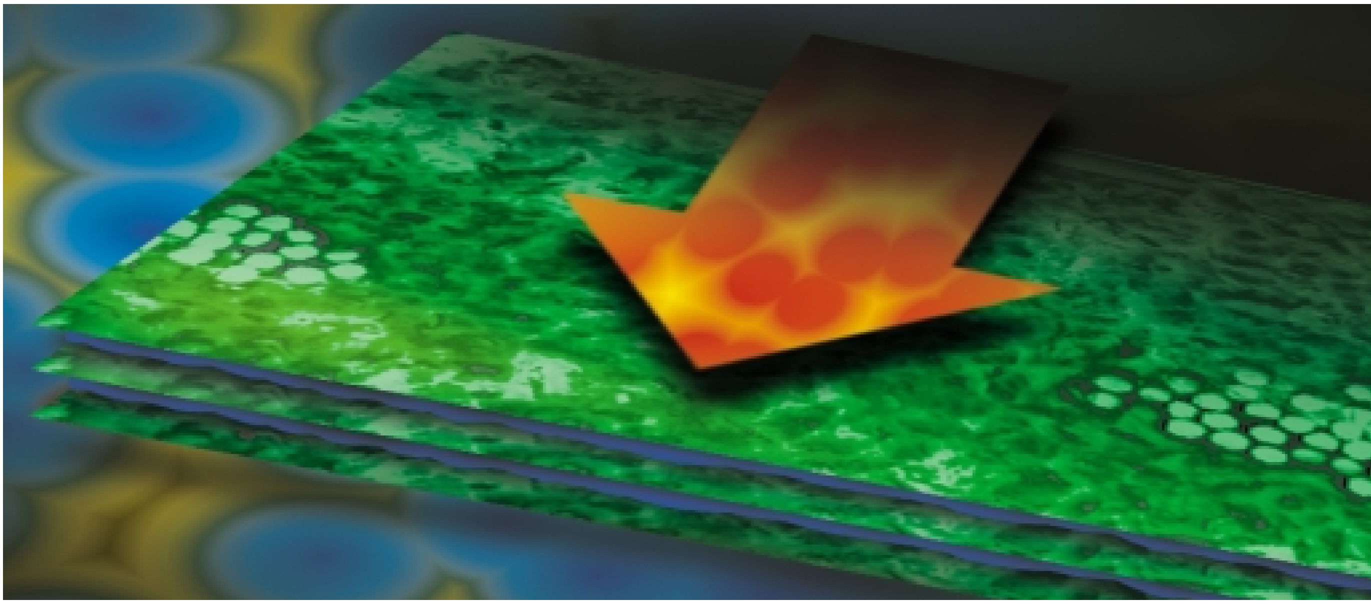
High Reliability/ Low CTE Epoxy Technology:

An Overview of the Advantages of Low CTE Materials



As our industry becomes less Tg oriented and more performance based, the use of low CTE epoxies is likely to grow significantly.

By Bob Forcier and Bob Schor

Introduction

As board reliability requirements have increased over the last several years, the multilayer industry has been enthralled with the continuing trend towards higher Tgs. For example, in North America, over 50% of the multilayer boards 12-layers and above (or ≥ 0.090" thick) typically require a minimum material Tg of 160°C or higher. This strategy of using higher Tg systems has been successful in producing higher yields in products that must survive the difficult thermal excursions experienced in assembly and BGA rework.

Low CTE Epoxy

Perhaps the most significant benefit of high Tg systems is the lower Z-axis expansion of the product when measured over a temperature range. The higher 170°C Tg resin system provides up to 22% less expansion when compared to standard 140°C Tg system (3.9 vs. 5.0%). This lower expansion minimizes the fatigue that a plated-through-hole would experience during a thermal excursion. Less expansion equates to less fatigue in the plated copper that might lead to reduced electrical opens of the plated-through-hole.

High Reliability/ Low CTE Epoxy Technology

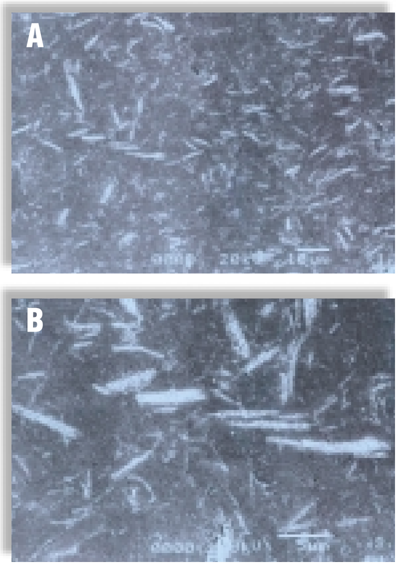


Figure 1. N4000-7 Filled Resin System.
A: Appearance at 1000X
B: Appearance at 3000X

A new series of mid-range Tg epoxies have been developed that have lower CTE values than a higher Tg system. This is achieved through epoxy chemistry formulation in conjunction with the use of inorganic based fillers as part of the resin matrix. Figure 1 provides SEM photomicrographs of this filler technology.

Low CTE Performance

In Table 1, a comparison of the thermal, mechanical, chemical and electrical properties are provided for the standard Tg, low CTE/mid-range Tg and high Tg systems. Of particular importance is the Z-Axis Expansion comparison of the three materials.

DSC, Tg [°C]	Z-Axis (50 to 260°C)
140	5.0 %
155 Low CTE	3.8 %
170	3.9 %

With a Z-axis expansion below 4.0%, the low CTE/mid-range Tg system provides reliable performance that meets or exceeds the properties of the high Tg system. All of the thermal and mechanical properties at least meet and in many cases exceed the higher Tg system, while allowing for easier processing.

Generally speaking, lower Tg systems are easier to drill. This is especially true with higher layer count designs that contain high aspect ratio holes with unused copper pads on several layers. The low CTE system drills in the same range as the 140°C Tg system and allows for higher stack heights, reduced drill wear and higher quality holes when compared to 170°C Tg systems.

Figure 2 illustrates an example of a high layer count (28 layers), high aspect ratio PTH utilizing the low CTE epoxy system. Notice the excellent hole wall adhesion and uniformity immediately adjacent to the copper plating of the hole wall. There are no interconnect defects or anomalies in this difficult design, even after a 2X 10 seconds solder dip at 288°C. Also, notice that there is no pad lifting after the solder shock test.

Reliability Testing

In order to confirm that the low CTE epoxy system performs at least as well as the higher

Table 1. N4000-7 Material Evaluation.1

Test	N4000-2	N4000-6	N4000-7
Tg (DSC)	140°C	180°C	155°C
Tg (TMA)	130°C	170°C.	150°C.
Tg (DMA)	—	—	160∞C.
X axis CTE (-40 to +125°C)	14.7ppm/°C.	15.5ppm/°C.	15.5ppm/°C
Y axis CTE (-40 to +125°C.)	12.8ppm/°C.	12.0ppm/°C.	12.5ppm/°C
Z axis CTE (below Tg)[2]	70ppm/°C.	70ppm/°C.	60ppm/°C.
Z axis CTE (above Tg)[2]	340ppm/°C.	340ppm/°C.	290ppm/°C.
Z axis expansion (50 to 260°C.)[2]	5.0%	3.9%	3.8%
Z axis expansion (50 to 288°C.)[2]	5.9%	4.9%	4.6%
Moisture Resistance (24 hr. immersion @ R.T.)	0.08%	0.14%	0.07%
DMF Resistance	0.30%	0.02%	0.05%
MeCl Resistance	0.90%	0.26%	0.31%
T260	16 min.	6 min.	16 min.
T288	52 sec.	19 sec.	80 sec.
Solder Float (4”x4” Cu Clad) (288°C. - time to failure)	120 sec.	120 sec.	263 sec.
Pressure Cooker (1 hr, 1 atm) Moisture gain	0.30%	0.31%	0.23%
Solder dip (288°C.)	160 sec.	100 sec.	240 sec.
Solder Float (288°C.)	>5 min.	>5 min.	>5 min.
Degradation Temperature (TGA - 5% weight loss)	302°C.	293°C.	317°C.
Volume Resistivity (96/35/90) MegΩcm	$1.3x10^{7}$	$2.5x10^{7}$	$3.9x10^{8}$
Volume Resistivity (24/125) MegΩcm	$5.2x10^{7}$	$3.6x10^{7}$	$2.6x10^{7}$
Surface Resistivity (96/35/90) MegΩ	$2.30x10^{8}$	$1.00x10^{9}$	$1.2x10^{8}$
Surface Resistivity (24/125) MegΩ	$1.00x10^{7}$	$2.30x10^{7}$	$8.4x10^{6}$
Dielectric Breakdown	>50KV	>50KV	>50KV
Electric Strength	1250V/mil $4.9x10^{4}$ V/mm	1300V/mil $5.1x10^{4}$ V/mm	1100V/mil $4.3x10^{4}$ V/mm
Arc Resistance	62 sec.	71 sec.	124 sec.
Flexural Strength	81,000 psi	80,000 psi	79,000 psi
Lengthwise	558 N/mm^{2}	552 N/mm^{2}	545 N/mm^{2}
Flexural Strength	58,000 psi	56,000 psi	59,000 psi
Crosswise	400 N/mm^{2}	386 N/mm^{2}	407 N/mm^{2}
Flexural Strength	43,000 psi	63,000 psi	44,000 psi
at elevated temperature	296 N/mm^{2}	434 N/mm^{2}	303 N/mm^{2}
Lengthwise % Retention	53%	79%	56%
Modulus (Mpa) below Tg	15,600	16,000	14,500
Modulus (Mpa) above Tg	2,600	2,700	3,000
Peel Strength (_ oz. foil)	7.4lbs/in 1.3 N/mm	7.4lbs/in 1.3 N/mm	6.8lbs/in 1.2 N/mm
Dielectric Constant (1MHz)[3]	4.44	4.44	4.58
Dissipation Factor (1MHz)[3]	0.021	0.021	0.018
Drill Robustness[4]	350	285	350
Flammability UL94	V0	V0	V0
Poisson’s Ratio	X – 0.14 Y – 0.16	X – 0.14 Y – 0.16	TBD
Young’s Modulus	X – 3.48Msi Y – 4.13Msi	X – 3.68Msi Y – 4.38Msi	TBD
Specific Heat	1.2 J/gK	1.2 J/gK	1.2 J/gK
Thermal Conductivity	0.4 W/mK	0.4 W/mK	0.525W/mK

All values based on actual laboratory test data.

Based on 0.062” core, 8 x 7628 construction, [a] 43% resin content.

Based on laminate with 50% resin content.

Nelco (#PNR-001) test method, 4-layer board, 3 high, 13 mil (#80) drill, infeed rate (in/min) at breakage.

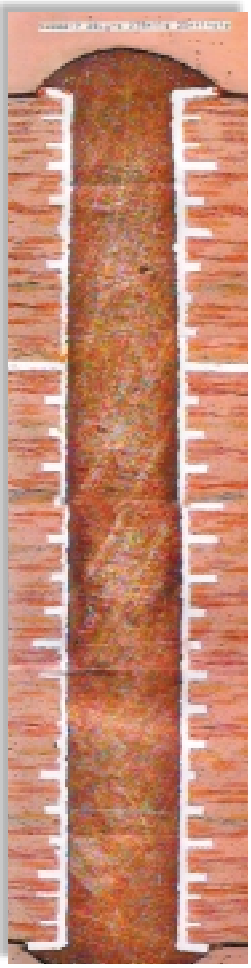


Figure 2. 28-layer router backpanel. 275-mils (7 mm) board thickness and 35-mil (0.89mm) diameter hole. Appearance after 2X 10 seconds solder dip @ 288°C. (also passes 6X 10 seconds solder float @ 288°C). Samples courtesy of Wu's Printed Circuit (Kunshan), China.

Tg systems, two automotive tests were performed that subjected actual multilayer boards to rigorous thermal cycling performance testing.

In the first test, a thermal cycle regimen from -40 to +125°C was performed for 1,000 cycles on a 6 layer daisy chain board. This is a difficult test (especially with small holes, i.e. ≤13 mils) for materials less than 170°C Tg to pass. Usually, lower Tg systems achieve 300–400 cycles out of the required 1,000 cycles, before failure of the PTH occurs. Figure 3 shows a typical photomicrograph of a board exhibiting no defects after 1,000 cycles that was constructed of the low CTE epoxy laminate and prepreg. The criteria for success is less than a 10% resistance change throughout the thermal cycling, and no copper cracking of the PTH. Figure 4 is a graph of the thermal expansion characteristics that provides a base for success in this test. Notice in Figure 4 that the slope of the CTE is lower than the slope of the standard technologies. This lower slope allows for less impactive stresses during thermal excursions.

In the second test, another automotive test requirement was performed where an actual multilayer board was subjected to high humidity conditions followed by an aggressive thermal excursion. The actual conditions are to prebake the samples @ 120°C for 8 hours, and then place the samples in a humidity chamber for 72 hours @ 40°C and 92% RH. After the humidity exposure, the sample is thermal shocked within 1 hour of removal from humidity chamber for 20 seconds @ 288°C by solder float. After this brutal test, the samples are examined for resin recession, which must be less than 15%.

High Tg epoxies cannot easily pass this test. However, the low CTE epoxy was able to pass this test with only 11% resin recession, which confirmed the robustness of this technology. Examples of the results of this automotive test are provided in Figure 5.

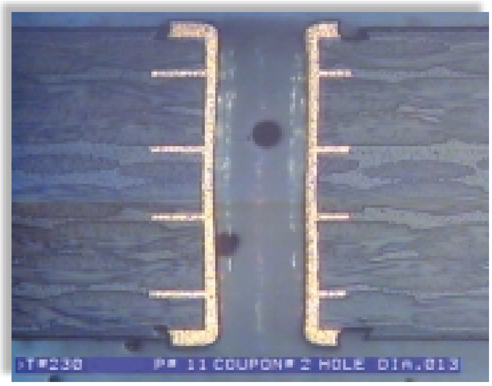
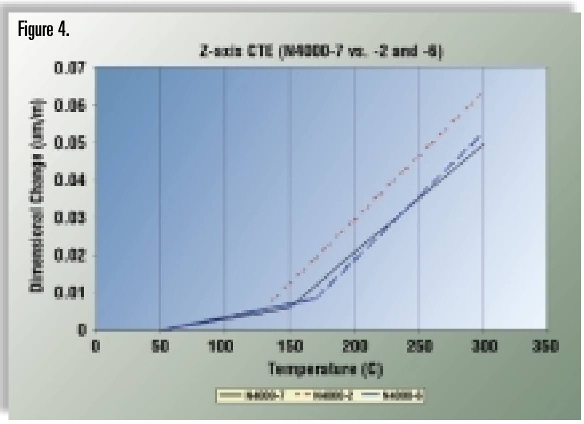


Figure 3. Automotive Q1000 Testing (-40 to +125°C). Typical 13-mil diameter PTH after 1,000 cycles.

Figure 4.



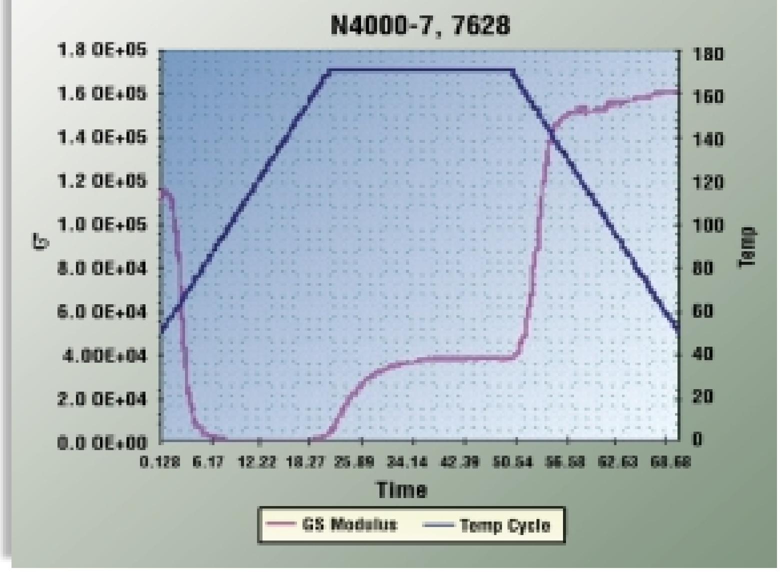
Dustless and Fast Curing

An additional benefit of the low CTE epoxy for the end user is the fact that this technology has a very low dusting prepreg. Prepreg dust can contribute to lower yields during the outer layer circuit formation steps and is a real benefit to maintaining a very clean work environment.

The low CTE epoxy system has a very fast cure cycle. Figure 6 illustrates this fast cure cycle performance. The advantage of faster curing is less queue time and faster cycle times for completion of the multilayer build. Also, issues related to undercure are less likely to occur with a quicker curing resin system. Using a heat rise of 6°C/min. (10.8°F/min.), and a product temperature of 171°C (340°F), a press cycle (close to open) of 50 minutes is achievable.

Figure 5. European (K8) Automotive Specification ≤15% Resin recession requirement. A: N4000-6/+ 30% recession (fail), B: N4000-7/11% recession (pass).

Figure 6. Quick Cure and Low CTE Epoxy.



Heat Rise 6 *C/mm	Tg (Hot Start) -2 Prepreg (>136°C)				-7 Prepreg (>150°C)			
	Center		Edge		Center		Edge	
Cure Time	1st scan	2nd scan	1st scan	2nd scan	1st scan	2nd scan	1st scan	2nd scan
0 min.	140.89	141.14	133.27	138.65	143.46	158.13	140.00	155.96
5 min.	139.81	138.85	140.96	141.73	153.08	159.33	141.54	155.72
10 min.	141.73	141.15	137.12	138.08	150.90	155.19	148.51	156.68
15 min.	140.77	141.54	137.31	137.50	159.33	159.09	155.00	158.13
30 min.	136.15	137.44	136.09	138.08	157.40	156.20	151.15	151.32

Buried Via and Low CTE Epoxy

Another advantage of the low CTE epoxy is its excellent compatibility with buried via constructions. Since the low CTE epoxy is very tough and has excellent adhesion and low shrinkage characteristics, it is superior in "plated cap" constructions. Figure 7 illustrates the difference between a standard epoxy and the low CTE epoxy on adhesion and shrinkage of the filled resin with the external plated copper.

Wide Process Window

Table 2 and Figure 8 provide some typical processing parameters of the low CTE material and illustrate the standard printed circuit processing window that is possible.

Conclusion

As we rethink the reasons for higher Tg's in multilayer printed circuits, it is important to note that a good balance of thermal and mechanical properties and a wide process window are possible by lowering the Tg slightly and enhancing the resin with low CTE technology. In this manner, it is possible to manufacture multilayers that are extremely reliable and cost effective in high volumes.

Low CTE epoxies are being utilized extensively in a variety of programs and offer a good solid solution that is outside the box in concept and application. As our industry becomes less Tg oriented and more performance based, the use of low CTE epoxies is likely to grow significantly. ◆

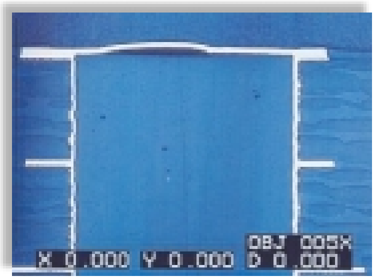


Figure 7A. Plated cap with resin filling 60 mils (1.5mm) diameter PTH. N4000-7 Acceptable. N4000-7 after 6x 20 seconds solder float at 288°C.

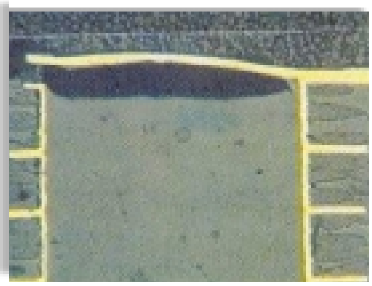


Figure 7B. Standard Tg FR4 Fails. Standard FR4 after 6x 10 seconds solder float @ 288°C. Photographs courtesy of Viasystems, South Tyneside

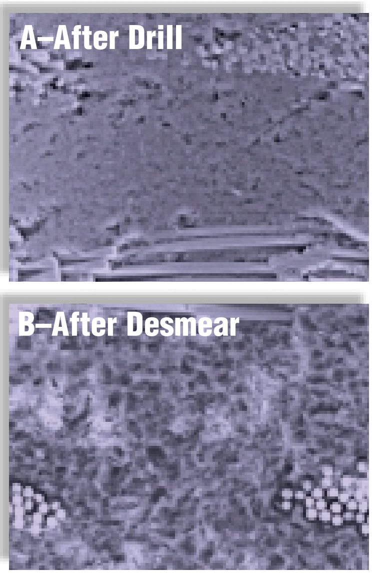


Figure 8A and 8B. Desmear Parameters.

Solvent: Butyl/Hydroxide
70° to 80°C. (158°F to 176°F)
5 to 7 minutes.

Oxidizer: Alkaline/Permanganate
75° to 85°C. (167°F to 185°F)
8 to 10 minutes.

Table 2. Drilling Parameters.
The following drill parameters have been used successfully for an 18-layer, 220-mil (5.6 mm) thick backpanel with all 1 oz. (35m) internal copper.

Drill Diameter	Spindle Speed	Infeed Rate	Retract Rate	Chip Load
0.033" (0.85 mm)	45,700 rpm	103 ipm, 2616 mm/min	1000 ipm, 25400 mm/min	2.25 mils, 0.057 mm
0.045" (1.15 mm)	33,700 rpm	84 ipm, 2134 mm/min	1000 ipm, 25400 mm/min	2.49 mils, 0.063 mm
0.063" (1.6 mm)	39,000 rpm	114 ipm, 2896 mm/min	1000 ipm, 25400 mm/min	2.92 mils, 0.074 mm
0.118" (3.0 mm)	20,000 rpm	42 ipm, 1067 mm/min	1000 ipm, 25400 mm/min	2.10 mils, 0.053 mm

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