Influence of Corrosion Properties on Electrochemical Migration Susceptibility of SnPb Solders for PCBs

Y. R. Yoo and Y. S. Kim*

School of Advanced Materials Engineering, Andong National University, 388, Songcheon-dog, Andong-si, Gyeongbuk 760-749, Korea

Electrochemical migration is caused by the adsorption of water and the bias voltages between the electrodes or pads which form an electric circuit or in the solders used to connect the parts. This work focused on the elucidation of the mechanisms of electrochemical migration of pure Sn, Sn37Pb, and Sn55Pb solders in electronics. The electrochemical migration behavior was discussed on the basis of the polarization behavior of SnPb solders. After the water drop test, the time to failure decreased with increasing Pb content in Cl⁻ solution and increased with increasing Pb content in SO₄²⁻ solution. In the case of the SnPb solder alloys, the pitting potential, the passive current density, the cathodic current density and the efficiency of cathodic deposition of the alloying elements were closely related to the resistance of the electrochemical migration.

Keywords: electrochemical migration, SnPb, solder, corrosion, time to failure

1. INTRODUCTION

Some applications of solder joints entail the use of metal structures that are subjected to electrical voltages. Under such circumstances, the corrosion process may be affected by the voltage. The voltage actually alters the “natural” corrosion (charge) potential required for the initiation of half-reactions between the cathode and anode materials. This situation is termed voltage-assisted corrosion and is sometimes superimposed on galvanic corrosion. However, the effect of the applied voltage depends upon its magnitude, the selection of materials to receive the “+” and “−” terminals of the DC source and the difference in the corrosion potentials between the two materials. The applied voltage can be used to alter the relative corrosion potential between the two metal members, even to the point of switching the anode (corrosion) from one material to the other [1].

An important consequence that is often observed with voltage-assisted corrosion is electrochemical migration [2-9]. Two metal pads having the same composition are located on top of an insulating material. These two pads are connected to the terminals of a DC voltage supply [10,11]. An electrolyte is deposited across the two pads. The metal strip that is connected to the negative terminal forms the cathode and supports the reduction half-reaction. The path connected to the positive terminal forms the anode and supports the oxidation reaction. Metal ions are created at the surface of the anode pad as corrosion by-products. These ions can then travel through the electrolyte and reach the cathode. They are subsequently reduced to neutral atoms and will build up on the surface of the pad. The transfer of metal from the anode to the cathode under the applied voltage constitutes the process of electrochemical migration. The accumulation of anodic material will continue until either the anode material is completely consumed or the material built up from the cathode forms a ligament that reaches the anode and causes a short circuit.

The conductive ligament formed by electrochemical migration is typically short-lived. The path is vaporized by Joule heating almost immediately upon the passage of a current. The vaporization of the corrosion product often erases the evidence of its existence, thereby hindering failure analysis. This phenomenon has most often been observed in electronic circuit board applications. The momentary short-circuit induced by such a filament can damage sensitive electronic components or cause intermittent failures of electronic circuitry as the paths are created and destroyed. Nevertheless, electrochemical migration can be scaled up as a function of the applied voltage and electrolyte strength, causing a concern for larger structural members subjected to higher electrical voltages (for example, power distribution facilities). Electrochemical migration is sometimes the source of persistent “grounding problems” in both small-scale and large-scale electrical circuitry [2].
Corrosion mechanisms in electronic components have been extensively studied. Since electronic products are mainly used indoors or within enclosures, the troubles leading to corrosion problems are not easily defined. Problems can arise due to the fact that these systems are fabricated by a number of different processes and consist of a variety of dissimilar materials. Miniaturization and the requirement for a high component density have resulted in smaller components, closer spacing, and thinner metallic paths. Thus, the effect of the bias potentials and small defects is magnified [12]. Corrosion in electronic products manifests itself in several ways. Computers, integrated circuits, and microchips are now an integral part of all technology-intensive industry products, ranging from aerospace and automotive applications to medical equipment and consumer products, and are therefore exposed to a wide variety of corrosive environmental conditions. Corrosion in electronic components is insidious and cannot be readily detected. Therefore, when corrosion failure occurs, it is often treated as a simple failure and the part or component is replaced [13].

Electrochemical migration is caused by the adsorption of water and the bias voltages between the electrodes or pads which form an electric circuit or in the solders used to connect the parts. SnPb solders, which have been widely used to connect the outside leads of packaging, should be replaced because of environmental concerns. However, up until now, all electronic products in the world have used SnPb solders because of their long life-span. Thus, this work focused on the elucidation of the mechanisms of electrochemical migration of SnPb solders in electronics. The corrosion resistance of SnPb solder in aqueous and gaseous environments is a function of the alloy composition [14]. It improves significantly when the tin content is increased above 2 wt.% [15]. Lead forms unstable oxides, which easily react with chlorides, borates, and sulfates [16]. The standard potentials for the dissolution of Sn and Pb are −0.136 and −0.125 V (SHE) at room temperature, respectively [17].

In this work, the electrochemical migration susceptibility of pure Sn, 63 wt.% Sn−37 wt.%Pb (Sn37Pb), and 45 wt.%Sn−55 wt.%Pb (Sn55Pb) solders was determined by the water drop test (WDT) in chloride and sulfate solutions. The electrochemical migration behavior is discussed on the basis of the polarization behavior of SnPb solders.

2. EXPERIMENTAL PROCEDURES

2.1. Water drop test (WDT)

To evaluate the resistance to electrochemical migration, we used the WDT. The specimen used for the WDT was made on a Si wafer substrate. On the Si wafer substrate, a Ni under bump metallurgy (UBM) layer was sputtered (to a thickness of 3000 Å). A pad with a 300 μm space pattern was made by using the photo-resist and screen printing methods. Solder pastes were reflowed on the Ni UBM in a reflow oven and, after the reflow, the specimen was annealed for 5 h at 150 °C to minimize the phase transformation between the Ni UBM and solder alloy. Then, the reflowed pad patterned solder was polished to a thickness of 10 μm.

The WDT was performed to understand the failure mechanism in the pad patterned solder alloy in NaCl and Na2SO4 solutions at room temperature. First, we dropped 3 μl of the test solution between the pad patterned solders with a microsyringe and then applied a DC voltage of 3 V by using a potentiostat (EG&G, model 273 A). The current was measured and continuous images of the migration process were recorded with a video-microscope.

2.2. Polarization test

The specimen used for the polarization test was made on a Ni-electroplated copper plate, which plate was cut into 1×1 cm specimens. The solder pastes were reflowed then annealed for 5 h at 150 °C. After polishing the specimens with 0.05 μm of alumina paste, we connected a coated lead wire to the specimens and sealed the surface with epoxy resin (exposure area: 0.09 cm²). Anodic and cathodic polarization tests were performed in deaerated NaCl and Na2SO4 solutions at 25 by using a potentiostat (Gamry, model DC105). The solution was deaerated with N2 gas for 30 min at 100 ml/min. A saturated calomel electrode (SCE) was used as a reference electrode and a high-density graphite rod was used as a counter electrode. The scanning rate was 1 mV/s.

2.3. Anodic dissolution and ion analysis

To analyze the dissolved species and their concentration, we performed an anodic dissolution test and ion analysis. The test specimens for the anodic dissolution test were made as follows: to prepare the UBM, we deposited Ni thin film on a Cu substrate by electroplating; we then reflowed the SnPb solder on the Ni UBM in a reflow oven. The anodic dissolution test was performed by using a potentiostat (Gamry, model DC105) in deaerated 0.001 wt.%NaCl and 0.001 wt.%Na2SO4 solutions at room temperature. A dissolution potential was applied to the specimen for 1 h and obtained the anolyte. We used an ICP/AES (Spectro, model Flame Modula S) to analyze the ionic species and concentration.

2.4. Surface analysis

After the WDT, the pad patterned specimens were allowed to dry naturally and then the specimen was transferred to a SEM chamber. The images and composition of the pad and dendrite were observed using SEM-EDS (JEOL, model JSM-6300).

3. RESULTS

The WDT was performed to evaluate how the Pb content