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AN OVERVIEW OF CORROSION AND CLIMATE EFFECTS IN ELECTRONICS SYSTEM.

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ABSTRACT

Corrosion is a physical-chemical reaction of metal with its environment which causes changes in the properties of the metal and which can often lead to damages of the metal, its environment or the technical system. Climatic effects cause accumulation of water and impurities on the surfaces whereas heat and sunlight also decay the products and accelerate the progress of corrosion and other harmful effects. Water, dust, gases and organic compounds cause leakage currents, short-circuits and mechanical changes. The increase in the packaging density of electronics causes harmful effects to devices to a growing extent and these products are becoming sensitive to the harmful effects of humidity and corrosion. In electronics system, the contact resistances of the joints, leakage currents between the wires and decay materials increase corrosion and climatic effects which results in various operational faults, increase in electromagnetic disturbances and surfaces finishing deteriorates. This article presents an overview of corrosion and climate effects in electronics system.

Keywords: Environment, Electronic system, Climatic effect, Corrosion, Humidity, Mechanical changes.

INTRODUCTION

Corrosion is the destructive attack of a material by reaction with its environment. The serious consequences of the corrosion process have become a problem of worldwide significance. In addition to our everyday encounters with this form of degradation, corrosion causes plant shutdowns, waste of valuable resources, loss or contamination of product, reduction in efficiency, costly maintenance, and expensive overdesign. It can also jeopardize safety and inhibit technological progress. (http://www.lehigh.edu/~amb4/wbi/kwardlow/corrosion.htm). Electronics is increasingly integrated into various packet densities and the demand for miniaturization, multiplicity of materials used, effect of process residues together with unpredictable user environment has opened up serious corrosion problems. The packaging density of electronics has become so great in all major product areas, mobile phones, telecommunications equipment, computers, automation and high power electronics, that it makes the electronics sensitive to the corroding and contamination effects of the environment. Corrosion in electronic components manifests itself in several ways most of which are insidious and cannot be readily detected easily. Therefore, when corrosion failure occurs, it is often dismissed as just a failure and the part or component is replaced. Because of the difficulty to detect and identify corrosion failures, the cost of corrosion is difficult to determine. (https://corrosion-doctors.org/Electronics/Introduction.htm). The consumer electronics is one sector where the user environment is highly variable. Overall size of electronic equipment has also been decreasing presently at a faster rate, the reduction in size and distance between components makes the system more susceptible to corrosion problems. www.smtnet.com/library/files/upload/A-review-of-Corrosion-and-environmental-effects-on-electronics.pdf. The aim of this publication is to discuss the effect which the climate, contamination and other environmental factors, the users, the methods of use of the devices and their structure as well as the manufacturing affect the corrosion in electronics system. The rest of the paper is organized as follows. In Section II we discuss the Types and Classification of Corrosion. Corrosion resistance is discussed in section III followed by Corrosion, Water and Humidity in section IV. Materials in Electronic Systems is treated in section V. Causes of corrosion in electronic systems, Corrosion in the electronics industry, Contamination and parameters effecting corrosion and Corrosion control methods are presented in sections VI through IX respectively. This paper is concluded in section X.

Types and Classification of Corrosion

Differences in electrical potential occur on the surface of a piece of metal due to small differences in chemical composition, phase differences, amount of cold work, etc. These differences set up small corrosion cells each with an anode and cathode. Corrosion continues until the metal is consumed or the film of rust formed on the surface sets up a barrier to the electrolyte. https://www.allflexinc.com/blog/corrosion-considerations-for-electronic-packages/

The most common metals used in electronics are copper, tin-lead, silver, gold, graphite and nickel. Copper is relatively susceptible to corrosion while Gold is not. The relative order of metals in terms of corrosion susceptibility:

- Plated Tin (most susceptible)
- Lead
- Copper (plated, cast, or wrought)
- Nickel (plated)
- Nickel-silver (18% Ni)
- Copper 1 10
- Copper-nickel 715
- Silver
- Gold
- Graphite (least susceptible)

Gold and silver are called noble metals because they are resistant to corrosion and acid. Copper and Tin are considered base metals because they have a higher propensity to corrode. There are many types of corrosion; the following are typical in electronic packages using printed circuit boards or flexible circuits.

- **Atmospheric Corrosion**: The metal reacts with oxygen (via moisture) and gives up ions to form an oxide material. Bare copper is highly corrosive compared to other metals in electronics. From a mechanical integrity standpoint, copper corrosion is not a problem; copper is used in plumbing and other construction materials because copper does not lose its mechanical integrity. Electrical connection is a different story; oxidized copper has poor surface conductivity. So in applications where surface contact is used to achieve electrical connection, bare copper will eventually corrode to the point of impeding electrical contact.
- **Galvanic Corrosion**: Two dissimilar metals that are in electrical contact and in the presence of an electrolyte will tend to produce a galvanic corrosion. The more noble metal will tend to corrode at an accelerated rate and the less noble metal will corrode at a much slower rate. The rate of corrosion is based on the ionic concentration of the electrolytic solutions and the "corrosive difference" between the two metals. A highly corrosive metal combined with a highly noble metal such as gold or silver, will have a higher propensity for galvanic corrosion than two metals of similar corrosive activity such as nickel and copper.
- **Electrolytic Migration**: When two adjacent traces have an electrical voltage between them with ionic contaminated moisture bridging the gap, there is a potential for dendrite growth. One trace becomes the cathode and the other is the anode. The metal on the anode side gives up dissolved ions to the cathode side. The process tends to form "metal slivers" some which deposit on the surface between the conductors. Given enough time, these slivers will form a conduct path between the traces and cause a short circuit.
- **Fretting Corrosion**: This type of corrosion is applicable to solder plated contacts and switches. As contact is made by closing the switch, there is a small side to side motion that creates a wiping action on the surface. This wiping action removes the oxide layer that was formed on the surface, and then the new surface reacts with the environment and forms another oxide film layer. This process continues as layers are removed and new layers are formed. Eventually the oxide debris builds up to the point where the contact resistance is too high to activate the switch

All metallic materials consist of atoms having valiancy electrons which can be donated or shared. In a corrosive environment the components of the metallic material get ionized and the movement of the electrons sets up a galvanic or electrochemical cell which causes oxidation, reduction, dissolution or simple diffusion of elements.

The metallurgical approach of corrosion of metals is in terms of the nature of the alloying characteristics, the phases existing and their inter-diffusion under different environmental conditions. In fact, the process of corrosion is a complex phenomenon and it is difficult to predict the exclusive effect or the individual role involved by any one of the above mentioned processes. Based on the above processes, corrosion can be classified in many ways as low temperature and high temperature corrosion, direct oxidation and electrochemical corrosion, etc. The preferred classification is: Dry or chemical corrosion and wet or electrochemical corrosion.

Chemical corrosion: In which the metal is converted into its oxide when the metal is exposed to a reactive gas or non-conducting liquids.

Electrochemical corrosion: The formation of hydrous oxide film occurs when the metal is immersed in a conducting liquid containing dissolved reactive substance. The reaction is considered to take place at the metal-solution interface, due to the heterogeneity on the metal surface, which creates local anodic and cathodic sites on the metal

Corrosion resistance

Corrosion resistance means the ability of a product to function as intended and to tolerate corrosion and climatic effects during a certain life span without the product causing danger to its environment. Corrosion resistance; Corrosion resistance is formed of two entities, the factors increasing the corrosion risk and protective measures, in other words methods preventing corrosion.

The basic aim here is to draft a methodology that would yield a practical way of expressing and measuring corrosion resistance. This methodology can help in making the right decisions on action to optimize product reliability and corrosion resistance in product design. When defining the corrosion resistance of a product, the factors increasing the corrosion risk should be taken into account as presented in Figure 1.1: the aimed life span, corrosivity of the environmental conditions, sensitivity of the product construction to changes caused by corrosion and various protective measures or measures limiting corrosion.

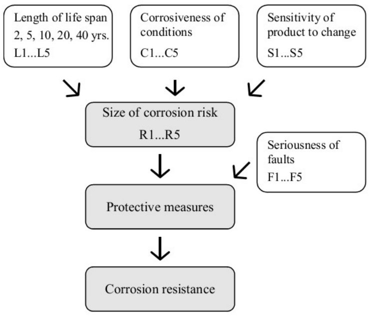

Figure 1.1. Definition of corrosion resistance of a product

The risk level in Figure 1.1 is presented on a scale 1...5, where 1 is the lowest and 5 the highest level of risk. In addition, the harmful effects of each fault category caused by corrosion on the function of the product should be evaluated in order to account for all factors. The more harmful a fault is, the more should be invested in its prevention. Each risk factor can be categorized to produce a measure for the effect of the said factor and a combined measure for the total product risk and, based on the protective action, a measure for the corrosion resistance of the product.

Corrosion here means all the decaying effects that corroding substances, oxidizing and climatic and other environmental effects produce through corrosion mechanisms in the function and appearance of the devices. Therefore, the concept of corrosion resistance is a sum of several factors.

Overall level of corrosion resistance: Corrosion resistance can be defined based on the above as: "Corrosion resistance" is the ratio of the efficiency of corrosion protection to the corrosion risk. Since the efficiency of corrosion protection cannot be exactly defined, field data on the efficiency of corrosion protection and their classifications must be relied on here. There are good recommendations on the use of painting and metal plating of contacts, for example, with ready classifications. In practice the use of this data can yield a fairly good estimate on the efficiency of various protections and the corrosion risk. When analyzing and developing corrosion resistance a more realistic picture of the whole is obtained if the differences between corrosion control of the outsideand the inside of the device is kept in mind during both risk evaluation and the realization of the protective measures. See figure 1.2.

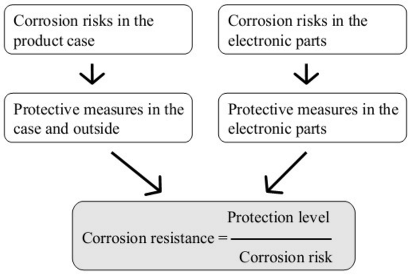

Figure 1.2 Definition of overall level of corrosion resistance.

The conditions outsideand inside the device are different, so are the fault mechanisms. Both must be analyzed separately considering also the corrosion risks covering the entire life span.

Corrosion, Water and Humidity

Concept of acidity; The acidity of the water solutions has a great effect on what types of reactions take place on the liquid-metal boundary surfaces. On the other hand acidity can be used to describe the status of a metal surface in relation to corrosion. Is the status favorable to corrosion, corrosive, are any corrosion products that partially protect the surface forming on the surfaces (passive state) or is the state inert (immune state) with no metal corrosion.

The acidity or alkalinity of a solution is expressed as the concentration of hydrogen ions in it. The greater the concentration the more acid the solution. The usual way of expressing the hydrogen ion concentration is the pH value. The pH value of a solution is the inverse value of the logarithm CH^+ of the hydrogen ion concentration.

As a formula: $pH = - \log CH^+$

The solution is acid if its pH is below 7 and alkaline when the pH exceeds 7. The pH of clean water is 7. Rainwater is usually slightly acid because some carbon dioxide is absorbed into it forming carbon acid with the water. The pH of dishwasher detergent exceeds 10; in other words the detergent solution is very alkaline. Even aluminum dissolves easily into water this alkaline.

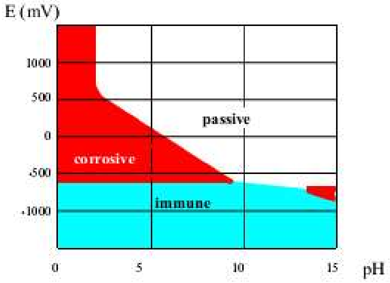

Figure 1.3. The simplified Pourbaix-diagram [Tunturi 1988].

The Pourbaix-diagram or the pH-potential diagram is the electrochemical balance chart of a metal (Figure 1.3). The point of zero potential is the potential of the hydrogen electrode with an agreed value of 0 V. The potential of the metal (corrosion reaction) is determined by comparison to this potential. When the potential is charted as a function of the pH of the measured solution, a Pourbaix-diagram results. If the chart is drawn up depicting only the corrosion of the metal (the metal reacts and corrodes), immunity (the metal does not react) and passive zones (the metal has reacted and reaction products protecting the metal have formed on the surface) the graph becomes clearer. For instance, by changing the potential of the metal with an outside voltage source the behavior of the metal surface can be shifted from the corrosion zone to the passive or immune zone. This is used for example in the electric protection of natural gas pipes or ships (catholic and anodic protection) (Mattsson 1996, pp. 95−103).

The electrochemical and galvanic voltage series of metals: The electrochemical voltage series of metals means the voltages of pure metals compared to standard hydrogen electrode. An electrochemical voltage series of metals is obtained when the potentials of various metals are compared in the same salt solution to the standard hydrogen electrode. The electrochemical voltage series classifies the mobility of flawless, clean metals completely free of oxide or passive layers. Since some metals are nobler than others are a voltage difference is created between them when they are put into the same solution. The ability of batteries to store and discharge electricity is based on this phenomenon. With regard to corrosion, this electrochemical voltage series is not interesting, because it does not describe the conditions in nature and the order of metals is different from the real metals and conditions.

The voltage series are called galvanic voltage series when actual metals which have been in touch with air and which are immersed in actual solutions, are measured and put into order of magnitude. The most commonly used galvanic voltage series is the sea water series. Seawater is a solution containing mainly NaCl, which is the most common and most harmful of all corrosive substances. NaCl is also present in palm sweat, which means that every surface touched by human being contains salt, also.

Therefore, when estimating the differences in the nobility of various metals or their alloys, they should be immersed into the same liquid as they would be in actual corrosive conditions before it could be determined which of the metals is the most noble in the conditions at hand

Absorption of water into plastics; the water vapor in the air absorbs quickly to nearly all plastic materials. Usually the absorption to plastics is 0...0, 5% (epoxy 0, 08...0, 15%). Plastics based on pulp and polyamides (nylons) are an exception. Nylon PA6 can retain a maximum of 10% of water when immersed. If the plastic itself does not absorb much water, glass fibre curing will increase the absorption of water. If the plastic absorbs a lot of water (PA6 10%) the glass fibre curing will decrease the absorption of water [Tormala et al. 1983]. Table 1.3 presents the figures for the water content of some plastics after they have exposed to humid air. Printed board is usually made of glass enforced epoxy. Water may absorb to the board trough the edge among the glass fibers. This is rather theoretical possibility because the board is normally faultless (no unevenness, air bubbles, etc.), which ensures the tightness of the border between glass fibre and epoxy. The transmission of water into the board is almost impossible. At about 70% RH the wetting of epoxy starts. The water in the epoxy weakens the binding between glass fiber and epoxy, and may lead to breakdown of the laminate structure [Lfebre et al. 1991].

The testing method presented in standard ISO 62 Plastics; Determination of water absorption describes the speed of absorption of water very well. The testing times are only one or a couple of days. The material tested in these tests is usually a square piece of a plastic sheet of a thickness of either 1 mm or 2 mm.

The side length of the sheet should be greater than 100 times the thickness of the sheet with at least heterogeneous materials (for example glass fibre cured epoxy sheet, printed board material). The test gives as the result the amount of water diffusing perpendicular to the surface of the sheet and it can be used for determining the diffusion coefficient in temperatures below the glass transition temperature of plastics.

ISO 62 has four absorption tests where the samples are dried before the test at a temperature of 50°C for 24 hours and weighed before and after the drying. Drying is repeated in 24 hour periods until the mass ceases to change more than 0.1 mg. The remaining mass is the initial mass of the sample (m1):

Permeability of water vapour for materials: The permeability of water vapour for materials is an important property in electronics, especially in component packaging, devices designed as watertight and in all kinds of transportation packages. Figure 1.4 shows the magnitudes of the water permeability of materials used for component cases.

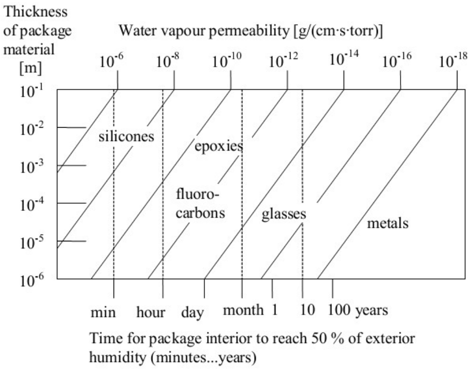

Figure 1.4. Permeability of water for case materials (Traeger 1976 and 1977, Schneider 1988)

The articles of [Traeger 1976 and 1977, Schneider 1988, Palmen 1990] have addressed the suitability of non-metallic materials for hermetic packages of hybrid circuits. As can be deduced from the figure it only takes a few hours or weeks for water to penetrate a layer of plastic one millimetre thick. Traeger's article gives the following equation developed by Jones in [1969] and Kassen [1974] for permeability of moisture for organic seals. The equation only gives the magnitude for permeability of moisture since the properties of the materials are usually not well known.

$$t = \frac{V \cdot L}{P \cdot A \cdot R \cdot T} \ln\left[\frac{p_o - p_1}{p_o - p_2}\right],$$

Where;

t = time for obtaining partial pressure p_2(s)
V = free inside space of the case (cm^3)
L = length of the diffusion route (cm)
P = permeability of water for the sealing material (g/(cm·s·torr))

A = cross section area of the seal (cm^2)
R = gas constant (3465 Torr $cm^3/K\ g_{H2O}$)
T = temperature (K)
K = Kelvin
po= partial pressure of water vapour in the outside space (torr)
p1= partial pressure of water vapour in the initial state of the case (torr)
p2= partial pressure of water vapour in the final state of the case (torr).

Hermetic packages and seams can be made only of metals, glass and ceramic materials. The metal used as a case for a device can be porous and let water and air through like a sieve; for instance porous pressure cast aluminum is not watertight. Even good quality plastics always let a certain amount of water through. Despite permeability of water good plastic cases for components function well even in applications requiring a high degree of reliability. IEC 60068-2-17 classifies leaks into big and small ones using 1 Pa cm^3/s (10^{-5}bar cm^3/s) as the limit. The method Qk is used for testing of small leaks (hermetic cases) in the IEC standard. The method uses helium as the indicator gas. Helium leak can be detected with a mass spectrometer.

Relative humidity of air: Figure 1.5 shows graphs (Mollier diagram) depicting the dependency of the water content of air on the relative humidity and temperature. Each graph presents the values of relative humidity corresponding to certain absolute air humidity (absolute water content) in the air in different temperatures. The values for absolute humidity (g/m^3) are given along the top edge, the relative humidity of the air on the left vertical axis (%) and the air temperature (°C) on the horizontal axis at the bottom. The bottom horizontal axis also gives the dew point temperatures corresponding to a certain air water content, in other words the temperatures where the relative humidity of the air reaches 100% resulting in condensation.

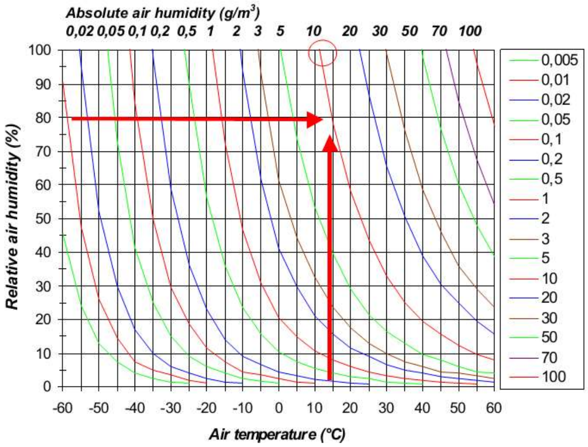

Figure 1.5. Relative air humidity as a function of absolute air humidity and temperature (IEC 60721-2-1, Amendment 1, Appendix B and SFS 5767, Appendix B).

From figure 1.5, if the absolute air humidity (water content) corresponding to a relative air humidity of 80% at 14,5°C is desired, the relative humidity is first pinpointed on the vertical axis and then the temperature 14,5°C is looked up on the temperature scale from the horizontal axis. If the graph is now followed upwards from the crossing point, the absolute air humidity 10 g/m3 can now be found on the scale at the top. The dew point temperature corresponding to a relative air humidity of 100% can be found at the location of the reading at the top by looking up the corresponding temperature directly on the bottom scale. The absolute air humidity (water content) of 10 g/m3 gives here 11.5°C as the dew point temperature. When the same graph (10 g/m3) is followed down towards relative humidity of 50%, the corresponding temperature is about 23°C and 32°C for relative humidity of 30%. The relative humidity of 80% corresponds to the usual humidity of outside air and 50% the usual humidity of air indoors. The temperature difference between these points (80% and 50%) is only about 8.5°C on the graph of 10 g/m3. The raise of 8.5°C on the temperature scale reflects the heating of air caused by an ordinary device or the change in the relative humidity of the air brought about by air entering the room space from the outside.

Effect of temperature on the ventilation of the case: The changes in air temperature cause changes in the pressure of the air inside the device case, which results either in a drawing in or blowing out effect with the air in the case. The flow of air is relatively great even at ordinary changes of temperature if the case has openings. In a closed space where the transfer of heat is minimal through the walls, the space equation of ideal gases is valid:

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} = nR = cons\tan t$$

Where;

p is air pressure (Pa)
V is air volume (m^3)
T is temperature (K)
n is amount of matter mol (with water 1 mol = 0,018 kg)
R is general gas constant = 8,314510 J/ (mol·K).

The constant therefore depends only on the quantity of substance n. If the quantity is 1 mol, in other words, n = 1 mol, pV/T = 1mol·8,314510 J/ (mol·K) = 8,314510 J/K.

In an isothermal change the temperature remains constant and pV = nRT = constant, in an isobaric change V/T = nR/p = constant and in an isobaric change p/T = nR/V = constant.

According to the Table 1.1, a change of 10°C in the temperature starting from 20°C results in a change of 3,4% in the air pressure provided that the volume remains constant and similarly a 3,4% change in the volume if the pressure remains constant. A change of 30°C in the temperature already results in a 10% change in the pressure/volume. This corresponds to a normal range of fluctuation in the pressure of outdoor air, 92...108 kPa at sea level.

Table 1.1. Air pressure and volume during changing of temperature.

Temperature °C	Air pressure when volume is constant kPa	Air volume when pressure is constant dm^3
-10	89,8	0,898
0	93,2	0,932
10	96,6	0,966
20	100,0	1,000
40	106,8	1,068
60	113,7	1,137
80	120,5	1,205

Materials in Electronic Systems

Corrosion in electronics is not a surprise due to the multiplicity of materials used simultaneously with several other factors conducive for corrosion. The Integrated Circuits (ICs), Printed Circuit Board (PCB), Switches, Magnetic Recording Media (Hard disc) and Packaging and shielding parts are the important materials that experience significant corrosion problems. www.smtnet.com/library/files/upload/A-review-of-Corrosion-and-environmental-effects-on-electronics.pdf.

Integrated Circuits (IC): An integrated circuit is basically made of silicon, although other metals such as gold, silver, copper, zinc, aluminum or their alloys are used for various purposes such as connecting leads, bumps etc. Connectors are for electrical contact between the different active elements on the silicon wafer. The silicon chip consists of semiconductors made with doping of impurities.

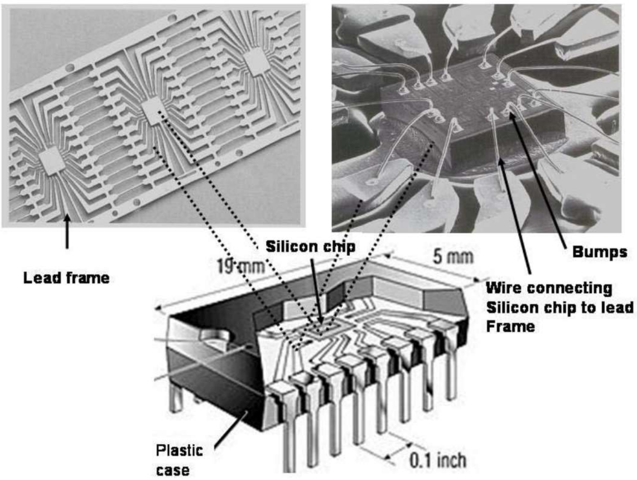

Figure 1.6 Integrated circuit and related components
(http://www.tiscali.co.uk/reference/encyclopaedia/hutchinson/m0030289.html)

The IC elements are connected to the PCB using lead frame. The lead frames, thus, are the connection between the electronic terminals (also called bumps) of the silicon wafer and the surrounding macroelectronic (PCB) part of the circuitry. The bumps on the silicon wafer are made of gold and they are connected to the lead frames with a bonding process for electrical connection using a gold or aluminum wire. Figure 1.6 describes in detail an IC circuit and components. Lead frames are often made of alloys like Cu/Zn37, CuFe2, FeNi42 (alloy 42), or CuNiZn (Vacon). The end of the lead, which needs to be bonded to the wafer is selective treated with 99.9% gold or 99.9% silver. The other end has treated with a solderable coating for connecting to the PCB. The ICs are protected by encapsulating in a polymer.

Printed Circuit Board (PCB): PCB is a macro-electronic structure compared to an IC, where a number of electronic parts are integrated (including ICs) on a fiberglass epoxy polymer with interconnecting lines as shown in Figure 1.7c. Typical PCB consists of copper connecting path integrated in a fiberglass reinforced epoxy polymer (Figure 1.7a). The PCB can be made of a series of layered structure (from double to multi-layer) with each layer consisting of interconnecting lines (Figure 1.7b).

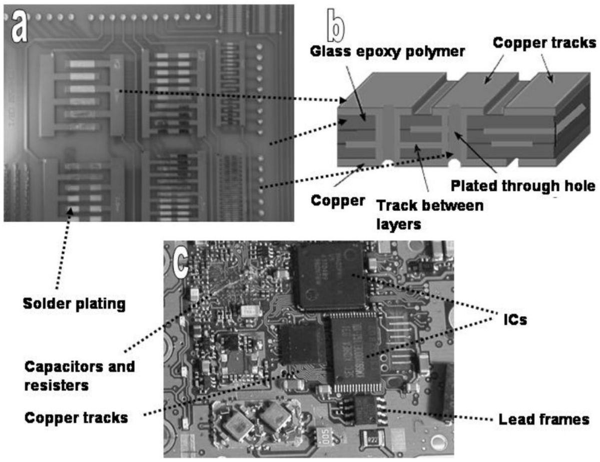

Figure 1.7. Description of a PCB: (a) PCB with connecting lines, (b) schematic of the cross section of a PCB, and (c) PCB with component mounted on it.

The line in each layer is connected to the lines on top and bottom through blind holes, which is plated. The connection paths are made solderable with a Sn-Pb coating, which also act as an etch-resist in the manufacturing process. Recent processes for PCB wiring use ENIG-process (Electroless Nickel-Gold). The ENIG consists of a few micron thick Ni-P (EL Ni) coating on the base copper on PCB, followed by a thin gold layer on EL Ni (C.W. Nielsen, 2004). Thickness of the gold layer varies from 50 – 100 nm. The reason for using the ENIG process in the first place is to produce a PCB with good solderability. However later, the good connecting property of the gold has also been used for connectors by using a thin layer of gold coatings. Figure 1.7c shows the PCB with various components mounted on them. If water layer is present, many of the components can get connected to each other, which is easier with reduction in spacing between them.

Electronic connectors: There is a large spectrum of materials used for electronic connectors. Figure 1.8 shows one type connection interface used for PCBs with gold layer on the top.

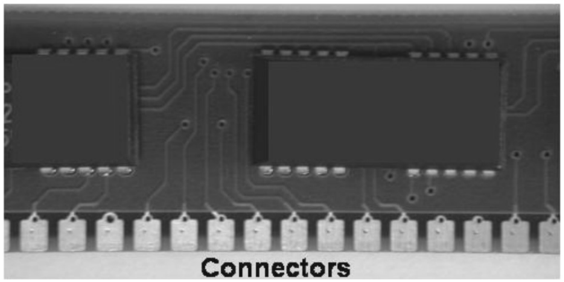

Figure 1.8 Electronic connecting part on a PCB

The classical materials used for low-voltage electronics are the copper and copper alloys, which are electroplated with a noble metal such as gold. Electronic connectors are mainly manufactured with reel to reel plating, which is an effective and cheap process so that it is possible to make selective deposition of the noble metal exactly at the area of contact. It is also possible to make coating with varying thickness having a thick layer at the connecting area to withstand greater wear. Electronic connectors made of graphite are often used in the "thick-film" techniques.

Computer hard disk: Inside of a computer hard disk drive consists of several components as shown in Figure 1.9.

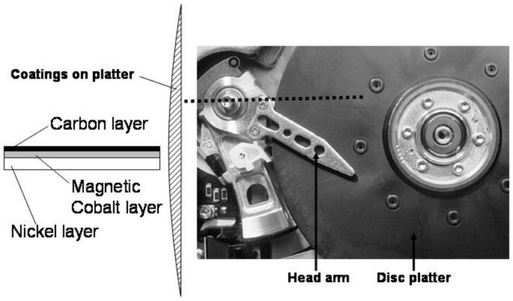

Figure 1.9 Computer hard disk with description of components (http://encarta.msn.com/media_701509097_761563087_-1_1/Inside_a_Computer_Hard_Drive.html)

The round disc platter is the magnetic recording media for hard disc. The platter is usually made of aluminum electroplated with nickel, and an over layer of 50 nm thick magnetically active cobalt alloy using PVD. Over the magnetic cobalt layer there is a thin layer of carbon, which is also coated using PVD. The arm like device that extends over the disc platter is known as the head arm, and is the device that reads the information out of the disc platter. The head arm is attached to the head actuator, which controls the head arm. Not shown is the chassis which encases and holds all the hard disk drive components.

Electronic encapsulation materials: The materials generally used for electronic packaging are metallic or polymeric materials. For electronic packaging, the material should have good conductivity in order to get good Electro Magnetic Interference (EMI) shielding. Therefore, if polymers are used, it is often necessary to coat the surface with a good metallic material to increase the shielding capability. For this purpose a thick layer of copper/nickel or aluminum coating is usually employed. The copper/nickel coating is usually made by electroplating, while the aluminum coating is made by PVD process. Rarely silver is used in some applications because of the high EMI shielding capability. The common metallic materials used for electronic structural parts are galvanized / chromated steel, but recently light metals such as magnesium is increasingly used for electronic packaging.

Lead free solder systems: A new set of lead free solder systems are emerging as replacement for lead solders due to potential health hazards of lead. European lead free legislation calls for total withdrawal of lead solders by 2008 (http://www.npl.co.uk/ei/documents/pbfreelegislation.pdf). Therefore, electronic industries are on a transition path to lead free solders. The candidate alloy components involve Sn as the base element, Ag, Bi, Cu, and Zn as the major alloying elements, and some other minor additions such as In and Sb. However, based on the market developments, it appears that the ternary system Sn-Ag-Cu emerges as the primary choice for replacement. Alloys within the composition range Sn-[3.4-4.1] Ag- [0.45-0.9] Cu are generally recommended. All lead free compositions consist of Sn as the base element with Ag and Cu. Although Sn itself is corrosion resistant, addition Cu and Ag could decrease the resistance. Copper and silver are two elements that have high migration susceptibility, and there are few reports (H. Tanaka, 2004, Rocak et al, 1997) suggesting that Sn-Cu-Ag systems are susceptible to electrolytic migration.

Hermetic Packages: Hermetic packages constitute a small part of total microelectronic packaging and generally provide extra protection from the environment. Hermetic seals are sometimes fragile and can crack to create leaks as a result of handling or while joining to circuit boards. Even devices in pin hole free hermetic packages can corrode. Moisture adsorbed on the inner walls of the package can desorb and initiate failure. Devitrifying glass is one type of sealing material with a high moisture content that is evolved upon vitrifying. Moisture trapped inside a sealed cavity can leach ions from the sealing glass or other sources to form a conductive electrolyte. Once an ionic path exist between conductors, corrosion and failure by any mechanism as like integrated circuit failure mechanism can occur. Corrosion behaviour of plastic encapsulated devices have been found similar to un-encapsulated devices. (Vimala et al, 2009).

Causes of corrosion in electronic systems

Materials and miniaturization has significantly contributed to the corrosion of electronic systems. However, there are several other environment related factors that could accelerate the corrosion process, which needs to be controlled in order to reduce the corrosion effects in electronics systems. The causes of corrosion will be discussed under the following;

- Conditions necessary for corrosion
- Effect of material selection
- Water intrusion
- Environmental factors
- Process and Service related residues

Conditions necessary for corrosion: Electrochemical corrosion is an important classification of corrosion. Four conditions must exist before electrochemical corrosion can proceed:

1. There must be something that corrodes (the metal anode).
2. There must be a cathode.
3. There must be continuous conductive liquid path (electrolyte, usually condensate and salt or other contaminations).
4. There must be a conductor to carry the flow of electrons from the anode to the cathode. This conductor is usually in the form of metal-to-metal contact such as in bolted or riveted joints. The elimination of any one of the four conditions will stop corrosion.

Effect of material selection: One of the fundamental factors in corrosion is the nature of the material. Materials are usually selected primarily for structural efficiency, and corrosion resistance is often a secondary consideration in design.

Water intrusion: Water intrusion is the principal cause of corrosion problems encountered in the field use of equipment. Water can enter an enclosure by free entry, capillary action, or condensation. With these three modes of water entry acting and with the subsequent confinement of water, it is almost certain that any enclosure will be susceptible to water intrusion.

Environmental factors: At normal atmospheric temperatures the moisture in the air is enough to start corrosive action. Oxygen is essential for corrosion to occur in water at ambient temperatures. Other factors that affect the tendency of a metal to corrode are:

1. Acidity or alkalinity of the conductive medium (pH factor).
2. Stability of the corrosion products.
3. Biological organisms (particularly anaerobic bacteria).
4. Variation in composition of the corrosive medium.
5. Temperature.

The presence of salts and acids on metal surfaces greatly increases the electrical conductivity of any moisture present and accelerates corrosion. Moisture tends to collect on dirt particles.

Process and Service related residues classification can be made for residues. (www.smtnet.com/library/files/upload/A-review-of-Corrosion-and-environmental-effects-on-electronics.pdf)

Process related residues: are the contamination on the surface due to the remains of the chemicals or decomposed fractions of a compound formed during the production cycle. These are the fluxing agents, etching medium, plating bath residues, or additives from the polymeric materials. Although the solder fluxes are designed to give (especially the no-clean variety) essentially no residue after the soldering process, depending on the temperature cycles and applications, small amount of original compound or decomposed products could remain on the surface. In practice, tiny fractions of these chemicals are enough to accelerate the corrosion process.

Service related residues: are the residues introduced during exposure to service environments. They can be aggressive ions like chlorides, SO_2 (g), NO_2 (g), or other types of chemically aggressive ions. Presence of such substances triggers corrosion to a large extent under humid conditions. The dust particle is another issue, which can act as a moisture trapping agent. Formation of water layer is easy on a dusted surface compared to the clean one. Therefore, corrosion is possible even at relatively low humidity such as 50-70%. If the surface of the electronic components is not contaminated, corrosion will not be a large issue.

Contamination and parameters effecting corrosion

An electronic device from manufacturing to use will pass through several steps that could have impact on its corrosion reliability during use. These are, equipment design, various stages of production process, storage, transport, and use. With increased requirements to electronic products reliability, corrosion resistance is an important property to consider already at the design and production phase. An important factor is the control of contamination at all stages of manufacturing process so that the inherent reliability of the product could be increased. Contamination can also be a problem during storage, transportation, and use. Contamination accelerating corrosion problems in electronic devices can be divided in to two categories, one occurring from the manufacturing process, while the other is due to device exposure to external environment during storage, transport, and in use. Controlling the contamination from the manufacturing process could enhance the inherent corrosion reliability of the device, while the contamination from external environment at all stage should be regulated for long term corrosion reliability. Conditions during use can not only cause new contamination to the product, but also could modify the already existing contaminants from the manufacturing process to initiate corrosion attack. (Jellesen et al, 2008)

Contamination resulting from production: Process related residues (contamination) on, say, PCB surfaces results from all stages of manufacturing process starting from base PCB production to components mounting, soldering, inspection and testing, device assembly, and packing. Base PCB manufacturing is a complicated process involving the use of plating and etching baths with complex chemistries and organic compounds (e.g. additives to the plating baths and solder mask), which could introduce tiny levels of contamination especially at regions where solution entrapment is easy such as via holes. Next step in the manufacturing process is the components mounting and soldering. Cleanliness of the component itself is an issue; while the soldering process will further introduce additional contamination due to presently used no clean fluxing. In addition, PCB handling between the production stages and during assembly using bare hands (without gloves) etc. could also introduce contamination in the form of fingerprints. All these factors could have great impact on the corrosion reliability. A particularly important factor is the residue resulting from no clean flux especially from the wave soldering process as this is generally the last step in the PCB manufacturing processes. Significant amounts of flux residues on the PCB surface after soldering process, which consists of both oil component and organic acid. Device failures are also seen resulting from exposure of these residues to humid environments causing corrosion under potential bias on the PCB. If residues dissolve in condensed water layer, they will increase the conductivity. This creates a risk of leakage currents on the PCB under humid conditions.

Contamination from environment during storage, transportation, and use: Corrosion behaviour of any material is determined by the external environment to which it is exposed.

Important environmental parameters related to user environment for electronic devices are humidity, temperature, aggressive chemicals and ions, dust and corrosive gases. Corrosion of electronics most often involves moisture and ionic contamination from the environment. Thickness of the moisture films formed on the material surfaces depend on the relative humidity and the temperature. Temperature variation can also create cycles of wet and dry conditions, often referred to as Time of Wetting (TOW).

For electronic devices, humidity and temperature variations can cause failures due to corrosion. The effect of airborne substances on metals in outdoor environments enhances more corrosion, whereas corrosion in indoor environments are considerably reduced. This reduction is clearly due in part to the lower indoor concentrations of corrosive gases (sulphur dioxide, nitrogen oxides, and chlorine-containing species). The airborne concentrations gives information about conditions on surfaces where corrosion is taking place. These are determined by the rates of arrival and sticking probabilities of the atmospheric species at a surface and by the amount of adsorbed water on the surface. It is the combination of adsorbed moisture and accumulated atmospheric species that provides the local environment for corrosion to occur. Dust, cleanliness and contaminants play a vital role in this respect. For electronic devices, corrosion is further accelerated by the presence of potential bias on the PCB. Contamination from the local environment can increase the conductivity of the water layer to increase the leakage current and subsequently corrosion.

Case study - Corrosion in PCB: Considering the PCB of say a TV and a Remote control system, a reddish-brown indicates some type of deposition. For soldering tin or lead or a combination of both are generally used. The brown deposition is caused by high heat during the process. Tin and lead both get oxidized at soldering part. After depletion of metallic tin, the oxides may react with atmospheric contaminants like chloride and sulfates to form low solids as fluxes. Fretting corrosion is caused by Sn and SnO flaking at the solder joints. In sulfur bearing environment creep corrosion occurs on PCB. Integrated circuit (IC) failure takes place when high current transfer exceeds the maximum rating of the fabrication process. Where a white fluffy precipitation is found surrounding the soldering, such deposition is termed as dendrites. As Printed circuit boards can suffer from variety of problems if the surface is contaminated with electrically conducting materials. When combined with moisture, contamination results in lowering of resistance between tracks and pads that can lead to corrosion of metals. The higher the humidity, the thicker is their moisture layer and faster the corrosion or dendrite growth. It is a type of electromagnetic migration caused by surface roughness. (Siddharth Dev, 2014).

Corrosion in the electronics industry

Corrosion of device components, manufactured by the electronics industry, is a problem that has occurred during a long time. Often, especially corrosion of one or more of the metallic elements of an electronic component is the primary cause of failure in various electronic equipments. The high density of components required to reduce the size of electronic equipment, also for a better signal processing, leads to the generation of enclosed corrosion between thin metal sections. Furthermore, when electronic devices are in more severe environments such as tropical, subtropical, contaminated deserts, etc., they have high failure rates. There are reported cases where small amounts of moisture have caused corrosion in tablets with printed circuits, nichrome resistors, fittings, electrical connectors and a wide range of components, and micro-electronic components, which have been coated with metallic films (Valdez B. et al., 2006, G. Lopez et. al., 2007) Corrosion of metal components in the electronics industry may occur at different stages: during manufacture, storage, shipping and service. The main factors in the onset of corrosion and subsequent development are moisture and corrosive pollutants, such as chlorides, fluorides, sulfides and nitrogen compounds, organic solvent vapors, emanating from the resins used as label, or coatings formed during the curing process and packaging of microcircuits. The sources providing aggressive pollutants are diverse, from flux residues used for welding processes, waste and vapors from electrolytic baths, arising volatile organic adhesives, plastics and acidification of their environment. The design of electronics equipment requires a great variety of different metals, due to their different physical and electrical features. (https://cdn.intechopen.com/pdfs-wm/41213.pdf).

Metals and alloys used in the electronics industry are:

- Gold (Au) coating and / or foil in electrical connectors, printed circuits, hybrid and miniature circuits.;
- Silver (Ag) for protective coating in contact relays, cables, EMI gaskets, etc..;
- Magnesium (Mg) alloys for radar antenna dishes and light structures, chassis brackets, etc..;
- Iron (Fe), steel and ferroalloys for guide components, magnetic shielding, magnetic coatings memory disks, processors, certain structures, etc..;
- Aluminum (Al) alloys for armor equipment, chassis, mounting frames, brackets, trusses, etc..;
- Copper and its alloys for cables, tablets printed circuit terminals, nuts and bolts, RF packaging, etc..;
- Cadmium (Cd) for sacrificial protective coating on iron and safe electrical connectors;
- Nickel (Ni) coating for layers such as barrier between copper and gold electrical contacts, corrosion protection, electromagnetic interference applications and compatibility of dissimilar material joints;
- Tin (Sn) coating for corrosion protection of welding; for compatibility between dissimilar metals, electrical connectors, RF shielding, filters, automatic switching mechanisms;
- Welding and weld coatings for binding, weldability, and corrosion protection.

Many of these metals are in contact with each other, so that in the presence of moisture, galvanic corrosion / bimetallic corrosion occurs.

Other corrosion problems can occur due to the characteristics of electronic components such as electromagnetic interference, electromagnetic pulse, flux residues, finishes and materials component tips, organic products that are used for various purposes and emitting gases during curing, whiskers, embrittlement inter-metallic electrical contacts. Metal components may corrode during manufacture and storage prior to assembly, needing protection against corrosion. In plants and warehouses, air conditioning systems must operate efficiently, removing moisture and suspended particulate matter. Filters and traps should be cleaned and replaced regularly. For closed containers, we recommend the installation of dryers with visual indicators, and the use of volatile vapor phase corrosion inhibitors. In the case of sealed black boxes, the temperature inside these drops should never be below the dew point (Veleva L. et al., 2008, Vargas L. et al., 2009, Lopez G. et al., 2010).

Corrosion control methods

Corrosion control as a protection method have become an important area of concern since electronics is increasingly integrated into different devices in highly corrosive conditions, as the increase in packaging environment. The mechanisms through which the climate, humidity, contamination, other environmental factors, the method of use of the device, its structure and the manufacturing process affect the corroding of the electronic components and system. Corrosion control is a process aimed at reducing the corrosion rate to a tolerable level (or predictable limits), it focuses mainly on materials and environments. Since corrosion involves interaction between materials and environment, this approaches to control corrosion and environment. (www.dmme-engineering.com/uncategorized/classic-methods-of-corrosion-control-summarized/).

Four primary techniques are used for limiting corrosion rates to practical levels include; Material Selection, Coatings, Cathodic Protection and Chemical Corrosion Inhibitors.

Material selection: entails picking an engineering material either metal alloy or non-metal that is inherently resistant to the particular corrosive environment and also meets other criteria. Variables that will affect corrosion are established along with materials that may provide suitable resistance for those conditions. Obviously other requirements such as cost and mechanical properties of the potential materials must be considered. Data needed to thoroughly define the corrosive environment include many of its chemical and physical characteristics plus application variables such as its velocity (or is it ever stagnant?) and possible extremes caused by upset conditions. Non-corrosion considerations include mechanical strength, type of expected loading and possibly the compatibility of the different candidates with the required fabrication method. After these criteria and other more unique ones are considered the list of materials that can generally satisfy all requirements usually becomes short. Final selection is then made but trade-off from optimal meeting of each criterion often are necessary.

Coatings: are the most widely used method for controlling corrosion. The possibilities cover a wide range and include such things as paints of many types, electroplating, weld overlays and bonding a thin, corrosion-resistant metal or non-metal onto a stronger substrate metal that is susceptible to corrosion. In many cases the coating simply acts as a barrier between the corrosive environment and the substrate material. In some cases such as in galvanized steel the coating (zinc in this case) provides a barrier but it also acts as a sacrificial anodic material to protect the steel below by preferentially corroding instead of the steel. This effect is cathodic protection. The coating selection, surface preparation, application and proper quality control throughout the process to attain an optimal coating for the given application requires special experience. When using organic and inorganic paint coatings there are engineering standards that aid the coating specialist. For those coatings the specific surface preparation required on the substrate is often critical to final success depending on the type of coating being used.

Cathodic protection: often known as CP is a corrosion control technology which provides a flow of DC current onto the protected surface to counteract corrosion current flow. It functions due to a fundamental characteristic of corrosion, i.e., when the electrochemical process of corrosion occurs there is a flow of DC electric current from the surface being attacked. The resulting rate of corrosion is greatly reduced to allow practical, long-term use of the protected metal, e.g., for 10 to 20 years or more, although corrosion is not stopped. The amount of current necessary to be supplied to the surface to control the rate to practical levels depends on the area exposed. Thus CP is most often used in conjunction with some type of coating. This greatly lowers the current needed for protection. No coating is 100% free of small areas where the substrate is exposed. Using CP with a coating means current is only needed at these bare spots. There are two types of CP. One is the sacrificial anode (also called galvanic) type in which a metal more susceptible to corrosion in the given electrolyte is electrically connected to a less susceptible metal to be protected. The former metal becomes the anode and is consumed over time while the latter metal becomes the cathode in a galvanic corrosion cell. Thus the zinc on galvanized steel is the anode while the steel substrate as the cathode is protected. The second type of CP is impressed current CP where an electric power rectifier is used to lower the voltage of AC line voltage feed to it while changing the AC to DC current. The rectifier is connected to non-consumable anodes that supply DC current to the metal surface to be protected. Each type of CP has its separate advantages and disadvantages.

Chemical Corrosion Inhibitors: are solid, liquid or gaseous compounds that are added in small quantities to the given corrosive environment to change its interaction with the metal to be protected. Corrosion is an electrochemical process that consists of an oxidation reaction on the anodic site (or sites) of the metal plus one or more reduction reactions on the cathodic site (or sites). These two types of reactions must always occur at the same rate. An effective inhibitor functions by chemically changing one or both of the two reactions so as to slow their rates. Thus the rate of the overall corrosion reaction is reduced to practical levels when a proper inhibitor is applied. Using and maintaining the correct concentration of inhibitor is essential. Using too much or too little can each have negative consequences. Inhibitors are most often used in circulating cooling water systems or to treat steam boiler feed water before usage in a boiler.

CONCLUSION

The electronic system and components consist of variety of metallic objects, when two or more of these metals are in combination that forms a galvanic cell. Accumulation of dust particles, gases, and other atmospheric contaminants along with moisture at the components of electronic devices results in corrosion. Corrosion decreases the service life of the equipment beyond expectation. Formation of scales and deposition of oxide residues in form of dendrites break the operation of the system. Another important aspect of corrosion is the contamination resulting from all stages of manufacturing process and service environments. Sources of contamination can also be human handling such as finger prints. Dust particles could be site for water trapping meaning corrosion can occur at lower humidity and source for aggressive ions. Electronic devices can fail due to a number of failure modes depending on inherent factors related to materials, design, and cleanliness under exposure to humidity and other gaseous conditions. Some failures can be avoided by simple remedial measures such as changes in materials, slight change in design, and optimal cleanliness

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