A New Cyclic TMA Test Protocol for Evaluation of Electronic and Dielectric Materials

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ABSTRACT

A Thermomechanical Analysis (TMA) test protocol is described that provides practical data for the comparison of different dielectric materials and their effects on performance based upon industry standard tests. The method is a combination of standard thermal test protocols, developed by PWB to determine the glass transition temperature (Tg), the thermal coefficient of thermal expansion (CTE), thermal stress cycles and time-to-delamination for their products, after an assembly and rework simulation.

INTRODUCTION

A series of standard test methods have been developed by the Institute for Interconnecting and Packaging Electronic Circuits (IPC) for the characterization of electronic packages and connectors. Some of these test methods are based upon thermomechanical analysis. PWB has combined a series of these tests, in a logical fashion, to obtain a large amount of relevant data from a single, linked experiment.

Their protocol has three distinct test zones and employs various thermal cycles, temperature program rates, and hold times. In Zone 1, the test emulates the thermal profile of IPC TM650 – 2.4.24.5 (Glass Transition Temperature and Thermal Expansion of Materials Used in High Density Interconnection (HDI) and Microvias), to obtain the glass transition temperature (Tg) and the out-of-plane (z-axis) coefficient of thermal expansion (1). In Zone 2 the thermal excursion associated with the high temperatures of lead-free assembly and rework is performed. In Zone 3, the time-to-delamination test profile is similar to the T260 protocol (2) established in IPC 2.4.24.1 Time to Delamination (TMA Method), but with a faster heating rate of 100 °C/min. Each of these test methods has its own series of experimental conditions that are interlinked to form a single TMA experimental protocol. The three zones are illustrated in Figure 1.

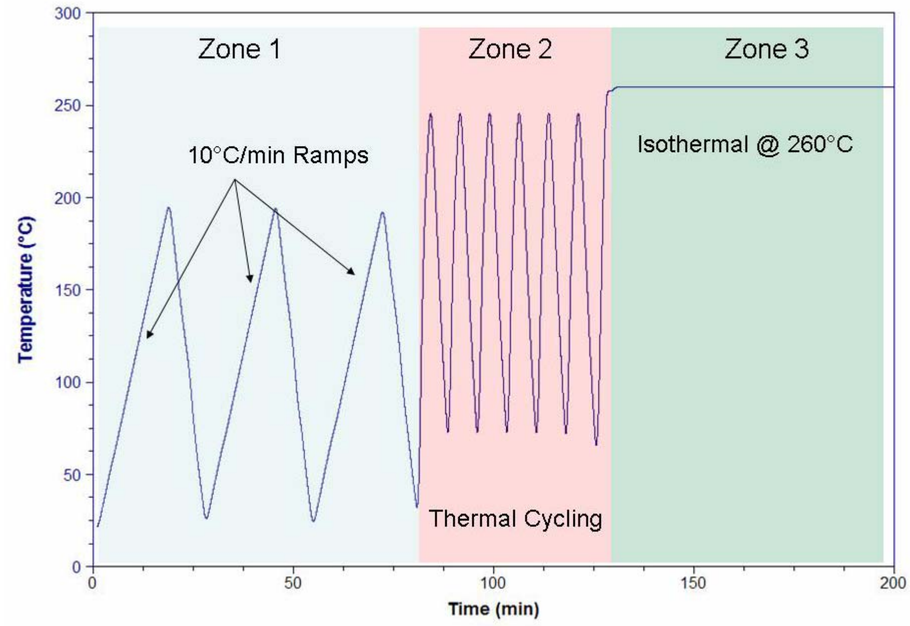

Figure 1: Illustration of Thermal Profile for Cyclic TMA Test

EXPERIMENTAL and DISCUSSION

Sample Preparation

Although clad and unclad "c" stage dielectric may be used; this test is typically preformed on samples of fabricated printed wire boards (PWB) with the copper ground planes extending throughout the sample. The sample is prepared in a manner to preserve the integrity of the dielectric material. It is cut to approximately 6mm by 6mm then placed on the TMA stage and oriented to measure z-axis expansion (out of plane with internal glass fibers) of the board.

Zone 1

This initial section has several functions, the primary objectives being to de-stress the sample and remove thermal history before the first glass transition (Tg) and coefficient of thermal expansion (CTE) measurement. The sample is cycled three times from ambient to 200 °C at a heating rate of 10 °C/min., and a cooling rate of 20 °C/min. A surface micro expansion probe is used with the pressure set to .05 N. The shape of the thermal expansion over time is noted for cycle 1. The CTE and Tg are measured on the second and third cycles.

In TMA, the Tg is detected as a change in the slope of the dimension change signal. The extrapolated onset temperature of this change is measured as the Tg. The CTE is measured as the slope of the data before and after Tg in each case. Delta T is determined as changes in Tg between cycles 2 and 3. Representative data from this zone are included in Figure 2. The CTE of the sample is a reflection of the strain that the board experiences in the end-use environment, and is a combination of the various components including copper, glass, and epoxy. With higher copper layer counts, the CTE should be reduced, while with high resin constructions it is increased. The Tg of the material is independent of the construction of the PWB. A delta Tg that is negative may reflect material that is degrading during thermal cycling, while a positive delta Tg may suggest the material is curing during thermal cycling. A delta Tg greater than +/- 5°C is considered significant.

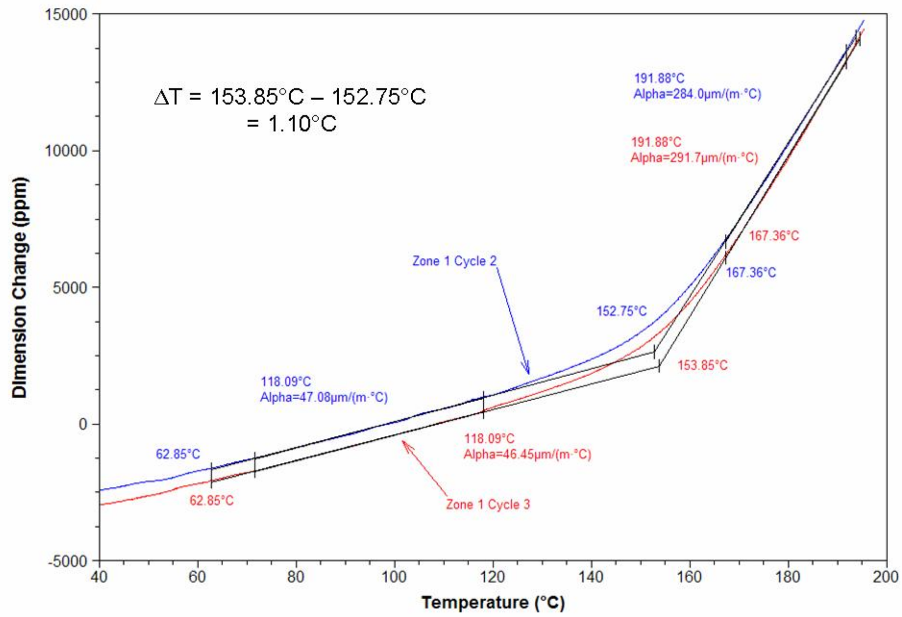

Figure 2: Calculation of CTE, Tg, and Delta Tg from Zone 1 Data

Zone 2

This zone functions as a "mechanical" evaluation as the materials are stressed to traditional or lead-free assembly / rework temperatures. It is expected that coupons that have poor physical adhesion between layers of dielectric or between the dielectric and copper might fail during this portion of the test. Outgassing, due to volatiles or entrapped water, should be complete by the end of this zone. Six thermal cycles emulate the non-linear ramp rates that are used in assembly to the elevated temperature of 260 °C. The thermal excursions of Zones 1 and 2 may have an effect of ageing or, in some cases, curing of the epoxy system, depending on how the materials were stored and how the fabricator processes the PWB. The six steps in the thermal profile in this zone are delineated in Table 1, and the programmed thermal method is given below.

Table 1: Overview of Cyclic TMA Protocol

Zone	Pre	Zone 1		Zone 2						Zone 3		
Cycles	1	3		6						1		
Ramp Rate	10	10	20	181	98	73	49	38	100	100	5	20
Temperature	22	200	22	100	160	200	230	260	22	255	260	22
Isothermal Time (min)	1	0	1	0	0	0	0	0	2	0	90	End

`TMA Thermal Method (TA Advantage Software)`

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1: Force 0.05 N
2: Data storage Off
3: Equilibrate at 22.00 °C
4: Isothermal for 1.00 min
5: Data storage On
6: Ramp 10.00 °C/min to 200.00 °C
7: Mark end of cycle
8: Ramp 20.00 °C/min to 22.00 °C
9: Mark end of cycle
10: Repeat segment 6 for 2 times
11: Ramp 181.00 °C/min to 100.00 °C
12: Ramp 98.00 °C/min to 160.00 °C
13: Ramp 73.00 °C/min to 200.00 °C
14: Ramp 49.00 °C/min to 230.00 °C
15: Ramp 38.00 °C/min to 260.00 °C
16: Mark end of cycle
17: Ramp 100.00 °C/min to 22.00 °C
18: Mark end of cycle
19: Isothermal for 2.00 min
20: Repeat segment 11 for 5 times
21: Ramp 100.00 °C/min to 255.00 °C
22: Ramp 5.00 °C/min to 260.00 °C
23: Isothermal for 90.00 min
24: Mark end of cycle
25: Data storage Off
26: Ramp 20.00 °C/min to 22.00 °C
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Zone 2 is the assembly and rework simulation. As there are many different thermal profiles used in assembly the profile given is an exact replication of the thermal profile achieved when coupons are preconditioned using the methods described in IPC standard TM 650 (IPC 2.6.26 Current Induced Thermal Cycle Test), with the exception of achieving 260 °C instead of 150 °C. Using this thermal excursion profile assures that this protocol is directly related to reliability testing results. Failure in this zone has been attributed to a mechanical failure similar to adhesive delamination. Trapped volatiles, outgassing, or poor adhesion between laminated layers, (copper or dielectric), may result in delamination in this zone.

Zone 3

The test profile in Zone 3 is analogous to the existing T260 test specified in IPC TM 650 2.4.24, Time to Delamination (TMA Method) standard test, with the ramp rate of 100 °C/minute and a maximum hold time of 90 minutes. Held at 260 °C, the epoxy component of the PWB tends to darken and may carbonize, if left for an extended period. It is believed that chemical decomposition is the dominant failure mode in this zone and that delamination at these temperatures is due to chemical rather than mechanical degradation. The rapid heating rate (100 °C/min) assures that the sample is not degrading during the thermal ramp to 260 °C. Because the sample size is small and copper is usually present, thermal gradients are minimized. (T260 times to delamination at the slower temperature ramp of 20 °C/minute have been noted to be shorter than T260 time to delamination obtained from the faster ramp rate of 100 °C/minute.)

Figure 3 contains a comparison of the Zone 3 data for two different samples. The dimensional change of Sample A is stable during the 260 °C isothermal duration, indicating both chemical and physical stability. However, delamination of Sample B is evidenced from the rapid expansion commencing at about 27 min.

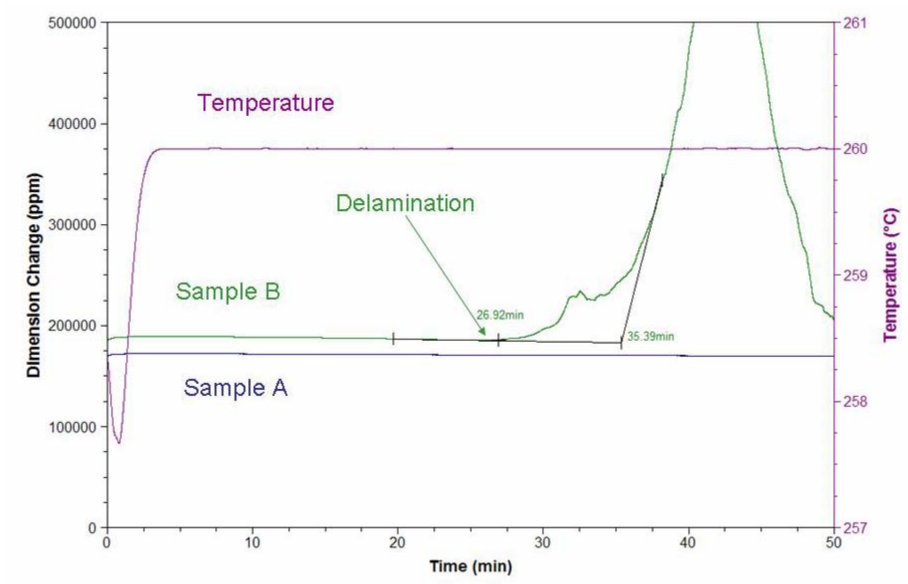

Figure 3: A Comparison of the Thermal Stability of Two Samples During Zone 3

No standards have been established as to how long a material should resist delamination after achieving the isotherm in Zone 3. It has been noted that a material, which fails before 10 minutes at 260 °C tends to perform poorly when subjected to reliability testing (IPC 2.6.26 Current Induced Thermal Cycle Test). It should further be noted that the reliability failure mode may be delamination, but early onset barrel cracks also appear in the plated-through-holes (PTHs). Failures in this zone frequently appear to relate to material degradation of the epoxy system, and appear to be less of a mechanical-based failure. Material ageing is evident, cross links are breaking in the epoxy, and cohesive delamination is observed. This delamination is not limited to the interfaces between laminated layers. Cracks may traverse the “C” and “B” stage boundaries.

CONCLUSION

In summary, the cyclic TMA test is an effective measure of the thermal stresses, (both physical and chemical), which the dielectric material undergoes during processing. It not only complements the industry standard tests and methods, but also provides additional information not obtainable by alternative protocols.

REFERENCES

1. TM-650.2.4.24.5 “Glass Transition Temperature and Thermal Expansion of Materials Used in High Density Interconnection and Microvias – TMA Method”, Institute for Interconnecting and Packaging Electronic Circuits, North Brook, IL.

2. TM-650.2.4.24.1 “Time to Delamination (TMA Method)”, Institute for Interconnecting and Packaging Electronic Circuits, North Brook, IL.

3. TM-650.2.6.26 "Current Induced Thermal Cycle Test", Institute for Interconnecting and Packaging Electronic Circuits, North Brook, IL.

KEY WORDS

TMA, Electronic materials, Dielectric materials, Tg, CTE, Stress, Delamination

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