ELECTROCHEMICAL MIGRATION – HOW FIELD FAILURES OCCUR AND HOW TO AVOID THEM / PART 1

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Electrochemical migration (ECM) is an important topic in terms of the reliability and life span of electronic components, and is repeatedly discussed as the possible trigger for field failures. Due to the ever increasing requirements in terms of greater packing densities/miniaturisation as well as external environmental influences, focus is being placed on field failures triggered by humidity or impurities, particularly in components that are exposed to changing environmental influences.

Examples of this are the automotive, aviation and telecommunications industries that serve a global sales market while having to ensure the electronic components functionality is maintained in each climate zone when subject to high temperature fluctuations and extreme humidity.

As a failure function caused by humidity, electrochemical migration (a form of corrosion) reduces the reliability and life span of electronic components and is frequently responsible for climate-related failures. Typical failure patterns that point to electrochemical migration are temporary and permanent short circuits. Even temporary short circuits generally result in failure of the electronics, which normally go into fault mode. Permanent short circuits can lead to local overheating of the circuit carrier board, causing the polymer material to graphitise or the component to burn.

But how does electrochemical migration occur? How can the risks be assessed and, most importantly, how can it be avoided? In practice, coating processes are frequently assumed to be a complete solution. The subject of the cleanliness of components is also discussed. But in order to provide a specific answer for individual cases, it is important to understand the details of the underlying processes.

The first part of this article explains the conditions and generation mechanism of electrochemical migration, the difference compared to other dendritic failures, and also addresses its consequences. The second part of the article discusses the various methods of preventing and avoiding field failures.

CONDITIONS LEADING TO THE OCCURRENCE OF ELECTROCHEMICAL MIGRATION

The main factor for electrochemical bridging is the presence of moisture, as this allows corrosion to develop. Moisture can occur on the component in two different ways; the first is moisture film being adsorbed on the surface, the second is condensation.

The critical humidity required for the adsorbed moisture film primarily depends on the surface energy and polarity (of the material), especially solder masks and their filling degree. Particularly with humidity, this is often reached considerably below the condensation point, i.e. the temperature difference when the first water drops form on the surface. A film thickness of just a few monolayers is enough to start the corrosion process.

In addition to adsorbed moisture film, condensation caused by a change in temperature can also lead to electrochemical migration. Compared to the moisture film, condensation is concentrated on the areas that emit heat the slowest, i.e. metallisation layers or on hygroscopic areas such as impurities. Typical soldering residue, such as organic acids or halides reduce the local condensation point to 60% relative humidity.

Another important factor is the material used. A sufficient number of layers for a moisture film forms e.g. on metals or metal oxide surfaces from a critical humidity of 60% - 70% RH (Relative Humidity) or on quartz solder masks. In addition, corrosive gases such as nitrogen compounds, H_2S and CO_2, have an impact and also dissolve into the moisture film (Image 1).

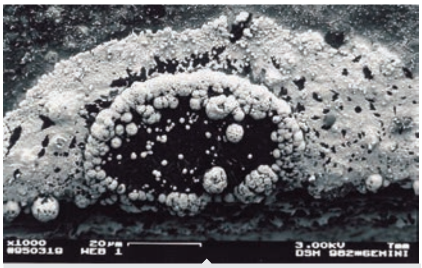

Image 1: Creep corrosion caused by corrosive gases

On aluminium oxide ceramics or unfilled, non-polar solder masks, a sufficient number of layers for a moisture film is reached at 90% RH or higher. On an Sn-plated epoxy substrate, i.e. on the circuit boards, the moisture tends to condense on synthetic resin surfaces under constant climatic conditions and is adsorbed and stored until the partial pressure is balanced.

Furthermore, a metallised or solder material must be present to enable electrochemical migration. This means that the material must have an active area in alkaline electrolytes (see grey areas in Image 2). Silver, copper, lead, tin, and cadmium in particular migrate in distilled water. The tendency to form a bridge very distinctly follows the potential of the galvanic series and the expansion of the active material behaviour in the alkaline area. In contrast, nickel, for example, does not migrate or corrode under condensation conditions. The pH potential diagram, the so-called Pourbaix diagram, can be used to estimate how susceptible an element is to electrochemical migration (Image 2).

In addition to humidity and the material used, residue and impurities in particular affect the generation of electrochemical migration on components. The formation of condensation is more likely in the presence of hygroscopic flux residue, dust or salt crystals on surfaces that act as condensation areas or nuclei for moisture and corrosive gases. In addition to aiding adsorption, these kinds of impurities act as a moisture store on the surfaces so as to guarantee, e.g. the otherwise quick drying of polymers at a relative humidity of less than 30% RH.

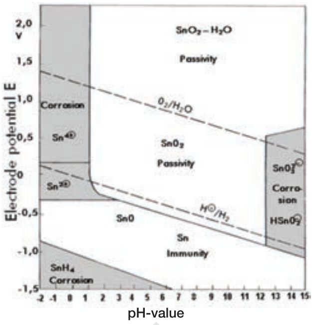

Image 2: Pourbaix diagram for tin

THE GENERATION MECHANISM

1. Anodic dissolution of metals

As a result of the moisture film adsorbed on the surface of the components, the surface resistance and therefore the required insulation of the solder masks or circuit boards is reduced. From a critical film thickness, the intrinsic conductivity of the adsorbed pure water film enables electrolysis. This causes a strong local alkaline effect on the anode, i.e. on the power supply (VCC) or contacts sending the signal. By increasing the pH, particularly silver, copper, tin, and lead, currently the most common plated elements, are polarised in an electrochemically active area.

As a result of the dissolution of the anode area proportional to the shunt current between the contact and ground, i.e. the ground contact, a high metal hydroxide, or depending on the electrolyte, a metal complex concentration is formed that spreads mainly along the concentration gradients (Image 3).

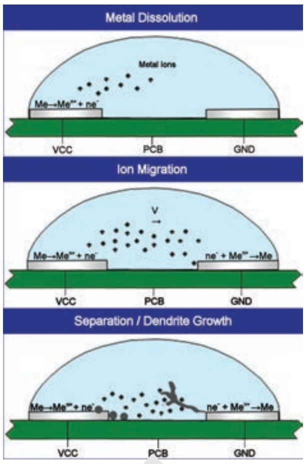

Image 3: Schematic representation of dissolution, ion migration and separation

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The kinetics of the dissolution is carried out by direct dissolution from the lattice, from the edges on dislocation areas that emerge on the surface and at flaw areas or by adsorbed adatoms during continuous hydration.

It can be seen that the tendency to form a bridge is linked to the dissolving or solvation power of the ions. For example, Ag(OH), which is easily formed in aqueous media and is very soluble, is enough for the migration of silver. In contrast, gold is only dissolved if a chloroauric complex can form. This shows that some elements cannot form bridges under pure water conditions and the tendency to migrate is greatly increased by impurities.

2. Migration of metal ions

It seems the migration of dissolved metallisation ions is only determined by the surrounding electrical field if the conductivity of the electrolytes is solely dependent on the metallisation ions and not the degree of contamination. This condition is met as long as the concentration of the contamination on the PCB does not exceed the concentration of the migrating metallisation ions.

The migration of the ions is determined by the potential and concentration gradients. The potential gradient is determined by the surrounding operating voltage and the conductor spacing, the concentration gradient is determined by the dissolution and diffusion speed of the solvated metallisation material ions; here the movement of the ions very much depends on the diameter of the complexes after solvation as well as the dissolution speed from the signal and stand-by current and the active surface. If the potential gradient of the migrating ions is small compared to the concentration gradients, the ions diffuse along the concentration gradient. If this is large enough, the ions may even migrate against the electric field from the ground to the contact.

3. Separation of metal ions

The actual bridge is formed either by galvanised separation from the cathode (GND) or, less frequently, by the precipitation of hydroxide, oxyhydrates or complexes as salts, so-called staining from the anode (VCC or signal contact).

Galvanic separation occurs more commonly in areas with a high field strength. If there is low solution conductivity due to a small concentration of ions, the field lines are concentrated at the tips and edges. This leads to further development of the lattice distortion on the surface in the solder joints or VCC metallisaton layers, as well as to micro roughness and the formation of dendritic structures via pyramid growth (Image 4). If the ion concentrations or gradients are high, this results in smoother growth structures. Either ribbons or fibre bundles are formed (Image 5).

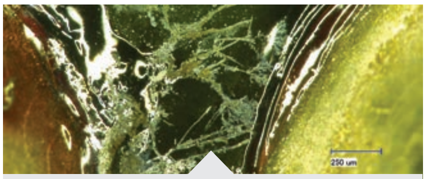

Image 4: Dendrite growth

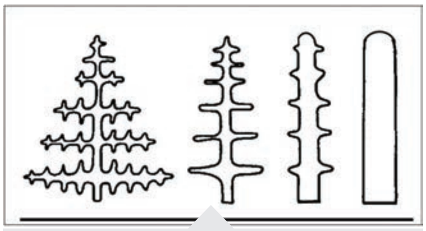

Image 5: Comparison of the growth structures - fibre bundles and ribbons

The speed at which the bridge is formed can be reduced by larger and aligned grains in the solder joint, i.e. by the solder profile. The larger grains reduce the number of faults as they introduce grain boundaries. Here, there is a conflict with the mechanical stability of the welds as the objective here is fine grains.

Staining occurs if the solubility of hydroxide or complexes in the adsorbed moisture or condensation film is exceeded and they precipitate as salts, e.g. tin adipates. During galvanic separation, the formation of mainly metal bridges can be expected. During staining, the composition of the bridge depends on the electrolytes, as metal salt and complex compounds form here.

The migration bridges can span over distances of up to several millimetres on the surface as well as inside the fibre-reinforced base materials. If the dendrites run along the fibres in the substrate, electrochemical migration is identified as CAF (Cathodic Anodic Filament Growth).

4. Differentiation between electrochemical migration and other dendrite failures

In order to remedy the cause of failures, it is important to differentiate between electrochemical migration and other failure mechanisms with the appearance of dendrite. This concerns mainly dielectric breakdown and graphitisation on components such as barium titanate condensers.

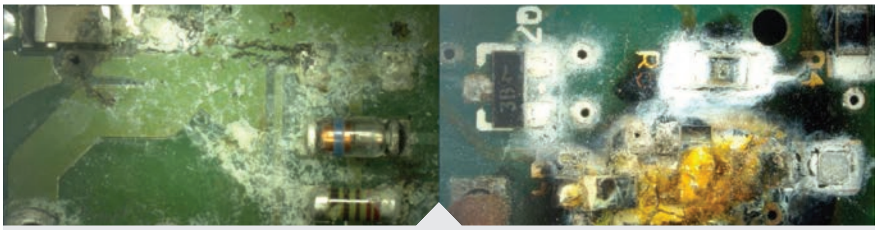

Image 7: Damage caused by electrochemical migration (left) and dielectric breakdown (right)

Dielectric breakdown is mainly caused by pores or blisters in the solder paint and less frequently in protective paint or casting compounds. Moisture deposits can further diminish the reduced insulation. Here, the coating must be improved in order to deal with porosity as the cause.

Depending on the quality standard, ceramic condensers with organic coatings appear on the market, the insulation of which can be too small for the application or as a result of moisture or impurities. Here, tree-shaped graphite structures also form due to dielectric breakdown, as with the porosity of the solder paint. Field experience shows that a certain degree of coating has a favourable effect on the stabilisation against electrochemical migration as these layers are mostly hydrophobic.

CONSEQUENCES OF ELECTROCHEMICAL MIGRATION

It is often impossible or extremely difficult to verify electrochemical migration (ECM) as the cause of damage or failures. While only small dendrites occur during short condensation times of typically a few minutes, they are not conductive and immediately burn off. This results in the end user being dissatisfied, as well as reputational damage and high follow-up costs for the failure depending on the application. To verify electrochemical migration, the affected boards must be taken out of the field and examined under a scanning electron microscope for ECM traces. Unfortunately, this is often not possible for logistical reasons alone. This is why these failures, together with software errors and creep effects, appear as non-specific failure functions.

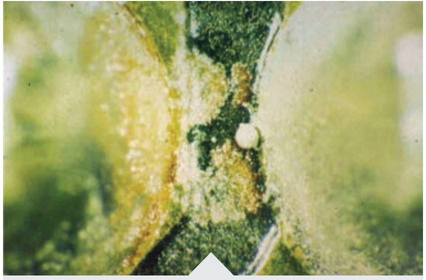

Image 6: Conductive dendrite formation, yellow and red tin oxide indicates high temperatures.

However, when stable, i.e. conductive dendrites form, temperatures of some 100°C quickly occur (Image 6).

If the board does not have the right fuse and switch-off function, these temperatures will cause burning. But because this destroys the board, it is a matter of speculation in many cases whether the burning was caused by electrochemical migration or e.g. dielectric breakdown (Image 7). However burning, from cars to wind turbines, generally causes a great deal of reputational damage.

Continue reading in our next issue:

Electrochemical migration - how field failures occur and how to avoid them

Part II: Avoidance and preventative measures

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