Glass Substrates for RF and Photonics Packaging and Integration

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Cadence Photonics Summit

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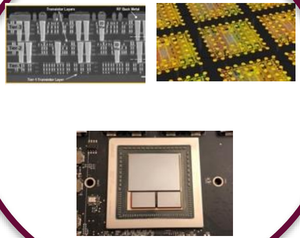
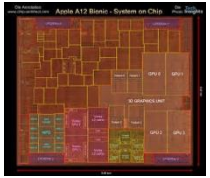
Outline

- Motivations for Advanced Packaging
- The Use of Thin Glass Substrates with Through-Glass Vias (TGV)
- Glass handling solution
- RF Applications
- Photonic Applications
- Thermal Control

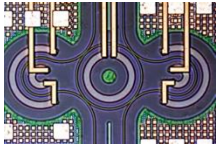
What’s Driving Advanced Packaging?

High Density I/O and
High Speed Memory





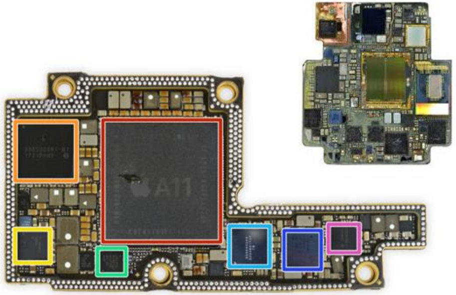
Cost and complexity
of SOC scaling



Integrated
Photonics

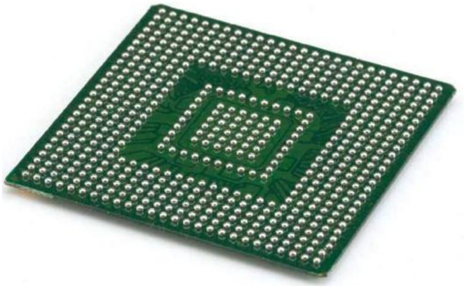
5G

5G Communications
& mm waves

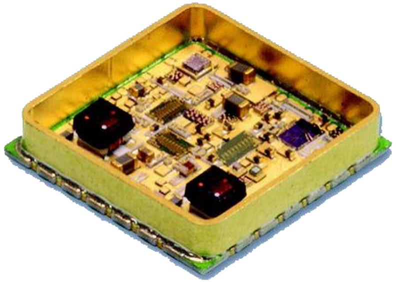


Heterogeneous
Integration

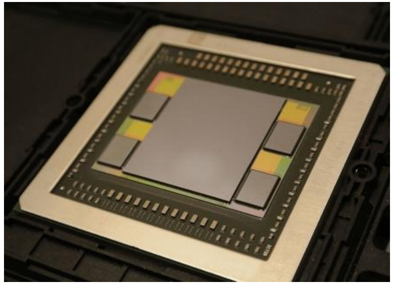
Substrate Materials



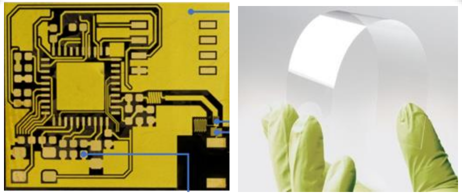
Organic Laminates



Ceramic (thin film, thick film, HTCC, LTCC)



Silicon



Glass

Glass Has Many Advantages

Characteristic	Ideal Properties	Materials: Glass	Si	Poly Si	Organic	Metal	Fused Silica
Electrical	▪ High resistivity ▪ Low loss and low k	Good	Poor	Fair	Good	Poor	Good
Physical	▪ Smooth surface finish ▪ Large area availability ▪ Ultra thin	Good	Fair	Good	Fair	Fair	Good
Thermal	▪ High Conductivity	Fair	Good	Good	Poor	Good	Fair
Mechanical	▪ High strength & modulus	Fair	Fair	Fair	Poor	Good	Fair
Chemical	▪ Resistance to process chemicals	Good	Fair	Fair	Fair	Poor	Good
TPV and RDL	▪ Low cost Via formation and fill	Fair	Poor	Fair	Fair	Poor	Fair
Reliability	▪ CTE matched to Si and PWB	Good	Good	Good	Fair	Poor	Good
Optical	▪ Low loss visible and IR, easy fiber attach	Good	Good	Fair	Poor	Poor	Good
Cost	▪ Low raw material and processing costs	Good	Poor	Fair	Good	Good	Good

Good Fair Poor

- ✓ Low dielectric constant and loss tangent through 100 GHz
- ✓ Dimensional stability – precise features
- ✓ Drawn in large sheets (1m x 500m) – low cost panel processing possible
- ✓ Can be drawn 100 μm thick – no grinding necessary
- ✓ Smooth surface (< 1 nm rms)
- ✓ CTE match to Si
- ✓ Inert, no moisture absorption
- ✓ Optical properties, fiber attach, waveguides
- ➢ Reduced SWaP-C

Chart courtesy of Georgia Tech PRC

Technologies and Markets for Glass Interposers

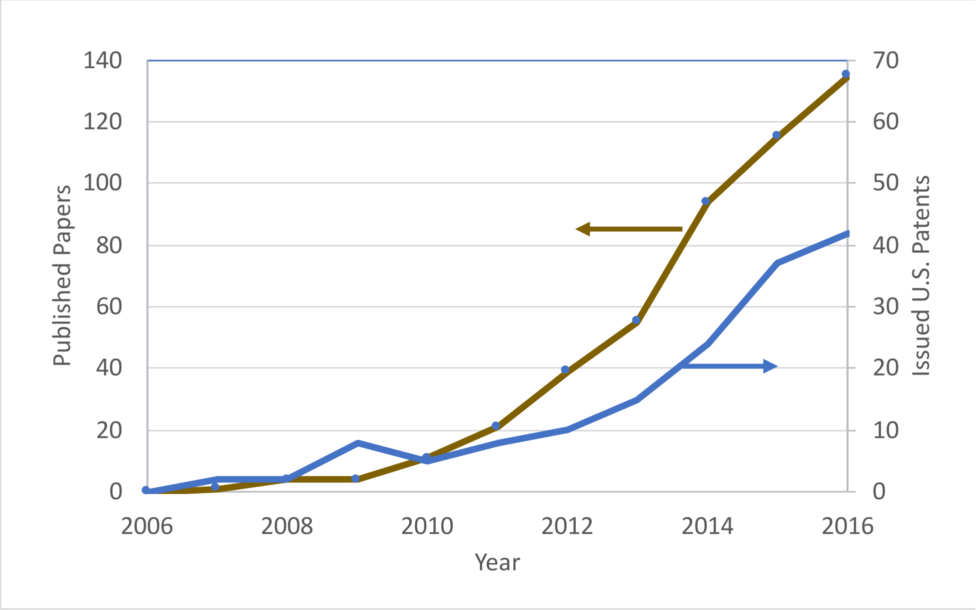
	RF	Optics & Photonics	Digital Interposer	MEMS & Sensors
Wireless Comms.	✓	✓	✓	✓
Datacom and HPC	✓	✓	✓	
Defense	✓	✓	✓	✓
Medical	✓	✓		✓
IoT	✓			✓
Consumer	✓	✓	✓	✓

Desirable RF and photonic properties make glass a promising choice for RF photonics

Increasing Interest in Glass

Companies

Corning
Asahi Glass Corp.
Schott
Mosaic Microsystems
Qualcomm
GE
Global Foundries
IBM
ST Micro
ASE
TSMC
Marvell
Samtec
Menlo Micro



Research Institutes

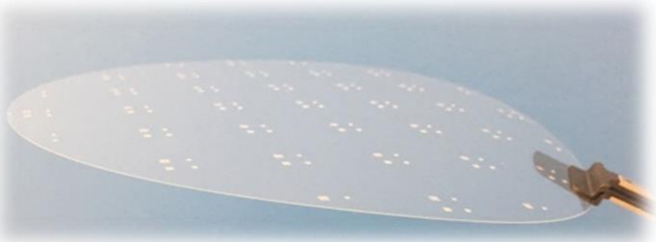
GA Tech
Univ. of Florida
Univ. of Rochester
McGill
Fraunhofer
IMEC

Published papers by Google Scholar and Patents by USTPO. Searches for “glass interposers”

Glass Wafer Handling Challenges and Solution

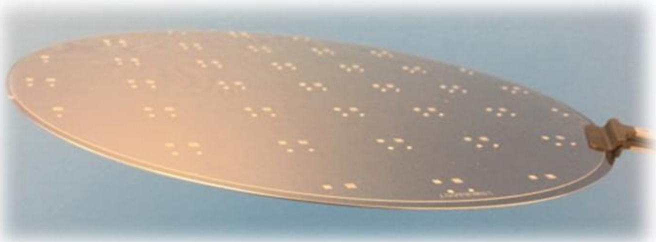
The Challenge:
Immature supply chain
Thin glass with through-holes has challenges:

- Excess sag
- Transparent to robotic sensing
- Breakage
- Concern over contamination

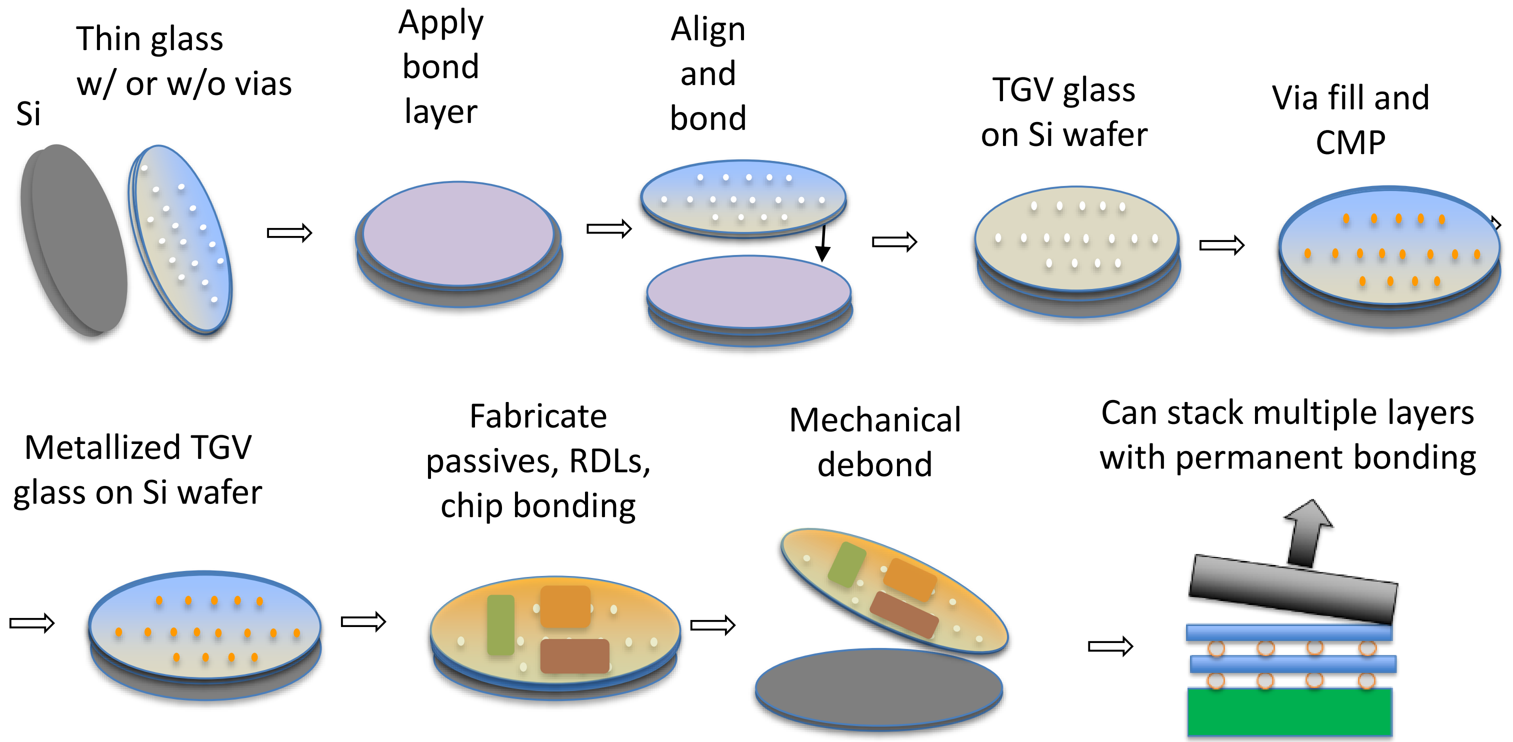


The Solution:
Thin glass with TGVs temporarily bonded to silicon carrier wafer

- Inorganic bond stable up to 400C
- No outgassing
- Simple mechanical de-bond
- Compatible with existing semiconductor processing and automation equipment



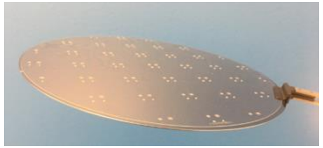
Wafer Handling and Processing Technology



Mosaic's Products: Bonded Glass Wafers

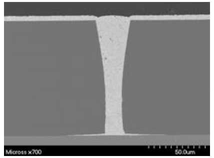
Thin glass on Carrier

Glass thickness 100 µm - 300 µm



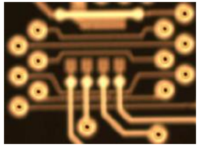
Glass with custom
through-glass holes

Hole diameter ≤ 35 µm



Fully or conformally
filled vias

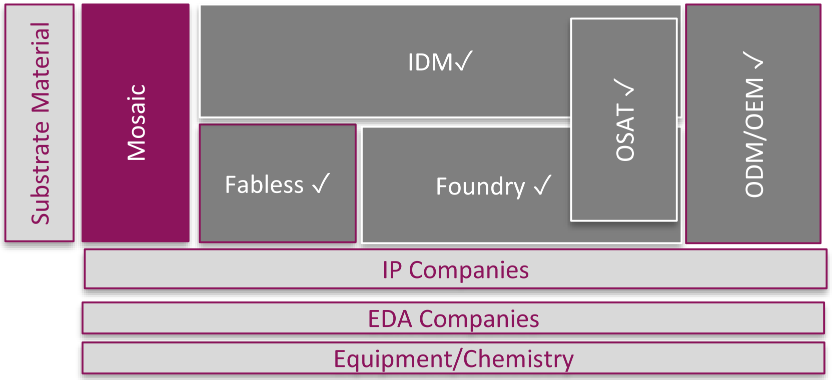
Filled vias w/ CMP



Thin glass with custom
structures and devices

Metallized wafer

Supply Chain



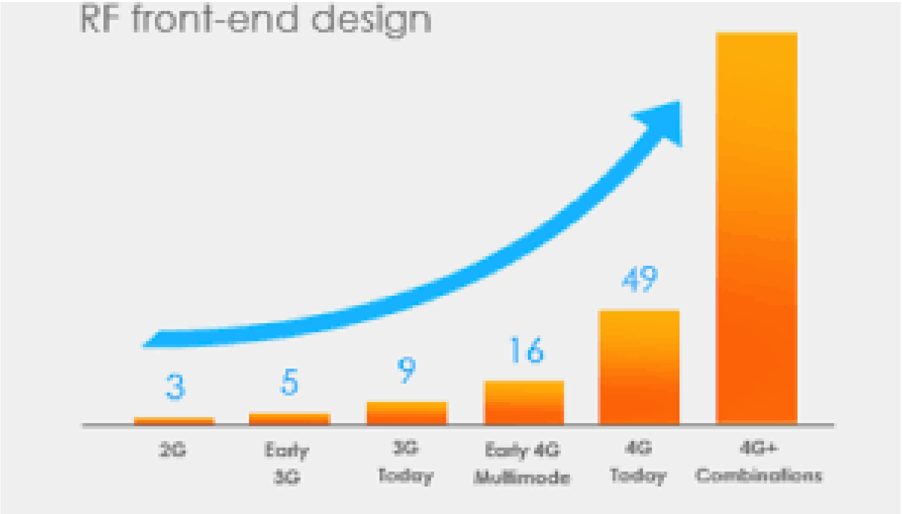
- Mosaic serves companies across the electronics supply chain.
- Some companies will buy direct while others will influence or specify the technology.
- The type of product we provide depends on the application and type of customer.

RF Applications of Glass

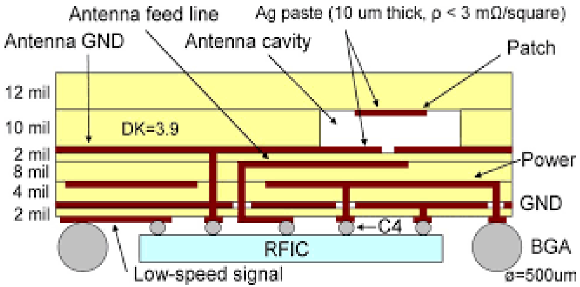
Increasing Complexity of RF Systems is Driving New Packaging Technology

- RF front ends for user equipment and infrastructure getting more complex
- Multi-bands, multi-carrier, multi-standards, and MIMO, along with WiFi, BT, and GPS
- 5G will make things even more complicated with both sub 6 GHz and mm waves.
    - ➢28 – 80 GHz and 2 – 10 Gbps
- Mm Waves will require beam forming and steering – so phased arrays.

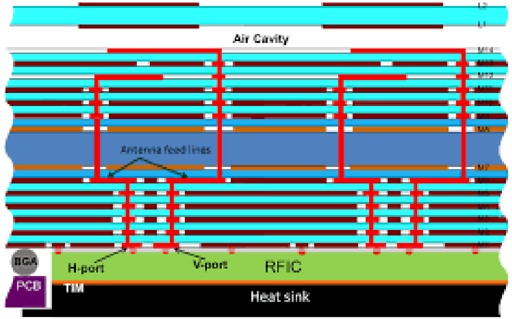
80+ Filters in LTE and 5G Phones



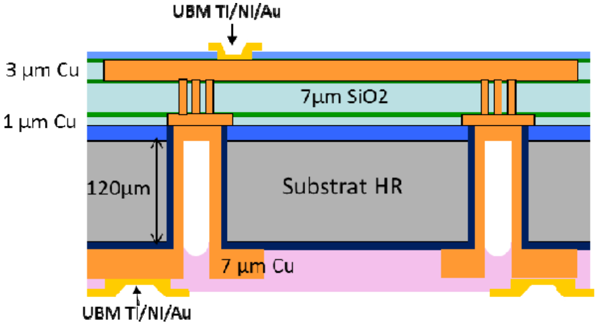
Millimeter Wave Packaging Substrate Materials



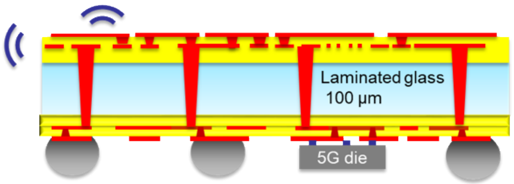
Ceramic (IBM)



Organic (IBM)



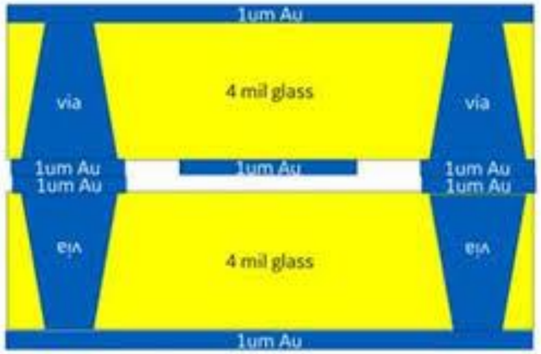
HR Silicon (LETI)



Glass with Organic Buildup (GA Tech)

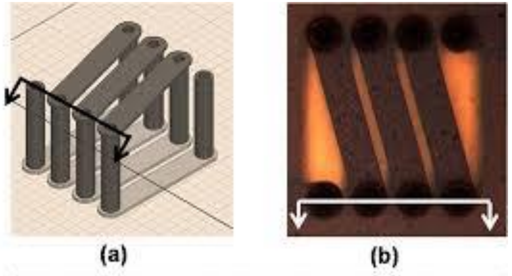
All Inorganic Package with Glass

- Multiple layers possible with thermo-compression bonding
- Au microstrip, CPWG, and Stripline
- CPWG loss < 0.4 dB/mm @ 30 GHz
- High isolation between transmission lines
- Ta resistors
- MIM capacitors
- Can be used to make a variety of mm wave devices including True Time Delay modules

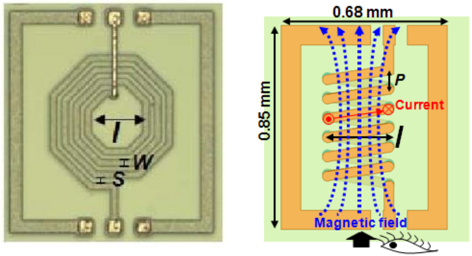


All Glass (GE)

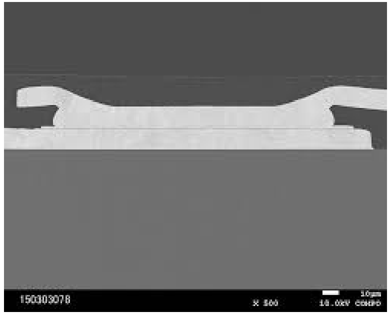
Thin Film Passives on Glass



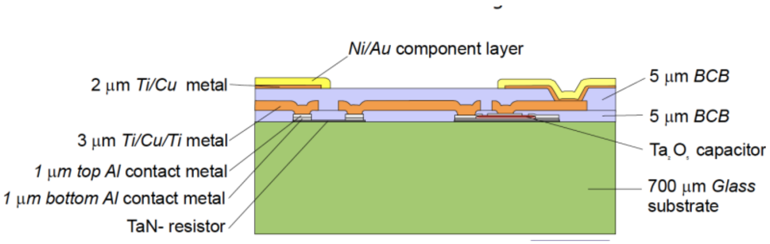
3D Helical Inductors
(Corning and Qualcomm)



Helical inductors on glass with TGV give 45% reduction in area vs. spiral (TSMC)

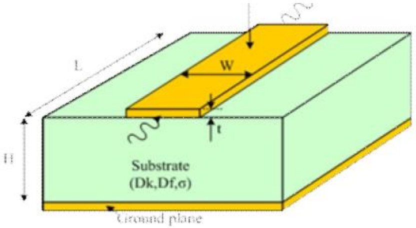


MIM Capacitor with SiN dielectric
(Corning and Qualcomm)

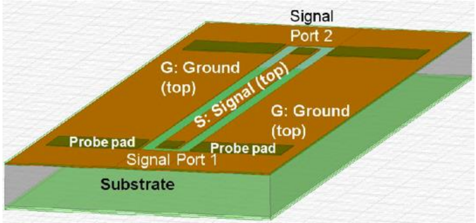


Ta and TaN thin film resistors (IMEC)

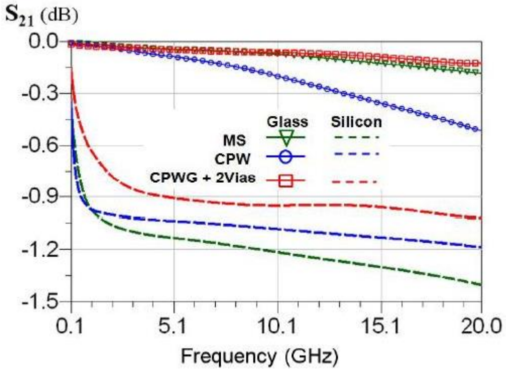
Transmission Lines on Glass



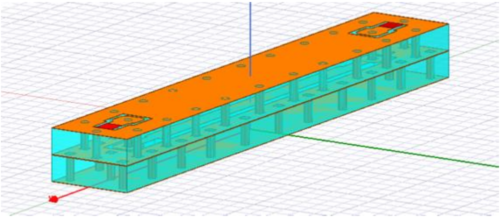
Microstrip (Corning, Qualcomm, and Dai Nippon Screen)



CPW (ITRI and Corning)



Glass vs. Si Performance Comparison (ITRI and Corning)



Stripline with TGV Array (GE and Mosaic)

Less than 0.1 dB/mm loss for CPWG @ 10 GHz

GE and Mosaic Capabilities and Design Rules*

TGV Glass (Mosaic)

Materials	Borosilicate Glass, Fused Silica
Substrate Diameter	100, 150, 200 mm, may add 300mm
Thickness	100 um – 200 um, will add 300 um
Surface Roughness	< 1 nm
Via Diameter max	35 um
Via diameter min	10 um
Via sidewall slope	2 degrees
Via pitch	< 150um now, going to 2X diameter

Packaging (GE)

Layers of Glass	
Metals	**Available from GE upon request**
Catch Pad Diameter	
Metal Thickness	
Line width	
Line spacing	
Capacitor material	
Capacitance/mm^2	
Resistors	
Wafer diameter	

* RF Diagnostics has experience in designing mm wave packages with TGV glass

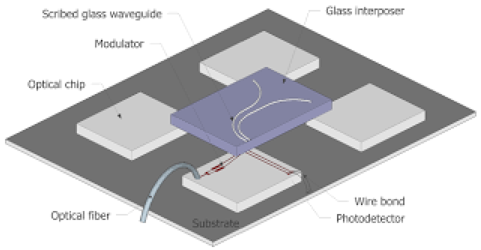
Photonic Applications of Glass

Si vs. Glass Interposers for Photonics

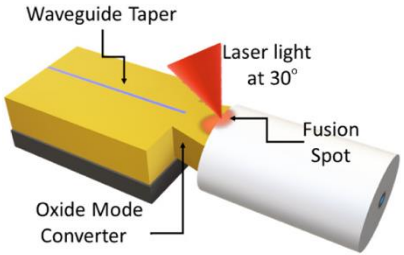
- Si most common substrate for photonic interposers
- Advantages of Si
  - Can be used for an active or passive interposer
  - Uses the same process technology as is used for SIP die
- Capabilities of Glass:
  - Transparent to wavelengths of interest
  - Can incorporate waveguides, either deposited or laser written
  - Can provide passive fiber attach solution
  - Better choice for RF photonics due to superior RF properties
  - Lower cost than Si

Laser Writing of Optical Waveguides in Glass

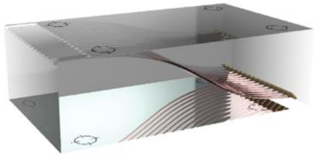
- McGill
- Optoscribe
- Harvard
- STMicro
- Corning
- IMRA
- SUNY Binghamton
- NIAIST (Japan)

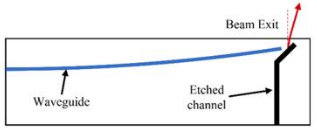


Waveguides can be written at any depth → after PIC attach. (McGill)



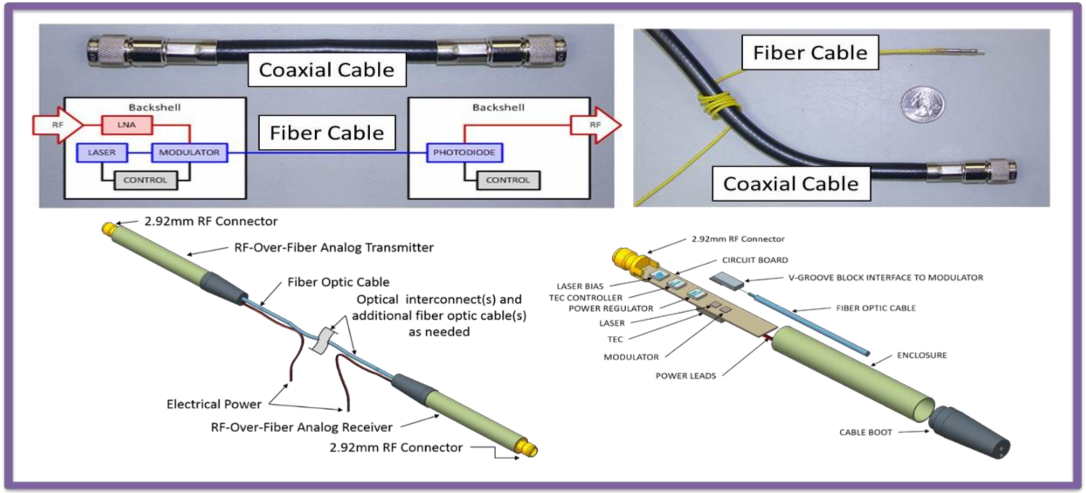
Direct welding of fiber to glass (University of Rochester)





Low Loss, 0.2 dB/cm (Optoscribe)

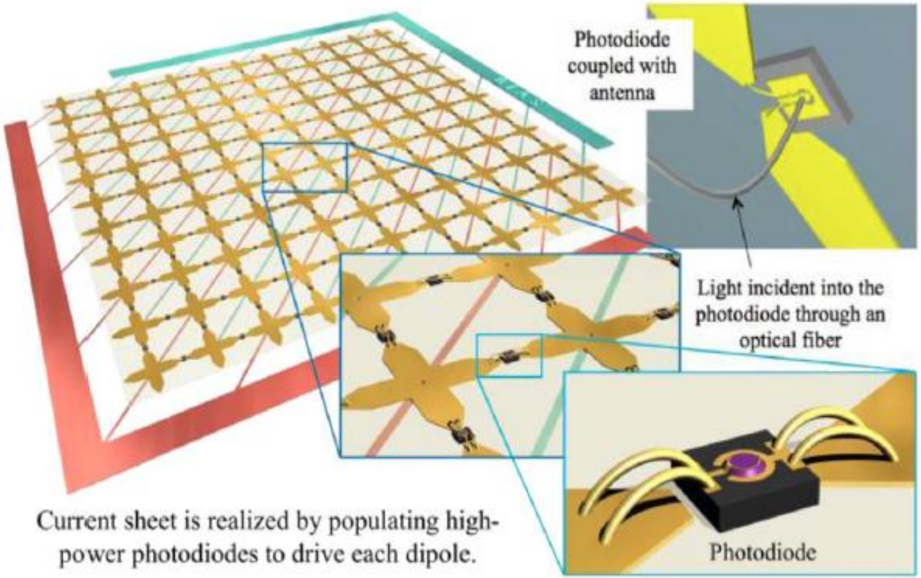
Potential Application: RF over Fiber



Class could be used as the substrate for this type of device.

Rick Stevens, Lockheed Martin

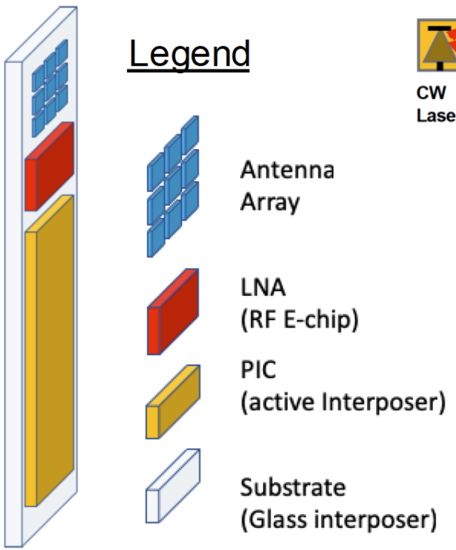
Potential Application:
Photonic mm Wave Array Using Photodiodes

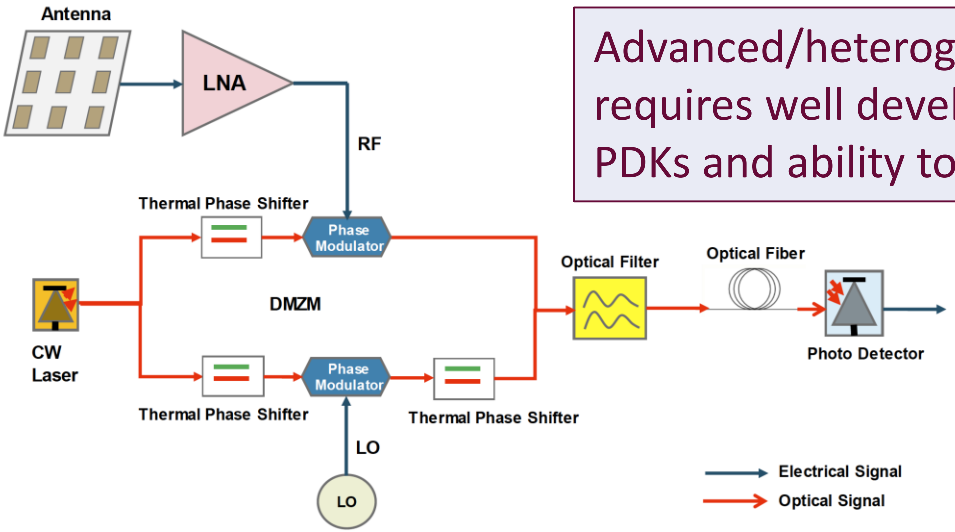


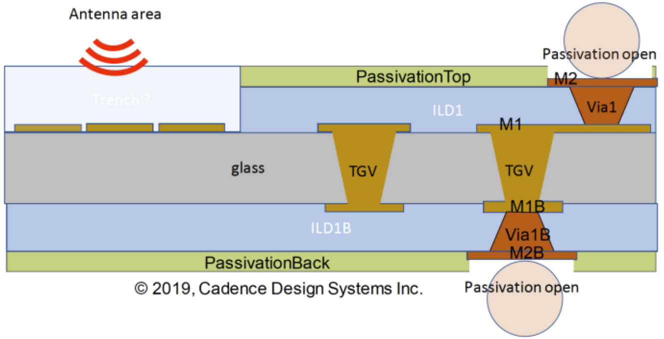
Dennis Prather, Phase Sensitive Solutions

Cadence Photonics Summit Design Example

Advanced/heterogeneous integration requires well developed packaging PDKs and ability to co-design

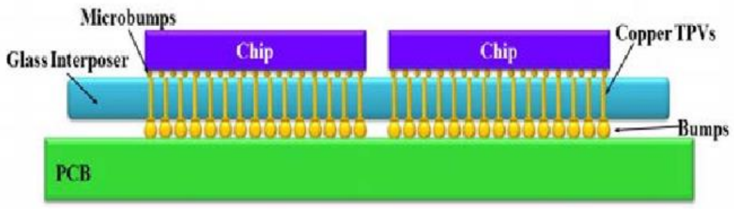




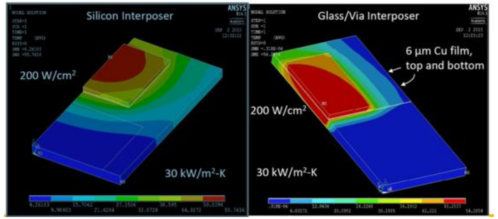


Thermal Control with Cu Vias

- K for glass = 1 W/m-K
- K for Si = 130 W/m-K
- K for Cu = 384 W/m-K
- Thermal effects with glass can be mitigated by using heat spreaders and thermal vias
- Low K can work to your advantage when you need to thermally isolate die.
- Need to model EM effects of thermal vais



GA Tech



University of Maryland

Summary

- Advanced packaging required advances in substrate materials
- Glass is a promising new material due to electrical, mechanical, and optical properties
- Challenges of weak supply chain and difficulty in handling thin glass are being addressed
- Desirable RF and photonic properties make gall attractive for mm wave and RF over fiber applications
- Low thermal conductivity must be taken into account and can be used to an advantage.
- Development of PDKs for glass packaging is a key part of the supply chain.

Thank You

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