Electromigration

Electromigration is an electrochemical process where metal on an insulating material, in a humid environment and under an applied electric field, leaves its initial location in ionic form and redeposits somewhere else. Such migration may reduce isolation gaps and ultimately lead to an electrical short circuit.

The process begins when a thin continuous film of water has been formed and a potential is applied between oppositely charged electrodes.

Positive metal ions are formed at the positively biased electrode[1] (the anode), and migrate toward the negatively charged cathode. Over time, these ions accumulate as metallic dendrites, reducing the spacing between the electrodes, and eventually creating a metal bridge.

1. Electromigration is closely related to corrosion, with the anode being attacked, but which circuit element is the anode is determined by the *applied* field rather than the oxidation potential of the metal used.

Whilst most often seen as a surface effect, vertical migration can also occur when moisture has penetrated into the bulk of a porous material.

Dendritic growth across tracks on a PCB

Dendrite growth across resist

The rate of electromigration increases with temperature and has four prerequisites – a mobile metal; a voltage gradient; a continuous film of moisture; soluble ions:

- Silver is the metal most susceptible to migration, since it is anodically very soluble and requires a low activation energy to initiate the migration process. Copper, zinc, and lead will also migrate, although only under much more severe conditions. Most other common electronic materials are not susceptible to migration: iron, nickel, and tin because of their low solubility in water; gold, platinum, and palladium because they are anodically stable.
- The severity of electromigration increases with applied potential gradient, the time to grow dendrites decreasing both with reducing electrode spacing and increasing voltage. The time to failure is a log-linear function of voltage at low voltages, but reaches a minimum as the effect becomes transport limited by the number of ions available.
- How much moisture is needed has been hotly debated. Whether the moisture needed represents just few monolayers, or several hundred monolayers, depends on the nature, structure, and porosity of the surface, and on its affinity for water. For example, phenolic resin laminates are more hygroscopic than ceramic substrates and are thus more susceptible to migration.
- The type of surface has another effect on electromigration, because nucleation sites are required for dendrites to initiate and grow, and these are provided by the surface roughness of the substrate and the presence of sharp corners and kinks.
- The rate of electromigration increases with relative humidity, but will become significantly worse if changing conditions encourage the formation of water droplets. This has been

reported as a main factor in MLC failure due to tin and silver migration.

- A soluble ionic species is essential to provide the conductive medium for the migration to occur, and the nature of the ionic contaminants has a major impact on performance. The severity of electromigration depends on the particular ionic species involved, and factors such as its mobility, ionic radius, electronegativity, electron affinity, and charge to size. Ionic contaminants come from a wide range of sources such as activators in the flux, reaction products of the soldering process, the breakdown of cleaning solvents, and fingerprints.

The move to finer pitch components, and consequently reduced spacings, makes electromigration more likely, because the voltage gradients between conductors increase and it becomes more difficult to eliminate the minute amounts of ionic contaminants which are sufficient to cause problems.

Three main methods have been used to reduce the electromigration problem:

- Alloying any silver with an anodically stable metal such as palladium or platinum. This is one reason (as well as the improvement in solderability) why palladium-containing silver alloys are preferred to pure silver for MLC terminations
- Using a coating of solder resist to shield the PCB surface from humidity and ionic contaminants. Exposed epoxy glass is much more hydrophilic than most solder mask materials, and the improvement in Surface Insulation Resistance is typically several orders of magnitude
- Plating any silver with metals such as tin, nickel, or gold. In MLCs, the nickel barrier coating improves resistance to electromigration as well as enhancing performance on exposure to molten solder.

Source : http://www.ami.ac.uk/courses/topics/0158_emgr/index.html