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The effect of electric current and surface oxidization on the growth of Sn whiskers

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ABSTRACT

Electric current was applied on pure Sn-plated leadframes to evaluate the effects of current-induced stress on the growth of Sn whiskers. The samples were stored at room temperate and 55 °C/85% relative humidity (RH) conditions with an induced current range of 0.1 A to 0.5 A. The samples stored at the room temperature did not grow the whiskers at any of the current conditions until 3000 hrs. As the current flow increased, irregular intermetallic compounds (IMCs) grew at the interface between the Sn finish and Cu substrate. However, various lengths of columnar and bent whiskers were observed under all current conditions, after exposure to 55 °C/85% RH conditions for 1000 hours. At the same temperature, the higher current levels showed longer whiskers than lower current levels. The Sn oxide had the α-SnO_2 structure of the rutile phase which was non-uniformly formed on the surface of the Sn finish. The grain size of the SnO_2 was estimated to be several nanometers. The SnO_2 film was up to a thickness of ~23 nm on the Sn whisker surface stored at 55 °C/85% RH conditions for 3000 hours.

1. Introduction

The need for a solution to the problem of environmental pollution caused by lead (Pb) has stimulated increasing interest in the elimination of Pb from electronic devices. For example, the hazardous substances restrictions (RoHS) were established. As a result, the use of Pb-free solder and finish, has been extensively studied. However, there is a potential problem in the replacement of Pb by Sn in this application, in that pure tin (Sn) and high Sn content alloy finishes on metal substrates tend to grow Sn whiskers. The growth of Sn whiskers has been observed since the 1950s [1]. It was found that the metallic whiskers on Sn surfaces grow spontaneously and can result in shorts circuits in electronic devices. In general, a compressive stress generated in the Sn finish is a necessary, but not a sufficient factor to cause the Sn whisker growth [2–4]. The compressive stress would be generated from two sources; i.e. from the formation of the Cu-Sn intermetallic compound (IMC) at the Sn/Cu interface and the Sn oxide phase on the Sn surface [5]. The Sn whiskers can be formed in many different shapes such as a filament, column, needle, and hillock. Recent industrial studies show that the nature of the current-induced whiskers differs from that of the spontaneously formed whiskers. Brusse *et al.* [6], Osenbach *et al.* [7], and Hilty *et al.* [8] observed no significant influences of either voltage or current on the Sn whisker growths. However, Liu *et al.* [9,10] reported the growth of Sn whiskers on pure Sn film at current densities of 10^5 A/cm^2, 7.5×10^4 A/cm^2 and 1.5×10^5 A/cm^2 both at the ambient temperature and 50 °C. Fukuda *et al.* [11] noted the impact of electrical current, mechanical bending, and thermal annealing on the Sn whisker growth. Lin *et al.* [12] reported Sn whisker growth induced by high electron current density. However, the results of previous work were obtained by using Sn-plated test coupons (e.g. copper (Cu) plate, n-type or p-type silicon wafer) under high current density. These are unrealistic conditions for electronic component applications. Because they do not take into account the shape variation of leadframes (LF)s or the influence of residual stress caused by the mechanical stamping. Accordingly, the effects of electric current on whisker growth were found to be different amongst several researchers.

In this study, whisker growth under the various electric current conditions was examined with using pitch of dynamic random access memory (DRAM) LFs. After observing the IMC morphologies on the bottom of the whisker, the correlation between the electric current and IMC morphology was analyzed. Simultaneously, the effect of the Sn oxide on the whisker growth was studied, too.

2. Experimental procedure and conditions

In this experiment, fifty-four thin small outline packages (TSOP, 22.22 × 10.16 mm) with stamped Cu LFs were used. The 0.125 mm thickness of leads with EFTEC-23Z(1/2H) were used in our test and the chemical composition of EFTEC-23Z(1/2H) was described in Table 1. The samples were pretreated by electrolytic cleaning

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Table 1
Chemical composition for EFTEC-23Z(1/2H).

	Cu	Ni	Si	Zn	Ag	Mn
Chemical comp. (wt%)	BAL.	2.2-3.2	0.5-0.7	0.45-0.55	0.02-0.05	0.1max

at room temperature for 60 s. For pure Sn plating, the chemical composition of the pure Sn solution was 97 ± 5 g/L of Sn^{2+} and 183 ± 10 g/L of methane sulfuric acid with 55 ± 3 ml/L of an additive. The applied current density was 11 A/dm^2, the plating time was 70 s, and the temperature was 35 °C. The average thickness of plating was 5.4-6.8 μm.

The pure Sn-plated LFs were stored at room temperature (20-25 °C/40-75% relative humidity (RH)) for 4300 hrs and high temperature/humidity conditions (55 °C/85% RH) for 1000 hrs and applied the electric current range of 0.1 A to 0.5 A, simultaneously. A 10 V power supply connected with a variable resistor was placed in a test circuit to induce the current loading as shown in Fig. 1. The current was induced for 240 s (on-state) periodically at 240 s (off-state) intervals using an electric circuit that was connected with a timer and relay. The corresponding current density estimated based on the area of LFs was 1.2 A/dm^2 for 0.1 A and 6.01 A/dm^2 for 0.5 A, respectively.

The whisker growths on the plating surface were observed at a 30° tilt by using field emission scanning electron microscopy (FE-SEM, S-4700). The axial length of a whisker is defined as the distance between the Sn surface and the tip of the whisker, according to JESD201 [13]. Microstructural analysis was carried out by using electron back-scattered diffraction (EBSD, INCA Crystal on JSM-7000F SEM). The grain orientations of electroplated Sn plating were analyzed by X-ray diffraction (XRD, X'Pert PRO). The scan axis was theta/2theta, and the scan speed was 0.04°/s. The experiments were carried out by using a Sn plating, which usually has a very rough surface, so mechanical polishing was used to remove a fraction of a micron from the top surface to improve the EBSD image quality. The morphology of the IMCs, which were grown at the grain boundaries and the interface of the Sn and Cu substrate, was observed with a focused ion beam (FIB, Helios NanoLab 400S and 600) as a gallium (Ga) ion source at an acceleration voltage of 30 keV. Final thinning of the TEM specimen was performed by micro milling with a 9.7 pA ion beam current. The sample surface was coated with platinum (Pt) and the cross-section was observed at a 52° tilt. The thickness of the layers was evaluated by using image analysis software to measure the total area of the IMC layer.

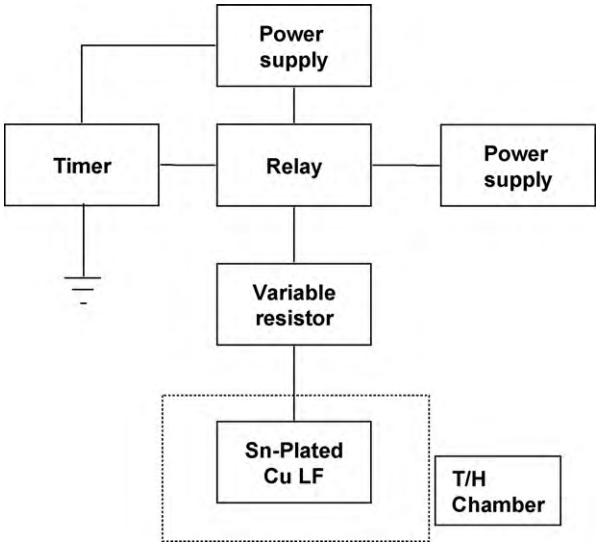

Fig. 1. Test circuit schematic.

The phase areas were divided by the interface length to yield the average layer thickness. The field-emission transmission electron microcopy (FE-TEM) specimens were observed with JEM-2100F and HD-2300A at an acceleration voltage of 200 keV. The Sn oxide and IMC were analyzed by scanning TEM-energy dispersive X-ray microanalysis (STEM-EDX), from the electron diffraction pattern (SAEDP) of the selected area. The analysis by auger electron spectroscopic (AES) of the oxide at the whisker surface was performed by using ULVAC Co. (PHI700). The measurement was performed under an ultra high vacuum of 4.0×10^{-9} Torr and Ar ambient. A static primary electron beam with an energy of 5 keV, beam current of 10 nA, and a beam diameter of about 1.5 nm were used. The angle of incidence of the electron beam was 30° with respect to the surface normal. The sample was sputtered in AES prior to the survey and the sputtering time was in the range of 0 to 300 s. Ar ions with kinetic energy of 2 keV for the sputtering of samples were rastered on a surface area which is larger than image area. The incidence angle for ion was about 50° with respect to the surface normal. For the given parameters, the sputtering rate was 70 Å/min calibrated by an SiO_2 layer, which has a similar sputtering rate.

3. Results and discussion

Fig. 2 shows the surface morphology near the edge of the LFs after storage at room temperature for 3000 hrs. Particularly,

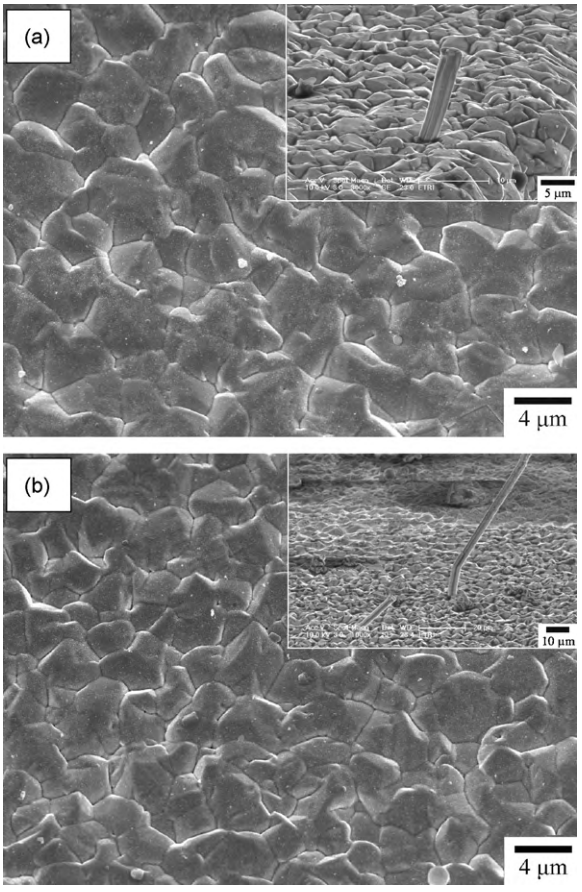

Fig. 2. FE-SEM images of whisker on pure Sn-plated Cu LF after storage at room temperature for 3000 hrs. (a) without current (b) 0.5 A.