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R/flex® 3000 Advanced Circuit Materials = LCP Stability & Performance from 1GHz to 110 GHz

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Abstract
This paper will discuss how R/flex® 3000 LCP materials from Rogers Corporation are "pushing the envelope" for high-frequency & flex designs by examining:

1. How the material set has now been characterized out to 110 GHz, and why this can open the door for "ground-up" liquid crystalline polymer (LCP) designs-ins.
2. What combinations of very thin film laminates and bond plys are now available, and how their electricals are virtually unaffected by environmental conditions.
3. Which foils are available on the laminates with suggestions on their application, including test results with resistive foils.
4. Where we see opportunities for producing tomorrow's circuit designs today.

Key Words
Attenuation, bond ply, coefficient of thermal expansion (CTE), flex, liquid crystalline polymer (LCP), mm-wave, nematic melt point, multilayer, printed circuit board (PCB), rigid-flex, W-band.

W-band Characterization
In a benchmark study [1] done at the Georgia Institute of Technology's School of Electrical & Computer Engineering, LCP film dielectrics were found to be on a par with GaAs substrates when characterized across the GHz frequency range up into the W-band (75 –110 GHz). Steady and stable Dk and Df performance was observed from 2 to 110 GHz as well as a near linear attenuation result.

In fact, attenuation (measured in dB/cm) comes in slightly ahead of that previously reported with GaAs and quite a bit better than those recorded by Si.

As seen in Figure 1, the attenuation on the LCP substrate is near linear versus frequency, and compares nicely to the performance of GaAs shown in Figure 2. When reviewing these results several practical application bands come to mind as illustrated by Table 1.

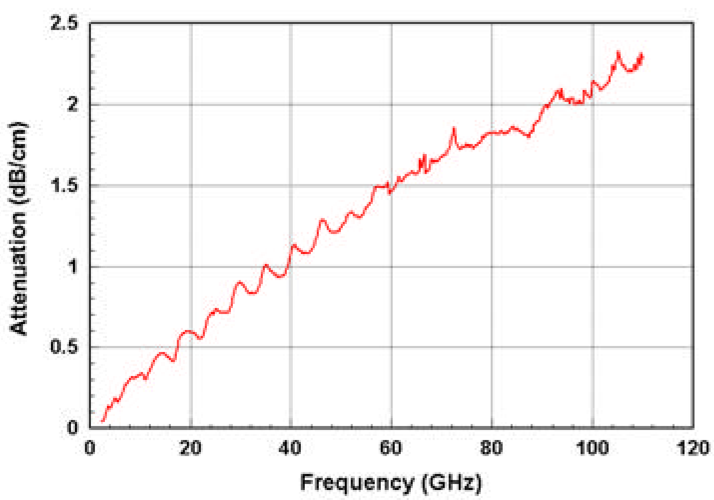

Figure 1 - Attenuation on LCP Substrate [i]

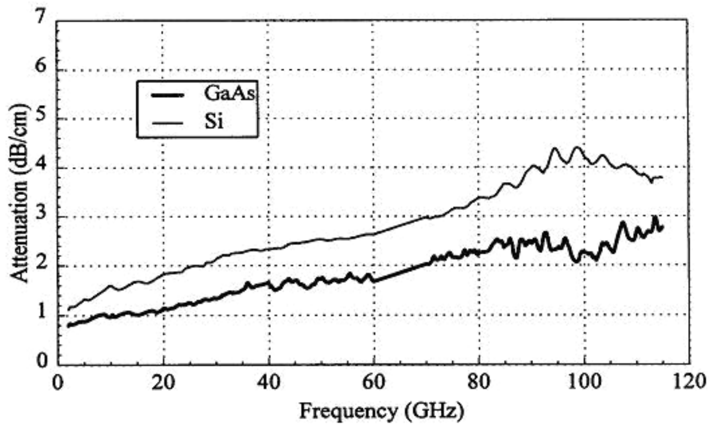

Figure 2 - Attenuation on GaAs & Si Substrates[2]

Table 1 - Practical Applications Showing Expected Attenuation at Selected Frequency[i]

Application	Frequency (GHz)	Attenuation (dB/cm)
Cordless phones, 802.11a	5.78	0.178
Precipitation sensor	13.88	0.461
Precipitat ion sensor	34.94	1.008
High BW short wave wireless	60.05	1.469

Note: Since a finite number of data points were measured, the frequencies listed are the closest approximations from the actual data set for the applications listed.

Design Example

Having characterized the substrate at thicknesses of 50, 100, and 200 microns that all resulted in near linear relationships to frequency, a 14 GHz (2 x 1) antenna array was constructed on a 425 micron LCP substrate and tested. The S_{1-1} parameter was found to be 40 dB down at 13.97 GHz, or in other words, all but 1/10,000th of the power was radiated. This speaks to not only the design efficiency, but also the excellent electrical properties of the LCP substrate.

A photograph of the test antenna is shown in Figure 3 and the S_{1-1} parameter graph, is shown in Figure 4.

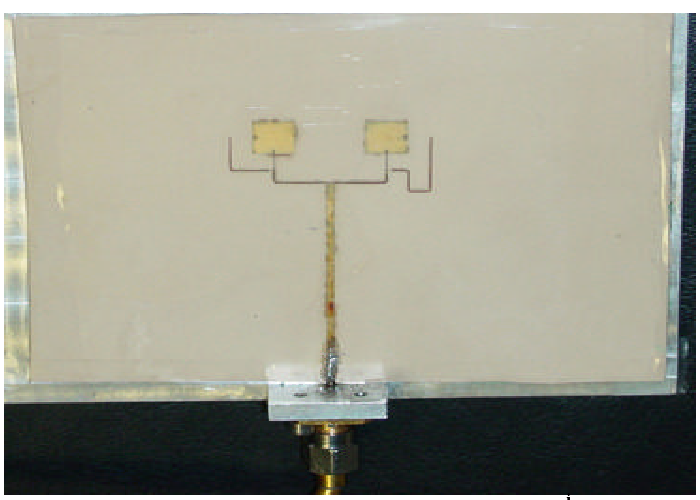

Figure 3 - 14 GHz (1 x 2) Antenna Array[i]

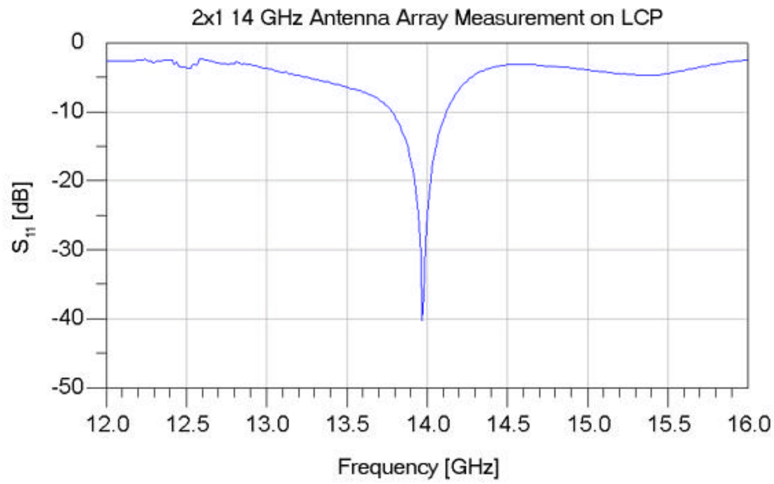

Figure 4 - 14 GHz (2 x 1) Antenna Array Measurement [i]

Further S-parameters measurements and verifications are available in the full study text while continuing work with other test vehicles is in progress at Georgia Tech in the areas of MEMS switching and integrated passives.

The LCP Materials

Core laminates (melt point = 315^{oC}) are now commercially available in 25, 50, & 100 micron dielectric thicknesses. Cap layers (melt point = 290 ^{oC}) for sequential lamination are produced in 50 & 100 micron dielectrics. Also available are 25 & 50 micron melt lamination bond plys (melt point = 280 ^{oC}) along with plied-dielectric laminates (melt point = 315^{oC}) in thicker cross sections (200 micron +). These standard materials are manufactured with a CTE of 17 ppm (in the x & y) to match copper, but can be modified to a CTE of 8 ppm (in the x & y) for matching to silicon. (Table 2)

Table 2 - Commercially Available LCP Materials [3]

Type	Cores matched to Cu	Cores matched to Si	Cap layers	Bond plys
Melt Point $^{(oC)}$	315	315	290	280
Solder resistance (oC)	288	288	260	260
CTE (ppm)	17	8	17 or 8	17 or 8

LCP Properties

In addition to its outstanding electrical properties, LCP exhibits very low moisture absorption and near-hermetic gas transmission values as shown in Figures 5 and 6.

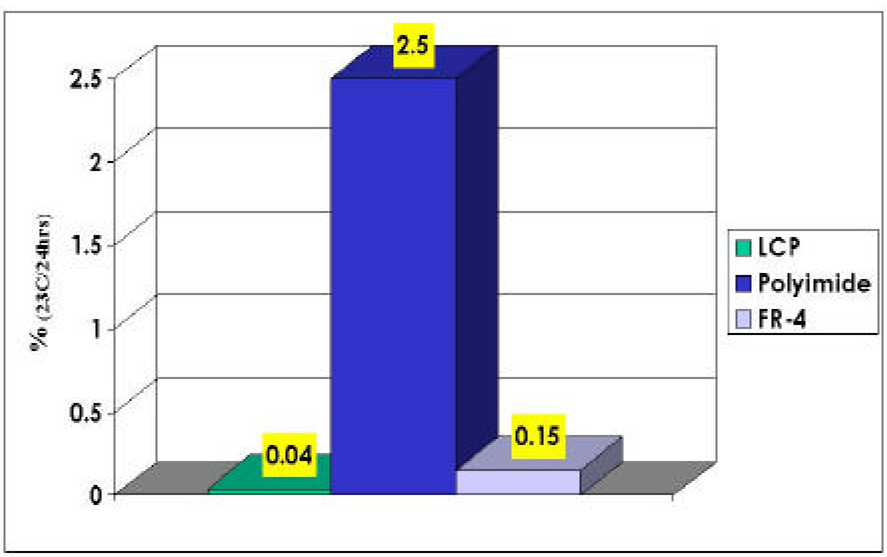

Figure 5 - Very Low Moisture Absorption [v]

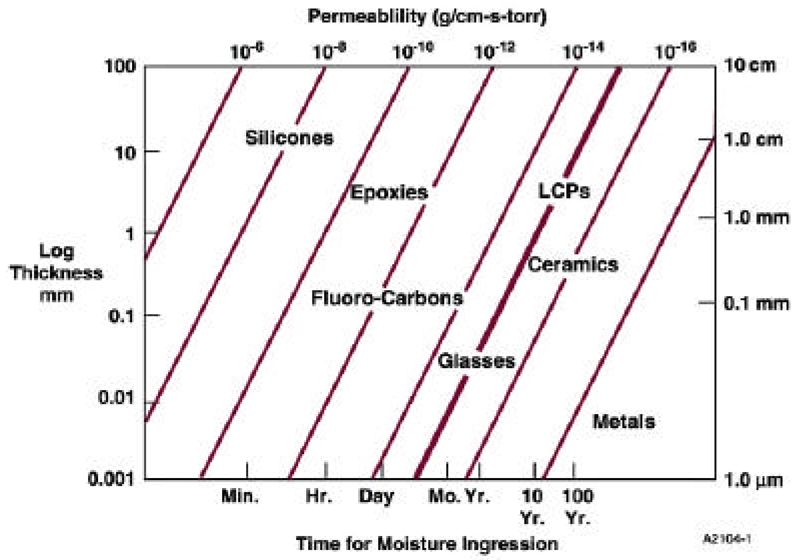

Figure 6 - Comparison of Hermetic Materials[4]

This equates to very stable electrical performance both wet and dry. This is shown in Figure 7.

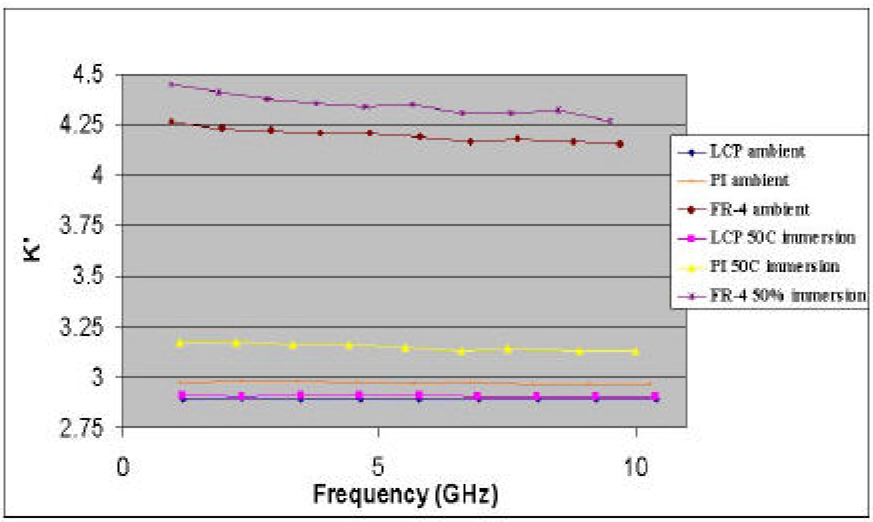

Figure 7 - D_f comparing LCP vs. FR4 vs. all-PI[v]

This data for LCP has now been extended out to 50 GHz in laboratory tests[5] and remains steady and stable under the above conditions.

Foils Available

The available laminates use a low profile electro-deposited foil in 12, 18, or 35 micron thicknesses. 35 micron rolled annealed foils are also available as are plated or sputtered resistive foils in various ohm values. Typical peel strengths are shown in Table 3.

Table 3 - LCP Peel Strengths on Various Foils[v]

Foil Type	18µ LP ED	18µ sputtered resistive[6] @ 75 O	18µ plated resistive[7] @ 75 O
Peel (PLI)	5.5	4.5	4.4

The 12 micron is particularly suited for HDI flex, and beta testing is in progress on 8 micron (foil-carried) versions. LCP also bonds well to aluminum foil, silica, glass, and alumna surfaces.

LCP Applications Today

The first applications for the LCP technology have been in the areas of single- and double-sided flex circuits as well as discreet inner or outer layers in mixed dielectric multilayer circuits (in combination with common rigid materials).

Taking up where polyimide leaves off, LCP can provide flex designs with high frequency capability and improved performance in humid conditions. Utilizing LCP's thin format in combination with its excellent electricals has proved advantageous when designing inner layer high frequency passives or strip-line interconnects (in particular broadside-coupled differential pairs). In most instances, the non-LCP prepreg or bond ply adhesive layers have shown very good adhesion results attaching the LCP layers. Some examples of the above are shown in Figures 8, 9, 10 and 11:

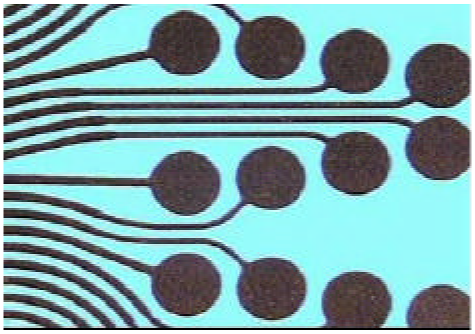

Figure 8 - HDI with 3 Mil Lines & Spaces Transitioning to 1.5 Mil Lines on a 50 Micron Cap Layer Laminate[8]

Figure 9 - Rigid/Flex Interconnect Combining LCP & FR4 in an 8 Layer Mixed Dielectric Multilayer[9]

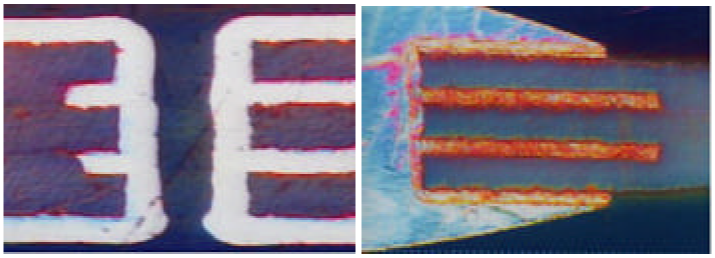

Figure 10 - 4 Layer Flex Multilayer Before and After Solder Shock (Combines a 50 Micron Core with 50 Micron Cap Layers)[10]

Figure 11 - Double-sided Flex Antenna from 425 Micron Core Laminate Illustrating the Flexible Nature of the Dielectric[11]

Fabrication Techniques

Single- and doubled-sided circuit designs and fabrications using the materials mentioned herein are well understood. In addition, 4 metal-layer circuits have been realized in production by using an additive cap-layer lamination technique (illustrated below) that is similar to the additive resin-coated foil technique used with FR4 constructions (Figure 12).

Using this method, 35 micron lines and spaces have been realized with 50 micron blind-vias and 75 micron plated-through-holes (PTHs). In this case the vias and PTHs were laser drilled. (Figure 13)

Going beyond 4 layer multilayers (as shown above) is now possible by following a sequential lamination technique[13] utilizing intermediate oven exposures to advance the additive layers' nematic melt points,[14] thus allowing successive cap layers to be processed into circuitry. Drilling and plating processes similar to those used for 4 metal-layer designs can be used to connect the sequentially added layers. 6 and 8 layer multilayers have been demonstrated by this method. (Figure 14)

Figure 12 - 4 Layer ML Using Cap-layers on a Double-sided Core[v]

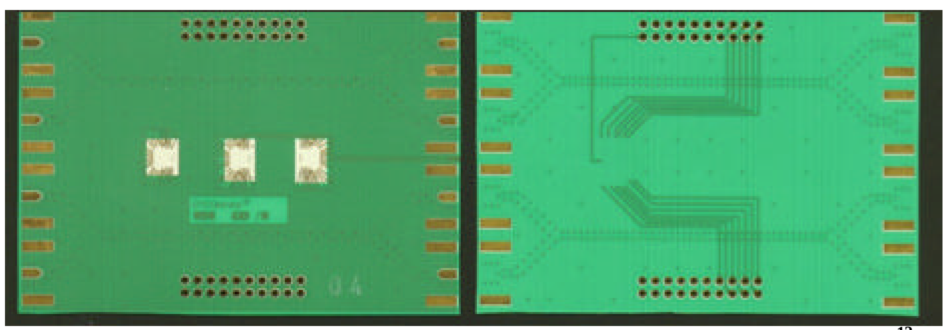

Figure 13 - 4 Layer Multilayer Using Cap Layer Additive Lamination Technique[12]

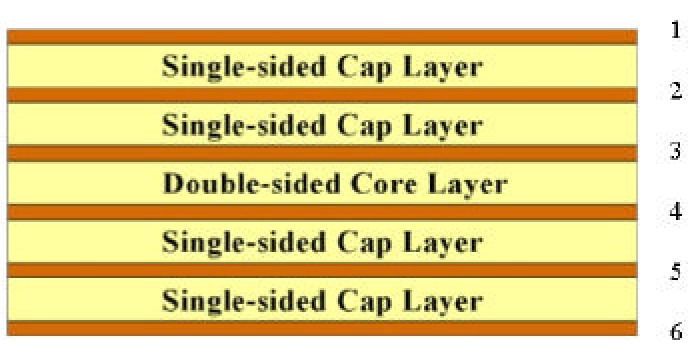

Figure 14 - Sequentially Built 6 Layer Multilayer Technique[v]

Starting with a double-sided core, blind-vias connecting metal layers 3 & 4 can be drilled and plated followed by an image and etch. Cap layers (metal layers 2 & 5) can then be laminated, drilled, plated, and circuitized, followed by an oven exposure to advance the cap layers' nematic melt points. The process can then be repeated adding 2 more cap layers (metal layers 1 & 6) to finish the build. This technique is possible because of the special liquid crystalline nature of the polymer used to produce these materials.

"Pushing the Envelope"

As work continues on new LCP constructions and combinations, we are finding that the current LCP materials have already expanded the design horizons for PCBs. LCP combines extremely good electrical performance with excellent moisture and chemical resistance. The 25, 50, and 100 micron dielectrics now in production also offer a "green" circuit alternative with improved performance in humid conditions plus steady and stable characteristics out to 110 GHz.

Interest in the material is high with applications being considered across many markets including: chip-on-flex, LCD drivers, sensors, controlled impedance flex interconnections, wireless handsets, specialty high performance chip packages, RADAR, optical-electrical devices, and phased-array antennas.

With LCP, tomorrow's designs may be within reach today.

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