

## Standardizing a Test Method for Conductive Anodic Filament Growth Failure

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### Abstract

The increase in board density, decrease in spacing between holes and features and the increased requirements for printed circuit boards to perform in high temperature/high humidity environments have led to increased concern on the growth of conductive anodic filaments (CAF). There has been a lack of information for standardized testing and failure analysis of various prepregs and laminates.

This paper will discuss a standard test vehicle design and test method, failure analysis and board manufacturing. It will also include the requirements for CAF resistance. There will be a discussion on material benchmarking and some preliminary results from the testing. These methods will be applicable to all market segments, including high density interconnect and automotive applications.

### Conductive Failure Background

The concerns with board reliability and the possibility of conductive anodic growth in printed wiring board assemblies has increased in the last few years. Original equipment manufacturers (OEMs) have increased the design density and are concerned with field failures due to conductive growth. The factors driving concern today are increased operating temperatures, such as under the hood applications, and designs that have increased the density of holes and features on a printed wiring board. These boards would be used in units that were operated in uncontrolled environments.

Conductive anodic filament (CAF) failure is the growth or electromigration of copper in a PCB. This growth typically bridges two oppositely biased copper conductors. This failure can be manifested in four main ways: through hole to through hole, line to line, through hole to line, and layer to layer. The most common failure mode is hole to hole.<sup>1,2</sup> See Figures 1, 2, 3 and 4.

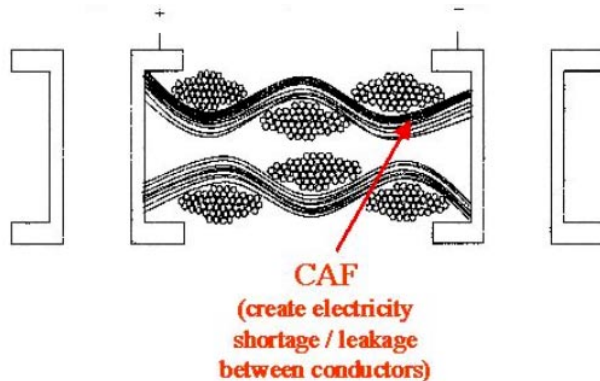


Figure 1 – Through Hole-Through Hole

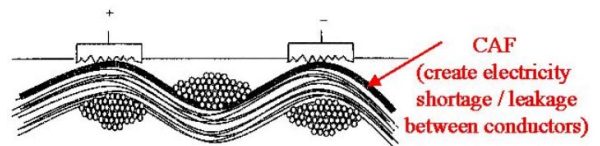


Figure 2 – Line-Line

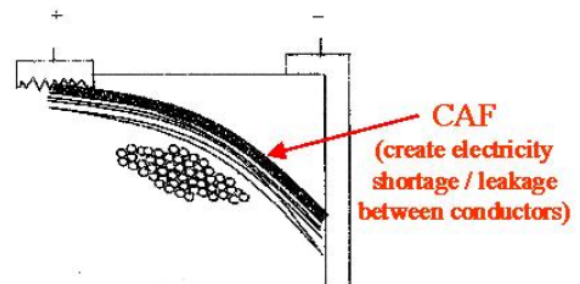


Figure 3 – Through Hole-Line

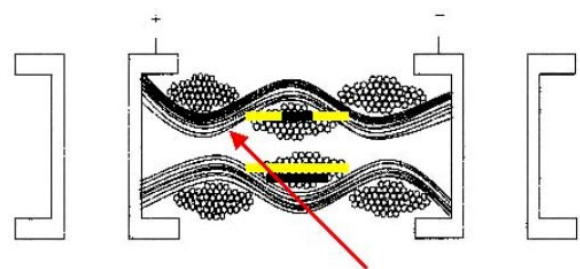


Figure 4 – Layer-Layer

It is known that a combination of bias voltage (voltage applied during the test) and high relative humidity (RH) can cause a CAF failure during testing. The electrical failure is caused when a filament grows from a copper anode to a copper cathode. This is most likely due to a chemical reaction that occurs when moisture in the epoxy, ion migration and corrosion of the silane bond takes place. This will result in a short<sup>2</sup> (see Figure 5).

## CAF - the Mechanism

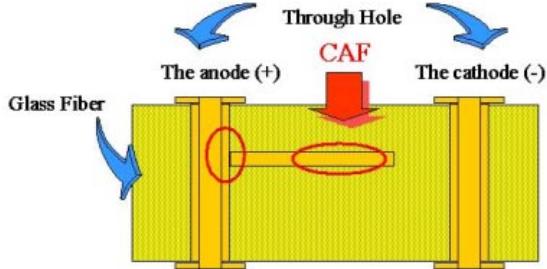
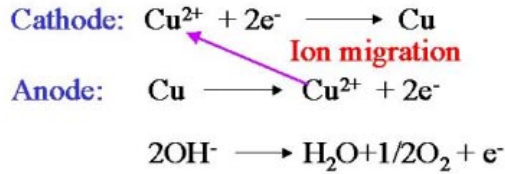


Figure 5 – A Short

Certain conditions must be present in order to achieve conductive failure. Several studies were completed by AT&T Laboratories and the Georgia Institute of Technology to determine the lower threshold of conditions required for a CAF failure.<sup>2,3</sup> Several kinetic models were developed and tested to determine the best equation model for CAF. These studies showed that CAF would not be a reliability issue in a controlled environment. Additional testing was to be completed to determine which model was the most useful and repetitive for reliability testing in finished assemblies.

There are several material conditions that have been attributed to causing a material to be more or less resistant to conductive failures. They are grouped into three categories; glass, resin and treating. Glass finish, hollow fibers and cleanliness need to be tested. Resin purity, the cross linking agent and moisture absorption characteristics are significant. Treating parameters for wetout (good resin/glass interface) and cleanliness are also important.<sup>4,5,6,7</sup> See Figure 6 and Figure 7.

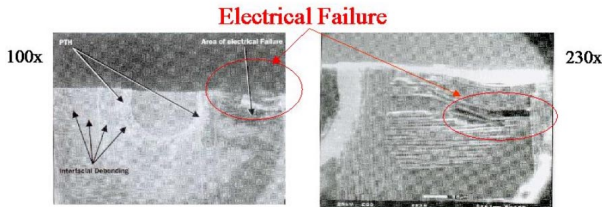


Figure 6 – Deformed & Cracked Epoxy Resin; Broken Glass Fiber

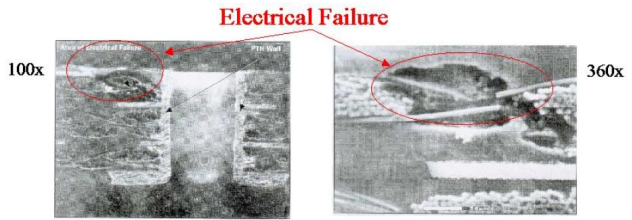


Figure 7 – Vaporized Epoxy Resin; Broken Glass Fiber

## Test Vehicle Design

In interviews with some of the PCB manufacturers and OEMs, it was determined that feature spacing and the hole spacing were critical in enabling the CAF to occur. Several board designs were reviewed and spacing, from 0.006 inch to 0.035 inch were determined to be the spacings of interest. A coupon was designed that will allow all of them to be tested. It consists of several rows of coupons with hole spacing from 0.006 to 0.035 inch. These are laid out in both the X and Y direction on the panel. The vehicle is a four layer board. The failure mode should be very easy to see with this design. The dielectric spacing can be changed with the use of different materials to understand its impact on CAF formation (see Appendix A). Due to interest in CAF failure in all aspects of the electronics industry, a standard test design must be implemented.

## Material Benchmarking

The initial testing accomplished at Isola was with a very simple all 7628 prepreg four layer (this was considered to be a “ worst case ” material construction due to the heavy glass and small drilled hole size). The hole to hole spacing was 0.024 inch, with rows along the X plane, the Y plane and diagonally. A variety of generic FR-4 materials were tested. The boards were all manufactured at the same time. The drilled hole size was 0.0135 inch. Half of the boards had solder, half had bare copper. (The influence of flux and soldering has had detrimental effects on CAF resistance.)<sup>5</sup> Figure 8 shows that all FR-4 epoxy boards failed at 400 hours under the following test conditions.

## Test Conditions

85% RH  
 85°C  
 13 VDC bias voltage  
 100 VDC test voltage at every 100 hours (Coupons were removed from the chamber and allowed to stabilize to ambient prior to testing.)

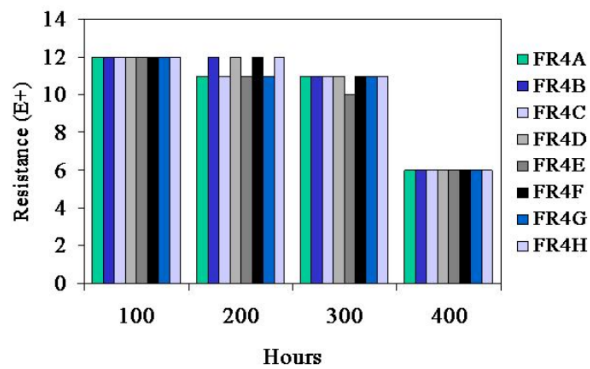


Figure 8 – FR4 CAF Failures

### PCB Manufacturing

The printed wiring board manufacturing process has an effect on allowing or creating a CAF failure. The critical areas are lamination, drilling and HASL.

In lamination, the pressing parameters must closely match what the laminator recommends. If the heat rise of the pressed book is too fast or too slow, the resin will not have enough time to properly wetout the cores that are being pressed. Laminated voids or other lamination defects may occur, which may allow a path for CAF failures.

Drilling is also important. The drilled hole should be smooth and straight. There should not be any exposed glass fibers in the hole, no extreme gouging and no fracturing of the resin in the hole. As the boards are processed through the electroless and plating chemistries, the hole wall may be further degraded, and moisture may be allowed to wick into the board. This may also contribute to CAF failures.

The HASL temperatures and fluxes can also contribute to CAF failures. The high temperatures exceed the Tg of the material, and depending on the type of coating used, moisture uptake may be enhanced. Any residue left on the board may also be an issue.<sup>4,5</sup>

### Test Conditions

There are several manufacturers of environmental test chambers. Each of them have different capabilities. Some of them have 100 plus connectors for test, others have quite a few less. Some chambers are totally automatic and can be programmed to test the coupons at specified intervals. Others use systems outside the chamber to apply the test voltage. The more automated a chamber is and the more connectors it has, the more expensive it will be. The costs vary significantly from chamber to chamber. Each chamber should have calibrated temperature and humidity functions. These functions should be easily changed depending on the test. The bias voltage function should have a range of 10 VDC to

300 VDC, which satisfies the requirements for 95% of the OEMs.

The testing intervals are going to be dependent on the environmental requirements. Testing has been done as high as 95% RH and as low as 50% RH. The temperatures have also varied from 65°C to over 100°C. Depending on the temperature and humidity requirements the testing interval may be every hour or every 100 hours. The higher (or more aggressive) the testing parameters, the faster the board will fail. At that point, it may be useful to test every hour to understand the failure curve.

There are also two ways to test the coupons. They can be tested in chamber or removed from the chamber, stabilized to ambient and then tested. Further studies need to be done to see if one method is more predictive of failure than the other.

### Failure Analysis

Finding and verifying a failure has been a challenge.

The first step that we took was to use an ohmmeter to measure the holes for a resistance drop, which was not effective. One-hundred volts were applied to the coupon, and the holes were again measured for a resistance drop. With this method, three or four holes were found with a resistance drop down to 10 E+03.

These coupons were mounted into a quick curing epoxy for grinding. The first coupon was ground in the X plane. It was inspected carefully at each layer of grinding to ensure that the copper was not missed (ground through) if it was present. Using this method, one copper spot was found. Unfortunately, we could not verify that it was an actual copper short, because the grinding plane was wrong (see Figure 9).

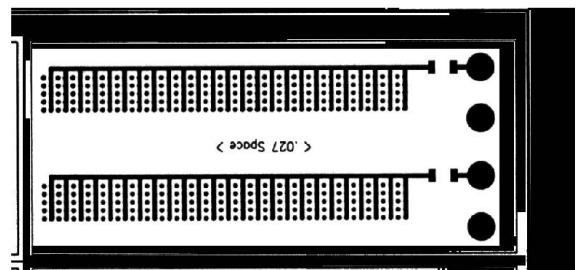


Figure 9 – CAF Failure Analysis Coupon

Using another technique for the next batch of coupons, the failure was very easy to identify. The surface layer of copper and soldermask was ground off. Using a 50 or greater power microscope, it was very easy to see whether or not there was a copper bridge. It was noted then that the failures, which were marked immediately after the coupon was removed from the chamber, did not show a CAF failure once it had returned to ambient temperature and dried out.

This indicated that one of the failure mechanisms was most likely moisture, and that once the board dried out, there was no failure. This is an area that needs to be reviewed. If the copper short cannot be found, is there a conductive filament failure?

### Conclusions

There seems to be many different coupons and methods to test for CAF failures. There does not appear to be any conclusive criteria for what constitutes a failure. The OEMs seem to have a general idea of what they are looking for, but not what is actually important. Conductive failures are a certainty, given the correct conditions and design, but few PCB field failures have been verified that the cause was due to conductive growth.

In the last few months of experiments, it has become clear that there are many questions that are unanswered, and no standards. I would like to propose that the coupon presented here be used as a baseline for the industry to use in testing for CAF failure. The design will be comparable from manufacturer to manufacturer. It can be revised as needed in the future.

A definition of failure also needs clarification by the industry. If a large drop in resistance is noted but a copper bridge cannot be found is that failure considered to be caused by conductive growth? Additional studies need to be conducted to answer that question.

Finally, to test a coupon for 2000 plus hours is very lengthy. An accelerated test program should also be discussed and benchmarked. A pressurized environmental chamber could be used, with a possible 90% reduction in time. If designs and materials could be tested to failure in 100 hours or less, the benefits to all facets of the industry would be great.

### Acknowledgements

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### References

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