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Alumina Ribbon Ceramic and its application in 5G mmWave filter

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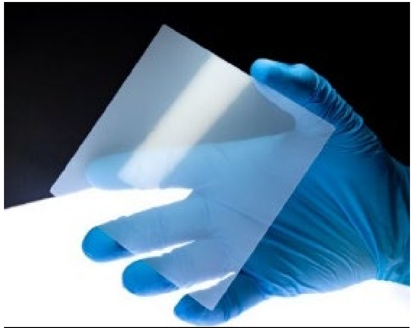
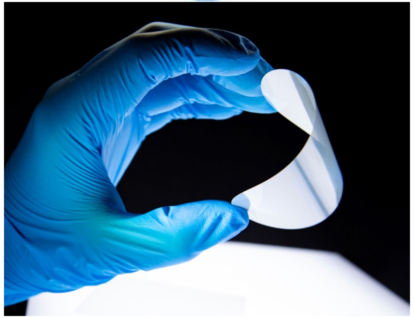
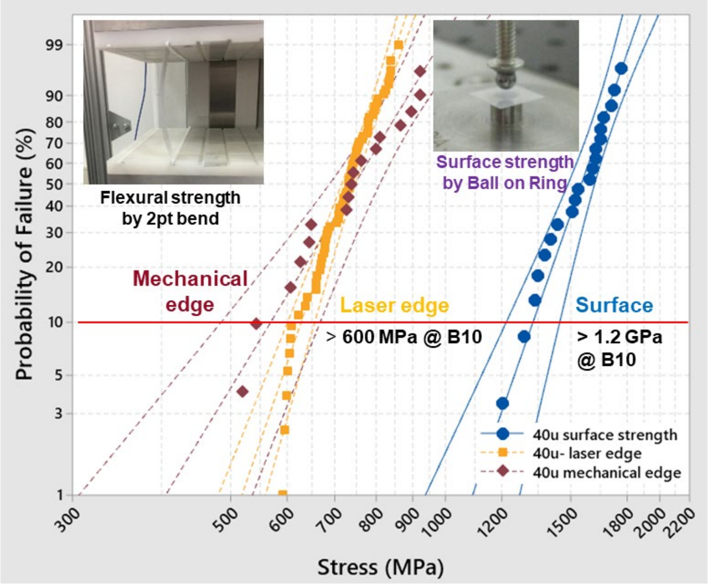
Corning's innovative Continuously Sintered Ceramic process enables breakthrough ceramic solutions in ultra-thin form factors with high strength

- Alumina Ribbon Ceramic – produced in roll, supplied as wafer/panels, available in multiple ultra thin thicknesses (40, 80 and 120umt)





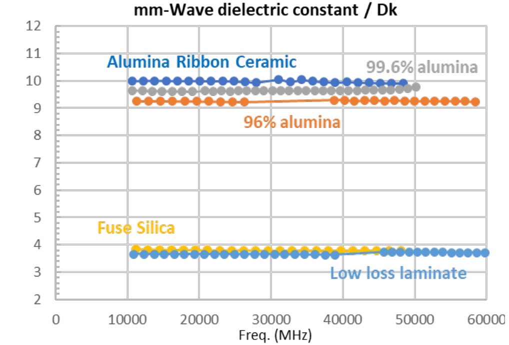
- Dense, fine-grain microstructure leads to > 1.2 GPa surface strength and superior edge strength > 600 MPa with laser cutting

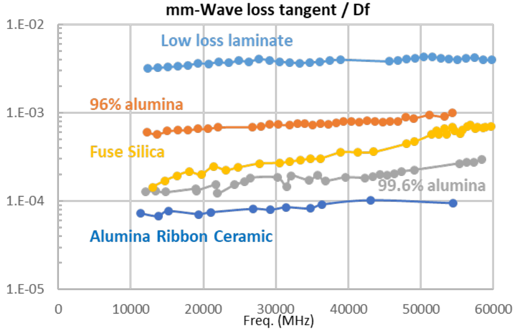


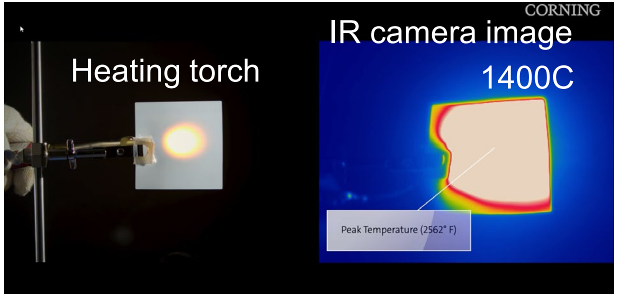
Reference: Zhuang et al. (2020). "Flexibility matters: High purity, thin, flexible alumina ribbon ceramic," *Ceramic & Glass Manufacturing* 1(4). Published within *ACerS Bulletin* 99(7): 54–58.

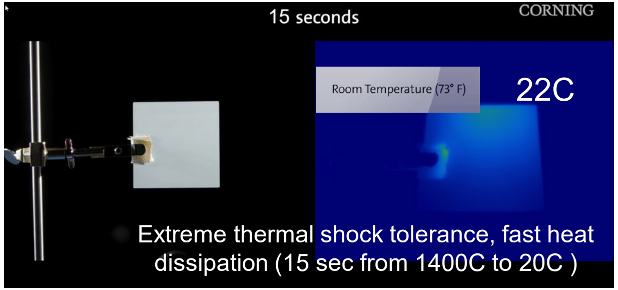
Upscale properties of Alumina Ribbon Ceramic – thin, low loss and good thermal, make it an ideal candidate substrate for 5G application

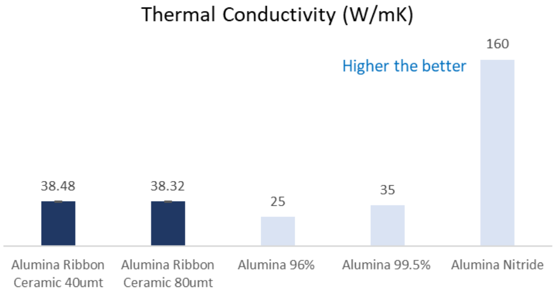
- Remarkable low loss and good dielectric strength are attractive for a variety of RF devices and power electronics
- Good thermal management capability due to its high thermal conductivity and low thermal mass – provides heat dissipation solution

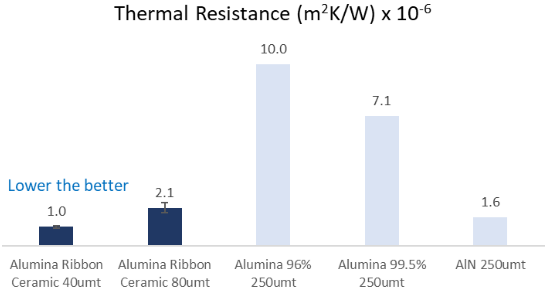








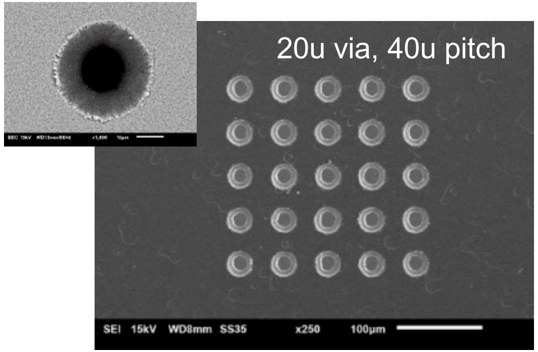


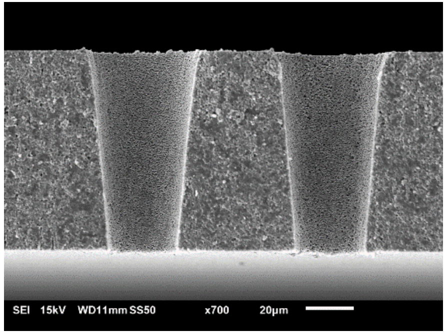


Reference: Zhuang et al. (2020). "Flexibility matters: High purity, thin, flexible alumina ribbon ceramic," *Ceramic & Glass Manufacturing* 1(4). Published within *ACerS Bulletin* 99(7): 54–58.

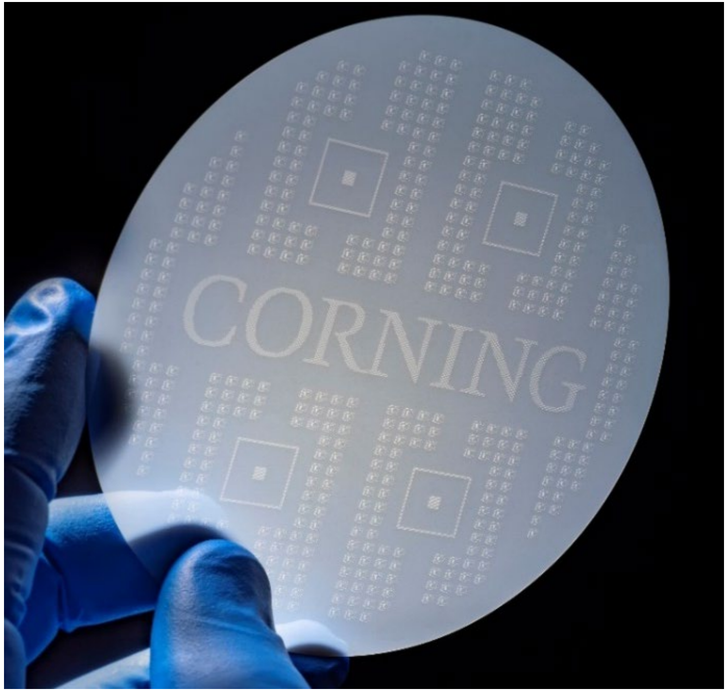
High quality, small and dense via demonstrated on Alumina Ribbon Ceramic, smoother surface (Ra~50nm) enables fine line capability as well as good Cu adhesion

High quality, small through substrate via

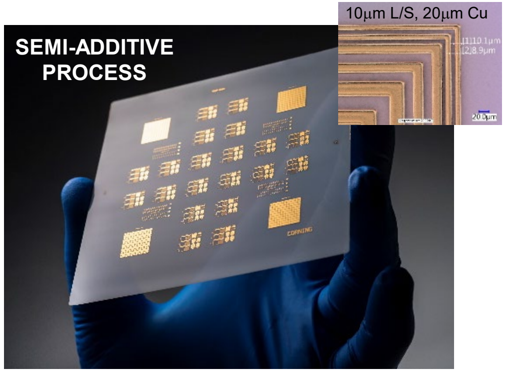


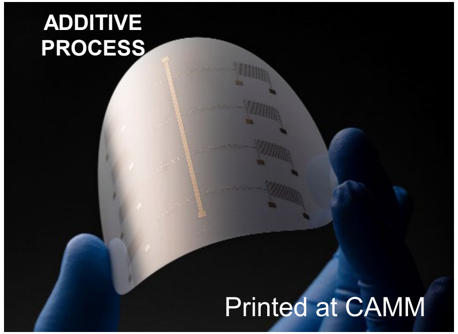


Pattern with 24,628 vias at 40um via size



Smooth surface, fine line



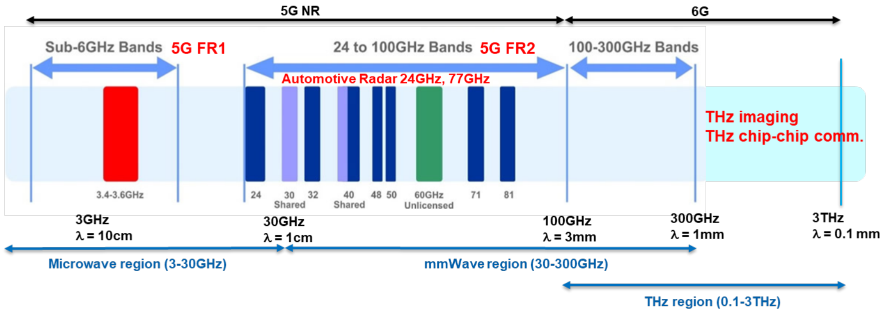


Reference: Zhuang et al. (2020). "Flexibility matters: High purity, thin, flexible alumina ribbon ceramic," *Ceramic & Glass Manufacturing* 1(4). Published within *ACerS Bulletin* 99(7): 54–58.

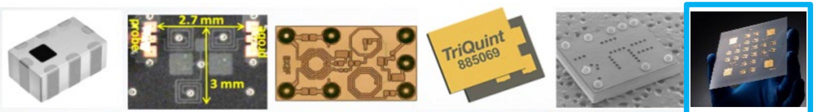
Alumina Ribbon Ceramic is the thinnest option for high frequency low loss substrates with excellent thermal conductivity and mechanical strength

- Wireless communication system is transitioning from 4G LTE to 5G to meet the increasing demands for higher data-rates, wider bandwidth, and lower latency
  - Increase number of bands lead to increasing of filters (over 60filter in a smart phone)
  - High operation frequency, broad band, integrated device functionality and miniaturization requires new substrate with thin thickness, low energy dispersion loss and good thermal management
- 5G NR (New Radio) uses two frequency ranges (FR)
  - 5G FR1, sub-6 GHz frequency bands – example n77(3.7GHz) / n79(4.7GHz) with 600-900MHz bandwidth
  - 5G FR2, mm-Wave range frequency bands (24-100 GHz) – n257(28GHz) with 3GHz bandwidth – higher data rate

5G and 6G bands



Evolution of passive component technologies



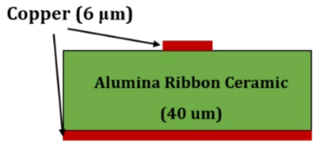
	LTCC	Laminate	Silicon	Acoustic Wave	3D Glass	Alumina RC
Performance	Low loss	Substrate loss	Substrate loss	High selectivity	Low loss	Low loss
Thickness	Thick	Thin	Thin	Thin	Thin	Thin
Size	Small footprint	Moderate footprint	Moderate footprint	Small footprint	Small footprint	Small footprint
Density	Low density	Moderate density	Moderate density	High density	High density	High density
Frequency	Low - high	Low - moderate	Low - moderate	Low	Low - high	Low-High
Cost	Mass production	Less in demand	High	High	Not in market	development
Thermal	Good	Low	Excellent	Good	Low	Great

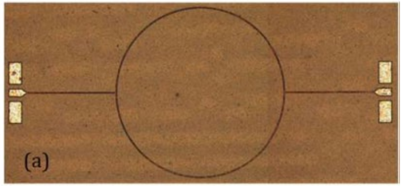
https://www.accton.com/Technology-Brief/the-emergence-of-5g-mmwave/

Watanabe et. al. IEEE Trans on Components, Packaging and Manufacturing Technology, vol 11, No. 1, 1.2021

Substrate low loss confirmed with Microstrip Ring Resonators in 30-170GHz on a test vehicle which is fabricated with a Semi-Additive Patterning (SAP) Process

- Test structure fabricated on 40umt ARC with a SAP process, dimensions showed the high accuracy of fabrication process
- D_k and D_f are extracted using microstrip ring resonator (MRR) method
- D_k is steady around **9.87** in 30-170 GHz, D_f varies from **0.0003 to 0.0013** in 30-170 GHz and outstands the most of 5G substrate materials
- Promising for high efficiency and ultra-miniaturized passive components and packages in 5G/mmWave frequency region



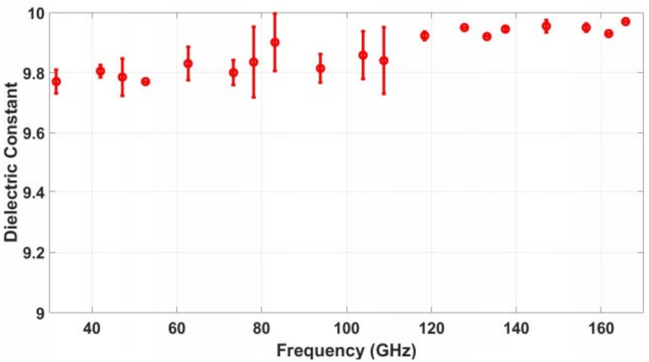


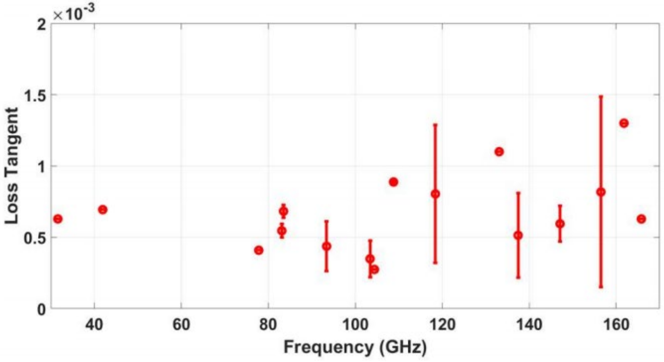
- Material stack-up and fabricated MRR

Substrate Material	ε_r	tan δ	f (GHz)
Polymer/Glass/Polymer [6]	4.6	0.009 at 103 GHz	75 - 110
LCP [7]	3.16 ± 0.05	0.0045 at 97 GHz	31.53 - 104.6
LCP [8]	3.17	0.0055-0.009	110 - 170
Astra [19]	2.82	0.001	125
Teflon [21]	2.1	0.00028	3
Rogers [22]	2.94	0.0012 at 10 GHz	8 - 40
Alumina Ribbon Ceramic (this work)	9.87 ± 0.03	0.0006 at 165.8 GHz	30 - 170

- Comparison to other 5G substrate materials

Extracted D_k, D_f of ARC in 30-170GHz range

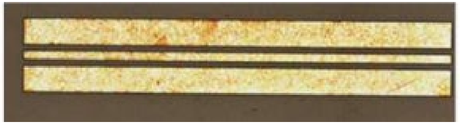




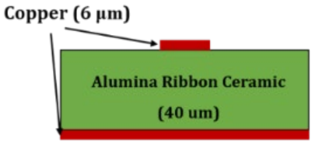
Co-Planar Waveguides exhibit one of the best insertion loss (dB/mm) against similar transmission lines structures on other substrates in 30-170 GHz

- Average insertion loss from CPW line varies from **0.053 dB/mm to 0.242 dB/mm** in 30-170 GHz
- Measured S_{21} of MS lines changes from **0.089 dB/mm to 0.29 dB/mm** in 30-170 GHz
- Alumina Ribbon Ceramic could be a promising ultra-thin material for 5G and 6G applications where low loss is an important attribute

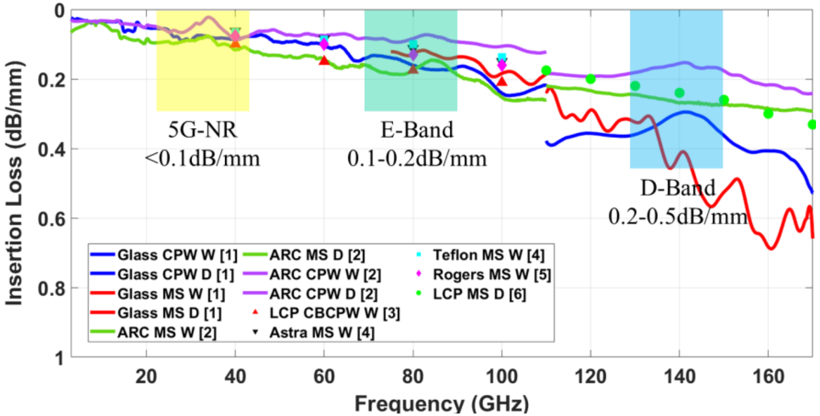
- CPW line Stack up structure and fabrication



- MS line Stack up structure and fabrication



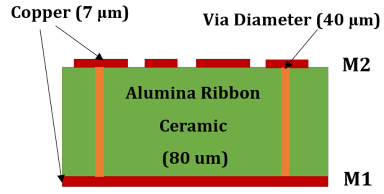
- Comparison of S21 (dB/mm) of ARC -based interconnects with similar structure on other substrates in 30-170 GHz



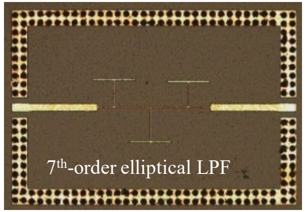
D. Thompson et. al, IEEE *ECTC*, 2003; F. Fesharaki et.al, IEEE *Access*, 2017; Astra MT77, A Teflon Replacement, Isola, July 2017; W. T. Khan IEEE *ECTC,* 2013; M. U. Rehman, IEEE ECTC, 2020.

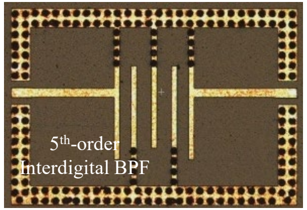
Note: All design conditions may not be the same

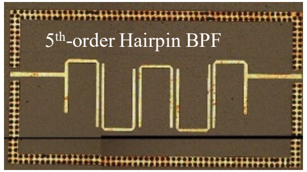
28GHz and 39GHz Low Pass Filter and Band Pass Filters were designed and fabricated on 80umt Alumina Ribbon Ceramic substrate with Through Alumina Vias

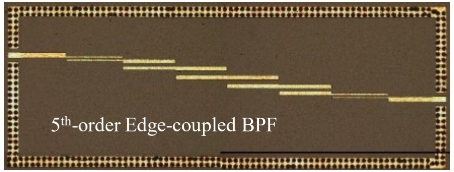


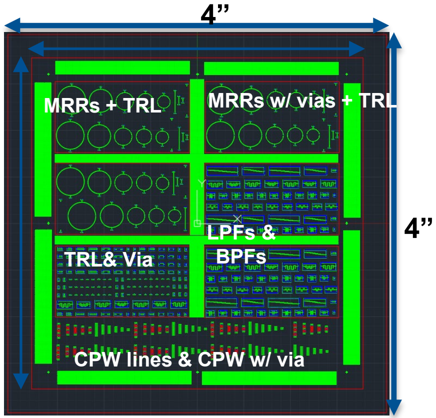
Filter stack-up structure with both sides metal layers and through-alumina-vias (TAVs)











Test vehicle design and fabrication

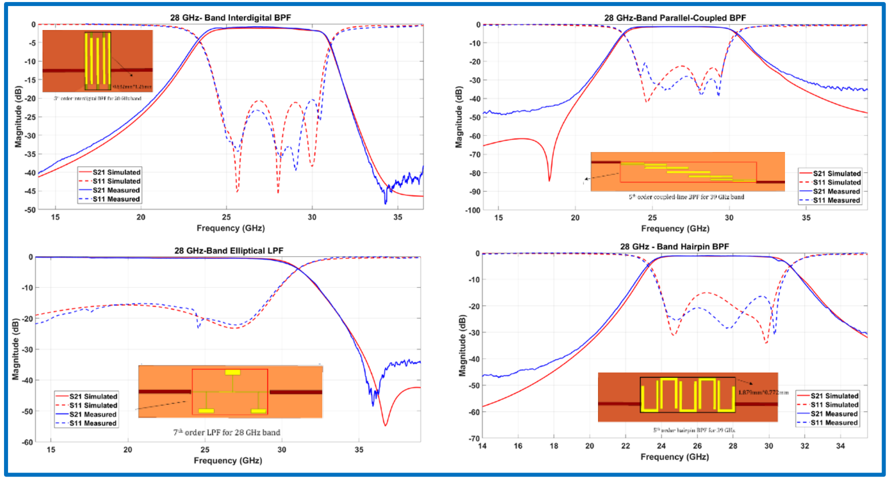
Design Requirements of mmWave Low Pass Filter and Band Pass filters

Design Specifications of Filters *	Value			
	LPF		BPF	
	28-GHz band	39-GHz band	28-GHz band	39-GHz band
Cut-off frequencies	29.5 GHz	43.5 GHz	24.5 & 29.5 GHz	37 & 43.5 GHz
Insertion loss at cut-off frequencies	< 2 dB	< 2 dB	< 2.5 dB	< 2 dB
30-dB attenuation point to band-edge ratio	< 1.24	< 1.24	< 1.20	< 1.20

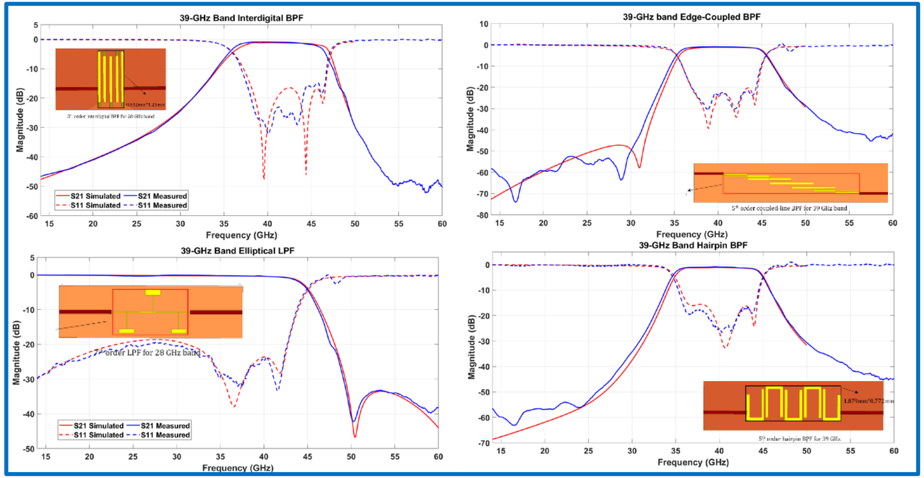
* M. Ali *et al.*, "Miniaturized high-performance filters for 5G small-cell applications," *IEEE ECTC,* May 2018.

All measured filters exhibit low insertion loss, good impedance match, and high selectivity, and stand out among literature reported in size, passband insertion loss, and out-of-band rejection

28GHz filters



39GHz filters



- Excellent correlations between simulation and measurement
- Low insertion loss, good impedance match, and high selectivity (30-dB attenuation point to band-edge ratio of 1.2 maximum)
- >80% size reduction compared to glass cored ABF structure [ref], <1.3dB passband insertion loss compared to 2dB design requirement

Y. M. Yan *et al*., "Highly selective microstrip bandpass filters in ka-band," *32nd European Microwave Conf*., Sep. 2002.

Conclusion

- Thin flexible Alumina Ribbon Ceramics available with expanding capabilities
  - Current 100 mm wide in 10’s m length, expect 200mm width in 2022
  - Alumina at 40um, 80um and 120um thicknesses

- Characteristics of Alumina Ribbon Ceramic makes it attractive for RF applications
  - Thin, flexible, smaller vias for device compactness
  - Smooth native surface for fine line metallization
  - Dense and fine-grained gives higher strength
  - High purity leads to improved thermal conductivity, loss tangent

- Low insertion loss transmission line (30-170GHz) and ultra-miniaturized (>80% size reduction compared to glass cored ABF structure), high-performance (<1.3dB) mmWave filters for 28 and 39GHz demonstrated on 80umt Alumina Ribbon Ceramic

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