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International Electronics Manufacturing Initiative

iNEMI MAESTRO: Glass Substrates for mmWave/sub-THz Applications

IMAPS DPC Conference

2023-03

Shelby Nelson (for Paul Ballentine)

Mosaic Microsystems, LLC

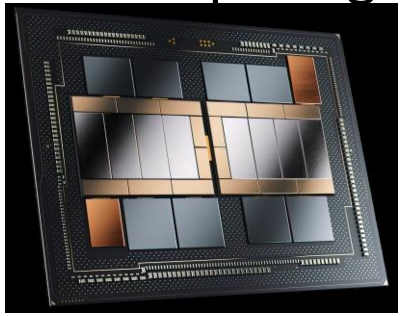
MOSAIC microsystems

About Mosaic Microsystems

- Advanced packaging company focused on thin glass for substrates and interposers

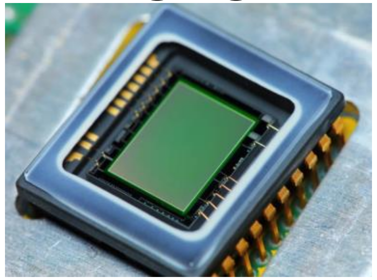
Hear more on Wednesday at 2:30 "High-yield Fabrication of Thin Glass Interposers"

Computing

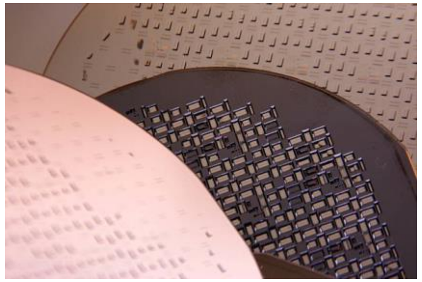


RF

Imaging



Sensors



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Agenda

- Glass properties that matter to mm-Wave packaging
- Stress considerations
- Application-specific choices

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What do we mean by "Glass"?

- Must contain silicon and oxygen!
- Examples
  - FS: Fused Silica SiO_2
  - ABS: aluminoborosilicate
  - PSG: photosensitive glass
  - Other
- Amorphous
- Compatible with semiconductor processing environments

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Intrinsic properties that most matter for mm-W

- Dielectric constant Dk (Er')
- Loss tangent Df (Tan δ)
- Coefficient of thermal expansion (CTE)
- Resistivity
- Low moisture absorption

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Extrinsic properties that matter for mm-W

- Smooth surface
  - Skin effect at higher frequency makes surface roughness increasingly critical
- Low Total Thickness Variation (TTV) of material
  - Need to count on this, to match design
- Ability to form through-glass vias (TGVs)
  - Size and shape can matter
- Ability to achieve correct thickness for given application
- Ability to form 3D structures as needed

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Is glass actually advantaged vs incumbents?

Property	Desired	Organic (Isola MT77)	High resistivity single crystal Si (Topsil)	ABS glass (Corning, Schott, AGC)	Fused Silica (Corning)	Photosensitive Glass Ceramic (3DGS)
Resistivity	High	10^{13} Ω-cm	10^{5} Ω-cm	10^{13} Ω-cm	>10^{15} Ω-cm	>10^{15} Ω-cm
Dielectric Constant	Low	3.0	11.7	5.0	3.8	As low as 1 with air cavity, bulk=6.4
Loss Tangent	Low	0.0017 @ 10 GHz	0.004 @ 35 GHz	0.006 @ 10 GHz	0.0004 @ 100 GHz	As low as 0.000001 with air cavity, bulk=0.014 @ 10GHz
Surface Roughness	Low	Depends on Cu foil, typically ~ 1 um	< 1 nm	<1 nm	< 1nm	<1nm

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Coefficient of Thermal Expansion (CTE) will influence packaging approach and reliability

- CTE of Aluminoborosilicate Glass (ABS): ~3.4 ppm/°C
- CTE of Fused Silica (FS): ~0.5 ppm/°C
- CTE of Photosensitive Glass (PSF): 8.53 ppm/°C

- CTE of Copper: ~16.7 ppm/°C
- CTE of organic laminates: 3 – 17 ppm/°C

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"Heterogeneous Integration Platform"

From Madhavan Swaminathan, GaTech,3/2021 presentation to iNEMI "**Packaging for mmWave Communications**"

- Materials with Silicon like properties that maximize chip and board level reliability and support larger body sizes required!
- CTE in the range of 7-9 ppm/C with low surface roughness, Young's Modulus and zero moisture absorption required.
- Glass Interposer is a good candidate!

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GT-3D Systems Packaging Research Center | iNEMI Seminar | Mar. 11, 2021

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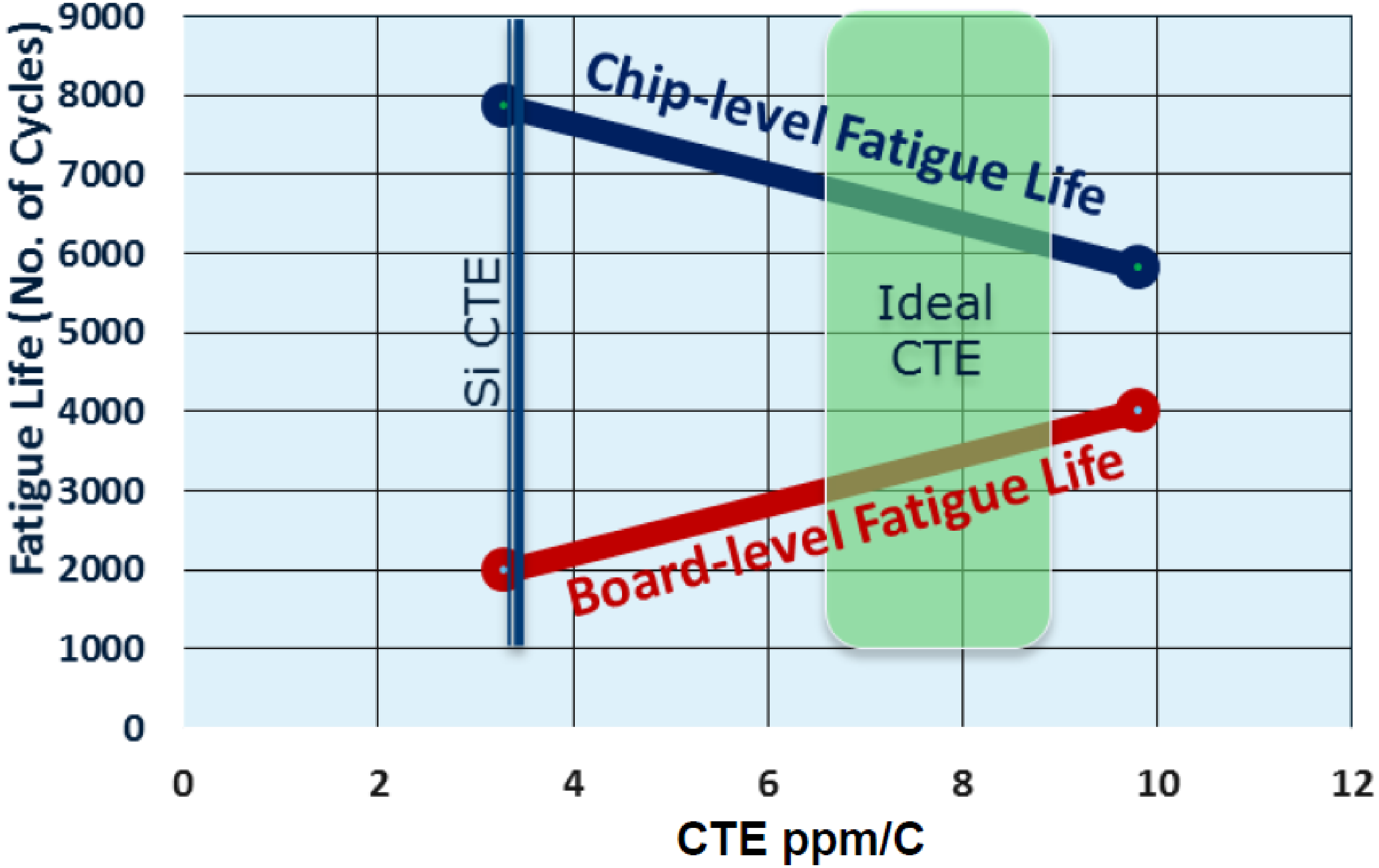
One view of how to optimize stresses of packaging for heterogeneous integration



Madhavan Swaminathan, GaTech,3/2021 presentation to iNEMI

Ideal CTE ~ 8 ppm/C

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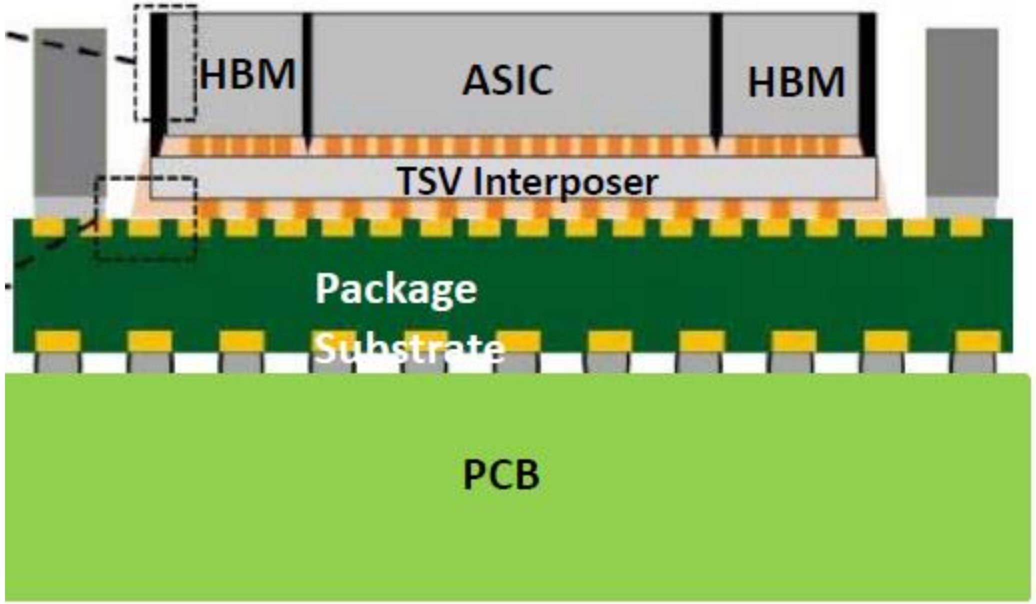
Alternative optimization of packaging stress

- Follow path of Si interposers
- Good CTE match with Si chips → **CTE of ~3 ppm/C**
- Separate optimization of interposer/package substrate interface



John Lau, ECTC 2022

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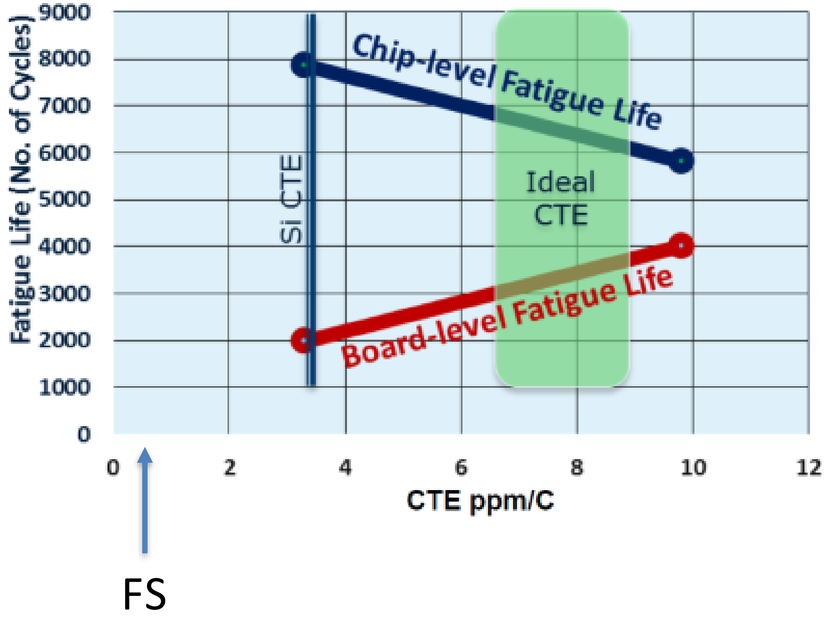
Fused silica has low CTE, but low loss properties may be worth it



Advantages of fused silica glass as substrate

- Fine pitch lines and spaces
- Micron-scale vias (TGV)
- High dimensional stability
- Low moisture absorption

Good, but not unique to fused silica

- **Low Dk and Df** : Testing of this was part of previous iNEMI project

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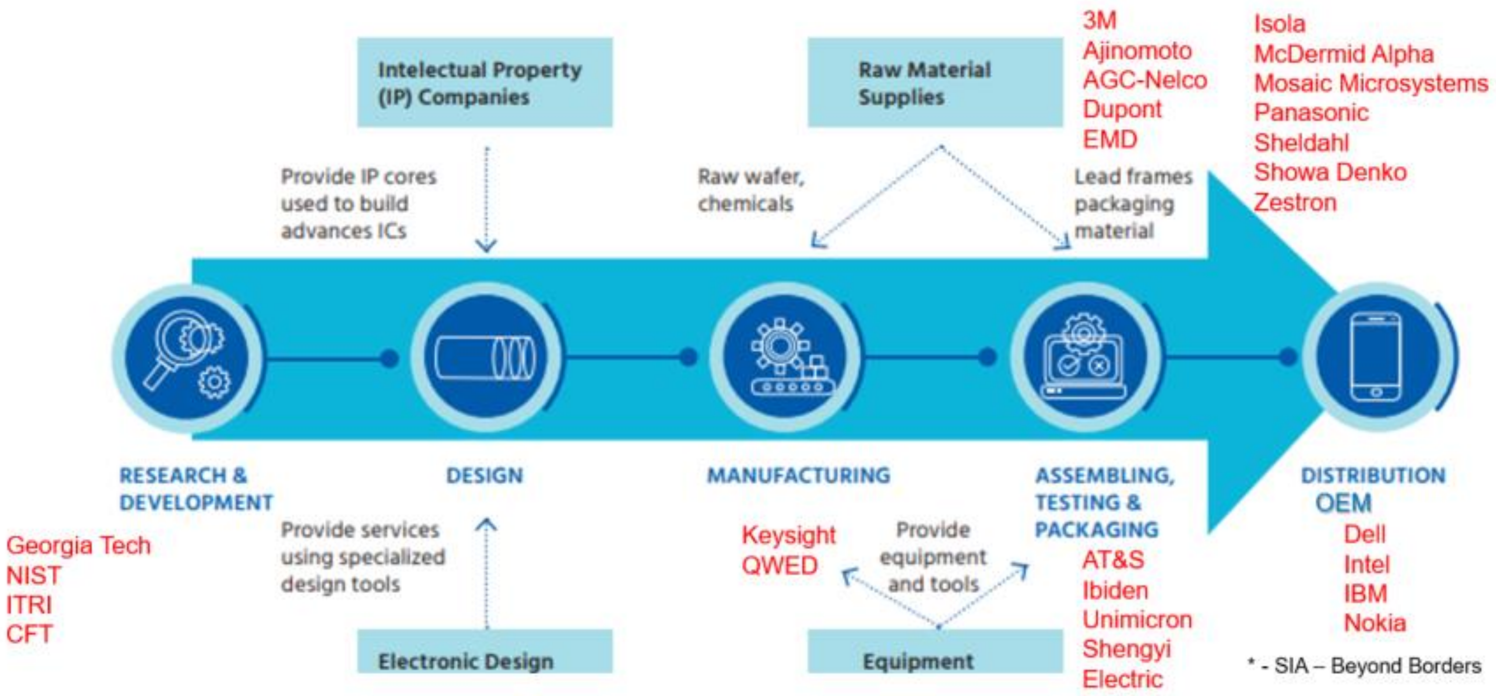
iNEMI 5G Material Project - Project Tasks [completed 2021]

- Task 1 – Benchmarking permittivity methods, potential reference materials
- Task 2 – Emerging technologies / 100GHz & beyond
- Task 3 – Multi Lab Round Robin Reference Experiment
- Task 4 – Extension to advanced substrate materials

From report by Michael Hill, Intel



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Task 4: testing “real” samples in different labs

- Keysight
- Intel
- NIST
- QWED
- Nokia

US Labs (Keysight, Intel, NIST)

EU Labs (QWED, Nokia)

Samples submitted by global project members from USA, EU and Asia

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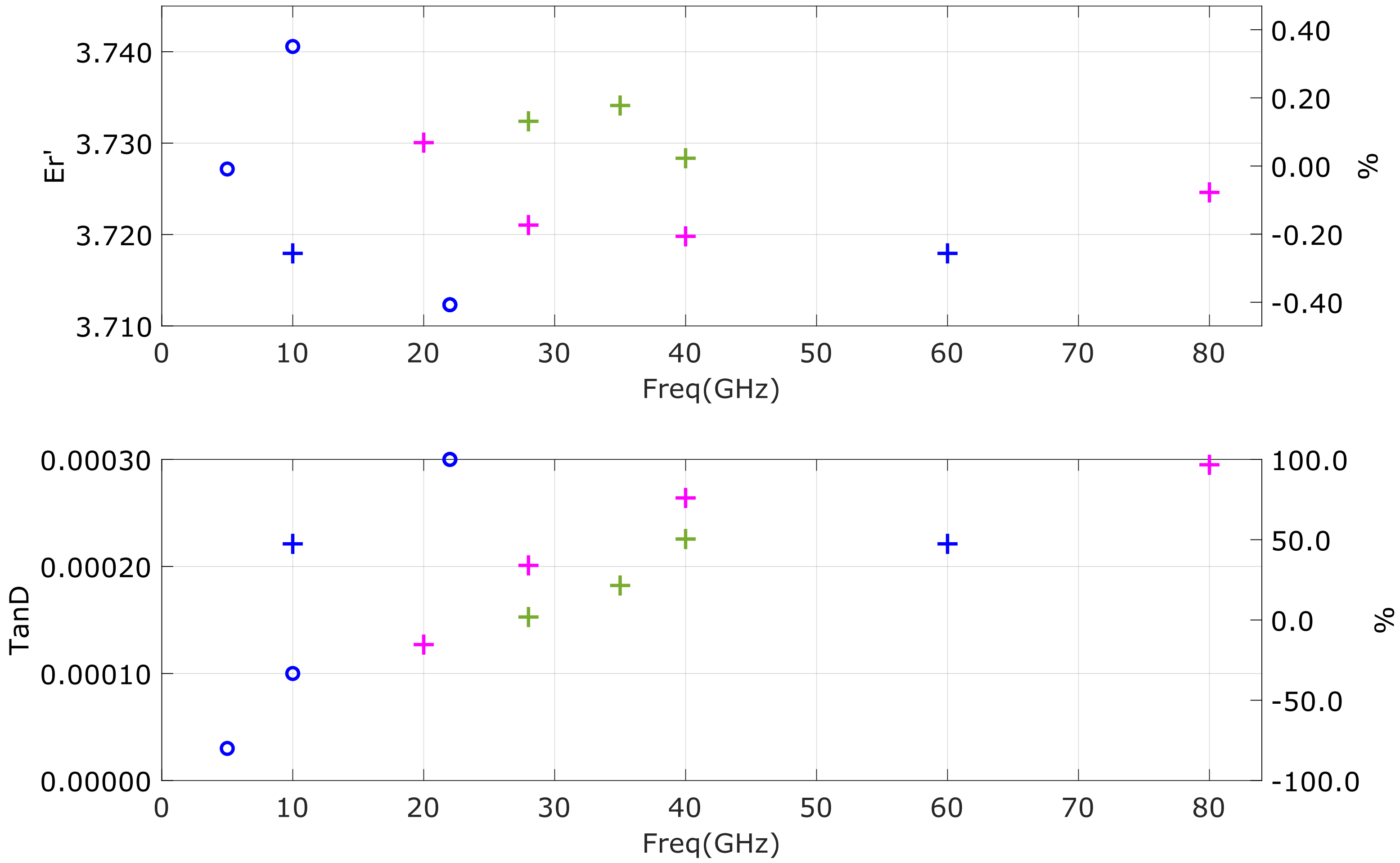
High Purity Fused Silica data from iNEMI Round Robin



Take away messages

- Different **expert** labs give different values

→see next talk by Lucas Enright!

- Overall, HPFS is very low loss at high frequency

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- **Application-specific choices**

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Application space for “5G / mm-W” glass materials is complex

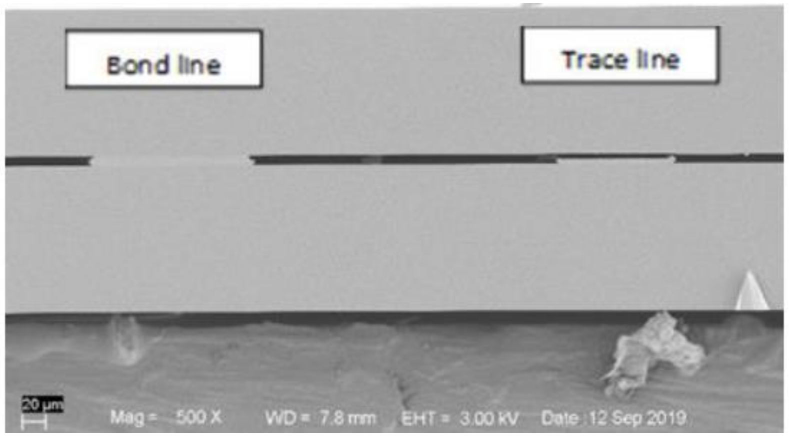
Glass is being used for:

- Heterogeneous integration for high frequency I/O
- Antenna structures for mm-W RF
- Splitters, combiners, band pass filters, diplexers, passive RF filters

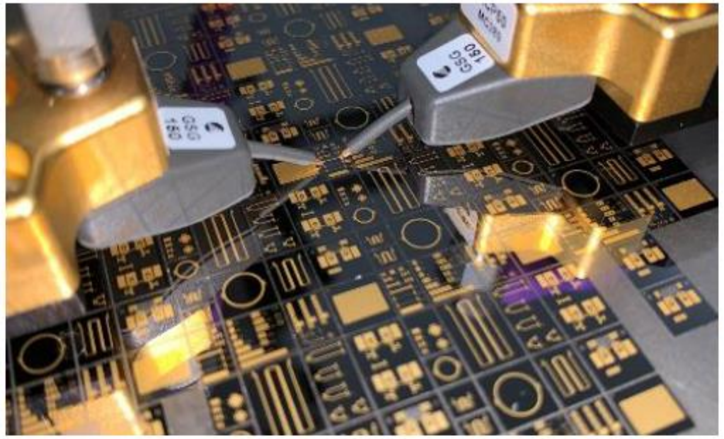
- Details of each application make a big difference
- Different glasses can be used to good effect

Example of mm-W packaging in thin FS glass (GE & Mosaic)

- 0.15 mm thick glass
- Thermal compression bond Au
- Wafers processed by GE Research



2-layer RF interposer cross section

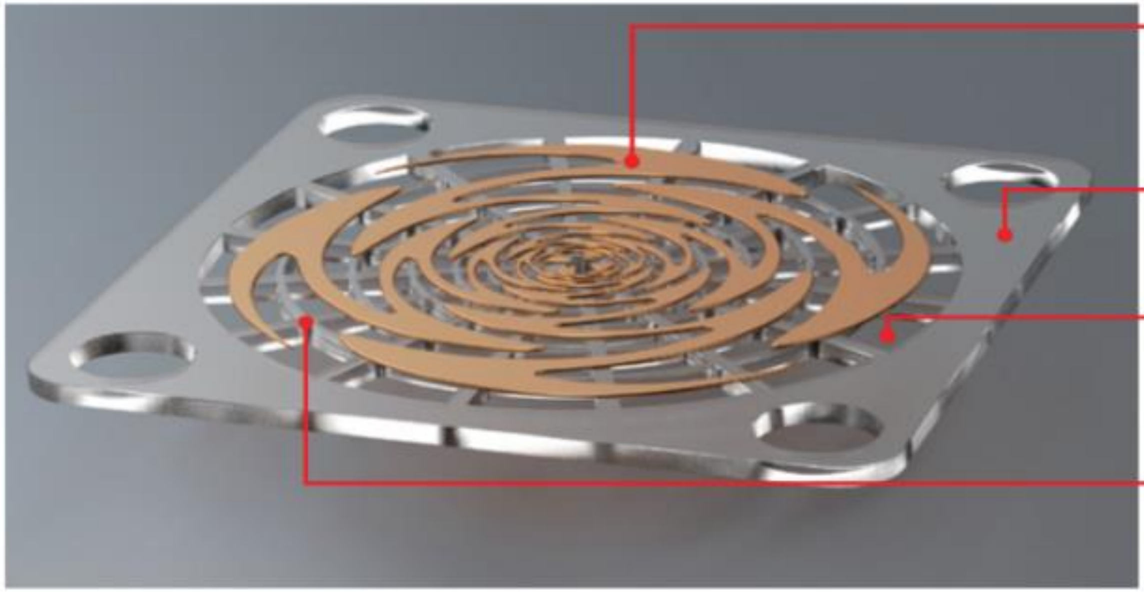


2-layer RF interposer under test

- Analysis shows glass based approach can provide 50% lower loss with standard glass. More than 70% with fused silica
- In some applications, >7x reduce package size volume (e.g. filters)
- Primary benefit of glass is from impact of roughness/skin effect, which is pronounced in these designs that can have conductor lengths as long as 50 mm

Example of mm-W packaging in photosensitive glass (3DGS)

Phased Array (PA), dipole, sinuous, and patch antennas with superior dielectric (Dk) and loss tangent specifications



1) Antenna Element
Custom-designed antenna element rests on thin glass rails, surrounded by ≥ 95% air

2) Glass Substrate and Frame
Glass support structure enables easy device handling

3) Air Gap
Dielectric constants from 1.5 to 6.4 are achievable by controlling the glass-to-air-gap ratios

4) Glass Support Rails
150-micron thick, 15-micron wide glass supports maintain the structural integrity of the antenna

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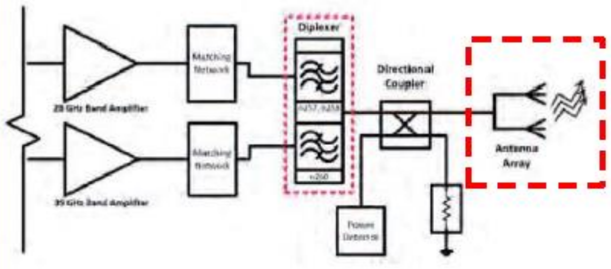
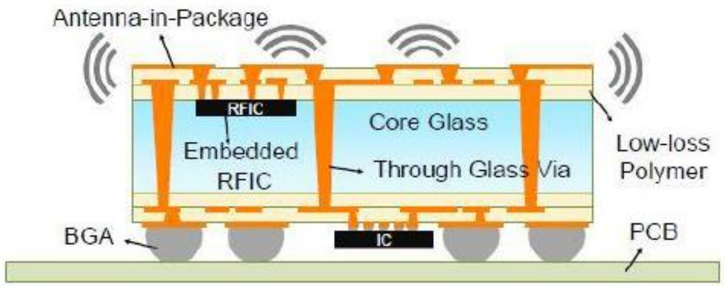
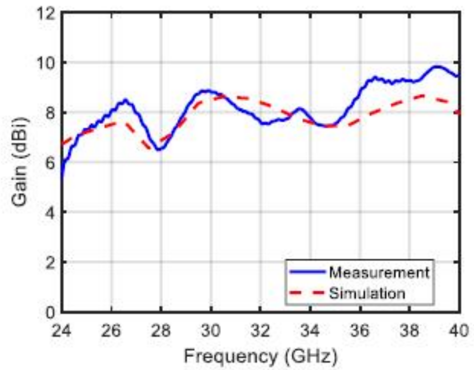
Example of mm-W packaging in ABS (Ga Tech)

Madhavan Swaminathan, GaTech,3/2021 presentation to iNEMI

Antenna Integration (Receive) – 5G n257-n261

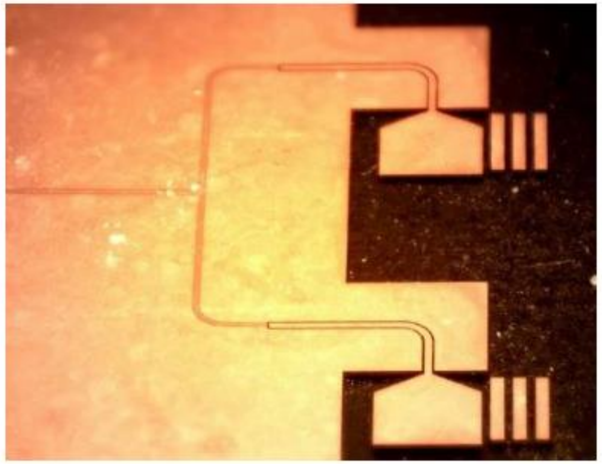


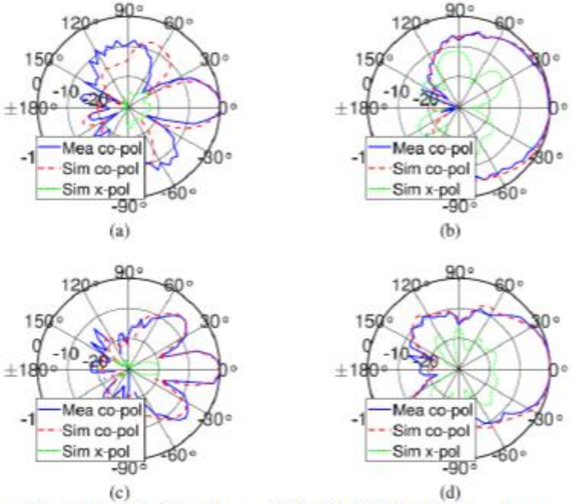




Layer	Thickness	Material
M1 (Top)	7 μm	Copper
Dielectric-1	15 μm	JSR polymer
M2	7 μm	Copper
Dielectric-2	15 μm	JSR polymer
Core-Glass	100 μm	AGC EN-A1
Dielectric-3(Bottom)	30 μm	JSR polymer

Tong Hong et al, IEEE AWPL, 2020





(a) 24.25 GHz E-plane, (b) 24.25 GHz H-plane, (c) 40 GHz E-plane, and (d) 40 GHz H-plane

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Conclusion

- Glass substrates are playing a role in mm-W packaging
- Types of glass are abundant, as are ways to use them
- This presents a challenge for the iNEMI Roadmapping team
  - Too much complexity makes the Roadmap hard to use
  - Too much simplicity makes the Roadmap irrelevant