

# Electrical reliability of electrically conductive adhesive joints: dependence on curing condition and current density

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## Abstract

The use of electrically conductive adhesives as interconnection materials in electronic assembly process is increasingly becoming a vital part of the electronics industry. Flip-chip joining technique using conductive adhesives has been identified as a key technology for future electronics assembly and manufacturing. The purpose of the present work is to investigate optimum conditions to achieve the best electrical performance in conductive adhesive joints. This study shows a comparison of electrical performance in conductive adhesive joints at various current densities with different curing conditions. Differential scanning calorimetry and resistance measurement were used to monitor curing condition in conductive adhesives. Accelerated life testing of conductive adhesive joints made of the selected conductive adhesive using different curing conditions was performed with various current densities. The current-induced degradation of conductive adhesive joints was investigated using optical microscopy and electrical resistance measurements. Results show a strong dependence of curing condition and current density on electrical performance of adhesive joints. Additionally, sample cured for less time exhibited better quality than sample cured for more time at high current densities. It is also found that conducting particles move with the current-induced aging, which shows that the migration of conducting particles can induce the failure of conductive adhesive joint during the current-induced resistance increase. © 2001 Elsevier Science Ltd. All rights reserved.

*Keywords:* Conductive adhesive; Ag/Ag–Cu filler; Cure degree; Current density; Contact resistance

## 1. Introduction

More recently, electrically conductive adhesives (ECAs) are playing an increasingly important role in the design and production of electronic package applications, because they require fewer processing steps and lower curing temperatures than solder connection technology. The ability of ECAs to provide thermal management, mechanical bonds and electrical connections simultaneously in applications is a particular advantage, so increasing demand for ECAs will be driven by several factors affecting the electronic packaging market. The most widely used conducting fillers are silver (Ag) flakes and powders due to their high electrical conductivity and chemical stability. Uncured ECAs have a very high resistance ( $>5\text{ M}\Omega$ ), which dramatically decreases to values as low as  $1\text{ m}\Omega$  upon curing and the shrinkage of the resin resulting from intimate contact of the filler [1–6].

Although conductive adhesives have been used for

decades in many other applications, they have recently gained much attention as an environmentally friendly alternative to tin/lead (Sn/Pb) solders. Not only do ECAs avoid the toxicity and environmental concerns from lead and chlorofluorocarbon-based flux cleaners, they also have the following technological advantages over their counterparts: (1) the lower curing temperature required for ECAs reduces joint fatigue and stress cracking problems enabling the use of heat sensitive or non-solderable materials; (2) fewer processing steps enable an increase in production throughput; (3) the higher flexibility and the closer match in coefficient of thermal expansion enable a more compliant connection and minimize failures; (4) the smaller filler particle size facilitates finer line resolution. However, there are some limitations of using conductive adhesives as interconnecting materials, which makes a wider application more difficult. High humidity, high temperature, and high current densities have been shown to increase contact resistance that could lead to circuit failure. Other relevant issues are that the weaker bond strengths in ECAs, rework is not as convenient, and ECAs tend not to be as reliable as metallurgical or separable interconnects because of the

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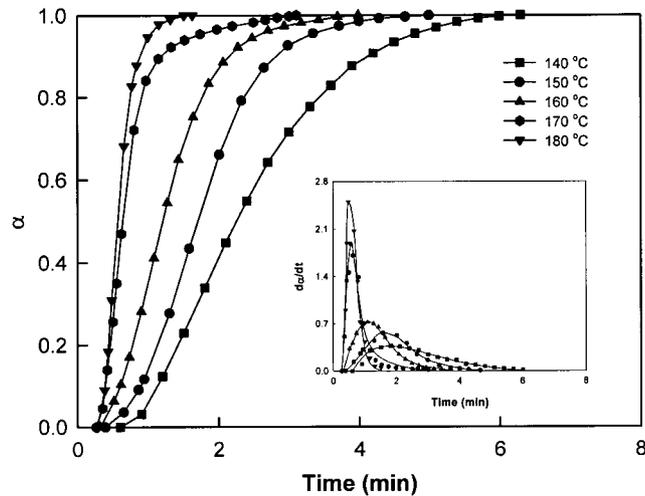


Fig. 1. Time dependence of the cure degree at each cure temperature from DSC experimental. Time dependence of reaction rate  $d\alpha/dt$  at different cure temperatures (Inserted graph).

vast number of particle–particle interfaces that occur [7–11].

One of the reliability issues concerning ECAs is the increasing contact resistance of the ECA joints with high current densities, since it is a significant cause for circuit failure. The current-carrying capability of ECAs used for flip-chip bonding is important for most circuit applications. Additionally, a trend toward the use of fine pitch in order to meet the increasing demand for high-density layouts results in a small contact area. Hence, a large amount of current is expected to pass through ECAs [12,13]. On the other hand, from a processibility standpoint, the cure degree of packaging materials is of critical importance in both the reliability of materials and the actual processing quality. Therefore, the temperature magnitude and duration of curing significantly influence the physical and mechanical properties of the ECA joints, and relatively small changes in the cure processing conditions can alter the properties of the end products [14–16].

In the present work, we investigated the reliability issues of ECA joints with different curing conditions and focused on comparing the dependence of contact resistance increase on the curing degree of conductive adhesives at different current densities. If the ECA exhibits favorable characteristics at a reduced cure time and at lower curing degrees, then process time could be significantly reduced. Therefore, the purpose of performing this curing degree dependent reliability study is to investigate the possible consequences of having ECA samples of different curing degrees with different current densities. ECA test joints of three different curing degrees were subjected to three different currents, i.e. 10, 20 and 30 A, for testing of joint reliability. Both differential scanning calorimeter (DSC) and conductivity measurements were performed to investigate curing degree as a function of time. However, the samples we made to perform reliability testing of the conductive adhesive joint

structures were cured in a different environment with the DSC system. Therefore, for a more accurate curing degree determination, we applied the resistance change data of curing for making ECA joints based on temperature selected from DSC data. Scanning electron microscope (SEM) image is included to reveal the morphology of the sample, and optical microscope and resistance measurements were performed to investigate the current-induced degradation of conductive adhesive joints.

## 2. Experimental

### 2.1. Material and characterizations

The conductive adhesive material used in this study was commercially available silver/silver–copper (Ag/Ag–Cu) filled epoxy resin adhesive. Thermal and kinetics data were obtained using a Perkin–Elmer instrument DSC-7. DSC is a technique that has been widely used to evaluate the kinetics of low molecular weight materials and is mainly divided into two categories; isothermal run and dynamic run. DSC scans are used to obtain the rate of heat generation as a function of time and temperature during curing. The conductive adhesive material was removed from frozen storage and was allowed to warm up to room temperature. Small sample quantities, i.e. <10 mg, were used for DSC scans with an aluminum hermetic pan. In order to obtain accurate heat flow data, a baseline was recorded for each experiment prior to conducting the cure procedure. An uncured sample was scanned at a heating rate of 20°C/min. Dynamic scanning experiments were carried out in the temperature range 25–200°C in an argon environment. Isothermal studies were conducted on the conductive adhesive in the temperature range 140–180°C at 10°C intervals.

In all DSC thermograms, the rate of heat generation ( $dH/dt$ ) is found to exhibit a maximum when it was plotted as a function of time. Fig. 1 shows the time dependence of the cure degree at each curing temperature for the adhesive material. The time for the curing of samples decreased from 6 to 2 min with increasing cure temperature from 140 to 180°C. For a higher cure temperature of 180°C, the curing procedure can be completed within 2 min. Therefore, in optimizing the cure temperature, one should select a high temperature below the decomposition. This enables a higher reaction rate that accelerates the cure, resulting in a shorter time required for complete curing. The time dependence of reaction rate  $d\alpha/dt$  for samples at different cure temperatures by DSC is also shown in the inserted graph in Fig. 1. The solid lines show the predictions by  $d\alpha/dt = k_2\alpha^m(1 - \alpha)^n$ , and good agreement is found between the model and DSC isothermal data, where  $\alpha$  is the relative degree of cure,  $k_2$  is the rate constant for the autocatalyzed reaction kinetics, which is related with the Arrhenius form,  $k_2 = A \exp(-E/RT)$ , and  $m$  and  $n$  are the reaction orders. It is clear that the rate of reaction increases up to a maximum

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