Advanced RF MEMS Switch Devices using Glass Packaging

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Outline

- **Development of Glass as a Substrate and Packaging Material**
  - **Material properties**
  - **Supply Chain**

- Evolution for Radio Frequency Front Ends

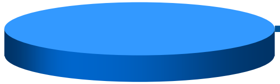
- RF Applications
  - LC-based Filters
  - MEMS Switches

The inherent properties of glass make it an excellent material of choice for RF and MEMS

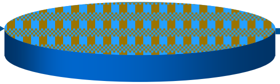
Properties of glass	MEMS and RF		
	Packaging	As a Carrier	MEMS Capping Material
Range of CTEs	✓	✓	✓
Optical transparency		✓	✓
Low electrical loss	✓		
Flatness & smoothness	✓	✓	✓
Stiffness	✓	✓	✓
Variety of thicknesses	✓	✓	✓
Scalability	✓	✓	✓

Leveraging Material Properties into Performance Advantages

Glass wafers tailor-made to specific applications



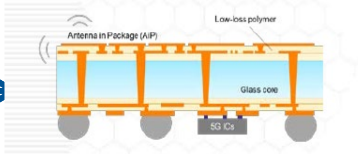
Glass wafer



Wafer w/ TGV

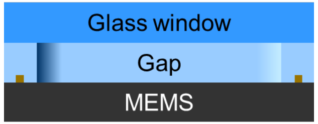
Wafer w/ cavities

RF Modules System



Glass' low electrical loss enables integration for RF modules

MEMS capping

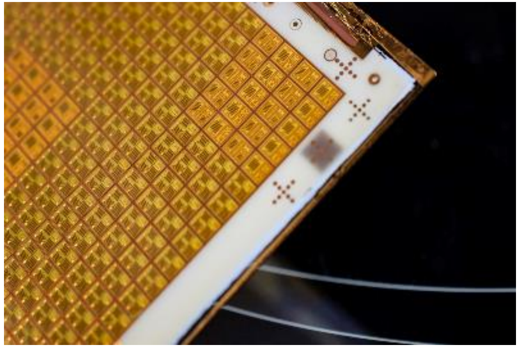


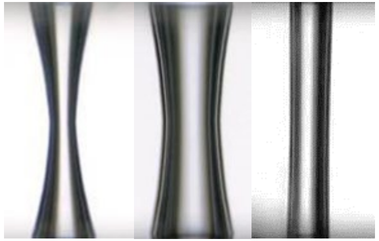
Glass caps create a **strong seal** which addresses hermeticity for MEMS

Corning's Through Glass Via Capabilities

We've made significant investments in precise TGV manufacturing

TGV (Glass + Vias)	**Dimensions**	Wafer: up to 300mm diameter Panel: up to 500x500mm
	Thickness	100µm - 500µm
	Via Diameter	30µm - 100µm → <30µm
	Pitch	Min. 2x via diameter
	Process Control	Positional accuracy: <± 10µm Yield: 42% improvement since '18 Metrology: 26x faster throughput since '18
	Volume	100s per month → 1000s in '19
Metallized TGV	**Process Control**	90% production grade selects
	Partners	Multiple in Asia and US
	Volume	100s per month





Precision via control at high throughput; Capabilities to make different via shapes

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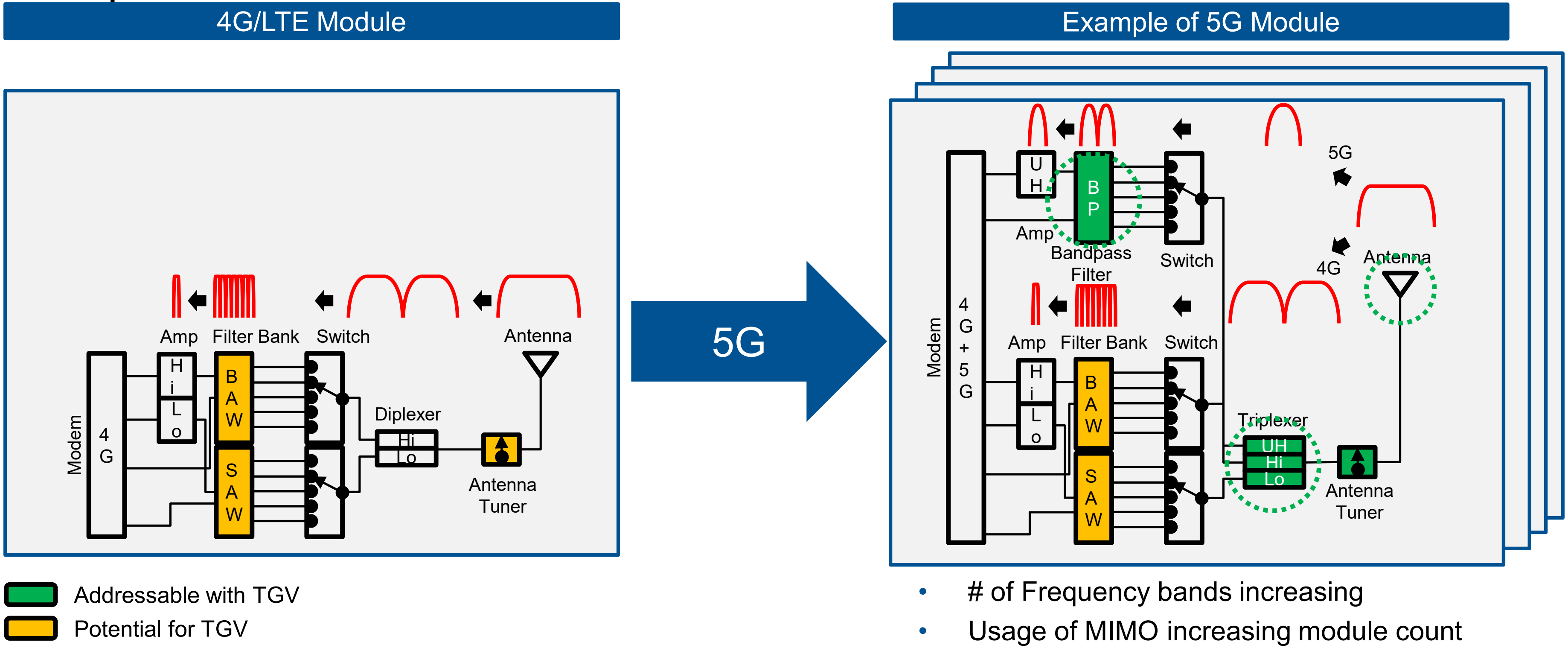
  - Material properties
  - Supply Chain
- **Evolution for Radio Frequency Front Ends**
- Use Cases
  - LC-based Filters
  - MEMS Switches

Handset RFFE evolution

4G → 5G is increasing demand for high performance substrates like glass with precision vias



- # of Frequency bands increasing
- Usage of MIMO increasing module count
- Integration and low loss instrumental for low cost

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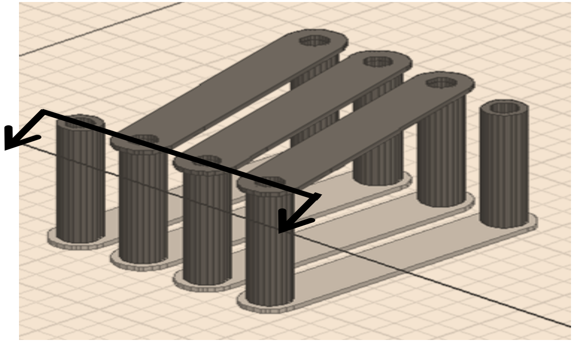
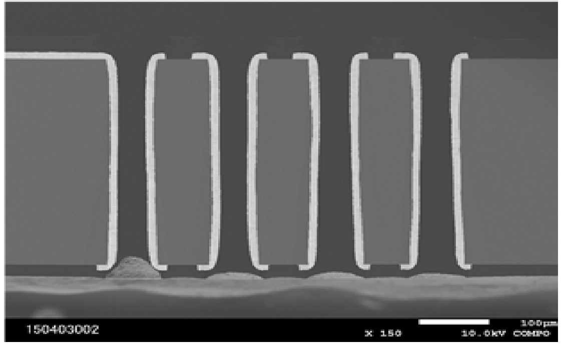
- **Use Cases**
  - **Filters**
  - MEMS Switches

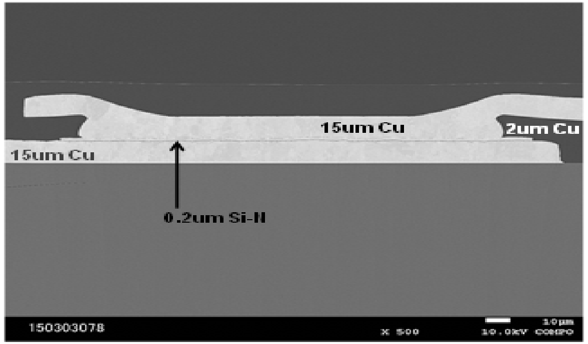
High Q inductors/capacitors have been demonstrated



3D rendering of inductor structure, top-down view

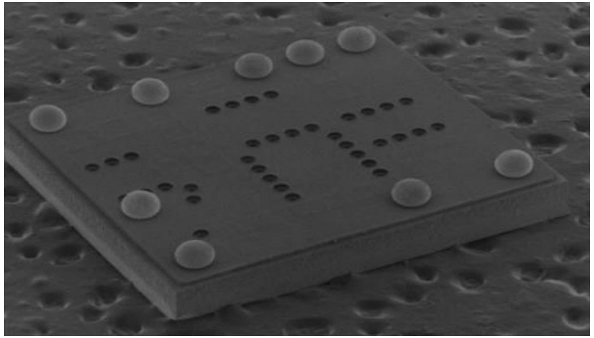


Cross-sectional SEM of a fabricated 3D inductor



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

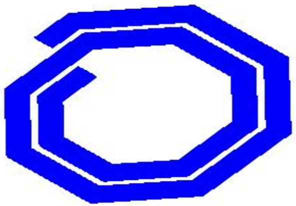
Source: Yun, Kuramochi, Shorey, "Through Glass Via (TGV) Technology for RF Applications", IMAPS 2015, Orlando, FL



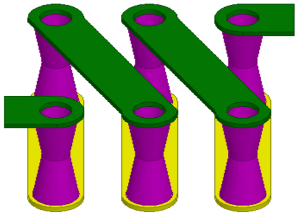
- Completed LC Network
- High Q inductance from 3D Solenoid inductor
- Capacitance achieved through MIM structure

Inductor Structures Compared

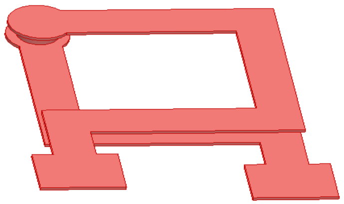
Inductor type	Inductance@ 100MHz (nH)	Q_{PEAK} @F /GHz	Q @900MHz	SRF (GHz)
LTCC	2.0	80 @ 3.95	55	8.68
TGV (SG3)	2.0	108 @ 3.95	61	>10
2D Glass	1.9	70 @ 5.94	27	>10
HRS	1.9	64 @ 4.48	25	>10



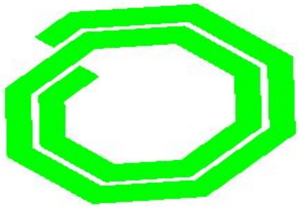
2D HRS inductor



TGV inductor



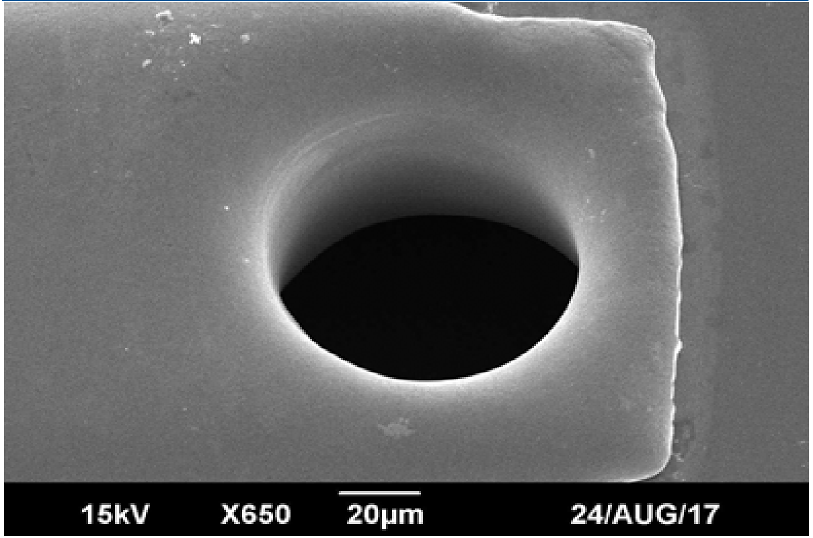
LTCC inductor



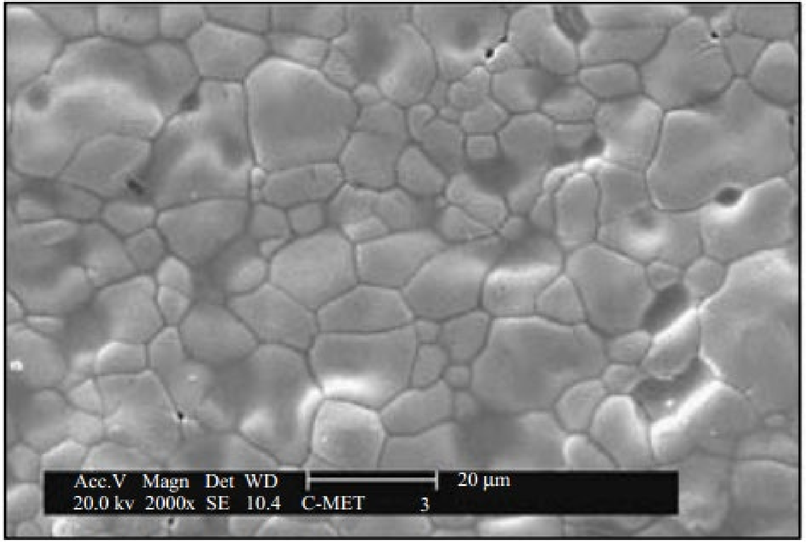
2D Glass inductor

Metal on glass achieves much smoother surfaces

Cu on glass	Ag on LTCC



Vs.

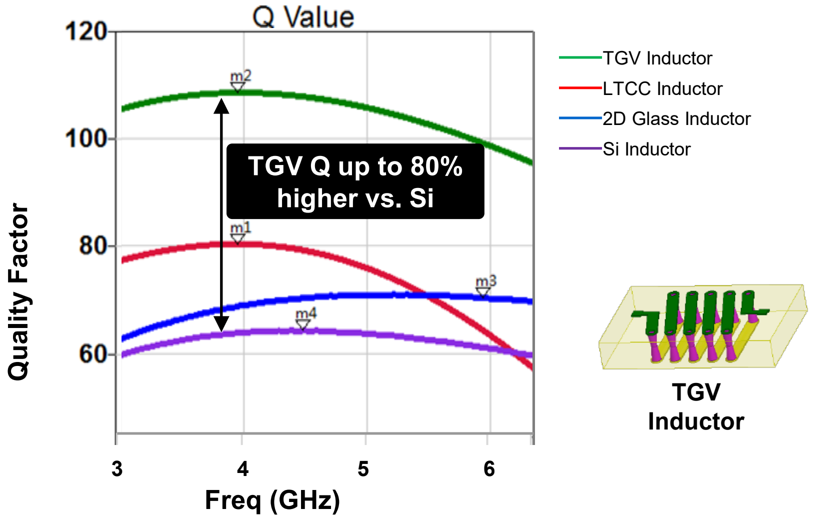


Source: U. of Florida

Source: S. Rane et al Soldering and Surface Mount Technology ·

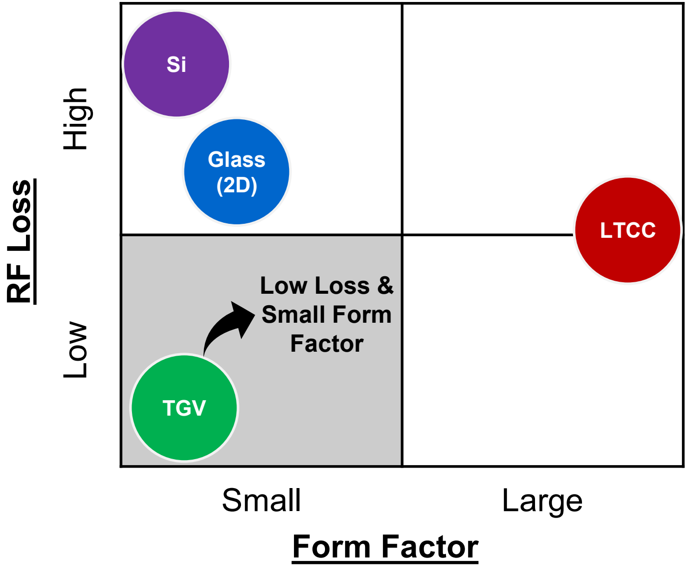
Handset RFFE evolution

TGV IPDs offer lower RF loss and small form factor



80% higher Q (lower RF loss) vs. Si

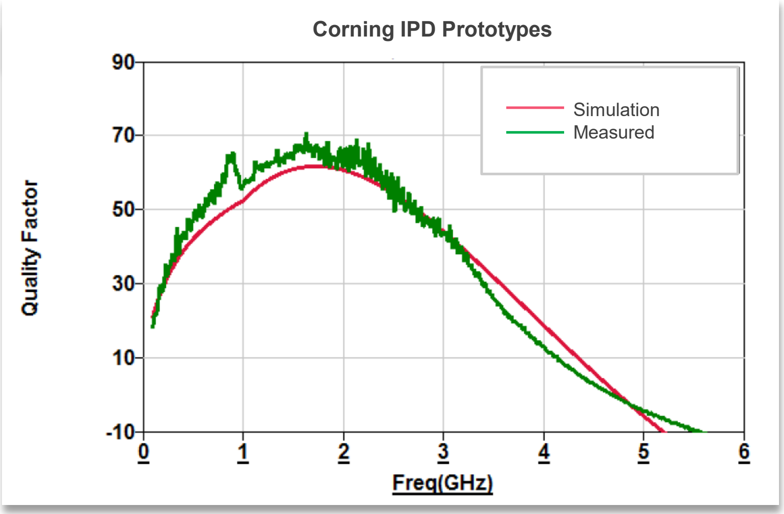
- Use same battery → Increase talk time
- Use smaller battery → Save space
- Use cheaper battery chemistry → Save up to ¢2/ phone

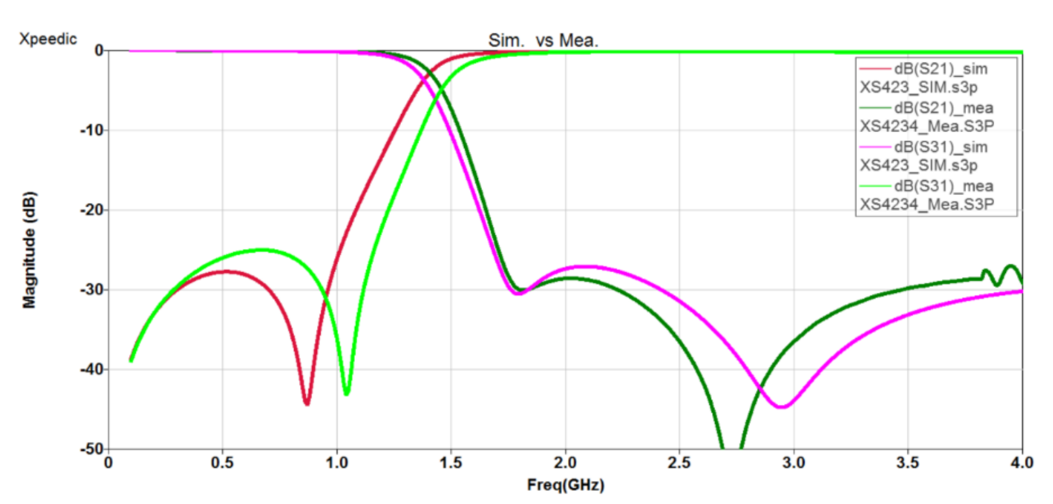


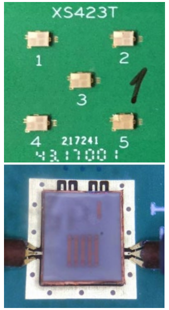
5-10X more components, same footprint

- Smaller thinner components→ slim devices

TGV IPD prototypes show high Q and low capacitance, which validates our model







- First TGV IPD prototype designed at sub-3 GHz shows higher Q (peak 70) vs. Si (peak 60) → Next, we are developing sub-7 GHz bandpass filter
- Developed knowledge in TGV and metallization processes with fab partners
- **We would like to propose jointly developing prototypes with your design**

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  - **MEMS Switches**

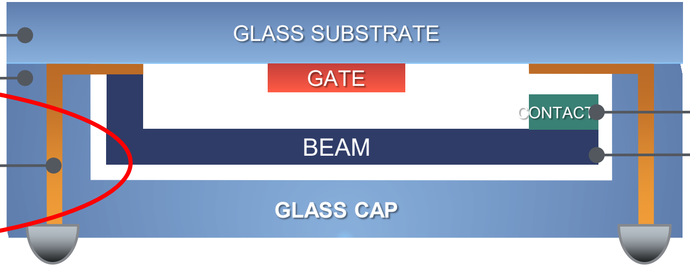
RF Switches

Menlo Micro introduces an ideal switch enabled by Corning TGVs

Simple & Scalable
Simple design lets us go very small (50µmx50µm unit cell)
Small → easy to scale power-handling through massive switch arrays
Small → easy to scale cost with volume : low-cost-roadmap

Unique glass packaging
Better thermals & power handling
Improved RF performance

Through Glass Via
Lower parasitics
Lower resistance
Smaller size package
Lower cost



Reliable
>3B cycles spec w/ roadmap to >20B
High-power capable

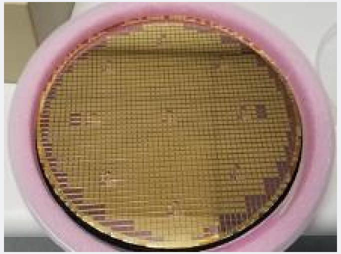
Versatile
Standard PDK to create many products
Shorter design cycles → Quicker to market

menlomicro

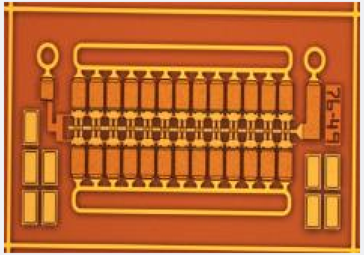
How is it made?

Revolutionary materials & processing combined with standard, scalable semiconductor manufacturing techniques

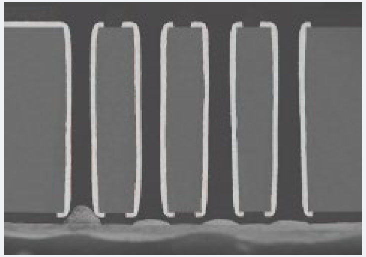
WAFER-LEVEL MANUFACTURING



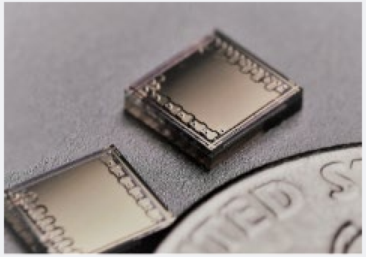
Wafer-scale manufacturing on 8 inch (200mm) glass substrates



Scalable series / parallel switch architecture: Design ability to scale up to 1000V+ and 10A+



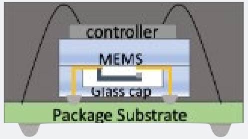
Through Glass Vias
Miniaturized packaging with highest performance



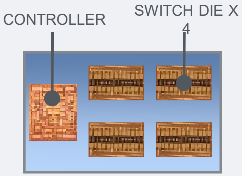
Wafer Level Chip-Scale-Package from $16mm^2$ to < $1mm^2$

APPLICATION-SPECIFIC CONFIGURATIONS

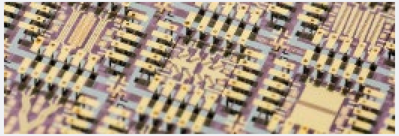
Core Switch
Simplest, smallest building block can be integrated into many power or RF applications.



Switch with integrated controls
Simpler control for high channel counts, decrease need for external components

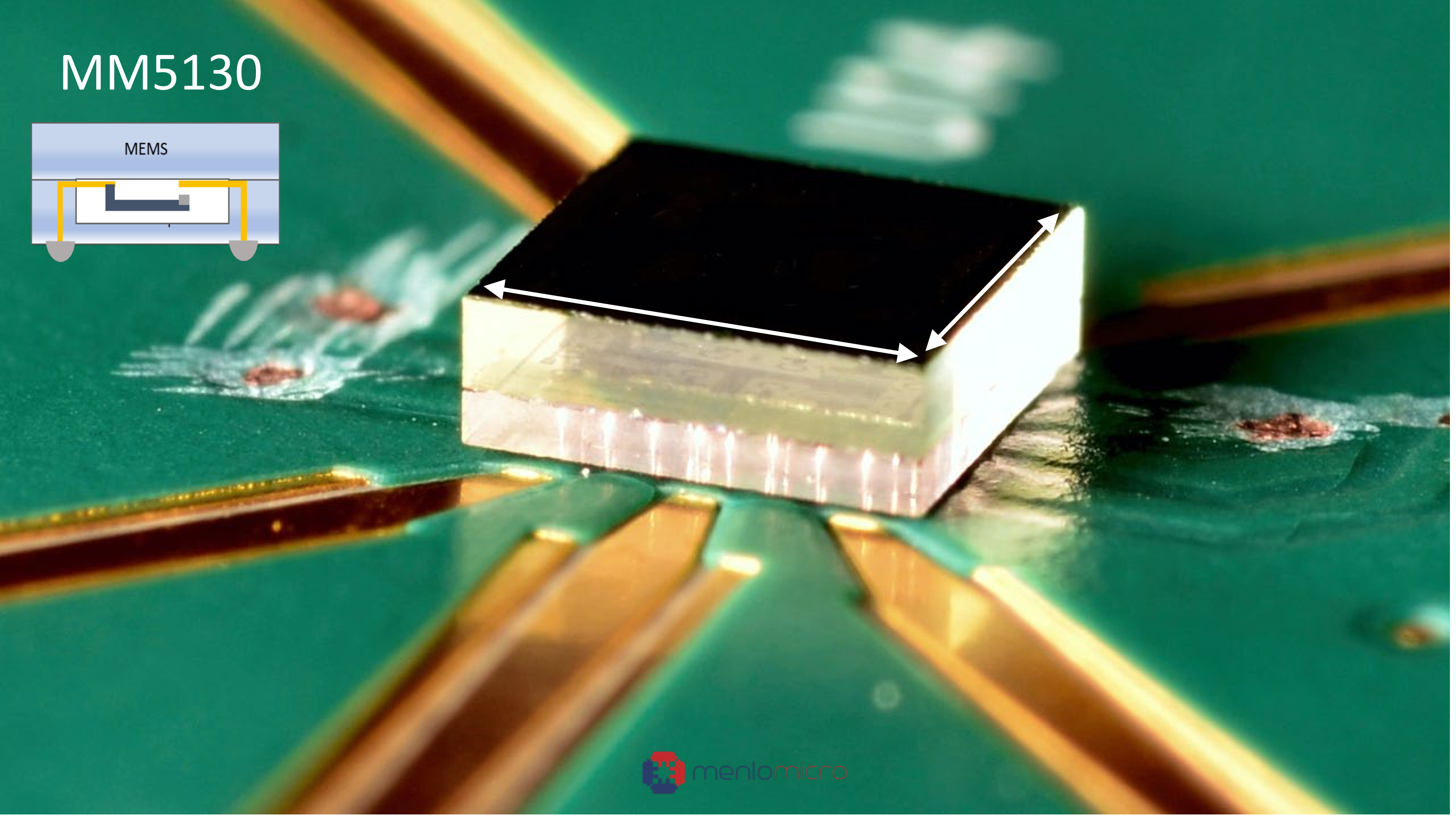


Multiple Switch die, w/routing & control: For matrix and high-density switching systems.



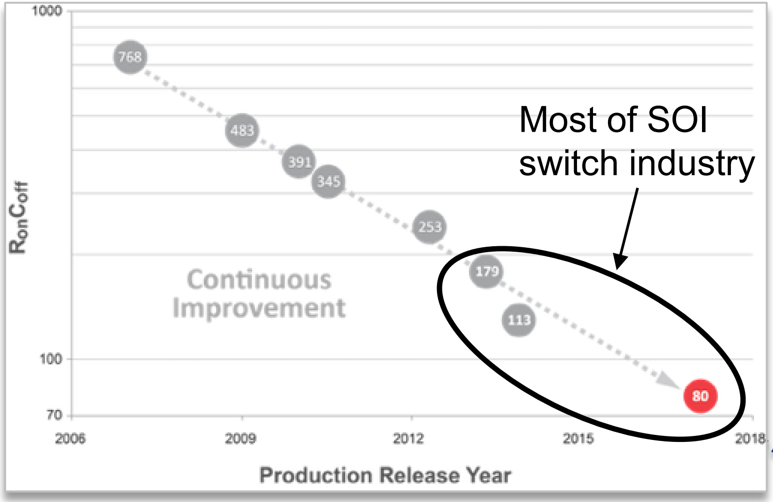
System-on-Chip
Integrate passives & other structures on die along with Menlo switches to create miniaturized RF & Power subsystems.

MM5130



RF Switches

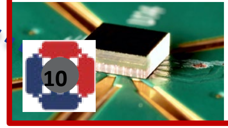
Metal-on-glass platform creates ideal RF environment for low Ron*Coff



Source: *Peregrine Semiconductor's next-generation platform, UltraCMOS® 12 technology*

Parallel	Series	R_On (Ohms)	C_Off (fF)	S21-on @ 6Ghz (dB)	S21-off @ 6Ghz (dB)	Power Handling	Standoff Voltage
1	1	1.16	6.2	0.10	32.5	26 dBm (0.4W)	150 V
1	2	1.6	7.6	0.18	45.0	26 dBm (0.4W)	300 V
3	1	0.86	14.2	0.09	24.5	35.5 dBm (3.5W)	150 V
3	2	0.72	17.3	0.10	37.5	35.5 dBm (3.5W)	300 V
5	1	0.86	18.5	0.11	20.0	40 dBm (10W)	150 V
5	2	0.80	28.3	0.14	31.5	40 dBm (10W)	300 V

**Various DMS unit cell configs measured at RF probe*



- Single series beam: Ron*Coff from **7 to 16fs**
- Dual series beam: Ron*Coff from **12 to 23fs**
- Significant margin for Vpeak, with power handling to go beyond UE

- For SOI, Ron*Coff is measured for *single transistor*
- Actual *switch product* needs transistor stacks for up to 80V

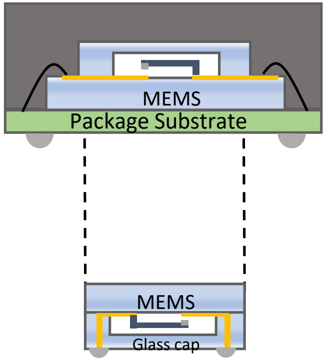
RF Switches

Lowest Losses from DC to mmWave

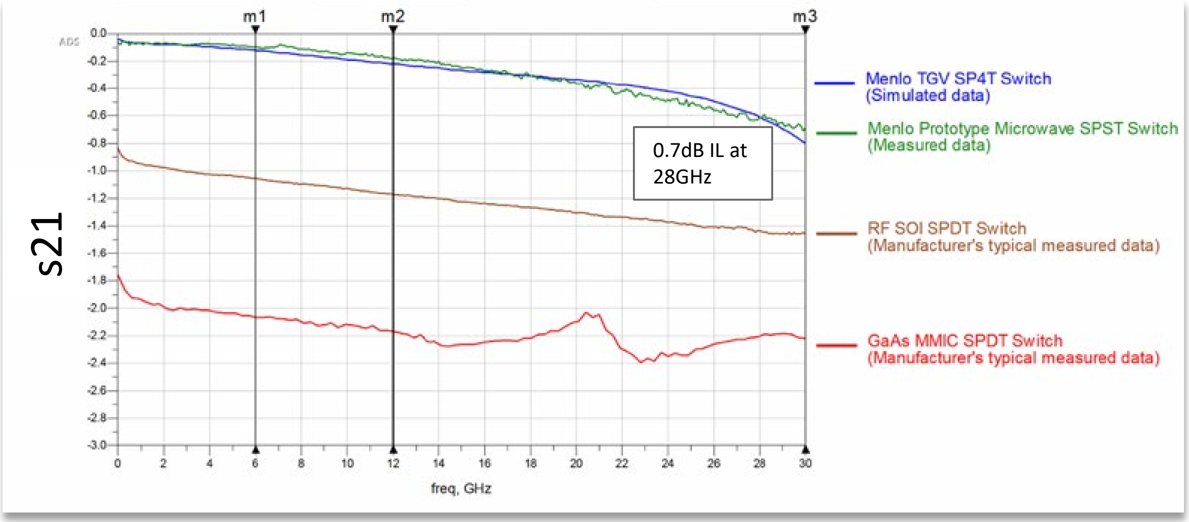
Previous generation of packaging (2017/2018)

Current generation of packaging

WL Glass Cap in **6x6mm** QFN



WL Glass Cap w/TGV CSP

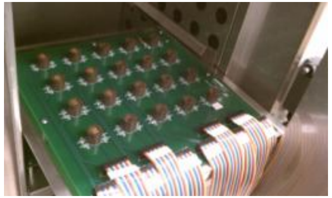


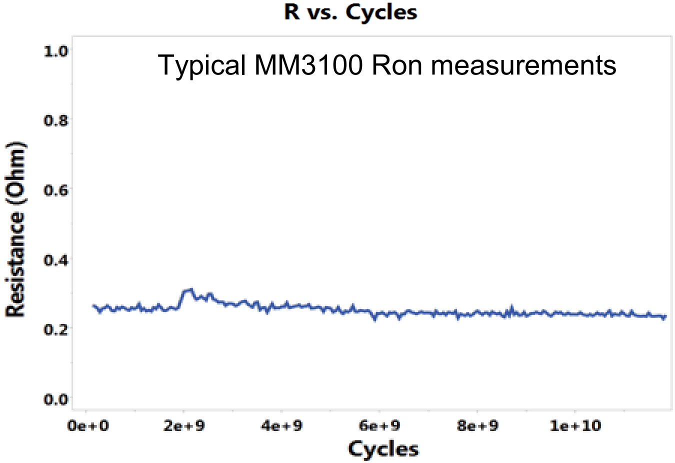
With TGV, everything gets better from an RF point of view:

- Lower parasitics, Lower bulk resistance/IL
- Improved thermals, better power handling
- Smaller size, lower cost

Advances in wafer-level glass packaging show mmWave performance is achievable

Reliability Testing shows Stable Operation





Continuous reliability testing for accelerated life evaluation:

- Multiple parallel automated testers capable of 20 die evaluation
- 3 ovens in operation at 3 different acceleration temperatures
- >10,000 die evaluated

Stable resistance <0.4Ω for over 12 billion cycles

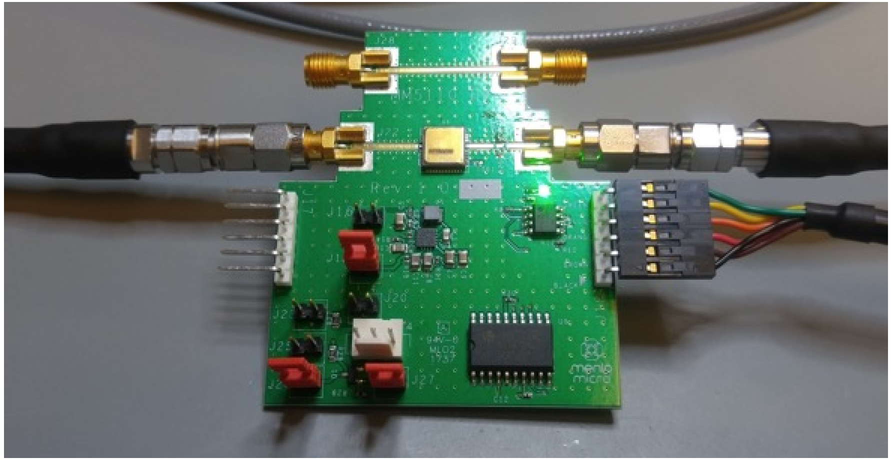
SPST 50W and 6GHz capability

- Switch ON:

Freq	S11	S21	S12	S22
1 Ghz	-32.48dB	-0.056dB	-0.061dB	-32.093dB
3 Ghz	-27.19dB	-0.100dB	-0.097dB	-33.716dB
6 Ghz	-19.00dB	-0.148dB	-0.156dB	-17.302dB

- Switch OFF:

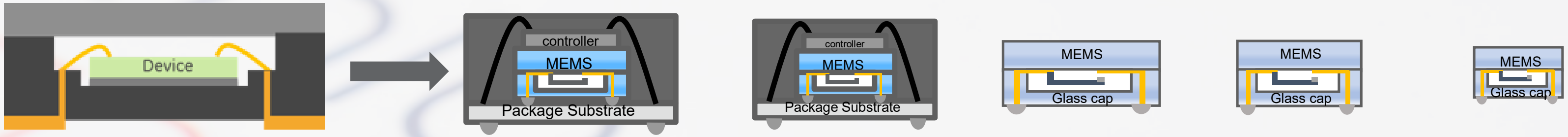
Freq	S11	S21	S12	S22
1 Ghz	-0.058dB	-24.809dB	-24.920dB	-0.097dB
3 Ghz	-0.535dB	-16.256dB	-16.557dB	-0.644dB
6 Ghz	-0.647dB	-10.229dB	-10.634dB	-0.916dB



RF Switches

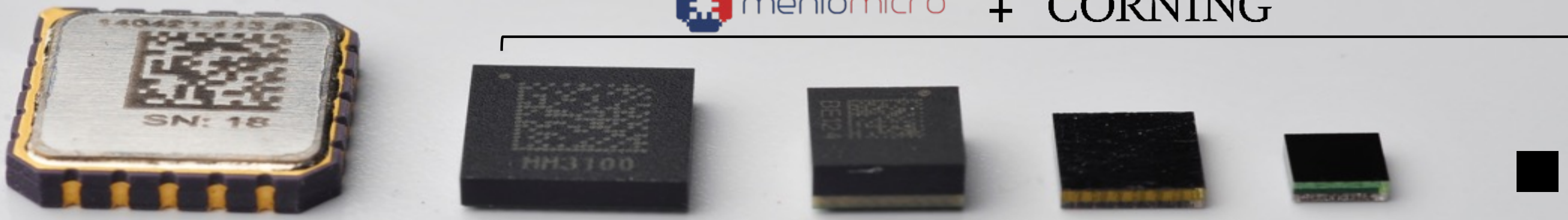
Packaging evolution

2017	2018	2019			2020
MM7100	MM3100	MM5120	MM3100	MM5130	



MEMS in hermetic **9x9mm** package	WL Glass w/TGV **6x6mm** BGA w/SPI	WL Glass w/TGV **4x4mm** BGA w/Vbst	WL Glass w/TGV **4x4mm** FC die	WL Glass w/TGV **2.6x2.6mm** FC die	WL Glass w/TGV **1x1mm** WL-BGA

menlomicro + CORNING



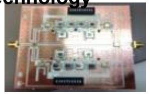
Corning-Menlo partnership is enabling the scale-up of a low cost TGV supply chain

RF Tunable Filter – Size, Weight & Power for RF

MM3100 Replacing PIN diodes in tunable radios

Ex. Mil Radio

Key metrics:
- Fast frequency tuning
- Lightweight
- Long battery life
- Reliability

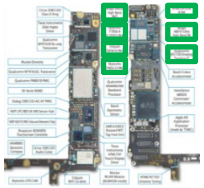
	With PIN diode  UHF interstage (2W)	**With DMS Technology**  UHF interstage (20W)	**Benefits:**
Max input:	**<2W**	**20W+**	• **10x increase in power handling**
Size:	**200+** components (2-sided board) 50% area for complex pin-diode switch biasing	**~25** components No pin-diodes, single-sided board, simple bias scheme	• **80%+ reduction in components** • **75% reduction in board size** • **Reduced need for thermal management, smaller box**
Insertion Loss:	> **3dB** @ 500MHz	< **2dB** @ 500MHz	• **33% reduction in RF losses, less heat, longer battery life**
Power Consumption:	**1.2W**	**<100mW**	• **90% reduction in DC losses, less heat, longer battery life**
Linearity:	**IP3: ~40dBm**	**IP3: ~65dBm**	• **Reduced distortion, higher data rates**

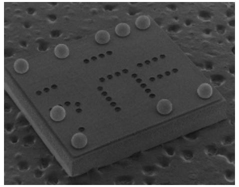
Potential to enable **high power handling (5W-20W)** in a **2W** form factor

High Performance Substrate Material

Glass and Through Glass Vias (TGV)

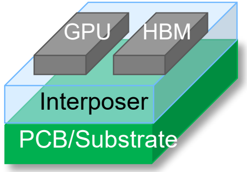
Radio Frequency Front End (RFFE)





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

Interposer (Photonics, High Performance Computing)



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

Summary

- Material properties being leveraged into device level performance benefits
- RF Front End Usage cases broadening into Filters, Switches, Antennas
- RF MEMS Switches gain on:
  - Insertion Loss
  - Figure of Merit
  - Harmonics
  - Packaging Footprint
  - Thermal/Power Handling

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