Electric Field Effects in the Production of ICA Joints

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Abstract

Concern over the use of toxic lead in electronic devices is driving research into lead free solder alloys and isotropic electrically conductive adhesives (ICAs). To replace the common solders with ICAs, it is both essential to know the behavior of the material during assembly process, and useful to be able to exert any form of control which will yield improved properties. The paper describes the possible influence of an electric field applied to the ICA during curing.

Introduction

Shortly after the Second World War, the development of ICAs began.[1] ICAs made electrical connections possible where soldering was not suitable. To date, electrically conductive adhesives (ECA), isotropic as well as anisotropic, have been in most cases just solutions for special applications where high temperatures should be avoided. An example for these are flat panel displays. But since it is obvious that the European Union (EU) will ban the use of lead (Pb) in certain categories of electrical and electronic equipment in the near future[2][3], ICAs will become a candidate along with lead-free solders, for replacing the conventional lead-containing solders. Whether ECA or lead-free solders will dominate the replacement of lead-containing solders depends mainly on the reliability, and the cost efficiency, and performance that each can achieve. The property of an isotropic resistance makes ICAs comparable to existing solders. ICAs show important advantages compared to metallurgical solders. The major advantages are

- low temperature processing, which means low thermal stress during processing
- connectable to a wide range of surfaces, even non-solderable substrates
- no lead content

But there are still some important disadvantages that limit the wide use of ICAs. These disadvantages are

- low surface tension
- oxidation between surface and adhesive[4]
- higher volume resistance

These drawbacks cause lower reliability and lower performance than metallurgical solders. To make ICAs marketable, it is essential to improve these properties.

Previous experiments at Binghamton University demonstrated a drop in the volume resistance when applying an electric field to ICA-paste before and during cure. The study did not ascertain whether the effect was actually due to ordering of the Ag flakes in the material, or to an atomic electromigration effect.[5] The tests reported here provide a closer investigation of the influence of the electric field during the production of ICA joints. Inada and Wong discuss effects of orientation of silver flakes in the epoxy in relation to adhesive strength.[6] They conclude that the orientated silver flakes cause worse strength and poor weakness in impact resistance. Nevertheless, the drop in volume resistance could be a crucial point to improve the electrical performance of ICA connections in surface mount technology (SMT) as well as in Flip-Chip (FC) interconnections.

Test Materials

Six isotropically conductive adhesives from various leading manufacturers of conductive adhesives were selected. They are all silver loaded epoxies, in one or two component versions. The test-adhesives are mostly designed for SMT, except adhesives D, which is designed for FC applications. There are significant differences in the recommended curing times. The manufacturer recommended curing times, the silver ratio, and the manufacturer specified volume resistivity are summarized in Table 1.

Table 1: ICA properties

Adhesive	Cure Temperature	Cure time (minutes)	Wt% Silver	Volume Resistivity (Ω cm)
A	150 °C	60	60	$1.23\cdot10^{-4}$
B	110 °C	60	50-70	$10\cdot10^{-4}$
C	150 °C	30	70-80	$10\cdot10^{-4}$
D	150 °C	3-5	>75	$9\cdot10^{-4}$
E	150 °C	6	50-75	$8\cdot10^{-4}$
F	150 °C	60	75-90	$5\cdot10^{-4}$

Assembly

Different test setups were developed to cure the samples.
Configuration A: Test Samples with three ICA-joints each were produced (Figure 1). The copper plated boards were mechanically pre-cleaned with grinding paper and divided into three areas isolated from each other. Adhesive bumps were printed on each area of the boards with use of a 100µm thick plastic stencil mask. The printed ICA-bumps had a diameter of 1.5875mm (1/16 inch).

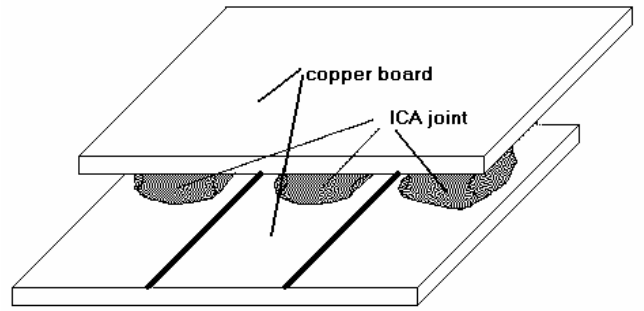


Figure 1 – Schematic Configuration A

Configuration B: Test samples with ICA-joints between parallel silver plated printed circuit lines in a serial connection were assembled as shown in Figure 2. Current could be supplied to the serial connection of Joints 1 to 4, or just to the serial connection of Joints 3 and 4. Joints 5 and 6 were the control samples.

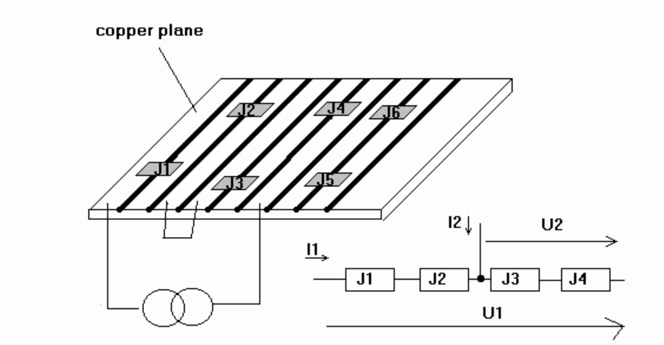


Figure 2 – Schematic Configuration B

Configuration C: A 3cm wide copper plated board was divided into four isolated areas. ICA-paste was then stencil printed over the 4 areas with a 200µm thick metal stencil. The electric field was supplied to the two inner copper areas.

Experimental Procedures

Configuration A: A constant current of 2.5A was supplied to two joints before curing. After 15 minutes the current was detached from one joint and the sample was cured.

Configuration B: The sample was supplied with a constant Voltage of 50V until the resistance of the ICA-paste dropped. After the drop in resistance the 4 joints were supplied with a constant current at the current limit. The amount of current was changed during different tests. After 5 minutes of constant current the joints J1 and J2 were detached (the current was still attached to ICA-joints J3 and J4) and the sample was cured as specified in Table1.

Configuration C: An electric field was supplied to the inner copper planes before cure. The voltage was slowly increased to the threshold voltage of the ICA-paste. After the voltage breakdown the current of 0.6A was constantly applied for 5 minutes. This procedure was preformed with two samples. A third sample was used as control sample (without field). After current was supplied to sample 2 for 5 minutes, all three samples were cured as specified in Table 1. The current supply to the second sample continued until end of cure.

Resistance measurement

After the curing for all configuration setups, a KEITHLEY® 580 Micro-Ohmmeter was used to measure the electrical resistance of the joints. For configuration C the four-point-method was used to determine the resistance between the inner copper planes. All samples were cured in a modified diffusion furnace according to the manufacturer specified cure schedules.

Curing setup

A modified diffusion furnace was used to cure the samples. The 3-zone furnace, which was originally designed to work over the temperature range of 400 °C to 1400 °C, was modified by disabling the temperature sensors in the first two zones. The thermal control circuit interprets the absence of thermocouple signals as an over-temperature condition and shuts off the heater elements in the zones. A temperature profile is developed from about 60 °C at the front opening to 400 °C at the end of the furnace tube. The temperature profile over the insertion depth is shown in figure 3. At the work point of 150 °C the temperature gradient was 2.6 °C per centimeter.

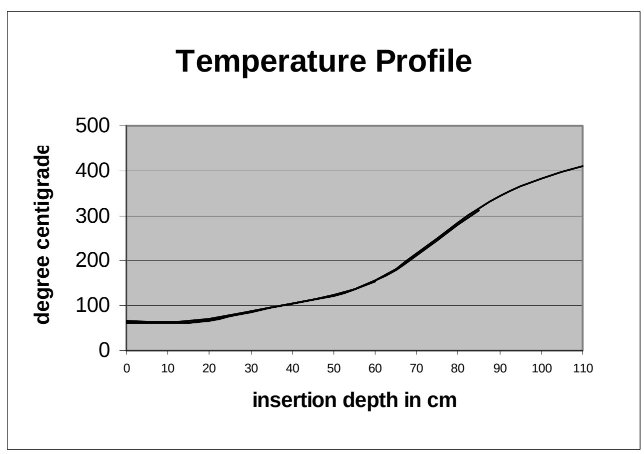


Figure 3 – Furnace Temperature Profile

A source of compressed air was supplied to the end of the furnace tube to get a constant airflow through the tube. The airflow was needed to take out the exhaust gas emissions, which accrue during curing. The relatively small diameter of the silica tube, and the modified temperature control unit, made it possible to get reproducible temperatures, with negligible decrease when the samples were put into the furnace.

Results

Configuration A:
This test was used with only adhesive type F. All measured resistances were in a range of 0.7mΩ and 1.2mΩ. On average there was no significant drop in volume resistance of the samples, whether supplied with an electric field before or during cure. In fact the average resistance of the samples, without an electric field was lower than the resistance of the two others (Chart 1).

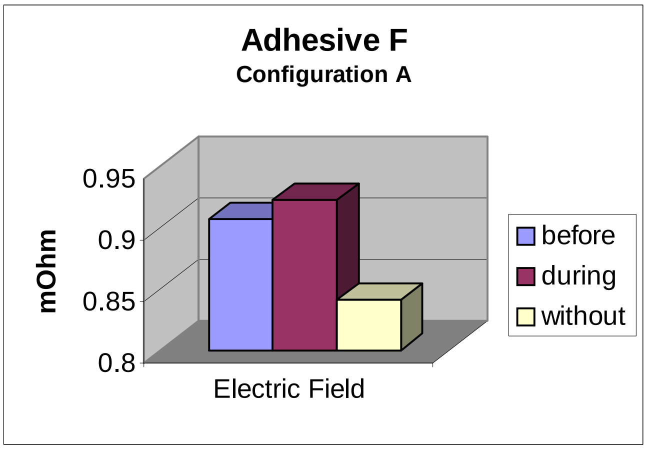


Chart 1 – Adhesive H in configuration A

After supplying the electric field to the ICA-joints before cure, the resistance drops suddenly at a threshold voltage of about 5 to 6 volts. The current rises immediately to the current limit 5A.

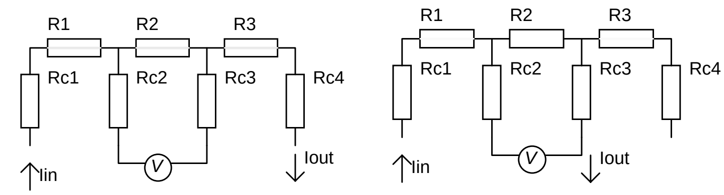
Configuration B:
Configuration B should provide a serial structure of ICA-joints. It was expected that after supplying the electric field to the samples the resistance of at least one joint should drop after passing the threshold voltage. That sudden drop in resistance should raise the voltage of the other serial joints over their threshold voltage, and the resistance of the circuit should drop again as each sample breaks down in sequence. But with the electric field applied one of the joints starts to burn and fractures. It seems that this breakdown is due to an arcing effect. The same thing happened in configuration C with Adhesives D and E (Figure 4a and b).

Figure 4a – ICA crack

4b – ICA crack

The figure shows the copper tracks and the stencil printed ICA-paste over the four tracks. The crack (Figure 4b) occurs suddenly when increasing the voltage and a light arc is visible in the crack.

The test shows a significantly higher ICA-joint resistance when connected to the silver plated copper tracks than those connected directly to the copper tracks. To verify this, two test structures were built with ICA-layers over four lanes. With this four point measurement structure it was possible to measure the contact resistance between the printed circuit lanes and the ICA.[7]



Measure R2 Measure Rm = R2+Rc3
Contact resistance Rc3 = Rm – R2

Figure 5 – four-point-measurement structure
ICA resistances R1 … R3
Pad-Contact resistance Rc1 … Rc4

The Test shows a contact resistance between copper and the ICA of 0.57mΩ and for the silver plated board 119.41mΩ on average. A possible reason for the high contact resistance could be the unsuccessful removal of an oxidation layer on the silver plated lines. A closer investigation of this fact with regard to plasma cleaning for reliability[8] and performance could be useful in future.

Configuration C
The test was realized with Adhesives F, B and C. After passing a specific threshold voltage the resistance of the uncured ICA-pastes decreased drastically. None of the three adhesives A, D and E showed the drop in resistance with the electric field before either the maximum voltage (50V) was reached, or before the ICA-joint cracks by arcing (Figure 4).

The drop in resistance did not persist after cure. Resistance measurements after the cure showed no significant difference between the samples with electric field applied and the samples without applied field. Chart 2 shows the average resistances of Adhesive F, C and B with electric field applied before cure (before cure), before and during cure (during cure), and without electric field (without) applied compared to the maximum resistance.

	Adhesive F	Adhesive C	Adhesive B
before cure	98.61%	93.09%	82.86%
during cure	100.00%	81.69%	100.00%
without field	78.15%	100.00%	61.07%

Table 2 – Average Resistance over max. Resistance

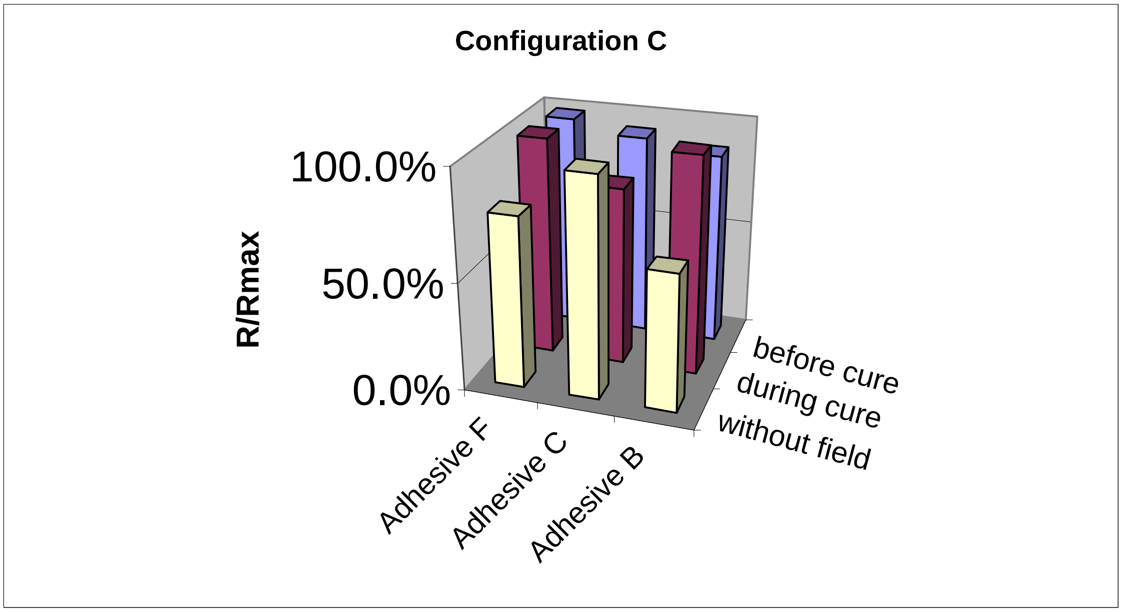


Chart 2 – Average Resistance over max. Resistance

Conclusion

There is a drop in volume resistance of the uncured ICA-paste when applying an electric field. But the data shows that this effect does not lead to a lower resistance of the joints after curing the paste. That the lower resistance of the pastes does not persist after curing makes it likely that the drop in resistance of the uncured paste is caused by silver electro migration, and not by alignment of the silver flakes. The experiments, which were done with ICAs, show also a strong influence of the substrate contact material surface metallurgy on the contact resistance.

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