# A Study of Critical Processing Technologies of Liquid Crystal Polymer Printed Circuit Board for High Speed Application

**K. C. Yung, H. Liem, H. Choy, T. M. Yue**

*Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong*

Received 22 July 2009; accepted 4 November 2009
DOI 10.1002/app.31728

**ABSTRACT:** Recent demand for high-frequency and high-speed signal transmission over GHz is driving the printed circuit board (PCB) industry towards a more advanced material-based era. To meet this market demand, liquid crystal polymer (LCP) has been suggested for its predominant material characteristics, such as high temperature resistance, low moisture absorption and excellent dimensional stability. However, former experimental and theoretical studies on the fabrication technology for processing the LCP PCB at different treatment conditions are lacking. This article thus evaluates the recent development of LCP PCB process technology. Different process approaches involving in lamination, drilling, desmearing, and metallization are proposed and compared, and associated reliability testing is addressed. Experimental results are shown to demonstrate the efficacy of the proposed approach for developing the process technology of LCP PCB. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 116: 2348–2358, 2010

**Key words:** liquid crystal polymer; printed circuit board; process technology

## INTRODUCTION

Liquid crystal polymer (LCP) offers its favorable characteristics for high performance electronic material, such as low dielectric constant, low moisture absorption, and excellent thermal stability. Laminated LCP with copper foil is used to form a printed circuit board (PCB), achieving a highly dense and functional electronic package. This package has the potential to surpass the conventional PCB material's limit for use in high-frequency and high-speed data transmission in wireless local area networks, 40 Gbps high-end routers and servers, microprocessors above 5 GHz, and 10 Gbps application-specific integrated circuits. The ultra-fine pitch circuit and multilayer interconnect design could then comes with these high-speed or high-frequency applications.

Noll et al.[1] proposed the requirement of certain modification in conventional PCB drilling processes for LCP, which is a unique thermoplastic. Beulque et al.[2] also observed the conventional permanganate desmearing to have limitations for removing LCP smears due to its strong chemical resistance. In addition, Kurihara et al.[3] demonstrated LCP had a weak interaction with copper or metal, resulting in low laminate peel strength. Moreover, the comparatively high coefficient of thermal expansion (CTE) in the z-direction (~150 ppm/°C from 30 to 150°C) of LCP is another potential problem in ensuring the final LCP PCB reliability. Consequently, using traditional drilling and chemical processing directly to produce the required LCP PCB has many drawbacks, such as poor drilling hole quality and inaccurate hole wall dimensions, causing poor electrical connection after plating. To compensate these drawbacks, the objectives of this study are therefore to tackle the processing barrier problems and to develop an effective fabrication technology for LCP PCB.

As the manufacturing concerns can lead to reliability problems associated with essentially the plated-through hole (PTH) in LCP PCB, the study thus focuses on the PTH-related areas. The rest of this article is structured as follows: Section "Lamination of test panels" highlights the details of the lamination process for all LCP PCB test panels in this work. Sections "Drilling" and "Demeasuring and metallization," respectively describes the process treatment of LCP PCB for (i) drilling, and (ii) desmearing and metallization. Different testing results are discussed to verify the effectiveness of the proposed process approach. The reliability

---

*Correspondence to:* K. C. Yung (mfkcyung@inet.polyu.edu.hk).

Contract grant sponsor: Government of Hong Kong SAR [Innovation Technology Fund (ITF)]; contract grant number: ITS/092/07.

Journal of Applied Polymer Science, Vol. 116, 2348–2358 (2010)

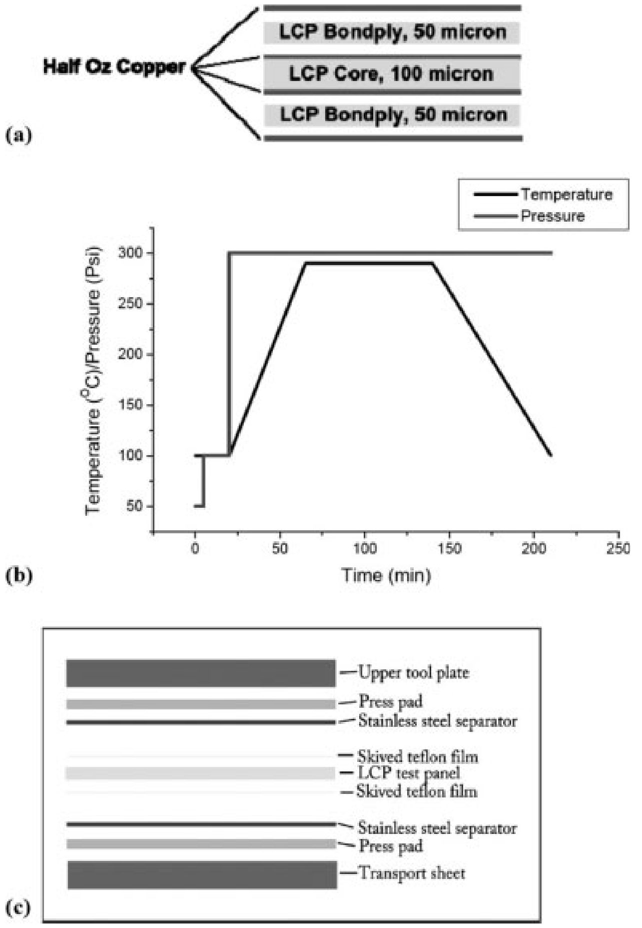

**Figure 1** Panel lamination for LCP PCB. (a) A lay-up construction of 4-layer LCP PCB. (b) Press cycle. (c) Stack up for a one layer book configuration.

testing is conducted and compared in section "Reliability of LCP PCBs" lastly "Conclusion" of the work.

## LAMINATION OF TEST PANELS

The test panels used to study the drilling (Section "Drilling") and reliability (Section "Reliability of LCP PCBs") are multilayer LCP PCBs. LCP copper-clad laminates (CCL) (or simply LCP laminates) and bondplies were from Rogers Corporation with a trade name of Ultralam.[4] Circuit imaging and black oxide treatment of the LCP laminates were conducted by the conventional PCB process without any significant parameter adjustment. A LAMV100 multilayer vacuum hot press was used for laminating all the test panels in this work. Figure 1(a) depicts the details of the lay-up construction of the 4-layer LCP PCB. The profile of the press cycle and the stack-up configuration for a one layer book are shown in Figure 1(b,c), respectively. The lay-ups of the remaining sets are the same, except with higher layer counts. The lay-up of the high layer count LCP test panels requires some additional LCP laminates and bondplies in between, and the cap layer lamination proposed by Roseen[5] is adopted. As the material characteristics and curing conditions for LCP PCB differs from conventional materials, special considerations on the presspad material and release film material are described in following sections "Presspad material" and "Release film material."

### Presspad material

As the LCP glass transition temperature, $T_g$, is above 260°C, the required temperature for laminating LCP PCB will be set to around 300°C. This high temperature setting excludes the possibility of using conventional stack-up materials, such as kraft paper and fluorinated ethylene propylene or silicon coated polyethylene terephthalate release sheet. Fiberfrax 970-J ceramic-filled fiber paper is therefore selected, which is capable of withstanding over 1000°C, as a presspad. The main concern in using this fiber paper is the dust and paper particles that may drop off. This problem can be solved by wrapping the fiber paper before use.

### Release film material

Pure Teflon release film from ENFLO (with initial melting temperature about 340°C) or copper foil with shiny face, were used as release films in this study. The Teflon film is manufactured by the skiving method (Fig. 2). The skiving involves the removal of material from a rotating billet by the use of a blade. The pressure of the blade determines the thickness of the film. A thicker Teflon film can also be used as a conformal coating material.

The peel strength of the pressed multilayer LCP test panels was found to be 8.46 lb/in. with a half oz of copper, which was comparable with the typical value of as purchased LCP laminate, 8.52 lb/in. The drilling and desmearing parameters determined in following sections "Drilling" and "Demeasuring and

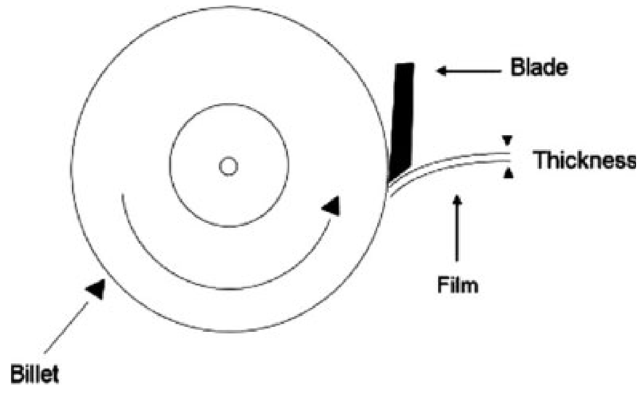

**Figure 2** Method of manufacturing skived Teflon film (Courtesy of Anrob).

**TABLE I**
**Test Matrix on Drilling Parameters and Results of Drilling Tests for 8-Layer LCP Test Panel**

| | Drilling parameter | | | | | | |
|---|---|---|---|---|---|---|---|
| Experiment no. | Hole diameter (mm) | Cutting speed (m/min) | Chip load (mm/r) | Entry/back-up | Stack height | Results[a] | Remarks[a] |
| D1 | 0.3 | 95 | 0.012 | 0.4 mm phenolic/0.4 mm phenolic + wood | 1 panel | A | Good quality |
| D2 | | 95 | 0.025 | | | NA | Severe rip out of LCP, copper burr |
| D3 | | 130 | 0.012 | | | NA | Rip out of LCP |
| D4 | | 130 | 0.025 | | | NA | Rip out of LCP |
| D5 | 0.5 | 110 | 0.025 | | | A | Good quality |
| D6 | | 110 | 0.045 | | | MA | CMAR |
| D7 | | 165 | 0.025 | | | A | Good quality |
| D8 | | 165 | 0.045 | | | MA | CMAR |
| D9 | 0.75 | 140 | 0.025 | | | A | Good quality |
| D10 | | 140 | 0.045 | | | MA | CMAR |
| D11 | | 180 | 0.025 | | | A | Good quality |
| D12 | | 180 | 0.045 | | | MA | CMAR |

[a] A, acceptable; NA, not acceptable; MA, marginally acceptable; CMAR, comparatively more amount of residues.

metallization" were used to prepare test panels for the reliability test in section "Reliability of LCP PCBs."

## DRILLING

Fu et al.[6] investigated the drilling process for PCB and understood that it was inevitable to have smear and chip formation in the drilling process. Special attention can still be taken in selecting the drilling parameters to minimize the unwanted formation. Typical PCB substrate materials, such as FR4 and polyimide, are thermosetting polymers. Although they are of the same type, the PCB industry has already encountered many problems when switching from FR4 to polyimide as their physical and chemical properties are quite different. For a completely new thermoplastic material, LCP, the drilling parameters have to be re-engineered and modified to avoid overheating, retaining good hole integrity.

PCB manufacturers have adopted two main approaches for hole formation, namely laser drilling and mechanical drilling. Laser drilling aims at forming buried microvias with the diameter ≤0.15 mm. For mechanical drilling, it is more suitable for mass production of large diameter PTHs. In the sections "Mechanical drilling" and "Laser drilling," both mechanical and laser LCP drilling was evaluated.

### Mechanical drilling

In this study, the interest is in the LCP substrate rather than the design of the drill bit. Therefore the effect of the drilling parameters on the hole quality of LCP PCB is explicitly investigated.

#### Experimental setup

A Schmoll mass production LM series machine was used for drilling the LCP PCB panels. Table I lists the details of the drilling parameters. The parameters were selected in such a way to cover a wide range of drilling parameters to determine their relationship with hole quality. New drill bits were used at the beginning and were then replaced after drilling 1000 holes. The panels used for the evaluation were 4 and 8-layer LCP PCBs with thicknesses of 0.28 and 0.64 mm, respectively.

#### Results and discussion

Chip clogging, LCP rip out, and copper burr were considered "Not Acceptable" in this study [Refer to Fig. 3 (a)]. In general, the quality of the large holes (>0.3 mm) was observed to be better than the small holes (≤0.3 mm). Also, a higher cutting speed and chip load were allowed in drilling larger holes. This suggested that the heat generated was minimized due to better heat conduction through the drill bit and easier evacuation of chips. By keeping the chip load constant, increasing the cutting speed (D7 and D11 as shown in Table I) did not show any adverse effect on the hole quality. This results in a higher throughput when drilling large holes.

Table I lists the results of drilled hole quality with various drilling parameters on LCP PCB for 8-layer LCP test panels. The results of a 0.30 mm hole suggested that there was a general trend: a lower cutting speed and chip load produced a better hole quality as shown in Figure 3(b). The drilling parameters with lower cutting speed and higher chip load (D2) were found to have severe LCP rip out from the holes [Fig. 3(a)], and have serious chip clogging in the holes. Chips were also found to accumulate in the drill bits, which affected the quality of the subsequent holes. Severe copper burring was also observed around the edge of some drilled holes. The

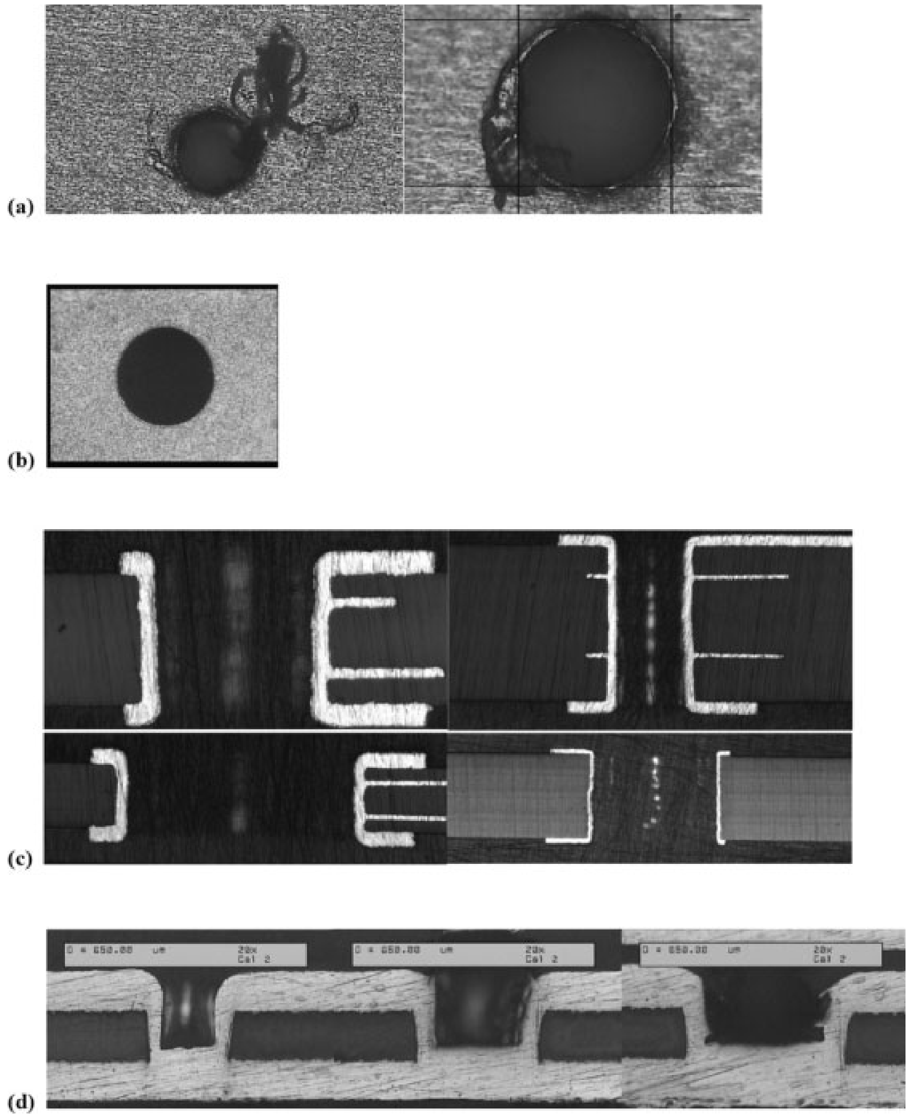

**Figure 3** Comparison between mechanical hole drilling and laser drilling. (a) A mechanical drilled hole showing (left) the rip out of LCP (50×), and (right) copper burr (100×). (b) A mechanical drilled hole without rip out of LCP rip out (100×). (c) Images of drilled and electroplated PTH (left top) 0.30 mm on 4-layer thick LCP PCB (250×), (right top), 0.30 mm on 8-layer thick LCP PCB (100x), (left bottom), 0.75 mm on 4-layer (125×), (right bottom), 0.75 mm on 8-layer thick LCP PCB (50×). Remark: Not all the layers are shown in the PTH. (d) Laser drilled microvias on LCP [left: 0.10 mm, middle: 0.15 mm, and right: 0.2 mm, (200×)].

above problems may be caused by the excessive heat generated inside the holes due to the high frictional force between the drill bit and LCP when the drill bit was piercing rather than drilling.

During the study, it was found that LCP chips are more difficult to be evacuated than those of conventional PCB materials such as FR4. This may be explained by the difference in material properties such as the toughness of the LCP. The LCP was torn out instead of broken down into powdered residue as in the case for FR4. Drilling depth is another concern, and excessive LCP clogging or rip out was observed if the drill bit tip penetrated too far into the wood core backup entry.

Fine tuning of the drilling parameters based on the above results was conducted. Table II shows the optimal drilling parameters for drilling 4- and 8-layer LCP test panels. The electroplated PTH using these drilling parameters (these PTHs were drilled on dummy LCP panels) is displayed in Figure 3(c). It was observed that the drilling parameters which are good for the 4-layer LCP PCBs were not applicable for the 8-layer count LCP test panels. Lowering of cutting speed and chip load were suggested. Apart from the above tests, drilling using 14-layer test panels was also conducted. Comparatively poor drilling quality was observed even at low chip load. LCP rip-out was observed, in particular, when

**TABLE II**
**Optimal Drilling Parameters for Drilling 4 and 8-layer LCP Test Panels**

| Hole diameter (mm) | Layer count | Speed (krpm) | Feed rate (m/min) | Cutting speed (m/min) | Chip load (mm/r) |
|---|---|---|---|---|---|
| 0.30 | 4 | 120 | 1.5 | 94 | 0.013 |
| | 8 | 80 | 1.0 | 63 | 0.013 |
| 0.50 | 4 | 80 | 2.4 | 126 | 0.030 |
| | 8 | 75 | 1.8 | 118 | 0.024 |
| 0.75 | 4 | 60 | 1.7 | 141 | 0.028 |
| | 8 | 60 | 1.6 | 141 | 0.027 |

drilling small holes. A technique called peck drilling was found to be helpful on reducing the amount of LCP residue as it helped to facilitate heat dissipation and evacuate chips in high-layer count drilling. The drilling parameter giving the best quality is thus a low cutting speed and chip load with the use of peck drilling at the high-layer count.

### Laser drilling

Laser drilling prevails in PCB industries due to advantages including noncontact processing, low heat input into the PCB material, flexibility for drilling a wide range of materials, accuracy and consistency. The other associated benefits are drilling blind microvias, this making high-density interconnects (HDI) possible. Since LCP is a homogeneous material without embedding glass fibers, as in conventional FR4, drilling LCP is similar to drilling resin coated copper (RCC) or polyimide. It produces much fewer drilling defects such as uneven drilling or fiber protrusion. LCP requires less energy to drill a given hole in comparison with FR4. From the evaluation results by using a UV-YAG ESI 5200 laser drilling system with typical production parameters, the throughput of laser drilling on LCP is about 30% quicker than on FR4, but about 80% slower than on RCC. Figure 3(d) shows the images of laser drilled and electroplated microvias on LCP, with hole diameters of 0.10, 0.15, and 0.20 mm, respectively. The hole quality is acceptable and therefore LCP microvias can be produced using laser drilling process.

## DESMEARING AND METALLIZATION

In drilling operations, residual resin will smear along the hole walls of multilayer PCB. The desmearing process is therefore of paramount importance to ensure the interconnects are free from smears for electrical connection, and to ensure the hole walls are conditioned for the subsequent metallization process, especially to solve the existing difficulty to form LCP bonding with copper. There are two approaches to the desmearing process, namely the chemical method and the plasma method. The chemical method includes permanganate ($KMnO_4$) or potassium hydroxide (KOH). $KMnO_4$ has been conventionally used to remove smears for conventional PCB materials such as FR4. Its desmearing consists of three main steps, swelling, oxidization and neutralization as summarized by Carano.[7] In contrast, Shohet[8] used the plasma desmearing process for advanced materials such as Teflon and polyimide. It consists of ions, electrons, neutrals, and radicals which react with LCP to cause a chain scission to achieve the desmearing. Since LCP is a new PCB substrate material, the effectiveness of the two desmearing methods is worth evaluating.

The aim of this section is to find out the most effective desmearing method based on (i) the desmearing rates, and (ii) adhesion strength in terms of the peel strength between the deposited copper and LCP. A high desmearing rate is desirable as it shortens the processing time and increases the yield. Simultaneously, high PCB reliability in an electronic device depends on good hole wall adhesion quality between the copper conductor and the dielectric material. An optimized desmearing method for achieving high adhesion strength and desmearing rate will be selected accordingly.

### Experimental setup

The test panels used for the evaluation were copper etched LCP CCL, having a trade name of Ultralam 3000. As the side of the copper facing the LCP of this LCP CCL had been roughened to enhance the bonding strength, this topographic surface was transferred to the surface of the LCP during lamination, forming a negative template. After etching the copper and redepositing it with electroless and electroplated copper, the adhesion strength of this specimen was measured by a peel strength tester as mentioned in section "Peel stregth results." The measured value was 1.34 lb/in. To assess the process effectiveness, this value was used as a control for comparing LCP samples treated with various desmearing methods.

Table III summarizes the processing conditions of test panels under different treatment with $KMnO_4$

**TABLE III**
**Parameter Setting for Different Desmearing Conditions**

Desmearing process and parameter setting conditions for the experiment C1–C5

| Experiment no. | Process | Concentration (g/L) | Temperature of sweller (°C) | Immersion time (sweller) (min) | Temperature of desmearing (°C) | Desmearing time (min) |
|---|---|---|---|---|---|---|
| C1 | Permanganate, $KMnO_4$ | 50 | 75 | 5 | 80 | 15 |
| C2 | | | | 5 | | 20 |
| C3 | | | | 5 | | 30 |
| C4 | | | | 10 | | 30 |
| C5 | KOH | 300 | NA | NA | 93 | 7 |

Desmearing process and parameter setting conditions for the experiment P1–P7

| Experiment no. | Process | Temperature (°C) | RF power (W) | Gas flow rate (cc/min) | | Desmearing time (min) |
|---|---|---|---|---|---|---|
| P1 | $CF_4 + O_2$ plasma | 90–115 | 1000–2000 | 300 ($CF_4$) | 1000 ($O_2$) | 30 |
| P2 | $O_2$ plasma | | | 1300 | | 30 |
| P3 | $N_2 + H_2$ plasma | | | 300 ($H_2$) | 700 ($N_2$) | 30 |
| P4 | $N_2 + O_2$ plasma | | | 300 ($N_2$) | 700 ($O_2$) | 30 |
| P5 | Step 1, $CF_4 + O_2$ plasma | | | 300 ($CF_4$) | 1000 ($O_2$) | 20 |
| | Step 2, $O_2$ plasma | | | 1000 | | 20 |
| P6 | Step 1, $CF_4 + O_2$ plasma | | | 300 ($CF_4$) | 1000 ($O_2$) | 20 |
| | Step 2, $N_2 + H_2$ plasma | | | 300 ($H_2$) | 700 ($N_2$) | 20 |
| P7 | Step 1, $CF_4 + O_2$ plasma | | | 300 ($CF_4$) | 1000 ($O_2$) | 20 |
| | Step 2, KOH | | | NA, with same process parameters as experiment No. C5 | | |

NA, not applicable.

with model MLB 214 from Rohm and Haas, KOH and gas plasma, respectively. Various treatment combinations were studied on the plasma evaluation; including gas types such as tetrafluoromethane and oxygen, nitrogen and hydrogen/oxygen and pure oxygen. These combinations were specifically chosen since they were known to be effective and widely adopted in polyimide desmearing, Teflon desmearing and general cleaning purposes respectively. Also, these ranges of input and fixed parameters were chosen through the previous work of Yung et al.[9], review of literature, industrial testing experience, and some preliminary investigations to effectively encompass the wide variety of desmearing recipes.

The desmearing rate of the test panel was measured by the weight difference before and after desmearing per process time. For facilitating the calculation, the desmearing rate was converted to etch depth/min (μm/min) by using the following equation:

$$\text{Desmearing rate of test coupon} = \Delta W/(\rho \times A \times T) \tag{1}$$

where $\Delta W$ = weight difference (in g), $\rho$ = density (in g/cc), A = area of test panel (in $cm^2$) and T = time (in min).

## Results and discussion

The desmearing rate using the chemical method or plasma method is discussed in sections "Desmeasuring rate of chemical method ($KMnO_4$ or KOH)" and 4.2.2, respectively. The peel strength results of LCP PCB obtained by these two methods are then compared in section "Peel strength results."

### Desmearing rate of chemical method ($KMnO_4$ or KOH)

Results of the desmearing rate study are shown in Figure 4(a). The desmearing rate of KOH (C5) is two times quicker than the highest desmearing rate of $KMnO_4$ (C4). In other words, the KOH is more effective than $KMnO_4$, and is more suitable for LCP desmearing in terms of the desmearing rate.

Li[10] proposed one purpose of swelling in chemical desmearing was to weaken the resin bonding for ease of $KMnO_4$ attack. Figure 4(c) shows a plot of the desmearing rate of LCP using $KMnO_4$ against time, with the immersion time in a sweller being 5 min. The sweller used was an aqueous solution from circuposit MLB conditioner 211. It was observed that the desmearing rate increased with desmearing time until it reached a maximum. It was because the sweller functioned as a solvent to weaken the LCP smear for subsequent $KMnO_4$ attack. When this weakened LCP was removed, i.e. at the maximum desmearing rate, the desmearing rate slowed down as the LCP became harder to be removed. However, by increasing the immersion time in the sweller from 5 (C3) to 10 min (C4), there was an increase of 73% in desmearing rate at a desmearing time of 30 min, as shown in Figure 4(a). The increase in

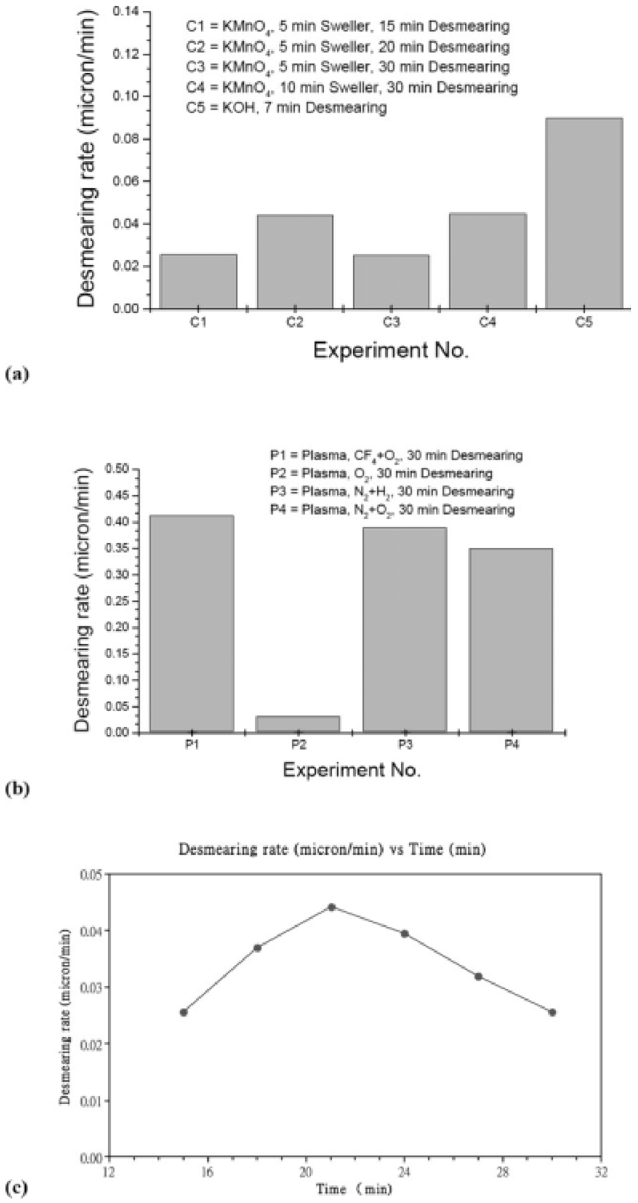

**Figure 4** The results of desmearing rate with varying treatment conditions. (a) Comparison of chemical desmearing rate with different treatment conditions. (b) Comparison of plasma desmearing rate with different treatment conditions. (c) Desmearing rate of LCP using chemical method for permanganate (Immersion time in the sweller: 5 min).

immersion time of the sweller extended the LCP weakened zone, thereby increasing the desmearing rate.

### Desmearing rate of plasma

A MK-II-1 plasma etch system is used for desmearing operation in this work. The plasma desmearing rates of each individual component of the gas combinations are shown in Figure 4(b). From the results, the desmearing rate of $CF_4 + O_2$ plasma (P1) is the highest, followed by that of the $N_2 + H_2$ plasma (P3), and then $N_2 + O_2$ plasma (P4), KOH (C5), $KMnO_4$ (C1-C4) and $O_2$ plasma (P2). In comparison, the chemical methods by $KMnO_4$ (C1-C4) or KOH (C5) are not effective to desmear LCP due to its slow desmearing rate. This may be attributed to the high chemical resistance of LCP. As for the high desmearing rate achieved by plasma method (P1, P3 and P4), it may be due to the formation of highly active ions such as oxyfluoride, and C- and NC-containing molecules, which interact vigorously with the LCP carbon polymer chain and then break it.

### Peel strength results

Metallization was then conducted on these plasma treated test panels and the peel strength between the deposited copper and the LCP was determined. Meanwhile, other desmearing treatments such as $KMnO_4$ and KOH (C1-C5) and $O_2$ plasma (P2) were also included in the test matrix for comparison, despite their lower desmearing rates. The reason is that desmearing treatments having a high desmearing rate may not offer a good surface condition for the metallization. Surface condition is a critical factor in forming a robust bonding between the deposited copper and LCP. A CECO TA636-10E model copper clad peel strength tester was used to monitor and test the peel strength of the copper clad test panels according to IPC-TM-650 2.4.8C. The results are then compared with a control (without desmearing) as shown in Figure 5(a).

The aims of this desmearing study are to remove the remaining drilling debris and optimize the hole wall condition such that the adhesion strength is enhanced. Even though $CF_4 + O_2$ plasma (P1) offers the highest desmearing rate, it is not suitable for LCP desmearing as the panels were observed to have a copper deposition problem [see Fig. 5 (b)]. The $N_2 + H_2$ plasma (P3) process having the second highest desmearing rate, with the highest peel strength, is thus regarded as the most suitable desmearing method for LCP.

## RELIABILITY OF LCP PCBS

Once the processing method and parameters for fabricating a reliable hole are developed, LCP PCB design parameters will be established by investigating the impact of the comparatively high out-of-plane CTE (~150 ppm/°C from 30 to 150°C) of LCP on the reliability. The quality issues associated with CTE lie on the mechanical stress in the hole, generated during thermal cycling, due to the thermal expansion mismatch with the electroplated barrel copper (CTE of copper is ~17 ppm/°C). This may

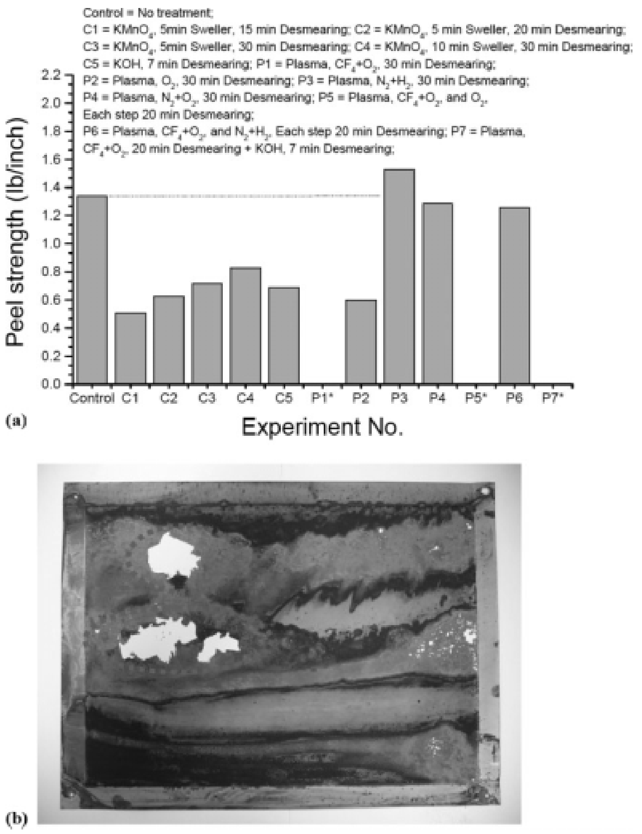

**Figure 5** Peel strength test result after metallization. (a) Results of peel strength test with different desmearing treatments. (* Metallization failure was observed in experiment P1, P5 and P7) (b) Image showing the copper deposition problem (in dotted circles) of LCP panel treated with CF4 + O2 plasma (P1) after electroless copper plating.

lead to PTH reliability problems when the LCP PCB is under thermal stress, especially during assembly. In serious case, the fatigue failure of copper may result in an electrical open circuit as suggested by Darveaux et al.[11]. By investigating the PTH stress behavior, proper design parameters, including board thickness and via diameter, improvement on the reliability of LCP PCB can then be determined.

Chen et al.[12] conducted an evaluation on the reliability of PCB with respect to the PTH when it was subjected to thermal stress. Models were devised to evaluate the stresses and strains in the PTH barrel and to predict the cycles-to-failure. The technical report of IPC[13] depicted a typical and basic model. From the model equations, a higher CTE will cause a higher stress in the PTH barrel, as in the case of LCP. These equations also imply that a thicker dielectric material will also lead to a higher stress. A higher stress will give a higher strain range and therefore lower the mean fatigue life. In reality, many PTHs fail at lower cycle numbers than using the calculated analytical values. This is due to the severe strain concentrations resulting from the nonuniformity of PTH and the poor copper plating quality. For better estimation, an effective maximum strain range is also introduced as shown.[13] In light of the above, a study was conducted to review how the CTE value affects the PTH reliability in LCP PCB. Besides, the impacts of typical PCB design parameters were also evaluated, such as hole diameter, board thickness, and presence of inner pad, on the PTH reliability of LCP PCB.

### Test details

Details of the test matrix are shown in Table IV. Three PCB design parameters were studied, namely the panel thickness, hole diameter, and the effect of the presence of dummy inner pads/layers. Two different thicknesses, 0.28 mm and 0.64 mm, of panels were tested. Different aspect ratios were compared, which is defined as a ratio of the thickness of LCP test panel over the hole diameter. All test panels were 4-layer circuits. However, dummy inner pads/layers were included in some 0.64 mm test panels, depending on the test matrix. No dummy inner pad/layer was present in the 0.28 mm test panels.

All test panels were laminated in accordance with Figure 6(a), and then drilled, electroless and electroplated to a 25 μm copper thickness. The test panels were then subject to a thermal shock test in according to IPC-TM-650 2.6.7a Condition D. A Climate Spirale model tester was used to perform the thermal shock and cycling test operation. The temperatures of the cycle ranged from 125 and −55°C respectively, with a dwell time of 15mins each and a recovery time of less than 2 min. A daisy chain coupon was designed on the test panels for the resistance measurement. Resistances of the coupons were measured by the four-point probes method with an Agilent 4338B milliohmmeter. A resistance change greater than 10% was considered as a failure. Microsectioning was conducted on the failed coupons to examine the PTH crack.

### Results and discussion

Figure 6(b) summarizes the results of the thermal shock test. It was observed that the 0.28 mm thick test panels were more reliable than the 0.64 mm thick test panels. In addition, for any given thicknesses of LCP PCB, the 0.30 mm PTH failed earlier than 0.50 mm and 0.75 mm PTHs, which had similar thermal strength. Figure 6(c) shows the PTH barrel crack (pointed with arrows) after the thermal shock test. The results matched with the model mentioned previously, in that the thicker the test panel the higher the PTH stress will be, and the higher stress was the cause of the failure. The 0.64 mm test panels also gave similar results, with or without a dummy inner pad/layer. This indicates that within this range of design parameters, the dummy inner pad/layer has no effect on the reliability of LCP test

**TABLE IV**
**Test Matrix of the Reliability Test**

| Experiment | Thickness (mm) | Hole diameter (mm) | Aspect ratio | Dummy inner pad/layer |
|---|---|---|---|---|
| 1 | 0.28 | 0.30 | 0.93 | No |
| 2 | | 0.50 | 0.56 | No |
| 3 | | 0.75 | 0.37 | No |
| 4 | 0.64 | 0.30 | 2.13 | No |
| 5 | | | | Yes |
| 6 | | 0.50 | 1.28 | No |
| 7 | | | | Yes |
| 8 | | 0.75 | 0.85 | No |
| 9 | | | | Yes |

0.28 mm test panel has no dummy inner pad/layer.

panels. It was also observed that even though LCP exhibited a much higher CTE than typical PCB materials, the results of the study on the PTH reliability were acceptable. This may be attributed to the thin LCP core and bondply, as thin as 50 μm, being used in comparison with about 75 μm of a 1080 and 178 μm of a 7628 for a typical FR4. This made the overall LCP PCB thickness as thin as possible for any given number of layers, in comparison with a typical FR4 PCB.

## Result comparison with other approach

Based on the test results, there was no concern for PTH reliability if the design parameters, such as

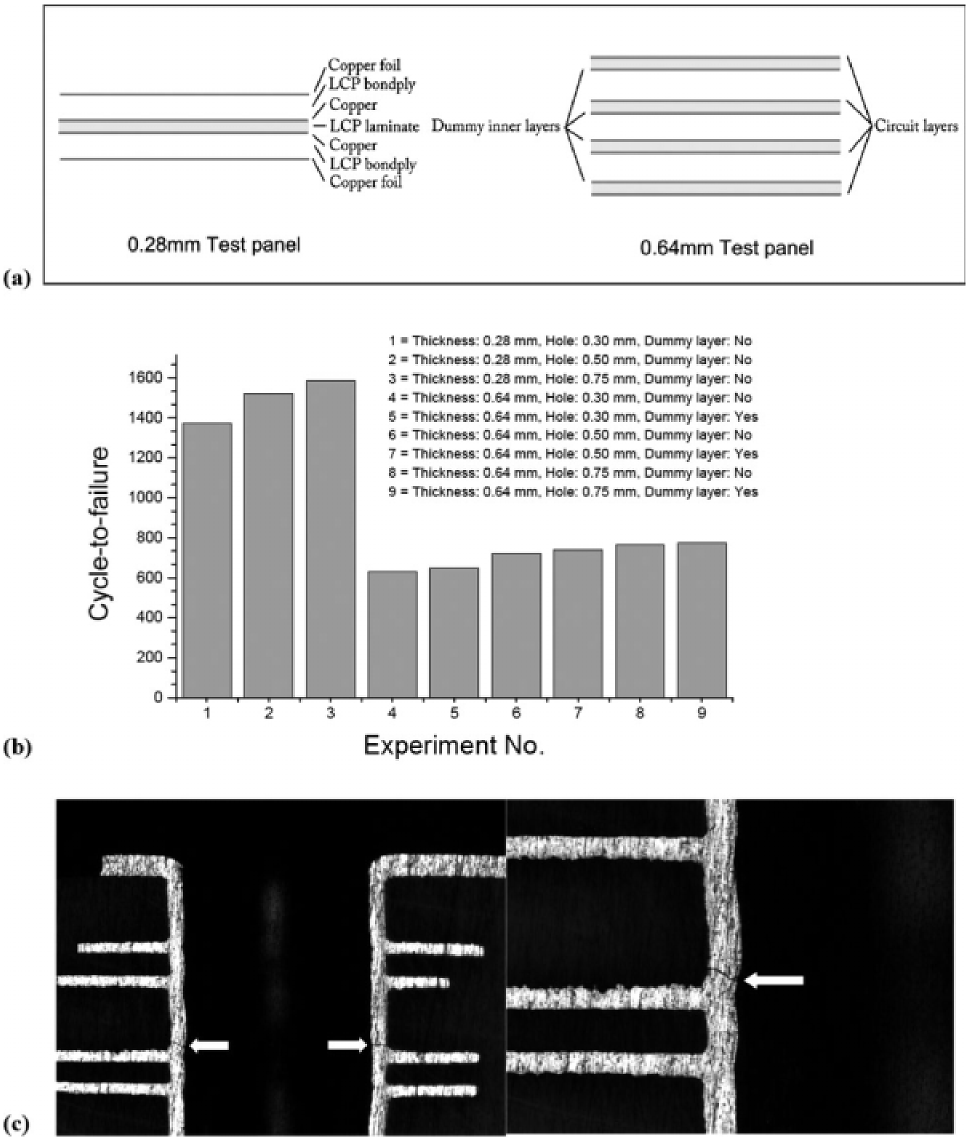

**Figure 6** The reliability test for LCP PCB. (a) Lay-up of test panels for the design parameter study (left) 0.28 mm 4-layer test panel, (right) 0.64 mm 4-layer test panel with or without the dummy inner pad/layer. (b) The results of the thermal shock test. (c) Barrel crack of PTH (pointed with arrows) after thermal shock test (Left: x100). Magnified view (×250) is on the right.

board thickness and hole diameter, were within the study range of this work. It could be specially designed when some typical PCB materials are used. The PTH reliability within the 0.64 mm thick LCP PCB was found to be independent of the inner pad/layer factors. In addition to the mathematical model described in the IPC technical report,[13] Fu et al.[14] investigated the PTH reliability using the finite element method (FEM). FEM analysis suggested that a high aspect ratio was detrimental to PTH reliability. When there was a decrease in hole diameter, the stiffness of the PTH decreased and therefore the strains increased accordingly. The strain range was also increased with the overall board thickness. From previous FEM analysis, the effect of reducing the board thickness on reducing the critical stress was more prominent than that of enlarging the hole diameter. This analysis matched with the results here, in that a lower aspect ratio was capable of withstanding longer thermal stress cycles.

## CONCLUSIONS

In this article, recent development of LCP PCB technologies is described. In particular, a process technology for fabricating LCP PCB is developed. The problems associated with each process including lamination, drilling, desmearing and metallization are highlighted. The design parameters concerning the reliability of LCP PCB are addressed. Critical findings are summarized as follows:

### Lamination

As high temperature lamination is required for LCP, traditional stacking materials such as kraft paper and release sheet, which cannot withstand temperatures above 250°C, are no longer applicable. Instead, it is recommended that ceramic-filled fiber paper can be used as a presspad while skived Teflon, or copper foil with shiny face, can be used to act as a release film.

### Drilling

Due to the difference in polymer properties, it is inevitable to avoid producing LCP drilling chips compared with conventional PCB materials. Cutting speed and chip load, in particular the latter, is found to play an important role in determining the drilling quality. A lower cutting speed and chip load are required, which are about 20% lower on average than in drilling polyimide. Further lowering of the cutting speed and chip load is then suggested for drilling high layer count LCP PCB and smaller holes. Peck drilling may be required for high-layer count drilling to improve the drilling hole quality. In contrast, laser drilling can produce more superior hole quality and it is also suitable for LCP microvias making.

### Desmearing and metallization

Conventional chemical method such as $KMnO_4$ or KOH is not recommended for LCP desmearing in consideration of its low desmearing rate resulting from the chemical inertness of LCP. Plasma desmearing using $CF_4 + O_2$, which is commonly used in polyimide desmearing, is also not applicable, as it tends to smooth the LCP surface rather than roughening it. This results in copper deposition problems after subsequent electroless copper plating. The $N_2 + H_2$ plasma gas is found to be effective in desmearing LCP in terms of the desmearing rate and the effect on surface metallization.

### Effect of PCB design parameters on the reliability of LCP PCBs

LCP has a comparatively high out-of-plane CTE that may impose a higher stress on the PTH when it is subject to thermal cycling conditions. However, as LCP is capable of being fabricated into a thin film laminate, this helps to release stress to a certain extent. Therefore there is no special concern for the design parameters when designing LCP PCB. In other words, LCP is suitable for PCB fabrication.

Last, it is expected that using LCP material in PCB fabrication requires solving technical problems which are not encountered in using conventional PCB materials. This paper addresses and highlights the difficulties encountered as the first step in incorporating LCP into PCB process engineering. In addition, the process technology developed in this research demonstrates that this advanced LCP PCB material is a promising candidate to meet the stringent market requirements for high speed applications.

### References

1. Noll, T.; Jayaraj, K.; Farrell, B.; Larmouth, R. In Proceedings of the International Conference on Multichip Modules, Denver, Colorado, 17–19 April, 1996, pp 1–6. Available at http://www.tetpct.com/pdffiles/Low%20Cost%20MCM%20&%20LCP%20Dielectrics.pdf.
2. Beulque, M.; Roseen, C.; Laere, B. V.; Laureys, M. Liquid crystalline polymer: A breakthrough. OnBoard Technology, 36–38, 2003. Available at http://www.wisemedia.it/ob/ob/postnuke/pdf/settembre/090306.pdf.
3. Kurihara, Y.; Ohata, H.; Kawaguchi, M.; Yamazaki, S.; Kimura, K. J Appl Polym Sci 2008, 108, 85.
4. Ultralam 3000 LCP Material, 2008. Available at http://www.rogerscorp.com/.
5. Roseen, C. Circuit World 2004, 30, 40.
6. Fu, L.; Qu, J.; Chen, H. Circuit World 2007, 33, 3.

7. Carano, M. Hole preparation and metalization of high aspect ratio-high reliability back panels. CircuiTree. 2003. Available at http://www.circuitree.com/Articles/Cover_Story/aa81b155dcfe7010VgnVCM100000f932a8c0____.
8. Shohet, J. L. IEEE T Plasma Sci 1991, 19, 725.
9. Yung, K. C.; Wang, J.; Huang, S. Q.; Lee, C. P.; Yue, T. M. Mater Manuf Process 2006, 21, 899.
10. Li, C. Innerlayer copper reliability of electroless copper processes. 2008. Available at http://www.pcb007.com/pages/zone.cgi?a=45534&_pf_=1.
11. Darveaux, R.; Yang, J.; Sheridan, R. In Proceedings of the 53rd IEEE Electronic Components and Technology Conference; IEEE, USA, 2003, 1181.
12. Chen, Y.; Huo, Y. J.; Xie, J. S. J Beijing University Aeronautics Astronautics 2007, 33, 954.
13. IPC Technical Report. Round robin reliability evaluation of small diameter plated through holes in printed circuit boards, IPC TR-579, 1988.
14. Fu, C.; Ume, I. C.; Mcdowell, D. L. Finite Elem Anal Des 1998, 30, 1.