

Electrolytic Electromigration of Metallic Material and Silver Filled Epoxy

Electrolytic Electromigration Basics

The most common electrolytic electromigration process in modern electronics is that associated with Ag from silver-epoxy, which is used as a die attach material in many components. When Ag epoxy is placed on an anodic (+) die pad with a cathodic (-) electrode near by, the silver filled epoxy can undergo dissolution creating Ag^+ ions with presence of moisture and ionic contaminants (such as traces of chlorine or bromine). Once this occurs, a dc electric field between the anode and cathode will pull the silver Ag^+ ions across to the cathode which will travel across the insulator in the presence of absorbed surface moisture layer acting as an electrolyte as shown in Figure 1

The silver ions are reduced at the cathode to pure silver and builds up resulting in the

growth of dendrite tree like structures as shown in Figure 2. This build up eventually bridges the gap between the anode and cathode causing a weak electrical short. At first, intermittent shorts occur as the shorting current fuses the dendrite opening the short. However, the build up continues usually until a lasting short causes circuit failure. In summary, electrolytic electromigration requirements of silver are:

- The presence of moisture on the surface of an insulator
- High dc electric field caused by a combination of voltage difference and narrow line spacing
- Silver epoxy on an anodic (+) site relative to a nearby cathodic (-) site
- The presence of contamination

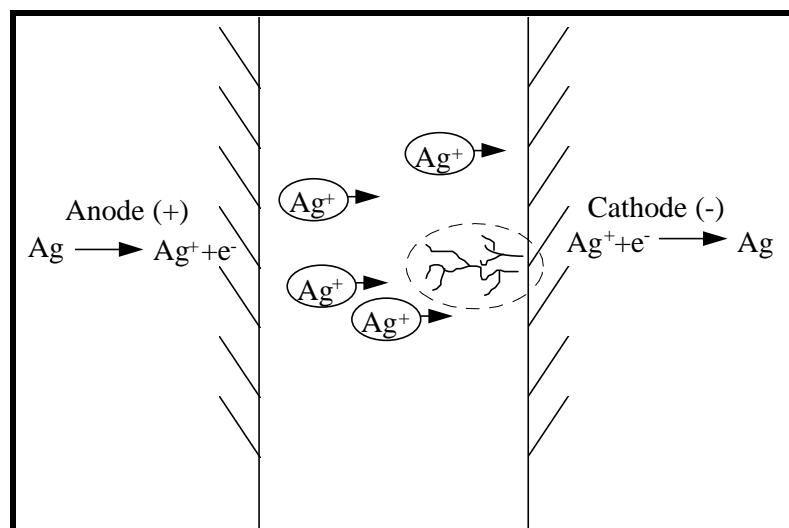


Figure 1 Schematic diagram of early stages of dendrite growth [1]

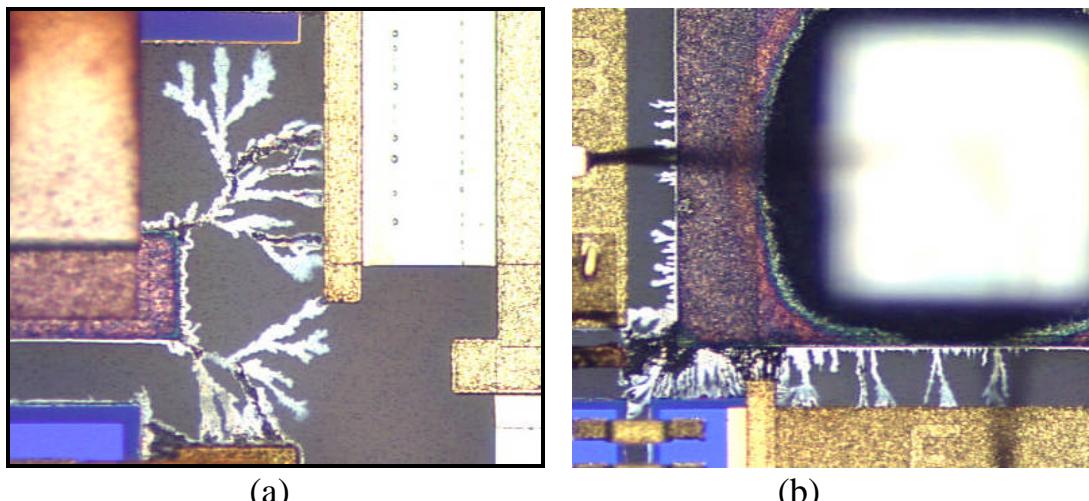


Figure 2 Silver dendrite resulting from 1000 hours of aging at 85°C/85%RH and 2.5 Volts dc bias of silver epoxy attachment. Dendrites traversed conductor spacing of approximately 50 to 125 μm having electric fields between 20,000 and 50,000 V/m.

Recommended Design Actions

- 1) Avoid placing silver epoxy on an anodic site
- 2) Use high quality silver epoxy with small as possible ppm of chlorine or bromine
- 3) Reduce the electric field in a critical region by increasing line spacing or decreasing voltage potentials. There is no rule of thumb. Fields strengths such as 1,000 V/M may seem low, however, electromigration can occur.
- 4) Improve die pad geometries to reduce high edge E-fields rounding die pad corners, etc.
- 4) Shielding low electric fields in critical situations can be effective in relatively low humidity conditions. This can be accomplished by using a large enough die pad that the epoxy is well contained away from the edges. Therefore, remains Faraday shielded edge fields.
- 5) Maintain low moisture content in the package
- 6) Substitute gold filled epoxy when the wrong polarity is required

7) Under critical situation protect the epoxy with a conformal coating like Silicon type Gel.

Tutorial Information:

Most of the information below is taken from the article IEEE Tutorial on Electrolytic Models for Metallic Electromigration Failure Mechanisms, IEEE Transaction on Reliability, Vol. 44, No. 4, 1995 December

Electrolytic Electromigration

Electrolytic electromigration usually includes all migration phenomena that involve the transport of metal (usually across a nonmetallic medium) under the influence of electric field. After migration, the metallic material functions as a conductor. This process differentiates itself from, corrosion (where corrosive by products are not fully conductive), and tin whiskering effects (resulting from mechanical stress not electrical field related).

The term electromigration in the literature usually refers to solid state electromigration

as compared with electrolytic (ionic) electromigration. Solid state electromigration is the movement of metal within a conductive path due to electron momentum transfer (scattering) resulting from high current densities ($> 10^4 \text{ A/cm}^2$) often at high temperatures of 150°C . In contrast electrolytic migration is the movement of metal across a non conductive path results at lower temperatures ($<100^\circ\text{C}$) at low current densities ($<1 \text{ mA/cm}^2$) in the presence of moisture.

Electrolytic Electromigration is an Electrochemical Phenomenon

Electrolytic electromigration is an electrochemical phenomenon that occurs primarily under normal ambient conditions, when the local temperature and current densities are low enough to allow moisture on the surface. This is because the actual mechanism of electrolytic electromigration is water-dependent, and tends to occur whenever the insulator separating the conductors has sufficient moisture to allow electrolytic (ionic) conduction when an electrical potential is applied.

This is primarily a dc phenomenon. Although these electrolytic effects can occur with many metals, only silver, and to a limited extent copper at high temperatures, normally undergoes electromigration under non-condensing, but humid conditions. Other bulk metals usually require a visible layer of water to migrate.

How Does It Work?

In the simplest case, metallic silver on the conductor with the more positive applied potential (anode) is oxidized to a more soluble form (see Figure 1). The resulting positively charged ions then move under the influence of the electric field through moisture paths or in the insulator towards

the negative conductor cathode, where they are reduced back to silver metal.

Electromigration leads to colloidal staining and filament dendritic bridging as shown in Figure 2. The dendritic growth results because ions tend to deposit at localized sites on the cathode in the form of needles or spikes. The build up of the deposits grows dendrites back to the anode bridging the circuit between anode and cathode and resulting in a low resistance type of short. There are three basic electromigration steps of silver:

- a. Oxidation or dissolution at the anode creating silver ions
- b. Migration across the insulator towards the cathode,
- c. Reduction and deposition back to pure silver

Although the magnitude of the initial resistance short is small, the dendrite thickens and rapidly increases in additional bridges and eventually lowers the resistance to the point of short circuit failure. Often initial intermittent type problems arise because the initial short, open as the current surges through the dendrite fusing the weak dendrite conductive path. Usually this intermittent behavior gives way to a permanent short as the dendrite thickens over time.

Conditions that Promote Electromigration

The primary operating conditions that promote electromigration in the presence of humidity $<100\%$ are

1. Moisture
2. Contamination such as Cl^- ion content in silver epoxy

- 3. Voltage difference between conductors with silver at the anodic electrode
- 4. Narrow (width) spacing promoting high electric field
- 5. Elevated temperatures

Moisture

Moisture is necessary to create a comparatively low resistance electrolytic path between two conductors of opposite polarity. This path is usually on the surface by an absorbed layer of moisture. This nature of the absorption is that it is related to the insulator type and quantity of surface contamination. However electromigration can migrate into insulators such as through a poor quality dielectric glaze.

It has been shown experimentally that the higher the RH, the faster the onset of electromigration and the greater the probability of low-resistance failures. However for any RH, the tendency of moisture adsorption on the insulator material depends on the surface type and its condition. Insulator materials with strongly polar groups, like phenolics, nylons, alumina, porcelain, or glass, have a much higher susceptibility to electromigration than hydrophobic materials like Mylar (polyester) or polyethylene since the latter materials have a much lower propensity for moisture adsorption.

Contamination

Many types of contaminants and impurities can be present on the insulator and interface effecting electromigration differently. Contaminants increase electromigration by increasing

- 1. Moisture absorption on surface
- 2. Conductivity of the moisture via ionic contaminants
- 3. Reactions with migrating ions

- 4. Surface solution stabilization

In general, ionic oxidants, such as ferric chloride etchant residues, encourage silver dissolution for migration. In other cases, ionic residues increase the conductivity of the absorbed moisture film increasing the migration current.

Voltage, Spacing and Conductivity

Many experiments have shown that the higher the polarizing dc voltage (bias), the greater is the rate and severity of the electromigration. Since the field is a function of the bias and line spacing (volts per meter), both are important considerations. In Figure 2 we see that the voltage bias is 2.5 volts with line spacing between approximately 50 to 125 μm yielding electric fields between 20,000 and 50,000 V/m. The electric field is a major driver in moving silver ions (Ag^+) from the anode to the cathode. Simply viewed, the microscopic ohms law is

$$\text{Current density} = \text{Electric field} \times \text{Conductivity} \quad (\text{or } \mathbf{j} = \sigma \mathbf{E})$$

Thus, the physics is fairly simple, electric field and surface (or bulk) conductivity are key factors effecting Ag^+ ions migration current density on the surface (or in the bulk).

One way to eliminate the electric field is to shield it. For example, if Ag epoxy is well contained within a die pad, the field may be shielded and contained between the nearest conductor and the edge of the die pad. That is, as long as the humidity does not cause excess wetting conditions or stays reasonably low, the E-field should remain shielded away from the epoxy.

Temperature

All other things being equal, the higher the temperature, the more extensive the migration. Temperature increase the conductivity of the electrolytic surface and speeds up the migration of silver ions towards the cathode. This increase in conductivity is due to the increase in ionic mobility with temperature.

Water Drop Test

A fairly quick method to see if a part is susceptible to electromigration under humid condition is the water drop test. For example, at 85°C and 85%RH the time to cause dendritic growth and cause a short may be one to four weeks. On the other hand, when a drop of water is placed between the conductors at room temperature, the same part will usually cause dendritic growth in minutes. Unfortunately, as line widths become smaller and smaller, wet electromigration may be an issue in normal use. For example, capillary condensation of water in the very small nooks and crannies can occur. Other problems arise from aqueous, semi-aqueous cleaning, and no-clean fluxes (many of which are water absorbing) on migration-susceptible surfaces.