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New Features For High-Frequency LCP Package Substrates

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Emerging RF system applications, especially in the field of radar or security technology, significantly drive RFIC packaging and HF PCB development. In order to keep pace with a multitude of complex requirements, innovation in substrate technology remains essential. To tackle these challenges, a set of process capabilities based on organic Liquid Cristal Polymer (LCP) base material has been introduced and perfected. Besides being a flexible material, LCP offers near-hermetic capability in combination with outstanding electrical (low loss, high frequency) and elevated temperature performance. Substrates using LCP can be manufactured at full production level quantities, even at maximum circuit design density. In addition, advanced features such as cavities, copper filled vias or composition with CTE core material can be incorporated to address major RF obstacles. Considering the LCP cost and workability advantage over ceramic, LCP substrates proves to be a very worthwhile alternative for high frequency packages.

High frequency packages must not only provide superior electrical characteristics at frequencies up to 100 GHz, they must often also meet special thermal and mechanical requirements. These additional requirements are typically driven by the application's operational temperature, heat losses of active components and the need to match their thermal expansion to components inside the package. In many cases these packages should also provide a hermetic or near hermetic enclosure since the active components are generally sensitive to humidity. Some applications (i.e. phased array radar) even require a multitude of packages so that cost and weight (to keep the g-forces low in moving applications) can be an additional factor. The sum of all these product characteristics cannot be accomplished by using a single material type, but rather a combination of materials should be used. The various material types should be selected such that, in unison, they combine their performance strengths to provide an ideal solution for the product application.

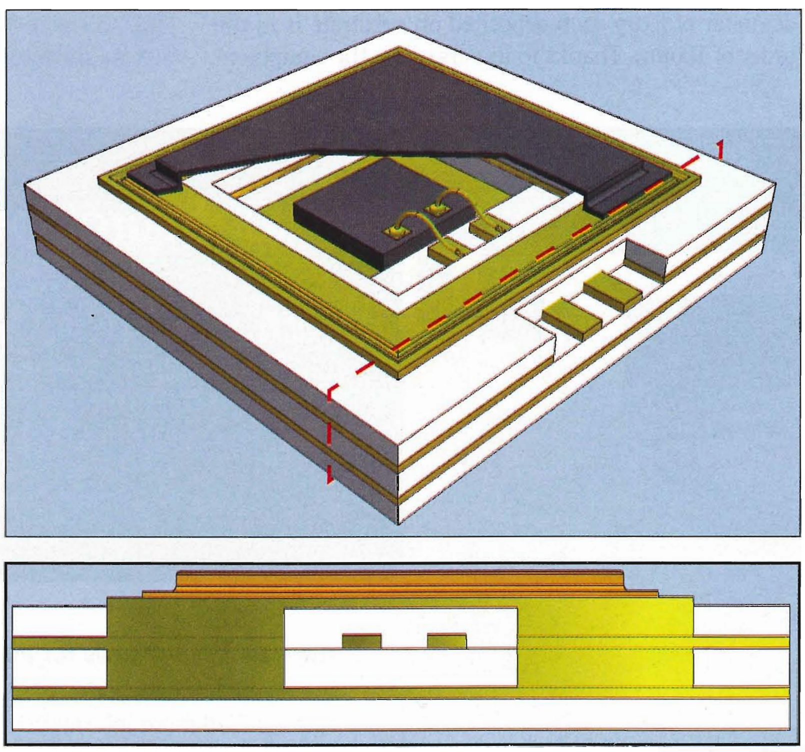
Characteristics of LCP

Liquid Crystal Polymer (LCP) is a film-based circuit board substrate material with superior and stable characteristics across a wide range of the RF spectrum (100 GHz and more) and temperatures. Due to the very low water absorption of LCP (0.04%) these properties remain constant even across a wide humidity range. The density 1.4 g/cm^3 of this material is significantly less then densities of many established high frequency base materials (i.e. RO 5880 2.2 g/cm^3, LTCC about 3.2 g/cm^3) which can be an additional advantage for mobile applications. The diffusion constants of oxygen and water through LCP are extremely low (0.13 g*m^{-2}-d^{-1} of water and 0.3 cc*m^{-2}*d^{-1}*atm^{-1} of oxygen through a 20μm LCP foil) for an organic substrate, making it an ideal candidate for use in near hermetic packaging.

Processing LCP substrates

Copper-clad LCP dielectric material clad as processed within the standard PCB (printed circuit board) process landscape generally provides better results in terms of conductor shape (trapezoid) compared to the

Figure 1 – 3-D and x-section rendering of LCP package with optimized hermetic and RF properties. Design artwork can be optimized to create an almost complete Cu enclosure, allowing for minimal water retention



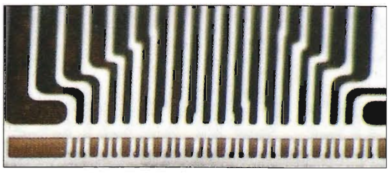
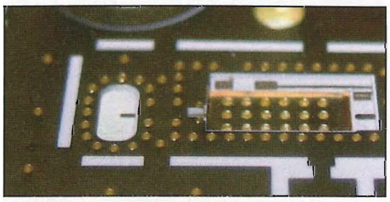


Figure 2 – 4-layer LCP substrate with wire bond pads adjacent to a cavity exposing 50µm lines

Figure 3 – LCP package with two cavities providing a direct access to inner layer levels



paste application methods employed in LTCC (Low Temperature Co-fired Ceramics) manufacture. As copper allows virtually no gas permeation, the artwork on the LCP substrate can be optimized to even further minimize the gas permeation through the substrate. This advantage has been demonstrated with LCP substrates that, as part of a hermeticity study, were exposed to 1000h at 85/85; in all cases, less than 200ppm of moisture (Mil-883 Method 1018 limit is 5000 ppm) was retained. Figure 1 shows a concept rendering for a hermetic package which would incorporate optimizations that would provide significant improvements to the above-mentioned concept.

To date, LCP substrates with up to 8 copper layers have been successfully constructed at Dyconex. In most cases, however, 4 conductor layers were sufficient to route the high frequency signals in the design given. The availability of very thin dielectric layers of LCP (25-100µm per layer) allows for a corresponding reduction of the line width for a given/targeted trace impedance. Given that PCB manufacturing processes can create comparatively fine features (lines and spaces down to 35/40µm), a high circuit density can be achieved and the required layer count can be reduced.

Figure 2 shows a 4-layer LCP substrate with 50µm L/S on an inner layer used for RF signals. Since the high frequency signal traces are assigned to the innerlayers, they can be ideally shielded by ground layers above and below. Taking advantage of the excellent laser workability of LCP, cavities in the substrate can be laser ablated for the purpose of allowing direct access to any trace on any inner layer. This approach avoids the need for interconnect vias which would otherwise decrease signal integrity. The laser cavities can be fashioned in such a manner so that active die can be placed inside the substrate. Ideally, the top surface of the die is at the same height (z-axis elevation) as the corresponding attachment pads on the LCP substrate – thus reducing the necessary length of bond wires to an absolute minimum. Figure 3 illustrates the flexibility of this concept.

Thermal dissipation

LCP constructions can likewise make use of additional advanced technology features. For example, high frequency semiconductors are often also high power devices. Heat generated during operation must be dissipated effectively. For small to medium power devices this, heat can be transferred using copper filled, thermally conductive micro vias. With these micro vias, up to 25% more copper can be introduced locally into the substrate. For high power devices, a metallic carrier can also be attached to the LCP substrate. This approach allows for a direct thermal contact between the metallic carrier and the active component, and thus maximizes the conductivity through the package. Due to the high temperature resistance/durability of LCP, a package constructed in this fashion can operate at a sustained temperature of 190°C, higher than most organic substrate material combinations available on the market.

Controlled thermal expansion

Packages requiring a predefined, controlled thermal expansion response can be achieved by using a CTE optimized core material in combination with LCP. By this means, the combined CTE can be tailored to match the boundary conditions of the application's field of use. The range of the available carrier materials is to some extend still limited by the process sequence required to build LCP substrates, but in most cases almost all CTE constraining materials (i.e. Cu/Mo/Cu, carbon fibre cores, Kovar, Invar) can be used. An example is given in Figure 4.

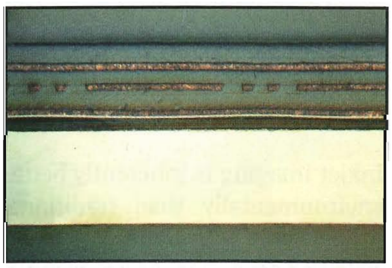


Figure 4 – 4-layer LCP substrate with a Kovar core for CTE control

Figure 5 – Schematic of a hermetic LCP substrate with metal core