

Determining the Lifetime of Silver-Filled Isotropic Conductive Adhesive (ICA) / Solder Plated Interconnections

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Abstract:

Electrically conductive adhesives have been used for many years for die mounting and terminal bonding of components in some types of hybrid circuits. In the area of isotropic conductive adhesives the preferred systems are silver filled epoxy adhesives. The interaction of silver with the finishes on the component and/or board side plays an important role in the reliability of the interconnect. This report reviews the possible failure modes in silver filled adhesives emphasizing the intermetallic formation in these systems. A silver filled adhesive was used to fix a thermistor to the base of a hermetically sealed laser module. The test specimens were subjected to 50°C, 85°C, 85°C/85%RH, 85°C, and 125°C under inert atmosphere, and the resistance changes over time were monitored. A standard lifetime prediction based on the results and work done previously is discussed.

Introduction

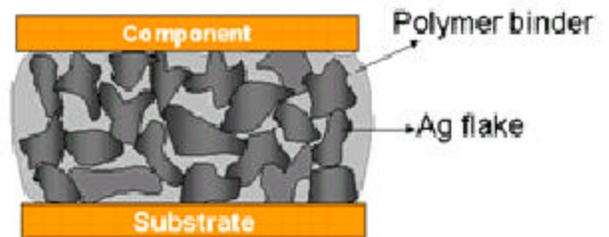
Electrically conductive adhesives have been used for many years for die mounting and bonding of components in some types of hybrid circuits. The advantages of conductive adhesives include ease of processing and low processing temperatures. They are also lead free, and they eliminate the need to clean after the bonding process.

Conductive adhesives can be either isotropic or anisotropic. Isotropic conductive adhesives (ICA's), similar to the adhesives used to die bond IC's, conduct in three directions. Anisotropic conductive adhesives (ACA's) provide unidirectional conduction, usually in the vertical direction.

ICA's are typically thermosetting polymers filled with conductive particles. ICA's have higher conductive filler content compared to ACA's. This lower level of conductive filler content is insufficient for inter-particle contact.

ICA's have been used for many decades as adhesive pastes applied by painting, screen-printing, stenciling, needle dispensing, pin transfer, pad printing, and other, less common, application methods. ICA's are typically used in hybrid circuit applications and in surface mount technology. Figure 1 shows a diagram and an example of an ICA joint.

ACA's have lower conductive filler content compared to ICA's. This lower level of conductive filler content is insufficient for inter-particle contact. ACA's are now used to connect flat panel displays, flip chips, and fine-pitch surface mounted components.



(a)



(b)

Figure 1: (a) Diagram of a typical ICA joint (b) Resistor attached using ICA.

Background

The reliability of any conductive adhesive joint is a critical issue that must be considered carefully before the adhesives can be widely used in a production setting. Poor electrical and mechanical stability upon exposure to environmental aging conditions, such as elevated temperature and humidity aging, and poor reliability in impact situation, are several major concerns that exist in the ICAs. In most cases, reliability testing is often accelerated by increasing load/stress, humidity, temperature, etc. to simulate environmental influence factors and cyclic thermal loads, shock tests, etc. Jagt, *et al.*

[1] Studied the influence of the component and board metallizations on the durability of the conductive adhesive joints. In their research, electrical and mechanical behavior of conductive adhesives was discussed for bonding R 1026 resistors with SnPb or AgPd terminations on bare copper, SnPb or Au plated boards before and after climate testing. They concluded that with the noble AgPd termination, the increase in electric resistance of the resistors in the climate was significantly less, compared with those with SnPb terminations. They believed that the deterioration of contact resistance on SnPb was due to a significant extent to surface oxidation and adhesion failure as also suggested by other researchers

[1][2][3][4] They also found that there was no clear correlation between mechanical and electrical properties after environmental aging. Liu *et al* [2] investigated reliability and failure mechanisms of ICA joints on Sn37Pb, Cu, and Au plated surfaces upon exposure to the 85°C, 85% RH environment. They observed that the mechanical strength and electrical performance were both reduced with increasing aging time in the Sn37Pb and Cu systems. They attributed these phenomena to the formation of Cu₂O on the copper metallization and the formation of PbO on the Sn37Pb surface, as both Cu₂O and PbO are both poor conductors and may form weak boundary layers at the interface. On the other hand, the gold metallization system exhibited stable electrical performance after the hot/wet humidity test. The mechanical performance of the gold metallization system after environmental aging, however, was not presented in their study. Studies by Lu *et al* [5],[6] revealed that galvanic corrosion rather

than simple oxidation of the metal at the interface between an ICA and the non-noble metal was the main mechanism for contact resistance shift. Lu *et al* showed that adding corrosion inhibitors and using low-melting-point alloy fillers to form metallurgical interconnections could be very effective ways to stabilize contact resistance of ECAs during environmental aging. Constable *et al* [7] performed pulling and fatigue tests on lap joints to study bond strength of conductive adhesive/copper joints. Constable used four different metallizations including Cu, Au, Pd and PdNi for the copper substrates and tested four adhesives. Based on the lap joints results, Constable found that no single surface finish gave superior performance for all adhesives tested. He concluded that the choices of adhesive and metal surface finish were interdependent and must be considered together with the application. His study also revealed that typical strains for a 1000 cycle fatigue life for conductive adhesives are on the order of 10%, which is in contrast to 1% for solders, though the operational stress range of conductive adhesives is 5-26 MPa, which is less than 17-42 MPa for solders. Perichaud *et al* [8],[9] compared the performance of two thermosetting and one thermoplastic conductive adhesive for surface mount technology assemblies. Perichaud *et al* showed that under thermal cycles from -55°C to +125°C, the thermoplastic adhesive had the best electrical stability, which was due to its higher flexibility and similar coefficient of thermal expansion (CTE) to that of component to be connected. On the other hand, their shear tests after thermal cycling showed that the adhesion strength was always higher for both thermosetting adhesives than for the thermoplastic one. They attributed this phenomenon to the nature of the bonds, where thermosetting resins can produce strong covalent and secondary links, while thermoplastic adhesives can form only secondary bonds. Vona *et al* [10] conducted a structure-properly-performance study of conductive adhesives to identify the key material properties for improved impact resistance. They concluded that the ability of a material to effectively dissipate energy was essential for better impact resistance, which accordingly could be achieved by designing materials with reduced Young's Modulus and increased loss factor (tan d) under drop test conditions. Lu *et al* [11] developed a class of conductive adhesives

with a broad loss factor peak with temperature and a high $\tan \delta$ at room temperature by combining modified resins and effective additives. Based on the drop test results, Lu *et al* claimed that this class of conductive adhesives showed superior impact resistance. Liu *et al* [2] demonstrated that conformal coating could improve the impact strength of conductive adhesive joints.

Test Methodology

The test method consists of accelerating failure by exposing to elevated temperatures and humidity. The following exposures were selected.

1. 50°C
2. 85°C
3. 85°C/85%RH
4. 85°C under inert (N₂) gas
5. 125°C

The test specimen is a chip thermistor with a Sn or SnPb finish (Figure 2). Initial runs with the thermistor in the loop did not prove useful as the high resistance of the thermistor (KΩ) masked the changes in the resistance of the ICA (mΩ). In order to bypass the thermistor, a gold wire was wedge bonded to the neighboring bond pad. Gold wire was the best option, as Aluminum is well known to form brittle intermetallics with gold. Other options such as palladium, copper are hard and difficult to bond and platinum and Sn based solder wire are expensive. Wedge bond was chosen instead of ball as it is a bigger bond physically and provides more control. The thermistor was gold coated as preliminary bonding resulted in poor bondability on the Sn/SnPb finish.



Figure 2 ICA test specimen

Test Setup

With the thermistor out of the circuit, it was possible to monitor the rise in resistance of the adhesive only. Four wire resistance measuring technique was adopted. The data acquisition system used in this experiment is the Agilent Technologies 34970A Data Acquisition / Switch Unit Datalogger with three HP 34901A 20-Channel Armature Multiplexer. The HP 34901A 20-Channel Armature Multiplexer has 20 channels of 300V switching and two channels for DC current measurements. This multiplexer connects to the internal multi-meter of the 39970A. The multiplexer is configured to take four-wire resistance measurements utilizing two channels. This system simultaneously applies a known current and measures the voltage for each individual channel.

The Datalogger is capable of making 5 resistance measurements per second with its internal digital multi-meter with no additional noise error caused by the system. The three multiplexers could be inserted into slots in the back of the Datalogger.

The tests at 85°C and 125°C were carried out in BMA temperature chambers while 85°C/85%RH exposure was carried out in ESPEC humidity chamber.

Test Results

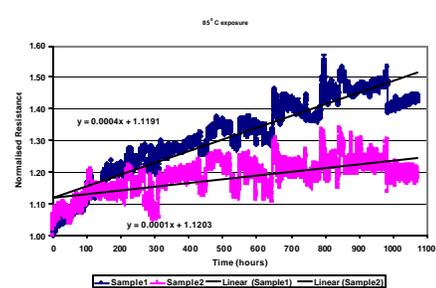


Figure 3 Plot of resistance vs. time for 1000 hours of exposure at 85°C/85%RH.

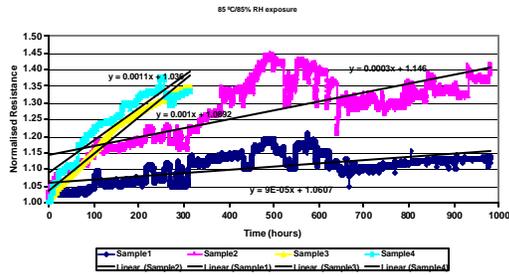


Figure 4 Plot of resistance vs. time for 1000 hours of exposure at 85°C/85%RH.

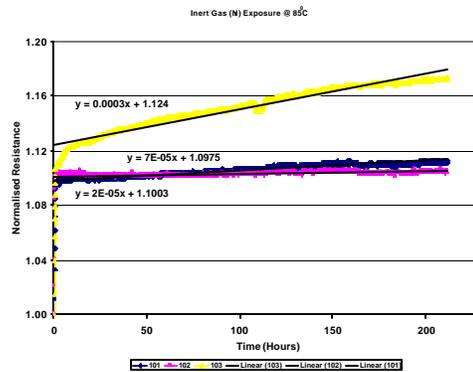


Figure 7 Plot of Resistance vs. time for inert (N₂) gas exposure at 85 °C.

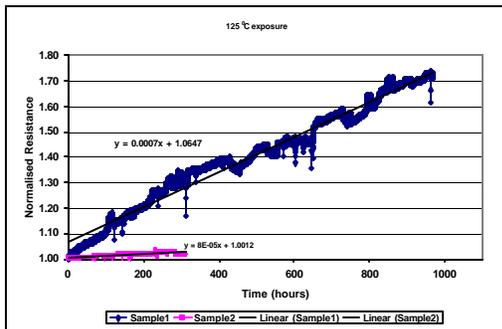


Figure 5 Plot of Resistance vs. time for 1000 hours of exposure at 125 °C.

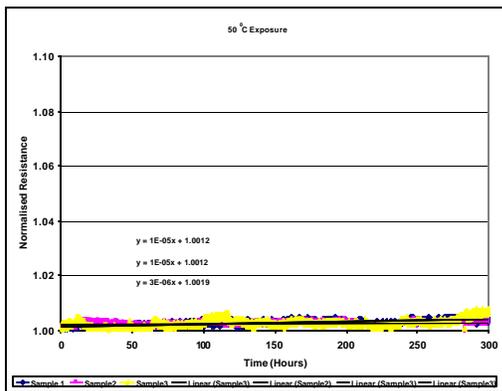
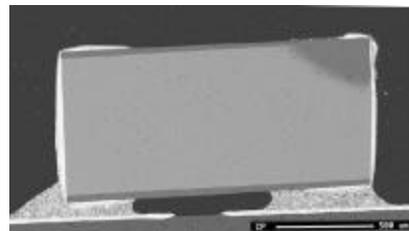


Figure 6 Plot of Resistance vs. time for exposure at 50 °C.

SEM/EDX Analysis

Scanning Electron Microscopy (SEM) in conjunction with Energy Dispersive Spectroscopy was used to analyze the results of the high temperature tests. AMRAY 1820D SEM with an EDX detector was used for SEM/EDX studies. The sample preparation was done as follows: the area of the module with the component of interest was sectioned out and potted in a room temperature cure epoxy resin. This insures that there is no relative motion of the part with respect to the board. After the potting mixture solidified, each sample was sanded using 240, 400, 600, 800 and 1200-grit silicon carbide till the area of interest, the midpoint of the solder joint, was reached. Final polishing was completed using 0.05-micron colloidal silica. The samples were carbon coated to achieve a conducting surface.

Figure 8 and Figure 9 shows the EDX results. Layer 3 is the SnPb finish and layer 4 is the ICA. From the initial EDX results layer 3 did not seem to contain Ag. SEM images show that the SnPb layer in both the treated and untreated sample have very similar morphology.



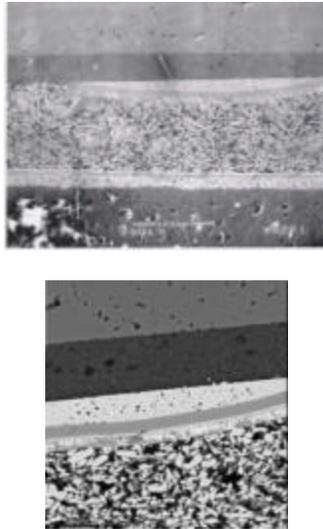


Figure 8 SEM images with EDX results of the untreated sample.

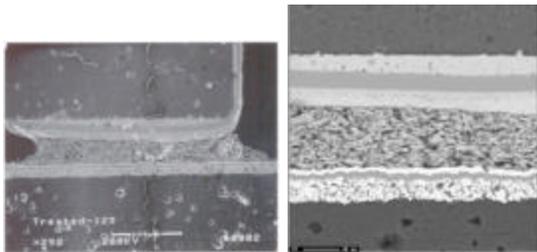
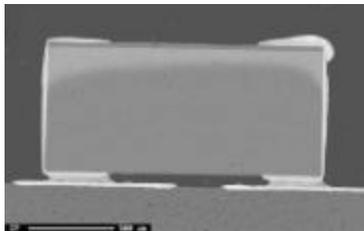


Figure 9 SEM images with EDX results of the sample treated at 125°C for two weeks.

Arrhenius Model

This is the most commonly used model relating time to failure (TTF) to high thermal stresses. Thermal stresses occur in solid-state diffusion, chemical reactions, many semiconductor failure mechanism, battery life, etc. The Arrhenius rate law that describes the (failure) rate, r , at which reaction to temperature of the test unit occurs, is given below.

$$r = C' a E / (k e .)?$$

where C' is a constant which is characteristic of the failure mechanism of the item under test, E_a = the activation energy measured in eV (= electron volts; close to vaporization energy for metals and chemical bond energies for polymers), k = the Boltzman's constant = 8.6171×10^{-5} eV/Kelvin, and T = the temperature in Kelvin = Centigrade +273.16 K. In RE engineering, the Arrhenius model is also used to measure the impact of temperature on reliability because we make the assumption the TTF is inversely proportional to the reaction (failure) rate, r , given in equation i.e.,

$$TTF = C a E / (k) e T$$

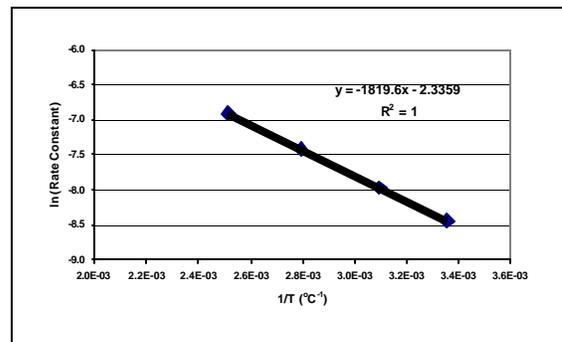


Figure 10 Arrhenius fit to the experimental data

Sen et al.[12], studied the intermetallic formation between Ag and Sn thin films and its affect on the contact resistance. The Ag_3Sn intermetallic was formed by the rapid diffusion of tin through the grain boundaries of the silver. Kay *et al* [13] have done similar studies to assess the growth of intermetallic compounds on base metals with tin and tin lead alloys. The finishes that were studied are electroplated tin in both matt and bright finishes, 60% tin-40% lead, 30% tin-70% lead, 10% tin-90% lead and 60% tin-40% lead that was applied by hot dipping. The base metals that were studied includes hard copper, soft copper, brass, nickel and silver.

Summary

From Figure 10 it can be seen that the resistance increases at a rate of 0.2mΩ/hour at room temperature. The initial resistance of the

adhesive joint is approximately 500mΩ. This however includes the resistance of the gold coating, wire bond and traces. The resistance of just the ICA is probably much lower than 500mΩ. As the sample was not wired in a manner that would measure only the adhesive resistance, a more sensitive measurement was not possible. Therefore the initial resistance of the ICA is assumed it to be around 10mΩ. If failure is defined as a 20% rise in resistance, the ICA joints is expected to fail with 50 hours at room temperature.

Effect of Humidity

To study the effect of humidity, the adhesive joints were subjected to 85°C/85%RH (Figure 4). Experimental results with and without humidity revealed no significant changes. As a result we speculate that humidity has little on no effect on the electrical performance of the adhesive joint. (See Figure 3 and Figure 4)

Effect of Oxygen

As these thermistors are housed within a hermetically sealed package, testing under air would not be appropriate. In order to study if failure was induced due to oxidation, the samples were tested under inert nitrogen atmosphere. Figure 7 is the plot of resistance vs. time under inert atmosphere. It can be seen that there are variations in the resistance rise within samples. As a result it is not clear whether there oxygen has an effect on the resistance rise.

As it is seen that some samples have a higher rate of resistance rise compared to others, a detailed study of the stability of wire bond would prove useful. Initial SEM/EDX studies did not provide clear information on the failure mechanism. In this study only the SnPb-Ag interface was studied. It could be possible that intermetallic formation could be occurring at the SnPb-Ni interface and the SnPb - Au interface created by the gold coating.

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