Setup, Procedures, and Patterns for CAF AND ECM TESTING

Finding CAF failures is tricky business. Test sample preparation, wiring, and placement within the chamber are not always addressed in test methods. A look at test methods for humidity and potential, and their differences. **by BOB NEVES**

Dendrites, filaments, and migration: They sound like evil characters from the *Lord of the Rings*. Unfortunately, they *do* exist – in and on electronics products. And, as in the movie, as their presence grows, good parts fail. Engineers who hunt for these problems are often called wizards – among other things – and they gather in groups – IPC committee meetings – to decide the best course of action for rooting out these evils.

Kidding aside, long-term reliability of electronics can be severely affected by these evils and the testing for their potential to exist is becoming widespread. As spacing and part sizes on PCBs decrease, requirements for conductive anodic filament (CAF) and electrochemical migration resistance (ECM) testing are becoming important. Unfortunately, procedures can be more magic than science: Current test methods do not fully describe the care necessary – and associated pitfalls – for testing for the presence of these evildoers. The 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 dendrite detecting test samples identify failures that occur on the surface of the material.

My discussions regarding environmental tests in use to detect dendrites, filaments, and migration invariably involve spending much time covering definitions and descriptions of these phenomena and the tests available to detect them. I always recommend IPC-9201, "SIR Handbook." It contains a wealth of information and is a must-have for anyone involved in environmental simulation. I am on the committee charged with updating this document and will shamelessly quote from it here from time to time.

Electrochemical migration and electromigration resistance (EMR) are sometimes confused and have been incorrectly used as synonyms. ECM occurs in high-humidity environments, which promote 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 environment (<10% RH), typically at an elevated temperature (as in an oven).

Electrochemical migration is defined in IPC-9201 as "the growth of conductive metal filaments on a printed wiring board 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 best understood filaments that occur are surface dendrites; visually represented as crystalline structures with needles attached, or, to the less technical, the "fuzzies" that grow between powered circuits (Figures 1a and 1b). Growth of dendrites occurs when water vapor from the humidity chamber combines with ionic and/or inorganic materials from 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 an electrochemical phenomenon is 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 salts (typically copper with hydroxyl, chloride, or bromide) that migrate through hydrolyzed glass/resin interfaces in the base material. This growth is fundamentally different from ECM in that conductive anodic filaments grow from the anode (hence the name), while dendrites grow back toward the anode from the cathode. Other articles describe this interesting phenomenon and its causes; here, I will focus on the testing parameters associated with ECM and CAF testing.

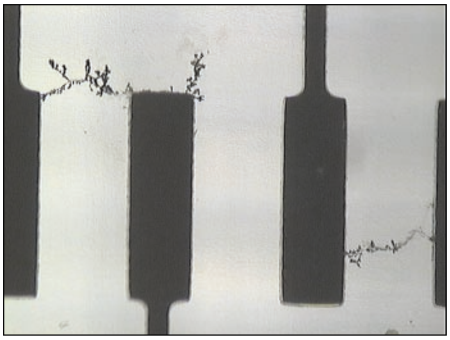

FIGURE 1a. Conductive metal filaments such as surface dendrites appear as crystalline structures ...

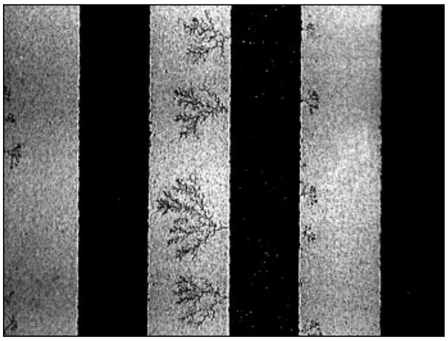

FIGURE 1b. ... with "needles" stemming between conductors (photos courtesy of Concoat Ltd.).

The Equipment

ECM or CAF testing requires more than the presence of a chamber, power supply, and megohm meter. Many other factors affect one's ability to perform these types of environmental simulations in an accurate and productive fashion.

Humidity chamber. Although the suppliers might not wholeheartedly agree, humidity chambers are not all created equal! 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, chamber size, 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. One non-chamber-related uniformity issue has to do with the placement of samples and 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.

Most CAF and ECM tests run for hundreds of hours in these humidity chambers. During these extended exposure periods, power outages and mechanical problems with the chamber can occur and cause environmental conditions to change. It doesn't take much of a drop in temperature to raise the relative humidity in the chamber to levels that can adversely impact the test samples. How these occurrences are handled is not defined in any test method and needs to be carefully researched, applied, and recorded in the test report. Efforts to minimize these factors include extensive scheduled preventative maintenance and a power backup generator. IPC-9201 has a section devoted to these issues and would be worth the time to review when considering the effects and remedies for chamber inconsistencies.

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 for measuring the polarity of the DC forcing potential versus the polarity of the testing potential. It appears that the current technical view (mine included) is that for CAF and ECM testing, polarity should remain the same for forcing and testing potentials.

Without a filament or dendrite present, very little current flows through the test circuit (micro- to nano-Amps). Filament or dendrite growth begins to reduce the test circuit resistance, thereby causing increased current flow of the forcing potential. As current flow increases, the power dissipated across the filament or dendrite starts to increase. There comes a point where the power dissipated exceeds the ability of the filament or dendrite to carry it, and the technical state known as "poof" occurs. "Poof" is what occurs when a fuse blows in a car or house; when this happens to a filament or dendrite, it is destroyed and the ions are re-dispersed around the poof area. The measured resistance of the circuit associated with the poof area then may not be as great as that typically associated with filament growth, and the assumption could be made that one did not form. In order to prevent poof from occurring, the maximum current permitted to flow through the test circuit must be limited. This is typically accomplished by placing a resistor of a value between 1 and 10 MΩ in line 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 (micro-Amps).

Despite a current limiting resistor, very small surface dendrites or CAF filaments may still "poof" and disperse. Interesting questions on forcing potential and current limiting strategies remain to be answered in order to maximize the detection of these phenomena.

Megohm meter. A megohm meter is essentially a very stable power supply, a voltage meter, and a pico-Amp meter packaged as a single unit. Resistance is calculated using Ohm's Law (resistance equals voltage divided by current). (These three units, set up individually, also offer a very capable measurement system.) Once a suitable meter setup is decided upon, the most time-consuming aspect is measuring the (typically) large number of individual channels. Given a 60 sec. measurement stabilization (electrification) time per measurement, coupled with the requirement for frequent measurements, it can take a long time to perform a large group of readings. (After taking readings for the first time, a technician will typically be seen in the boss' office, pleading for a switching system to be added to the setup.) Several manufacturers 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. A caveat:

They don't come cheaply.

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 the results. These cables have the dual role to maintain the connection to the test samples and isolate the test channels from each other. Poor cabling can cause false positive or negative results in the test data. There are a plethora of cable types available; attempting 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 and humidity. The best non-halogenated cables available use PTFE or PFE insulation and are of significant cost – a consideration when 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 open the possibility 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 hedge toward stranded cable, but with the recommendation that solid tin-lead solder (with no flux) be used for cable connections. This fluxless solder is used to prevent residues from entering the cable.

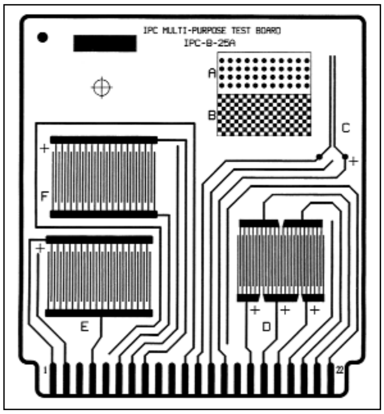

FIGURE 2. IPC-B-25A test board.

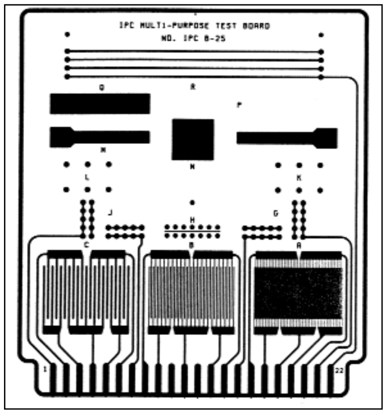

FIGURE 3. IPC-B-25 test board.

High-resistance measurements are very sensitive to electrical interference. The typical test area has computers, controllers, electronic instruments, and, of course, people. All these factors can dramatically affect the measurement of high-resistance values through the introduction of stray voltages into test wiring, thus negatively affecting the results. To minimize the effect of these influences, it is important to shield the cabling from these types of electrical interference. This can be performed via a metal shielding around the cables that is grounded to an earth ground. Unfortunately, this makes the cables bulky and very expensive, but it is necessary for stable test circuit measurements. Once the cables enter the chamber, shielding is typically not necessary because 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 provide another serious consideration. Systems using connectors to attach samples are very convenient, but can only be used when the samples are manufactured specifically for the connectors. Connectors have an end-life 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, thus automatic fixturing is not useful to us. We feel that soldering directly to the sample, although the most time-consuming method, is the most effective way to ensure 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 best efforts, problems arise with cabling systems. This makes it extremely important to test the 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 devise a board on which to mount the resistors and then connect it to the cabling for testing.

ECM/CAF Test Methods

There are several test methods in use that are targeted at ECM and CAF testing. Here, a few are highlighted to give an idea of the basic environmental exposure involved.

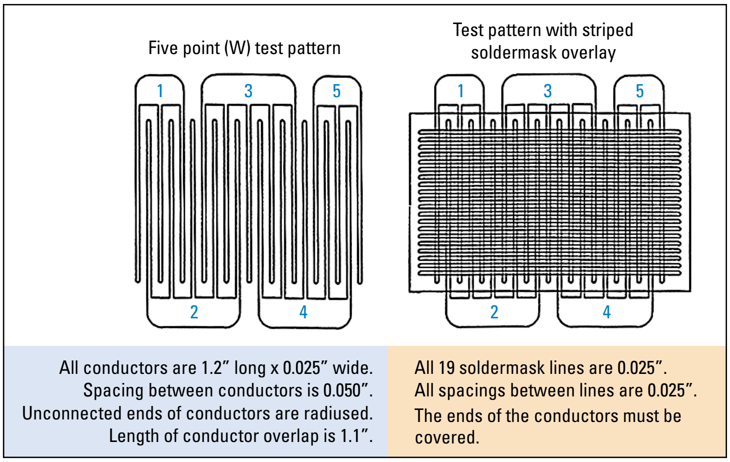

FIGURE 4. Telcordia GR-78-CORE test sample.

IPC. IPC test methods for electrochemical migration resistance are IPC-TM-650, method 2.6.14 for soldermasks and 2.6.14.1 for liquid fluxes, flux cored wires, and solder paste. These test methods require either the the IPC-B-25A (Figure 2) or IPC-B-25 (Figure 3) board test coupon for evaluation. The samples are wired up with 10 MΩ (method 2.6.14) or 1 MΩ (method 2.6.14.1) resistors in-line to each circuit and placed into a chamber that produces one of the following environments (as required 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 hr. stabilization period, insulation resistance measurements are taken 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 hrs. 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.

Telcordia (Bellcore). Telcordia GR-78-CORE has a test method (section 13.1.5) for electrochemical migration that includes a test pattern developed by Bellcore (Figure 4). Samples are wired and placed into a chamber that produces an environment of 65±2°C, 85% minimum RH for 96 hrs. After 96 hrs., insulation resistance measurements are taken at a voltage between 45VDC and 100VDC. The samples are then connected to a 10VDC power supply with 1 MΩ resistors in-line for a period of 500 hrs. with the voltage polarity in the same direction as the measurement voltage. After 500 hrs., 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. Sun's CAF test is performed in a fashion similar to Telcordia GR-78-CORE, with a few 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 PCB (Figure 5). 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 otherwise cloud the results of the potential CAF structures. This test method has been submitted to the IPC Cleaning and Coating Committee for review as an IPC test method. (Sun has also graciously consented to make its test vehicle public, through IPC, to laboratories like mine.)

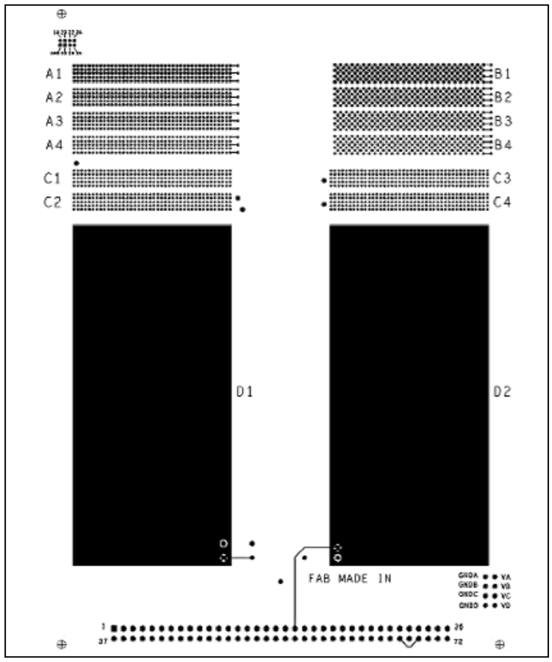

FIGURE 5. Sun Microsystems' CAF test board.

Although ECM and CAF testing may appear easy, there are many obstacles to the proper setup and performance of these tests. Significant capital expenditure and engineering expertise are required to create the conditions under which these tests will work. Do your homework on equipment, fixturing, and test procedures before diving in: The price of an error can be many dollars and thousands of hours of testing. ○

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Ed. note: For more on CAF and its causes, see:

Hein, Marc, "Conductive Anodic Filament Failure: A Materials Update," IPC Printed Circuits Expo Proceedings, March 2001.

Varnell, William, "Conductive Anodic Filament Resistent FR-4 Substrates," IPC Printed Circuits Expo Proceedings, March 2001.

Sauter, Karl, "Electrochemical Migration Testing Results – Evaluating Printed Circuit Board Design, Manufacturing Process and Laminate Material Impacts on CAF Resistance," IPC Printed Circuits Expo Proceedings, March 2001.

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