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Electrical and reliability properties of isotropic conductive adhesives on immersion silver printed-circuit boards

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Abstract Electrically conductive adhesive (ECAs) have been used for many years in both the anisotropic conductive adhesive (ACA) and isotropic conductive adhesive (ICA) forms for microelectronic packaging applications and as an alternative to lead (Pb) soldering technology. Especially, environmentally friendly ICAs offer many advantages over solder, such as simple and low temperature process conditions and better thermo-mechanical performance. However, a number of reliability questions linger, and continue to be studied. In particular, the ICA-to-pad contact resistance can increase with time due to the galvanic corrosion of dissimilar contact and ICA-filler metals (Lu et al., IEEE Trans Electron Packag Manuf 22:228–232, 1999). ICAs are usually silver (Ag) epoxy composites, and the corrosion potential should be completely eliminated by the use of Ag contact pads. To completely eliminate lead (Pb) from electronics, the printed wiring board (PWB) must also change from hot-air-leveled solder (SnPb) to alternative metallic finishes, such as immersion-silver (Ag), immersion-tin (Sn), electroless nickel (Ni)/immersion-gold (Au) and organic solderability preservative (OSP) (Pas, in European institute of printed circuits summer conference, 2005). Especially, immersion-Ag is one of the leading Pb-free final finish choices for many OEMs in the telecommunications, computer, automotive and consumer electronics industries, because of its excellent properties and reasonable cost. This paper presents the electrical properties of Ag epoxy composite ICAs materials on Cu-finished and immersion-Ag finished PWBs, as solder replacements for SMT or flip chip technologies. All PWBs were subjected to 85°C/85% relative humidity (RH) aging testing, with junction resistance monitored for comparison of the immersion-Ag board to the Cu-finished board as a control. We expected that the corrosion potential, which is one of main causes to degrade conductivity between ICAs and PWB, should be eliminated by the use of Ag contact pads with the Ag epoxy composite ICAs materials. Not only is the junction resistance of immersion-Ag finished boards lower than that of Cu finished boards, but its junction resistance changes are smaller than those of Cu-finished boards, as expected.

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1 Introduction

Soldering technology using tin/lead (Sn/Pb) solder has played an important role in electronic packaging, such as surface mount technology (SMT), flip-chip, solder ball connection in ball grid arrays (BGA), and integrated circuit (IC) package assembly to printed wiring boards (PWBs) (Tummala and Rymaszewski 1989). As the microelectronics technology has grown, some problems associated with Sn/Pb solders have become recognized. Especially, from an environmental point of view, worldwide electronic packaging companies and researchers are eliminating lead from electronic components because Sn/Pb solders are harmful to the environment and human beings.

Electrically conductive adhesives (ECAs) have been used for many years on both anisotropic conductive adhesive (ACA), [including anisotropic conductive film (ACF)], and isotropic conductive adhesive (ICA) forms for

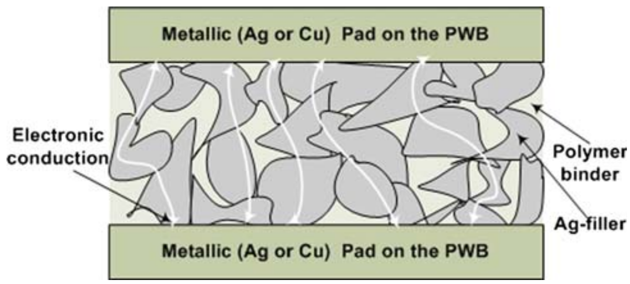

Fig 1 A cross-section of an ICA joint with metallic pad

microelectronic packaging applications and as alternatives to Sn/Pb soldering technology (Lu and Wong 2000; Zwolinski et al. 1996). Compared to the soldering technology, ECAs have advantages: they can be used at low processing temperatures and at low processing cost, they can be used for fine pitch applications, and they are environmentally friendly being lead free with no cleaning process after the bonding process. However, compared to the matured soldering technology, a number of reliability questions linger, and continue to be studied. In particular, the contact resistance between ICA and metallic pad can increase with time due to the galvanic corrosion of dissimilar contact and ICA filler metals (Lu and Wong 2006). Figure 1 shows a basic structure and concept of electronic conduction between metallic pads and ICAs materials.

To completely eliminate Pb from electronics, the PWB must also change from hot-air-leveled solder (SnPb) to alternative metallic finishes, such as immersion-Ag, immersion-Sn, electroless Ni/immersion-Au and organic solderability preservative (OSP) (Pas 2005). New finishes now available on the market can meet the demands from both the end-user and the fabricator. Especially, immersion-Ag finished PWBs is one of the leading Pb-free final finish choices for many OEMs in the telecommunications, computer, automotive and consumer electronics industries, because of its excellent properties and reasonable cost.

This paper presents the electrical properties of Ag epoxy composite ICAs on Cu-finished and immersion-Ag finished PWBs, as solder replacements for SMT or flip chip technologies. All PWBs were subjected to 85°C/85% RH aging testing, with contact resistance monitored for comparison of the immersion-Ag boards to the Cu-finished board as a control.

2 Experimental

2.1 Materials

These studies used two different ICA materials, which are designated as type-A and type-B in the Table 1. Both ICAs are based on the Ag-filled conductive epoxy adhesive as shown in Fig. 1, and were obtained from two different suppliers. Type-A ICA material is designed to address popcorn cracking and can be used with a high degree of stress without delamination from the lead-frame and die. So, it is suitable for microelectronics assembly. Type-B ICA is designed as an alternative to solder in applications where solder's high peak reflow temperatures will result in component or substrate damage, i.e., it is for solder replacement in microelectronic interconnect applications and for chip bonding applications.

Table 1 Curing condition for test devices

ICA	Curing	Sample	PWB
Type A	185°C, 22–24 min	A1Cu	Cu
		A2Ag	Ag
	170°C, 27–30 min	A3Cu	Cu
		A4Ag	Ag
Type B	185°C, 22–24 min	B1Cu	Cu
		B2Ag	Ag
	170°C, 27–30 min	B3Cu	Cu
		B4Ag	Ag

2.2 Test device

The junction resistance test coupons are defined by drawing the metallic pad on the PWB by a circuit board mill, LPKF Protomat 92s, and dispensing the ICA materials using the Asymtek Automove 402 dispensing system on the 2 mm × 2 mm square junction area. Then another metallic bar was crossed and attached together with a controlled thickness of conductive adhesive, as shown in Fig. 2, based on the Kelvin Cross-Bridge Geometry (McCarthy 1996). All of the test devices cured using a four-zones NOVASTAR reflow-oven to establish the mechanical adhesion and electrical conduction between the metallic pads and ICA materials. All samples were cured at the manufacturers' recommended curing times and temperatures. The curing conditions are shown in Table 1. Figure 3 shows cured junction resistance test devices with two junctions for each sample identification on Table 1.

2.3 Electrical measurement

All cured samples were tested using a Despatch LEY1-35H environmental chamber to monitor changes in junction resistance due to environmental aging in the presence of different metallic surface finishes. The testing condition used here was set to 85°C/85% relative humidity (RH) for monitoring the junction resistance shift. Figure 4 shows the simple schematic of the junction resistance measurement circuit system (McCarthy 1996), based on the four-point

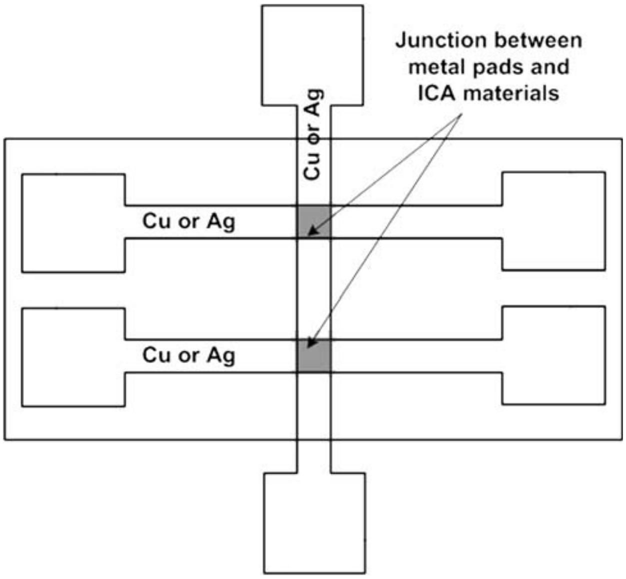

Fig 2 Schematic of a junction resistance test device

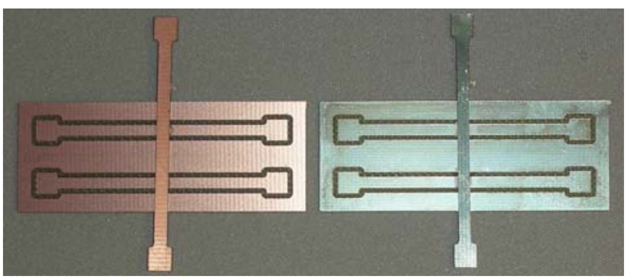

Fig 3 Junction resistance test devices

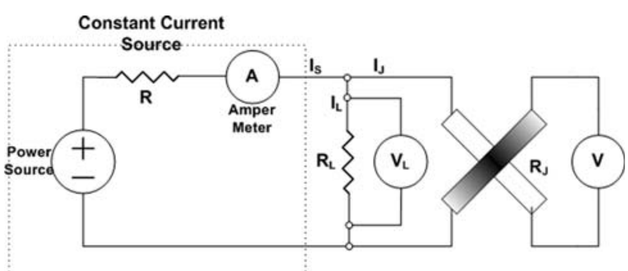

Fig 4 Schematic of measurement system

measurement system. To get the junction resistance, R_J, the voltage, V_L, across the resistor, R_L, was monitored with a digital multi-meter. As known the V_L, the current through the junction, I_J, can be calculated through the following equation:

$$I_J = I_S - \frac{V_L}{R_L}$$

The junction voltage, V, was measured using a Keithley 2182 Nanovoltmeter and the junction resistance, R_J, was calculated by the following equation:

$$R_J = \frac{V}{I_J}$$

R_L, (for $R \gg R_L \gg R_J$), acts as a protection circuit for the constant current source I_S, if the junction is opened at the cross-bridge system. The system is used to measure the junction resistance characteristics during the 85°C/85% RH aging test.

3 Results and discussion

The junction resistance measurements were made of multiple cross-bridge samples of different surface finishes such as Cu and immersion-Ag. An initial 25°C junction resistance was measured when the samples were loaded into the temperature/humidity environmental chamber.

Figure 5 and Table 2 show the junction resistances and ratios of junction resistances to initial values for two commercial conductive adhesives (types A and B) and different PWB metal finishes with the 85°C/85% RH aging test. The total ICA junction resistance as measured is composed of the ICA bulk resistance and the interfacial resistance between the ICA and metallic pad. Previous works (Lu and Wong 2006; Klosterman et al. 1998; Li 1996) have shown that Ag flake-filled conductive adhesives have relatively stable bulk resistance during aging, provided they are adequately cured, so the changes are assumed to be dominated by the interface.

As shown in Fig. 5 and Table 2, the junction resistance values between ICAs and immersion-Ag PWBs is smaller than those of Cu-finished PWBs and most immersion-Ag PWB samples (except A4Ag1 and B2Ag2 in Fig. 5d, b) do not increase as much during the elevated temperature and humidity aging. In other words, junction resistance of the immersion-Ag boards is not degraded by RH aging. However, for the Cu-finished PWB, it increases dramatically, as expected. Many people have proposed that the increasing junction resistance between ICA and Cu-finished PWBs with elevated temperature and humidity aging is due to simple oxidation (Jagt et al. 1995; Nguyen et al. 1993) of the non-noble metal surfaces. More recently galvanic corrosion has been identified as the dominant cause of increasing junction resistance of non-noble metal interfaces between ICA and metallic pad due to mismatch of the electro-chemical potential (Lu et al. 1999; Tong et al. 1999). Therefore, we expected that the corrosion potential should be almost or completely eliminated by the use of Ag contact pads, e.g., with immersion-Ag boards, with the Ag epoxy composite ICA materials, as the above results show. However, to use the immersion-Ag PWBs with Ag epoxy composite ICA materials for electronic packaging applications with confidence, more fundamental research is needed on both the Ag epoxy composite ICAs

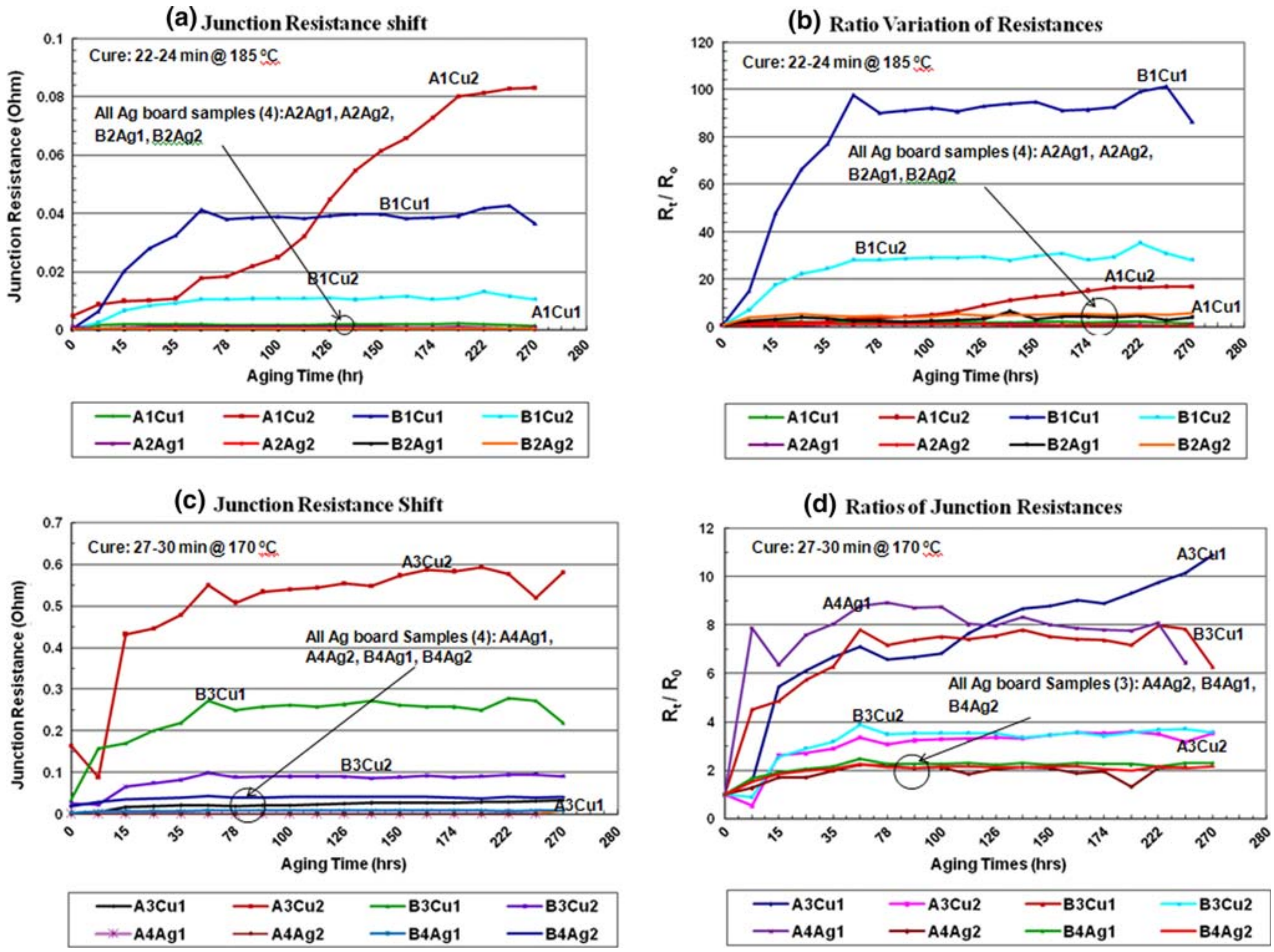

Fig 5 **a**, **c** Junction resistance shift; **b**, **d** ratio of junction resistance with different ICAs, curing conditions, and pad surfaces

Table 2 Initial resistance at room temperature and varied junction resistance after 270 h at 85°C/85% RH aging test

Type A	R_0 (mΩ) at 25°C	R_h (mΩ) at 85°C/85% RH	R_h/R_0	Type B	R_0 (mΩ) at 25°C	R_h (mΩ) at 85°C/85% RH	R_h/R_0
A1Cu1	0.89	1.27	1.43	B1Cu1	0.42	36.42	86.71
A1Cu2	4.82	82.98	17.22	B1Cu2	0.37	10.54	28.49
A2Ag1	0.94	0.90	0.96	B2Ag1	0.07	0.28	4
A2Ag2	0.29	0.17	0.59	B2Ag2	0.09	0.52	5.78
A3Cu1	3.07	33.39	10.88	B3Cu1	34.87	219.13	6.28
A3Cu2	163.93	580.94	3.54	B3Cu2	25.64	91.55	3.57
A4Ag1	0.04	0.23	5.75	B4Ag1	3.75	8.62	2.3
A4Ag2	0.12	0.25	2.08	B4Ag2	19.14	41.27	2.16

and immersion-Ag boards, e.g., improvement of impact resistance through the drop test.

4 Conclusions

We have monitored the junction resistance variation between Ag epoxy composite ICA materials and Cu and immersion-Ag finished PWB during the 85°C/85% RH aging test. The junction resistances of immersion-Ag PWB are lower than those of Cu-finished PWB and the junction resistance shift of immersion Ag PWB is much smaller than those of Cu-finished PWB during the 85°C/85% RH aging test. In other words, the junction resistances of immersion-Ag boards were stable for the 85°C/85% RH aging test. Therefore, we expect that Ag epoxy composite

ICA with immersion-Ag board can be used to improve the junction resistance stability.

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