Flex for 5G – Why Materials Matter

Electronics & Imaging
Circuits & Industrial Technologies

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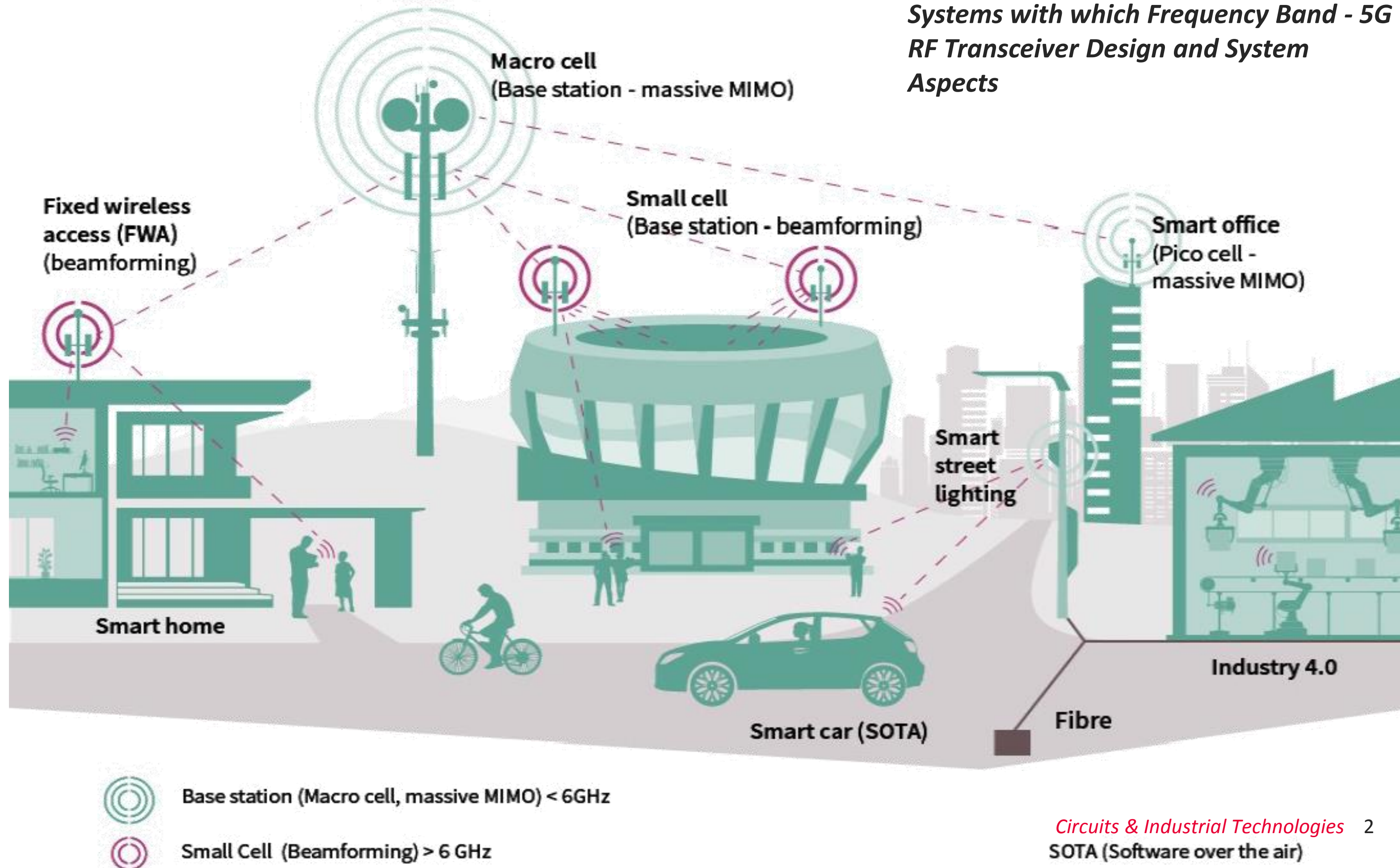
5G Market Needs

- Low Relative Permittivity and Loss Tangent Material Needed for:
  - Low Latency – Low relative permittivity decreases latency due to substrate
  - Low Loss – Low loss tangent improves insertion loss and enhances efficiency
  - Larger Antenna Apertures – Low relative permittivity improves gain
- Applications include:
  - Mobile Handset
  - Base Stations
  - Smart Devices
  - Small Cells/Beam Formers
  - Hybrid Substrates
- Critical Frequencies:
  - <6 GHz
  - 28 GHz (mmWave)
  - 39 GHz (mmWave)

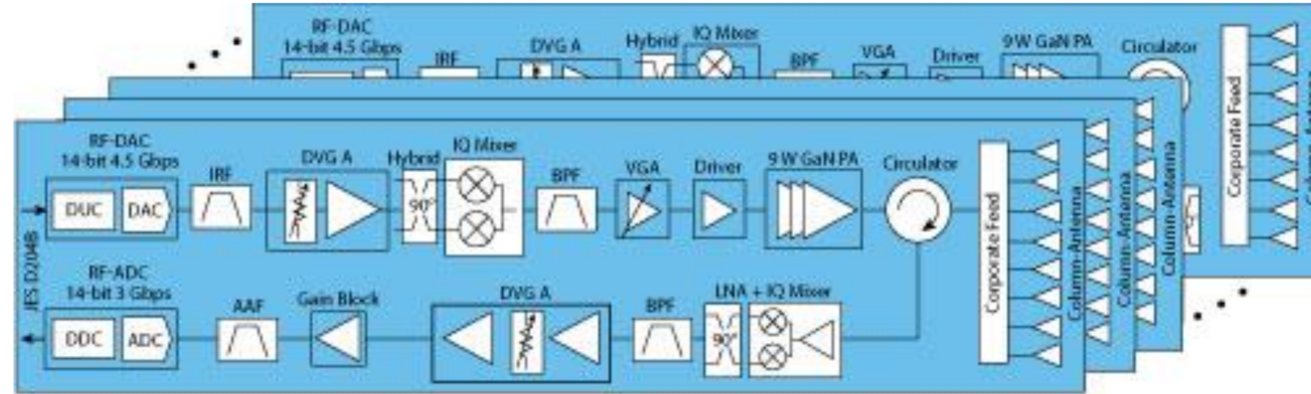
[1] Millimeter Wave for 5G: Which Systems with which Frequency Band - 5G RF Transceiver Design and System Aspects

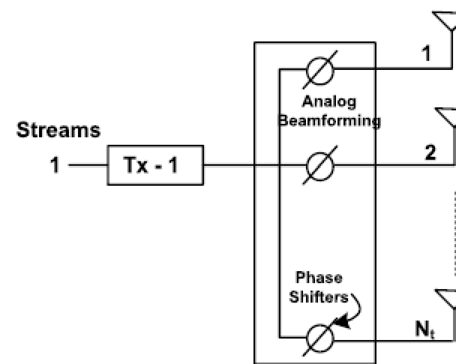


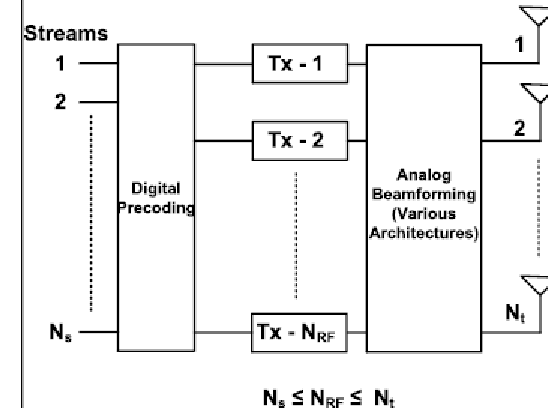
Materials for 5G

- What is 5G, or more specifically, what is 5G to you?
  - Is it simply faster 4G-LTE?
  - Increased Connectivity (IoT)?
  - Wave of the Future?
- What are the Components?
  - DAC/ADC, Filters, Mixers, Circulators, PA
  - Digital/Analog/Hybrid Beamformers
  - Antenna Feedlines and Arrays
- Where do Materials Matter?
  - Active Beam Steering (Phase/Amplitude Adjusters)
  - Analog Beam Formers (Serial, Corporate, Rotmann)
  - Antennas and Feedlines ***[3]***
- What Properties are Important?
  - Frequency/Phase Stable (uniform/isotropic Dk)
  - Loss Performance
  - Processability

[2] 5G Fixed Wireless Access Array and RF Front-End Trade-Offs



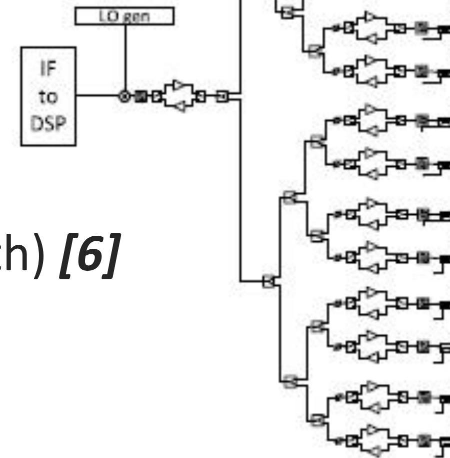


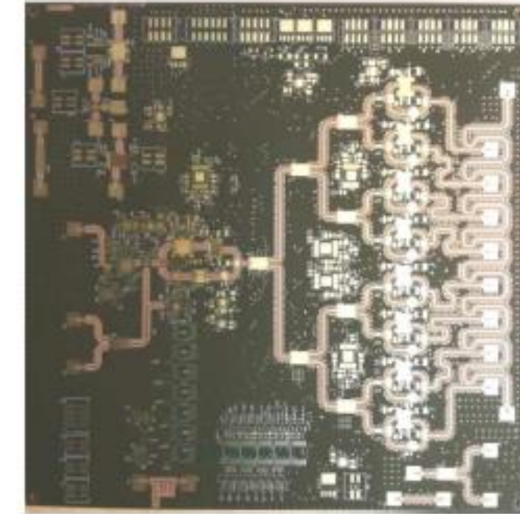


[4] 5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice

Flex for 5G

- Why Flex?
  - Flex is “still” primarily driven by packaging needs
  - Separation of digital/analog/antenna components
  - Elimination of cables and connectors (rigidflex)
- Where Do Flex Materials Play?
  - Feedlines, Beamformers, Antennas (1%-5% Bandwidth) ***[6]***
  - Hybrid board layers
- Benefit to Flex Materials?
  - Glass-Free (Skew Elimination, Phase Flat Transmission Lines)
  - Low relative permittivity and loss tangent vs glass epoxy

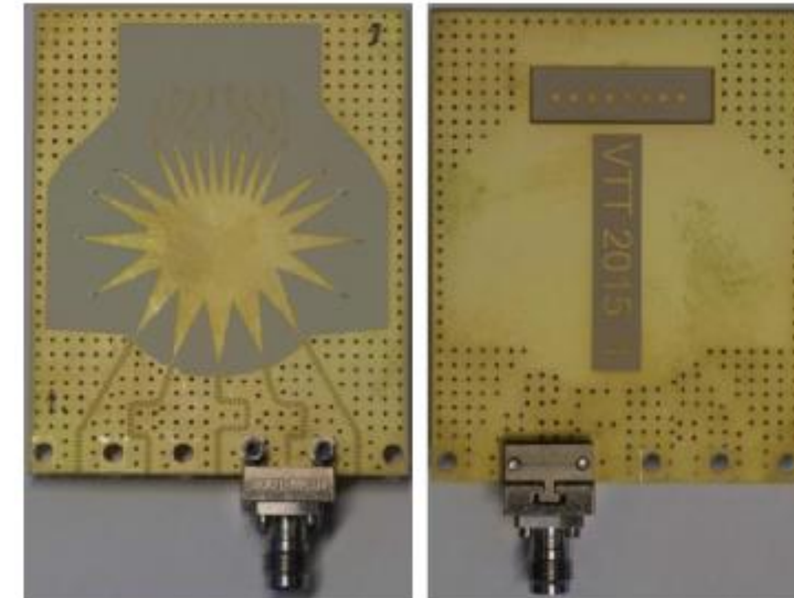




[5] Development of 5G CHAMPION Testbeds for 5G Services at the 2018 Winter Olympic Games

Layer	Material
Layer 1	Cu 38 um (feed network)
	Ultralam 3850HT 100um)
Layer 2	Cu 18 um (groundplane)
	Rogers 2929 bond film 50 um
	Rogers 3003 250 um
Layer 3	Cu 30 um (antenna patches)
	No Flow Prepreg
Layer 4	Cu 33 um
	Rogers 3003 500 um
Layer 5	Cu 38 um

[7] Millimetre-wave beam-switching rotman lens antenna designs on multi-layered LCP substrates

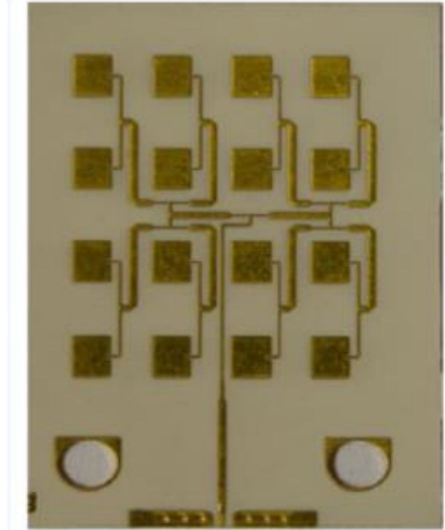


Comparison of all polyimide laminates to LCP laminates

- It is often assumed that LCP is the only dielectric substrate capable performing at high frequencies due to:
  - Low dielectric property values (Dk ~ 2.9-3.1 and Df ~ 0.001-0.003)
  - Minimal moisture absorption (0.04%)

- However, there are some limitations:
  - Bulk material properties do not directly correlate to circuit performance
  - Mechanical properties can limit processing/performance/yields

- All polyimide substrates can exhibit excellent performance:
  - Some all polyimide substrates have electrical properties comparable to LCP
  - Polyimide and LCP test vehicles show similar performance in a high moisture environment



[8] 60 GHz Patch Antenna Array on Low Cost Liquid-Crystal Polymer (LCP) Substrate

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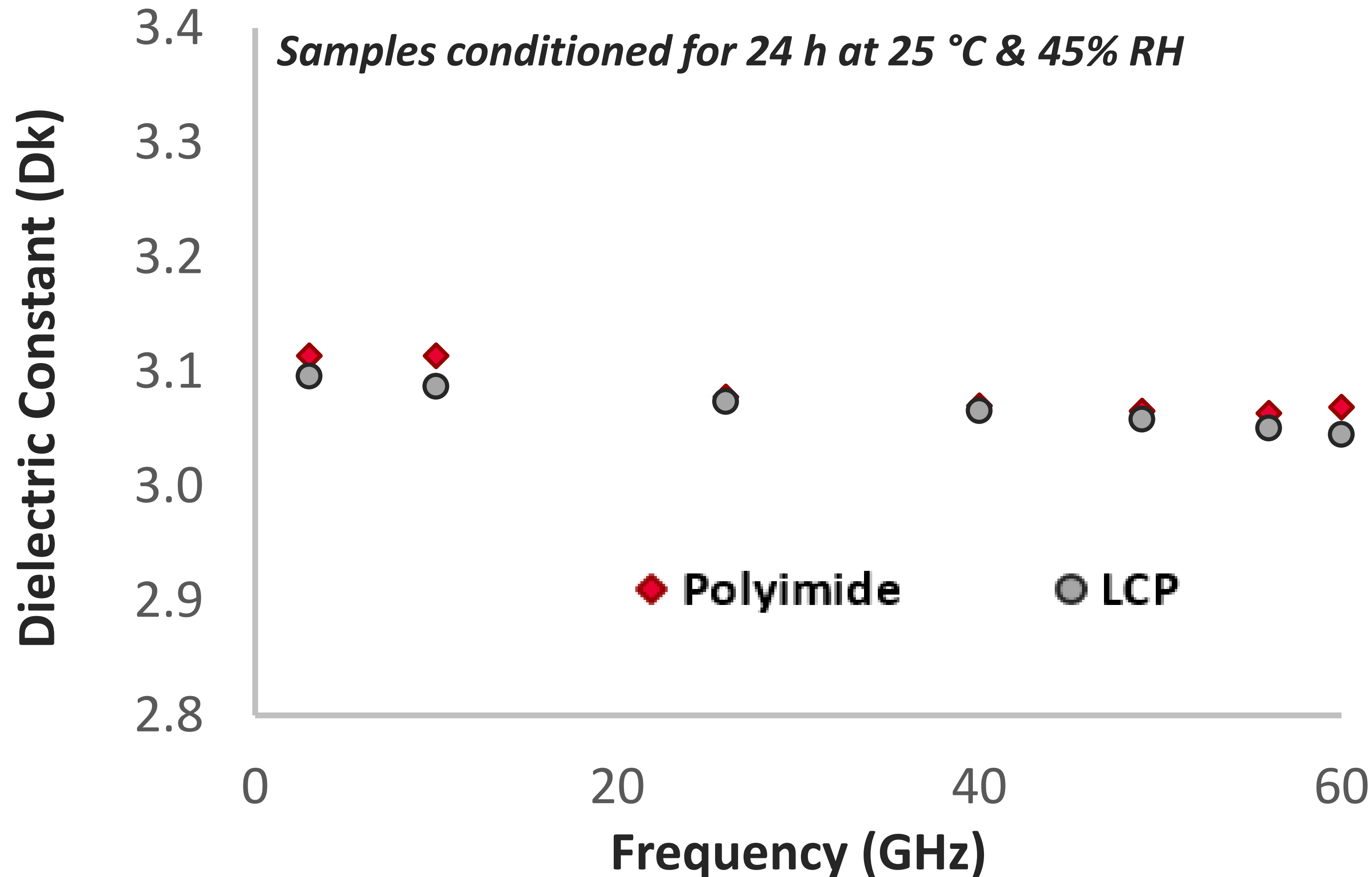
Bulk Properties of Dielectric Films

Processability of polyimide is superior to LCP due to:
1) Stability at lamination temperatures (no Tm) & 2) High peel strength

Property	Unit	Method	Polyimide	LCP
Dk @ 10 GHz	–	Method 2.5.5.5	3.2	3.0 - 3.1
Df @ 10 GHz	–	Method 2.5.5.5	0.002 - 0.003	0.001 - 0.002
% moisture uptake	%	Method 2.6.2	0.8	0.04
CTE (x-y axis)	ppm/°C	50 to 250 °C	25	18
CTE (z axis)	ppm/°C	50 to 250 °C	90	120
Peel strength	N/mm	IPC-TM650	1.6 (RA Cu)	1.0 (ED) / 0.4 (RA)
T glass trans.	°C	DMA	220	–
T melting	°C	DSC	–	280 - 315
Flammability	–	UL94	V-0	V-0

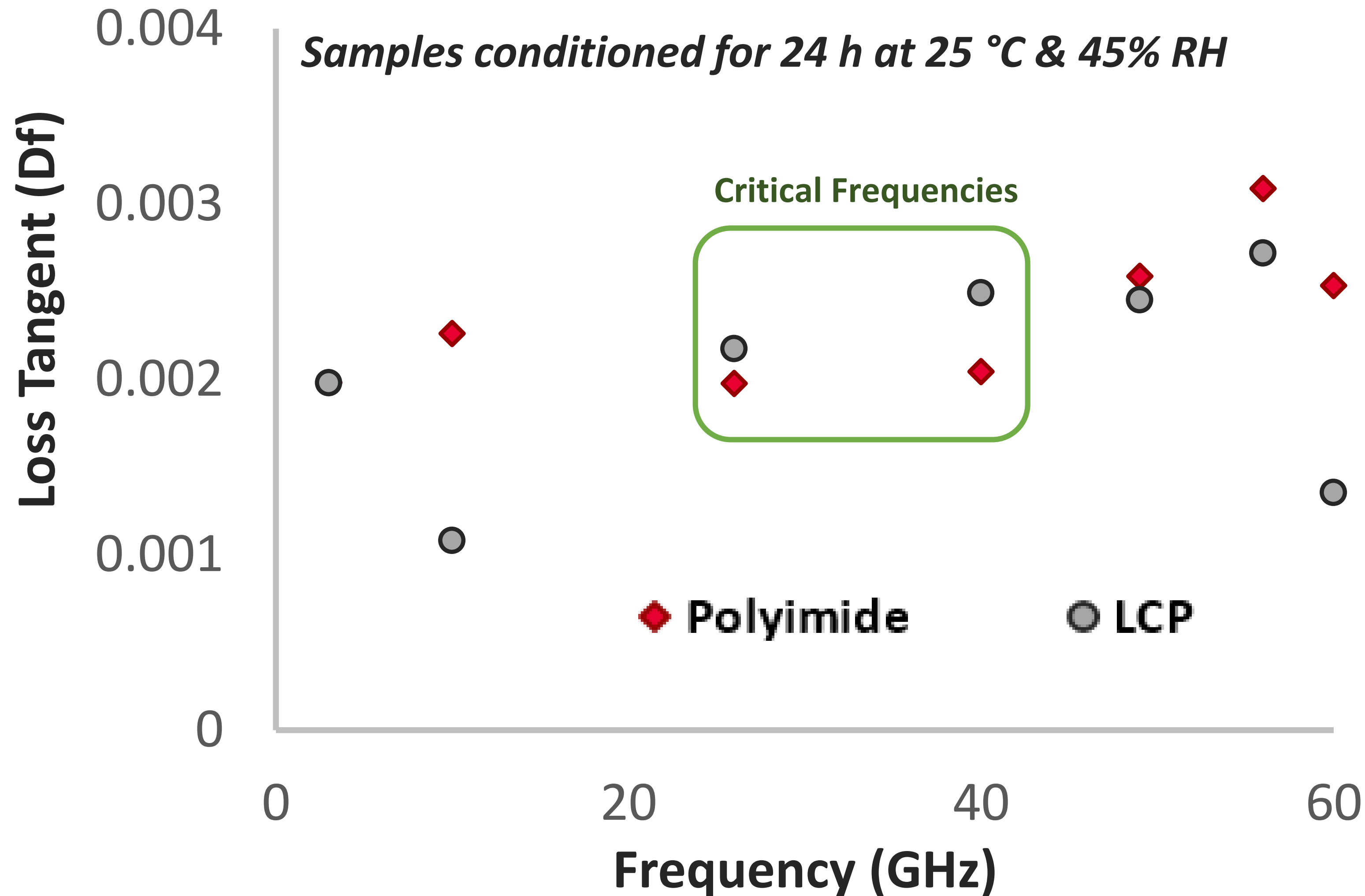
Bulk Dielectric Constant (Dk) for Conditioned Samples at High Frequencies

Polyimide bulk dielectric properties are comparable to LCP across the frequency band with LCP having a slightly lower Dk



Bulk Loss Tangent (Df) for Conditioned Samples at High Frequencies

Polyimide and LCP trade places on loss tangent across the performance band



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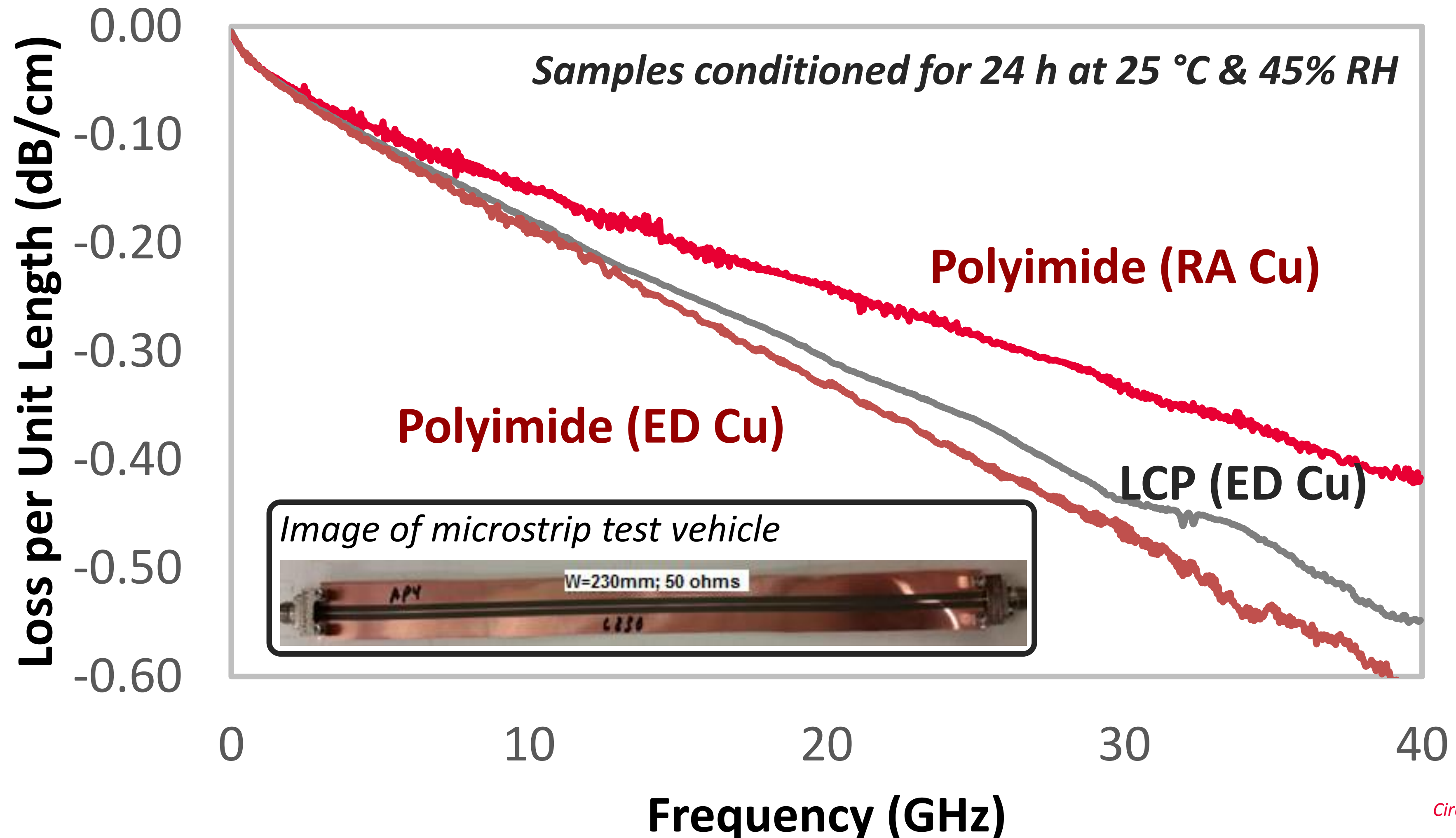
Insertion Loss (dB/cm) Values for Microstrip Test Vehicles (4 mil thickness)

Polyimide insertion loss is superior to LCP in some instances

High loss in LCP microstrip is attributed to ED copper



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Insertion Loss (dB/cm) Values for Microstrip Test Vehicles (4 mil thickness)

Copper type and roughness have a dramatic effect on insertion loss

Samples	Ra	Rz
9 um ED	0.43	3.89
12 um ED 1	0.45	4.04
12 um ED 2	0.28	3.05
12 um ED 3	0.24	2.65
12 um RA 1	0.19	2.73
12 um RA 2	0.26	3.38
18 um ED 1	0.28	3.18
18 um ED 2	0.29	3.63
18 um ED 3	0.42	3.70
12 um RA 3	0.13	1.80
18 um RA	0.11	1.82

Note: All values above are the average of 3 measurements and are recorded in microns.

Ra: Roughness average - typically used to describe the roughness of machined surfaces. It is useful in detecting general variations in overall profile height characteristics.

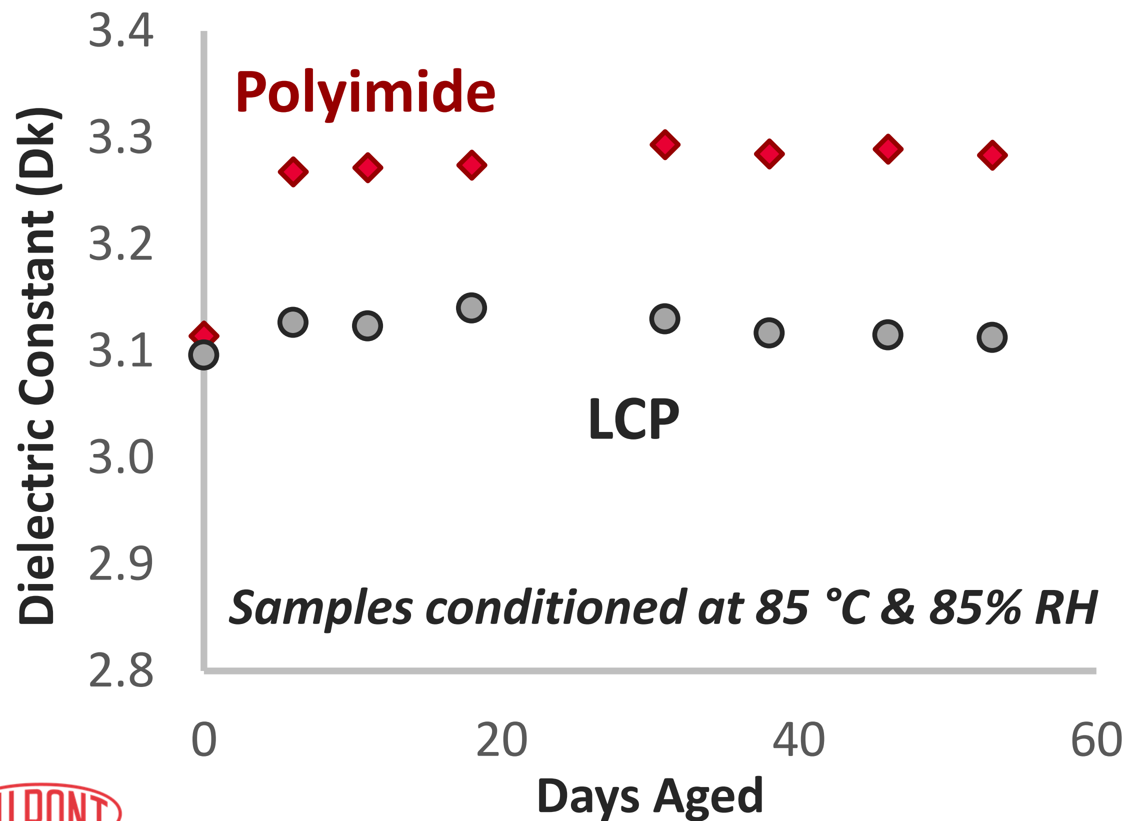
Rz: Average maximum - profile height averages the ten greatest peak to valley separations in the evaluation area.

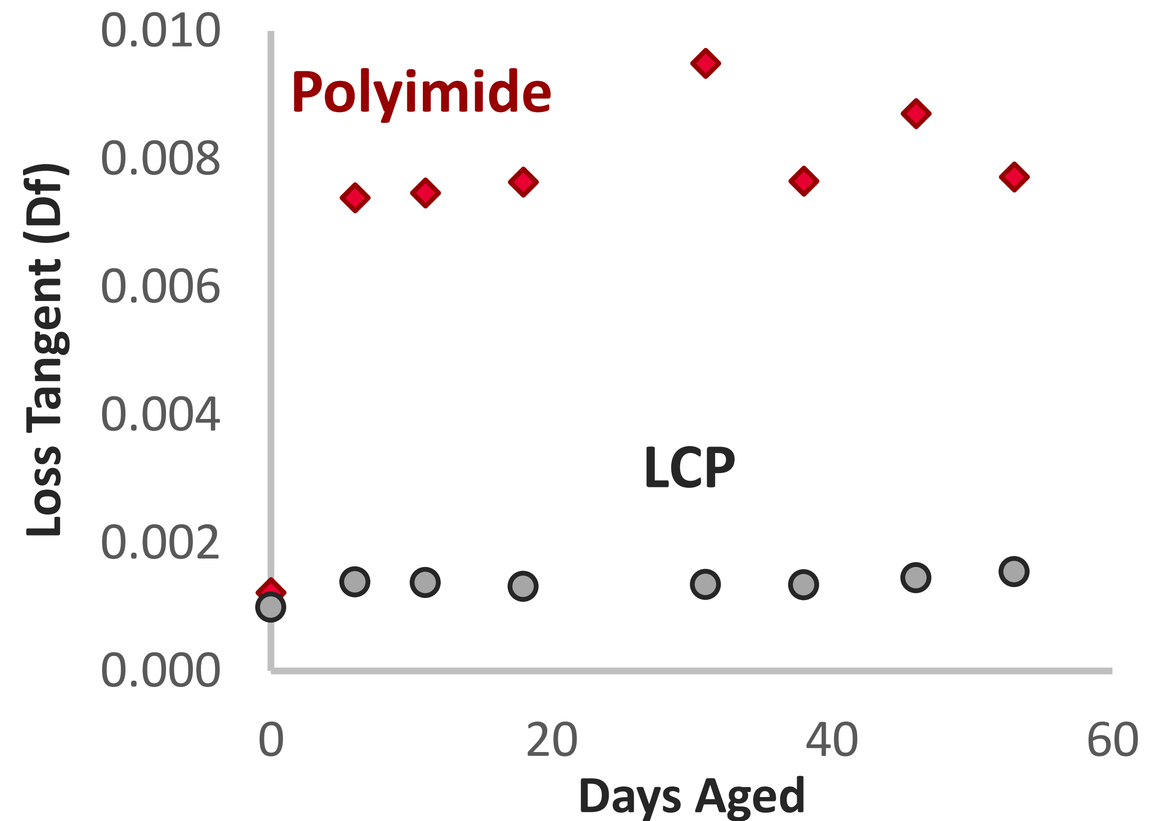
Loss per Unit Length (dB/cm)
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
0
5
10
15
20
25
Frequency (GHz)
18 um RA
12 um RA 3
12 um RA 2
12 um RA 1
12 um ED 2
12 um ED 1
9 um ED
12 um ED 3
18 um ED 3
18 um ED 1
18 um ED 2

Effect of Environmental Aging on Bulk Dielectric Properties at 10 GHz

Bulk dielectric properties after environmental aging remain stable for LCP and increase for polyimide, due to moisture absorption; HOWEVER

<u>BULK FILM PROPERTIES DO NOT DIRECTLY CORRELATE TO CIRCUIT PERFORMANCE</u>





Effect of Environmental Aging on Insertion Loss (dB/cm) Values

Water entrained between copper layers effects performance

Polyimide & LCP-based circuits exhibit comparable loss after aging

Loss per Unit Length (dB/cm)

0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8

Signal

Ground
Dielectric 2 mil
Adhesive 1 mil
Dielectric 3 mil
Ground

Samples conditioned at 85 °C & 85% RH

0 5 10 15 20 25

Frequency (GHz)

LCP Baseline

Polyimide Baseline

Data spread from 20 to 54 Days

Development of New Polyimides for 5G and High Frequency Applications

New low Dk polyimide materials have been developed, providing a "toolbox" for future flex laminates.

Ground
Dielectric 3 mil
Ground

Dielectric Constant (Dk)
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2 4 6 8 10
Frequency (GHz)

Summary

- LCP is not the only dielectric substrate suitable for high speed/high frequency applications up to 40+ GHz
- Bulk material properties do not necessarily correlate to circuit performance
- Copper roughness and type have a dramatic effect on high frequency performance, especially in thin laminates
- Insertion loss of all polyimide systems are comparable to LCP circuits
- Similarity in environmental aging affects of polyimide and LCP likely due to moisture entrainment between copper layers

Next Steps

- Validate conclusions with additional testing and third party labs (underway)
- Repeat environmental aging tests with *in situ* data collection (underway)

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[1] Rüddenklau, U., "*Millimeter Wave for 5G: Which Systems with which Frequency Band - 5G RF Transceiver Design and System Aspects*," in International Microwave Symposium, Jul. 2017.

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[5] S.H. Won et al., "*Development of 5G CHAMPION Testbeds for 5G Services at the 2018 Winter Olympic Games*," in Signal Processing Advances in Wireless Communications (SPAWC), Jul. 2017.

[6] Bahl, I.J., Bhartia, P., *Microstrip Antennas*, Artech House, Inc., M.A., 1982, pp. 62-75.

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