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Effects of salt spray test on lead-free solder alloy

A. Guédon-Gracia [a,*], H. Frémont [a], B. Plano [a], J.-Y. Delétage [a], K. Weide-Zaage [b]

[a] Laboratoire IMS, Université de Bordeaux, Talence, France
[b] RESRI Group, Institute of Microelectronic Systems (IMS-AS), Leibniz Universität Hannover, Hannover, Germany

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ABSTRACT

This paper starts with a bibliographic survey about solder corrosion and experimental results of the corrosion on lead-free solder balls during salt spray tests. Focus is made on the SnAgCu solder alloy. Ball Grid Array assemblies and "Package on Package" components were put up to 96 h in a salt spray chamber at 35 °C with 5% sodium chloride (NaCl) aqua according to the ASTM B117-09 standard. The weight is measured during the test. The solder alloys are observed and analysed along the ageing with optical microscope and scanning electron microscope equipped with an energy-dispersive x-ray system. The solder alloy deterioration is visible after 48 h. The microstructure is analysed in order to determine the corroded residues found on the surface solder balls after the salt spray test. Tin oxychloride (Sn(OH)Cl) is found on BGA solder joints after reflow and on PoP solder balls before reflow. The size of the solder balls has an influence on the corrosion state. Finally a method is developed in order to measure the corrosion product growth on the same sample during the salt environment exposure.

1. Introduction

Salt mist environment, commonly found on snowy or oceanfront roads, induce galvanic corrosion in cars, boats, naval surveillance systems or tour helicopters, to name a few. Integrated circuit corrosion is a major cause of electronic system failures - it is responsible for about 20% of them. The main cause is surrounding humidity that speeds up electrolytic and galvanic corrosion, especially in biased circuits. Corrosion is even more accelerated by the presence of chemical pollutants in the humid air, like sodium chloride.

Although corrosion of dense materials and large industrial equipment has been widely described in the literature, few data are available on thin-film materials and microelectronic assemblies.

After a bibliographic survey, this paper presents an experimental study of lead-free assemblies aged in a saline environment. In the first part of our study, printed circuits boards (PCB) populated with BGA were aged in a salt spray oven. Copper traces as well as SnAgCu (SAC) solder balls were analysed during the ageing. In a second part of the study, focus is on the solder alloy: PoP (package on package) components were aged in saline conditions and the evolution of corrosion was observed and analysed.

2. Bibliographic survey

Few papers relate the behaviour of SnAgCu solder alloy in presence of NaCl. There are two kinds of tests to assess the corrosion of material: the polarization measurements, which provide information on a given metal, and the accelerated ageing tests to estimate the corrosion of systems.

2.1. Polarization measurements

The electrode potentiostatic polarization enables the determination of the behaviour of metal in salt water. The principle lies in the measurement of the electrical potential as a function of the current in order to determine the anodic and cathodic areas of this material. Most papers present results of electrochemical corrosion of bulk material in a NaCl solution measured through polarization curves, as in [1,2] or [3] for instance. In [1], the corrosion behaviour of SAC330 alloy in a NaCl solution is compared with that of the SAC305 by potentiodynamic polarization and impedance spectroscopy measurements. The presence of tin oxychlorides or oxyhydroxychlorides was detected at the surface of both alloys investigated after the electrochemical tests. In [2], PCBs with SAC307 were investigated in NaCl solutions and dendrite growth has been observed and correlated with the NaCl concentration. In [3], SAC305 material is studied. In this paper the time to fracture and the critical stress for fracture under mechanical stress in a saline solution are investigated. The authors highlight that the reliability of lead-free solder alloys should be evaluated considering the effects of the combination of environment and applied mechanical stresses.

2.2. Ageing tests in a marine environment

The ageing tests in a humidity chamber and in a salt spray chamber enable to observe the corrosion phenomena on electronic assemblies.

* Corresponding author.
E-mail address: alexandrine.gracia@ims-bordeaux.fr (A. Guédon-Gracia).

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Corrosion is accelerated by the presence of chlorine. Some papers relate the behaviour of SAC solder joints during salt spray ageing.

In [4], the effect of pre-ageing in a saline environment on the long-term reliability of wafer-level-chip-scale-package (WLCSP) was investigated. WLCSPs assembled with SAC 305 were thermally cycled to failure, with and without 96 h pre-treatment in a 5%NaCl salt spray environment. Pre-ageing resulted in strong (43%) life-time reduction. Moreover, the authors correlated the corrosion path and Sn lattice basal plane by orientation imaging microscopy.

The surface morphology and microstructural changes in Sn-4.0%Ag-0.5%Cu lead-free solder balls subjected to salt spray (5%NaCl solution) tests were investigated by Song and Lee [5]. They investigated the effects of corrosion on the mechanical strength of solder balls. Compared to the Sn-37%Pb solder balls, Sn-4.0%Ag-0.5%Cu (SAC405) lead-free solder balls are more easily corroded in the salt spray test (see Fig. 1). Two kinds of corroded residues are found on the surface of solder balls after the salt spray test. The presence of Ag_3Sn in SAC solders accelerates the corrosion of tin during the salt spray test because of the galvanic corrosion mechanism. The galvanic corrosion forms a brittle Ag_3Sn structure at the corroded regions.

As for SAC a passivation layer (made of oxides and hydroxides most of the time) appears on the alloy as a protection against chloride ions attacks (see Fig. 2). The alloy is thus only a little corroded on the surface and remains unaltered in depth. The copper percentage increases the corrosion resistance.

In [7] the creep corrosion of SnAg (Sn-3.0Ag) and SnCu (Sn-0.5Cu) solders under NaCl solution is investigated at room temperature. The propagation of surface cracks was studied with the result that creep corrosion cracking should be incorporated in the reliability evaluation of lead-free solder alloys.

In a harsh environment, with high chloride content, SnCu alloy shows a corrosion similar to that of SnAgCu. It is corrosion-resistant thanks to the formation of a thin passivation layer that protects the alloy against corrosion sub-products. In SnAg solder, the presence of a

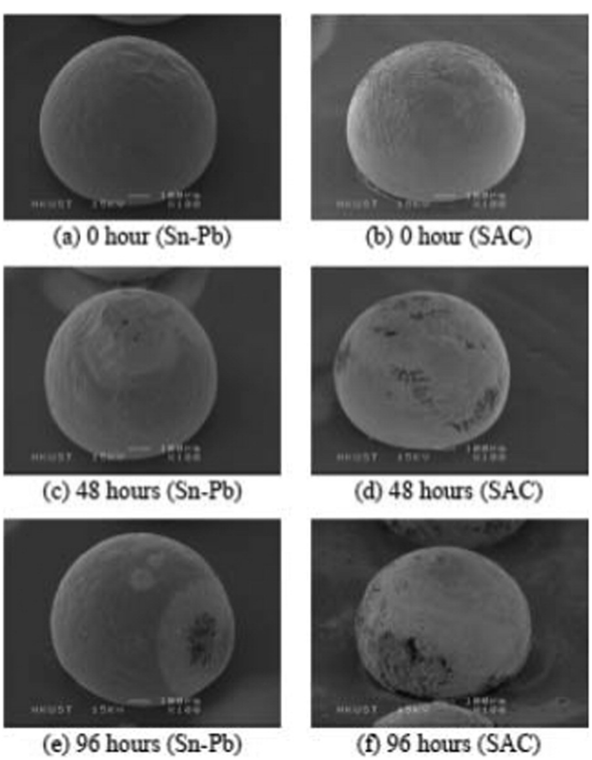

Fig. 1. Surface morphology changes of solder balls (diameter 760 μm) after the salt spray test [5].

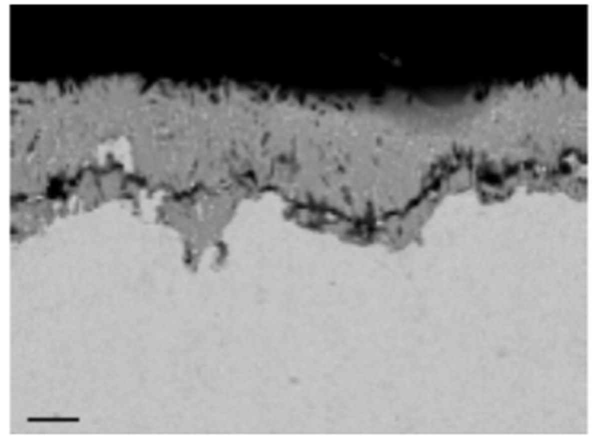

Fig. 2. Cross-section of Sn-Ag-Cu solders after potentiodynamic polarization test [6].

noble corrosion-resistant metal, namely silver, provides good corrosion resistance.

3. Experimental study on assemblies

The test vehicle was a 10.2 × 14 cm FR4 board with 6 daisy chained components in BGAs. Solder balls (256 per BGA: 16 × 16) and solder alloy are in SAC305 (see Fig. 3). The board was cut into 6 parts containing a measurable daisy-chain structure and some copper pads without connections on the other board side. Each part was submitted to different ageing durations. Ageing was performed in a salt spray chamber at 35 °C (Salt Spray chamber Ascott CC450iP). The saline fog was generated from a 5% sodium chloride (NaCl) solution, as defined by ASTM-B117 [8], one of the most widely used tests for evaluating corrosion resistance of materials and assemblies to an aqueous salt atmosphere. The experimental procedure was detailed in [9].

Corrosion was mainly observed on the metallic compounds, that is to say the copper traces and the solder alloy. On the free copper pads,

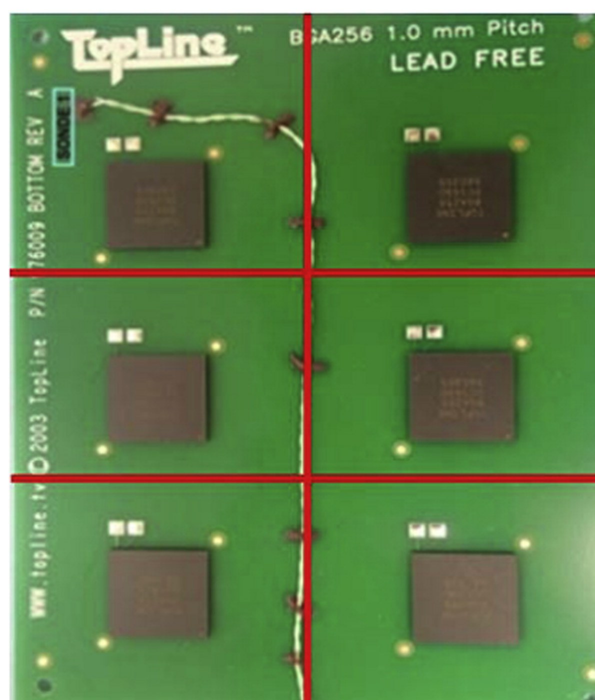

Fig. 3. BGA assembly (cut along the red lines). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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