

Effect of Applied Voltage Bias on Electrochemical Migration in Eutectic SnPb Solder Alloy

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Smaller size and higher integration of electronic systems make narrower interconnect pitch not only in chip-level but also in package-level. Moreover electronic systems are required to operate in harsher conditions, that is, higher current / voltage, elevated temperature / humidity, and complex chemical contaminants. Under these severe circumstances, electronic components respond to applied voltages by electrochemically ionization of metals and conducting filament forms between anode and cathode across a nonmetallic medium. This phenomenon is called as the electrochemical migration. Many kinds of metal (Cu, Ag, SnPb, Sn etc) using in electronic packages are failed by ECM. Eutectic SnPb which is used in various electronic packaging structures, that is, printed circuit boards, plastic-encapsulated packages, organic display panels, and tape chip carriers, chip-on-films etc. And the material for soldering (eutectic SnPb) using in electronic package easily makes insulation failure by ECM. In real PCB system, not only metals but also many chemical species are included. And these chemical species act as resources of contamination. Model test systems were developed to characterize the migration phenomena without contamination effect. The serpentine-shape pattern was developed for analyzing relationship of applied voltage bias and failure lifetime by the temperature / humidity biased (THB) test.

Keywords : PCB, electronic package, conductive anodic filament, dendrite, corrosion, reliability, solder

1. Introduction

Electronic devices are miniaturized and integrated with a higher density, so that electronic packages have smaller pitches between the leads and are more vulnerable to insulation failure. This is the reason why the leads, under certain environmental conditions such as high humidity, temperature and applied voltages, are likely to be electrochemically unstable. Under these circumstances, electronic components respond to applied voltages by electrochemical ionization of metals, and a conducting filament forms between the anode and cathode across a insulation medium.¹⁾ This leads to short-circuit failure of the electronic component, which is known as electrochemical migration (ECM). There are two mechanisms mainly responsible for the ECM phenomena: the formation of conducting anodic filaments (CAFs) and dendritic growth.^{2),5),6),7)} A CAF is a filament formed as metal leads become ionized and begin to migrate. This process is driven by an applied electric field from the anode to the cathode. Dendritic

growth⁴⁾ occurs as a result of metal ions going into solution at the anode and plating out at the cathode, growing in needle- or tree like formations. The formation of CAFs or dendrites is a significant failure mode in electrical and electronic systems, particularly in microelectronic components on PCBs and electronic packages.³⁾ Real electronic components on PCBs may be exposed to many contamination sources during manufacturing process such as Al, Si, S, Cl, As, Sb and Ba. But the mainly activated elements during ECM phenomenon are Sn, Pb and Cu. To analysis solder alloy effect on ECM, we devised a model test system which can exclude the contamination effect. ECM characteristics of eutectic SnPb used in electronic packaging structures were evaluated by using the THB test. In high temperature and high humidity condition, constant DC voltage bias was applied to the specimen. By acquiring current level, we can get ECM characteristics of eutectic SnPb. These (DC voltage bias and harsh environment) are acceleration condition easy to observation of ECM failure. Scanning electron microscopy, energy-dispersive X-ray spectroscopy were used to understand fundamental growth mechanism and microstructural

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changes.

2. Experiment

Model test structures were designed to characterize the migration phenomena without contaminant. The test pattern was made using conventional under bump metallurgy deposition, patterning, and screen printing processes. A p-type <100> oxidized Si wafer was used as the substrate. A 3000-Å-thick Ni thin film was deposited on the substrate using sputter as UBM (Under bump metallurgy) layer. The Ni film was subsequently patterned by photo-lithography and wet etching. Eutectic SnPb solder paste (type of water-soluble flux) was printed on the Ni pattern by screen printer. And it was reflowed at 190°C on a hot plate. The shape of specimen is serpentine shape pattern for analyzing the failure lifetime statistics. The pitch of the pattern is 300 μm and the eutectic SnPb thickness is approximately 10 μm, and the specimen was polished with 0.5 μm alumina powder for the removal of flux residue (Fig. 1.).

Multi-specimen ECM test systems (Fig. 2.) using a

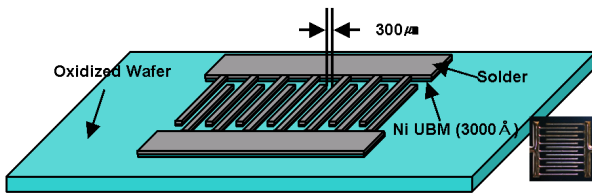


Fig. 1. Model test systems (Serpentine-shape pattern).

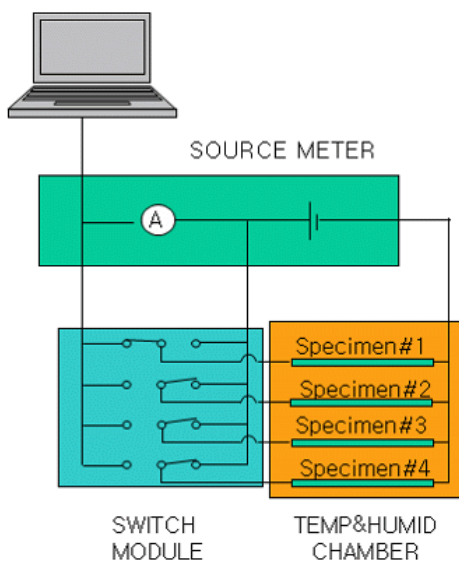


Fig. 2. Multi-specimen ECM test system.

switch-module were developed. Constant DC voltage was applied to all specimen all the time. And one of the specimens was measured its current level for some time by source-meter through the bypass which is formed by switch-module. Insulation breakdown time was measured at 85°C, 85%RH condition with 180~200V DC bias range.

3. Results & discussion

Failure analysis on the specimen which is insulation failed after testing (85°C, 85%RH, 180V and 200V) showed that CAFs and dendrites were observed between anode and cathode. Fig. 3. shows the typical damage morphologies. CAFs formed at anode with the shape of granule. This can be considered as comparable process as corrosion phenomena which are much more complex than typical corrosion process. In the case of dendrite, filaments grow up from cathode as like electroplating phenomena. In Fig. 4., CAFs and dendrites (C1~A3) has higher relative concentration of Pb than eutectic SnPb (Sn:Pb=63:37, wt%). On the other hand, the composition of the anode and cathode region has higher Sn concentration than CAFs and dendrites. EDX mapping data shows this migration behavior more clearly. Pb concentration of anode (47.71wt%) is lower than that of cathode (51.81wt%). It means that Pb dissolved easily at anode. Pb in a eutectic SnPb is more susceptible to ECM than Sn. The filament is mainly consisted of lead as shown. This result well matched the polarization test of eutectic SnPb solder alloy.

A lifetime tests were performed at the acceleration condition with 180 V and 200 V for 800 hours. 20 specimens were used for statistical treatment in each test condition. Generally, the resistance drop was found within 30~40 days.(Fig. 5.)

Each lifetime result showed a well defined log-normal

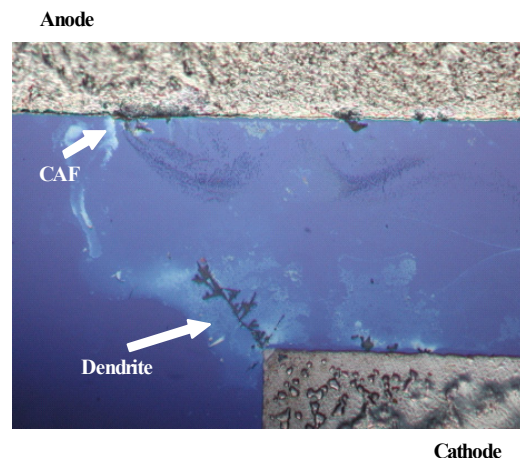


Fig. 3. The typical damage morphologie of ECM

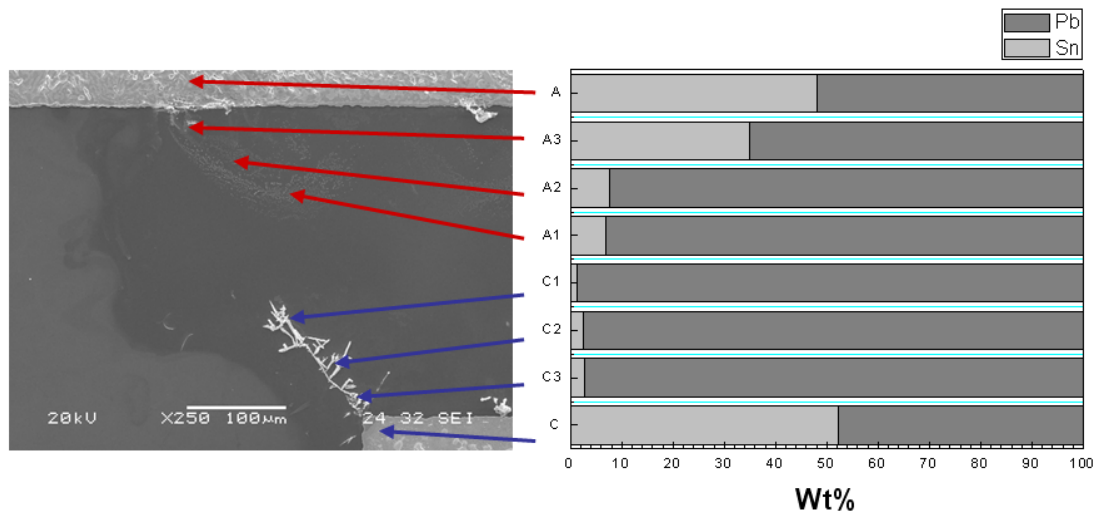
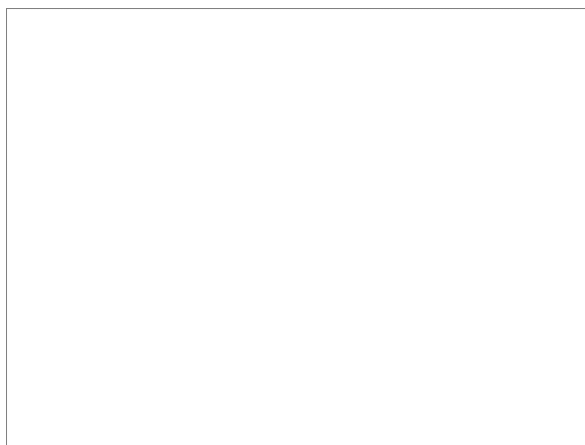
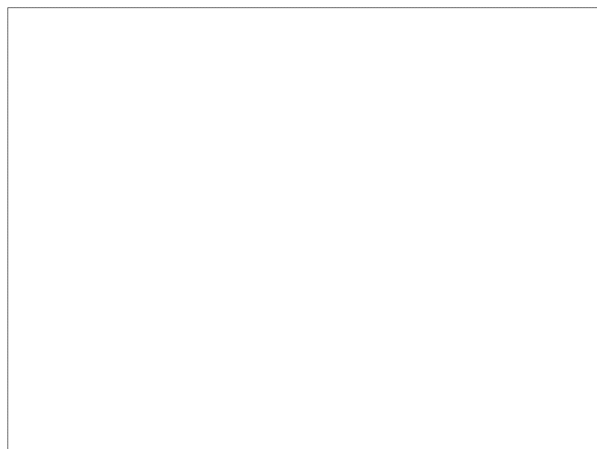


Fig. 4. Compositions of the the CAF region around anode and the dendrite region around cathode in the Serpentine-shape pattern determined by EDX after testing at a temperature of 85°C, a relative humidity of 85%, and a voltage of 200V



(a)



(b)

Fig. 5. ECM test results; (a) Time to failure distribution for 180V, 85°C, 85%RH, and (b) Time to failure distribution for 200V, 85°C, 85%RH

distribution (Fig. 6.). The median time to failure (t_{50}) and the lognormal standard deviation (σ) were determined by a linear fit to a log-normal distribution. The median time to resistance drop of 180 V test (94.45 hour) is longer than 200 V test (11.28 hour). Higher biased voltage induces shorter resistance failure time.

It was found that the lifetime is in inverse proportion to the applied voltage (Table. 1). A biased voltage exponent ($n=20.17$) was obtained by voltage scaling, as shown in Table 1.(THB test, model system) For the Water-drop test(model system), as reported in our previous study, a biased voltage scaling is 0.874 ($n=0.874$).⁹⁾ And a biased voltage scaling is 2 ($n=2$) in the case of PCB by THB test.⁸⁾

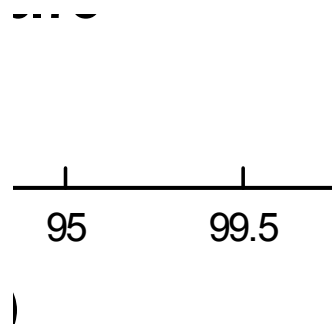


Fig. 6. Lifetime of THB test with the acceleration voltage of 180V and 200V (log-normal distribution).

Table 1. Biased voltage exponent by voltage scaling.

	T ₅₀ (hour)	σ
DC 180V	94.45	1.33
DV 200V	11.28	0.73

$$\frac{t_{50,200V}}{t_{50,180V}} = \left(\frac{180V}{200V} \right)^n \quad n = 20.17$$

4. Conclusions

Model system without contaminants was used to determine the ECM characteristics of a eutectic SnPb with varying DC bias voltages under 85°C/85%RH condition. CAFs and dendrites were observed between anode and cathode. The resistance drop was found within 30–40 days. We found that life time is in inverse proportion to applied voltage. The median time to resistance drop of 180 V test (94.45 hour) is longer than 200 V test (11.28 hour). Higher biased voltage induce shorter resistance failure time. Lifetime results showed well defined log-normal distribution which resulted in biased voltage factor (n=20.17) by voltage scaling in the case of THB test on model system.

Acknowledgments

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