

Liquid Crystal Polymers (LCP) for High Performance SOP Applications

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ABSTRACT

Electronic devices will increasingly rely on new materials with improved properties such as lower coefficient of thermal expansion preferably close to silicon, higher modulus, lower permittivity & loss, lower moisture absorption, better thermal conductivity, good dimensional stability, and more importantly reduced warpage particularly after the build-up process. The thermal properties of LCP's have led to increasing interest for the packaging community. This work deals with the evaluation of LCP's for future electronic packaging applications. LCP samples obtained from industry were analyzed using TA instruments. The samples with the properties best matched to the needs of future electronic packaging applications will be chosen based on the thermal analysis data presented for (i) fabrication of a base substrate using solely reinforced LCP, (ii) evaluating LCP for use as a carrier film, (iii) performing laser ablation techniques for via formation in the build up layers, and (iv) plating of the vias and the films for through hole Z-direction connections and X, Y, signal lines. In the present work, application of LCP as a dielectric layer for the system-on-package process has been evaluated. It is expected that the reinforced LCP films can also be utilized as a substrate material thereby providing the unique opportunity for superior compatibility between the substrate and the dielectric layer.

Keywords: liquid crystal polymer, substrate, dielectric layer, electronic packaging, system-on-package

INTRODUCTION

Electronic packaging technology involves both system and materials considerations. Systems considerations pertain to the packaging schemes, whereas material considerations pertain to the improved materials necessary for more demanding packaging schemes to be possible. Miniaturized packages with increased performance, lower price, and a faster time to market, are the general trends in the electronic packaging industry. Traditional printed circuit boards are comprised of a supporting substrate and copper foil circuit traces. Epoxies, such as FR4, still represent the most common type of polymers used to make circuit laminates. Further research developments will require new materials with improved properties. Liquid crystal polymer (LCP) is a novel material that is expected to meet the demand.

LCP's are high performance materials that combine the properties of polymers with those of liquids. It is a state of condensed matter between crystalline solids and isotropic liquids. The condensed matter is characterized by a combination of physical properties of a liquid crystalline state and specific polymer properties. LCP's are highly crystalline materials based on aromatic ring-structured compounds that are very stable after polymerizing. The liquid crystalline material can have its molecules realigned using magnetic or electrical fields, and in the process acquire the properties of both solids and liquids. Formulations of LCP's depend on the

manufacturer, but they are currently available in a variety of unfilled, glass-filled, mineral-filled, carbon fiber reinforced, and glass fiber-reinforced grades which allow for numerous options in melting points and other key properties. LCP is a promising material because it has exceptional properties that make it well suited for use as a substrate material.

The unique properties of LCP's have led to increasing interest and development in the field. The combination of polymer specific properties together with properties specific to the liquid crystal phase has led to a multitude of new perspectives that are not possible for conventional materials. LCP's have a high modulus, high melting temperatures, and good impact strength as a result of the fibrous nature of liquid crystal morphology. They are unaffected by acids, dilute bases, and organic solvents over a broad temperature range and demonstrate minimal dimensional changes after exposure to a wide range of solvents. Strong concentrated bases at elevated temperatures hydrolyze LCP's. This is convenient for molded circuit board applications and as a method of promoting copper adhesion to LCP's. Other important properties relative to electronic packaging include a low coefficient of thermal expansion, flame retardant, low moisture absorption, and the ability to resist attacks by solvents used in defluxing and cleaning printed wiring boards. On the other hand, LCP's are extremely difficult to align in devices, and they tend to be more viscous than low molecular weight liquid crystal materials. LCP's also have high anisotropical mechanical properties.

There is good processability and a high flowability in the melt state, but in the flow direction the properties are quite different compared to those perpendicular to the flow direction.

Exceptional barrier properties make LCP's well suited for use in packaging applications. LCP technology can replace materials such as ceramics, metals, composites, and other plastics due to outstanding mechanical properties such as: strength, resistance to virtually all chemicals, extreme temperatures, and weathering to name a few. The properties of LCP's discussed are practical/relevant for current packaging concerns. These concerns involve addressing heat removal with a higher thermal conductivity, lower thermal expansion materials to better survive thermal stresses during temperature cycling in a system, and alternatives to solder lead content issues. Currently, polymers are widely used in electronic packaging as adhesives, encapsulants, insulators, dielectrics, molding compounds, and conducting elements for interconnects. These are typical applications requiring resistance to high temperatures and chemicals, and where thin walls, dimensional stability, strength, and rigidity are essential. The thermal analysis data presented will show the need for LCP in future electronic packaging applications.

EXPERIMENTAL

Materials

The LCP materials were shipped in sheet form. Sample A was a 5x5 in² sheet. Samples B & C are glass or mineral reinforced sheets with different thickness from the same company. Sample D is a high performance flexible laminate that comes in 10x10 in² sheets and 10x10 in² single-sided copper clad (Cu-clad) sheets. Samples E & F are 2-4 mil laminates with different melting temperatures. They also come in double-sided Cu-clad sheets. Sample G is a 30% glass and mineral reinforced resin plaque. Sample H is similar to samples B & C, but has a lower thickness. Biaxial directions were defined on the sheets and samples were cut to appropriate dimensions for thermal analysis experiments. The samples with Cu-clad backing were etched using ferric chloride. Those samples exhibiting the best properties were selected for use as the dielectric layer on different substrates. The decomposition temperature, filler content, liquid crystal transition temperature range, modulus, and CTE were studied using TA instruments.

TGA-thermogravimetric analysis

A thermogravimetric analyzer from TA instruments was used to measure the amount and rate change in sample mass as a function of temperature. The melting temperature of LCP samples was determined from the weight loss as a result of decomposition. The experiment was done using a heating rate of 10°C/min

from room temperature to 800°C under a nitrogen atmosphere. The sample mass did not exceed 5mg.

TMA-thermomechanical analysis

The thermomechanical analyzer was used to measure the thermal expansion of the LCP films as a function of force and temperature. The force used was 0.030N with a heating rate of 5°C/min from room temperature to 250°C under a nitrogen gas atmosphere. From the data collected the coefficient of thermal expansion (CTE) is calculated from the change in dimensional area as a function of temperature.

DMA-dynamic mechanical analysis

The modulus was obtained using a dynamic mechanical analyzer. The dimensions of the specimens did not exceed 20 x 6 x 2 mm³. The samples were tested using a film tension clamp/fixture and were heated at a rate of 3°C/min from 25°C to 250°C in air.

Moisture Absorption

Moisture absorption methods were conducted using an environment chamber set at 85°C and 85% relative humidity. Prior to being placed in the chamber, all specimens were heated at 150°C for 30 minutes to remove any excess moisture and an initial weight was recorded. The specimens were removed at 24-hour intervals, dried, weighed, and immediately returned to the humidity chamber. The amount of moisture absorbed was determined based on the initial mass of each specimen.

Lamination Press

The lamination press is used to bond LCP as a dielectric layer onto carbon and FR-4 substrates with varying time, pressure, and temperature. LCP has a much higher melting temperature than the substrates, therefore obtaining good adhesion was challenging. The objective is to use LCP to combat warpage that occurs with the current epoxy dielectric layer. During the test, LCP materials selected after thermal analysis were directly laminated on the carbon and FR-4 substrates. Low temperature LCP was also used to promote better adhesion in addition to surface treated substrates. This set of tests involved using high temperature and low temperature LCP, FR-4 substrates with and without the copper layer, surface treated FR-4, and carbon substrates.

RESULTS AND DISCUSSION

Fig. 1 is a view graph comparing the TGA results from 8 LCP samples and an FR-4 substrate. LCP is a high melting polymer with a liquid crystal transition temperature. Table 1 lists the decomposition

temperature range at 5-10% weight loss. It can be seen that LCP's have high melting temperatures in comparison to the FR-4 substrate. This will become a concern when attempts are made to laminate LCP as a carrier film to FR-4 substrates and get good adhesion. LCP materials have excellent thermal stability that may be attributed to the ordered state they maintain below the melting point. Below the melting temperature the polymer is a solid and the polymer chains line up to form crystals. Above the melting temperature the crystals melt to form a fluid with random order.

Table 1: Thermal Analysis Data

Sample ID	TGA @ 5% (°C)	CTE x (ppm/°C)	CTE y (ppm/°C)	Modulus x (MPa)	Modulus y (MPa)
A	501.51	13.6	12.9	6142	4836
B	499.21	48.4	-22.7	15924	2327
C	525.50	47.9	-18.6	22249	2208
D	528.08	18.2	12.7	2026	4312
E	496.30	30.5	32.8	2408	2818
F	495.79	28	35.3	6218	3786
G	510.70	-----	-----	-----	-----
H	494.30	-----	-----	-----	-----
FR-4	295.25	52 (in-plane)			

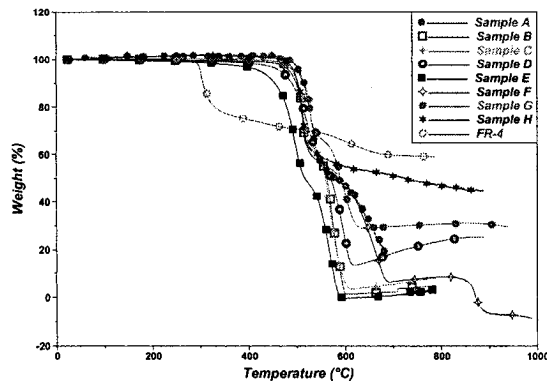


Figure 1: TGA Curve

Fig. 2 shows the data collected from the 85/85 humidity chamber. The LCP samples maintained their weight after 300 hours with a weight loss less than .05%. There is very low water uptake for LCP materials.

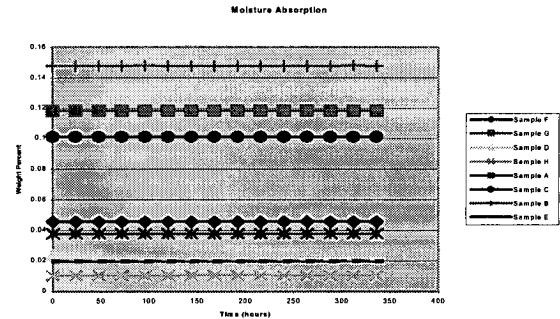


Figure 2: Moisture Absorption Data

Figs. 3 & 4 are important because the TMA data is used to calculate the CTE values. LCP is a possible candidate material believed to have high dimensional stability. Currently there is a CTE mismatch between the board and the IC chip. The substrate typically has a CTE value of 18-20ppm/°C while the IC chip has a CTE value of 2-3 ppm/°C. After reflow, during cooling, the substrate wants to shrink but is prevented due to the IC chip holding it flat thus causing stress and warpage for the electronic package. A material with a lower CTE value will aid in eliminating the stress and combat warpage between the substrate and the IC chip. Samples B & C expand greatly in one direction and shrink greatly in the other direction. It is believed that the large expansion in one direction causes the shrinkage in the opposite direction. Samples A & D have the lowest CTE values of all the samples tested while samples E & F have higher CTE values than expected. The CTE values are of great importance since a major concern is the mismatch between the IC and the substrate. Currently there are methods being used to enhance reliability, but the ultimate solution will be to develop a substrate without a CTE mismatch.

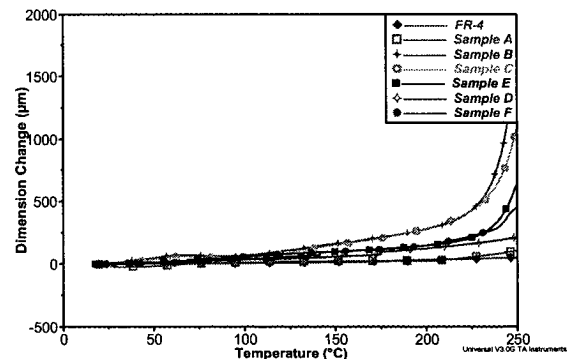


Figure 3: TMA x-direction

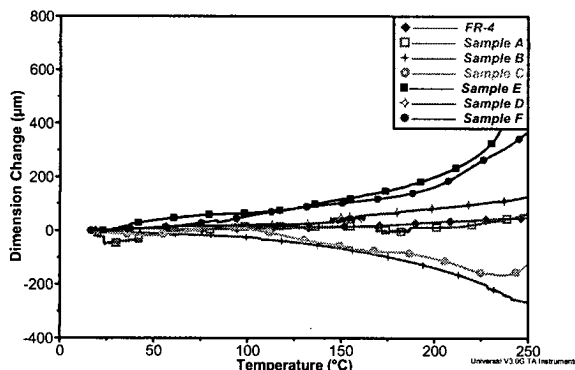


Figure 4: TMA y-direction

Figs. 5 & 6 exhibit the storage modulus of the LCP materials. All the samples have a decreasing modulus as the temperature increases. Samples B & C decrease faster, but have the highest recorded modulus data. The other samples appear to decrease at a slower rate but still have a much lower modulus than at room temperature. From this data it is expected that reinforcement materials will be used for the LCP base substrate test vehicle and the LCP dielectric material test vehicle. Although LCP materials have high dimensional stability, they have very low stiffness. Modulus data is important for minimizing warpage in the package. Warpage comes from thermal mechanical stresses (TMS) that are directly related to the modulus and CTE values of a material. In order to minimize TMS, a low CTE and high modulus is preferred. The modulus of LCP materials may improve with reinforcement materials such as carbon fibers. The materials used currently have both a high CTE and a high modulus, which causes the warpage within the package.

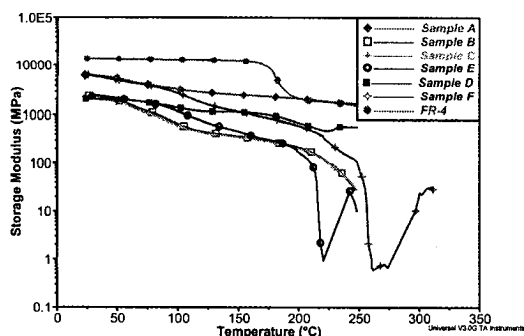


Figure 5: DMA x-direction

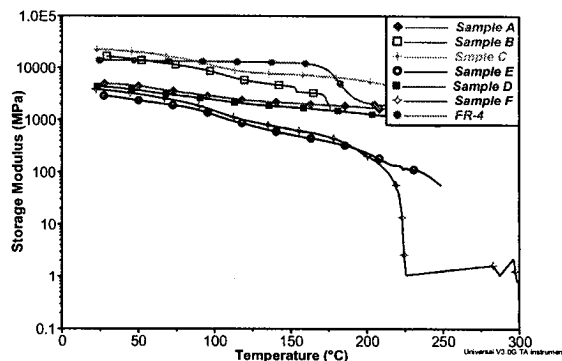


Figure 6: DMA y-direction

The lamination press was used to determine the standard parameters necessary for bonding LCP as a dielectric layer. The important parameters considered were temperature, pressure, and time. LCP melts at a much higher temperature than FR-4 and the carbon substrates. Initial tests were done by slowly ramping to the desired temperature while the sample was in the press. Unfortunately the samples degraded due to the long exposure, subsequently the time was decreased and the results are presented in table 2. In order for LCP to be effective it is important to bond the laminates at a temperature that will not distort the unique LCP properties or cause the substrate to decompose. The low temperature LCP was used to bond the high temperature LCP with and without Cu-clad backing to the FR-4 substrate. This proved to be a fundamental step to ensure good adhesion. Many tests were run to determine the correct parameters for bonding. Sample D (single side Cu-clad) has the best results at 536F with a pressure of 81.63kgf/cm² for 3 minutes on a double treated FR-4 substrate with low temperature LCP to ensure excellent adhesion and few voids.

TABLE 2: Results of Lamination of LCP Dielectric

Substrate Type	Sample D	Sample F	Low Temp LCP	Parameters temp (°F), pressure (kgf/cm ²), time (mins)	Results
Cu foil, shiny surface		✓	✓	536, 72.6, 3	Good adhesion, voids present
Cu foil sheets, rough side			✓	545, 9.1, 5	LCP adheres, voids present
Double treated FR-4		✓ Cu-clad (single sided)	✓	482-536, 72.6, 3	LCP sheets adhered, Cu layer peeled

					from Sample D
Double treated FR-4, Cu sheet-rough side			√	536, 72.6, 3	Good adhesion, difficulty in peeling Cu layer
Double treated FR-4	√ Cu-clad single sided		√	536, 81.6, 3	Good adhesion, but not uniform, minimal voids

Laser ablation techniques were performed using an Excimer Laser on a 60 μ m film. The wall angle θ is 77.32°. The next step will involve plating the vias for through hole Z-direction connections and X, Y signal lines.

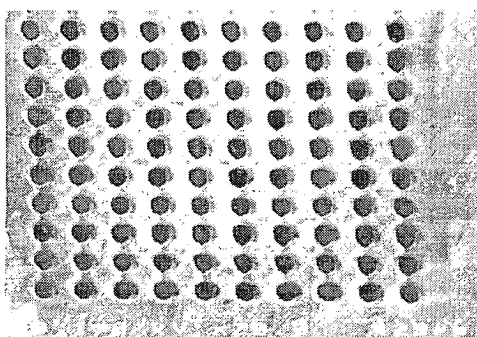


Figure 7: Laser ablated LCP film

SUMMARY AND FUTURE WORK

From the data collected samples D & F will be used for further research since they exhibit the superior properties overall. Sample D is available at even lower CTE values from the manufacturer. Sample F is processed in both a high and low temperature sheet. The low temperature sheet will be beneficial in achieving adhesion among the LCP layers for the base substrate and in adhering high

temperature LCP to substrates as a dielectric material. Standard parameters were determined for the lamination process and a test vehicle is being developed to continue with the goals of this project.

ACKNOWLEDGEMENTS

The work was supported by National Science Foundation through the Georgia Tech NSF-Engineering Research Center for Electronic Packaging and the Materials Science Department at Georgia Tech.

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