Microvia Reliability
Concerns in the Lead Free Assembly Environment

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Abstract
Traditionally microvias have been considered to be the most reliable interconnect structure within a printed wiring board (PWB). With the advent of lead free assembly the vulnerability of high density interconnects to fail has increased, due to the elevated temperatures experienced during surface mount assembly and rework. Throughout the past 18 months microvias have been found to fail during assembly and in their end use environment. This paper outlines a case study of microvia failure; reliability test methods, failure analysis, fabrication process considerations, and assembly process considerations for tin/lead and lead free application and problem resolution of microvia reliability issues.

Background
Curtiss-Wright experienced open and intermittent opens during electrical testing of their printed circuit board (PCB) assemblies, they occurred in specific lots in early 2003. Processing include high-end assemblies with double sided surface mount components in addition rework procedures were tightly controlled. The opens demonstrated sensitivity to thermal change and mechanical stress. Specifically, opens would become conductive under thermal or mechanical stress on the assembled board. Using infrared thermal imaging techniques the defective interconnections were located, subsequent microscopic evaluation demonstrated random failures associated with microvias. The first microvias reviewed demonstrated a target pad to copper plating separation, at the bottom of the microvia. Ongoing investigations showed that a small percentage of microvias exhibited barrel cracks, and, on occasion, knee/corner cracks.

Test Method
The reliability test method used throughout this study was Interconnect Stress Testing (IST), as per IPC TM650 – 2.6.26, DC Current Induced Thermal Cycling Test). The associated coupons were preconditioned by exposing them to five thermal excursions to 2300 C, in exactly three minutes. This method of preconditioning was established as the standard for Curtiss-Wright based on significant volume of data points used in previous testing. This preconditioning method is meant to emulate, but not replicate, three assembly cycles and two rework cycles. IST thermal cycling to 1500 C was completed on the suspect lot of microvia coupons, the results surpassed the customer's acceptance criteria of a lot mean of 150 cycles, and a minimum of 100 cycles to failure. The suspect lot had achieved a mean of 750 cycles with a max of 1000 cycles (end of test).

In addition to IST evaluation microsections were used to determine the cause of failure. The microsection methods used were in accordance to IPC –650 2.1.1 Microsectioning Manual Method. Microscopic evaluations of microvia were preformed after a mild microetch.

Microvia Study - Goals
A multi-disciplined study was undertaken to understand the various types and mechanisms of microvia failures. The joint effort was established to resolve these microvia reliability concerns. Certain factors that contributed to this investigation, included improvements to metallurgical methods (metrology), necessary to identify and evaluate microvias. Analysis of various process parameters required to eliminate the underlying cause of these failures. Develop modifications to the test methodology to quickly and accurately determining the reliability of microvias and the establishment of criteria for product acceptance or rejection. This study was undertaken knowing that the stress of thermal excursions in a lead free environment would be significantly higher and therefore reliability testing needed to account for, and reflect the stresses associated with the anticipated elevated thermal excursions.

Curtiss-Wright Concerns and Considerations

Assembly was conducted at their in their Kanata and United Kingdom facilities. A high degree of assembly and rework discipline had been established assure PCBs were subjected to controlled temperature rise during assembly and rework. It was determined that the suspect lots were not exposed to excessive thermal excursion in assembly or rework.

Failure Analysis of Microvias

The established method for evaluating microvia by microsection requires the evaluation of the microvia to target pad interface to be examined without the use of a microetch. It was determined that this methodology was inadequate, due to poor definition between the various copper surfaces. Known failed microvias would have passed visual examination when a non-microetched microvia was assessed. In Figures 1 and 2 below a nom-failed microvia was photographed before and after a mild micro-etch. The figure demonstrate that the layer one foil, electroless copper, interface between the bottom of the microvia and the capture pad and the plating on the top of the capture pad are not visible with a mild micro-etch. It was demonstrated that a well-controlled microetch using hydrogen peroxide and ammonium hydroxide greatly enhanced the physical detains of the failing interconnect and improved the ability to objectively evaluate failures and causative mechanisms. The microvias evaluated in this study employed the use of a mild microetch.

The failing coupon have circuits that are still electrically conductive and therefore the process of identifying microvia that is contributing the highest resistance in a circuit may be achieved using thermal imaging cameras. Failure locations can be single or multiple interconnections that individually or collectively contribute to the10% increase in resistance. Thermo-graphic imaging of the failed coupon allows the operator to find the worst microvias. Since the failed coupon has experienced only a 10% increase in resistance, a DC current can be applied to the test circuit permitting the interconnection to heat. Because the compromised microvia has a higher resistance compared to other (robust) microvias, a thermal camera allows direct visualization of the exact location of the offending microvia(s). Using a low current, the coupon is heated while being observed under the thermal imaging camera; the failing microvia is seen as a higher temperature (hot spot). This is a powerful tool for finding failure locations for subsequent microsection analysis.

IST equipment has the inherent ability to stop testing an individual coupon automatically when it achieves a 10% increase in resistance, in any test circuit. This assures that the failing circuit is stopped before the coupon has achieved a catastrophic failure. Figure 3 is of an obviously failing microvia, while Figure 4 is one the subtle failures. Both coupons were stopped at a 10% increase in resistance and then identified, with thermal imaging techniques, as the microvias contributing the highest resistance to the failed circuit.

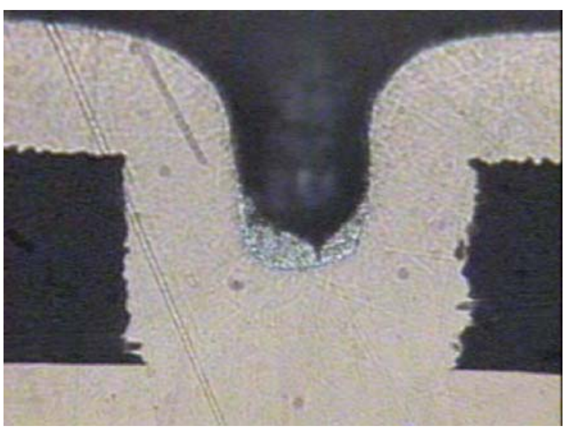

Figure 1 - Un-Etched Microvia

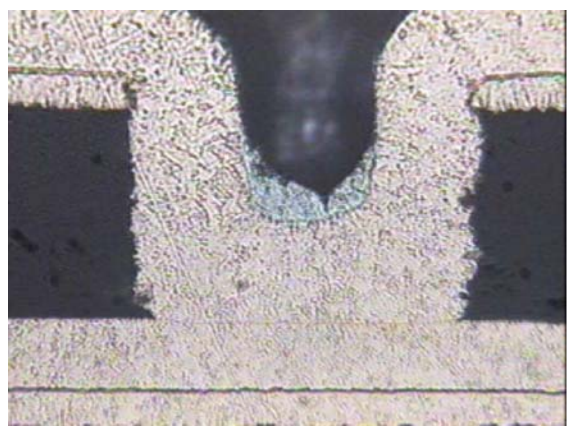

Figure 2 - Etched Microvia

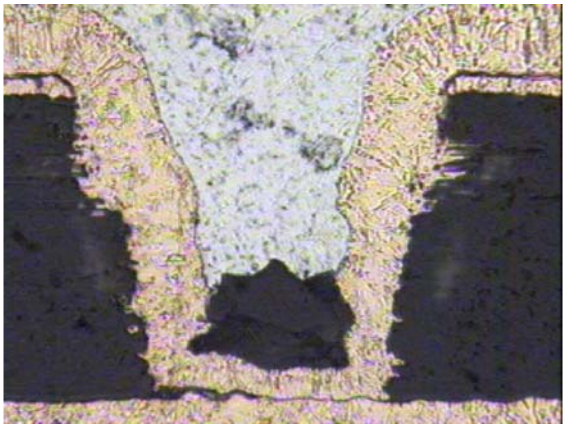

Figure 3 - Microvias Contributing a 10% Increase in Resistance

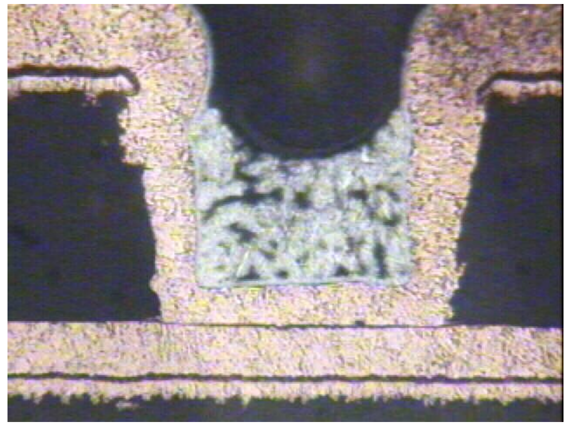

Figure 4 - Microvias Contributing a 10% Increase in Resistance

Failure analysis suggested that there were two distinct failure mechanisms; barrel cracks at the base of the hole wall and/or debris under or within the electroless copper deposit, at the interface with the capture pad. The analysis suggested that the dominant underlying contributor to the microvia failures in this study was an inherent weakness at the interconnection between the base of the microvia and the target pad. The electroless and electrolytic copper thinned from the knee to the bottom of the microvia.

After analysis of a large number of failed microvia some common characteristics came. One of the characteristics of failing microvias due to a capture pad separation is that they usually exhibited inclusions between the electroless copper and the capture pad or the electroless copper and the electrolytic copper. Because we are viewing failing microvias that have not failed completely (fully separated), we have the opportunity to review the failure in progress. The microsection is acting to capture a moment in time of the failure. We were able to review the most electrically degraded microvia and the neighboring microvias that are in various stages of failing. Frequently failing microvias exhibited precursor black dots that tend to become small micro-cracks and the micro-cracks coalesced into large cracks. Commonly the cracks would appear in the center and at one edges of the microvia. Microvia that were advanced in the failing process had the appearance of a crack that started on one side of the base of the microvia and progressed completely across the interface. It is most probable that the crack started as small cracks that coalesced into a large crack rather than a wedge crack intruding from the edge of the microvia. Figures 5 and 6 exhibit the precursor black dot above and below the electroless copper. Figure 7 shows coalescing micro-cracks both above and below the electroless copper.

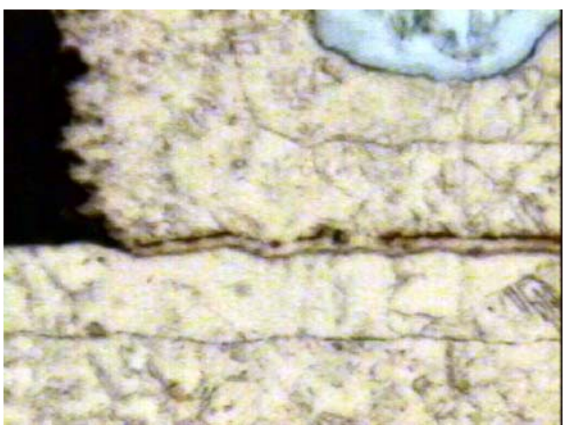

Figure 5 - Precursor “Black Dots” and Coalescing Micro-cracks

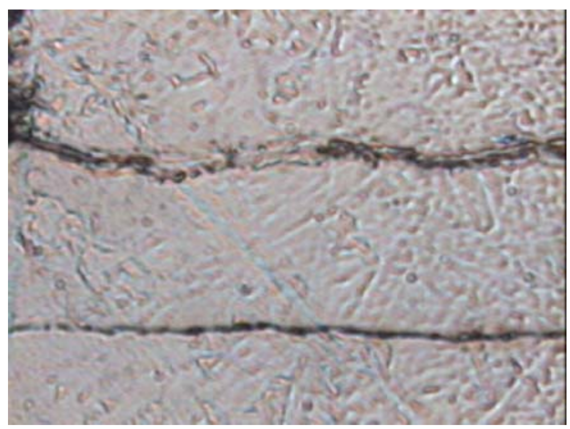

Figure 6 - Precursor “Black Dots” and Coalescing Micro-cracks

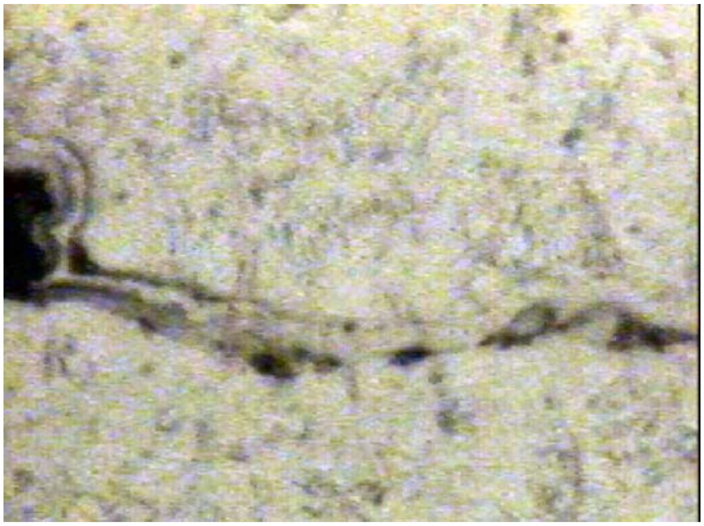

Figure 7 - Precursor - Inclusions that Coalesce into Cracks – Two Cracks Forming

Another common observation is that the electroless and electrolytic copper quickly thins below the knee of the hole. Electroless that measured 120 millionth of an inch on the surface of the pad can be un-measurable at the base of the microvia. The thickness of the electroless and electrolytic coppers was reduced, in some cases dramatically, as the deposit descends into the microvia. The effect of thinning electroless can produce a condition commonly called step plating. Figure 8 demonstrate the reduction in electroless, which is plainly visible on top of the surface foil and only barely discernable at the base of the microvia. Figure 9 is an extreme example of wedge plating on a microvia processed with direct metalization.

Another observation was that the shape of the microvia was also contributing to its robustness of a microvia. A dish shaped microvia appeared to have a more uniform copper distribution to the base, compared to a microvia shaped like a traditional cylinder. Dish shaped microvia were found to achieve higher cycles to failure.

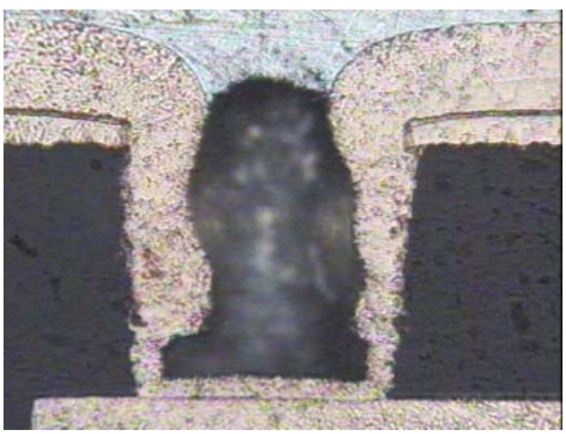

Figure 8 - Thinning of Electrolytic

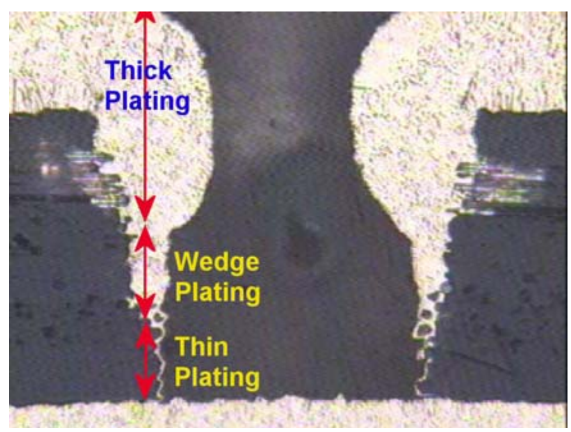

Figure 9 - Electroless Copper Below the Knee of the Hole

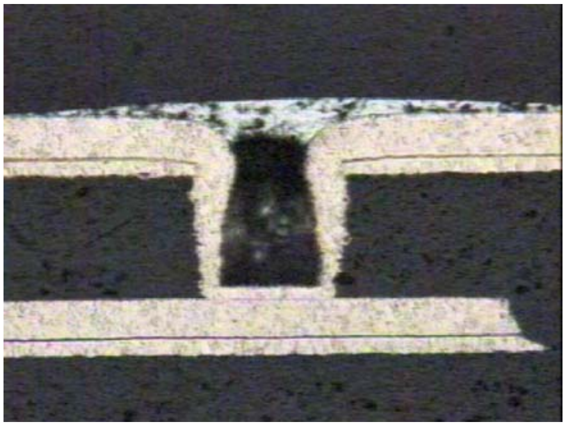

Figure - 10 Cylindrical Microvia

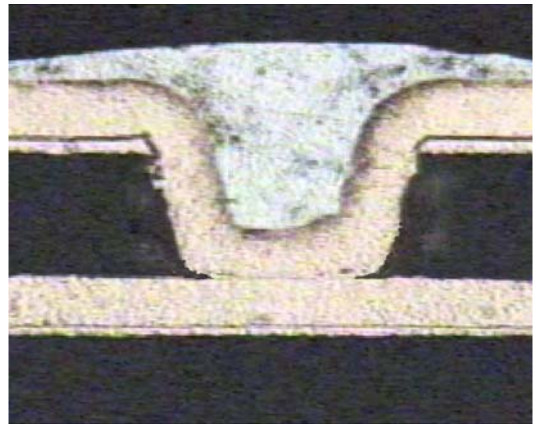

Figure 11 - Dish Shaped Microvia

In conjunction with the microvia failure analysis; Coretec was investigation method of improving microvia reliability.

Coretec Concerns and Considerations

Suggestion - Microvia are commonly produced using a process of laser ablation followed by metalization (electroless copper) and electrolytic copper plating. There are a few physical factors that make microvias a challenge to metalize. The microvia has a relatively low aspect ratio combined with the unique properties of being blind, plus being so small that capillary action (the inherent surface tension of the processing solutions) impedes fluid exchange. Chemical efficiency into the microvia is quickly depleted of active and/or cleaning components during hole preparation and electroless plating. Electroless copper frequently had a minor degree of out-gassing and bubbles can be easily trapped. Sharp (right angle) corners exacerbate these physical hurdles and provides a most challenging process to produce repeatedly reliable interconnect structure.

Armed with failure analysis and the new insight into improved microsectioning techniques, Coretec undertook a complete review of their microvia ablation and plating processes.

IST Test Method of Microvias

The main strain on the microvia is from the Z-axis expansion of the dielectric between the top of the microvia (outer layer) and the capture/target pad. The amount of stress exerted into the interconnecting structure is in proportion to the thickness of the dielectric. It is obvious that the relatively thin dielectric in two layers of a microvia structure (as compared to the dielectric thickness between layers 1 and X in a PTH), is the major contributing factor to why the “microvia is the strongest interconnect”. There in only .002” to >004” of dielectric to exert strain on the microvia. Microvias are the least stressed electrical interconnection in a typical PWB and therefore considered the strongest interconnection structure

An IST study was undertaken to determine the most effective IST testing parameters for determining if a microvia was robust. It was decided that five cycles of preconditioning to 230 °C would be kept as a constant. After preconditioning marginal microvia coupons were tested to temperatures of 1500C, 1700C, 1900C, 2100C and 2200C. Coupons tested at 1500C lasted 1000 (1 sigma limit) cycles (See Table 1).

Table 1 - IST Thermal Cycles to Failure – Preconditioned 5 X 230 °C

	1500 C	1700 C	1900 C	2100 C	2200 C
Mean	1000	789	464	76	44

Based on this data, the IST testing temperature for microvia reliability testing was raised to 1900C (for microvia testing only). The cycles to failure of know marginal coupons were determined to be less than 500 cycles. Testing to 1000 cycles at 1900C, IST is capable of differentiating between good and marginal coupons. Failure analysis of coupons IST tested at 210C or higher revealed failures due to microvia separation but also there were knee cracks, material delamination/breakdown and barrel cracks. Knee cracks; delamination and material breakdown were considered testing artifacts. Even though the tests easily demonstrated that the microvias were not robust the presents of artifacts was considered to be an undesirable condition. At 1900C the coupons appeared to exhibit the same failure mode as seen in PCBs that failed during assembly.

A control test of well made microvias which did not exhibit inclusion, black dots or copper plating concerns where subjected to 1000 IST thermal excursion after 5 X 230C preconditioning. The results were no failures at end of test, 1000 cycles. Robust microvias easily survive 190C testing to 1000 cycles. One of the caveats is that the material used was phenolic-based FR4 capable of lead-free temperatures.

Lead Free Temperature Testing

An extension of this study was to see the effect of Lead-Free assembly on know marginal microvias. In this part of the study a group of coupons that had known marginal microvias were preconditioned six times at 2600C. These were then tested at the conservative temperature of 1500C. The effect on microvias is profound. The most recent data suggests that the coupons that were able to achieve 788 cycles at 1500C were reduced to a mean of 443 after 6 X 2300c and 4 cycles after lead free preconditioning (See Table 2.)

Table 2 - IST Thermal Cycles to Failure – Various Preconditioning

	As Received	6 X 2300 C	6 X 2600 C
Mean	788	443	4
Minimum	375	204	2
Maximum	925	925	5

Another way to look at this data is to consider the robustness of a coupon in the “as received” state as the coupons entitlement. Aggressive thermal cycling may cause the degradation of this entitlement. The coupon tested in this part of the study had an entitlement of 788 cycles, or 100%. After precondition at tin-lead temperature (6X 230c) the entitlement was reduced to 56% and with lead-free assembly emulation the entitlement dropped to 1%. Lead-Free assembly and rework reduced the cycles to failure by 99%.

It appears that RoHS assembly and rework temperatures requirements will be adding enough extra stress that marginal microvias may fail at assembly.

Conclusions

Microvia continue to be the most robust structure in a PWB. There are certain conditions in PWB fabrication that can degrade microvias that include material stack-up, microvia formation and geometry, microvia cleaning and hole wall preparation, metalization, electrolytic plating, surface finish and the use of filled microvias. Failure mode analysis is improved with microsections that have been subjected a mild micro-etch. Microscopic evaluations should in the recognition of certain interface characteristic as precursors to compromised microvias. Effective and accurate reliability testing requires preconditioning at the appropriate tin/lead or lead-free temperatures for the accurate assessment of microvia robustness. Test temperatures of thermal excursion need to be increase to 190C in order to generate strains from Z-axis expansion sufficient to fail marginal microvias. Thermal cyclic testing at elevated temperatures to improves accuracy testing and time to results.