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COMPARISON IN BETWEEN GOOD AND OXIDIZED LEADFRAME: A CASE STUDY IN PACKAGE DELAMINATION ANALYSIS

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ABSTRACT

The new electrical conductive material, copper alloy, C194 in situ composite, has been developed for the application to leadframe, high field magnet and trolley wire. This material has a low cost, high thermal and electrical conductivity, easy fabrication and joining, and also has a wide range of attainable mechanical properties. In C194, copper is one of the core materials in producing leadframes, interconnection wires, heat sinks and foils for flexible circuits in electronic packaging. Copper oxidation is considered as a serious reliability problem in microelectronic package. Unlike aluminum oxide, the copper oxide layer is not self-protected which could lead easily to the oxidized condition. This study focused on copper leadframe which consist two types of condition, good and oxidized since good leadframe and oxidized leadframe have a different structure and composition. Both leadframe were applied in Quad Flat No-Lead (QFN) package. It was found that oxidized leadframe has a negative effect on package reliability. It will produce cracks at Cu-Al interface on the copper interconnection wire that will causes delamination between the leadframes die pad and molding compound. It also induces poor adhesion between the copper leadframes and molding compound.

INTRODUCTION

Copper is widely used as the core material in producing leadframe for microelectronic packaging. The application of copper is popular because it serves primarily in order to mechanically support the chip during the assembly of plastic package and to connect the chip electrically. Copper alloy is an ideal material in producing leadframe because of electrical resistance and thermal conductivity standpoint [1].

Among the choice of material that is used in semiconductor packaging, are argentums (Ag), aluminum (Al), aurum (Au) and copper (Cu). Copper offers low electric resistively compares to Ag that has a resistivity about 5% lower than copper electrical resistance [2]. Furthermore, Copper has high thermal conductivity that can allow faster heat dissipation than a low thermally conductive material. Copper also has a wind range of attainable mechanical properties, easy of deposition, fabrication, and joining.

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Unlike an aluminum oxide, the copper oxide layer is not self-protected, so the copper can be easily oxidized even at low temperature storage. Therefore, study on copper oxidation has becoming very important in microelectronic packaging.

There are two different mechanisms of copper oxidation. In aqueous environments at ambient temperature, a thin layer of Copper (I) oxide (Cu_2O) forms first on the copper surface by the oxidation and reduction partial reactions [3]:

$$4Cu(s) + 2H_2O(l) \rightarrow 2Cu_2O(s) + 4H^+(eq) + 4e^- \qquad \text{(anode)}$$

$$O_2(s) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(eq) \qquad \text{(cathode)}$$

A Cu_2O is a p-type semiconductor with negatively charged vacancies. The growth of the Cu_2O takes place on the top of surface through the mass transport of the Cu^+ ions and electrons in a direction normal to the surface via vacancies. However, Cu_2O is hardly detected in experiments because Cu_2O is unstable in air, which will immediately change to copper (II) oxide (CuO). The second stage of oxidation, the formation of the CuO from Cu_2O is usually a slower process. It is governed by the in-diffusion of oxygen into the oxide [4].

Figure 1 shows the corrosion rate of copper leadframe as the function of autoclave test time. Initially, Cu has higher percentage than CuO, which is 59% and 41%. However, the CuO concentration increases gradually after 384 hours under autoclave test. At 576 hours, the Cu turns into CuO completely, while no Cu is detected [5]

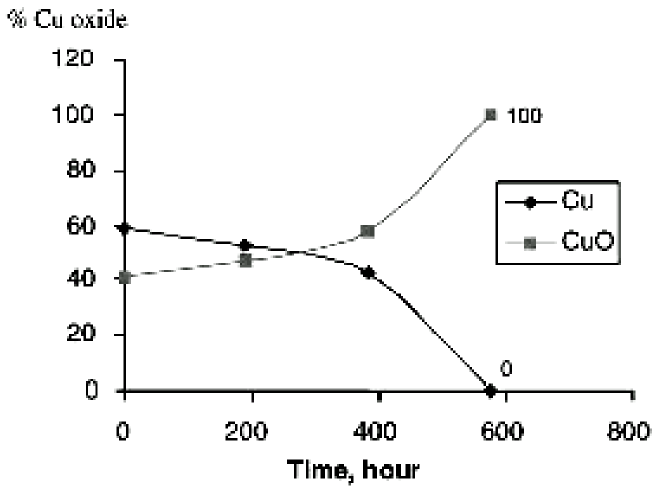

Figure 1: Copper oxide concentration and rate of corrosion as a function of exposure time [5].

In this paper, the good and the oxidized leadframe have a different structure and composition was used. Both types of leadframe are mainly used in Quad Flat No-

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Lead (QFN) package. By using the oxidized leadframe in a QFN design, the effect on package reliability can be monitored. From industrial point of view, it is very important not to use the oxidized leadframe since it may lead to the package delamination occurrence.

EXPERIMENTAL WORKS

The fresh die-pads from leadframe were subjected to oxidation under constant temperature in an ambient environment of 30°C/70% relative humidity (RH) with 360 hours. Infinite Focus Microscope (IFM) was used to measured the volume of the sputter craters on copper oxide. Due to the surface roughness of the copper leadframe, a thicker oxide sample was required to calibrate the sputter rate using IFM.

On the other hand, Energy Dispersive x-ray (EDX) was used to measure the surface roughness of leadframe, and quantities information on the chemical nature of surface. The surface of the oxidized layer is bombarded by an electron beam, and the x-ray is produced to identify the elemental nature at the point of impingement on a copper leadframe.

The tensile stress between the good leadframe and the oxidized leadframe are measured using the uniaxial universal tester machine in order to determine the Young's modulus value. An average of three runs was performed on each sample to measure the thickness of the oxide. Both samples were put under reliability testing, i.e. the Moisture sensitivity Level 3 (MSL3), in condition 168 hours, ≤ 30°C/60% RH and three times of infra red (IR) reflow (260°C).

RESULTS AND DISCUSSION

Surface analysis of the leadframe

Surface roughness is the measurement of the finer surface irregularities in the surface texture. These are the result of the manufacturing process employed to create the surface. Surface roughness, R_a is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micrometers. The observation for the microstructure and surface roughness between good and oxidized leadframe are shown in Figure 2 and 3. Based on the result, average roughness for the good leadframe is 4.143 µm and for the oxidized leadframe is 3.205 µm. The surfaced roughnesses for the oxidized leadframe are lower than the surfaced roughness for the good leadframe because it has thin oxidation layer. The layer of oxidation gives the lower adhesion strength to the epoxy and molding compound which lead to delamination on epoxy and molding compound in the QFN package.

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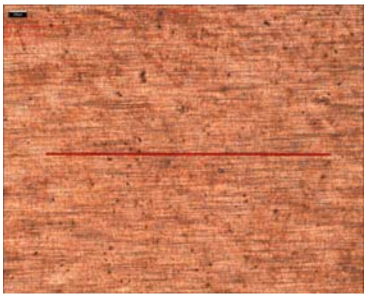
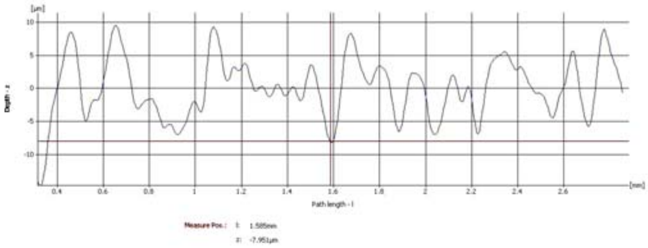


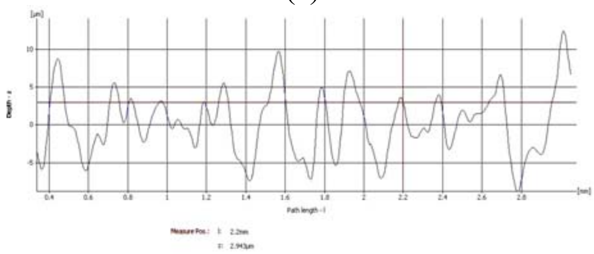
(a)



(b)

Figure 2: Good leadframe (x25): (a) Microstructure view, (b) Surface roughness graph, R_a 4.143 µm.

(a)



(b)

Figure 3: Oxidized leadframe (x25): (a) Microstructure view, (b) Surface roughness graph, R_a 3.205 µm.

The surface analysis of leadframe using the EDX demonstrates that the oxidation in the copper interface occurs after under constant temperature in an ambient environment of 30°C/70% RH at 360 hours. Figure 4 shows an amount of 80.77% of Cu, 7.69% of C and 11.54% of O at 0 hour corrosion, the oxidation of this leadframe is 19.23% oxidation (CuO or Cu_2O). Figure 5 shows an amount of 67.86% of Cu,

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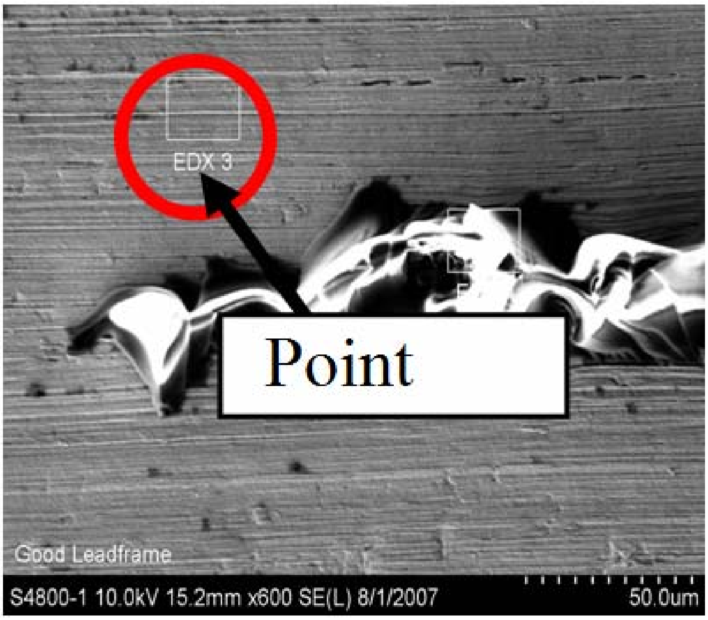
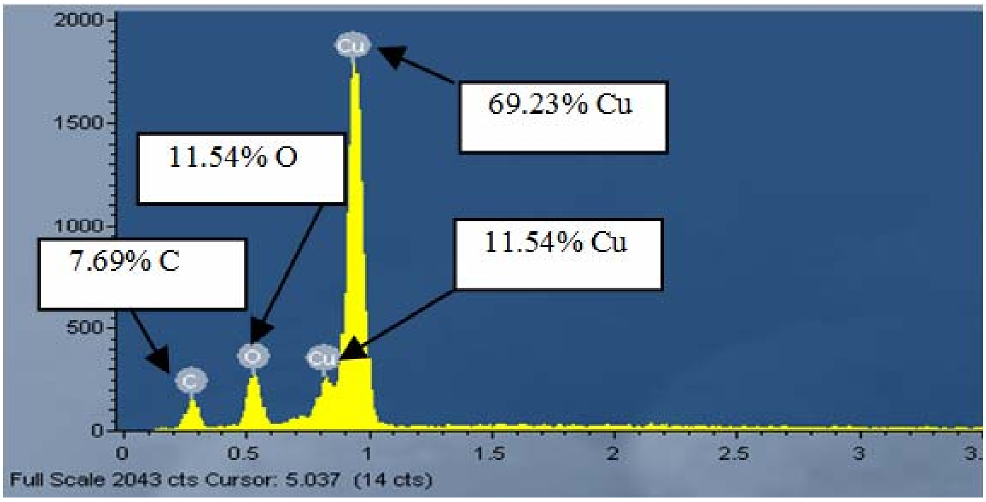
10.71% of C and 21.43% of O. This shows decreasing Cu and increasing CuO or Cu_2O after 360 hours (15 days) corrosion and the oxidation of this leadframe is 32.14% oxidation. Figure4 shows the different result of the good leadframe compared to and Figure5 shows the oxidized leadframe.



(a)



(b)

Figure 4: EDX results for a good leadframe: (a) Microstructure scanning view (50 µm), (b) spectrum view to shown material composition.

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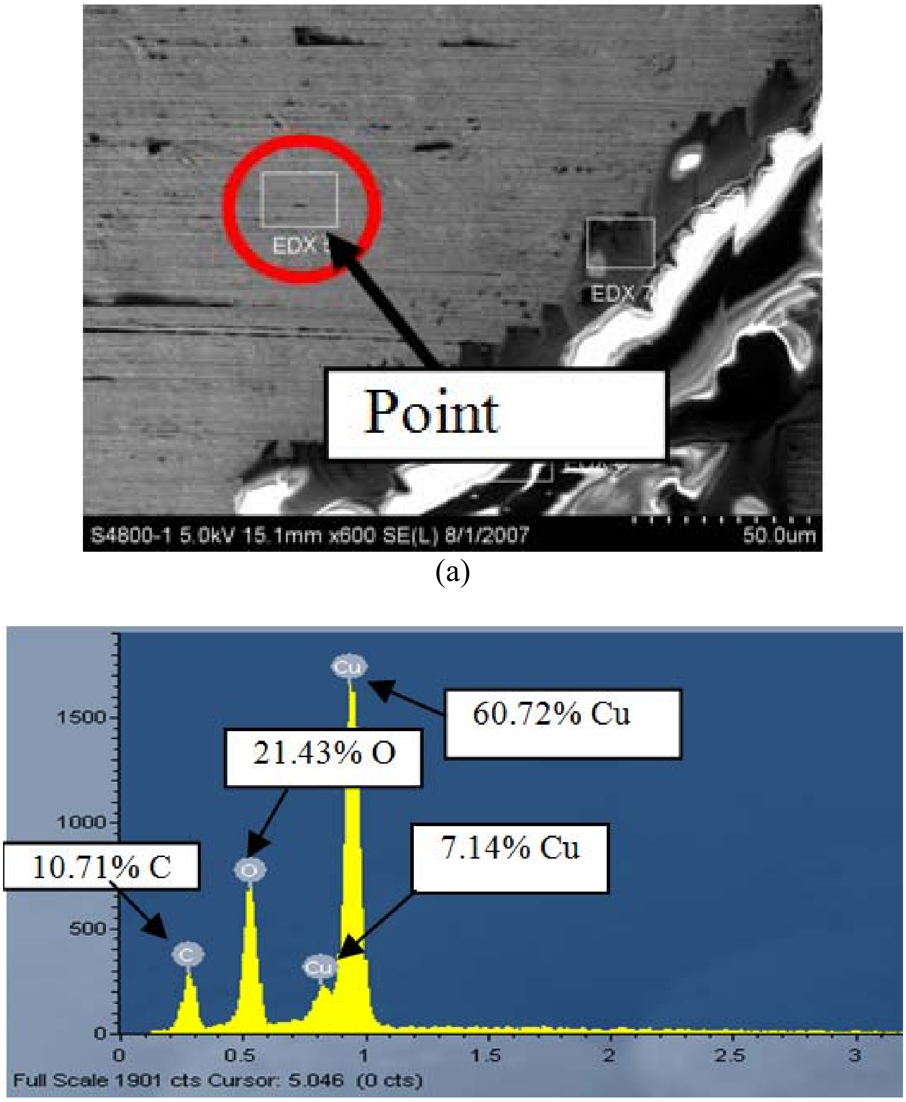

Figure 5: EDX results for an oxidized leadframe: (a) Microstructure scanning view (50 µm), (b) spectrum view to shown material composition.

Young's modulus of the leadframe

From the tensile stress result, the good leadframe has higher Young's modulus which is 64.39 GPa as shown in Figure 6. The Young's modulus for oxidized leadframe was far lower which is 56.45 GPa as shown in Figure 7. The oxidized leadframe has lower Young's modulus because of the oxidation layer gave lower strength for metallic materials.

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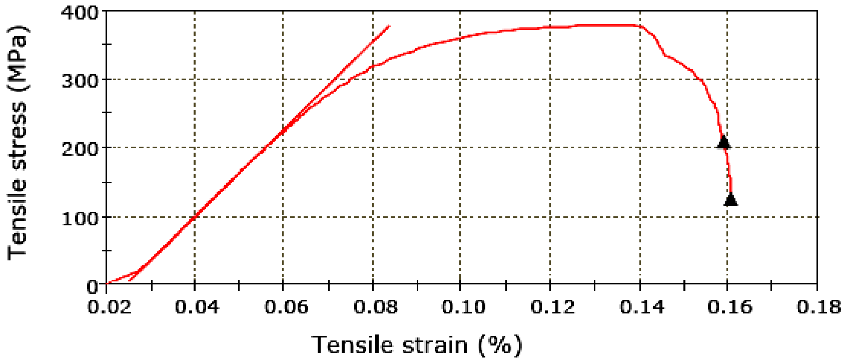

Figure 6: Graph of stress versus strain good leadframe C194.

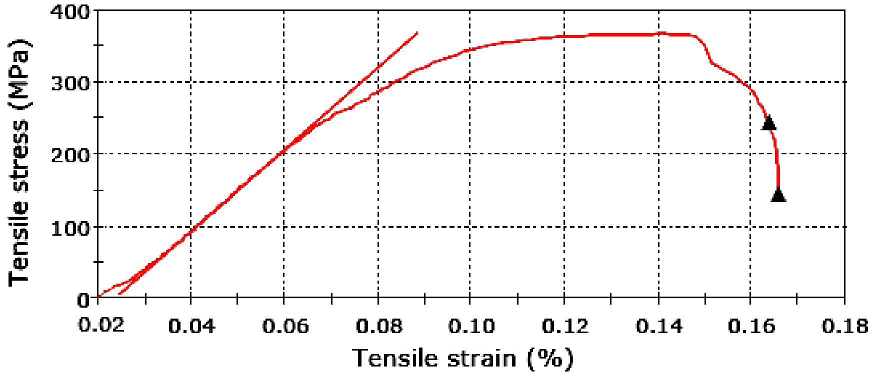

Figure 7: Graph of stress versus strain oxidized leadframe C194.

Application of leadframe in QFN package

The copper oxidation causes delamination in the area of the leadframes die pad, epoxy and die and molding compound in QFN package. In this study, the effect of the copper leadframe oxidation on package delamination is also investigated by Scanning Acoustic Microscope (SAM). Two types of SAM were applied, i.e. the C-SAM for detecting the delamination effects on surface on the package, and the through scan for detecting the delamination effect on interface die and epoxy. The typical image of the delamination by C-SAM and through scan is shown in Figure 8 and 9.

In Figure 8, the area of the delamination on this interface is qualified as good unit after MSL 3 test and three times IR reflow process to characterize the impact of copper oxidation on package delamination. Figure 9 shows that the area of delamination on this interface is not qualified and it is considered as bad unit after MSL 3 test and three times IR reflow process. It can be concluded that when the adhesion strength between die pad and compound and epoxy and die increases, the integrity of the other interfaces within the package become critical. This appears to support the anticipation of many previous works that package failures always tend to

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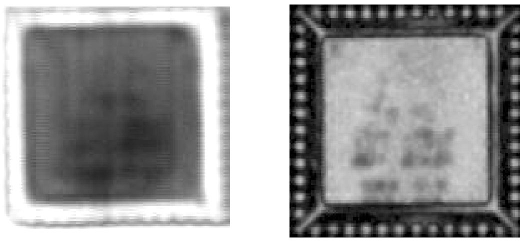
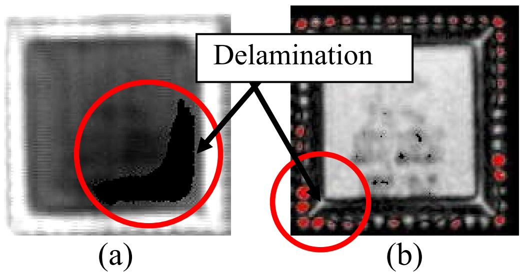
occur at the weakest interface.



(a) (b)

Figure 8: Good leadframe scanning delamination QFN package: (a) Through scan, (b) C-SAM.



(a) (b)

Figure 9: Oxidized leadframe scanning delamination QFN package: (a) Through scan, (b) C-SAM.

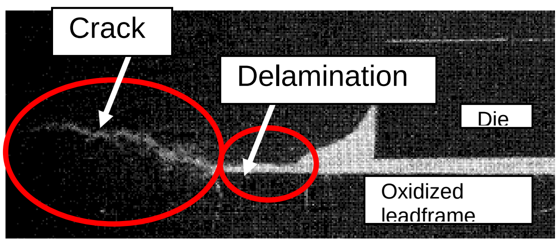


Figure 10: Cross section image delamination at the die attach interface and package crack using oxidized leadframe.

The reliability package condition has a vapor pressure of moisture inside a nonhermetic package increases greatly when the package is exposed to the high temperature of solder reflow. Under certain conditions, this pressure cause internal delamination of the QFN package from the die and the lead using oxidized leadframe. The stress result for this condition in external package cracks using the oxidized leadframe is shown in Figure 10. According to the related literature [7], this is commonly referred to as the ‘‘popcorn’’ phenomenon because the internal stress causes the package to bulge and then crack with an audible ‘‘pop.’’

CONCLUSION

The surface of oxidation leadframe under a constant temperature in an ambient environment of (30°C/70% RH) is mainly composed of Cu_2O with very thin CuO on

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it. Either severe oxidation or slight oxidation may cause poor adhesion between leadframe, epoxy and molding compound interface. The oxidized leadframe is proven to have delamination or cracking effects after MSL 3 and three times IR reflow. Process control nowadays is trying to suppress oxide growth as much as possible. However, extremely low oxidation may cause poor adhesion, so oxidation to some degree must be considered in case of low pin count packages. The failure mechanism of delamination seems to be related to the weakening effect caused by internal void growth along material interface.

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