EFFECT OF CURING DEGREE ON ADHESION STRENGTH AND CONTACT RESISTANCE OF FLIP CHIP ON FLEX PACKAGES

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Abstract
The purpose of the present work is to investigate optimum curing conditions to achieve the best performance in ACF joints. Differential scanning calorimeter (DSC) was used to measure the curing degree. Adhesion strength was evaluated by 90 degrees peeling test. The contact resistance has also been studied as a function of bonding temperature and curing degree. Results show a strong dependence of curing condition on the electrical and mechanical performance. Adhesion strength increases exponentially with the curing degree. Whereas the contact resistance decreases with the curing degree and achieve the minimum value at 87% of curing. Co-relation of the curing degree of the ACF was also studied through the detailed investigation of the fracture surfaces under Scanning Electron Microscopy (SEM).

1. INTRODUCTION
Two critical reliability issues of conductive adhesives applications are contact resistance shift and poor adhesion strength [1]. Extensive studies have been done for the former subjected to various environmental stresses [2-3] and slightly work on the latter. High adhesion strength is a critical parameter of fine pitch interconnection that fragile to shocks encountered during assembly, handling and lifetime. Initial efforts at this aspect mostly focused on isotropic conductive adhesive (ICA) for surface mount lead attachments, which involve structure-property-performance study [4] and dropping mounted chip and board assemblies onto hard surfaces from certain height [5]. Anisotropic Conductive Adhesive(ACA) is a special variety of ICA which conduct electricity only in one direction. ACA contains less conductive particles (lower percentage of metal fillers in volume) than that of ICA. The concentration of particles is controlled in such a way that just enough particles are present to assure reliable electrical conductivity in the z direction (normal to the plane of adhesive film) while concentration is far below a critical value to achieve percolation conduction in the x-y plane [2]. Thus it has been attracted much interest because of ultra-fine capability [6].

Because of the anisotropic property, ACA can be deposited over the entire contact region as film (known as Anisotropic Conductive Film, ACF), thus it is predicted to increase mechanical reliability [6-7]. However, there is still some sort of uncertainty of using ACF considering proper formulation and optimized curing profile which lead to unstable contact resistance, poor adhesion strength etc. Due to poor adhesion with the flex, void may nucleate at the ACF/Flex interface, which might propagate to the interconnection to loss the electrical conduction [8]. Successful bonding involves the selection of proper bonding parameter during which chemical reactions proceed to completion, in order for it to develop its service strength [9]. There is little work done elsewhere on the adhesion strength of flip chip, especially with the curing degree of ACF matrix. Current work focuses on the understanding of the curing degree that affects the peel strength and contact resistance of Chip on Flex (COF) in terms of fracture microstructures.

2. EXPERIMENTS

2.1 Materials
The flexible substrate contains polyimide film as a base materials, Cu trace as conductor and an adhesive in between. The thickness of the polyimide base film, adhesive and Cu trace is 50, 10, and 5 micron. The thickness of Ni coating and Au flash was about 1–2 μm and 0.1–0.4 μm, respectively. The dimension of the test chip have a size of 11 × 3 mm², with 46 × 46μm² square shaped opening around the periphery. These openings are
material \( Q_x \). The relationship can be written as follows [10]:

\[
\alpha = \frac{Q_T - Q_R}{Q_x} \quad (1)
\]

Figure 2: Typical DSC traces of ACF for both uncured and cured at different temperature.

Figure 3: Curing degree of ACF for different bonding condition.

\( Q_T \) \& \( Q_R \) were measured from dynamic DSC scan of the sample of uncured and cured at different temperature respectively. Figure 3 shows the curing degree of ACF for different bonding condition. The result shows that the ACF was only 24\% cured, when the bonding temperature was 150\°C. In contrast when the bonding temperature was 250\°C, the ACF becomes 98\% cured.

3.2 Adhesion study:
The results of the peel strength measurement are plotted in Figure 4. The curve shows that as bonding temperature increases, the curing degree of this epoxy-based adhesive increases resulting in stronger chemical bonding at the interface and leading to increase in adhesion. As the curing of ACF proceeds, the linear polymer chain in the epoxy resin grows and branches to form cross-links [10]. At the lower degree of cross-linking, the polymer chains are capable of moving relatively easily and exhibit less adhesion strength. Again, as the bonding temperature increases the degree of cross-linking as well as adhesion also increases. Because, the polymer chains locked together and their movement become consequently somewhat restricted. Cross-linked polymer chains are chemically bound together to give a three-dimensional "chicken wire" structure [11]. So, the higher the curing degree, the stronger the chemical bonding and the better adhesion strength at the ACF interface.

For understanding the fracture mode, it is essential to study the fracture surface along with the peel test data. Figure 5 shows the fracture surfaces of the substrate side and chip side after the peel strength test for the samples cured at 150\°C. Fractured surface at both flex and chip sides are very smooth. It is clear from the SEM images that debonding occurred at the flex/ACF layer interface. At the flex side only some uncured monomer of adhesive was observed. ACF was found on the chip side. It could be said that the adhesion between ACF and flex is weaker.
than that of the ACF/chip. It also indicates that this curing temperature is not sufficient and needs to be set at a temperature higher than 150°C for optimum bonding of ACF for reliable flip chip bonding.

However, the failure mode changes at high temperature bonding. Figure 6 depicts the failed surface of the interfaces when the bonding temperature was 230°C. The ACF was found in both sides and the fractured surfaces are very rough. Extensive deformation and smearing of the ACF was noticed for such high temperature bonding. It is also interesting to get the conductive particles in the both sides. Thus it is confirmed that fracture occurred through the ACF. Inter-diffusion of the ACF to the flex is clear. During the bonding process at a temperature of 230°C, substantial heat passes through the ACF to flex substrate. Therefore, the temperature of this laminated adhesive reaches far more than its Tg. As a result, it melts, inter-diffused and/or reacts with the ACF. After cooling, it re-solidifies and strengthened the bond between ACF to flex substrate. Thus peel strength increases extensively for this high temperature bonded sample.

Figure 6: Fracture surfaces of the substrate side and chip side after the peel strength test for the sample cured at 230°C.

### 3.3 Contact resistance:

Figure 7 shows the variation of the contact resistance with the bonding temperature for bumpless FCOF. From the curve, it is clear that the contact resistance of the packages decreases with the increase of bonding temperature up to 210°C and then increases when the bonding temperature was used above 210°C. FCOF packages assembled at 210°C showed the best contact resistance when compared to those assembled at other different temperatures. For the bumpless FCOF packages assembled at 210°C, the average contact resistance was 0.12Ω.

During the early stage of the bonding process, the ACF becomes soft and rubbery and this transformation allows the conductive particles to move within the ACF. When the curing process is completed, the ACF becomes hardened and the mobility of the conductive particles is lost. Higher bonding temperature results in higher curing degree shortly, and the ACF becomes stiffer with higher modulus. After the bonding process, the conductive particles only recoil a little for highly cured ACF. Thus the higher contact area of the deformed particles remains
of aluminum metal with 1% silicon limited by chip-passivation layer. There was not any bumping on the Al metal pad. Thus this kind of chip is known as bumpless chip. There are 368 Al pads in the chip. Among them, 300 pads run parallel to the length of the chip for electrical connection. These Al pads are arranged in sets of five as a group; with two adjacent bumps for measuring insulation resistance and three for contact resistance. The type of ACF used in this study was consists of an epoxy layer and filled with conductive particles. The conductive particles are made up of polymers plated with a thin layer of nickel and gold followed by a thin insulation layer. The thickness of ACF is 35 µm and particle diameter is 3.5 µm. Concentration of the conductive particles is about 3.5 million /mm³. The glass transition temperature (Tg) of the ACF is 130°C.

2.2 Bonding Process:
A manual flip-chip bonding machine (Karl Suss 9493 Mauren) was used to carry out the pre-bonding, i.e. placement of ACF on flex. The pre-bonding pressure was 1 MPa, while the temperature and time were 100°C and 7s respectively. A semi-automatic flip chip bonding machine (Toray SA2000) was used to conduct the final bonding. The substrate pattern and the position of the chip bumps were aligned automatically by the flip chip bonder. Finally, the chip is bonded to the substrate by applying heat and pressure simultaneously. For final bonding, the pressure and time were 100 MPa and 10s respectively, while the bonding temperature was varied from 150-230°C. The alignment accuracy is ±2 µm.

2.3 Contact Resistance Measurement
The contact resistance of FCOF assemblies was measured by using the four-point probe method. In the test, 1mA constant DC current was applied to the circuit and the voltage was read from the HEWLETT PACKARD multimeter. Then the contact resistance was obtained simply by using Ohm’s Law, R = V/I.

2.4 Adhesion measurements
The 90° peel test has been widely used to measure the adhesion strength of multilayer films. To measure the adhesion strength of the ACF, flexible substrate were cut from the side of the chip to make it to 3.5 mm width and then peeled out from the bonded sample keeping the chip fixed. Special accessory was prepared for small-scale peel strength measurement. Figure 1 shows the schematic arrangement for measuring the peel strength. The test was carried out by the Instron Model Mini 44 Tester, (Intertek testing Services, England) with a cross-head speed of 10 mm/min. Instrument was adjusted deliberately in order to peel out the flex from the whole chip. Five samples were tested per given condition.

2.5 Failure analysis:
After the peel test, the fracture surfaces of the samples (both the chip side and substrate side) were examined by optical microscopy and Scanning Electron Microscopy (SEM) to study the fracture characteristics of both chip and substrate sides. 30° tilting of the stage was used to get the perspective view of the surface morphology.

2.6 Differential Scanning Calorimeter (DSC) tests
Curing degree of ACF was examined with a Modulated DSC instrument (by TA Instruments, Model 2910). Dynamic curing experiments were performed from 50-250°C with ramp rates of 10°C per min. In this way, two kind of samples (1) the raw ACF and (2) Cured ACF after peel out the bonding were examined. For raw ACF, it was removed from the refrigerator and allowed to warm up to room temperature for one hour before conducting the experiments. For cured ACF, small amount of adhesive was taken form the fractured surface after the peel test and prepared the samples for DSC tests. The reaction was considered complete when the rate curve levels off to the base line.

3. RESULTS AND DISCUSSION

3.1 Curing Degree:
Figure 2 shows the typical DSC traces of ACF for both uncured and cured at different temperature. Based upon the assumption that the exothermic heat evolved during the cure is directly proportional to the extent of cure, the curing degree α can be expressed by the relationship between the total exothermic heat of raw material Qr and the residual or exothermic heat of previously cured

Figure 1: Schematic arrangement for measuring the peel strength.
Figure 7: Variation of the contact resistance with the bonding temperature for bumpless FCOF

stable to the pads and the contact resistance is relatively low.

At the bonding temperature of 210°C, the ACF becomes cured adequately (87%) and the conductive particles within the epoxy layer remains stable throughout the ACF joints. 210°C is optimum in respect of the contact area requirement having less possibility of the oxidation than the bonding temperature of 230°C. Therefore, this bonding temperature creating the best contact and show the low contact resistance. However, when the bonding temperature was 230°C, the ACF was cured much (98%) but the contact resistance becomes high. This may be due to the heat being absorbed by the FCOF packages and acting as a catalyst for oxidation of the Al pads.

4. CONCLUSIONS

The performance of the ACF interconnects is greatly influenced by the bonding temperature as well as curing degree during the assembly of FCOF packages. The results show that the high temperature cured samples have higher reaction rates and a greater curing degree as well as high adhesion strength compared with low temperature cured samples. Contact resistance was also found to be strongly dependent on the curing degree. In this study, the optimum temperature for bonding FCOF with ACF was concluded to be at 210°C. Fracture modes were studied by SEM after the adhesion strength measurement. From the fracture surface images, it was found that epoxy of the ACF matrix start to react and inter-diffuse with the thin adhesive layer on the polyimide substrate at about 210°C. After that reaction or inter-diffusion, fracture mode changes from flex-to-ACF to the ACF itself. This reaction or inter-diffusion of the ACF is proposed to be responsible for higher adhesion strength at higher bonding temperature.

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