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Test Setup, Procedures and Patterns for Conductive Anodic Filament (CAF) and Electrochemical Migration (ECM) Testing

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Abstract
Reliability assessment of Printed Wiring Boards and Assemblies using High Humidity at elevated temperatures has been done for a number of years. Many companies, including the IPC have published test requirements for products at high humidity at elevated temperatures. We currently perform testing to at least 10 different variations of these types of tests.

In addition to variations in Temperature and Humidity, these tests also vary in whether a forcing potential is used during the test cycle. When a forcing voltage is used there are a variety of voltages specified. There are also differences in test voltage and whether the test voltage is applied in the same direction as the forcing voltage.

This paper will describe the varying test methods used to conduct these environmental tests along with detailing the differences between them. It will highlight the different test patterns used and the benefits and limitations they represent. It will also encompass issues concerning test sample preparation, wiring, and placement within the test chamber that are not always addressed in the test method procedures.

Dendrites, Filaments and Migration sound like they could be evil characters from the Lord of the Rings movie. Unfortunately these "evil characters" exist in and on the electronic products we manufacture and use. And just like in the movie, their presence grows to the point where they cause the good parts to fail. The engineers that chase these problems down have often been called wizards (among other things), and like wizards they gather in groups to decide the best course of action against these evil creatures (IPC Committee meetings).

All kidding aside, long-term reliability of electronic products can be severely affected by these evil characters and the testing for their potential to exist is becoming widespread. Requirements for Conductive Anodic Filament (CAF) and Electrochemical Migration Resistance (ECM) testing are becoming increasingly important as spacing and part sizes on PWB's decrease. Unfortunately testing procedures can be more magic than science as the current test methods do not fully describe the care necessary and pitfalls associated with testing for the presence of these evildoers. The testing methodology for these forms of electrochemical migration differ in both the test samples used for and environmental conditions associated with the testing. CAF test samples are geared to specifically look for failures that occur within the material while the dendrite detecting test samples are geared to identify failures that occur on the surface of the material.

When I speak to people regarding the environmental tests that are in use to detect dendrites, filaments and migration, I spend a lot of time on definitions and descriptions of these phenomenon and of what tests are available to detect them. One thing I always recommend is to get a copy of the IPC-9201 "SIR Handbook". It contains a wealth of information and is a must for anyone involved in environmental simulation. I am currently involved in the committee work to update this document, and will shamelessly quote it here in my article from time to time.

Electrochemical migration (ECM) and Electromigration resistance (EMR) are sometimes confused and have been known to be incorrectly used interchangeably. Electrochemical migration occurs in high humidity environments, which promote the formation of an electrolyte solution, which in the presence of an applied voltage creates a plating cell (in a humidity chamber). Electromigration on the other hand occurs in the presence of an applied voltage in a dry (< 10%RH) environment typically at elevated temperature (in an oven).

Electrochemical Migration (ECM) is defined by IPC-9201 as the growth of conductive metal filaments on a printed wiring board (PWB) under the influence of a DC voltage bias. This may occur at an external surface, an internal interface, or through the bulk material of a composite (e.g. paper/phenolic laminate). The most well understood filaments that occur are surface dendrites that are visually represented as crystalline structures with needles attached or to the less technical, they are "fuzzies" that grow between powered circuits. Growth of these dendrites occurs because of the fact that water vapor from the humidity chamber combines with ionic and/or inorganic materials found on the surface of the sample and produces an electrolytic solution. This solution and the presence of an electrical potential forms a small plating tank in which metal ions migrate across the surface of the sample to the cathode and grow back toward the anode of the test circuit.

Another type of electrochemical phenomena that happens is conductive anodic filament (CAF) growth, which occurs inside the material. While dendrites are typically comprised of any or all of the metals found on the surface of the board, CAF failures are typically metal salt (typically copper with hydroxyl, chloride and/or bromide) that migrates through hydrolyzed glass/resin interfaces in the base material. This growth is fundamentally different than electrochemical migration in that conductive anodic filaments grow from the anode (hence the name conductive ANODIC filament) while dendrites grow back toward the anode from the cathode. I will let other scholars describe this interesting phenomenon and it's causes and will focus the rest of this article on the testing parameters associated with ECM and CAF testing.

The Equipment

Many people think that they can buy a chamber, power supply and a megohm meter and they are ready to perform ECM or CAF testing. Unfortunately there are many more factors that affect the ability to perform these types of environmental simulations in an accurate and productive fashion.

Humidity Chamber

All humidity chambers are not created equal! There it has been said although the individual manufacturers of chambers might not agree wholeheartedly with me (about their own unit). Uniformity in the test chamber is crucial for consistency in humidity and successful test completion. Test chamber uniformity is influenced by airflow technique, method for humidity production, insulation around the chamber, size of the chamber, air cooling method, system control method and humidity sensor types, to list a few. If the chamber is not uniform, condensation on the sample can occur, and if it occurs while the circuit is powered many strange and unflattering things will happen to your samples. One non-chamber related uniformity issue has to with the placement of the samples and the routing of test cables within the humidity chamber. Test samples need to be placed in a manner so that the airflow in the chamber travels freely past both sides of the sample. They should not be placed too closely together and the mass of wires and cables that connects them to the outside world must be carefully routed so that airflow is not obstructed.

Power Supply

ECM and CAF testing requires a forcing potential to help create any possible dendrite or filament growth. Voltages currently range from 10VDC to 100VDC, although there is some movement in Europe toward the use of AC power sources. There is also a difference in test methods we see in the polarity of the DC forcing potential versus the polarity of the testing potential. It appears that the most current technical view (mine included) is that for CAF and ECM testing the polarity should remain the same for both forcing and testing potentials.

Without a filament or dendrite present there is very little current that flows through the test circuit (pico to nano amps). Filament or dendrite growth begins to reduce the test circuit resistance thereby causing increasing current flow of the forcing potential. As current flow increases, the power dissipated across the filament/dendrite starts to increase. There comes a point where the power dissipated exceeds the ability of the filament/dendrite to carry it and "Poof" happens. “Poof” is what occurs when a fuse blows in your car or house, and when this happens to a filament/dendrite, it is destroyed and the ions are re-dispersed around the "poof" area. If you then go back and measure the circuit, the measured resistance that is associated with the “poof” area may not be as great at that typically associated with filament growth and you could make the assumption that one did not form. In order to prevent “poof” from happening, the maximum current allowed to flow through the test circuit needs to be limited. This is typically accomplished by placing a resistor of a value between one to ten megohms inline with the power supply circuit on each test pattern. This resistor adds no appreciable resistance to the test circuit while limiting current flow to very small levels (pico-amps). Even with a current limiting resistor very small Surface Dendrites or CAF filaments may still go “poof” and disperse. There are still some interesting questions that need to be answered in regard to forcing potential and current limiting strategies in order to maximize the detection of these phenomenon.

Megohm Meter

A megohm meter is basically a very stable power supply, a voltmeter and a pico-amp meter packaged together as a single unit. Resistance is calculated using Ohms Law (resistance = voltage / current). You can also set up these three individual units and have a very capable measurement system, but a megohm meter packages these three units into one package. Once you have decided on a suitable meter setup, the most time consuming issue that you will face is in the fact that there are typically a lot of individual channels to be measured. With a 60 second measurement stabilization (electrification) time per measurement, and the fact that measurements are often required frequently, it can take a LONG time for a technician to perform a large group of readings. After the first time a technician does this he will typically be seen in his bosses office pleading for a switching system to be added to the test setup. Several manufacturers have heard these cries for help and have created systems that combine a megohm meter and switching system into a unit specifically geared to make multiple high resistance measurements and supply forcing potential during the time that measurements are not being made. These manufacturers are very proud of their units, and you can expect to spend a significant amount of capital to acquire one.

Wires and Fixturing

The type and quality of the cabling used to connect the measurement system to the test samples can have a great impact on test results. These cables are in charge of both the maintaining connection to the test samples and keeping the test channels isolated from each other. Poor cabling can cause false positive or negative results to appear in the test data. There are a plethora of cable types available and working through all the possibilities can be daunting. I strongly believe that the use of non-halogenated cables is essential to maintaining the insulation resistance of the cabling when it is exposed to high temperature/humidity. The best non-halogenated cables available use PTFE or PFE insulation and are a significant cost factor to consider when looking at setting up an environmental measurement system. Another decision to be made when considering cable types is whether to use solid or stranded cable. Stranded cable is more flexible and easier to obtain, but leaves the possibility open for wicking of residues into the insulation at the attachment points. Solid cable reduces the residue possibilities but is not very flexible and can break with repeated use. I personally hedge toward the stranded cable, but only with the caveat that solid tin/lead solder (with no flux) is used for cable connections. This fluxless solder is used to prevent residues from entering the cable.

High resistance measurements are very sensitive to electrical interference. Typical test areas have computers, controllers, electronic instruments and people in them. All of these factors can dramatically affect the measurement of high resistance values by introducing stray voltages into the test wiring that can negatively affect test results. In order to minimize the effect of these outside influences it is important for the cabling used to be shielded against these types of electrical interference. This can be done with a metal shielding around the cables, which is grounded to an earth ground. Unfortunately this makes the cables bulky and very expensive, but is necessary for stable test circuit measurements. Shielding is typically not necessary on the cables after they enter the chamber as external interferences are naturally shielded by the chamber. Electrical interference can also occur between test channels (crosstalk), and it is important to use cables that contain grounded wires (guard bands) between the test wires in order to minimize this interference.

Test sample attachment and fixturing is another serious consideration that must be made. Systems using connectors to attach samples are very convenient, but can only be used when the samples are manufactured specifically for the connectors. Connectors also have a life associated with them and can cause erroneous readings if not regularly checked and changed. As an independent test facility we have to be prepared for all types of samples so automatic fixturing is not useful to us. Although it is the most time consuming method, we feel that soldering directly to the sample is the most effective way to assure good connection to the sample. We use solid core (non-flux bearing) solder to make the attachments between the test board and the cable in order to prevent flux contamination.

Despite everyone's best efforts problems still do arise with cabling systems. This makes it extremely important to test your sample fixturing and cables regularly with a resistor network. Building a suitable resistor network is another daunting task as stable, accurate Teraohm resistors are very expensive and difficult to find. These resistors are bulky and it is usually necessary to come up with a board to mount the resistors on that is then connected to the cabling for testing.

Test Methods

There are several test methods in use that are targeted at ECM and CAF testing. I wanted to highlight a few here to give an idea of the basic environmental exposure involved.

IPC Test Method

IPC-TM-650 test methods for Electrochemical Migration Resistance are method 2.6.14 for Solder masks and Method 2.6.14.1 for liquid fluxes, flux cored wires and solder paste. These test methods uses one of the IPC-B-25 (Figure 1) or IPC-B-25A (Figure 2) board test coupons for evaluation. The samples are wired up with 10 Megohm (method 2.6.14) or 1 Megohm (method 2.6.14.1) resistors inline to each circuit and placed into a chamber that produces an environment of one of the following as given by the controlling specification: 1) 40±2°C, 91-93% Relative Humidity; 2) 65±2°C, 85-92% Relative Humidity (recommended); 3) 85±2°C, 85-92% Relative Humidity. After a 96-hour stabilization period, insulation resistance measurements are made at a voltage between 45VDC and 100VDC. The samples are then connected to a 10VDC power supply for a period of 7 days or 500 hours with the voltage polarity in the same direction as the measurement voltage. After the exposure period, the power supply is disconnected and insulation resistance measurements are repeated. The Resistance values are then logarithmically averaged. The samples are also visually evaluated for signs of migration.

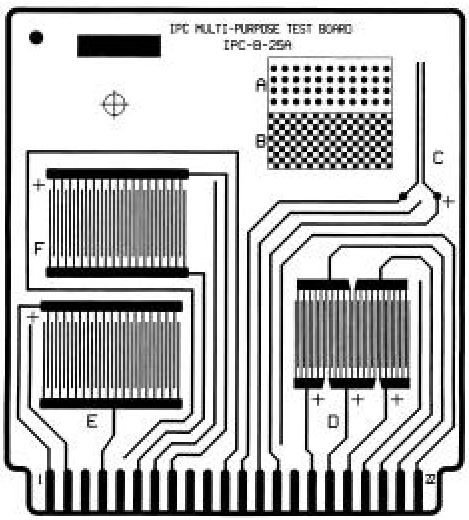

Figure 1 – IPC-B-25A Test Board

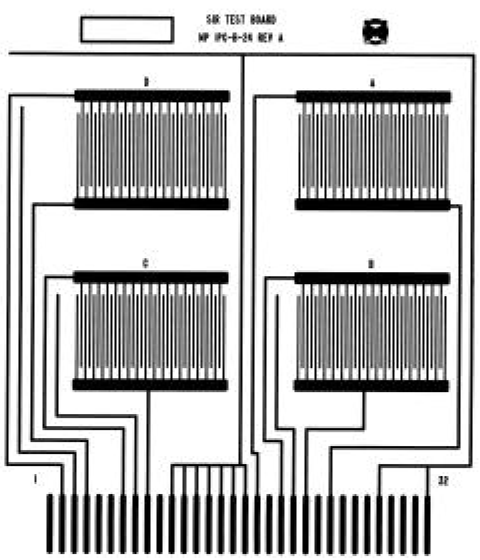

Figure 2 – IPC B-25 Test Board

Telcordia (Bellcore) Test Method

Telcordia GR-78-CORE has a test method (Section 13.1.5) for Electrochemical Migration that uses a Test Pattern developed by Bellcore (see Figure 3). The samples are wired up and placed into a chamber that produces an environment of 65 (±2)°C, 85% minimum Relative Humidity for 96 hours. After this 96-hour period, insulation resistance measurements are made at a voltage between 45VDC and 100VDC. The samples are then connected to a 10VDC power supply with 1 Megohm resistors inline for a period of 500 hours with the voltage polarity in the same direction as the measurement voltage. After 500 hours, the power supply is disconnected and insulation resistance measurements are repeated. The Resistance values are then logarithmically averaged. The samples are also visually evaluated for signs of migration.

Sun Microsystems CAF Test

The Sun Microsystems CAF test is run in a similar fashion to the Telcordia GR-78-CORE test with a couple of notable exceptions. Since CAF testing is intended to test the Anodic filament growth potential between holes, traces and planes (all internal to the material), the test pattern is inherently different and consists of several groups of parallel holes and planes in a 10 layer test PWB (see Figure 4). There is also a special cleaning cycle in a heated isopropanol and DI water solution intended to clean ionic residues from the surface of the sample that might cloud the results of the potential CAF structures. This test method has been submitted to the IPCs cleaning and coating committee for review and eventual adoption as an IPC test method. Sun has also graciously consented to make their test vehicle public through the IPC to facilities like my own.

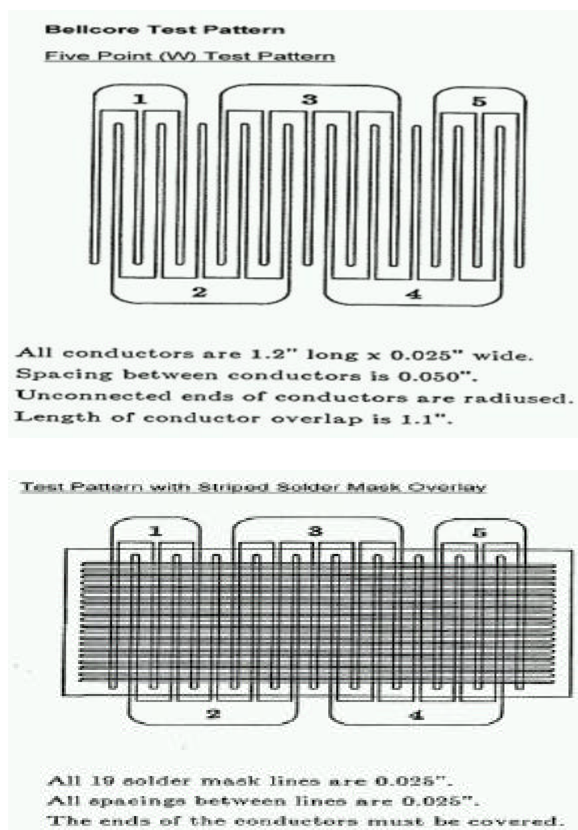

Figure 3 – Telcordia GR-78 CPRE Test Sample

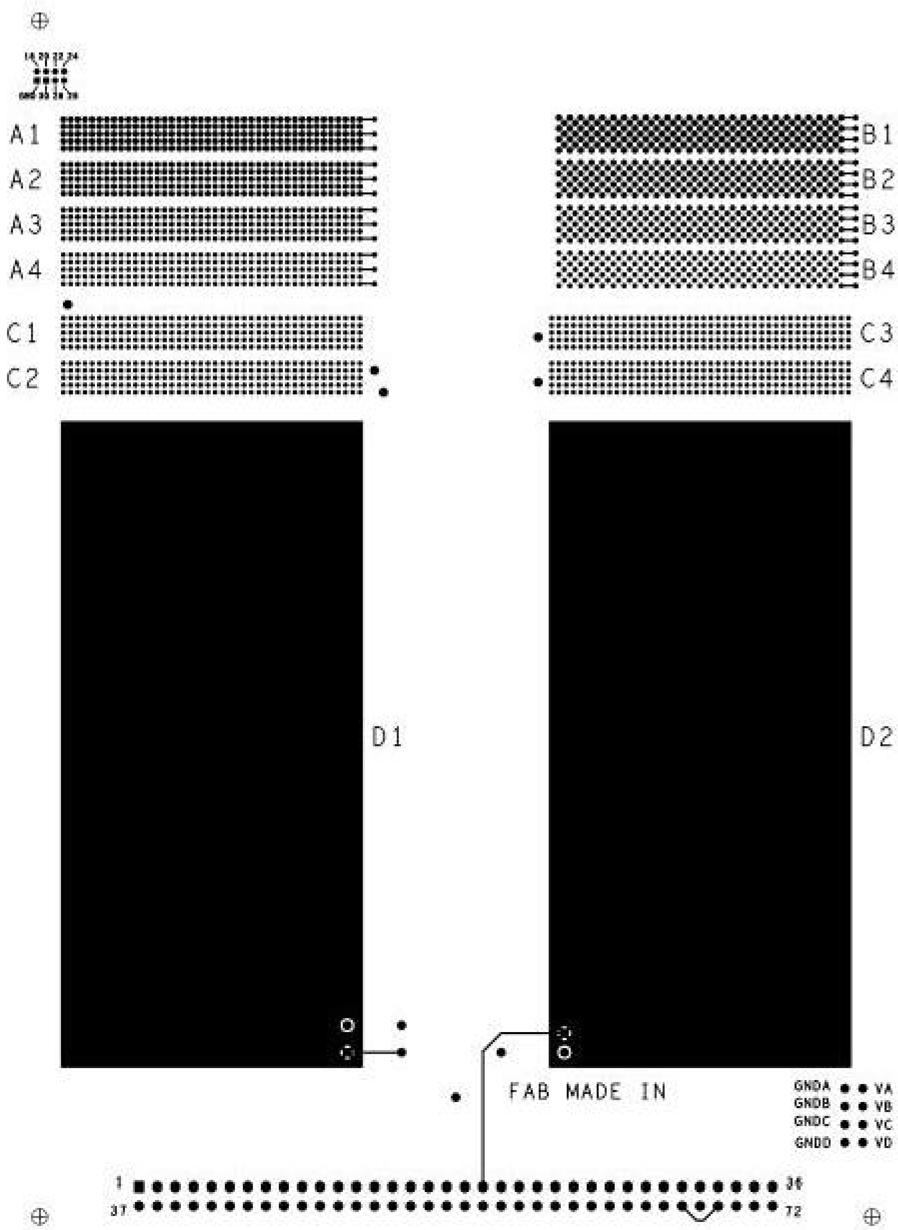

Figure 4 – Sun Microsystems CAF Test Board

Summary
Although ECM & CAF Testing may look easy from the outside, there are many obstacles to the proper setup and performance of these tests. Significant capital expenditure and engineering expertise is required to set to make these tests work. Do your homework on equipment, fixturing and test procedures before diving in as it is difficult to find out that you have made an error after umpteen dollars and 1000 hours of testing.

Acknowledgements
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