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Insulation Material for Next Generation Packaging Substrates

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Abstract

With the progress of miniaturizing electronic equipment with higher performance, packaging substrates for semiconductor devices are required to cope with finer patterning and higher wiring density. The semi-additive wiring process has been needed in place of the conventional subtractive wiring process because the former can achieve higher wiring density than the latter. To realize high-density wiring, the surface profile is very important. Besides wiring process ability, improvement in several properties has been required because high-performance and complicated packaging substrates need higher reliability and lower transmission loss.

A new insulation material for the semi-additive process has been developed in these situations. This new material is applicable to the semi-additive process and features higher elongation, better dielectric properties, satisfactory plating peel strength with smoother surface profile, as well as being environmentally friendly.

In generally, most of the thermosetting resins, including epoxy resin, have a fragile nature compare to the thermoplastic resins. However, this new materials has relatively low modulus and high elongation in spite of using epoxy resin-based material; it also has a low coefficient of thermal expansion (CTE). The material proved to have enough insulation resistance and electrical reliability. The transmission loss for the material was smaller because of its lower surface profile. This new material is expected to find applications as an insulation material for next generation packaging substrates.

Introduction

With the progress of miniaturizing electronic equipment with higher performance, the type of semiconductor devices has been changing to leadless type and the flip-chip assembly has been increasing.[1] The packaging substrates that are mounted on semiconductor devices are required to have finer lines and higher-density wiring because the requirements for larger numbers of I/O, narrower line pitches and smaller chip sizes, etc. have been accelerating. The semi-additive process has the advantage for producing finer lines and higher-density wiring on packaging substrates by using the build-up process with interstitial via holes (IVHs), and this process is becoming widely used in these days.[2] However, it is difficult to get higher-density wiring by conventional technologies, because a rougher surface profile is essential to obtain enough plating peel strength by the process. The rougher surface profile will make it difficult to get higher-density wiring.[3,4] A new technology that affords enough plating peel strength with a smoother surface profile is then needed; a smoother surface profile also has the advantage of reducing transmission losses. On the other hand, the insulation material has been required to improved its properties, such as higher heat resistance for lead-free soldering, lower CTE for lowering internal stress, and higher resin toughness for crack resistance.[5, 6]

The change of packaging technology needs all these improvements that will lead to enhance the reliability of packaging substrates. Moreover, the material having better dielectric properties (i.e. lower dielectric constant and dissipation factor) is required for high frequency applications. The increasing global interest in environmental protection is calling for new materials that do not use halogenated compounds and antimony as flame retardants.

We have therefore developed a new insulation material for next generation packaging substrates. The material is applicable to the semi-additive process and features higher elongation, better dielectric properties, satisfactory plating peel strength with a lower surface profile, as well as being environmentally friendly.

In this paper, we will present our current activities to develop new insulation materials for next generation packaging substrates.

Development concept

The main semi-additive process has the following basic three processes:

1. Desmearing of insulation layer
2. Electroless plating of base metal on the insulation layer surface
3. Electroplating of wiring

In the desmearing process to make a proper surface profile on the insulation layer chemically, it is the most important to control the profile to get finer lines and higher-density wiring. Since the peel strength will depend on the surface profile in general, we have had to get rougher surface to realize higher plating peel strength so far. However, it is difficult to obtain fine lines and high-density wiring by using rough surface profiles. A new insulation material is required to realize good plating peel strength with lower surface profiles.

In addition, for the insulation material itself, toughness and low CTE are becoming more important, because more complicated packaging substrates require higher reliability. We therefore we set the following three conceptual requirements:

1. Adoption of a resin system hardly soluble to the desmearing solution
2. Adoption of a new epoxy resin and hardener featuring superior toughness and general properties
3. Adoption of surface-treat inorganic filler to realize good filler dispersion

Figure 1 shows the conceptual design model of a new insulation material for the semi-additive process. Here we applied several new technologies. We used a rigid rodlike and relatively high-molecular-weight epoxy resin. The epoxy resin cured with a new hardener has an enough long crosslinking distance to realize both high elongation and high glass transition temperature (Tg). The resin system is hardly soluble to the desmearing solution. We further realized low CTE by adding greater amount of surface treated inorganic filler.[7] This surface treatment also proved useful for more homogeneous dispersion of fillers, further resulting in finer surface profiles.

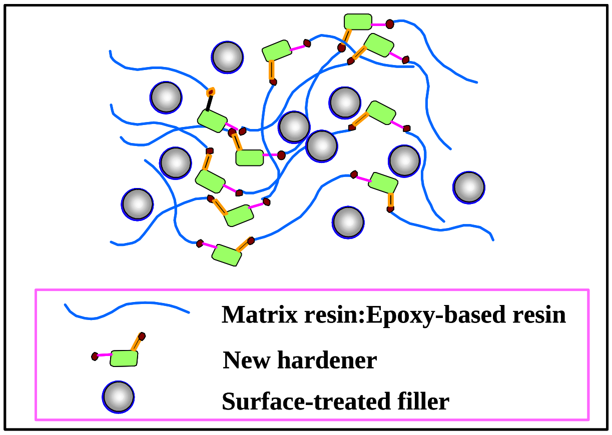


Figure 1 - Conceptual Design Model of New Insulation Material for Semi-Additive Process

General Properties of New Insulation Material

Table 1 shows the general properties of the new insulation material based on the new technologies.

Table 1 - General Properties of the New Insulation Material

Items	Condition	Units	New insulation material
Elongation	RT	%	10 - 12
Young's modulus	RT	GPa	2.5 - 2.7
Tensile strength	RT	MPa	80 - 90
Dk	1 GHz	-	3.1
Df	1 GHz	-	0.014
Tg	TMA	^{o}C	170
Peel strength	RT	kN/m	0.8 - 0.9
Surface roughness	Rz Ra	um	1.0 - 2.0 0.3 - 0.4
HAST	130^{o}C/85%RH, 3.5 V dc Insulation layer: 15 um	h	>300
Solder heat resistance	288^{o}C, Floating	s	> 120
CTE	25-100^{o}C	ppm/K	44
Water absorption	D-24/23	%	0.83
Flammability*[1]	UL-94	-	V-0

*[1] Two 200-um insulation materials were laminated on both sides of a 0.2-mm-thick MCL-E-679FG base board

It is obvious from Table 1 that this new insulation material has superior properties in many items, such as elongation, dielectric properties, surface roughness, CTE, and various reliabilities. In particular, this new material proved to have enough plating peel strength with a low surface profile. The surface profile for the conventional materials is about 5 micron in terms of Rz; that for the new material was 1.0 to 2.0 micron. The low surface profile will have advantages not only for fine line patterning but also in reducing transmission loss.

This new insulation material has relatively low dielectric constant (Dk) and dissipation factor(Df), which is advantageous for high frequency applications, also resulting in lower transmission loss. The low CTE characteristic will affect an advantage when the construction of packaging substrates becomes complicated. The internal stress for the low CTE materials will be smaller than that for the conventional materials.

The Mechanism of High Plating Peel Strength with a Low Surface Profile

In general, rougher surface profile is necessary to obtain higher plating peel strength. However, it is difficult to get fine lines and high-density wiring on a rough surface. Additionally, the strong desmearing process to obtain a rougher surface profile will sometimes cause damage in packaging substrates.

Figure 2 shows the inferred mechanism for the new material to have high plating peel strength with a low surface profile.

Figure 2 indicates that there is an evident relationship between the fracture energy and peel strength.[8] Here, we calculated the fracture energy values from the stress-strain curves. Higher peel strength will be resulted from higher fracture energy. When the plating copper foil is peeled off, the cohesion failure will occur inside the new insulation material. It is then important to use materials with high elongation. The new insulation material has a relatively high elongation for epoxy-based resin compare to the conventional epoxy resin systems. We have realized enough plating peel strength by affording high elongation to the new insulation material. The fracture energy of the conventional materials is so small that they need rough surface profiles to realize enough peel strength. The development concept was different between for the new insulation material and for the conventional materials.

Moreover, we have made use of some kinds of interactions between the new insulation material and plated copper foil. Figure 3 shows the analysis of the copper binding energy by X-ray photoelectron spectroscopy (XPS).

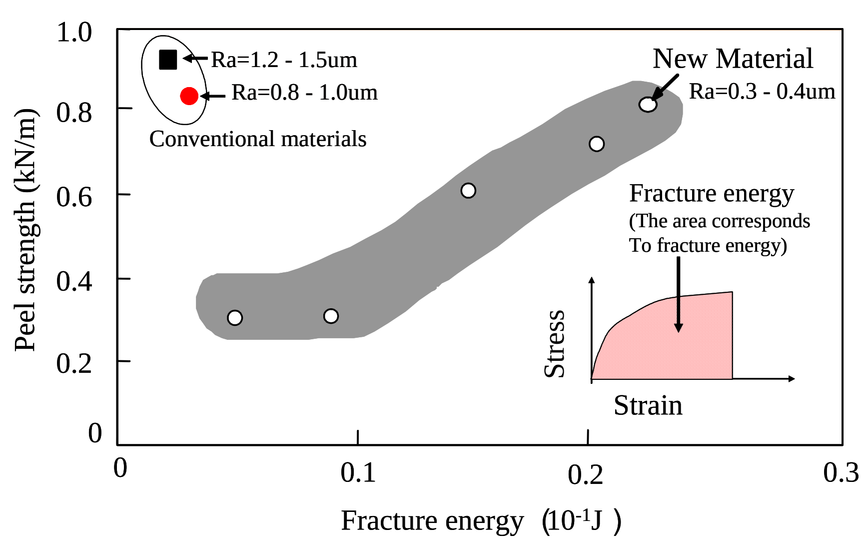


Figure 2 - Relationship between Fracture Energy and Peel Strength

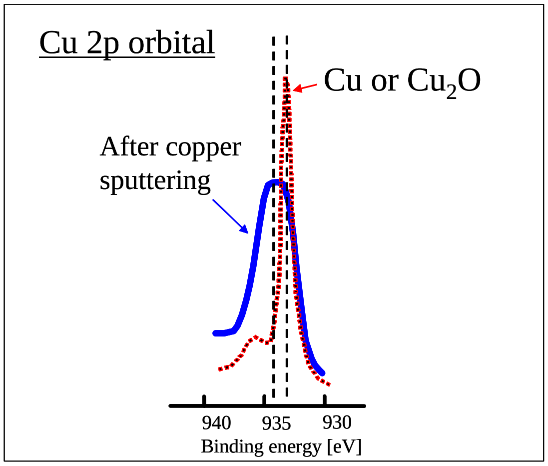


Figure 3 - XPS Analysis of the Interaction between the New Insulation Material and Copper Foil

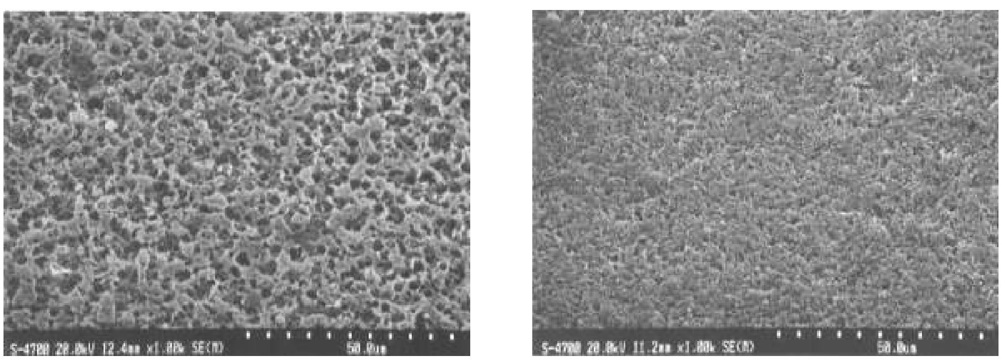
The peek for the copper sputtered on the new insulation material shifted to higher binding energy. This means the existence of interactions between the new insulation material and copper foil. We think these interactions will have the effect to enhance copper peel strength.

Low Surface Profile of the New Insulation Material

This new insulation material has a lower surface profile after desmearing compare to the conventional materials. Figure 4 shows the SEM photographs of their surfaces after desmearing.

The surface profile of the new insulation material proved smoother than that of the conventional materials; the average roughness(Ra) of the former was 0.3 to 0.4 micron whereas that of the latter was 1 to 2 micron.

We have achieved this low surface profile by adopting a new resin system hardly soluble to the desmearing solution. Figure 5 shows the solubility of the materials in terms of the weight loss against desmearing time.



New insulation material　　Conventional material

Figure 4 - SEM Photographs of the Insulation Material Surfaces after Desmearing

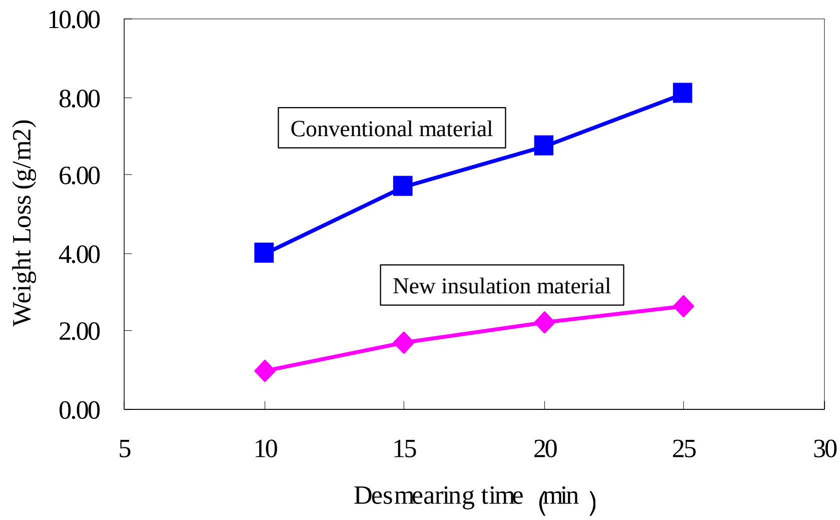


Figure 5 - Solubility of Material in the Desmearing Solution

The weight loss of the new insulation material was about one-third that of conventional material. We think this hardly soluble resin system must have afforded the low surface profile.

Effect of Surface Profile on Transmission Loss

We estimated the effect of the surface profile on transmission loss by using a simulation technique. We used a Microwave Design System as the calculation tool for this simulation. The results are shown in Figure 6.

We used the surface roughness values just at the interface of the copper pattern and insulation material. Figure 6 indicates that transmission loss will depend on the surface roughness. The transmission loss increases with increasing surface roughness. For the new insulation material, the effect of the smoother surface on reducing transmission loss is 10 to 25% depending on the frequency. It can be expected that further reduction of transmission loss is possible if the surface profile becomes less than 0.1 micron in Ra. We think this new insulation material is suitable for high-frequency applications in that it is hardly soluble to the desmearing solution and will maintain a smoother surface all the time in the desmearing process..

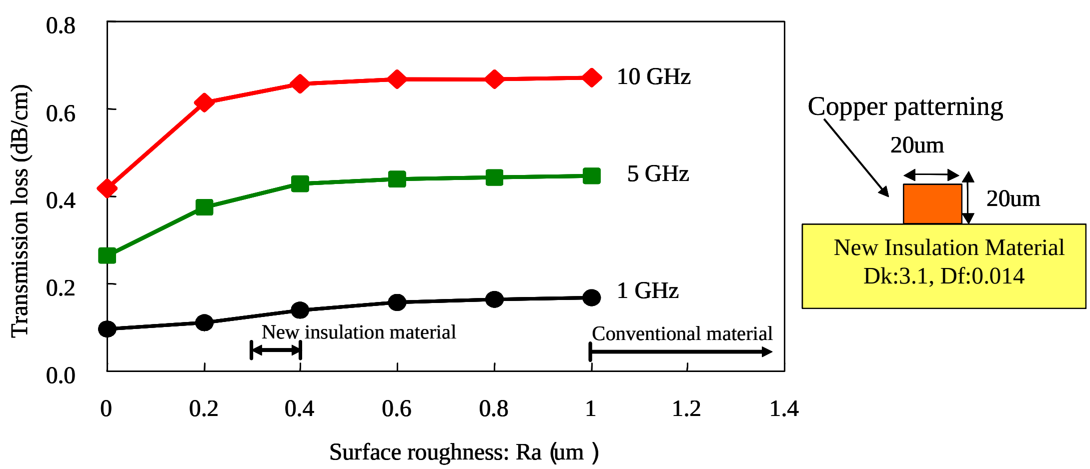


Figure 6 - Effect of Surface Profile on Transmission Loss

Reliability of New Insulation Material

This new material has a relatively high elongation. We found this high elongation is effective in improving the reliability of the packaging substrates. Figure 7 shows the results of crack development during thermal cycle testing.

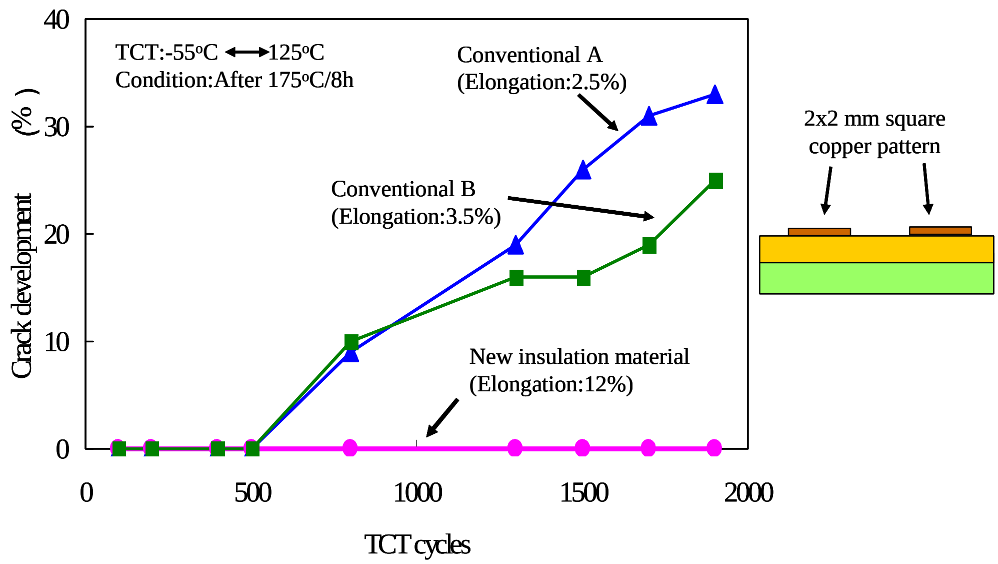


Figure 7 - Thermal Cycle Test Results

We used specimen boards having 2x2 mm copper patterns on each insulation material layer. For the conventional materials A and B, cracks were observed at the corners of the cooper patterns after 500 cycles. However, no crack was observed even after more than 1800 cycles for the new insulation material. Several factors, such as material strength and CTE, are considered to be responsible for the crack occurrence. However, we think high elongation of the material is the most important factors in preventing crack occurrence.

We also evaluated electrical reliability. The results are shown in Figure 8.

We evaluated the electrical reliability of the insulation material by an interlayer electrical migration test. Figure 8 shows that this new insulation material held high insulation resistance even after 200 hours application. We used 15-um-thick material in this test; minimum thickness is considered to be 20 micron for application to packaging substrates in these days.

From these two reliability tests, we found that this new insulation material has satisfactory reliability. We think this new insulation material is suitable for next generation packaging substrates because of its many excellent properties.

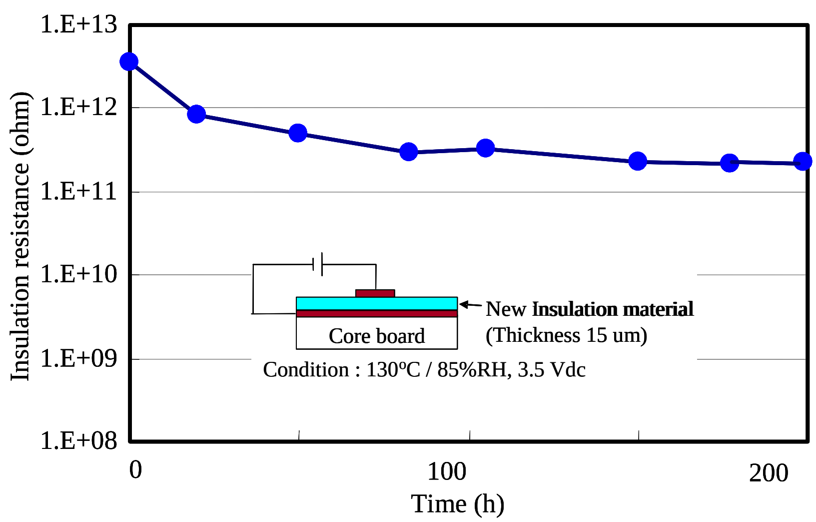


Figure 8- Electrical Interlayer Reliability of the New Insulation Material

Conclusions

1. We have developed a new insulation material for next generation packaging substrates.
2. The key point of the development is the adoption of a new hardly soluble and high-elongation resin system to afford excellent reliability with a lower surface profile.
3. This new insulation material has superior general properties, such as high elongation, better dielectric properties(lower Dk and Df), low surface roughness, and low CTE compared to the conventional materials.
4. Good plating peel strength has been achieved by the improvement of material toughness.
5. We proved that there will be some kinds of interactions between copper and this new insulation material.
6. The low surface profile of this new insulation material has been achieved by adopting hardly soluble material, which is suitable for high frequency applications.
7. This new insulation material has sufficient reliability for next generation packaging substrates.

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New Insulation Material for Next Generation Packaging Substrates

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Hitachi Chemical Co., Ltd.

Introduction

Required Specifications

- PKG Design:
  Smaller, Higher Density, Higher Integrated

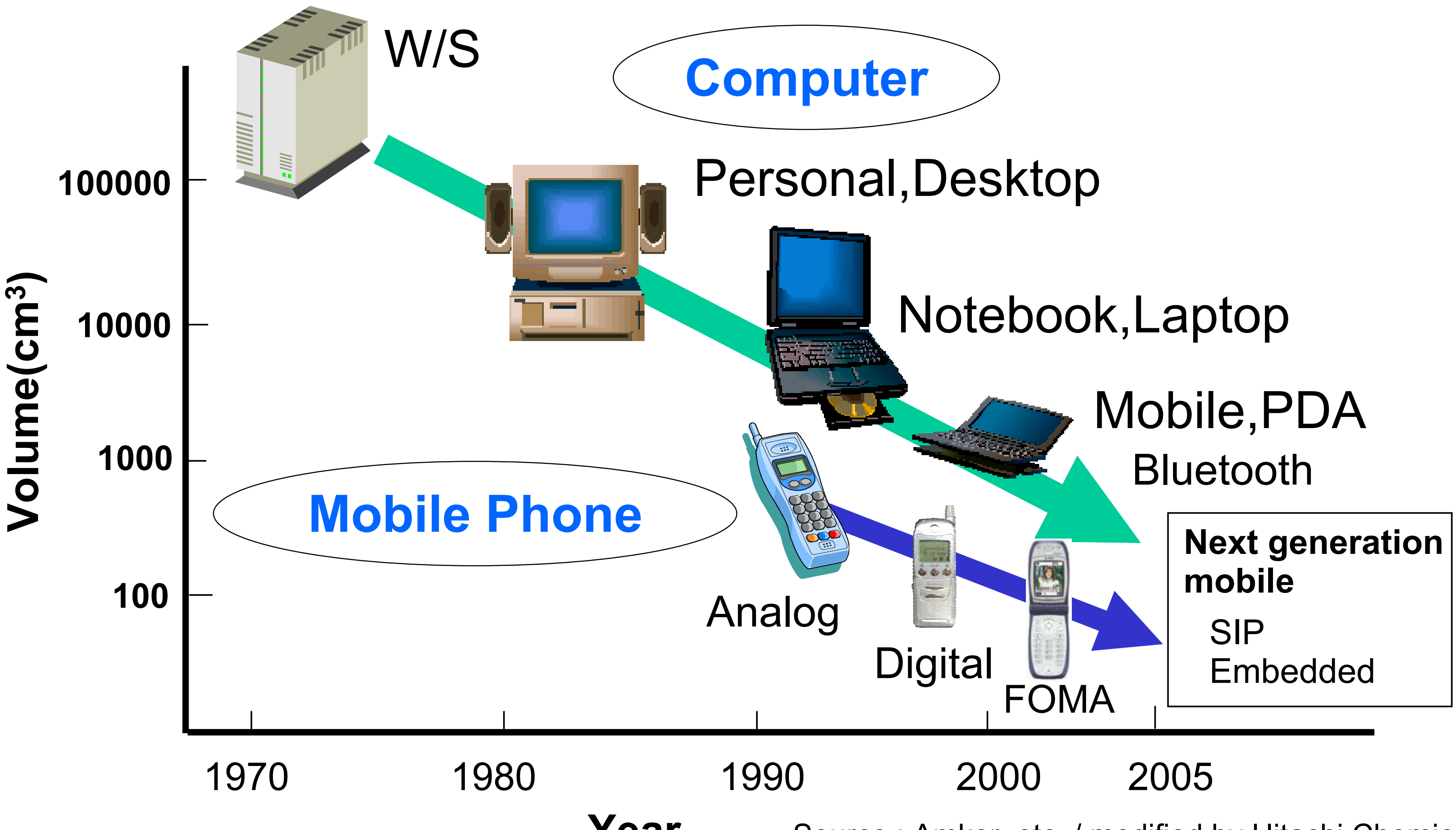
- Circuit Design:
  Finer Line/Space, Smaller Holes
    Semi-Additive Process Applicable
    Good Laser Drilling Performance

- High Frequency Applicable

- Environmentally Friendly

Trend of Electronic Devices

Miniaturization



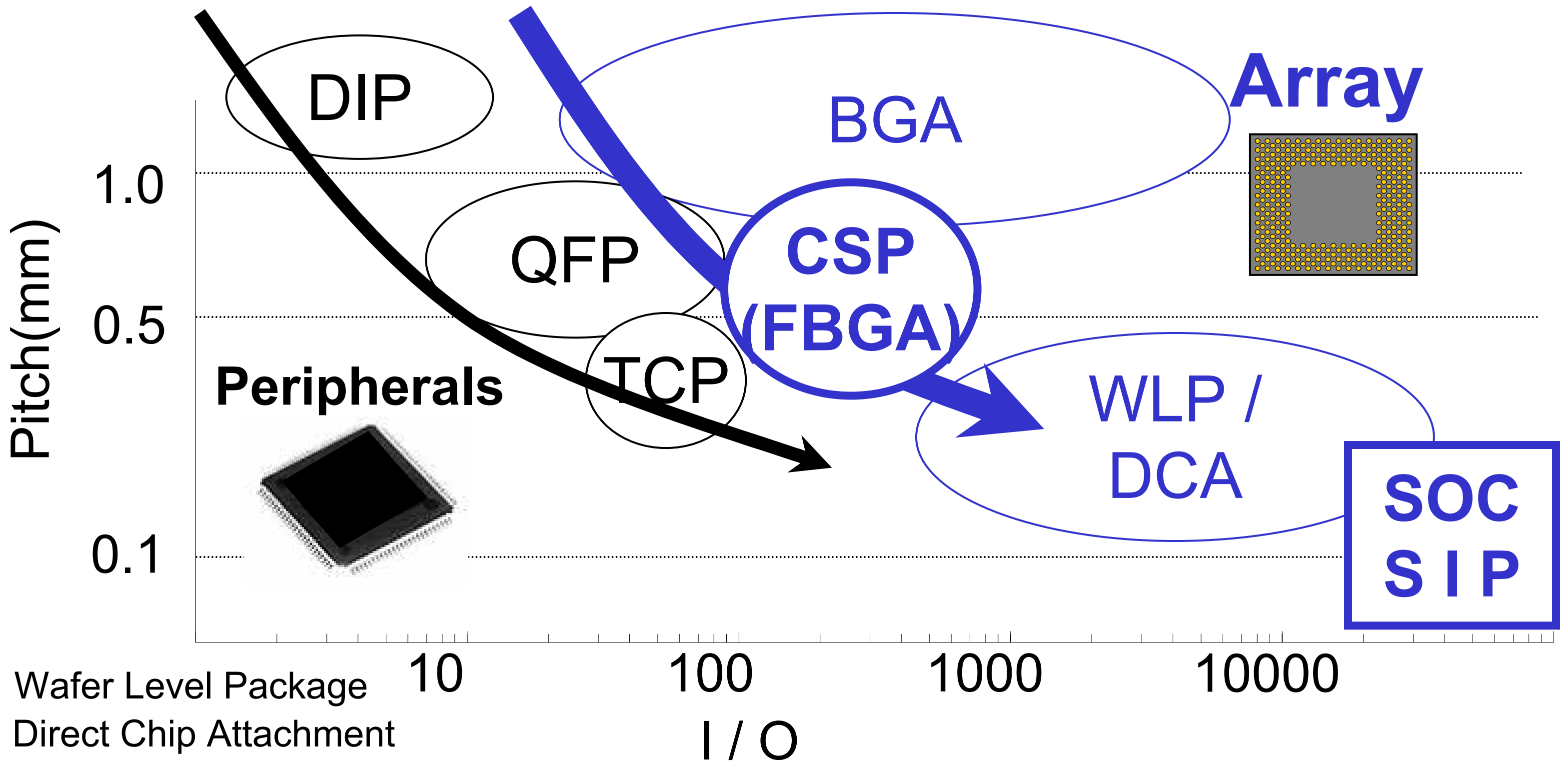
Source : Amkor, etc. / modified by Hitachi Chemical

PKG Trend

Products Shrink and High-Performance ICs Change Packaging and Assemble

-Narrow pitch ➔ <1.0 mm

-Peripherals ➔ Array (BGA, CSP)



WLP : Wafer Level Package
DCA : Direct Chip Attachment
SOC : System on a Chip
SIP : System in a Package

Source : CSP / MCM Assemble Technology (1999)

Packaged Chips Road Map *(High-Performance)*

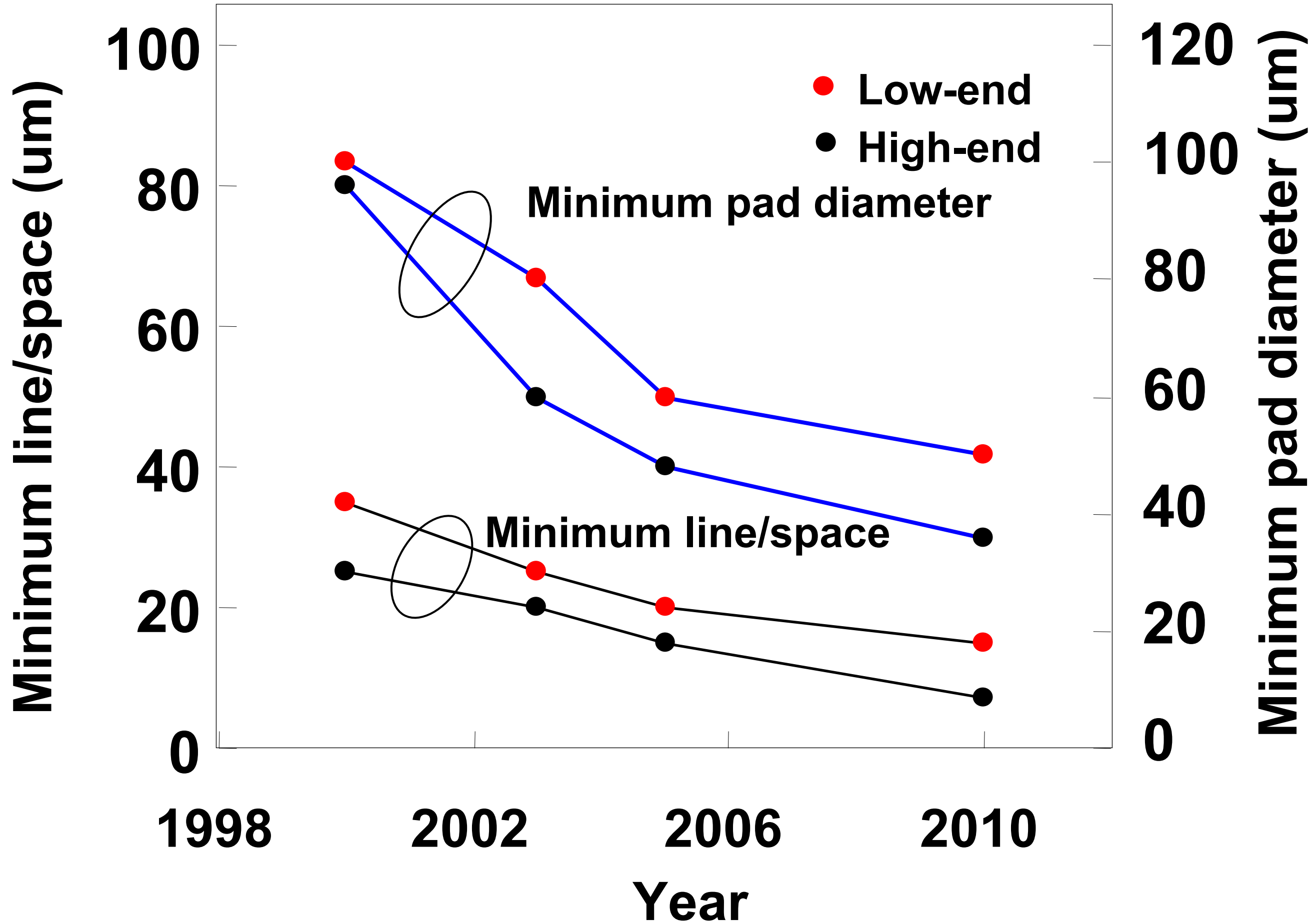
Performance of Packaged Chips

Year of production	2003	2004	2005	2006	2007	2008	2009
DRAM 1/2 pitch (nm)	100	90	80	70	65	57	50
MPU/ASIC 1/2 pitch (nm) (uncontacted Poly)	107	90	80	70	65	57	50
Number of chip I/Os -Maximum Total pad-ASIC	3,400	3,600	4,000	4,200	4,400	4,400	4,600
Chip frequency (MHz)							
On-chip local clock	2,976	4,171	5,204	6,783	9,285	10,972	12,369
Chip-to-board (off-chip) speed (for peripheral buses)	2,000	2,500	3,125	3,906	4,883	6,103	7,629

ITRS : 2004 UPDATE

Substrate Trend

Design Rule



Source：JEITA Japan Jisso Technology Roadmap 2001

Material Design Concept

1. **Adoption of resin system hardly soluble to the desmearing solution (semi-additive process)**

   → Low surface profile for fine patterning

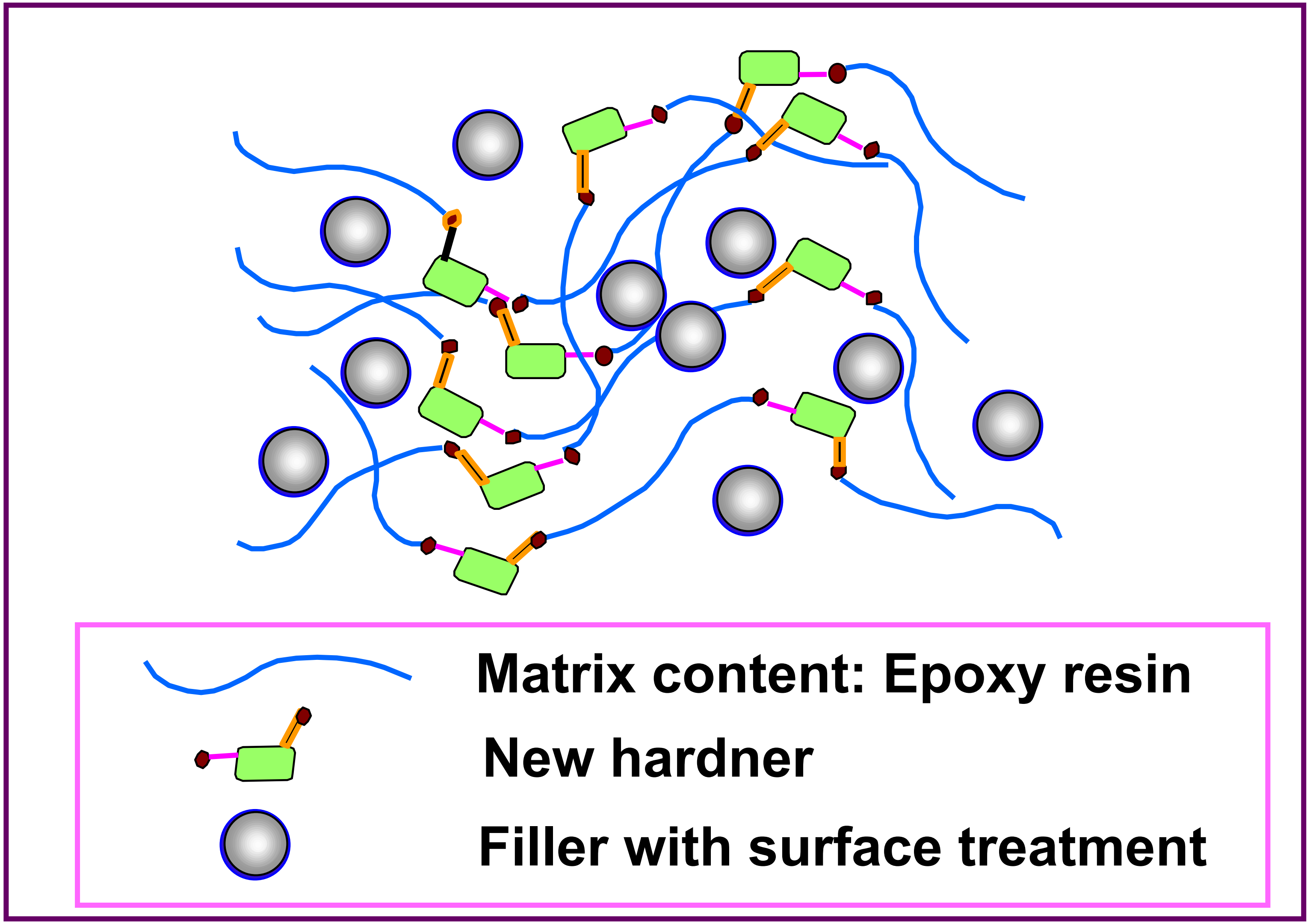
2. **Adoption of a new epoxy resin and hardner system featuring superior toughness and general properties**

   → High elongation and low dielectric Dk and Df

3. **Adoption of surface-treated inorganic filler to realize good filler dispersion**

   → Low CTE for good reliability

Conceptual Model of New Insulation Material



General Properties

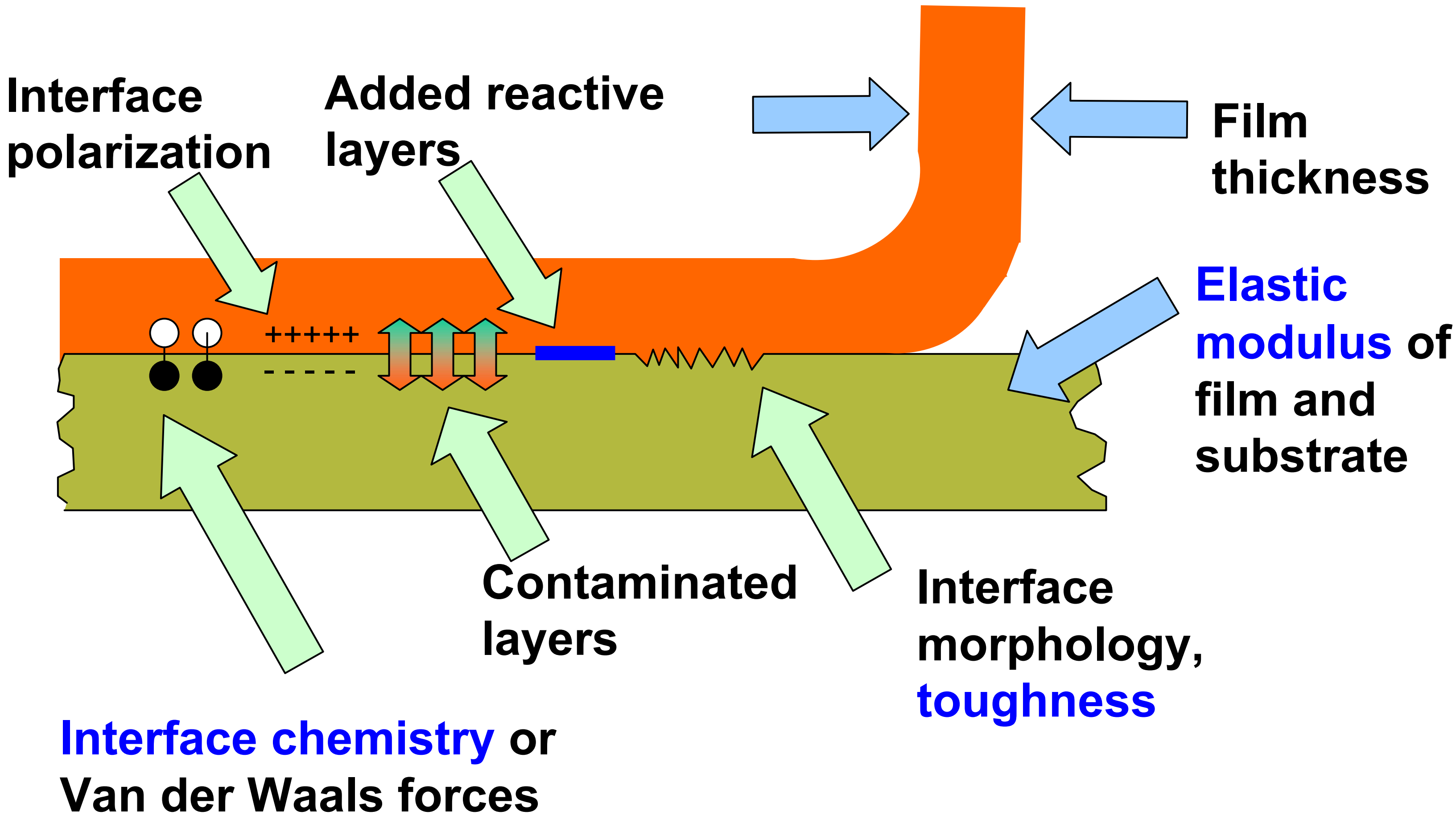
Items	Condition	Units	New insulation material
Elongation	RT	%	10 - 12
Young's modulus	RT	GPa	2.5 - 2.7
Tensile strength	RT	MPa	80 - 90
Dk	1 GHz	-	3.1
Df	1 GHz	-	0.014
Tg	TMA	°C	170
Peel strength	RT	kN/m	0.8 - 0.9
Surface roughness	Rz Ra	um	1.0 - 2.0 0.3 - 0.4
HAST	130°C/85%RH, 3.5 V dc Insulation layer: 15 um	h	>300
Solder heat resistance	288°C, Floating	s	> 120
CTE	25-100°C	ppm/K	44
Water absorption	D-24/23	%	0.83
Flammability*[1]	UL-94	-	V-0 (Halogen free)

*[1] Two 200-um insulation materials were laminated on both sides of a 0.2-mm-thick MCL-E-679FG base board.

Features of New Insulation Material

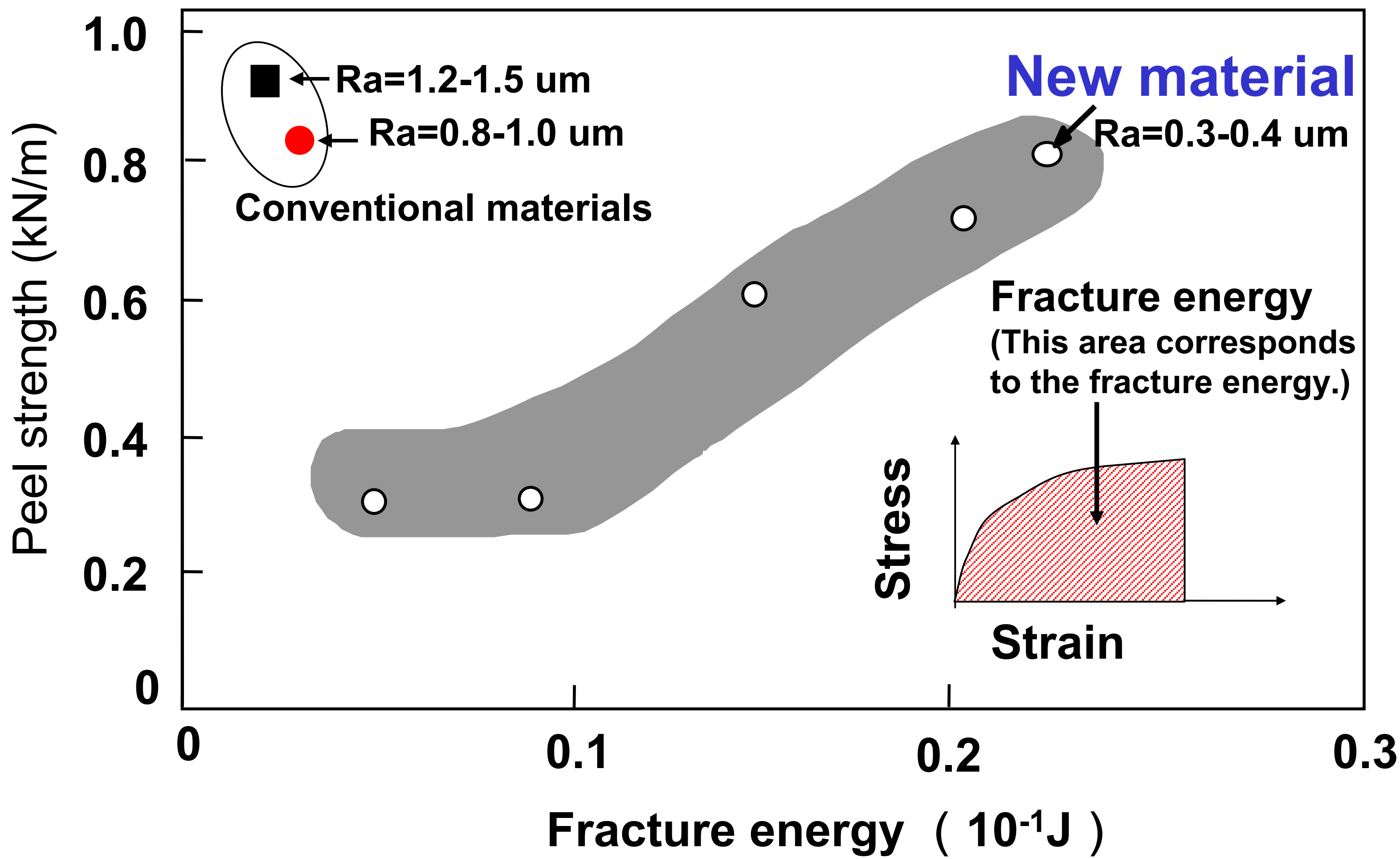
1. High elongation with relatively low CTE
2. Satisfactory plating peel strength though with low surface profile
3. Low Dk and Df at high frequency
4. Environmentally friendly (halogen-free)

Factors Controlling for Peel Strength

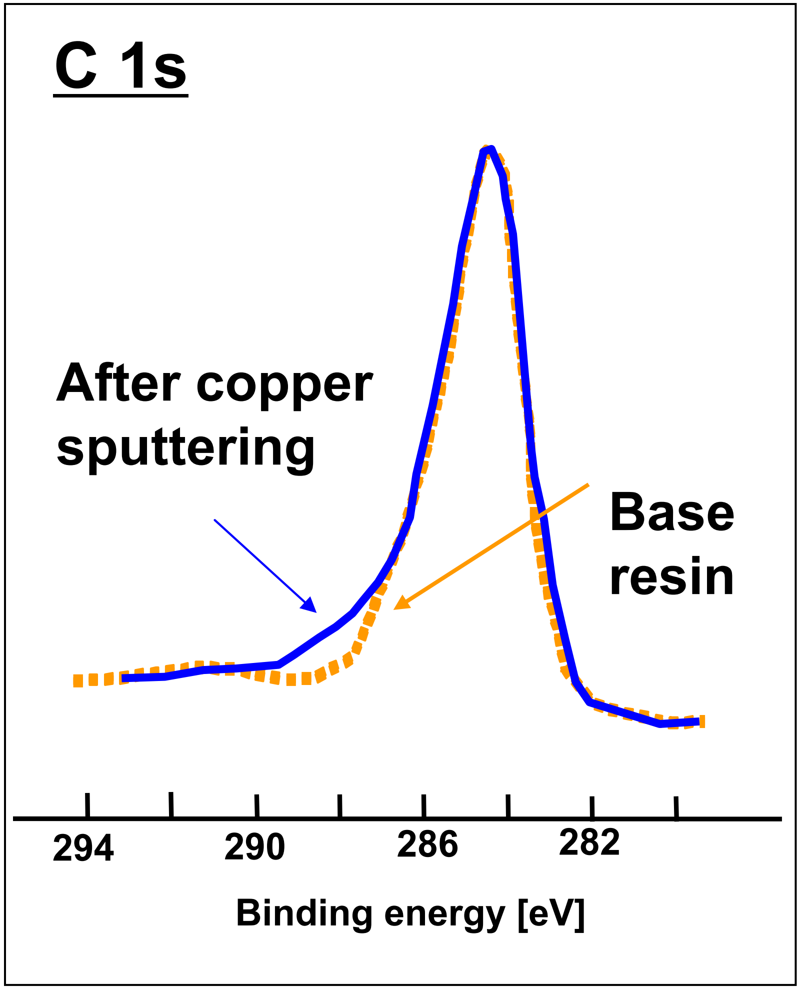


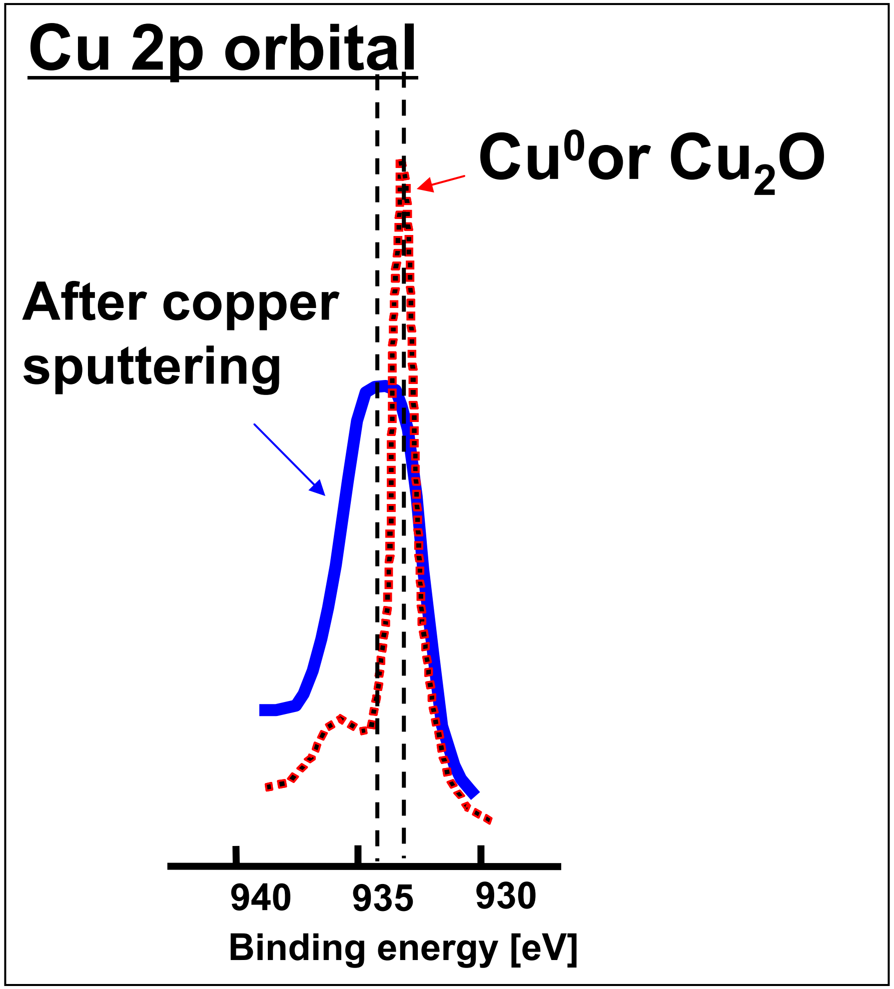
J.E.E.Baglin,Fundamentals of Adhesion, ed.L.H.Lee(Plenum Press,N.Y.,1991)

Fracture Energy against Peel Strength



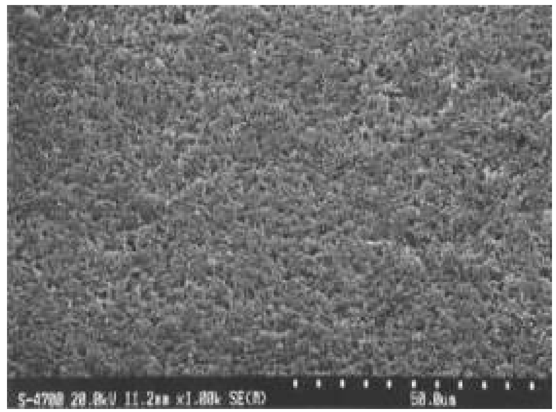
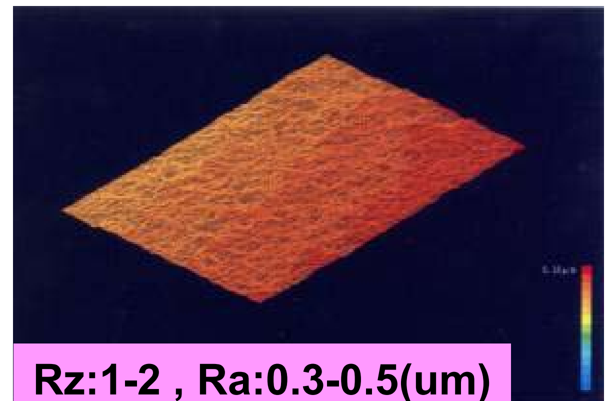
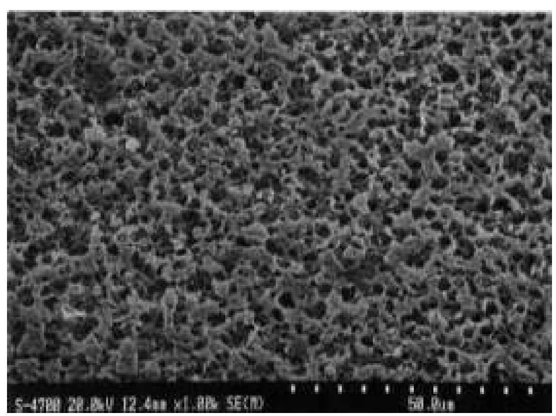
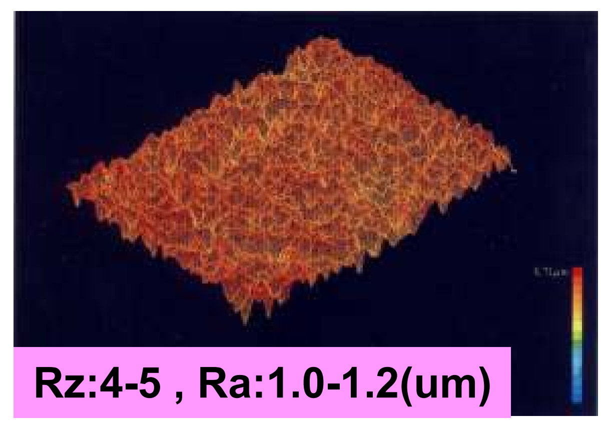
Interaction Between Copper and New Material



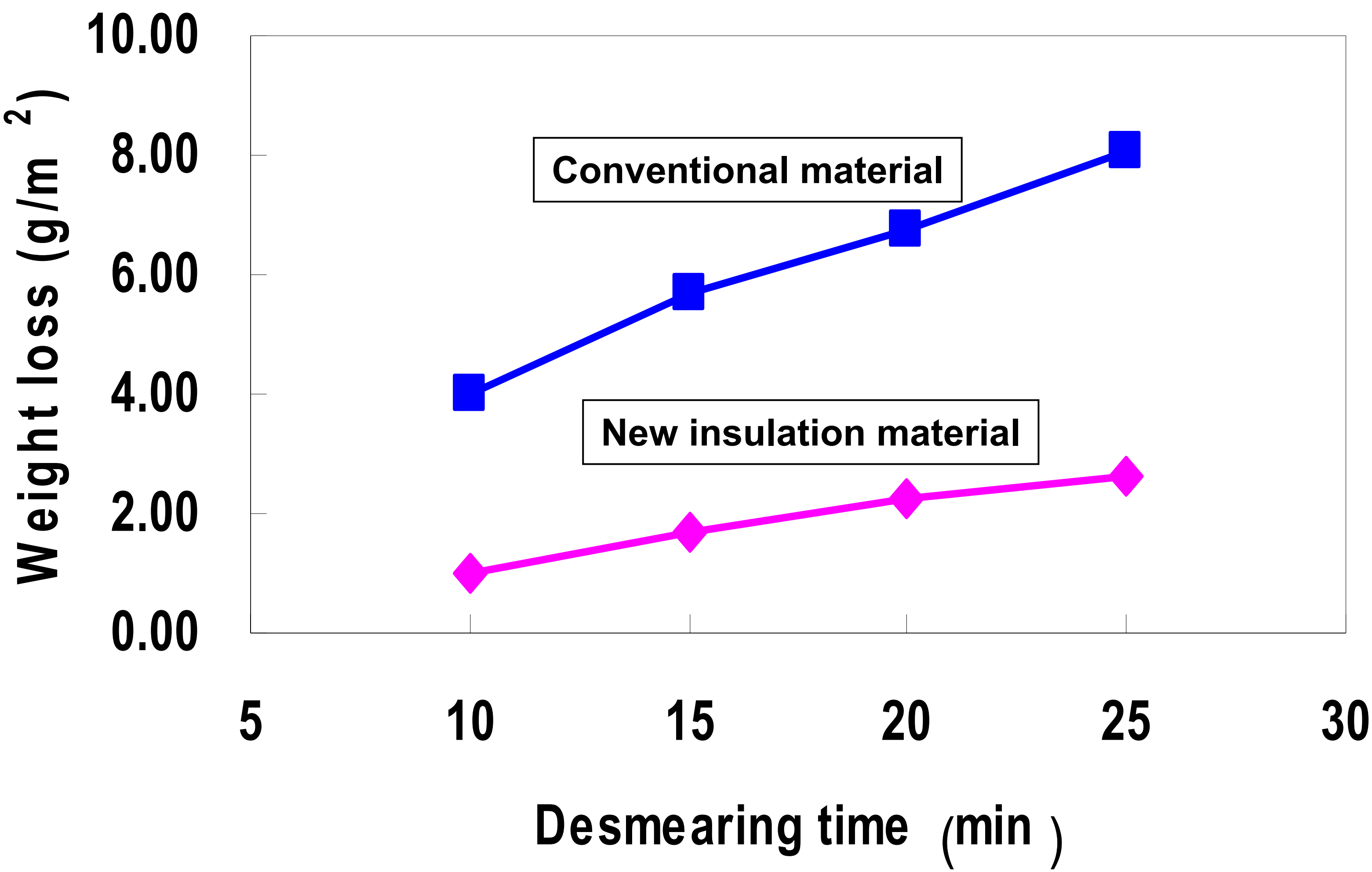


Low Surface Profile

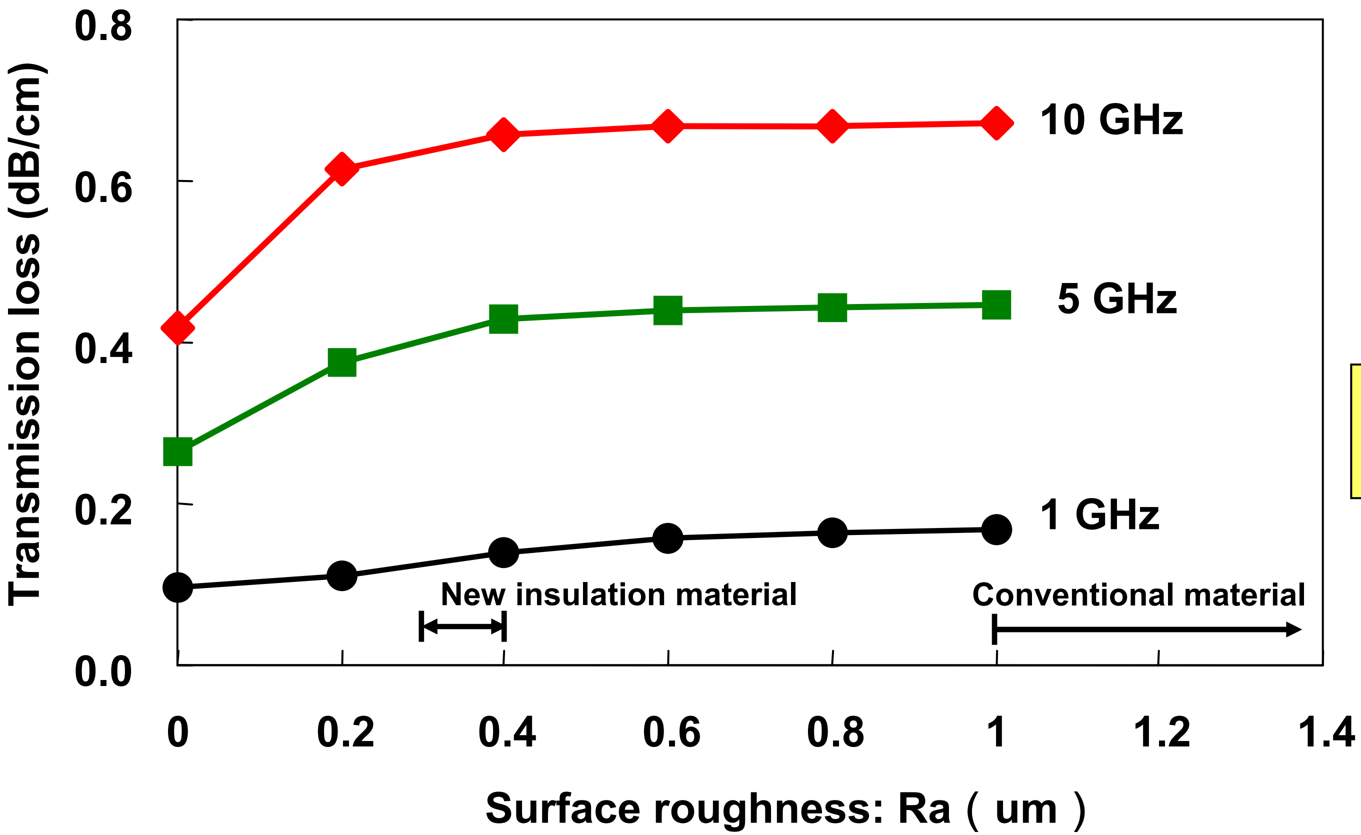
- Surface Profile after Desmearing

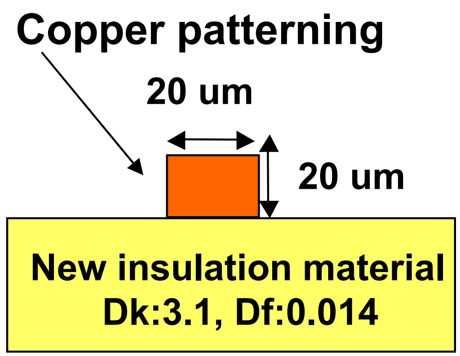
New insulation material		 Rz:1-2 , Ra:0.3-0.5(um)
Conventional material		 Rz:4-5 , Ra:1.0-1.2(um)

Solubility of Materials in Desmearing Solution

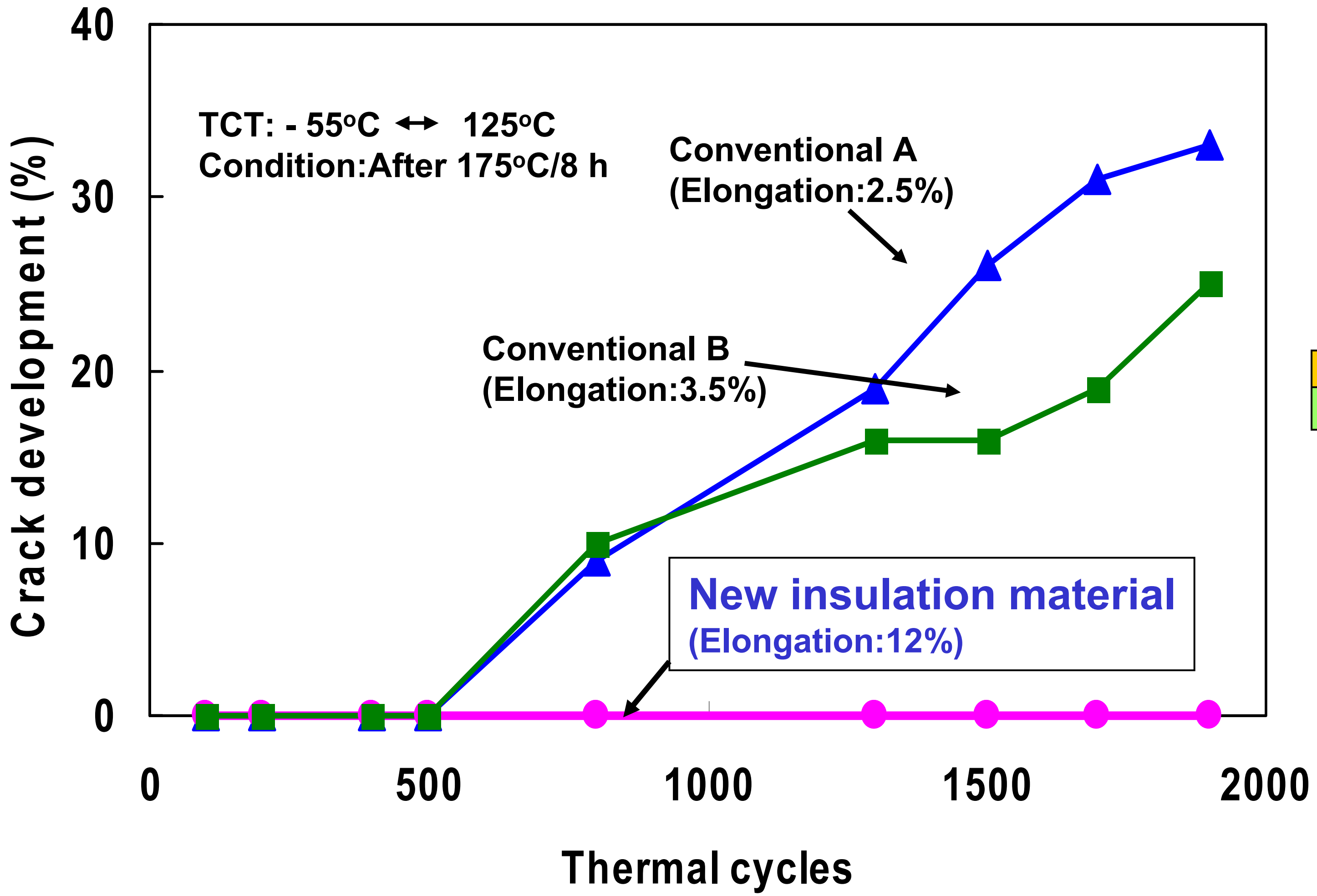


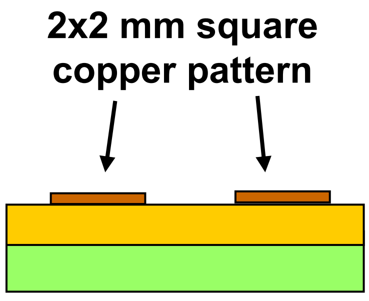
Effect of Surface Profile on Transmission Loss



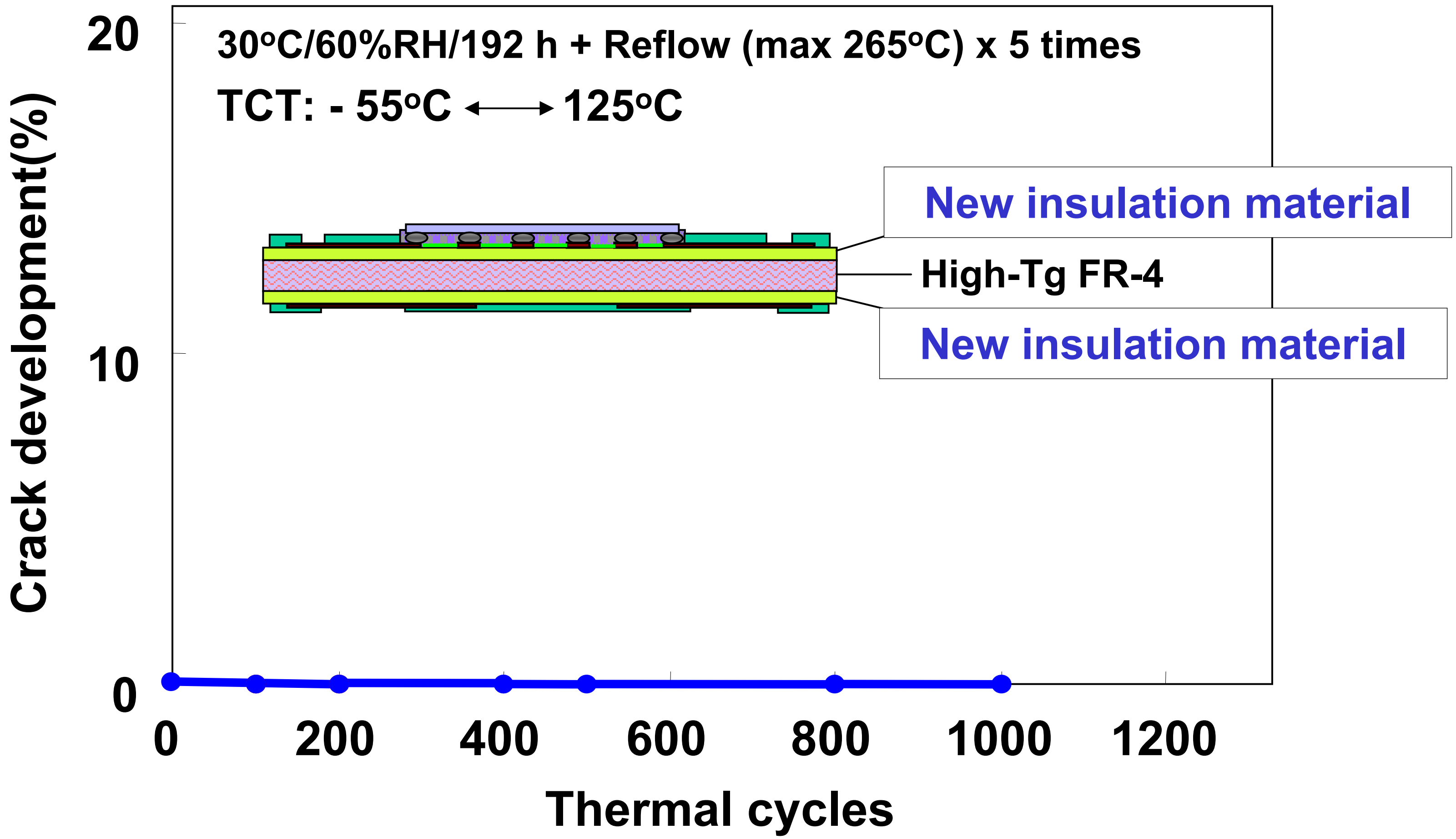


Thermal Cycle Test Results (1)

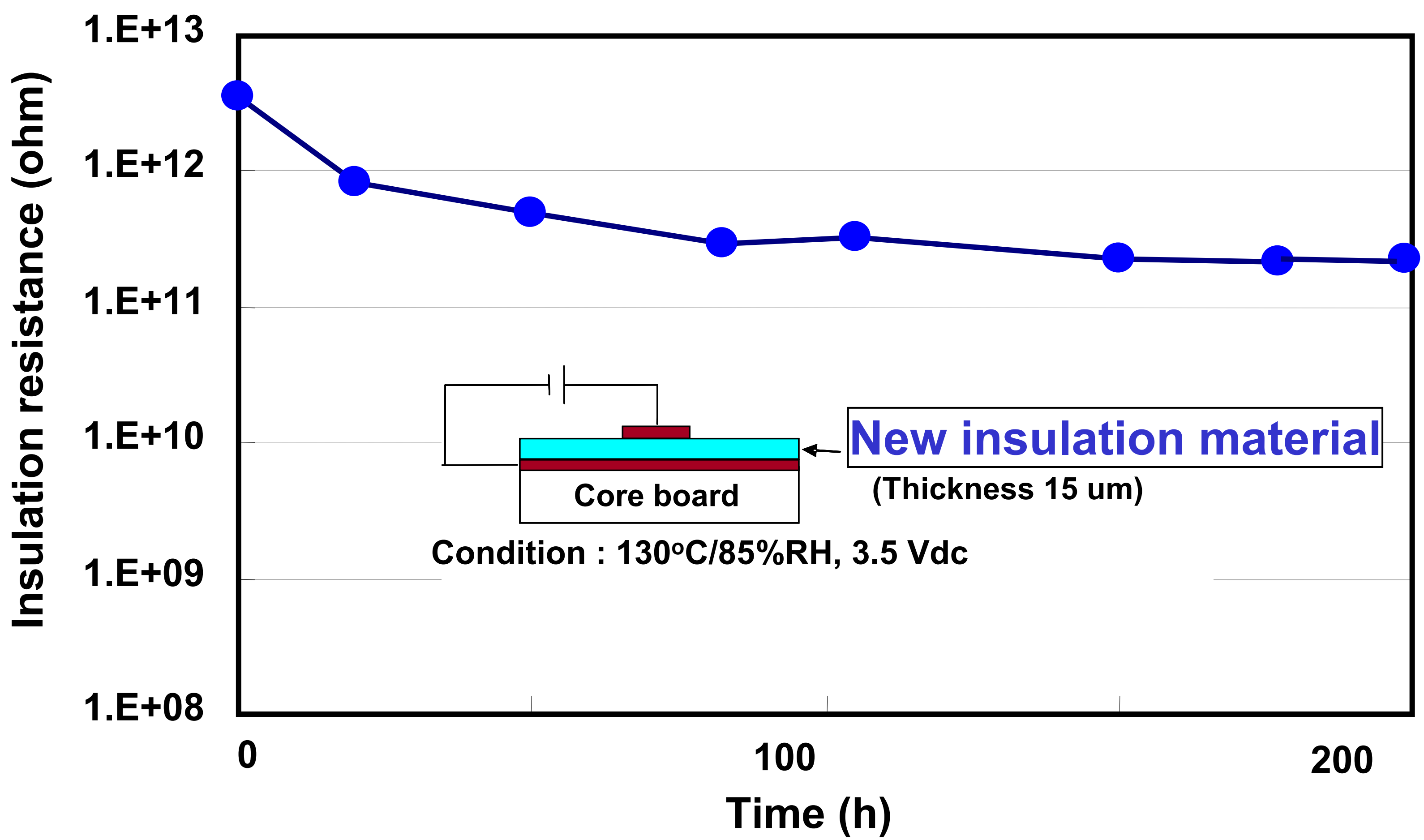




Thermal Cycle Test Results (2)



Electrical Reliability of Interlayer



Conclusion

1. We have developed a new Insulation material for next generation packaging substrates.

2. The key point of the development is the adoption of a new hardly soluble and high-elongation resin system.

3. The new Insulation material has low Dk and Df, as well as superior general properties.

4. Good plating peel strength has been achieved by the improvement of material toughness.

5. This new insulation material has sufficient reliability for next generation packaging substrates.