A Novel Thermal Material for Multi-Layer Metal Core Printed Circuit Boards

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Abstract

Today, the metal core printed circuit board (MCPCB) business is booming thanks to the rising popularity of LED TV. The majority of MCPCB is single sided. However, the demand for multi-layer board is increasing since the interconnection density becomes higher. There are several approaches for this problem. One of them is to press resin coated foil (RCF) on the single side MCPCB. And even though there are many RCF products, RCF with high heat dissipation is rarely available. Therefore, the industry is looking for new thermal RCF material for multilayer MCPCB.

To meet this demand, a novel RCF material with high heat dissipation has been developed. Alumina fillers have been carefully selected, surface treated and highly loaded to the modified epoxy resin system. Only good dispersion with high power mixing can secure the material which has more than six times the thermal conductivity, 1.5W/mK, than that of conventional RCF. It also shows a good thermal stability, withstanding longer than 10min at 288C, which makes it suitable for lead-free process. The other properties of this material, such as copper adhesion, dielectric properties and laser via whole processibility will be presented.

Introduction

Electronic devices are becoming smaller, lighter and multifunctional, which increases power density. In order to cope with this trend, thermal conducting materials need to be improved [1]. At the same time, the advancement in head light of automobile, street lamps, and light emitting diode (LED) lighting modules, etc, drives the use of thermal management system. Especially, high power LED becomes popular due to its high brightness. However, the thermal problem associated with LEDs becomes a big challenge as the power of LEDs continuously increased. Therefore, the thermal management is growing more important. MCPCB has been widely adapted for these applications because of higher heat dissipation compared with that of conventional FR-4 based PCB. Even though the majority of MCPCB is single sided, the demand for multi layer board is increasing. The major approach is to use thermal prepreg between double sided PCB and MCPCB as a dielectric adhesive. It is easy to adapt since the materials are readily available and economical. Unfortunately, the board tends to be thick and heavy, which makes it unfavorable for consumer electronic applications. New approach to address this problem is to adapt thin build-up materials like RCF. There is a major technical challenge, which is to develop the thermal RCF with improved thermal conductivity without compromising on other key properties like thermal reliability, PCB processibility and lead-free process compatibility. Since RCF is composed of dielectric and copper, our study focuses on proper resin system and ceramic fillers. The effect of resin and filler at various conditions on the thermal conductivity and other properties are discussed in this paper in addition to some reliability tests that were carried out.

Table1. Thermal properties and density of various materials [2]

Material	Thermal conductivity (W/mK)	CTE (10-6/℃)	Density (g/cm3)
Aluminum	247	23	2.7
Gold	315	14	19.32
Copper	398	17	8.9
Lead	30	39	11
Molybdenum	142	4.9	10.22
Tungsten	155	4.5	19.3
Invar	10	1.6	8.05
Kovar	17	5.1	8.36
Diamond	2000 ~ 3000	0.9	3.51
Beryllium oxide	260	6	3
Aluminum oxide	18	8.1	3.69
Aluminum nitride	320	4.5	3.3
Silicon carbide	270	3.7	3.3
Silicon nitride	30	3.3	3.3
Boron nitride (XP)	71	0.6	1.9
CNT(single wall)	~ 6000	~ 10-7	1.33 ~ 1.40
CNT(multi wall)	~ 3000	~ 10-7	1.40 ~ 1.60
Graphite	25 ~ 470	1.2 ~ 8.2	1.3 ~ 1.95

Strategy of New materials

A high filler loading is necessary in order to increase thermal conductivity of dielectric layer. In addition, dielectric layer should have good thermal stability to be a part of PCB. One of the most widely used approaches to improve thermal performance of a dielectric is to increase cross-linking density with multifunctional resins. The other is to increase packing density by adding fillers. Among the factors that may influence the thermal conductivity of a dielectric, the type and the portion of fillers are of paramount importance. Other factors such as the filler shape and the surface treatment with coupling agent were also studied. However, increasing packing density with filler has adverse effects on peel strength, thermal resistance and PCB processibility. Instead of increasing packing density of a dielectric with multifunctional resin, modified epoxy with polyester such as liquid crystalline polymer has been adapted to compensate for decreased properties. It was possible to decrease filler portion yet to improve thermal conductivity. In addition, the new coupling agent which has two different reactive groups[3] was adopted. Two chemical groups, hydrolysable and organo-functional groups, enable the coupling agent to be a bridge between organic and inorganic materials. This improved bonding leads to the increased thermal conductivity by minimizing the heat scattering at the interface.

In addition, the adoption of hardener with high mole volume and low functional group content boosted the thermal stability. The resin system fulfills three requirements of thermal PCB material, which are high thermal conductivity, good thermal performance and excellent PCB processibility. It also has proper operation window in coating and pressing processes due to the slow curing in contrast to fast reaction of traditional multifunctional system.

Properties of New materials

a. Heat dissipation properties

We present a study of a new resin system loaded with alumina particles. The thermal conductivity was studied as a function of the loading ratio compare with conventional resin system (Epoxy). Characteristic properties of input materials are shown in Table 2. Average diameter of filler particles is listed in table 2 ; their SEM micrographs are shown in Fig. 1. The thermal conductivity of conventional resin (epoxy system) is typically 0.23W/mK.[4-6]. On the other hand, new resin has a thermal conductivity of 0.42 W/mK. Four different samples labeled 1 to 4 were evaluated for this study. Each sample was prepared by gradually adding the appropriate amount of alumina to resin/hardener mixture, stirring with a high shear device, degassing the mixture and pressing it at 180℃ for 2hours. Fig 2 shows the thermal conductivity of the dielectric layer with varying shapes and portions of alumina. It is clear that the thermal conductivity is higher with a round alumina and a new resin system. New resin system supports to shorten the thermal conductive path and to establish high thermal conductive network for heat conduction.

Table 2.Material properties of resin systems

Type	1	2	3	4
Materials	New resin with platelet alumina	New resin with spherical alummina	Conventional resin with platelet alumina	Conventional resin with spherical alumina
Thermal conductivity (W/mK) of Resin	0.42	0.42	0.23	0.23
Thermal conductivity (W/mK) of Filler	36	36	36	36
Density(g/cc) of Resin	1.28	1.28	1.19	1.19
Density(g/cc) of Filler	3.98	3.98	3.98	3.98
Particle mean diameter size(㎛)	4.2	5	4.2	5

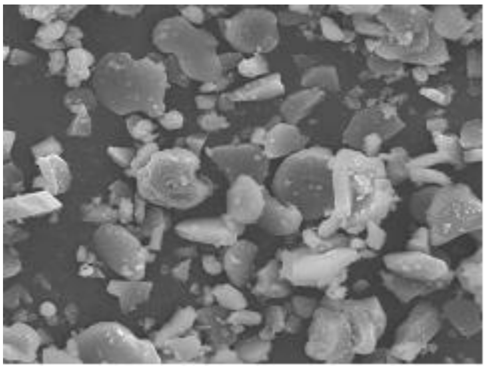
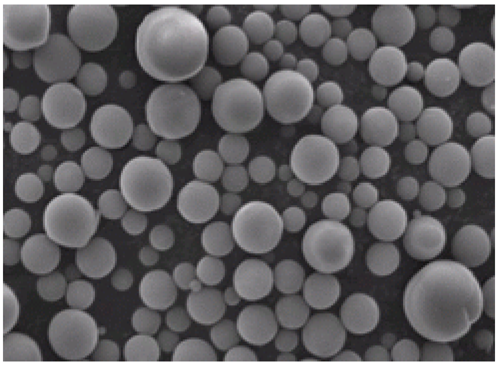
Platelet	**Spherical**
	

Fig. 1. SEM images of Al2O3

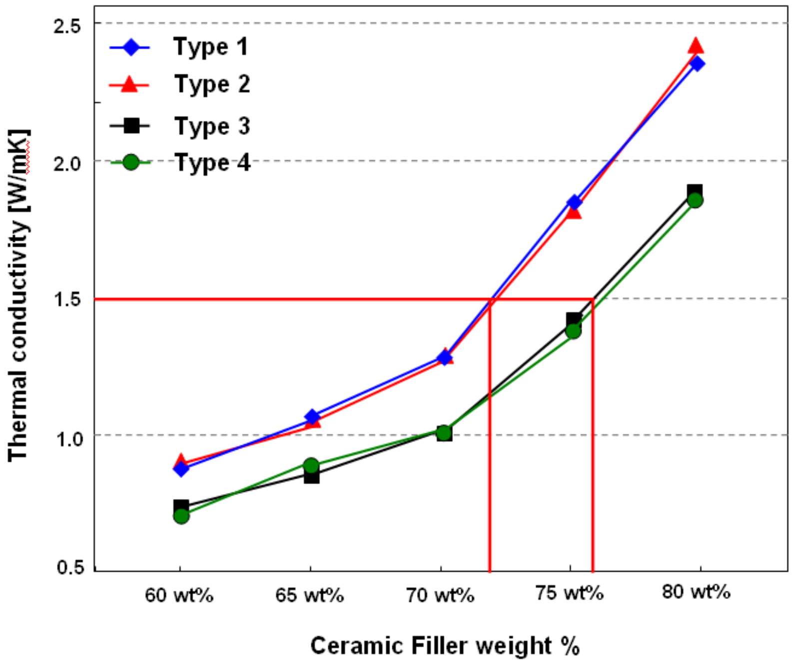


Fig. 2. Thermal conductivity as a function of filler loading

b. Thermal resistance for Lead-free Requirements

There are numerous work groups and industry organizations involved in a "lead-free solder initiative", including IPC, NEMI, and HPD. Thermally stable materials that can tolerate high temperature (260℃) during the IR flow process have become necessary. In order to measure thermal stability, time to delaminate at high temperature such as 260℃ (T-260) or 288℃ (T-288) is widely used together with Td due to the limitation of Td as a indicator of thermal stability. Td and T-260 data of conventional RCF material and new materials are shown on Fig. 3. T-260 of new material is longer than 2 hours, which is 8 times longer than that of conventional RCF materials. In fact it can withstand almost 3mins at 300C while conventional RCF material delaminates immediately upon heating.

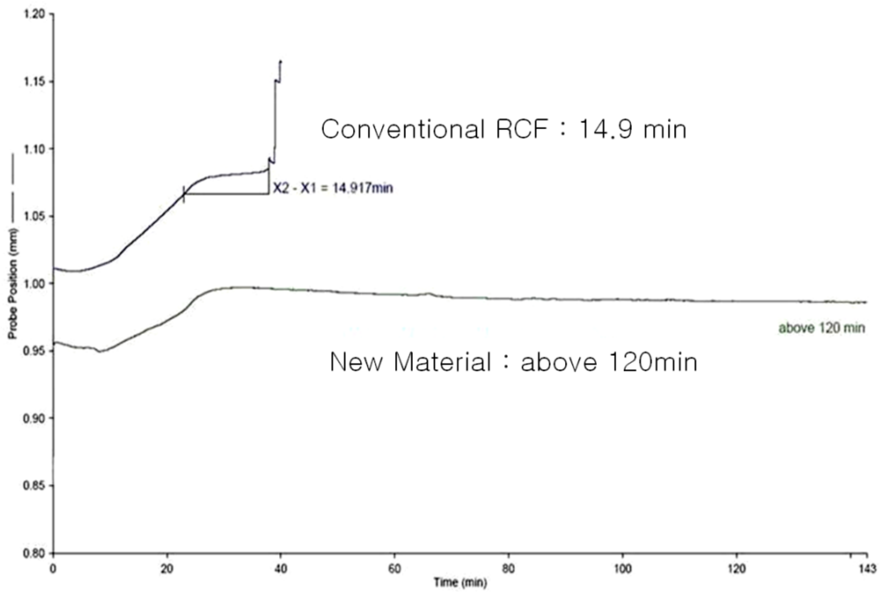


Fig. 3. T-260 data of new material

Decomposition temperature (Td) by thermal gravimetric analysis (TGA) is one of the most important properties for lead-free process. The mass change of the sample is measured as temperature rises. At the beginning of heating, the water and the non-volatile ingredients evaporate (within 5%) and the gas is released as the high temperature breaks the chemical bonds of resin. The temperature where the mass of sample is reduced by 5% is called the decomposition temperature. The importance of Td was recently recognized because the PCB process will be greatly influenced by emitted gas at high temperature as the lead free solder is processed at higher temperature. The TGA results of new material and conventional RCF material are shown in Fig.4. It shows that new material is more than suitable for lead-free process because its Td is more than 40 degrees higher than that of the conventional.

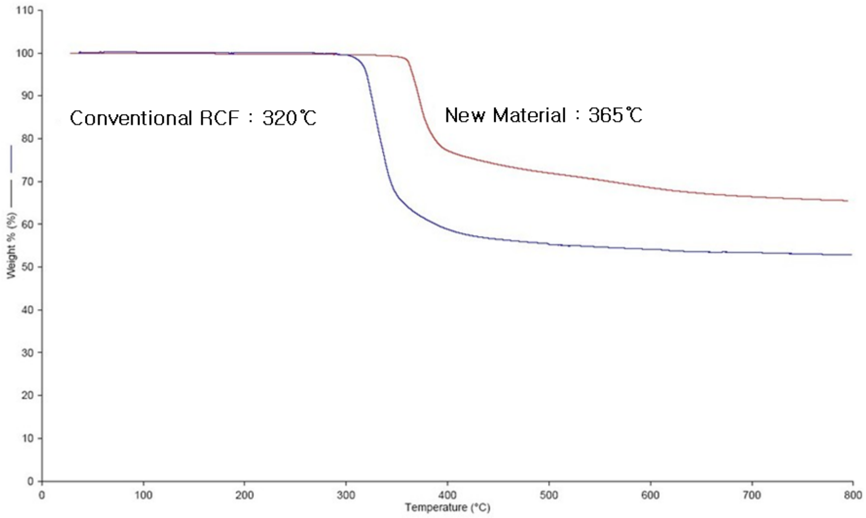


Fig. 4. TGA data of new material

c. General properties of new material

New materials have been developed for improving thermal performance. Their properties are better than those of conventional RCF material as listed in below in Table 3. In addition, they are compatible with lead free process, which require high thermal stability.

Table 3. General Properties of new material

Properties	Condition / Method	Unit	Value
Mechanical			
Peel Strength (1oz Cu)	**IPC-TM-650.2.4.8**	**kgf/cm**	**1.4**
z-CTE (before Tg / after Tg)	**IPC-TM-650.2.4.41**	**ppm/℃**	**30/ 99**
z-axis Expansion	**50℃-260℃**	**%**	**1.5**
Electrical			
Dk @1GHz	**IPC-TM-650.2.5.5.1**		**5.7**
Df @1GHz	**IPC-TM-650.2.5.5.1**		**0.014**
Volume Resistivity	**IPC-TM-650.2.5.17.1**	**ohm-cm**	**5.0E+13~5.0E+14**
Surface Resistivity	**IPC-TM-650.2.5.17.1**	**ohm**	**1.0E+13~1.0E+14**
Thermal			
Thermal conductivity	**ASTM E1461**	**W/mK**	**1.5**
Tg (DMA)	**IPC-TM-650.2.4.25c**	**℃**	**120**
Pressure Cooker	**IPC-TM-650.2.6.16**		**Pass**
Chemical / Physical			
Water Absorption	**E-24/50 + D-24/23**	**%**	**0.5**
Flammability	**UL94**		**V-0**

Reliability of new material

a. Anti-migration property

The movement of metallic ion from anode to cathode under fixed voltage at high humidity is called electrochemical migration and the most typical migration is called the conductive anodic filament (CAF). CAF is a significant and potentially dangerous source of electrical failure in the PWB and, thus, the overall system of which it is a part. Especially, as PWB's circuit density gets higher and line space between patterns become narrower, the CAF resistance becomes much more important among the reliability properties. The 2 layer test coupon (LED bar of 2 layer structure, 6 channels) was prepared and preconditioned by similar treatment as the actual PCB process through reflow. As shown in figure 5, the CAF didn't occur even after 500 hours.

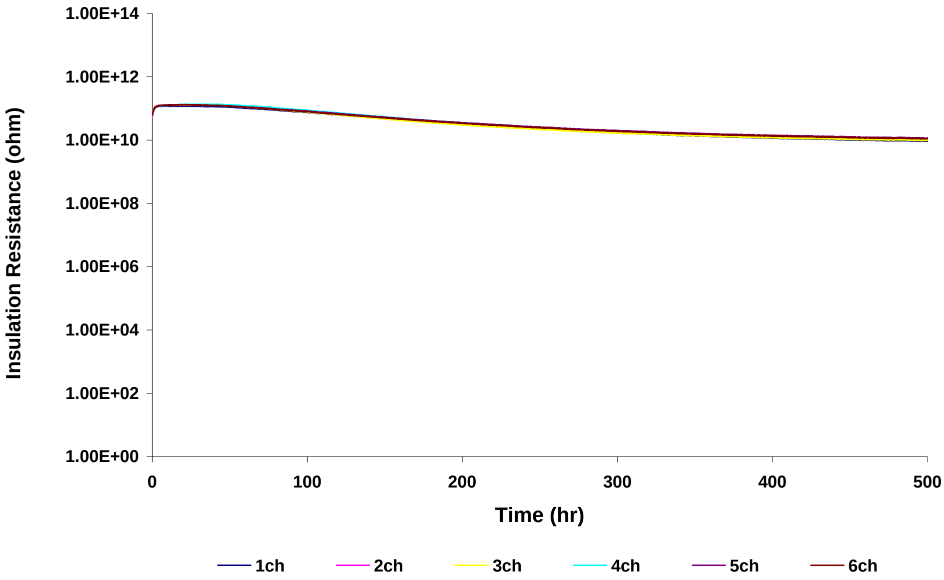


Fig. 5. CAF test data of new material

b. Thermal stress test

The PCB reliability test was performed at same temperature (255℃~265℃) as the actual lead-free process after preparing 2 layer test coupon (Laser via hole in PCB coupon) and preconditioning them at fixed temperature and humidity. The coupons were micro-sectioned and checked the resistance change (ohm) if there was any defect in LVH part. There were no abnormal point and cracks/delaminations in the board under microscope regardless of the degree of conditioning as shown in Fig.6-7.

Pre-treatment Condition	Reflow Condition	1st Result	Thermal Cycling Condition	2nd Result
E-4/125, C-96/30/70	Peak 250℃ x 3 cycles	OK	-25℃, 9min ↔ 125℃, 9min x 1000 cycles	OK

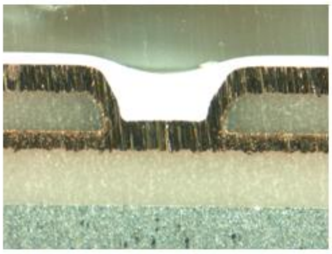
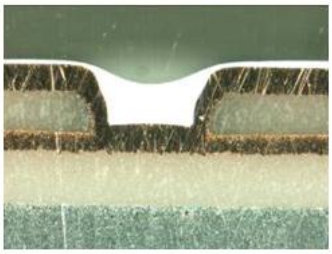
After Reflow	After Thermal cycling
	

Fig. 6. Micro section after mild conditioning and following reflow

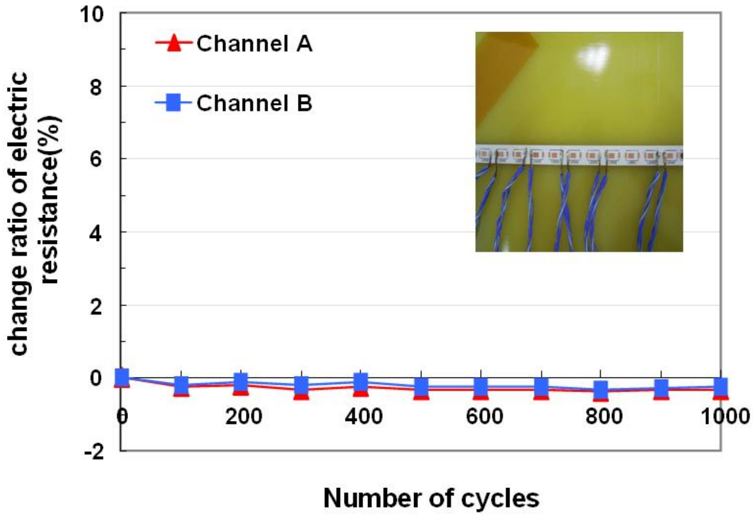


Fig. 7. Change ratio of electric resistance after Thermal Cycling Test

Conclusion

New material for thermal management system has been developed. The high thermal conductivity of the dielectrics fabricated in this project was accomplished by maximizing the formation of conductive paths and minimizing the thermal barrier. In order to develop such material, the modified epoxy with polyester was selected. This new resin system can be decreased the loading percent of filler as well as to improve thermal conductivity. The materials obtained demonstrated lead free process compatibility as well as good reliability.

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APEX EXPO IPC

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  - PCB Reliability
- Conclusion

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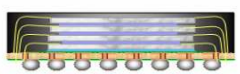
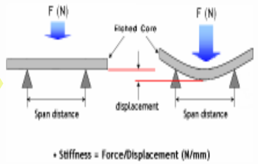
Needs for Thermal conductivity Laminates

Miniaturization → *Light Weight* → *Thin Thickness* → *High Performance*

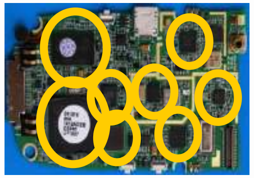
Electronics | **Assembly** | **PCB** | ***Materials***



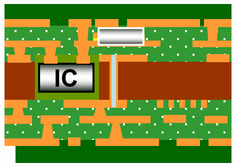
Thin Package



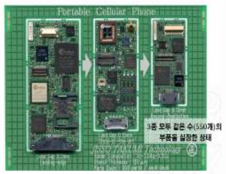
Thin Core PCB

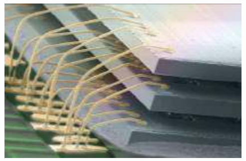


High Integration

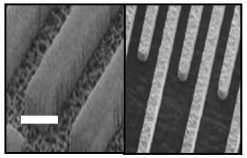


Chip in PCB





High Density



Fine Pattern

High Heat

High Power

- ***High Thermal Conductivity***
  - ➔ ***MCCL***
- ***Low CTE***
  - ➔ ***Thermal PKG***
- ***Multi-Layer***
  - ➔ ***TRCC, T-Sheet***
- ***Halogen Free***
  - ➔ ***Thermal FR-4***
- ***Cost Reduction***
  - ➔ ***Thermal CEM-3***

Properties of Dielectric Component

Resin

- Adhesive
- Thermal Resistance
- Chemical Resistance
- Toughness

Filler

- Thermal Conductivity
- CTE
- Toughness

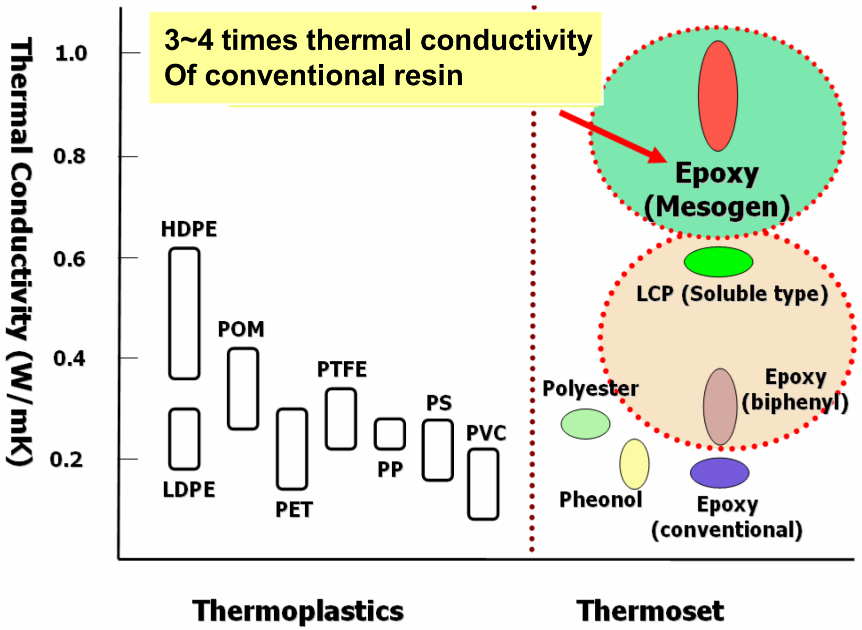
→

- Low CTE
- High heat conductance
- PCB Workability

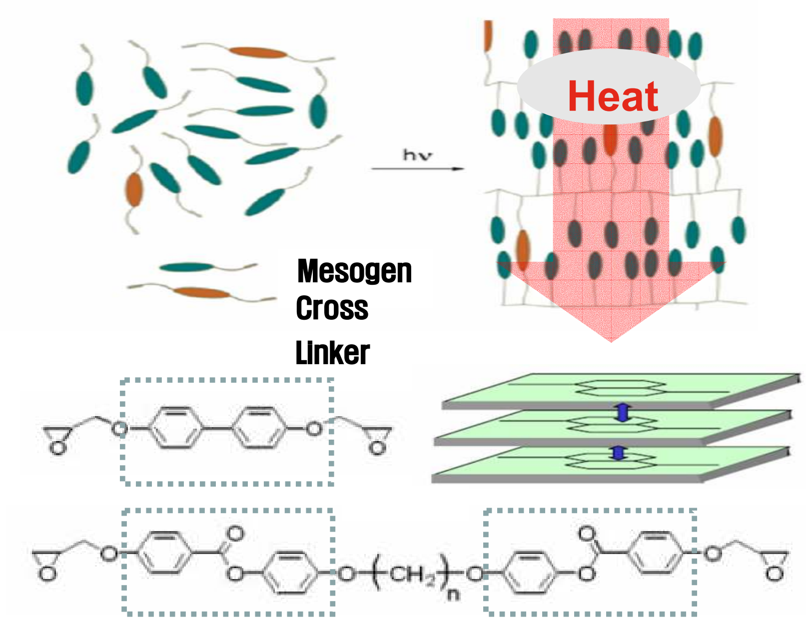
Resin for High Thermal conductivity materials

Resin Choice

How to develop Filler System ? → High Thermal Conductivity Excellent Adhesion



Resin system Design



- Resin system of Crystal structure
- Blending resin & Hybrid process

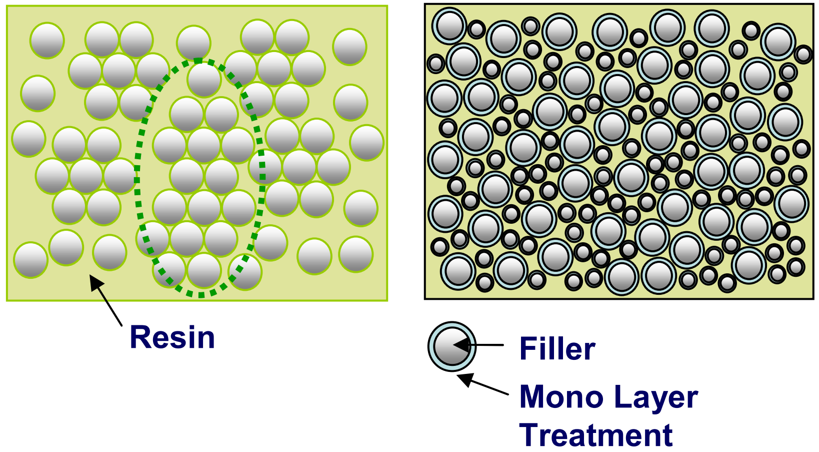
Filler for High Thermal conductivity materials

Filler Choice

How to develop Filler System ? → High Thermal Conductivity Excellent Adhesion

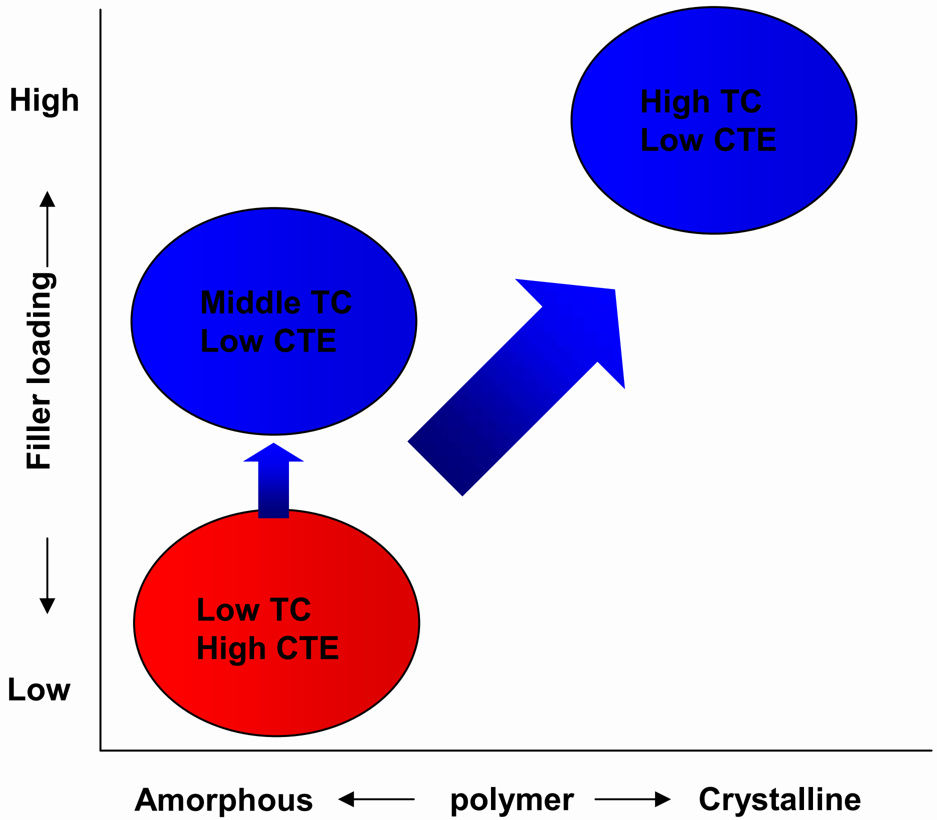
Material	Thermal conductivity (W/mK)
Diamond	2000 ~ 3000
Beryllium oxide	260
Aluminum oxide	18
Aluminum nitride	320
Silicon carbide	270
Silicon nitride	30
Boron nitride (XP)	71
Graphite	25 ~ 470

Filler Dispersion Control



- High filler loading & dispersion
- Interface adhesion between resin & filler by filler surface treatment

Strategy of New Resin System



Properties improving

- High loading of Ceramic filler
  - High TC in conventional resin system
  - Low CTE
- Epoxy resin with Crystalline backbone
  - High thermal conductivity with low filler loading

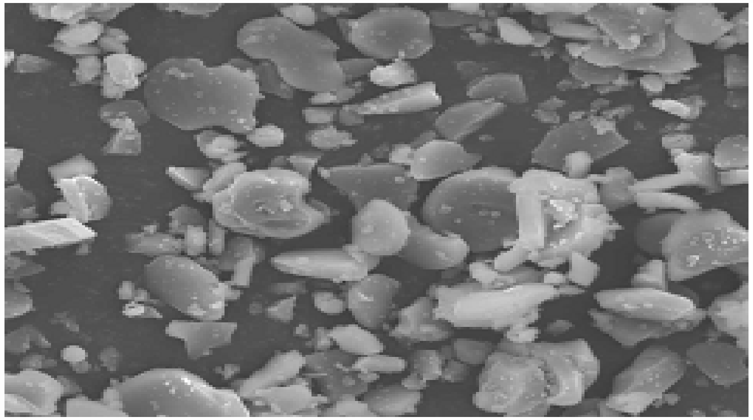
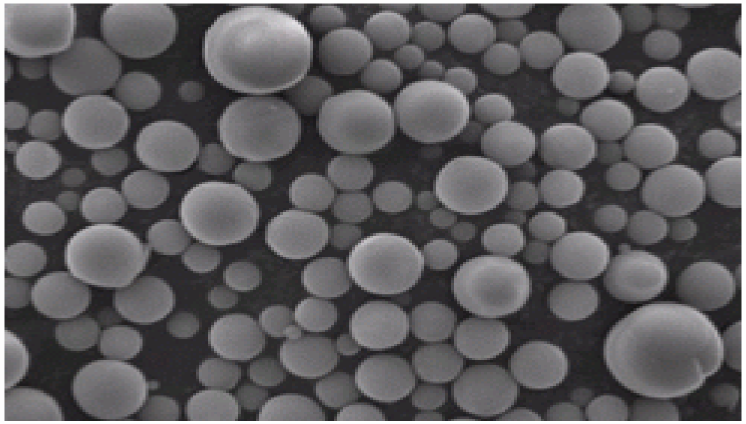
New Resin System

Which Epoxy Resin ?	Epoxy Resin with Crystalline backbone
Which Inorganic Filler ?	Spherical Alumina
Application of Inorganic Filler	60 ~ 90 wt%

Table of Contents

Material properties of resin systems

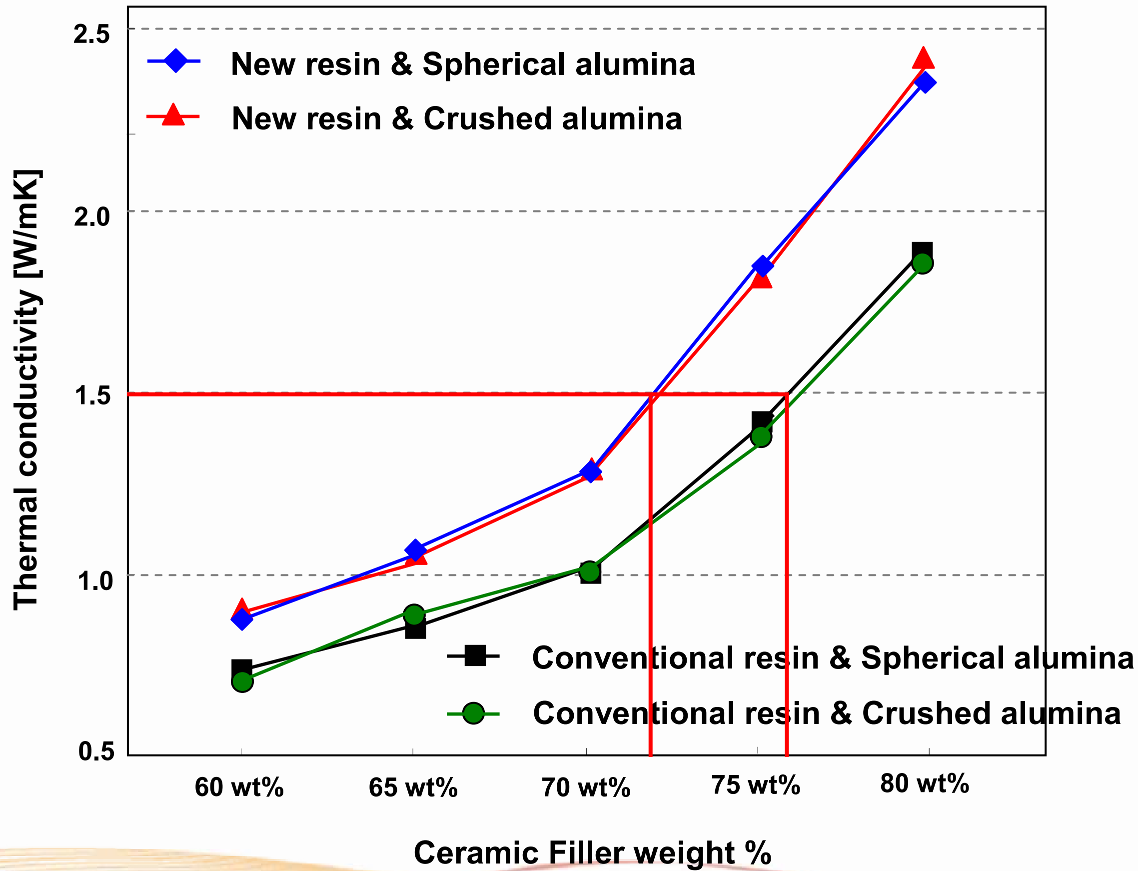
Type	1	2	3	4
Materials	New resin & platelet alumina	New resin & spherical alumina	Conventional resin & platelet alumina	Conventional resin & spherical alumina
Thermal conductivity (W/mK) of Resin	0.42	0.42	0.23	0.23
Thermal conductivity (W/mK) of Filler	36	36	36	36
Density (g/cc) of Resin	1.28	1.28	1.19	1.19
Density (g/cc) of Resin	3.98	3.98	3.98	3.98
Particle mean diameter size (㎛)	4.2	5.0	4.2	5.0

Platelet	Spherical
	

Thermal Conductivity

Measuring condition

- Laser flash (ASTM E1461)
- Temperature and Humidity condition : 25℃ - 60%RH

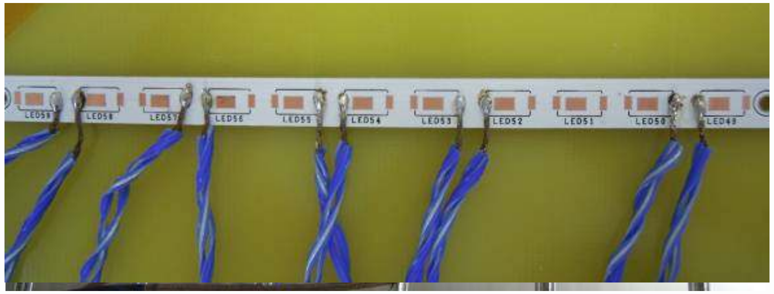


Thermal Properties of New Laminate

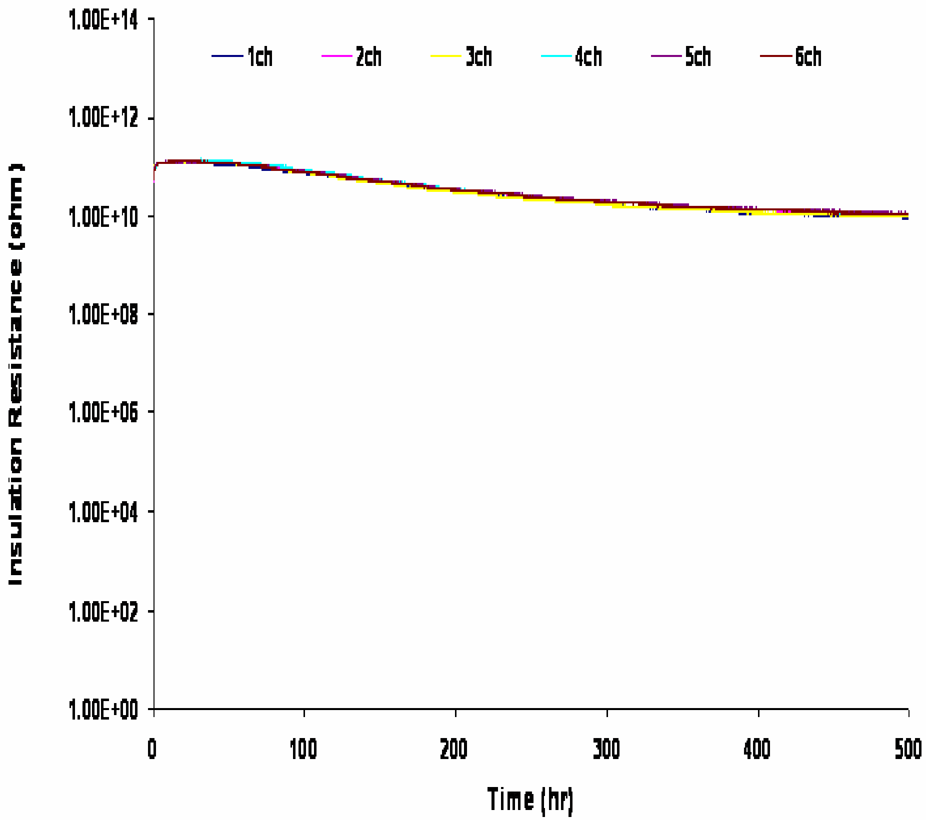
• **High decomposition temperature due to rigid backbone of resin**

	Conventional material	New material
DSC Tg	140	140
TMA Tg	135	132
T-260	14min	120min
Td (5% Loss)	320	365

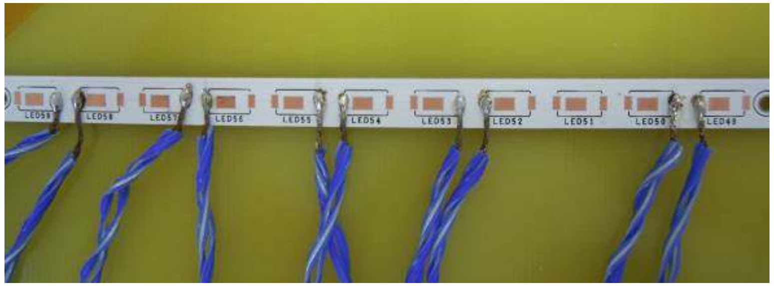
Anti- migration



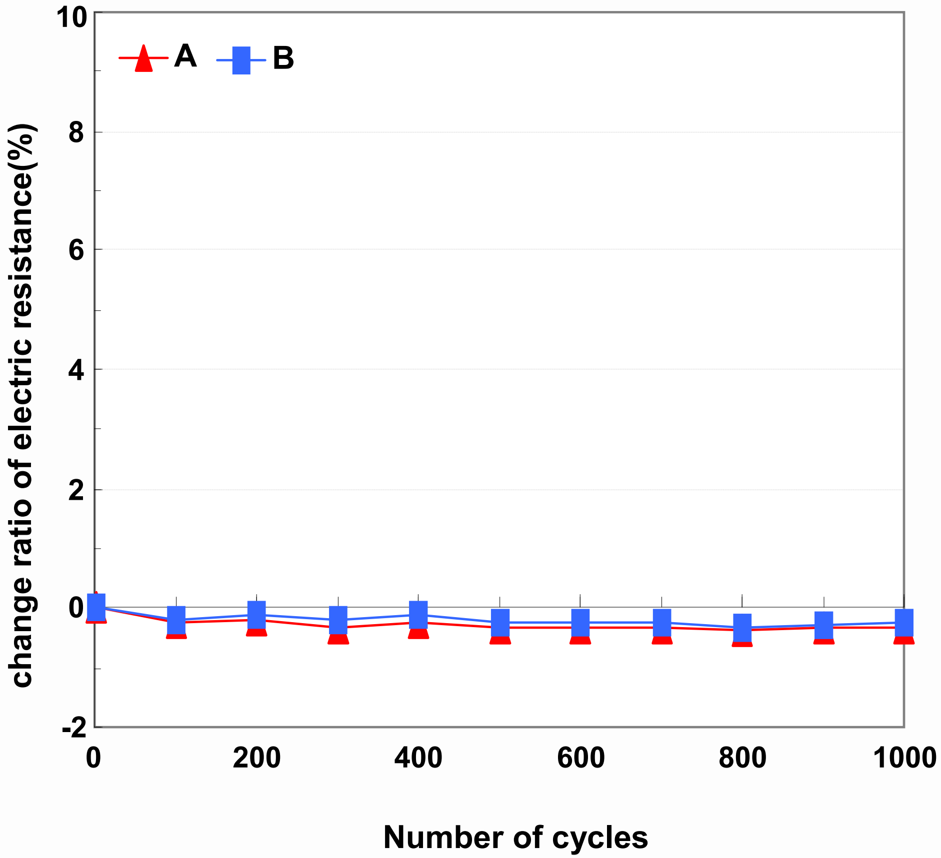
- Sample construction
  - 2 Layer : H oz & 100 um dielectric layer
  - Base : 1oz & 95 um dielectric layer & 1.5T Al
  - 0.2Φ
- Pre-conditioning
  - E-4/145 + C-96/30/70 + Reflow (peak 250℃)
- CAF conditioning
  - 85℃/85%/ DC 50V
  - Resistance (ohm) over 10^8 after 500 hr



Thermal Cycling Test



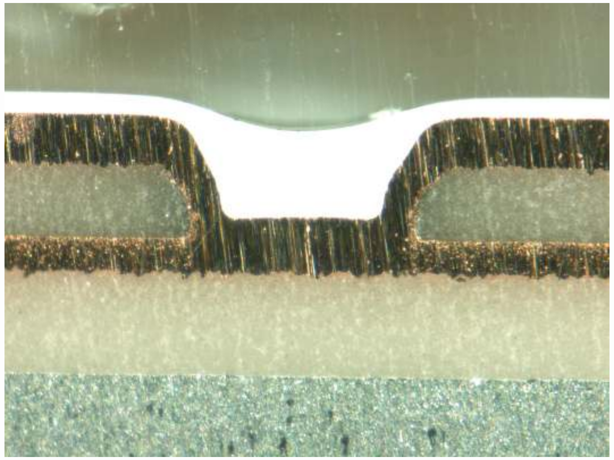
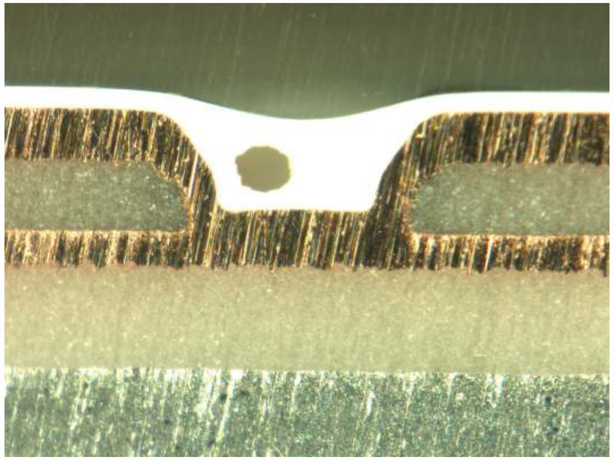
- Sample construction
  - 2 Layer : H oz & 100 um dielectric layer
  - Base : 1oz & 95 um dielectric layer & 1.5T Al
  - 0.2Φ
- Pre-conditioning
  - E-4/145 + C-96/30/70 + Reflow (peak 250℃)
- TCT conditioning
  - -25℃/9min ↔ 125℃/9min, 1000 cycle
  - Change ratio of electric resistance below 0%



Thermal stress Test (2L MPCB)

Measuring condition

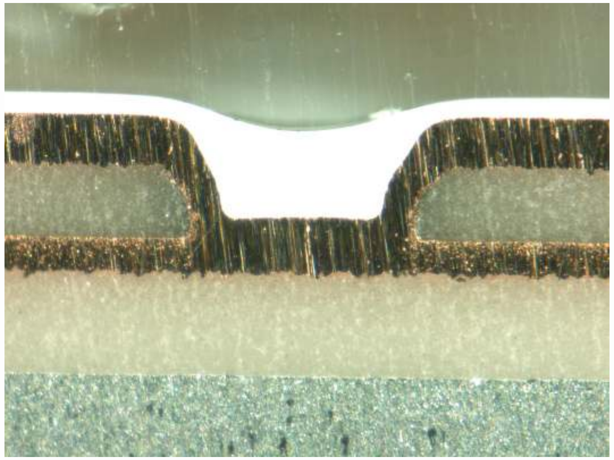
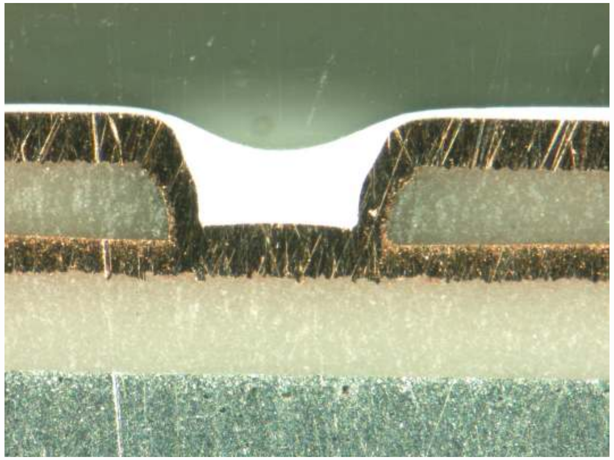
- **Solder Dipping (288℃， 10 sec) : 5 times**

	before S/D	after S/D
Hole 0.2mm		

Thermal stress Test (2L MPCB)

Measuring condition

- **Reflow test (Max peak 265℃) : 3 cycles**

	before Reflow	after Reflow
Hole 0.2mm		

General Properties of New Laminate

Properties	Condition / Method	Unit	Value
Mechanical			
Peel Strength (Hoz Cu)	IPC-TM-650.2.4.8	kgf/cm	1.4
z-CTE (before Tg / after Tg)	IPC-TM-650.2.4.41	ppm/℃	30 / 99
z-axis Expansion	50℃-260℃	%	1.5
Flexural Modulus	IPC-TM-650.2.4.4	GPa	20 ~ 25
Flexural Strength	IPC-TM-650.2.4.4	MPa	400 ~ 500
Electrical			
Dk @1GHz (DS-7409D/DS)	IPC-TM-650.2.5.5.1		5.7
Df @1GHz (DS-7409D/DS)	IPC-TM-650.2.5.5.1		0.014
Volume Resistivity	IPC-TM-650.2.5.17.1	ohm-cm	5.0E+13 ~ 5.0E+14
Surface Resistivity	IPC-TM-650.2.5.17.1	ohm	1.0E+13 ~ 1.0E+14
Thermal			
Thermal Conductivity	ASTM E 1461	W/mK	1.5
Tg (DSC)	IPC-TM-650.2.4.25c	℃	120
Pressure Cooker	IPC-TM-650.2.6.16		Pass
Chemical / Physical			
Water Absorption	E-24/50 + D-24/23	%	0.5
Flammability	UL94		V-0

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Conclusion

- Novel materials of high Thermal conductivity have been developed using epoxy resin with crystalline backbone.

- New resin system composed of base resin with crystalline have low loading alumina comparing with the conventional resin system.

- New materials demonstrated excellent heat resistance and reliability, which make them compatible with lead-free solder process.