Packaging Substrate Applications of Ultra Low CTE Polyimide

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We succeeded in development of a thick laminate polyimide sheet composed by ultra low CTE polyimide films which showed low CTE comparable to that of silicon. A key issue in realizing a reliable through-hole interconnection in the package substrate is a CTE gap in Z-direction between an ultra low CTE polyimide sheet (100ppm/K) and copper (17ppm/K). In this study, reliability in double-sided PCB test pieces fabricated on the sheet was evaluated by thermal cycling test. The ultra low CTE polyimide sheet showed an adequate reliability after 5000 thermal cycles between -55°C and 125°C. This result shows the possibility of the use of the sheet as a core material for advanced package substrates.

Keyword: ultra low CTE, polyimide film, package substrate, laminate sheet, reliability

1. Introduction

Because of recent requirement of downsizing, miniaturizing, and performance improvement for electronic devices, interconnection of a silicon chip to substrate is changing from wire bonding to flip chip bonding. And also demand for fine pitch interconnection is increasing [1].

But in flip chip bonding, a CTE (Coefficient of Thermal Expansion) gap between a silicon chip (3 ppm/K) and a package substrate (17 ppm/K) causes package warpage and consequently induces high stress on the solder joints during fabrication of package. There is possibility to damage a chip and degrade field life of the connection joint. This is one of the most critical issues in securing reliability for a high-density packaging.

To resolve this problem, an underfill has been used widely to reduce the stress on the solder joint by encapsulating. However, the

stress on the solder joint is still induced and remains. It is the ideal solution to reduce the CTE gap between a silicon chip and a package substrate.

The CTE of a package substrate is mainly controlled by core material. So, lowering the CTE of core material is the most effective way to lower the CTE of substrate. Up to now many attempts have been made for low CTE core materials, for example, a substrate including inorganic filler, a substrate used low CTE and high modulus fiber, and package substrates used low CTE materials such as silicon interposer. But they have many technical and cost issues and they haven't widely spread yet [2]. For fundamental solution of the CTE gap issue, a new core material which has the same CTE with silicon chip is needed.

Polyimide is well known to have the highest level of heat resistance and flame retardancy among various organic materials,

and widely applied for print circuit board and semiconductor packaging.

Previously, we developed a new type of polyimide film XENOMAX[®] [3]. It shows ultra low CTE, which is almost equal to that of silicon over wide temperature range. Recently, we succeeded in development of a thick laminate polyimide sheet composed by XENOMAX[®] films which also shows ultra low CTE comparable to that of silicon.

In this study, plated through-hole (PTH) reliability in a double-sided PCB test piece fabricated with the XENOMAX[®] sheet was evaluated by thermal cycling test.

2. Experimental

2.1 Materials

XENOMAX[®] sheet was prepared by lamination of XENOMAX[®] films.

Double-sided plated circuit board test pattern of XENOMAX[®] sheet with the thickness of 234 μm was processed as Figure 1. Through-holes were formed by using UV-laser drilling process and its diameter was 100 μm . After through-hole formation, seed layer was formed by sputtering. Then, test pattern was formed by semi-additive process.

Figure 1. Plated through-hole formation process.

2.2 Through-hole reliability test

Thermal cycling test was performed on ESPEC TSA-11A thermal cycle tester at -55°C and 125°C ($\Delta T=180$) after the treatment of each processes listed on Table 1. The through-hole resistance value was measured by Agilent 4338B milliohm meter at room temperature after every 250 cycle. The failure criterion was 10% increase in resistance value.

Table 1. Thermal cycling test condition

Process	Condition	References
Pre-baking	$125^{\circ}\text{C} \times 24 \text{ hrs}$	
Conditioning	$30^{\circ}\text{C} \times 60\% \text{RH} \times 96 \text{ hrs}$	JEDEC LV4
Reflow model	$260^{\circ}\text{C} \times 5 \text{ min} \times 3 \text{ times}$	
Thermal cycling	$-55^{\circ}\text{C} / 125^{\circ}\text{C} \times 15 \text{ min} / 15 \text{ min}$	JEDEC JESD22-A104-B

3. Results and Discussion

3.1. Ultra low CTE Polyimide film, XENOMAX[®]

The chemical structure of XENOMAX[®] is totally different from those of conventional polyimides. By introducing benzazole structure in polymer backbone, ultra low CTE, which is almost equal to that of silicon, is successfully achieved over wide temperature range with keeping original heat resistance and flame retardancy.

Figure 2 shows the temperature dependence of XY-direction CTE of polyimides, silicon wafer and copper foil, respectively.

XENOMAX[®] demonstrates very flat temperature dependence of CTE as well as very low absolute value of CTE over wide temperature range. This homogeneous dimension stability in a very wide temperature range especially in higher temperature over than 300°C is one of the most critical characteristics of XENOMAX[®]. Its CTE is significantly low and stable until 450°C , around 0ppm/K. This value is almost equal to that of silicon and glass.

Figure 2. Temperature dependence of CTE (XY).

Clearly this distinction shows that XENOMAX[®] is much more desirable than

other polyimides to be used nearby silicon chips in semiconductor packaging.

Figure 3 shows the temperature dependence of Z-direction CTE of polyimides. XENOMAX[®] has similar Z-direction CTE to those of conventional polyimides, about 100ppm/K until 250 °C. But in higher temperature over than 300°C, XENOMAX[®] is more stable than others.

Figure 3. Temperature dependence of CTE (Z).

Figure 4 shows polyimide films warpage after maintained on each temperature hot plate for 5 minutes. Conventional polyimide films curl when heated at high temperature over 200°C. On the other hand, XENOMAX[®] keeps planarity even at 450°C and exhibits extreme flatness at high temperature than other polyimide films.

Figure 4. Warpage of polyimide films.

This distinction shows that XENOMAX[®] is much more desirable film than other polyimides to be used as a base material for thin film deposition in flexible flat displays or flexible photovoltaic cells. Thin film

process generally requires high temperature treatment in which the maximum temperature may reach 500°C. XENOMAX[®] can be a desirable heat-resistant substrate material which withstands a high-temperature annealing process for a variety of deposited thin films such as silicon and compound semiconductor.

Figure 5 shows the dynamic viscoelasticity of XENOMAX[®] in comparison with those of conventional polyimides. The storage modulus for polyimide A begins to decrease around 300°C and the value at 400°C falls in one tenth of the value at the original room temperature. Its maximum value of loss modulus observed at 330 °C shows a possibility of structural transition, which may correspond to the inflection point in Figure 1.

Similar tendency of the storage modulus and the loss modulus for polyimide B is also confirmed, which implies structural change. In the case of XENOMAX[®], although an unclear dispersion is observed at around 400°C, the decrease of the storage modulus is much smaller than that of polyimide A and B. Even at 500°C, XENOMAX[®] maintains the storage modulus value more than 1GPa as shown in Figure 4. This clearly shows a significant advantage of XENOMAX[®] in retention of mechanical strength at high temperature.

Figure 5. Comparison of dynamic viscoelasticity.

XENOMAX[®] has similar mechanical and electrical properties to those of conventional polyimides (Table 2). This indicates that XENOMAX[®] does not require the special care for its handling in the various film processes.

Table 2. Comparison of mechanical properties.

Polyimide Film		XENOMAX®	Polyimide A	Polyimide B
Thickness	μm	25	25	25
Tensile Modulus	GPa	9	5	9
Tensile Strength	MPa	500	360	540
Elongation at Brake	%	40	70	50

Table 3 summarizes the electrical properties of XENOMAX® in comparison with conventional polyimides. The dielectric constant and the dielectric strength show that XENOMAX® can be used for an insulating film in most electric/electronic applications.

Table 3. Comparison of electrical properties.

Polyimide Film		XENOMAX®	Polyimide A	Polyimide B
Surface Resistivity	Ω	$>10^{17}$	$>10^{17}$	$>10^{17}$
Volume Resistivity	Ω•cm	1.5×10^{16}	1.5×10^{16}	1.5×10^{16}
Dielectric Constant (12GHz)	—	3.8	3.8	3.5
Dissipation Factor (12GHz)	—	0.01	0.01	0.01
Dielectric Strength	kV/mm	350	450	390

* Surface and volume resistivities are measured at DC500V.

XENOMAX® also has the same flame retardancy as those of other polyimides. Table 4 summarizes the UL certification of XENOMAX®. 5, 10, 25 and 50 μm XENOMAX® have been already certified. Temperature index is 260°C, which ranks at the top of all organic films.

Table 4. UL certification in XENOMAX®.

Thick ness	CLASS	HWI	HAI	RTI[°C]		D 495	C T I
[μm]	UL94	PLC	PLC	Elec.	Mech.		
5	VTM-0	0	4	220	220	4	3
10	VTM-0	0	3	240	240		
25	V-0	0	3	240	240		
50	V-0	0	2	260	260		

UL File No.QFZ2, E247930

3.2. Ultra low CTE Polyimide sheet

We succeeded in development of a thick laminate polyimide sheet composed by XENOMAX® films which shows ultra low CTE comparable to that of silicon. The laminate sheet shows almost the same properties with original film (Table 5). The laminate sheet shows still ultra low CTE.

Table 5. Mechanical and electrical properties of XENOMAX® laminate sheet and film.

		XENOMAX®	
		Laminate sheet 1.4mm	Film 25μm
Flexural Modulus	GPa	10	9 (Tensile)
Flexural Strength	MPa	440	-
Rockwell Hardness	-	75	-
CTE	ppm/K	XY:3 Z:130	XY:0 Z:130
Volume Resistivity	Ω•cm	1.5×10^{16}	1.5×10^{16}
Dielectric Constant	—	3.0 @1MHz	3.8 @1GHz
Dielectric Tangent	—	0.003@1MHz	0.008@1GHz

Figure 6 shows processability of XENOMAX® sheet with thickness of 500 μm. It can be processed by router or laser into desired shape as well as general engineering plastics.

Figure 6. Processing of XENOMAX® sheet by CO₂ laser.

Figure 7 shows examples of through-hole formation by UV-laser and mechanical drill process. Both processes can make straight and narrow pitch through-holes on XENOMAX[®] sheet with high aspect ratio.

Figure 7. Through-hole formation on XENOMAX[®] sheet by (a) UV-laser (355nm) and (b) mechanical drill.

Thus, XENOMAX[®] sheet shows ultra low CTE comparable to silicon wafer and SiN, and yet it can be easily processed in making through-hole by mechanical or laser drilling process with high aspect ratio. It is highly expected to perform as a core material for a thermally- reliable package substrate. But a Z-direction CTE of XENOMAX[®] sheet is about 100 ppm/K, which is much larger than that of copper. So, it may be a concern for through-hole reliability.

3.3. Through-hole reliability test

Figure 8 shows a cross sectional SEM image of a through-hole. The thickness of Cu plating on the surface and internal of through-hole was both 15 μm, respectively. Figure 8 also shows the plating has uniform thickness.

Figure 8. A cross sectional SEM image of a through hole in a test piece.

Figure 9 shows the change of 10-holes daisy-chain resistance value as a function of cycle number. Until 5000 cycles, each daisy-chain kept its resistance value at almost the same with initial value. The resistance value increase of each daisy-chain after 5000 cycle was below 5% and no failure was observed.

Figure 10 shows a cross sectional SEM image of a PTH after 5000 cycle. No crack was observed in PTH.

Figure 9. The change of relative resistance value of PTH in XENOMAX[®] sheet in the thermal cycle test.

Figure 10. A cross sectional SEM image of a plated through-hole in a test piece after the thermal cycle test.

4. Conclusion

We succeed in developing a new ultra low CTE polyimide, XENOMAX[®] sheet. Its CTE is almost equal to silicon wafer and it has

good processability with both mechanical and laser drilling. Through-holes in the XENOMAX[®] sheet showed an adequate reliability after 5000 thermal cycles between -55 and 125 degrees C. This result indicates further possibility of XENOMAX[®] sheet to use as a core material for advanced package substrate.

References

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