Improved Reliability of Embedded Passives for Lead-Free Assembly

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Abstract
Embedded passive components are resistors, capacitors and inductors buried within a multilayer PCB. Embedded components pass standard reliability test methods, however, the higher temperatures required for lead-free solders increase the physical stress in the board. Component failures, although rare, are typically caused by high z-axis expansion, lifted pads or innerlayer delamination that cracks and/or opens the embedded component.

High performance laminates designed for lead-free assembly offer a higher Tg and decomposition temperature and a lower CTE but bond strengths are lower than a corresponding FR-4 substrate. Metallic embedded components can withstand higher temperatures than organic substrates, however when the PCB is tested to failure by multiple solder shocks, the embedded component layer fails preferentially due to the lower bond strength.

A Design of Experiments for a PCB with embedded passives and lead-free assembled SMTs showed that laminates with light weight glass and high resin content giving the best results (no delamination after multiple thermal excursions). The conclusion is that embedded passives in multilayer PCBs built with high performance laminates using improved copper topographies, high resin content and light weight glass constructions are reliable for lead-free assembly.

Introduction
PCBs with embedded components that pass physical and electrical testing at the bare board level generally perform well after assembly, however failures have been known to occur after assembly that are detected at in-circuit testing. Embedded resistors become an integral part of the multilayer PCB and any separation of an adjacent layer to an embedded resistive layer may crack the resistive element and open the resistor. The cause and corrective action of the delamination may be unrelated to the embedded component (e.g. moisture entrapment or dry cloth), however such failures may be manifest over the embedded component because of lower bond strengths or resin deficiency. Peel testing of opposite sides of the same epoxy core, one side with an embedded layer and one side standard copper foil, show a 0.2 to 0.3 Kg/cm drop in bond strength. Both sides meet minimum specifications but the weaker side fails first.

High profile copper foils improve bond strength but are not be acceptable due to high voltage dielectric breakdown and high frequency conductor losses. Low profile coppers with improved topographies (added treatment to increase surface area) offer higher bonds and equivalent peel test results over an embedded resistive layer.

An embedded component failure after assembly is confirmed by horizontal cross-sectioning and backlighting. Cracking of the resistive element at the copper termination would be the worse case scenario but subsurface phenomena such as measling, crazing or other weave disruptions that might go undetected in a standard PCB, may raise the ohmic value of an otherwise undamaged resistor. It's been well established that heavy weight glass such as 7628 should not be laid against thin-film metallic resistive layers because of the low resin content and because the large glass knuckles damage the layer in a manner similar to measling and crazing and other aforementioned subsurface phenomena.

To assure reliability, thermal stress testing of resistive-conductive materials are performed at T260 with a maximum allowed change in resistivity of 0.5% or 1.0% after multiple thermal excursions depending on the specific laminate being tested.

To improve the reliability of embedded components in laminates for lead-free applications, experiments were conducted to determine the optimum construction of a thin core embedded resistive substrate in a multilayer PCB.

Methodology
Thermal stress testing is used to test the physical integrity of standard PCBs. For PCBs with embedded components, both vertical and horizontal sections are required to detect delamination and evaluate the separation of the pre-preg or core material from the resistor element. To optimize the reliability PCBs with embedded resistors DOEs were performed for both standard and "lead-free" laminates, meaning standard glass reinforced laminates with modified epoxy resins for lead-free assembly applications. PCBs were built using alternative glass constructions that yielded the same dielectric thickness and were then thermal stress tested by increasing numbers of thermal excursions.

Standardized testing was per IPC-TM-650, using the following methods:

Peel test method 2.4.8, condition A, as received (no solder float), and,
Thermal Stress test method 2.4.13.1, T288°C for 10 seconds, after preconditioning.

Design of Experiments

The primary question was the choice of materials. Does lead-free laminate impact embedded component reliability? Secondary questions concern the laminate construction; are differences in the lighter weight glass styles significant? With asymmetrical constructions, does it matter which ply is laid against the embedded resistor?

To answer these questions, tests were performed on a sequentially built PCB with five mil cores and two-ply constructions using epoxy laminate cores and pre-pregs. One material type was a "standard" 170Tg high performance multifunctional epoxy and the other type was a "lead-free" 190Tg modified epoxy laminate for lead-free assembly.

All of the PCBs were made with twenty-five ohm/square OhmegaPly® laminates using one-ounce low-profile ED copper foils with an enhanced treatment (higher surface areas) for improved bond strength. Peel testing was done for each laminate construction of both material types. There was no significant difference in bond strength between alternative glass weights but there was a big difference between standard and lead-free laminate test results. The peel test results shown below are for the two-ply 1080 construction:

Standard Tg 170 laminate core:

Laminate side:	1.6 Kg/cm
Non-laminate side:	1.5 Kg/cm

Lead-free Tg 190 laminate core:

Laminate side:	0.8 Kg/cm
Non-laminate side:	0.9 Kg/cm

A Design of Experiments was conducted by a board fabricator skilled in the manufacture and testing of multilayer PCBs with embedded resistors. Two $\mathbf{L_9 2^3}$ full factorial DOEs of nine experiments each was conducted for each material type, standard and lead-free with the two factors being glass style and number of thermal excursions.

The three levels were:

- Construction: 1080/1080, 2113/106R and 106/2113R (R=against the resistor)
- Thermal stress: zero, three and six thermal cycles (T288).
- Response: the number of measle-sized "spots" on the 2 x 2 inch test specimen.

Findings

There was no gross delamination in any sample and little significant difference between alternative constructions in either of the two DOEs, however the standard epoxy was slightly better than the lead-free material and there was some correlation between the glass weight (size of the bundles and resin percentage) of the pre-preg against the resistive layer and the amount of delamination after three and six thermal excursions:

Best result:	106R	smaller bundles – higher resin percentage
Second best:	1080	medium bundles
Third place:	2113R	larger bundles – lower resin percentage

Conclusion

The "lead-free" laminates may have other desirable properties but they don't seem to make a difference to the physical integrity of the multilayer PCB or the reliability of the embedded components under thermal stress testing. The advantage of the standard multifunctional epoxy laminates may higher bond strengths but that has yet to be proved. What is clear is that embedded resistors in PCBs built with high performance epoxy laminates using enhanced copper topographies, high resin content and light weight glass constructions are reliable for lead-free assembly applications.

Acknowledgement

The author would like to thank Jeffrey Wallace of DDI-Virginia for his work on this project and his assistance in preparing this paper.