

# **Conductive Filament Formation Failure in a Printed Circuit Board**

Keith Rogers, Craig Hillman, and Michael Pecht  
CALCE Electronic Products and Systems Consortium  
University of Maryland  
College Park, MD 20742

Suzanne Nachbor  
Honeywell Inc., Minneapolis, MN 55413

## **Abstract**

A defective printed circuit board assembly that exhibited excessive current leakage was examined to determine the responsible failure mechanisms. Observation of the failure site (determined electrically) by optical and electron microscopy revealed an area in the circuit board where debonded fiber bundles bridged a from plated-through-hole (PTH) to a copper plane. This phenomenon is highly suggestive of conductive filament formation.

## **Background**

The second level of electronic packaging, printed circuit substrates, involves materials and architecture capable of reliably performing multiple tasks critical to system operation. These tasks include supplying power to single-chip devices, precisely timed signal transmission, structural support, and thermal conduction. In consideration of these performance requirements, printed circuit substrates are laid out in a laminate architecture, consisting of sheets of copper between layers of dielectric material. The circuit interconnection pattern, created from the copper sheets, is used to carry power, signal, and in some cases thermal energy. The dielectric, in most substrates, consists of an organic resin reinforced with high-strength fibers.

The demands of space and performance has led to an increase in the number of components and the necessary interconnection density on printed circuit boards (PCBs). This has driven the evolution of the printed circuit substrate to the multi-layered printed circuit boards in use today. Reduced conductor spacing, small diameter vias, and plated-through-holes (PTHs) on multiple levels can result in PCBs becoming more susceptible to conductive filament formation (CFF).

CFF is an electrochemical process that involves the transportation (usually ionically) of a metal through or across a non-metallic medium under the influence of an applied electric field [1-3]. CFF can result in either leakage currents which reduce performance or catastrophic shorts that cause complete failure. The biased conductors act as electrodes providing a driving potential while ingressed moisture between the organic resin and the fiber reinforcement will serve as an electrolyte (see figure 1). As metallic ions migrate and form a bridge between two biased conductors, the loss of insulation resistance results in a current surge. The current surge will eventually result in a short and a large increase in localized temperature. This increase in localized temperature can manifest itself as a burnt or charred area

between the two conductors involved.

The prime factors influencing CFF are board features (resin materials, conformal coatings, and conductor architecture) and operating conditions (voltage, temperature, and relative humidity). Path formation, necessary for the occurrence of CFF, will occur due to interfacial delamination of the interface between the individual fibers and the organic resin matrix. This degradation is often precipitated by poor drilling and thermal cycling (Figures 2a and 2b). Previous studies have gathered data on the quantitative effect of these various elements on the occurrence of electromigration [4-6]. Based upon this empirical evidence, models have been presented that predict the operational lifetime assuming an eventual failure mechanism of CFF [6,7].

More recent experiments have shown that CFF can also occur in the presence of hollow fibers [8,9]. The environmental considerations are the same, however in this case the path formation occurs within the fiber itself, instead of along the fiber/matrix interface. The scenario of electromigration within the fiber and its effect on time-to-failure has also been modeled [10].

## **Experimental Procedure**

A failure analysis was conducted on the defective PCB that had experienced an electrical short during operation. This 6 layer board is approximately 70 mils thick with 5 mil lines and 5 mil spacing. 1 ounce copper is used for the internal layers and 1/2 ounce copper for the external layers. The PTHs are approximately 12.5 mils in diameter. The distance between the electrically shorted PTH and copper trace of the ground plane is about 14 mils. Conditions suggested possible failure due to CFF. The exact area of the failure was determined by electrical testing. Substrate material was then removed perpendicular to the z-axis of the PCB until the failed copper interconnect plane was located (Figures 3a and 3b). The sample was then sectioned diametrically through one of the plated-through-holes (PTHs) so that the defective area could be observed along with the top view (Figures 4a and 4b). Observations were made using optical and environmental scanning electron microscopes (ESEM).

## **Results**

In Figure 3a, a dark, deformed region can be observed near the PTH. The charred color and deformation of the resin suggests burning of the organic matrix occurred. Images of broken fibers seen in Figure 3b are another indication of large amounts of heat generated in the failure area. The glass fibers used as reinforcements are nominally flexible. However, exposure to high temperatures can cause them to become brittle and thus more susceptible to fracture.

It can also be observed in Figure 4a that this dark, charred region extends from the outer wall of the PTH to a copper trace (top-left corner). The path of damage and the indication of high temperatures suggest that failure is due to conductive filament formation (CFF), which created a conduction path between the PTH and the copper trace of the ground plane.

## **Discussion**

A failed printed circuit board (PCB) was electrically tested, cross-sectioned at the identified site of electrical failure, and examined using optical and environmental scanning electron microscopy. Based upon the appearance of the epoxy, breakage of several glass fibers, and a damage path from a plated-through-hole (PTH) and a copper trace, the failure mechanism was identified as conductive filament

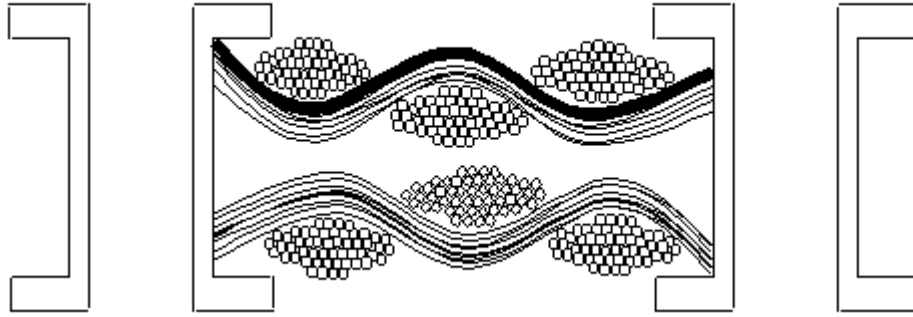
formation (CFF). The occurrence of conductive filament formation deep within the PCB can easily be misdiagnosed as "Failure Unknown". A complete failure analysis was necessary in order to ensure proper identification of the failure mechanism. Without proper identification, the electronic system will continue to perform below specifications because the user and the vendor are prevented from making the necessary adjustments to the environment or substitutions in material to prevent this sort of failure from reoccurring.

## References

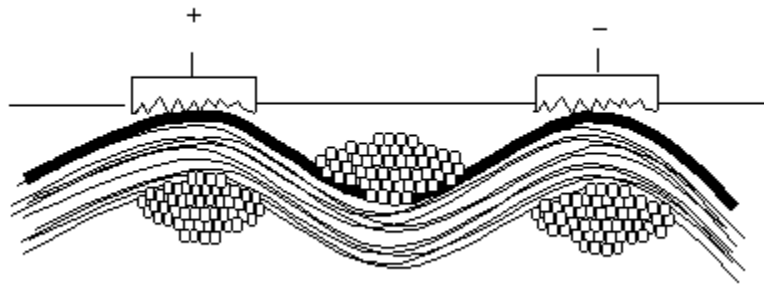
1. G. Kohman, H. Hermance, and G. Downes, "Silver Migration in Electrical Insulation," *The Bell System Technial Journal*, 1115-47, 1955
2. D. Lando, J. Mitchell, and T. Welsher, "Conductive Anodic Filament in Reinforced Polymeric Dielectrics: Formation and Prevention," *Proceedings of the Seventeenth International Reliability Physics Symposium*, 51-63, 1979.
3. M. Pecht, B. Wu and D. Jennings, "Conductive Filament Formation in Printed Wiring Boards," *Thirteenth IEEE/CHMT International Electronics Manufacturing Technology Symposium*, 74-79, 1992.
4. J. Lahti, R. Delaney, and J. Hines, "The Characteristic Wearout Process in Epoxy-Glass Printed Circuits for High Density Electronic Packaging," *Proceedings of the Seventeenth International Reliability Physics Symposium*, 39-43, 1979.
5. S. Krumbein, "Metallic Electromigration Phenomena," *IEEE Transactions on Components, Hybrids, and Manufacturing Technology*, **11**, [1], 5-15, 1988.
6. B. Rudra, M. Pecht, and D. Jennings, "Assessing Time-to-Failure due to Conductive Filament Formation in Multi-Layer Organic Laminates," *IEEE Transactions on Components, Packaging and Manufacturing Technology, Part B: Advanced Packaging*, **17**, [3], 269-76, 1994.
7. B. Rudra and D. Jennings, "Failure-Mechanism Models for Conductive-Filament Formation," *IEEE Transactions on Reliability*, **43**, [3], 354-60, 1994.
8. A. Shukla, M. Pecht, J. Jordan, K. Rogers and D. Jennings, "Hollow Fibers in PCB, MCM-L and PBGA Laminates May Induce Reliability Degradation," *Circuit World*, **23**, [2], 5-6, 1997.
9. A. Shukla, T. Dishongh, M. Pecht, and D. Jennings, "Hollow Fibers in Woven Laminates," *Printed Circuit Fabrication*, **20**, [1], 30-2, 1997.
10. M. Pecht, C. Hillman, K. Rogers, and D. Jennings, "Conductive Filament Formation: A Potential Reliability Issue in Laminated Printed Circuit Cards with Hollow Fibers," *IEEE Transactions on Electronics Packaging Manufacturing*, 1999.

## Acknowledgements

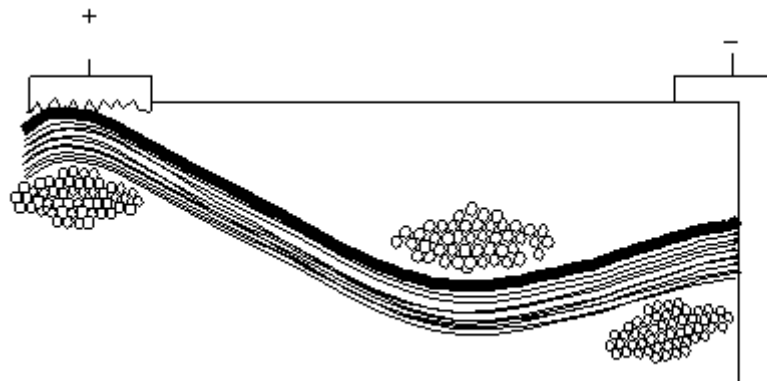
The authors would like to thank R. Uppalapati for his assistance in sample preparation.



Between two plated-through-holes (PTHs)

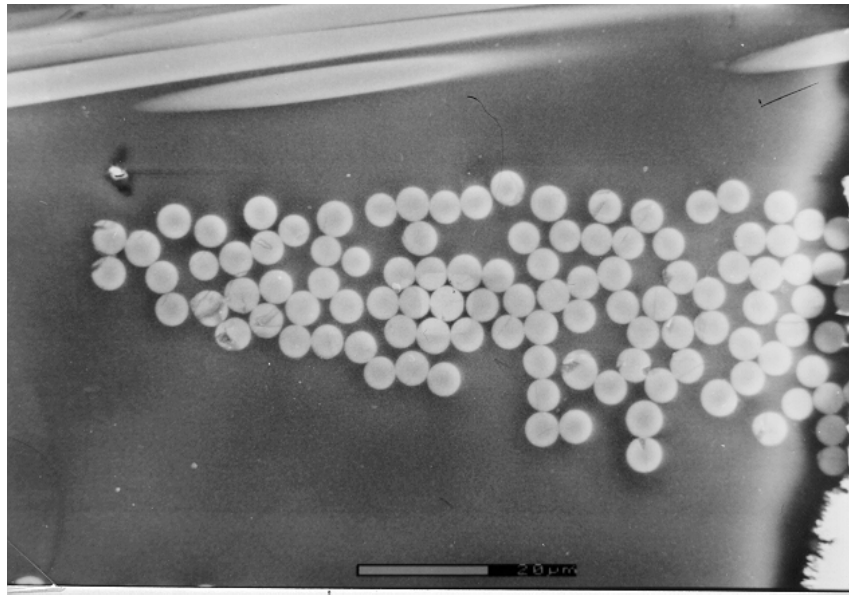


Between two surface traces

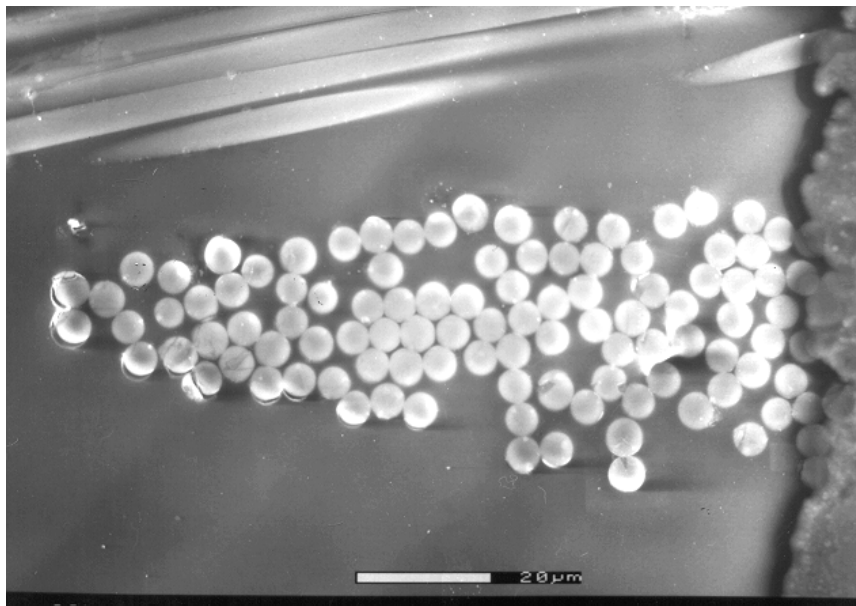


Between a surface trace and a plated-through-hole (PTH)

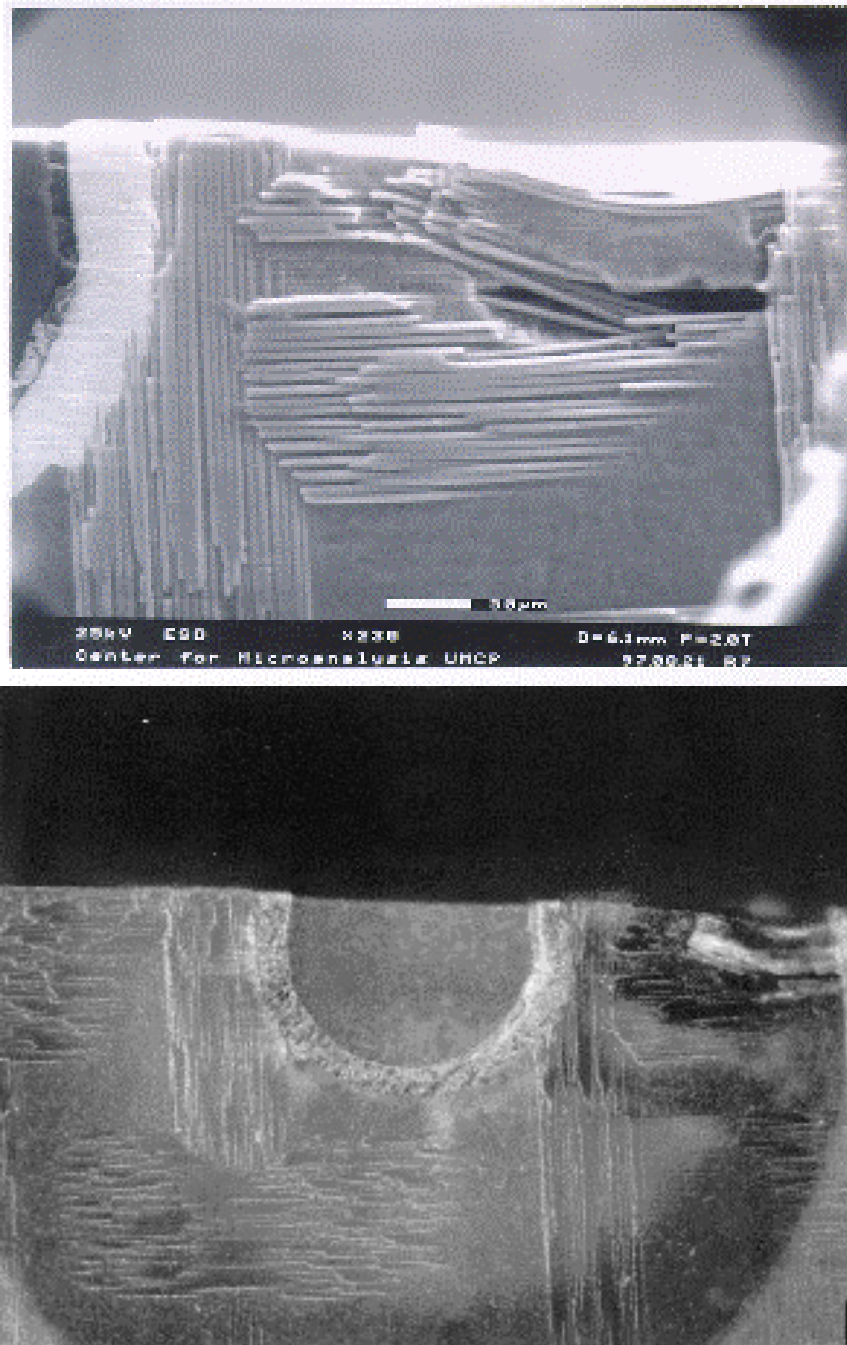
**Figure 1:** Conductive filament formation (CFF) configurations



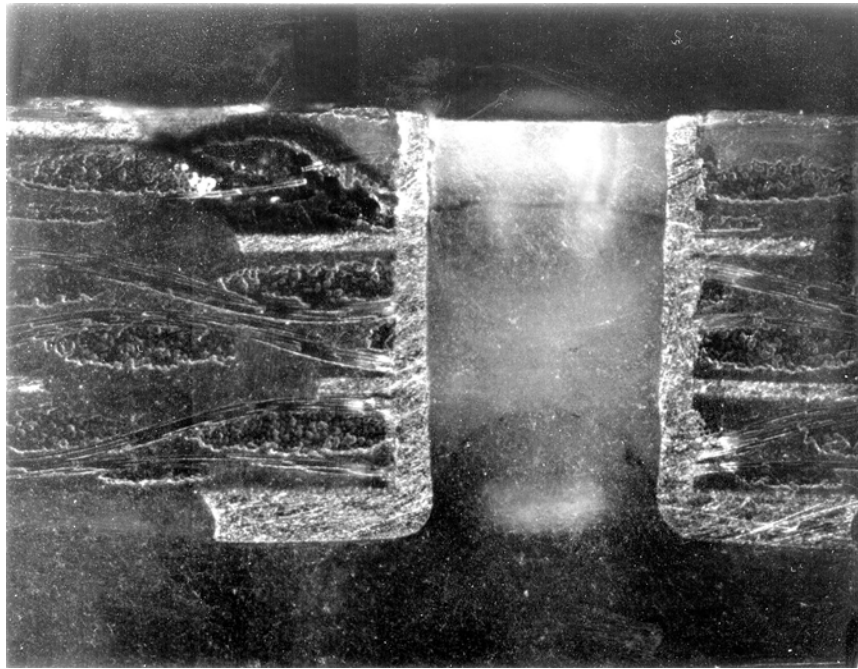
**Figure 2a (820x):** Before thermal cycling, this electron micrograph of a fiber-reinforced laminate shows good interfacial bonding at the fiber/epoxy resin interface prior to thermal cycling.



**Figure 2b (820x):** After thermal cycling, several instances of interfacial degradation (debonding) can be seen to have occurred at the fiber/epoxy resin interface.



**Figure 3:** (a) An optical micrograph (100x) shows a view of the interior of the PCB, parallel to the fiber weave. The plated-through-hole (PTH) and the area identified as the location of electrical failure are marked. (b) This electron micrograph (230x) is a higher magnification of the area of electrical failure marked in Figure 3a. The epoxy resin matrix is deformed and cracked and many of the reinforcing glass fibers are broken.



**Figure 4a (100x):** This optical micrograph shows a cross-section of a PCB that has failed by conductive filament formation (CFF). In the top left corner of the plated-through-hole (PTH), a dark, hollow region is observed. This charred region was identified as the area of electrical failure. It can be seen to extend from the outer wall of the PTH to the copper trace observable at the far left hand side of the picture.



**Figure 4b (360x):** This electron micrograph is a higher magnification of the area of electrical failure marked in Figure 4a. Note the dark hollow region, suggesting some of the epoxy resin has vaporized. Several broken glass fibers can also be identified.

---

All Material Copyright 2000 by CALCE and the University of Maryland  
Please report problems with this web site to [webmaster@calce.umd.edu](mailto:webmaster@calce.umd.edu)