# CORROSION IN MICROELECTRONICS

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## Abstract

Corrosion induced failure plays an important role in microelectronic device and package failures. It depends on package types, materials, fabrication and assembly processes, and environmental conditions such as moisture condensation, temperature, residual and thermal stress, ionic and organic contamination, and electrical bias. The most commonly used metals and alloys in microelectronic devices and packages include aluminum, gold, copper, silver, tin, lead and their alloys. There are three major corrosion types – galvanic corrosion, pitting corrosion and stress corrosion cracking. The driving force for electrochemical corrosion is the potential difference between anode and cathode. Aluminum is a very active metal and acts as anode to be corroded when coupled with another metal such as Al/Au in the electrolyte solutions. Metals such as aluminum and Kovar also suffered from stress corrosion cracking when exposed to halide ion containing electrolyte solutions and under tensile stress, which may be applied externally or residual or thermal stress. In order to reduce corrosion of microelectronic devices and packages, it needs a better design for stress management, better protection of the die from moisture environment, elimination of contaminants and adding proper protective barrier layer.

## 1. Introduction

Fifty years ago, the invention of the transistor revolutionized the electronic industry. Today, microelectronic products have been widely used in all kinds of industries and the microelectronic industry has become the most important industry which acts as driving engine for science, technology, manufacturing and overall economy. Currently its worldwide annual market is about 1 trillion and is expected to reach 2 trillion within 10 years. Of the 1 trillion worldwide markets today, electronic packaging takes up about 109 billion. This huge market is still fast expanding [1].

In order for microelectronic components and devices to perform their functions properly, a high reliability packaging is must. Failures of microelectronic devices and packages not only cause the malfunction of the devices selves but also sometimes lead to catastrophic affairs for the whole systems, which may cause a huge loss of lives, properties and safety. Among all microelectronic device failures, corrosion related failure is responsible for more than 20% [2]. Corrosion in microelectronic packaging depends on the package type, electronic materials, fabrication and assembly processes, and environmental conditions such as moisture condensation, ionic or organic contaminants, temperature, residual and thermal stress and electrical bias etc. With the ever-reducing feature sizes of microelectronic components and devices, they are more susceptible to corrosion-induced failures. The better performance and reliability requirements drive to improve corrosion-resistance of packaging systems.

There are basically three types of packaging for microelectronic components and devices. They are ceramic, metal and plastic packaging. Ceramic and metal packages are hermetic packages mainly used in the military, aerospace and automobile microelectronic devices because those devices are subjected to variable and often severe environments, but they are required to have a high reliability. Plastic packaging is non-hermetic package and become more and more widely used because of its commercially cheap cost and better manufacturability. Compared to other package types, plastic packaging systems have more corrosion-related problems because the polymeric materials used in plastic package systems provide more chances for the leakage and permeation of moisture and corrosive gases into the inside dies, wires, bond pads, lead frames and solder joints. Therefore, problems with corrosion will be long-term issues in microelectronic packages.

## 2. Corrosion mechanisms in microelectronic packaging

Microelectronic packaging systems are constructed from a wide range of materials. They make use of almost all major kinds of materials, such as metals, alloys, polymers, ceramics and fibers. Corrosion-induced failures in microelectronic packaging become more significant when the feature sizes become smaller and smaller because small features are more sensitive to corrosion-induced failure. Corrosion involves essentially electrochemical processes except for those oxidized at the elevated temperature and in the dry environment. The basic requirements for electrochemical corrosion include electrically conductive anode, cathode, interconnecting electrolyte (humidity environment) and driving force. The driving force for electrochemical corrosion is the difference of electrochemical potentials between anode and cathode. The driving force can result from coupling of two dissimilar materials, concentration gradient or externally applied electrical bias. Any corrosion reaction must be analyzed from two aspects: its thermodynamic feasibility and its kinetics. Driving force gives the thermodynamic feasibility and kinetics is determined by the variables of the system.

The electrochemical corrosion kinetics (rate) depends on a number of factors, which include the area ratio of anode to cathode, the polarization resistance of anode and cathode, conductivity of electrolyte solution, solution pH value, temperature, contamination, and driving force. Small anode and big cathode system corrodes much faster than big anode and small cathode. This is the case for the active metal coated with noble metal. For instance, gold is deposited onto aluminum pad to prevent aluminum from corrosion. If defects of deposit gold layer exist and small area of fresh aluminum is exposed to the corrosive environment, aluminum is corroded much faster because of small anode of exposed aluminum and big gold deposit layer around. Another example is paint coated aluminum wire. Polarization occurs when a current passes through an electrochemical system. There are three types of polarization phenomena such as resistance polarization, concentration polarization and electrochemical activation polarization. For those metals or alloys with stable protective oxide/hydroxide layers formed on their surface, the resistance polarization is very significant and their corrosion rate may be very low due to the high resistance (R) in the electrochemical cell. This is basically how corrosion resistant metals and alloys such as stainless steels, nickel and its alloys, copper and its alloy work well in some corrosive environment. Halide ions such as chloride, bromide are good depolarizers to break the stable oxide/hydroxide layer and reduce resistance polarization. The resistance polarization can also be caused by poor conductivity of the electrolyte solution. Concentration polarization occurs when there exists concentration difference between around electrode and inside the solution or concentration difference at difference sites of the electrode. The consequence of concentration polarization will yield potential difference due to concentration gradient. Corrosion due to concentration gradient is controlled by diffusion of reacts and products in the electrolyte. For electrochemical activation polarization, it relates to the rate-determining step for an electrochemical reaction process. For example, Al-Au galvanic couple in the electrolyte solution, Al acts as anode and Au acts as cathode. Aluminum loses electrons to be oxidized and these electrons are transferred to gold cathode. Electrons will be accumulated at the cathode if the cathode reduction reaction is very slow because it needs higher activation energy. The consequences of the activation polarization in this case will change the cathode reduction potential to more negative and slow the corrosion rate. Hydrogen evolution reaction and oxygen reduction reaction are two-cathode-depolarization reactions.

In microelectronic devices and their packaging, there are three major types of corrosion. They are galvanic corrosion, pitting and stress corrosion crack. Since aluminum and its alloys are the most widely used metal and corrosion of aluminum is one of the commonest problems in microelectronic devices and packages, aluminum is used as an example material for describing and discussing corrosion mechanisms.

## 2.1 Galvanic corrosion

Galvanic corrosion is also called dissimilar metal corrosion. Basically it refers to a corrosion phenomenon induced when two different metals or alloys are coupled in a corrosive electrolyte. When two dissimilar metals or alloys are brought into electrical contact under electrolyte such as water with ions, one of the metals or alloys with lower electrochemical reduction potential acts as anode and corrodes faster than its natural corrosion while the other one with higher electrochemical reduction potential acts as cathode and corrodes slower than its natural corrosion or even is stopped from corrosion. Galvanic corrosion can also occur in an alloy with multiple phases such as aluminum-copper alloy. Different phases have different electrode potentials, which results in one phase with lower electrode potential acting as anode and being selectively corroded.

In the microelectronic packaging, the commonly used metals or alloys are aluminum, copper, gold, silver, tin, lead, nickel and their alloys. There are lots of places involving two-dissimar metals electrical contact together such as die pad (Al/Cu), wire to die pad bond (Au/Al), bump metallization [1, 3] (Al/Ni/Cu, Al/Ti/Cu, Al/Pd/Cu, Al/Zinc/Ni) for flip chip. Table 1 [4] gives galvanic series of metals used in electronic packaging. From Table 1, it is found that aluminum is the most active metal and gold is the noblest metal. If two metals are compared, the one in the lower place of Table 1 is more active. For example, aluminum is more active than tin. If aluminum and tin contact together in an electrochemical system, aluminum acts as anode and tin acts as cathode.

Table 1 Galvanic Series of Metals in Seawater

| | |
|---|---|
| | Cathodic (Noble) |
| Gold (Au) | ↑ |
| Titanium (Ti) | |
| Silver (Ag) | |
| Nickel (passive) | |
| Copper | |
| Nickel (active) | |
| Tin | |
| Lead | |
| Iron | |
| Zinc (Zn) | |
| Aluminum | |
| | Anodic(active) |

When Al/Cu couple is exposed to the water solution, galvanic corrosion occurs. Since aluminum has a lower reduction potential ($E_{Al^{3+}/Al} = -1.66 V vs. SHE$), it acts as anode. If the intermetallic compound phase ($Al_2Cu$) like Al/Cu bond pads exists, the local cathode is $Al_2Cu$. If $Al_2Cu$ does not exist, the cathode is copper ($E_{Cu^{2+}/Cu} = +0.34 V vs. SHE$). The driving force for Al/Cu under standard condition is 2.00V. The corrosion product of aluminum is usually believed to be $Al(OH)_3$ in the microelectronic packaging because the moisture environment is usually weak acid or neutral, but it actually depends on the pH value of electrolyte solution and activity of aluminum ions in the solution. (see Figure 1). There are three general reactions [4] by which aluminum may react anodically in the presence of water.

At anode, dissolution of metal:

(a) At low pH value,

$$Al - 3e \rightarrow Al^{3+} \qquad E_{Al^{3+}/Al} = E^0_{Al^{3+}/AL} - \frac{RT}{3F}\ln a_{Al^{3+}} = -1.662V - 0.020\ln a_{Al^{3+}} \tag{1}$$

$$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \tag{2}$$

(b) At some pH value in a range of weak acid to neutral,

$$Al + 3H_2O - 6e \rightarrow Al_2O_3 + 6H^+ \tag{3}$$

$$E_{Al_2O_3/Al} = E^0_{Al_2O_3/AL} - \frac{RT}{F}\ln\frac{1}{a_{H^+}} = -1.55V - 0.059\,pH \tag{4}$$

(c) At some high pH (strong base solution)

$$Al + 2H_2O - 3e \rightarrow AlO_2^- + 4H^+ \tag{5}$$

$$E_{Al_2O_3/Al} = E^0_{AlO_2^-/AL} - \frac{RT}{3F}\ln\frac{a_{AlO_2^-}}{a^4_{H^+}} = -1.26V + 0.020\ln a_{AlO_2^-} - 0.079pH \tag{6}$$

At cathode, the reactions may be following:

(a) Evolution of hydrogen from solutions

$$2H^+ + 2e \rightarrow \frac{3}{2}H_2 \quad (acid\ solutions) \tag{7}$$

$$E = E^0_{H^+/H_2} - \frac{RT}{3F}\ln\left(\frac{P_{H_2}^{\frac{3}{2}}}{a^3_{H^+}}\right) = 0.0V - 0.059\ln\left(\frac{P_{H_2}^{\frac{1}{2}}}{[H^+]}\right) = 0.0591pH - 0.0128\ln P_{H_2} \tag{8}$$

$$2H_2O + 2e \rightarrow H_2 + 2OH^- \quad (neatral\ or\ alkalinesolutions) \tag{9}$$

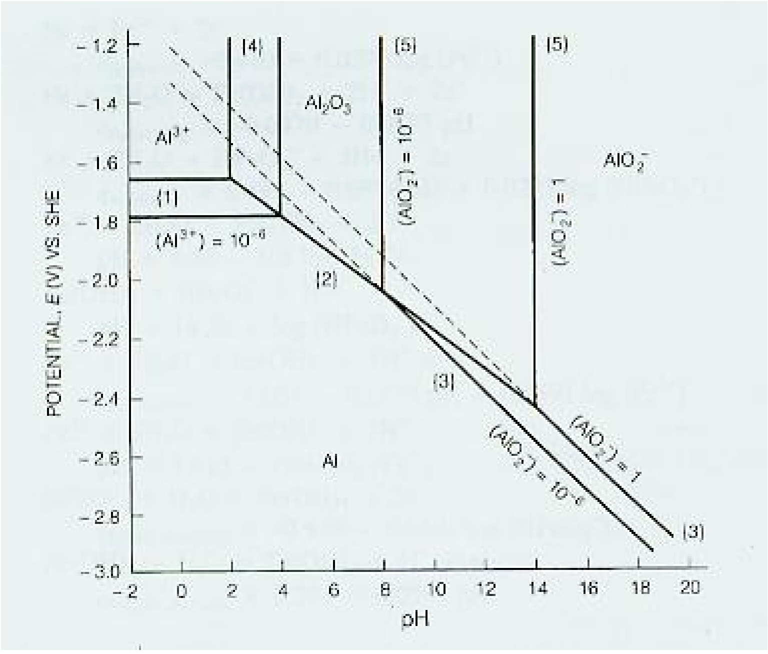

Figure 1. Potential/pH diagram for aluminum

(b) Reduction of dissolved oxygen in solutions

$$\frac{3}{4}O_2 + 3H^+ + 3e \rightarrow \frac{3}{2}H_2O \quad (acid\ solutions) \qquad (10)$$

$$E = E^0_{H^+H_2O/O_2} - \frac{RT}{3F}\ln\left(\frac{1}{P_{O_2}^{\frac{3}{4}}a_{H^+}^3}\right) = 1.23V - 0.0591pH + 0.0064\ln P_{O_2} \qquad (11)$$

$$\frac{3}{4}O_2 + \frac{3}{2}H_2O + 3e \rightarrow 3OH^- \quad (neatral\ and\ alkaline\ solution) \qquad (12)$$

$$E = E^0_{OH^+H_2O/O_2} - \frac{RT}{3F}\ln\left(\frac{a_{OH^-}^3}{P_{O_2}^{\frac{3}{4}}}\right) = 0.41V - 0.0256\ln\left(\frac{a_{OH^-}}{P_{O_2}^{\frac{1}{4}}}\right) = 1.23V - 0.0591pH + 0.0064\ln P_{O_2} \ (13)$$

(3) Reduction of dissolved oxidizer in a redox reaction

$$Cu^{2+} + 2e \rightarrow Cu \qquad (14)$$

$$E = E^0_{Cu^{2+}/Cu} - \frac{RT}{2F}\ln\left(\frac{1}{a_{Cu^{2+}}}\right) = 0.340V + 0.0256\ln a_{Cu^{2+}} \qquad (15)$$

## 2.2 Pitting corrosion

Pitting corrosion occurs for metals and alloys with protective passive layers. It usually initiates at or around the precipitates, inclusions, grain boundaries, and other defects, where the protective layer is not perfect, by breaking the layer locally. The most sensitive environment for pitting corrosion of metals and alloys are solutions with halides ions such as fluoride, chloride and bromide. In microelectronic packages, halides ions can come from the fabrication processes such as etching, plating, wafer sawing or materials used for packages such as epoxy resin for encapsulation. The reactions [5] for chloride ion to attack aluminum metal interconnection are following:

$$4Al(OH)_3 + 4Cl^- \rightarrow Al(OH)_2Cl + 4OH^- \qquad (dissolution\ of\ native\ oxide\ layer) \qquad (16)$$

$$Al + 4Cl^- - 3e \rightarrow [AlCl_4]^- \qquad (dissolution\ of\ base\ metal) \qquad (17)$$

$$[AlCl_4]^- + 3H_2O \rightarrow Al(OH)_3 + 3H^+ + 4Cl^- \qquad (hydrolysis\ of\ dissolved\ metal\ ions) \qquad (18)$$

Pitting corrosion is an autocatalystic corrosion process. Corrosion within pits will form an environment that accelerates the rate of corrosion. This environment is that pH value decreases due to hydrolysis of dissolved metal ions and concentration of chloride ion increases due to migrate of chloride from outside of pits for charge balance.

## 2.3 Stress Corrosion Cracking

Stress corrosion cracking (SCC) is a corrosion phenomenon of metals or alloys under tensile stress and exposed to sensitive corrosive environment. Therefore it is mechanical-chemical interacted failure mechanism. To some extent, all metals or alloys are susceptible to stress corrosion cracking in their sensitive environment; however, metals or alloys with protective passive layers on their surface are more susceptible. Aluminum has stress corrosion cracking problems because aluminum is very active metal and the fresh surface of aluminum can be oxidized to form a protective layer of aluminum hydroxide or aluminum oxide with a very short time (seconds). The passive oxide or hydroxide layer is brittle. If the passive layer ruptures under the tensile stress, the fresh surface of metals such as aluminum at the point of rupture is exposed and is selectively corroded so that an SCC crack can be initiated at the point of broken. Once initiated, the crack can grow by anodic dissolution mainly at its leading edge because the stress is concentrated at the crack tip so that the electrode potential at the crack tip becomes lower due to the more strain energy [6] and fresh exposed surface. The failure modes of SCC are usually intergranular and brittle. The stress for SCC can be either externally applied or process induced residual stress or thermal stress due to the mismatch of coefficient of thermal expansion (CTE) of dissimilar materials or stress due to moisture absorption of polymeric materials. In microelectronic packages, materials used include metals, polymers ceramics and fibers. The CTEs are significantly different between different types of materials such as CTEs are 23ppm for aluminum and 60-80ppm for epoxy. The CTEs may be significant different even for the same type of materials. Residual stress and thermal stress are dominant for SCC in microelectronic packages. The stress for SCC can be much lower than the yield stress of materials. Therefore catastrophic failure may occur without significant deformation or obvious deterioration of the devices. Most of the metals and alloys like aluminum are sensitive to SCC in the halide ion contained corrosive environment. Since pitting corrosion may occur for metals and alloys in the halide ion solution, it is usually associated with SCC.

## 3. Case study of corrosion induced failures in microelectronic packages

### 3.1 Metal bond pad corrosion

Aluminum and its alloy are widely used as a thin film metallization for contacting silicon and forming interconnect lines on integrated circuits to carry current to and from the outside world. Aluminum is alloyed with copper to improve its properties such as hardness, strength, fine grain size, homegeneity and electromigration resistance so as to meet process and reliability requirements. The content of copper can be from 0.5 to 4.5 weight percent. However, Aluminum alloyed with copper has shown to be more susceptible to corrosion than pure aluminum during wafer fabrication and post wafer fabrication assembly. From the Al-Cu binary phase diagram (Figure 2) [7], it is found that there exist two phases for Al-Cu alloy used here: $\alpha_{Al}$ (Al rich solid solution with very little Cu) and θ phase (intermetallic compound $Al_2Cu$). The electrode potentials for these two phases are different. The reduction potentials are –0.85V for Al and –0.73V for $Al_2Cu$, which are relative to 0.1N calomel scale [8]. Since the reduction potential of Al is more negative than that of $Al_2Cu$, $Al_2Cu$ acts as the local cathode and anodic aluminum around $Al_2Cu$ dissolves. Thus this corrosion is essentially galvanic corrosion. The corrosion of aluminum around $Al_2Cu$ precipitates continues until $Al_2Cu$ precipitates become electrically isolated from the surrounding metal. Figure 3 [9] shows the typical SEM images of the bonding pad surface. From this Figure, small corrosion pits with a particle centered inside pits are found. EDS analysis proved that the particles were $Al_2Cu$. Al-Cu bond pads have poor bondability because the corrosion product $Al(OH)_3$ in pits has poor adhesion to the gold wire.

Corrosion of Al-Cu bond pads was found to occur during metal etching and post metal etch processing such as deionized (DI) water rinsing, solvent cleaning, wafer sawing [10]. DI water with some ionic impurities such as fluoride provides the electrolyte environment for corrosion.

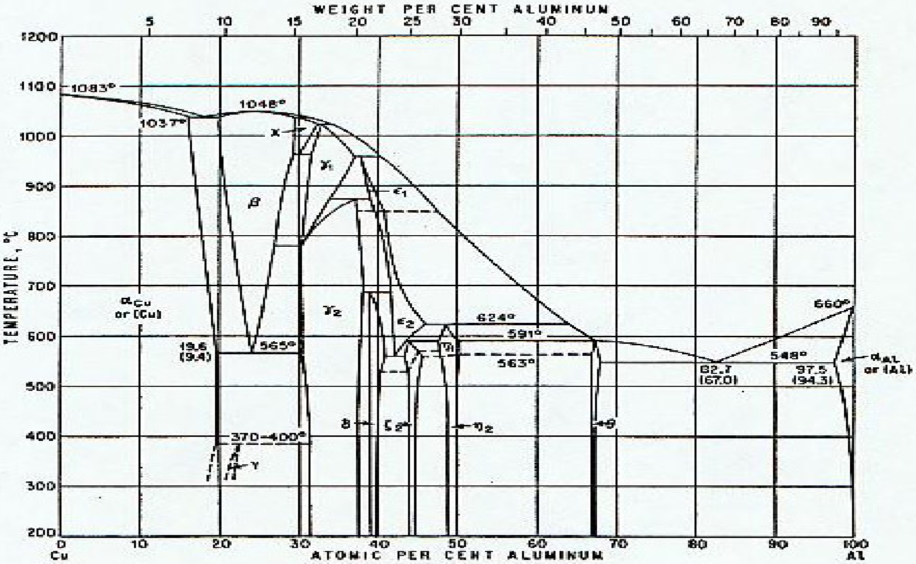

Figure 2. Aluminum-Copper binary phase diagram

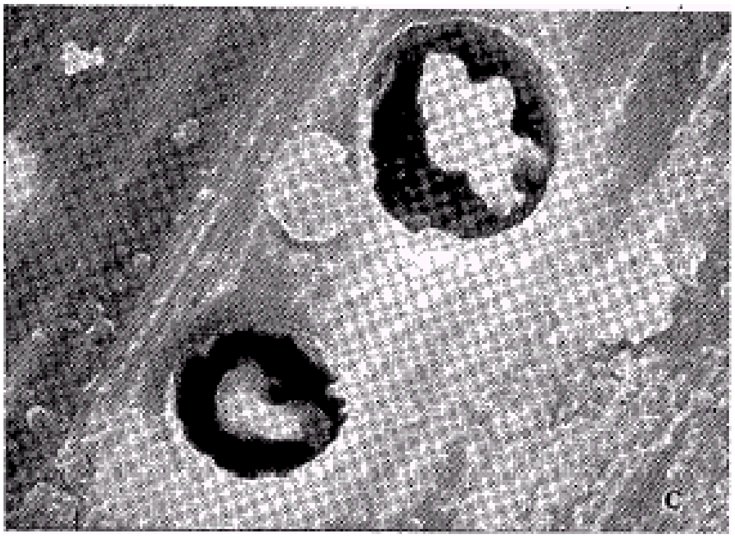

Figure 3. SEM image of bond pads of Al-1.5Cu metallization showing pitting corrosion around $Al_2Cu$ particles

## 3.2 Lead frame corrosion

### 3.2.1 Corrosion of lead frame in plastic packaging

The primary purpose of the lead frame is to support the chip mechanically and connect the chip electrically with printed wiring board (PWB). The most widely used lead frame material is copper alloy. Copper lead frames for nonhermitic packaging are plated with gold (Au) or silver (Ag) to protect connector leads from corrosion and increase electrical conductivity. In many cases, the lead frame needs to be bent after plating. When bending the lead frames, the gold or silver plating may form crack. If the crack penetrates to the base metal, the fresh surface of the base metal (copper alloy) was exposed to the atmosphere. During the subsequent manufacturing process, the cracks were contaminated with chlorine. If these lead frames with the cracks are exposed to moisture condensed electrolyte environment, galvanic corrosion occurs. The exposed copper acts as anode to be corroded and gold or silver acts as cathode (See Figure 4). In the case the conductive epoxy adhesive was used to secure the fiberglass bar to the connector leads and the PWB and electric bias exists between leads, another kind of corrosion phenomenon occurs – electrochemical dendrite formation [11] (see Figure 5) in the epoxy adhesive during corrosion of lead frames. The consequence of the dendrites may cause electrical shorts. Dendrite structure first formed at the epoxy-lead interface and grew toward to the adjacent leads, which were at a lower potential. Mass transfer was due to migration of charged species in the electric field. The electrochemical process consists of the dissolution of copper at anode and cupric ions migrate to cathode through conductive epoxy and reduction of cupric ions at cathode. The reactions at two electrodes are following:

Anode: $Cu-2e \rightarrow Cu2^{+}$ (19)

Cathode: $Cu^{2+}+2e \rightarrow Cu$ (20)

The driving forces for the above reactions are from applied electric bias between leads.

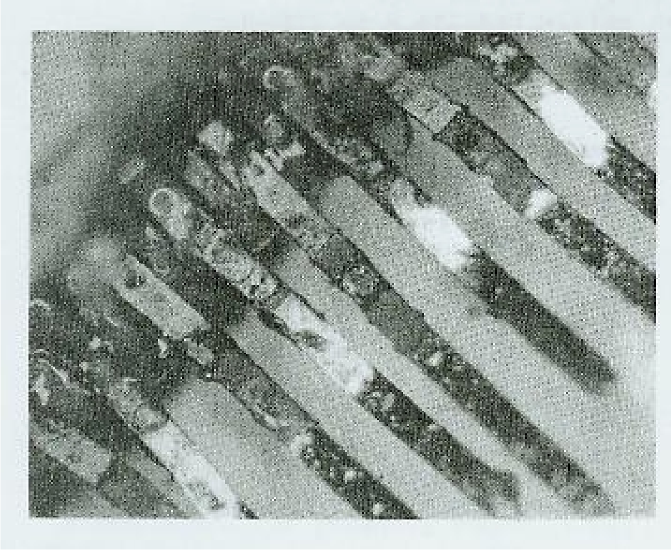

Figure 4. Corrosion products formed on connector leads

Figure 5. The dendritic appearance of corrosion products in the epoxy adhesive

### 3.2.2 Corrosion of lead frames at lead-glass interface

The glass-to-metal seals are employed for manufacturing the high-reliability microelectronic packages such as military, aerospace and automobile microelectronic packages. The commonly used lead metals include Kovar (iron-cobalt-nickel alloy), cold rolled steel, copper and molybdenum. The glass materials used are borosilicate glass. The technology of the glass sealed metal packages has been well established, but corrosion issues associated with this technology still exist. Failure data [12] indicate that corrosion problem mainly occurs at lead-glass interface. The corrosion problem at lead-glass interface actually includes two parts - creation of a moisture ingress pathway between the base metal and the environment and accelerated corrosion at lead-glass interface. The factors that contribute to provide a moisture pathway include glass meniscus crack and chipouts, lack of bond between glass and plating, undercuts and plating pulled away from glass. The factors that may accelerate corrosion at the lead-glass interface include electrochemical potential difference between base metal and plating material, tensile stress and trapped contaminants. For example, for gold plated Kovar lead, there was a significantly electrochemical potential difference between gold and Kovar because the reduction potentials are +1.498V for gold [1] and about –0.325V (the averaged reduction potential of iron, nickel and cobalt) for Kovar. Salt fog corrosion test results indicate that gold plated Kovar lead suffered severe corrosion at lead-glass interface (see Figure 6). Another example is tin plated Kovar lead. Salt fog corrosion test results have shown that there was no localized base metal attack at the glass seal of packages for tin plated Kovar lead. From the point of driving force, this is because the electrochemical potential difference between tin and Kovar is very small compared to the difference between gold and Kovar. In this case, tin-plating works better than gold plating and gold plating should be avoided. It is known that Kovar is susceptible to stress corrosion crack [13-14], especially in the presence of chloride. Laboratory test [12] demonstrated that failure due to stress corrosion cracking was more frequently at the lead-glass interface than at other areas of the lead. This is because larger residual stress at lead-glass interface is evoluted during the formation of the glass seal and moisture easily goes through the lead-glass interface.

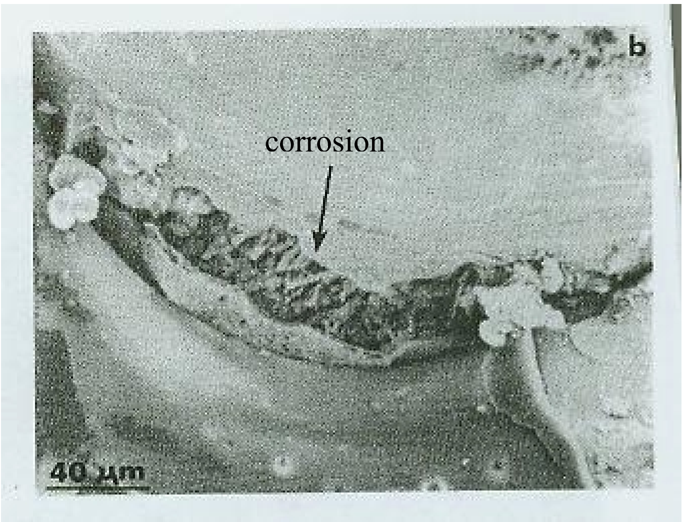

Figure 6. SEM micrograph of TO-5 type package lead showing corrosion at the glass-lead interface

### 3.3 Solder corrosion

Lead tin alloys are the most commonly used soldering alloy system in today's electronic packaging because they have low melting point and have been proved to be well suited in electronic applications. Both lead rich and tin rich alloys are employed so long as they provide the useful range of metallurgical properties such as hardness, creep, melting point and fatigue life. The standard reduction potentials are 0.15 V for tin and -0.126 for lead [1]. If tin and lead contact together in the electrolyte solution, a galvanic cell is formed and lead acts as anode to be corroded faster than it stands alone because the potential of lead is more negative than tin. Lead-Tin phase diagram is shown in Figure 7. From this Figure, it is found that the partial solid solubility of tin in lead at room temperature is about 2wt% and the partial solid solubility of lead in tin is very low (less than 0.5wt%) at room temperature. The lead-tin alloy with a content of less than 2wt% tin has single phase (lead rich phase) and chemical potential of lead in this phase is similar to pure lead. For the lead-tin alloy with a content of tin in the range 2 to 99.5 wt%, there exist two phases (lead rich phase and tin rich phase) and the chemical potential for each species does not change with overall composition in this range. This means that the driving force for oxidization of each species has no change for lead-tin alloy with overall composition falling in this range. For lead-tin alloy with a content of more than 99.5wt% tin, there exist only one phase (tin rich phase) and the chemical potential of tin in this tin rich phase is similar to pure tin. The experimental data [15] have a good agreement with the above predictions from the point of thermodynamics. The corrosion resistance of the led-tin alloys is a function of the tin content (see Figure 8). Alloys with less than 2wt% tin has quite poor corrosion resistance like lead; alloys with more than 99.5wt% tin has good corrosion resistance like pure tin; alloys with tin content in a range of 2 to 99.5 wt% has fairly good corrosion resistance and do not change much with tin. From Figure 8, it was also found that lead-tin alloys had much higher (two orders of magnitude higher) corrosion rate in air-saturated water than in nitrogen-saturated water. This is because the cathode reaction is reduction of dissolved oxygen with a standard potential of 1.23V in the saturated oxygen water and is evolution of hydrogen with a standard potential of 0V in the nitrogen saturated water. Thus the driving force for electrochemical reactions for lead-tin alloys in the air saturated water is much larger than that in the nitrogen saturated water due to the different cathode reactions in these two cases.

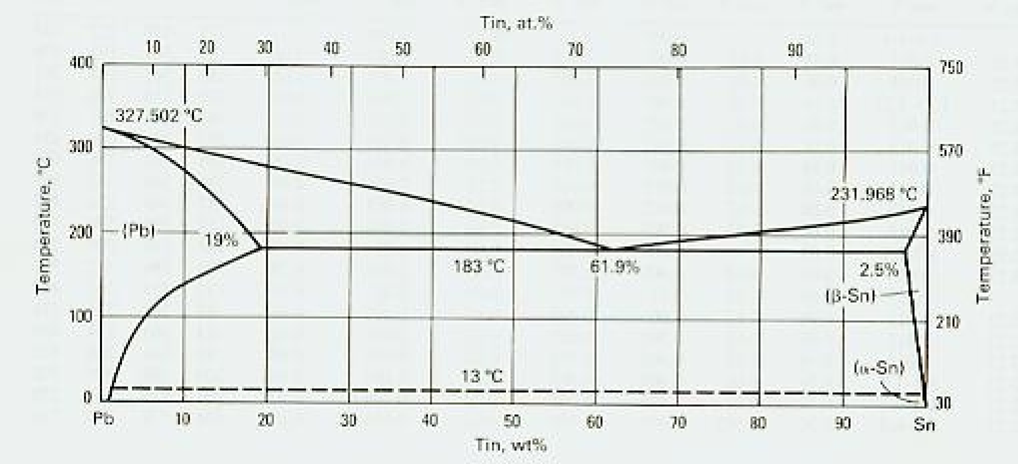

Figure 7. Lead-Tin phase diagram

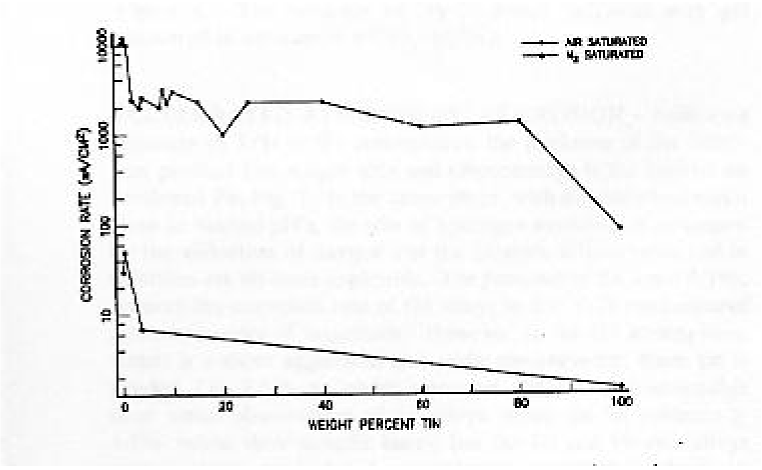

Figure 8. Corrosion rate measured in distilled water, air or nitrogen

### 3.4 Moisture induced corrosion

With the minaturization of integrated circuit features and package sizes and increase of I/O counts, the potential of failures resulting from moisture ingress and corrosion increases. Although encapsulation is employed in microelectronic packages to prevent die from moisture outside, permeation and leakage are still possible. The amount of contaminants within a package depends on the permeation and leak rate of the package [16]. The driving force for permeation and leakage is the water vapor pressure difference between outside atmosphere and package inside. Since permeation rate of metals and glasses are 2 to 5 orders of magnitude less than plastics, permeation of moisture for metals and glasses can be negligible. Permeation of moisture through a plastic package involves the transport of water vapor to the surface of the package from atmosphere, condensation and absorption on the package encapsulant and then diffuses through encapsulant and interfaces; then desorption and evaporation into the packages interior voids and cavities. At temperature lower than the dew point for inside package, condensation and absorption will occur on internal surfaces of packages such as die metallization, wire bond, lead frame, etc. Leakage typically occurs through defects and flaws located in the lid, lead seals such as cracks, debond at interface of dissimilar materials, etc.

A moisture induced corrosion model was described in reference 16. The equation for this model is following:

$$\frac{dC}{dt} = -\alpha(C - Ca) \qquad (21)$$

where $C_a$ is the maximum allowable or self-limiting amount of corrosion per unit volume (corrosion density) of a part in the package ( $0 \le C \le C_a$ ) and $\alpha$ is a corrosions rate factor which is a function of the corrosion materials, the contaminants and the environmental conditions such as temperature, corrosion history, relative humid, electrical bias (externally applied or galvanic bias).

## 4. Conclusions

Corrosion phenomena encountered in microelectronic devices and packages were analyzed and summarized in this paper. Corrosion induced failure was and will be a long-term concern in microelectronic packages. Corrosion in microelectronic packaging depends on package types, electronic materials, fabrication and assembly processes, and environmental conditions such as moisture condensation, ionic or organic contaminants, temperature, residual and thermal stress and electrical bias.

Any corrosion reaction must be considered from two aspects: its thermodynamic feasibility and its kinetics. The thermodynamic feasibility is given by the driving force and kinetics is determined by the variables of the system. For electrochemical corrosion in microelectronic devices and packages, the driving force is the electrochemical potential difference between anode and cathode in the electrolyte solutions, which may result from the dissimilar metals/alloys electrical couple, concentration gradient, applied electrical bias. The most commonly used metals and alloys in microelectronic devices and packages include aluminum, gold, copper, silver, tin, lead, nickel and their alloys. Under high electrical bias, all these metals including gold and silver will be corroded if they exposed to the electrolyte solutions. More often, it was found that aluminum and other active metals such as copper and Kovar are corroded when these metals are exposed to the corrosive environment, especially when they are electrically coupled with other noble metals such as pad bond metallization used Al/Cu, Al/Au and lead frame used Cu/Ag and Kovar/gold because there exists a big driving force for corrosion and active metals act as anode to be fast corroded.

Another key factor for electrochemical corrosion is conductive electrolyte (moisture condensation water with ions). If there does not exist conductive electrolyte solutions in the microelectronic packages, there is no electrochemical corrosion. Encapsulation and achievement of good adhesion at all internal interfaces are very important, especially for plastic packages.

**References**

1. Charles A. Harper. Electronic Packaging and Interconnection Handbook. Third Edition. McGRAW-HILL, 2000.

2. Electronic materials handbook, vol.1, ASM international, 1989.

3. A.J. Griffin, S.E. Hernandez and F.R. Brotzen. “A galvanic series for thin-film metallizations and barrier layers commonly used in the microelectronics industry”, Journal of electrochemistry society, 141(3), 807-809 (1994).

4. Deny A. Jones. “Principles and prevention of corrosion”. Prentice Hall, Upper Saddle River, second edition, 1996.

5. W.M. Paulson and R.P. Lorigan. “The effect of impurities on the corrosion of aluminum metallization”, Proceedings of the IEEE Reliability Physics Symposium, IEEE, 42-47 (1976).

6. Andrew H. Rawwicz. “Stress induced corrosion of wire micro-joints in microelectronics – a quantitative model”, Microelectronics and Reliability, 34(5) 875-882 (1994).

7. M. Hansen and K. Anderko. Constitution of binary alloys. Mcgraw-Hill, 1958.

8. W.W.Binger, E.H. Hollingsworth and D.O. Sprowls. Aluminum, vol.1, American Society of Metals, 1967.

9. Simon Thomas and Howard M. Berg. "Micro-corrosion of Al-Au bonding pads", IEEE transactions on components, hybrids and manufacturing technology, 10(2), 252-257(1987).

10. Joseph Fauty, Steve Strouse, Jay Yoder, Carlos Acuna, and Phil Evard. "Al-Cu metal bond pad corrosion during wafer saw", The International Journal of Microcircuits and Electronic Packaging, 24(1), 19-29(2001).

11. Fu-gin Chen and A. Jean Osteraas. "Electrochemical dendrite formation during corrosion of connector leads", Proceedings of ASM's third conference on electronic packaging: materials and processes and corrosion in microelectronics, 175-179(1987).

12. Kim A. Berry. "Corrosion resistance of military microelectronics packages at the lead-glass interface", Proceedings of ASM's third conference on electronic packaging: materials and processes and corrosion in microelectronics, 55-61(1987).

13. M.J. Elkind and H.E. Hughes. "Prevention of Stress-Corrosion failure in iron-nick-cobalt alloy semiconductor device leads", Proceedings of Failure in Electronics Symposium, 5, 477-495 (1966).

14. K.W. Rosengarth. "Corrosion Protection for semiconductor packaging", Solid State Technology, 27, 1991-196 (1984).

15. Vlasta Brusic, Doreen D. Dimilia and Robert D. Maclnnes. "Corrosion of lead, tin and their alloys", Proceedings of ASM International 3rd electronic materials and processing, 261-268(1990).

16. Michel Pecht. "A model for moisture induced corrosion failures in microelectronic packages", IEEE transactions on components, hybrids and manufacturing technology, 13(2), 383-389(1990).