A Case Study of the Reliability of Copper Bond Wires In Plastic Encapsulated Integrated Circuits

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Abstract

Sixteen plastic encapsulated integrated circuits were initially received as part of a root-cause failure investigation, twelve of which contained copper bond wires and the other four containing gold bond wires. It was reported that eight of the integrated circuits had failed in the field with intermittent or complete malfunction of the components. Electrical testing confirmed the reported failure and found temperature sensitive, intermittent open circuits on various pins coinciding with the sample history.

C-Mode scanning acoustic microscopy (CSAM) was performed on the devices, with each sample exhibiting varying degrees of delamination between the lead-frame and the plastic encapsulant. The backside of the package was polished into the underside of the lead-frame to preclude the introduction of any contamination due to chemical decapsulation. This allowed the mechanical removal of the leads from the package and inspection of the stitch bonds. Scanning electron microscope (SEM) inspection revealed that the copper stitch bonds had corroded to some extent (ranging from mild corrosion to complete consumption of the stitch bond) in each of the examined bonds, whereas the gold stitch bonds were unaffected. Overall inspection of the leads identified chlorine contamination along the delaminated interface.

Key words

Copper wire bonds, copper corrosion, decapsulation, CSAM

I. Introduction

Copper wire bonding poses reliability concerns in areas not formerly attributed to failures with gold wire bonded devices. Papers in the past several years have discussed reliability concerns of copper wire bonding, focusing on the copper ball bond-aluminum bond pad interface and the effects of chlorine on the various Cu-Al intermetallics, both of which are significant considerations as the industry continues to progress from gold to copper wire bonding for reductions in cost [1], [2].

Discussions of the copper stitch bond at the post have been less abundant, with the primary topic being the shape and quality of the stitch bond [3].

The following case study examines copper wire bond corrosion at the lead frame, which resulted in the electrical failure of the end product in the field, and discusses the methodology of the failure analysis.

II. Case Study

The initial failure analysis request involved six, dual in-line package (DIP) integrated circuits with reported intermittent operation in the field. The samples consisted of four of one part type and two of another, each manufactured by the same vendor (Vendor A) with recent date codes. Radiographic inspection of the samples found that the wire bonds were copper, but no anomalies were noted.

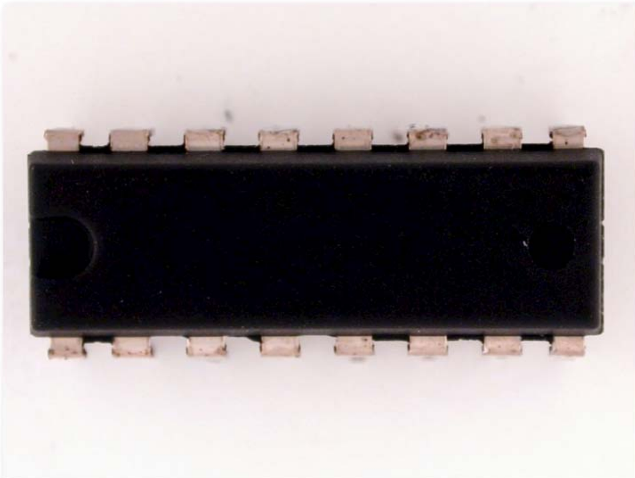

Figure 1. Optical macrograph of a typical sample.

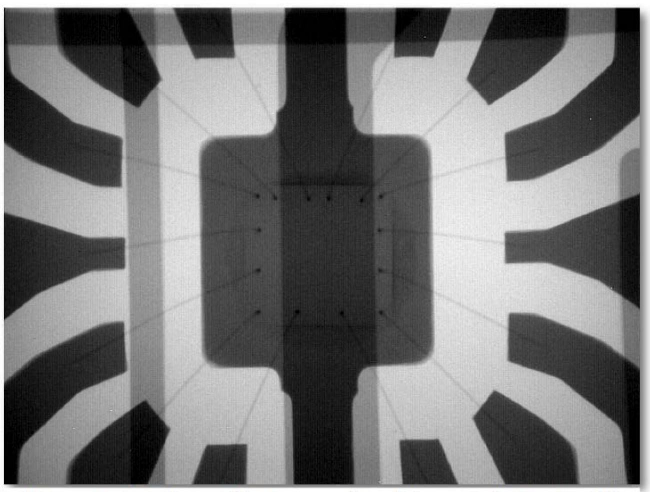

Figure 2. Radiographic image of an integrated circuit with copper wire bonds. Copper bond wires can be identified by their lower density when compared to gold.

Electrical Testing

Electrical testing of the devices revealed that one or more pins were open circuited in each sample. Application of heat during testing caused the open circuits to reconnect. Evaluation of the test data found that various, but random pins were open circuited, negating the possibility of circuit manufacturing defects. Because of the random nature of the open circuits, the most probable failure mechanism was bonding issues.

Decapsulation

The typical decapsulation method for plastic integrated circuits involves chemically dissolving the plastic encapsulant away from the die. With copper wire bonds a 1:1 mixture of HNO_3 and H_2SO_4 is preferred to preserve the integrity of the wires. Decapsulation was performed on one sample using this method and optical inspection of the die bonds revealed no anomalies that would contribute to the observed failure.

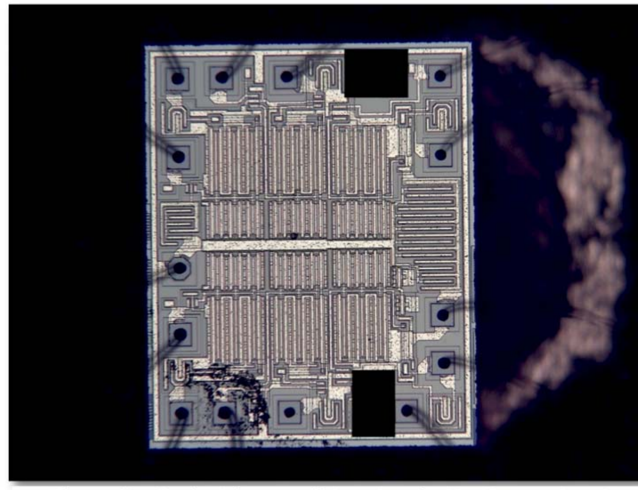

Figure 3. Optical image of the chemically decapsulated sample.

CSAM (C-Mode Scanning Acoustic Microscopy)

CSAM was performed on the five remaining samples to inspect for any delamination that could result in the failure of the devices. Each sample exhibited varying degrees of delamination between the lead frame and the encapsulant, including water ingress into the wire bonded area in each of the components. Figure 4 depicts delamination on pins 1, 3, 4, 5, 6 and 7.

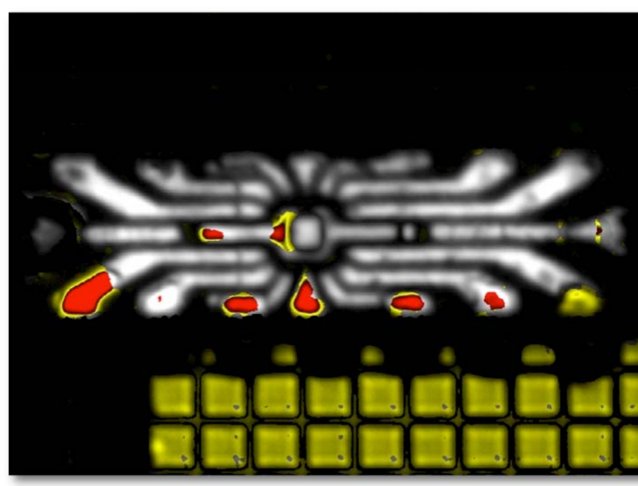

Figure 4. CSAM image of a representative sample. The red areas indicate significant delamination.

Metallographic Cross-Section

Cross-section analysis was then performed on two of the samples into the suspected stitch bonds. Microscopic inspection found that the copper stitch bond had been entirely consumed by corrosion in both samples (figure 5). Inspection of a non-failed wire bond revealed that the bond was intact, but with the onset of corrosion (figure 6).

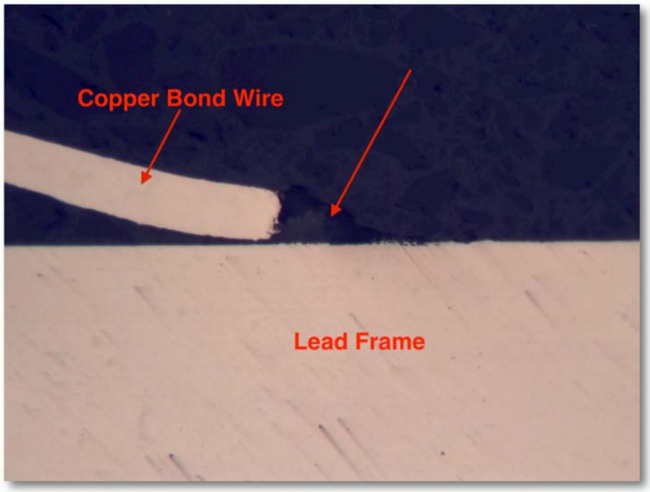

Figure 5. Cross-section image of a failed copper stich bond at the lead frame. The arrow indicates where the bond had corroded.

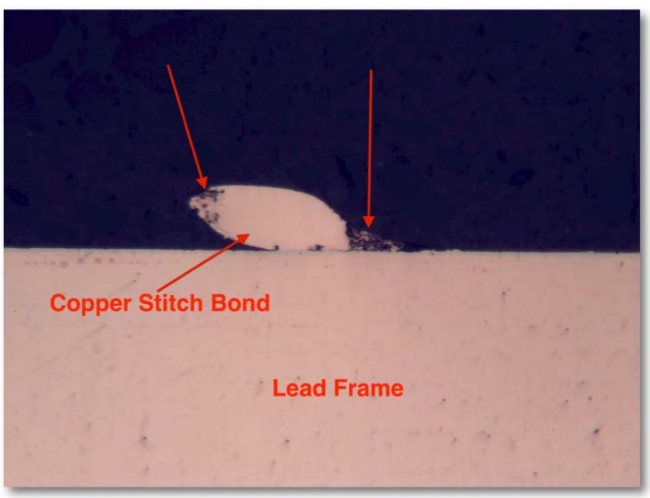

Figure 6. Cross-section image of a non-failed stitch bond. Note the onset of corrosion.

Dissection Method

Due to the aggressive nature of chemical decapsulation and limitations of cross-section analysis, mechanical decapsulation was performed on the remaining samples by dry grinding through the backside of the devices until the underside of the leads were uncovered. This allowed the removal of the leads from the package quickly and efficiently without introducing any contamination to the area of interest.

The following images detail the mechanical decapsulation method utilized during the analysis:

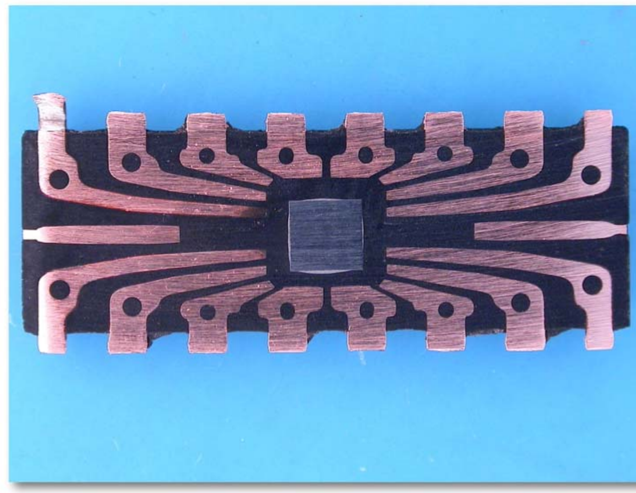

Figure 7. Optical macrograph of a DIP after dry grinding the backside of the encapsulant away, exposing the lead frame and the underside of the die.

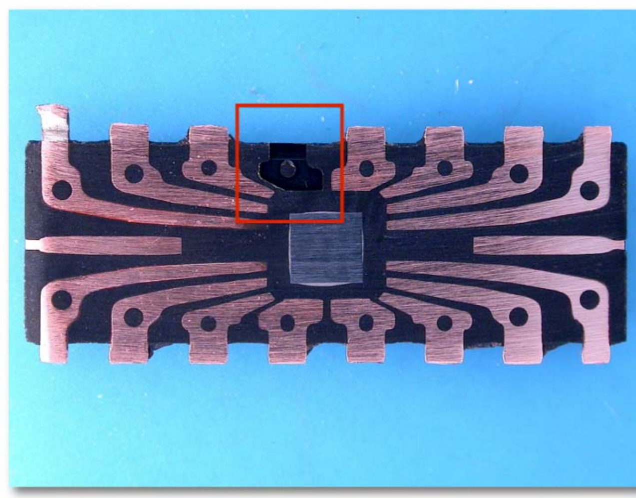

Figure 8. Optical macrograph of the device in figure 7 after removal of the pin 4 lead.

The images in figures 9 and 10 document the condition of the removed lead and the impression in the encapsulant. The only induced damage is due to the tensile overload of an intact bond wire, which is easily distinguishable from a corroded stitch bond.

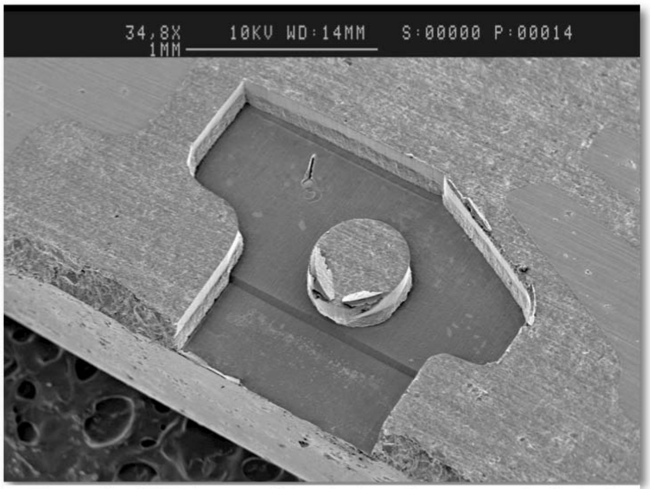

Figure 9. SEM image of the device after removal of pin 4 showing the impression of the lead.

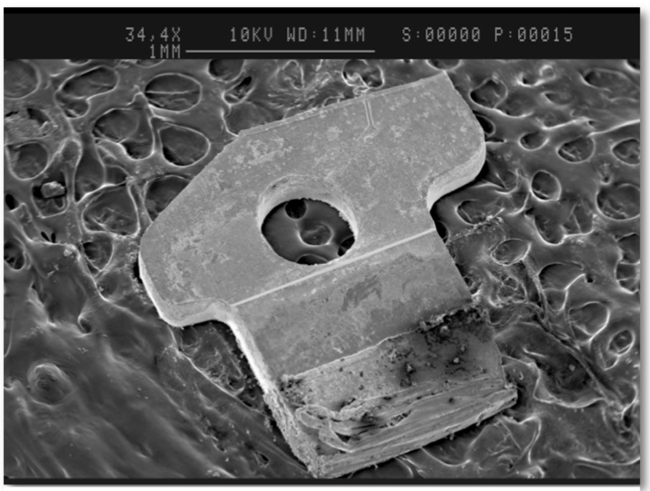

Figure 10. SEM image of the pin 4 lead after removal from the package.

Optical microscope and scanning electron microscope (SEM) inspection were performed on the failed leads and corrosion similar to that noted during cross-sectioning was found in each sample. Energy dispersive spectroscopy (EDS) of the corroded stitch bonds found substantial levels of chlorine contamination. It was also noted that the lead was plated with gold (Au).

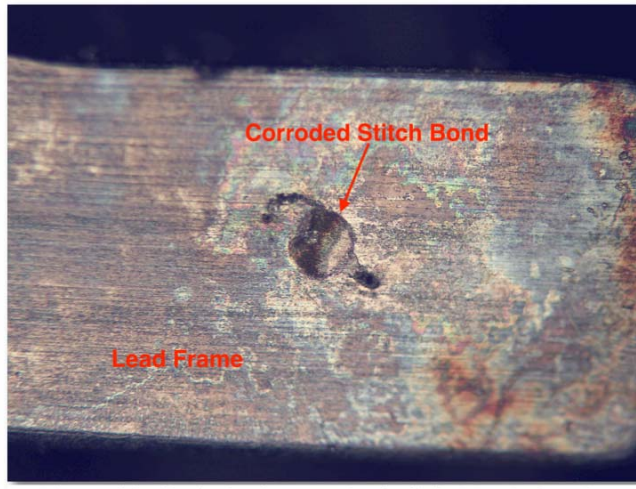

Figure 11. Optical micrograph of a failed lead after the mechanical removal of the lead from the package.

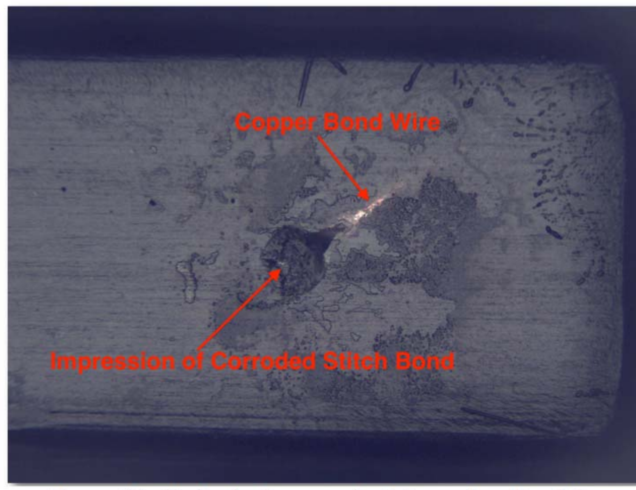

Figure 12. Optical micrograph of the underside of the encapsulant corresponding with the lead in figure 11.

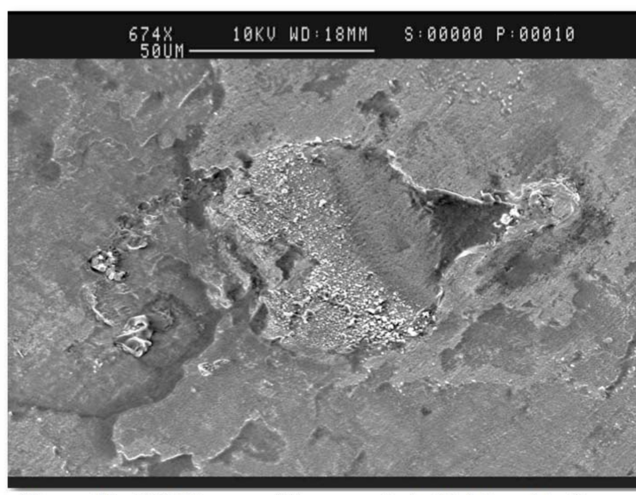

Figure 13. SEM image of the corroded stitch bond in figure 11. Note that the majority of the copper has been consumed.

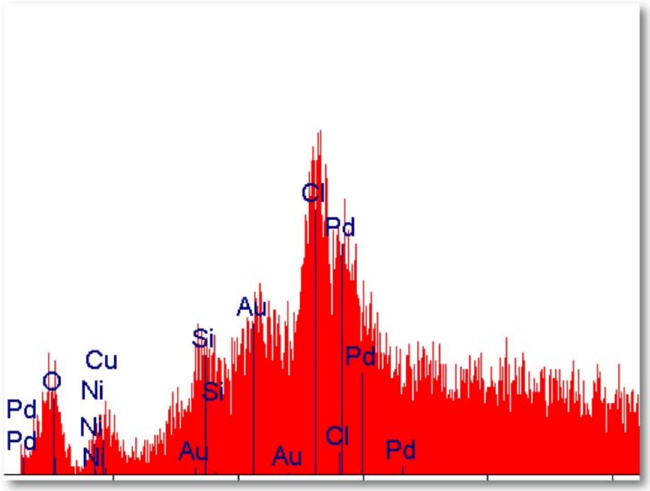

Figure 14. EDS spectrum of the corroded stitch bond at 10 kV. Note the chlorine (Cl).

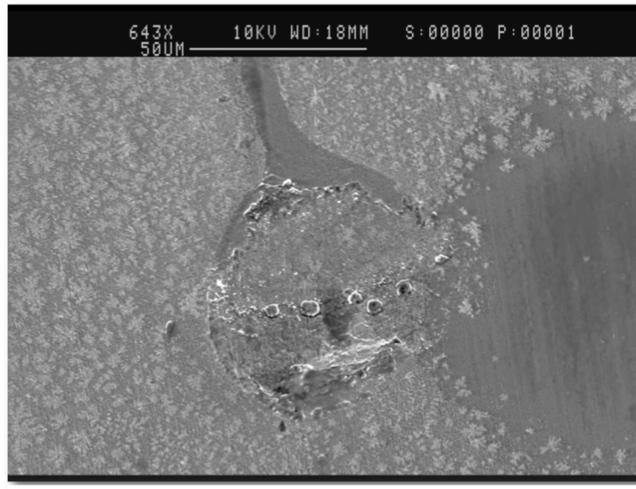

Figure 15. SEM image of the corroded stitch bond from sample 1b. Note that the majority of the copper has been consumed when compared to the stitch bond in figure 16.

Once the results of the analysis of the original six components were provided, ten additional samples from the same vendor with various date codes were received for inspection. See table 1 for details of the ten samples. The gold wire bonded devices corresponded with the older date codes.

Table 1. Details of the ten additional samples.

Serial #	Condition	Wire Bonds
1a	Failed	Copper
1b	Failed	Copper
2a	Functional	Gold
2b	Functional	Gold
3	Functional	Copper
4	Functional	Copper
5a	Functional	Gold
5b	Functional	Gold
6a	Functional	Copper
6b	Functional	Copper

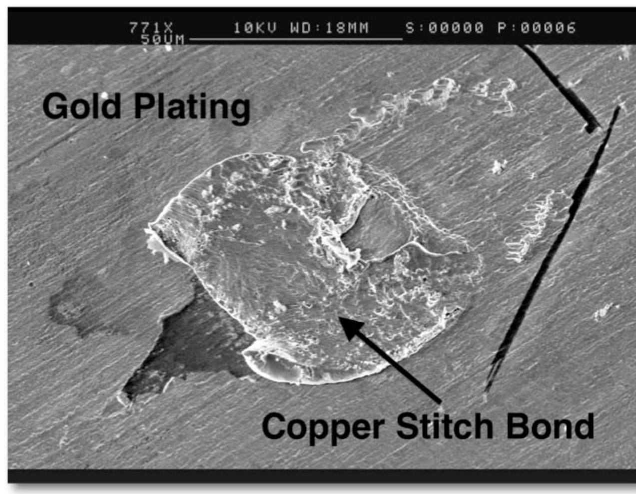

Figure 16. SEM image of the onset of corrosion to the copper stitch bond in sample 4.

CSAM of the additional samples revealed similar levels of delamination in each device. Optical and SEM inspection of the failed/suspect leads found chlorine contamination along the lead frame as noted in the previous analysis and each device with copper wire bonds exhibited corrosion of the stitch bonds. The gold wire bonded devices were not affected by the chlorine contamination.

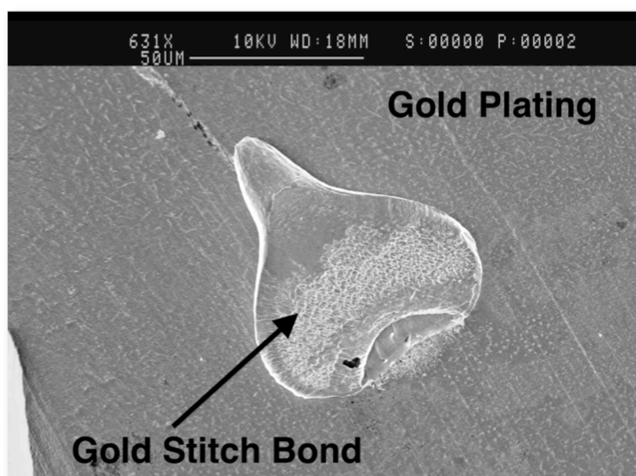

Figure 17. SEM image of the gold stitch bond in sample 2. Note that the stitch bond is not corroded.

The failure analysis determined that the integrated circuits used in the application were delaminated during manufacturing or the assembly process. The delamination allowed the chlorine contamination to propagate along the delaminated interface to the wire bonded area. The chlorine alone would result in the corrosion of the copper bond wire, however, due to the gold plating of the lead, the galvanic coupling of the gold (+) and copper (-) accelerated the corrosion of the copper wire bond [4].

In the older, gold wire bonded devices the delamination and contamination was still present, but did not result in the failure of the component due to both the chemical resistance of the gold, and the zero potential difference between the wire bond and the lead plating [4].

III. Conclusion

The primary concern in this case study was the delamination of encapsulant from the lead frame and subsequent corrosion of the copper wire bond. CSAM analysis of the samples found delamination across several part revisions from the original vendor. Because of the gold wire bonds in the older components, the delamination never resulted in the electrical failure of the devices.

As copper wire bonds inevitably become more common in plastic encapsulated components, previous manufacturing practices may prove to be unreliable. Furthermore, failure analysis of components containing copper wire bonds presents significant challenges. In this case, standard failure analysis procedure would either introduce contamination to the failure site or destroy the evidence entirely, necessitating the development and implementation of a cost effective, time efficient dissection method to preserve the condition of the corroded wire bond.

CSAM analysis was determined to provide adequate screening for the delamination that resulted in the failure of these components. The customer submitted numerous samples from two additional vendors (Vendor B, Vendor C) for inspection following this analysis. CSAM inspection found similar degrees of delamination in Vendor B when compared to Vendor A. No delamination was noted in Vendor C and the decision was made to re-populate circuits using the components from that manufacturer.

References

[1] Hidenori Abe, “Cu Wire Package Reliability Failure Mechanism and Factors Including Molding Compounds” for IMAPS Workshop & Tabletop Exhibit on Wire Bonding, 2013

[2] S. Murali, Ei Phyu, Siew Mei, Johnny Yeung, Roman Perez, “Microelectronics Interconnection Using Alloyed Copper Wire with Homogeneous Structure” for IMAPS Workshop & Tabletop Exhibit on Wire Bonding, 2013

[3] M. Özkök, H. Roberts, H. Clauberg, “Copper Wire Bonding on Pure Gold Surface Finishes – Eliminating the Gold Cost From the Electronic Package”

[4] M. Fontana, N. Greene, *Corrosion Engineering*, 2nd ed. McGraw-Hill, Inc., 1978, pg. 31, table 3-1 “Standard EMF Series of Metals”.