# Material Properties of LCP Film and its Broad Applications in IT-Related Devices

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**Abstract**
All-aromatic polyester, one of the super engineering plastics, is highly regarded as a base material of electronic circuit for its environmental compatibility, moisture resistance, dimensional stability and heat resistance. With Type-I all-aromatic polyester having the highest heat resistance of the three types of aromatic polyesters, we succeeded in making it into a film material with a highly controlled orientation. This liquid crystal polymer film, hereinafter referred to as LCP FILM (I), has great solder heat resistance up to 280°C and high dimensional stability. Its Coefficient of Hygroscopic Expansion is 1.5 ppm/% and the Coefficient of Thermal Expansion is controllable to match with that of copper foil (16ppm/°C). In addition, LCP FILM (I) has very low water absorption of 0.1%, which is approximately 1/10 that of polyimide film, and shows great performance in a high frequency range. It is also notable that LCP FILM (I) is a recyclable material as its raw material is thermoplastic resin. Having these advantages, applications of LCP FILM (I) have been expanded to PWB and IC packages for IT-related devices that require HDI and high frequency performance.

**Background**
In IT-related fields, the amount of information that is transmitted and processed is not only important for daily business operation, it is also a selling point of many applications. It is necessary to combine optic fiber (wiring) transmission and wireless transmission effectively in the information transmission field, and to improve the process-ability of computer in the information-processing field.

While further technical progress in both hardware and software fields is essential to meet the above needs, the following trends are seen in the hardware field where our technology can make a contribution.

To begin with, we can say that optical transmission technology has become a standard technology in the information transmission field. For wireless transmission technology, on the contrary, materials to be used (including plastic materials) are still in the development stage, while devices and transmission logic are already established. In wireless transmission technology, a higher frequency range will be applied in the future due to the need for more information to be transmitted per unit time; however, there is no material with low dielectric loss and great stability to be readily used in a high frequency range.

In the information-processing field, it is necessary to have a higher clock frequency in order to improve the processing capability of a computer, as well as increasing the number of terminals (I/O). Actually, the development of a high speed and a high performance LSI with the above-mentioned properties is progressing rapidly. This field also requires a material with extremely fine dimensional accuracy, which can support finely mounted terminals as a base material, in addition to low dielectric loss and stability in a high frequency range.

In order to meet such requirements, some plastic materials and composite materials, with those plastic materials, have been recently developed for use as a base material with low dielectric loss in high frequency range and good stability. However, some of the base materials using glass cloth as reinforcement for thermosetting resin (such as BT and PPE) or thermoplastic resin (such as PTFE) have a problem with recycling. Consequently, we chose all-aromatic polyester, one of super-engineering plastics, in respect to its dimensional stability, moisture resistance, and heat resistance as well as its high frequency performance and environmental compatibility.

We started working with all-aromatic polyester with liquid crystallinity in 1996 and succeeded in making it in film form. Now, we are expanding test-marketing activities with our pilot machine. Accordingly, applications of this liquid crystal polymer film have been developed mainly in IT fields.

The properties of this liquid crystal polymer film and its application in IT-related devices are discussed in the following sections.

**Liquid Crystal Polymer Film**
Liquid crystal polymer (LCP) can be divided into two types: reotropic LCP such as aromatic polyamide and thermotropic LCP such as aromatic polyester. Although reotropic LCP has the disadvantage of high moisture absorption, it is a very tough material with great heat resistance. Its application has expanded mainly in the fabrics field. Kevlar®, Technora® (para type), Nomax® and Conex® (meta type) are well-known trade names.

On the other hand, thermotropic LCP has extremely low moisture absorption and dimensional change by moisture absorption. Its heat resistance is not as high as polyimide or aromatic polyamide, but high enough to be in the group of thermoplastic resins with highest heat resistance. This thermotropic LCP, which is a thermoplastic resin, is classified into 3 groups by heat resistance; Type-I, Type-II, and Type-III (Table 1). Type-I and Type-II contain all aromatic polyester and Type-III contains aliphatic polyester partially (Figure 1). Hot water resistance such as PCT performance is often required for electronic materials. However, it is difficult to use Type-III because of hydrolyzing caused by aliphatic polyester.

Contrarily, Type-I and Type-II all-aromatic polyester has high hydrolyzing resistance by steric hindrance of the benzen ring, so applications in electronic materials are possible.

In the following, LCP FILM (I) , a film made from Type-I resin with highest heat resistance, is explained.

**Table 1 - Heat Resistance of Thermotropic LCP**

| | Liquid Crystal Transition Temp (C) | Solder Heat Resistance (C) |
|---|---|---|
| Type-? | 350 | 280 |
| Type-? | 300 | 230 |
| Type-? | 250 | 180 |

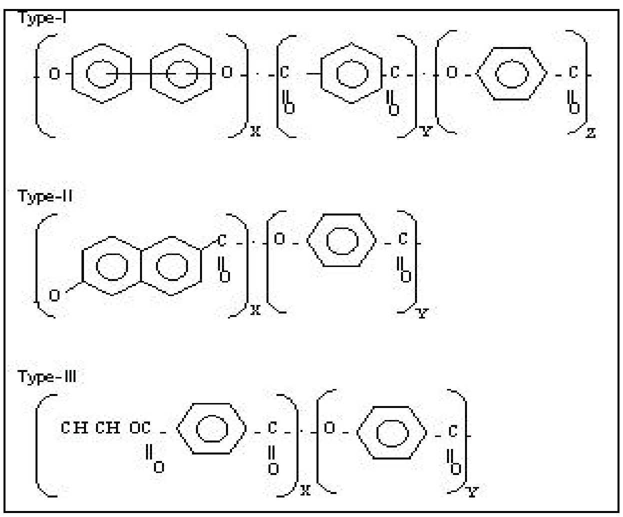



**Figure 1 - Molecular Structure of Thermotropic LCP**

**Uniform Molecular Orientation of LCP Film**

While other crystalline and non-crystalline thermoplastic polymers consist of random coils, thermotropic LCP consists of rod molecular called methogen group, as Figure 2 illustrates. This rod molecular forms the domain.

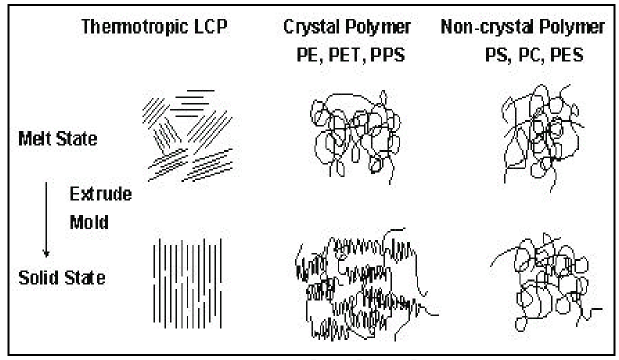



**Figure 2 - Molecular Shape**

LCP FILM (I) is also made from liquid crystal polymer that consists of pneumatic liquid crystal. As Figure 3 shows, this rod molecular is anisotropic having a small CTE and a high dielectric constant in the X direction; therefore, in-plate material characteristics of the X and Y directions become uneven when the molecular is mono-axially oriented. Base film for a circuit board needs to have uniform in-plate properties in the X and Y directions. If the CTE is not equivalent to that of copper used as a conductive material (16ppm/°C) or is uneven in the X and Y directions, it may cause warping of the base material. In addition, it is difficult to design a circuit board with matched characteristic impedance when the dielectric constant is different in the X and Y directions.

For use as a base film for a circuit board, it is necessary to make a liquid crystal polymer film with a precisely controlled rod molecular orientation. However, it has been very difficult to uniformly orient molecular of LCP and make it in film form.

The solution to this problem was achieved through a unique manufacturing method of LCP FILM (I). Figure 4 shows the in-plate orientation of this liquid crystal polymer film, LCP FILM (I), taken by a molecular orientation analyzer using 12GHz microwave at 20? intervals. The in-plate dielectric constant is uniform, which suggests a precisely controlled orientation.

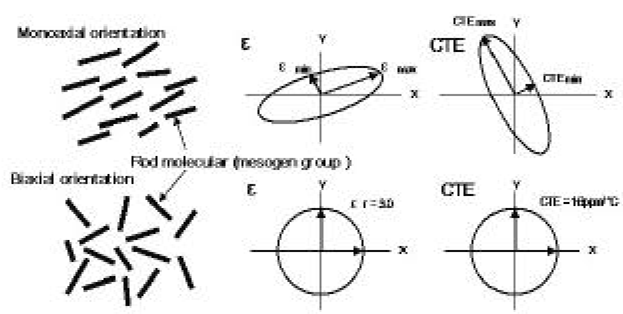



**Figure 3 - Molecular Orientation and Material Properties**

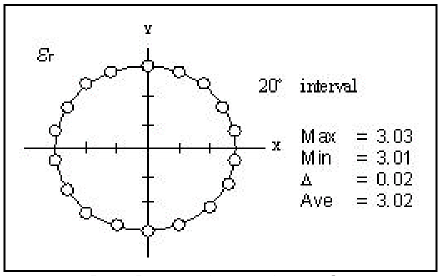


**Figure 4 - Molecular Orientation of LCP FILM (I)**

## Material Properties of LCP Film

### *Dimensional Stability*

Tables 2 and 3 show the test result of Coefficient of Thermal Expansion (CTE) and the Coefficient of Hygroscopic Expansion (CHE), respectively. LCP FILM (I) is manufactured to match the CTE to that of copper, and its CHE is approximately 1/10 that of polyimide film. These results indicate it is expected to be used as a base film for circuit boards, which is applicable to the recent trend of finer pitch patterns.

### *Water Absorption*

Table 4 shows the water absorption test result. Just as CHE, it is approximately 1/10 of polyimide film. Reliability problems caused by moisture absorption such as the popcorn phenomenon can be improved by applying this film as a base material in IC packages.

**Table 2 - Coefficient of Thermal Expansion (ppm/C)**

| | LCP FILM (I) | Polyimide Film |
|---|---|---|
| 23 - 100 C | 16 | 12-16 |

**Table 3 - Coefficient of Hygroscopic Expansion (ppm/%)**

| | LCP FILM (I) | Polyimide film |
|---|---|---|
| 50C<br>20 - 80%RH | 1.5 | 14 |

**Table 4 - Water Absorption (%)**

| | LCP FILM (I) | Polyimide Film |
|---|---|---|
| 23C,24hrs<br>Soaked in water | 0.1 | 1.5 |
| 85C,85%RH<br>96hrs in the air | 0.1 | 1.2 |
| PCT 96hrs<br>(121C,2atm) | 0.2 | 2.0 |

### *Electric Properties*

*Frequency Properties*

Figure 5 shows the test results of the dielectric constant and the dissipation factor measured by the 1-15Ghz strip line resonance method and the 15-75GHz cut-off method. These results indicate the LCP film can maintain great dielectric properties (dielectric constant of 3.0 and a dissipation factor of 0.003) under a wide frequency range (1-75GHz).

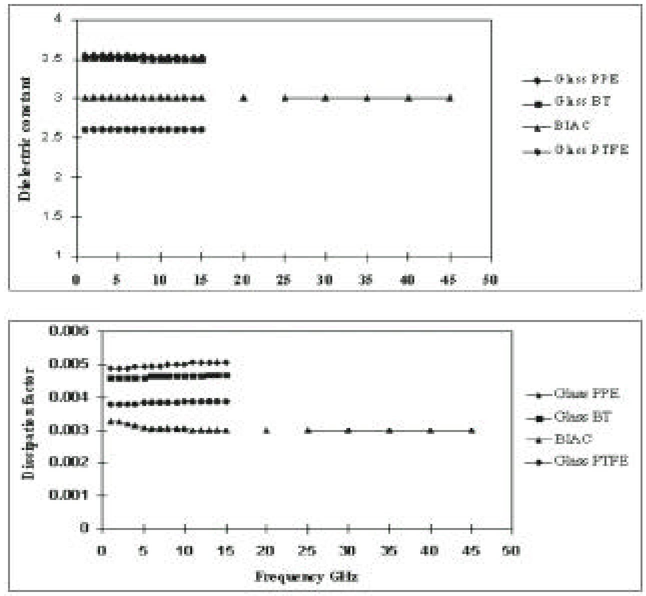


**Figure 5 - Frequency Properties**

*Temperature Dependence*

Figure 6 shows a test result of the dielectric constant and a dissipation factor for 1-15GHz by the strip line resonance method under 25°C and 100°C. The dielectric properties of LCP film are dependent on temperature; however, the dielectric constant changed from 3.00 to 3.02, which is only a 0.7% increase, and the dissipation factor changed only from 0.0003 to 0.007-0.009. This degree of change would not cause any problem.

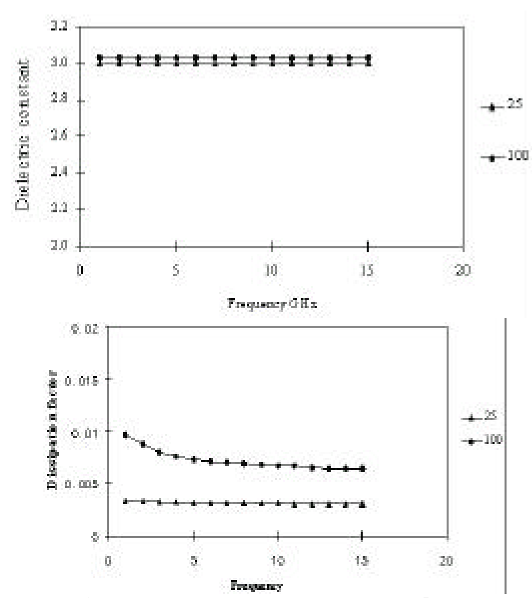


**Figure 6 - Temperature Dependence**

*Dielectric Constant and Dissipation Factor under Moist Conditions*

Figure 7 shows the test result of the dielectric constant and the dissipation factor under moisture-absorbing condition at 3GHz by the dielectric resonance perturbation method. There was hardly any change in the dielectric constant or the dissipation factor because LCP film has extremely low moisture absorption, compared to polyimide film. Consequently, a small impedance change is expected when LCP is applied in a circuit board with a micro-strip line or a strip line structure.

***Thermal Properties***

Table 5 shows the test result of thermal properties. LCP FILM (I) has the highest heat resistance among thermoplastic films, and its solder heat resistance is as high as 280°C.

However, thermoplastic film of LCP FILM (I) cannot be used under conditions above its liquid crystal transition temperature (335°C), whereas the thermosetting type of polyimide film can be sustained at 400-500°C for a short time. Although it may restrict the type of mounting technology used, I believe it can be solved by developing a mounting technology suitable for LCP FILM (I), or modifying current technology.

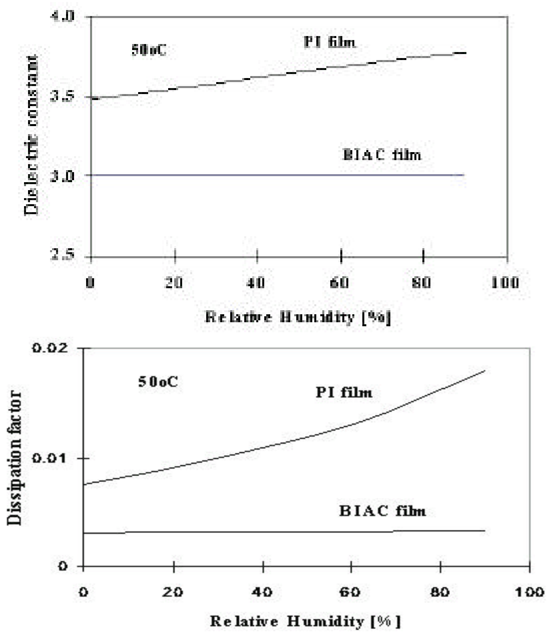



**Figure 7 - The Dielectric Constant and the Dissipation Factor in a Moisture-Absorbing Environment**

LCP FILM (I) does not contain any flame retardant such as halogen or phosphorus, so its flammability is certified as VTM-0 by UL94. Another feature of LCP FILM (I) is its heat conductivity, which is twice that of polyimide film. This means we can expect a better heat release property when it is used in certain applications such as adhesive tape on an IC chip.

**Table 5 - Thermal Properties**

| | LCP FILM (I) | PI film |
|---|---|---|
| Solder heat resistance 280°C,120sec float | OK | OK |
| Liquid crystal transition temp. [ °C] | 335 | N/A |
| Glass transition temp[ °C] | N/A | 500 |
| Specific heat [cal/g/C] | 0.24 | 0.27 |
| Heat conductivity ( 25°C) [ W/(m · K)] | 0.41 | 0.20 |
| Flammability UL94 | VTM-0 | VTM-0 |
| Limited oxygen index[ %] | 35 | 66 |

***Mechanical Properties***

Table 6 shows the test result of mechanical properties. The tensile strength and tensile modulus are not as good as polyimide film. However, as a thermoplastic film, LCP FILM (I) has a flex resistance that is twice that of polyimide film. While it is true that tension control or some technical modifications may be necessary when it is used in TAB, it may be easier to use in some applications such as TAB tape and in the bending-mount process for FPC.

**Table 6 - Mechanical Properties**

| | | LCP FILM (I) | PI film |
|---|---|---|---|
| Tensile strength[MPa] | | 120 | 250 - 400 |
| Modulus [GPa] | | 6 | 3.5 - 9 |
| Elongation[ %] | | 5 | 30 - 80 |
| Tear resistance [N/mil] ( ASTM D 1922) | | 1.9 | 2.4 |
| Flex resistance[ cycle] (MIT method) | R=2.0mm | 5,000,000 | 1,000,000 - 2,000,000 |
| | R=0.25mm | 20,000 | 5,000 - 10,000 |
| Density [ g/cm$^3$] | | 1.40 | 1.45 |

**Application of LCP Film in Circuit Board Material**

LCP FILM (I) is currently being examined for use in the following applications in electronic materials.

- Flexible board
- Insulation tape for IC package
- Multi-layer board for high density interconnect
- High frequency board

Competitive advantages of LCP FILM (I) in these electronic material markets are:

- Stable CTE (and controllable)
- Low water absorption
- High heat resistance
- Great insulation property
- Great high frequency property

- Recycle-ability
- High heat conductivity
- Excellent flexibility
- Self-bonding property (thermoplastic material which provides process capability of heat heat-bonding)

**TAB Application**

Currently, the leading evaluation of LCP FILM (I) is the TAB application.

***Experimental TAB for LCD and Accumulated Dimensional Stability Test***

2-layer CCL was prepared by laminating LCP FILM (I) with copper foil by heat-welding. Using this 2-layer CCL, experimental TAB tape for LCD shown in Figure 8 was prepared and tested using:

- Flexible material: 50 micron thick film and 12 micron thick copper foil
- TAB tape: 35 mm width super wide
- TAB for LCD driver (COF)
- 23mm accumulated pitch
- Polyimide based 2-layer CCL as a comparative sample.

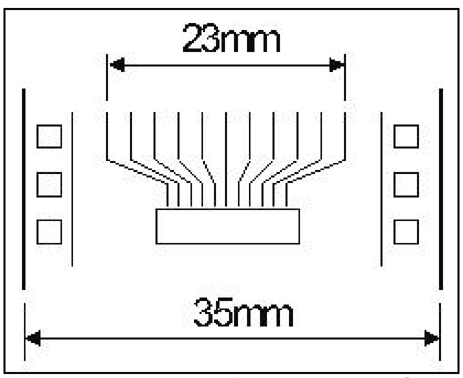



**Figure 8 - Experimental TAB pattern for LCD**

An experimental TAB pattern is tested for accumulated pitch change during 0-120 hours at 60°C and 60%RH.

Figure 9 is the test result. Properties of bare film are well reflected in the dimensional stability test results of an actual patterned circuit board.

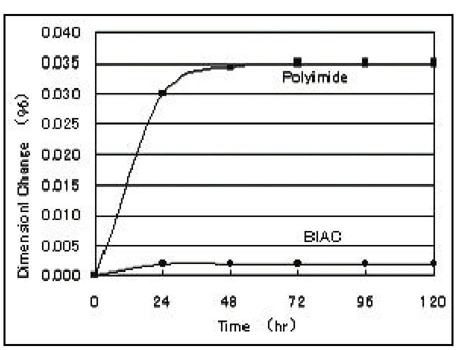



**Figure 9 - Accumulated Dimensional Stability Test**

***Experimental TAB for T-BGA and Moisture Resistance Test***

Using the same preparation process for experimental TAB for LCD, an experimental TAB tape using LCP FILM (I) based 2-layer CCL for T-BGA was prepared. An experimental board for T-BGA package was made by attaching the TAB pattern to a heat sink with epoxy based bonding sheet (Figure 10).

- flexible material: 50 micron thick film and 18 micron thick copper foil
- 48mm wide TAB tape
- TAB for T-BGA (WB type)
- Package with a heat sink attached
- Polyimide based 2 layer CCL as a comparative sample

Applying JEDEC level-1 conditions (85°C, 85%RH, 168hr+240°C, ball bonder re-flow 3 times) to the prepared experimental board for T-BGA, the existence of bubbles on the interface of the film material and bonding sheet was checked by a supersonic flaw detector to evaluate its moisture resistance as a package board.

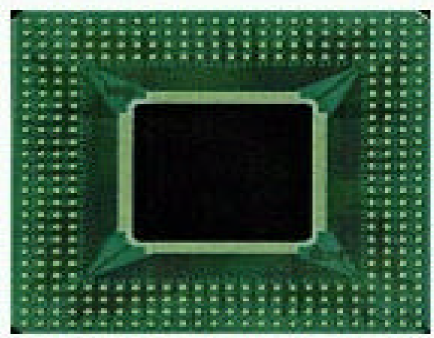
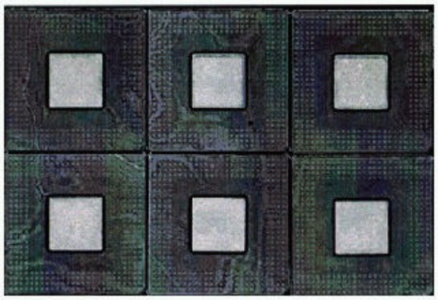
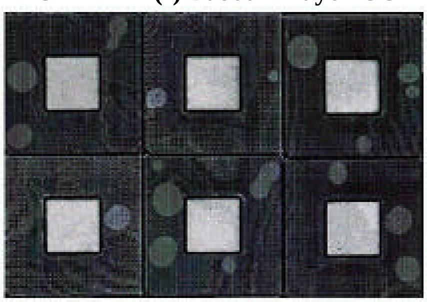


**Figure 10 - Experimental Board for T-BGA Package**

Figure 11 shows the test result. It indicates that a T-BGA board using LCP FILM (I) 2-layer CCL has superior moisture resistance to a T-BGA board using a polyimide based 2-layer CCL. The material characteristic data of a raw film is greatly reflected in the actual package board performance regarding this point, as well.



**LCP FILM (I) Based2-Layer CCL**



**Polyimide Based 2-layer CCL**

**Figure 11 - Moisture Resistance Test**

### New Applications of LCP Film

LCP FILM (I) is a thermotropic LCP film with thermoplasticity allowing it to be laminated quickly by pressing it under a temperature above $330^0$C. Taking advantages of this feature, a new type of high density wiring board is developed in which lamination of copper foil and via formation with high density can be done simultaneously in a short time. This new type of high-density wiring board is explained in the following:

### Application in NMBI Technology

NMBI (Neo Manhattan Bump Interconnection) technology is a manufacturing technology of a wiring board by laminate press using copper foil with bumps for via formation. Because bumps are made from copper formed by etching as Figure 12 shows, this technology can make the IVH pitch width much narrower compared to the conventional copper foil with conductive resin bumps, thereby making it more desirable for HDI than the conventional technologies. By combining this NMBI technology and LCP film, it is possible to provide a high performance 2-metal tape interposer and FPC for transmission with a micro-strip line structure. In the following, the test result of the 2-metal tape interposer for the HDI application is discussed.

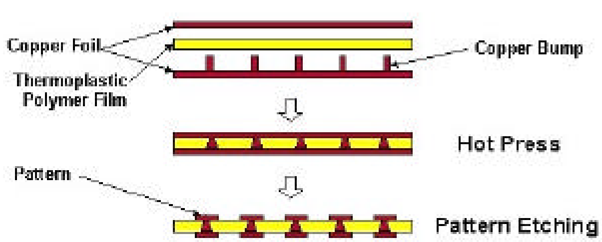



**Figure 12 - Mounting Method of HDI PWB by**

### NMBI Technique Extended Application in System-in Package

While System-on-Chip technology seems to have reached its technical limit, such as micro-fine wiring and mounting different kinds of LSI, one possible resolution was System-in-Package in which a 2-metal interposer using LCP FILM (I) and NMBI are laminated. This technology makes it easy to integrate Si and GaAs, digital and analog, logic and memory, or RF devices in one system. Prior to explanation of this concept, the history of LSI packaging technology is shown in Figure 13. It indicates that the LSI package will become a multi-stacked System-in-Package in the future.

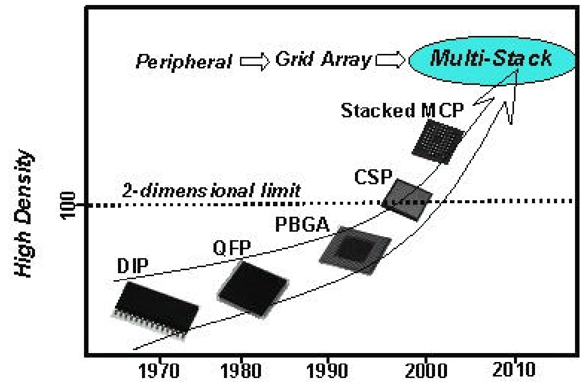



**Figure 13 - History of LSI Packaging Technology**

Figure 14 is a structure of an experimental 2-metal tape interposer using LCP FILM (I) and NMBI. An ultra-thin tape interposer with a total thickness of 40 microns was prepared using a 25 micron thick LCP FILM (I).

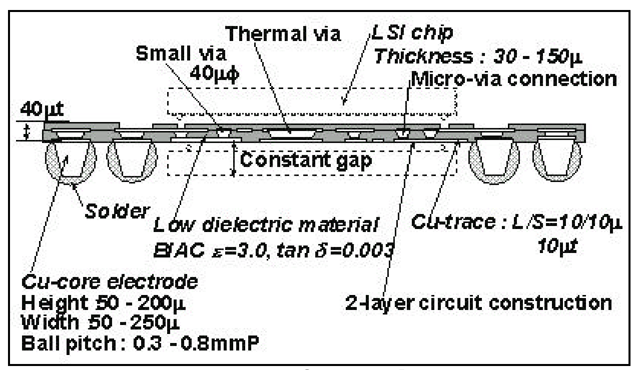



**Figure 14 - Structure of 2-Metal Tape Interposer**

A 3-D stacked package is constructed by stacking several layers of this ultra-thin tape interposer. Figure 15 illustrates this structure and connections between each tape interposer. Connections between tape interposers are made by solder bumps formed on the periphery of each tape interposer (NMTI). The height of the copper bumps inside these solder bumps creates stable gaps for each connection. Figure 16 shows the stacking procedure. This technology can also solve the problem of KGD because it enables IC chips from different wafers to be mounted on tape so each tape interposer can be tested before stacking them into one package. We expect this technology of mounting plural IC chips on one interposer, as shown in Figure 17, will be established to extend the scale of System-in-Package further.

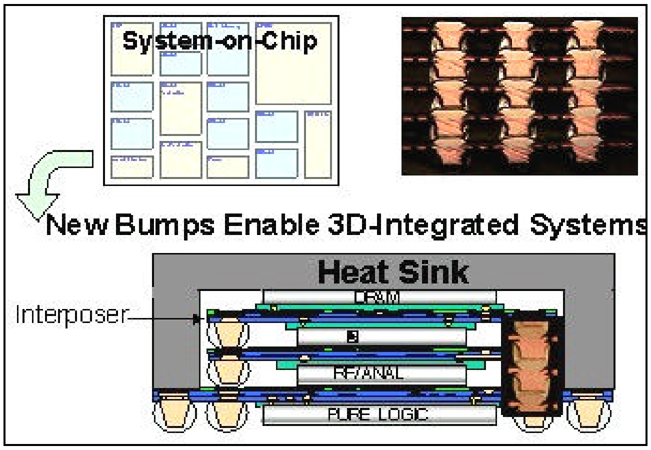



Figure 15 - 3D Stacked Package using NMTI

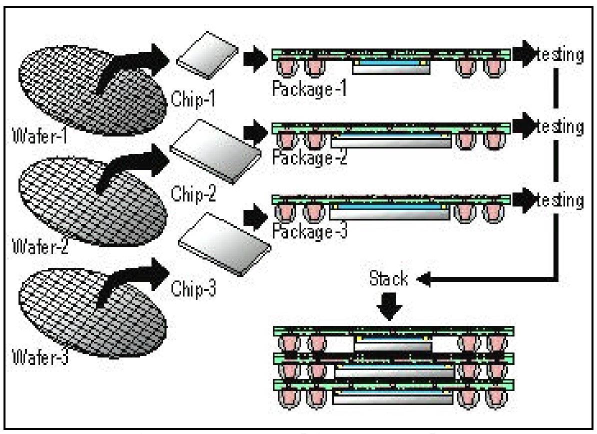



Figure 16 - Stacking Procedure

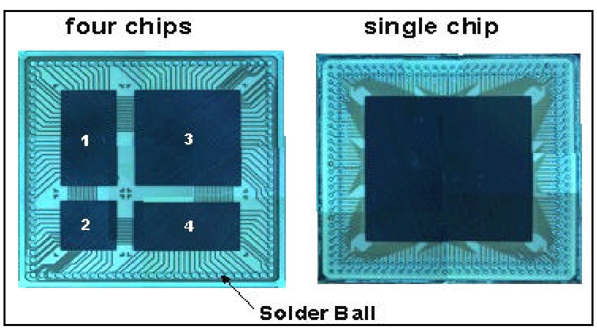



Figure 17 - NMBI with LSI Chips High Frequency

**Property Test of an Experimental Tape Interposer**

The test result of the high fequency property for the experimental ultra-thin tape interposer is discussed below. The test pattern and analyzer are shown in Figure 18. The test circuit pattern has a micro-strip line structure with a 25 micron thick dielectric. A network analyzer was used to determine the transmission property up to 20GHz.

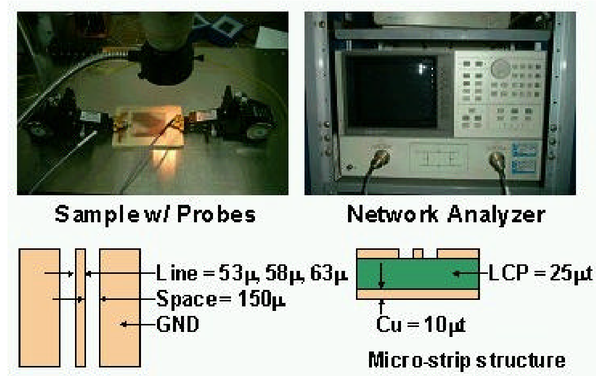



Figure 18 - Test Pattern and Analyzer

**Characteristic Impedance Test**

Figure 19 shows the test result of characteristic impedance up to 20GHz for Line/Space 53/150, 58/150, 63/150 microns. It is most stable when the line width is 63 microns. What we can see from this result is when LCP FILM (I) is 25 microns thick and the line width is 63microns characteristics impedance is 50 ohm, and the frequency dependence of this value is particularly small. This indicates that LCP FILM (I) has great transmission performance.

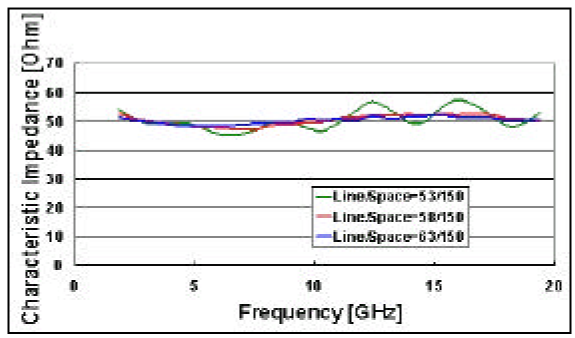



Figure 19 - Characteristics Impedance Test Result

**High Speed Clock Capability**

Figure 20 shows a correlation of the number of copper bumps and attenuation. The wiring pattern was a micro-strip line with line width of 63 microns, which showed most stable at a characteristics impedance of 50 ohm, and when the number of copper bumps was varied (0, 2, 4, and 6). The transmission property up to 20GHz was determined using a network analyzer. Attenuation is kept under –3dB for frequencies up to 20GHz. As shown by this test, the high frequency property is great also in the bump area, which indicates it is a promising material to be used in the tape interposer for System-in Package.

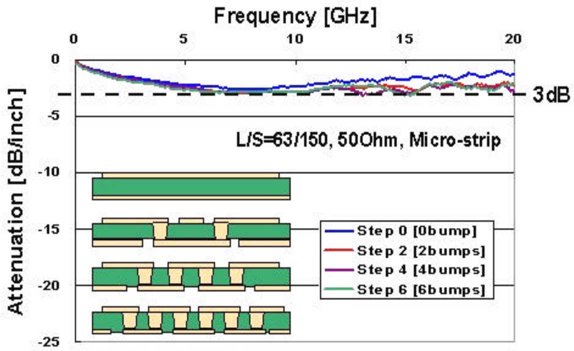



**Figure 20 - Attenuation Test Result**

**Future PWB using LCP Film**

*Expansion of Application to Embedded PWB and "Eco" PWB-*

*Embedded PWB Application*

LCP FILM (I) is made from thermoplastic resin and does not contain reinforcing material consisting of glass cloth or non-woven cloth, which is an advantage in that it is easy to embed an IC Chip and component. Focusing on this feature, a 3-D embedding PWB application is being studied. International Packaging Research Consortium on Panel-Size Component Integration (PCI), consisting of University of Tokyo, Chalmers University of Technology, Helsinki University of Technology, State University of New York at Binghamton, and Georgia Institute of Technology, is one of the groups conducting such studies. There must be other fields where LCP film can be advantageously used. These applications can benefit from LCP FILM (I) because no other thermoplastic film other than LCP film can control its CTE to around 10ppm/°C, the center value between an IC chip's CTE (3ppm/°C) and the CTE of copper as a conductive material (16ppm/°C), which is considered difficult for a super-engineering plastic such as PEEK film. It is also notable that this film has low outgas, ionic contamination and water absorption. Although there are still some problems to be solved, such as the component embedding method and the circuit formation method, this field is gaining attention, particularly for future HDI technology.

*Eco-PWB Application*

The establishment of a new system for recyclable PWB is planned for 2005-2010. The thermoplastic of LCP FILM (I) is being considered for this. It is a so-called emission-free field. It is currently just in the stage of examining methods of separating conductive (metal) and resin, and recycling separated resin.

Another feature of thermoplastic resin is that it does not require a curing process but only a brief press. It is also better than PWBs made from thermosetting resin such as epoxy for energy savings. Furthermore, all-aromatic polyester has good flame retardance, and LCP FILM (I), which is film-formed all-aromatic polyester, does not contain any flame retardant but maintains great flame retardance. This is important to be noted in terms of environmental compatibility. LCP FILM (I) is expected to get more attention as a material for future Eco-PWB.

**Conclusion**

LCP FILM (I) is made from Type-I all-aromatic polyester resin that has the highest heat resistance among all types of liquid crystal polymer. The film itself can resist 280°C solder heat resistance. Its high dimensional stability is shown by a coefficient of hygroscopic expansion of 1.5ppm/% and a coefficient of thermal expansion can be controlled to match that of copper foil (16ppm/°C). Moreover, it is a base material with particularly high resistance to the environment in terms of reliability and electric properties as its water absorption is 0.1%(23°C, 24hr). This was verified by the test result of an experimental TAB pattern using 2-layer CCL in which LCP FILM (I) is used as base material.

LCP FILM (I) has great high frequency properties, which was verified by high frequency transmission test of a 2-metal tape interposer using NMBI.

From what has been discussed so far, LCP FILM (I) can be considered a material that outperforms conventional base materials, particularly with environmental resistance, such as high moisture resistance environmental compatibility including recycle-ability as a material used in IC packages, and PWB fields such as TAB and FPC applications. The System-in Package, in which 2-metal tape interposers are laminated, will be commercialized in the near future.

Even for IT-related devices, a lower price is strongly demanded for general-purpose devices such as PC, communication appliances, cellular phones, mobile terminals, ID cards, wireless LAN, satellite, communication and ITS. In order to respond to this demand, the cost reduction of electronic materials is very critical. LCP film can possibly solve this problem because demand for thermotropic liquid crystal polymer has been rapidly increasing for injection molding applications, and resin prices are expected to continually fall with the continual rise in demand for resin production.

Actually, worldwide production volume of thermotropic liquid crystal polymer was approximately 10,000 tons in 2000. It was expected to be approximately 15,000 tons in 2001 and to possibly double in 2002.

Although LCP film cannot yet benefit directly from the cost reduction of resin, we expect costs to decrease so that it can be used in general-purpose IT-related devices. We will continue to develop higher performance LCP film, lower the cost, and establish a recycling method to establish LCP FILM (I) a standard base material for IT-related devices.

**References**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