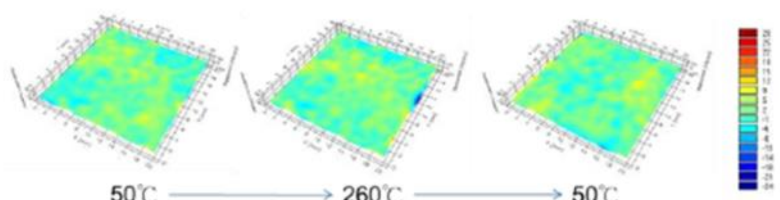


Left: Warpage measurement of glass substrate (2 build-up layers)

Right: Warpage measurement of organic substrate (2 build-up layers)

508 x 508mm glass panel





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

Source: YH Chen et al., Unimicron Technology Corp., Qualcomm Technologies, Inc., Corning Incorporated, "Low Cost Glass Interposer Development", 47th International Symposium on Microelectronics, San Diego 2014.

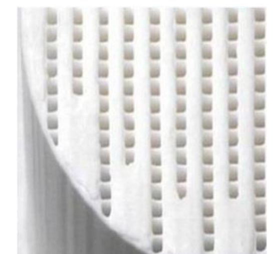
Corning has a strong portfolio of emerging innovations

- 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

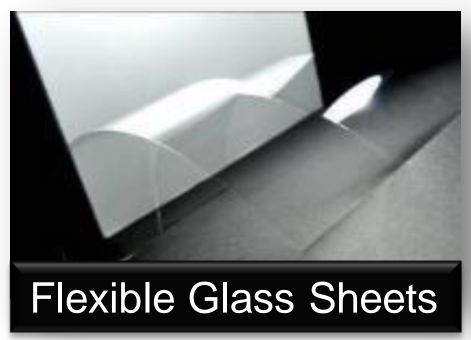
- Specialty Surfaces
  - Developing surfaces such as antimicrobial glass, anti-reflective, and easy-clean coatings

- 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

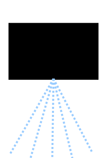
Substrate choice critical for device fabrication and performance

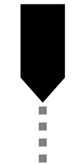
Continuous device fabrication has been demonstrated using flexible glass

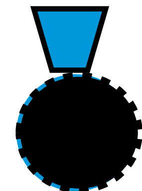
Conveyance

Vacuum Deposition

Coating & Lamination







Flexible glass barrier

Photolithography & Patterning

Wet Processing

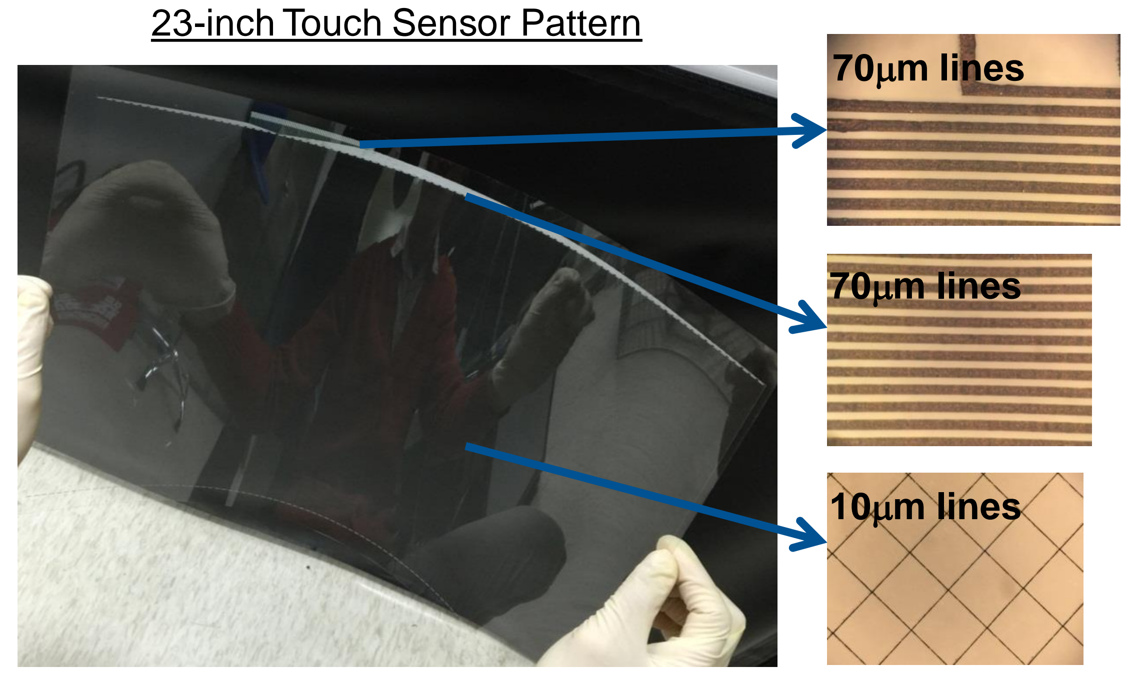
Printing

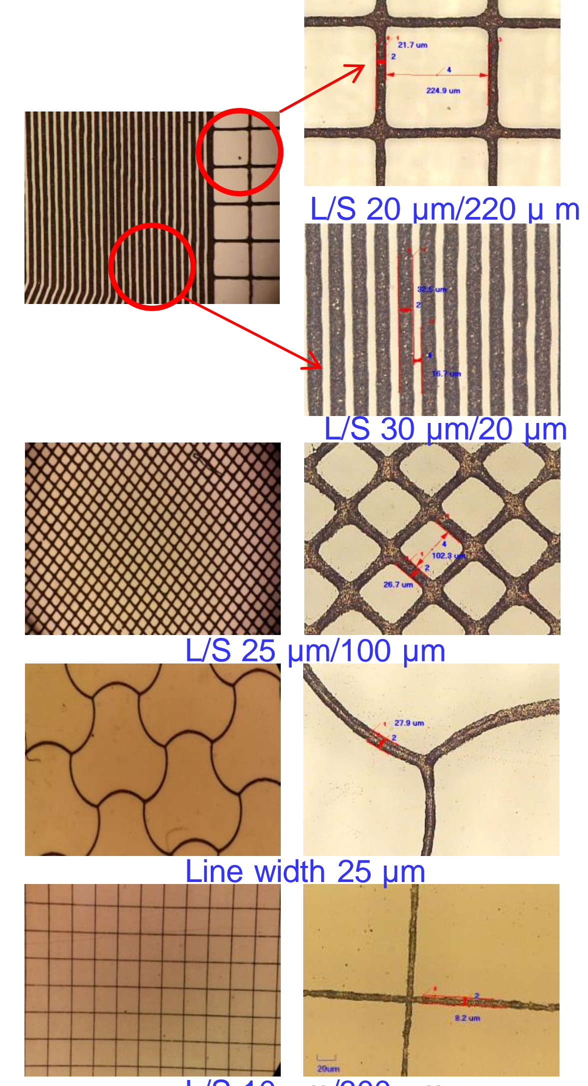
Demonstrated R2R Gravure-Offset Printing on Flexible Glass

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



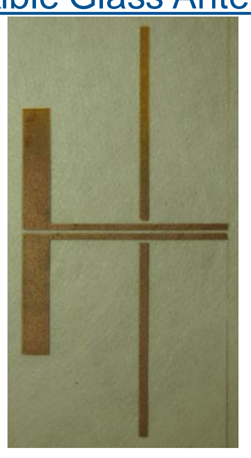


Gravure-Offset Printed Functional Devices on Flexible Glass

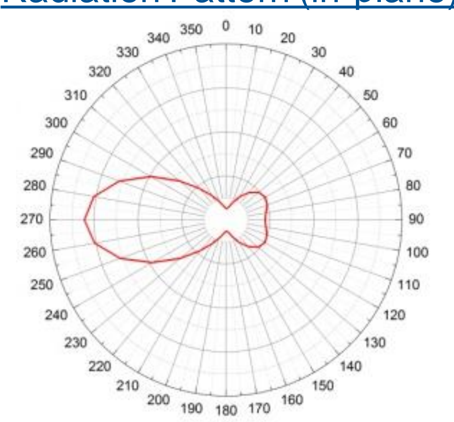
Demonstrated 10GHz antenna and metal-mesh touch sensor performance

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

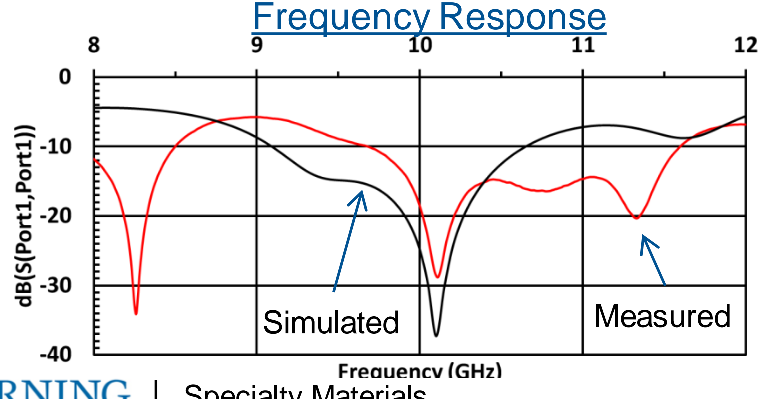
Flexible Glass Antenna



Radiation Pattern (in-plane)



Frequency Response

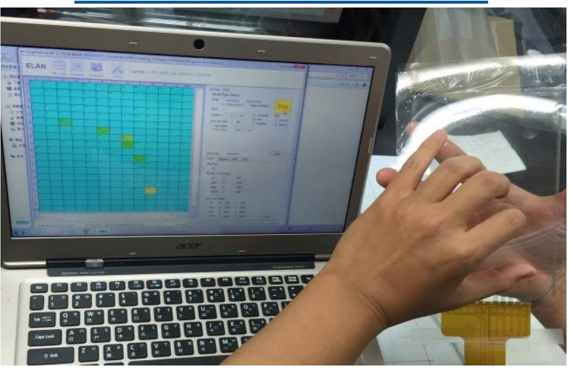


- 7-inch touch sensor fabricated
- Single-layer, single-side device
- Linewidth = 13.6μm
- Sheet resistance = 55Ω/sq
- Transmission = 85% (no AR coatings)

Singulated Device

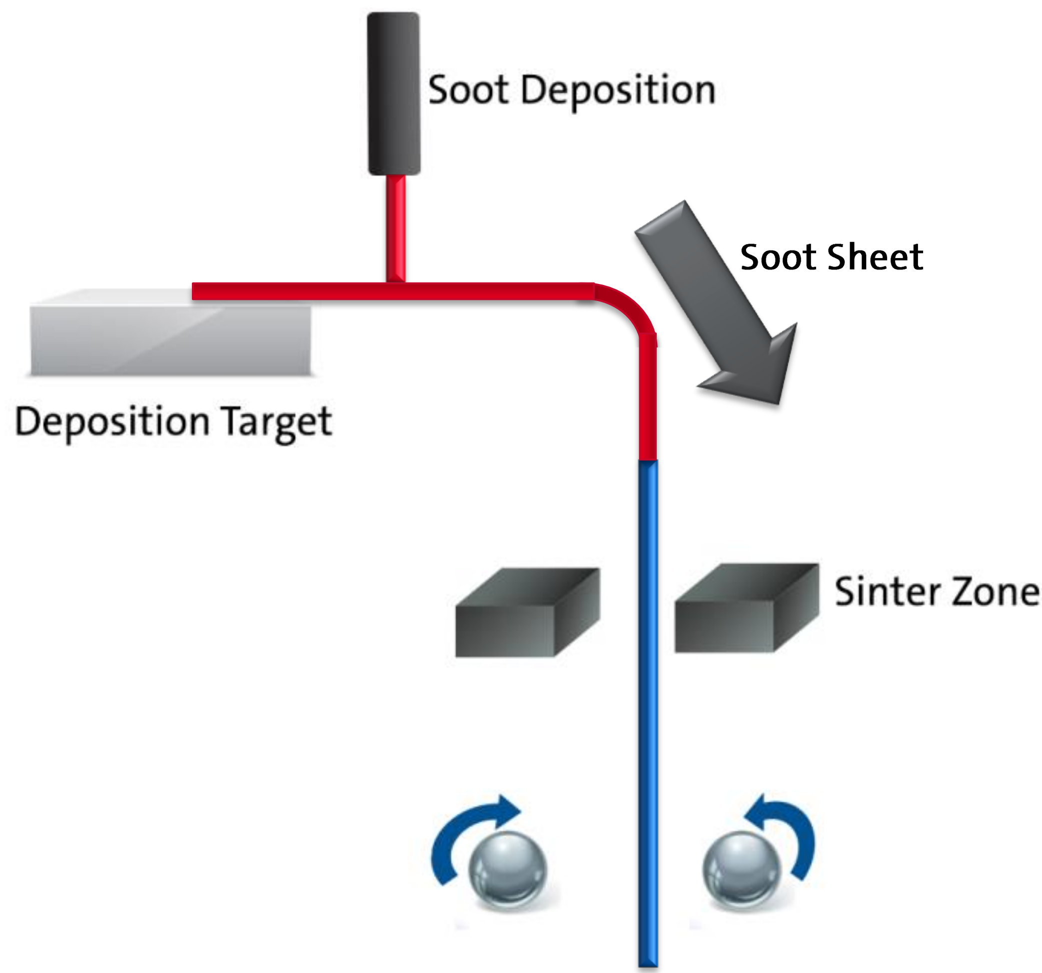
Connectorized Device

Multi-Point Touch Sensor

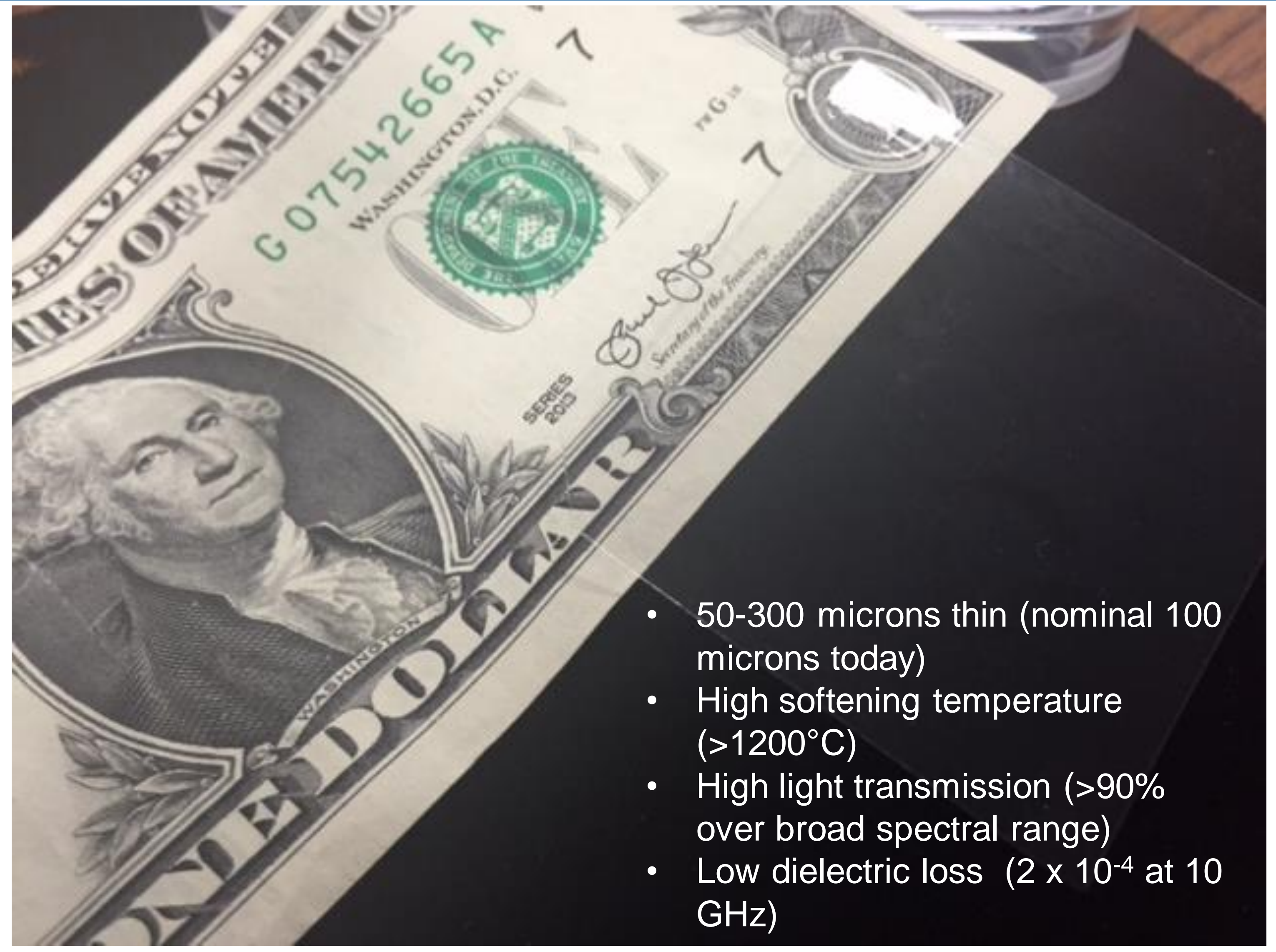


New process for thin glass with excellent electrical properties

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 x 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