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CONTACT RESISTANCE OF ANISOTROPIC CONDUCTIVE ADHESIVE FILM BASED FLIP-CHIP ON GLASS PACKAGES

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Abstract. In a flip-chip-on-glass (FCOG) assembly, anisotropic conductive film (ACF) is used as the adhesive to bind the desired interconnection between the flip chip and glass substrate. However, it remains a challenge to develop the ACF bonded flip chip packages with low contact resistance. Considerable research has been conducted recently to investigate the effect of different parameters on the contact resistance. This review article will discuss the critical issues that can easily control the contact resistance of ACF joints in flip chip on glass packages. These mainly include surface cleanliness, bonding tracks, process parameters and operating environmental related issues. The findings can serve as a guide for minimizing the contact resistance of flip chip on glass packages with ACF. By such minimization, ACF can be used as an environmental friendly solder replacement in the very large scale integration (VLSI) industry.

1. INTRODUCTION

Popular interconnect methods for micro-electronic packages include wire bonding, tape automated bonding (TAB), soldering and physical connections. The first three methods rely on metallurgical joining, and result in permanent electrical joints. Physical connectors rely on a mechanical normal force to keep the two mating surfaces in intimate contact [1]. Conductive adhesive technology is such an attractive interconnects method that depends on connections of the conductive particles with the input/output terminals. They have recently gained much attention as an environmentally friendly alternative to metallurgical joining [2-3].

Conductive adhesive not only avoid the toxicity and environmental concerns from lead and chlorofluorocarbon-based flux cleaners, but also have the following technological advantages over their counterparts: (1) the lower curing temperature required for adhesive reduces the 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 enable a more compliant connection and minimize failures; (4) the smaller filler particle size facilitates finer line resolution. Adhesive could also provide most of the needs for flip chip technology by themselves: create short electrical path, ensure good horizontal gap insulation, reduce joint stress and provide strong mechanical adhesion. Furthermore, no cleaning/flux is required, secondary under-fill is not necessary, and placement of adhesives is not critical. Therefore, more recently, conductive adhesives are playing an increasingly important role in the design and production of very large scale integration (VLSI) [4-5].

Fig. 1 shows the schematic cross-sectional view of flip chip conductive adhesive joints. The conductive particles are made up of polymer spheres plated with a thin layer of nickel and gold followed by a thin insulation layer. During the bonding process, when

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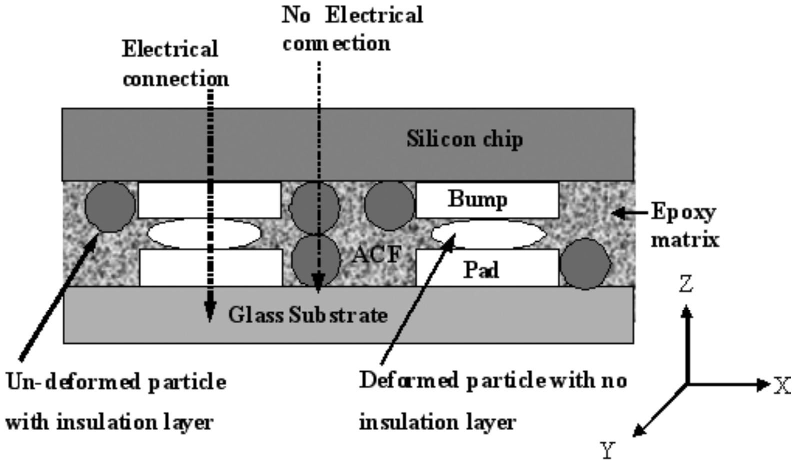

Fig. 1. Schematic cross-sectional view of flip chip conductive adhesive joints.

the anisotropic conductive adhesive film (ACF) is being compressed thermally, the conductive particles between the connecting bumps & pads are sandwiched and would change from being spherical to oval. At this stage, insulation layer of the conductive particles wears out and electrical connections are formed in the *z*-direction. The other conductive particles remain as usual with insulation layer and prevent electrical conduction in the *x*- and *y*-direction. The concentration of particles is controlled in such a way that just enough particles are present to assure reliable electrical conductivity in one direction only. ACF thus has the capability achieving of ultra-fine pitch for very large scale integration (VLSI) [6].

The FCOG packages are made up of three different parts, namely glass substrate, silicon chip, and ACF [3]. They can be in different structure with different types of materials.

1.1. Glass substrate

The glass substrate can be about 1.1 mm thick without bump at pads, and the conductive trace pattern can be sputter-deposited indium tin oxide (less than 1 μm thick).

1.2. Silicon chip

The typical Flip chip also contains with square shaped (typically 50 × 50 μm^2) opening around the periphery. These opening consist of aluminum metal with 1% silicon limited by chip-passivation layer on the periphery of the die. Such type of chip is called bumpless chip. Additional electroless Nickel layer of 4-5 μm height with/without Gold (Au) flash can be deposited on that aluminium metallization to form Ni bump. The bump pattern of the chip is similar to the pad pattern of the glass substrate to make exact alignment.

1.3. Anisotropic conductive adhesives film (ACF)

The type of ACF used in this study consists of an epoxy layer and is 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. Fig. 2 shows the schematic cross-sectional view of a typical conductive particle. The insulation layer of the particles trapped between the bumps and substrate pads, will become soft and cracked during the bonding process to achieve electrical conduction in the z-direction. While insulation layer of the other particles will not experience pressure and remain unchanged for keeping insulation in *x*, *y* planes to prohibit short circuit between the adjacent joints. The thickness of ACF is 35 μm and particle diameter is 3.5 μm. Concentration of the conductive particles is about 3.5 million /mm^3. The glass transition temperature (T_g) of the ACF is 130 °C.

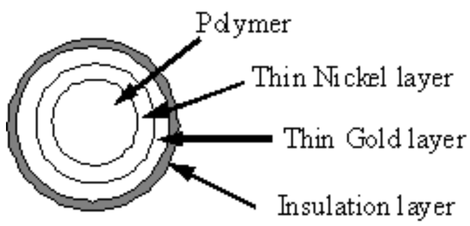

Fig. 2. Schematic cross-sectional view of a typical conductive particle.

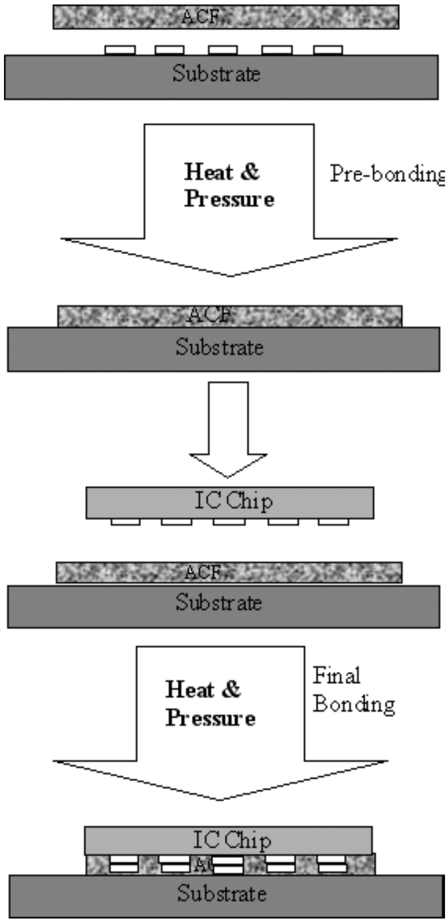

Fig. 3. Schematic of the bonding process of flip chip on glass packages.

Two critical reliability issues of conductive adhesive in this application are the poor adhesion strength and contact resistance shift. The technique of achieving higher adhesion strength is described in earlier studies [7]. Our purpose of this review is to have a better understanding in minimizing the contact resistance of ACF bonded flip chip on glass packages. The failure criteria of ACF bonds are usually indicated by an increase in contact resistance beyond a certain limit for a specific application [8]. Successful bonding involves the contaminant free surface, the selection of proper bonding parameters, suitable bonding tracks in a proper operating environment. Therefore, there is still some sort of uncertainty of using ACF considering above-mentioned issues which lead unstable contact resistance.

Contact resistance of ACF joints mainly depends on followings: [9]

1. The number of conductive particles trapped between bumps & pads.
2. Contact area of deformed particles.
3. The successful removal of insulation layer.
4. Surface cleanliness and many other related parameters.

The first one depends on the rate of curing of ACF and temperature of the bonding process. The 2nd point, i.e. deformation of the particles depends on the applied pressure during bonding. Insulation layer removal occurs during the early stage of the bonding time. When pressure is just applied, entrapped particles moves between the pads, by the way due to friction, insulation layer wear out and conductive metal coating come in contact with the pads. Therefore the above-mentioned issues are uniquely critical for minimizing the contact resistance of ACF bonded flip chip joints.

2. CONTAMINATION FREE BONDED SURFACE

Contaminants may introduce in ACF bonded flip-chip packages during the production of the substrate & flip chip and also from the environments. The contaminant mainly includes organic or oxide layers and can play havoc with circuits to cause costly failure [10]. Therefore these impurities must be thoroughly removed before the bonding process. Air bubbles may entrap during ACF lamination process. Such defect reduces the contact area for electrical connection and also provides stress propagation path for crack, resulting in easy delamination under low force. The voids may nucleate at the interface and may propagate through the interconnection resulting in the loss of electrical connection [11]. Therefore an important part of the minimizing contact resistance is the control of contamination and ensure the clean bondability between various mating surfaces [7].

3. TYPICAL BONDING PROCESS

Generally, ACF material is cured during the bonding to mount with bonding tracks; substrate and flip chip. When the curing process is completed, the ACF becomes hardened and the mobility of the conductive particles is lost. The conductive particles within the epoxy layer remains stable throughout the ACF joints. The ACF can be cured by using thermal or UV energy. High curing temperature usually leads to an increase in cross-link density and a homologous increase in heat resistance. Nevertheless, curing process under high temperature problems can occur such as the inclination for the adhesive materials to shrinkage, cracks, voids and it would probably lower the dielectric properties [12]. On the other

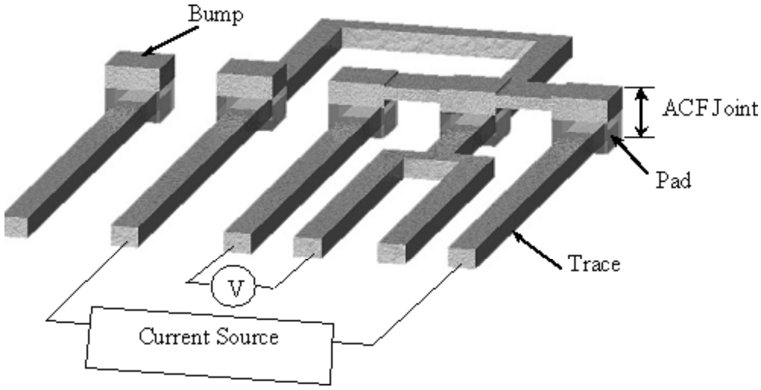

Fig. 4. Schematic circuitry to measure the contact resistance using the four-point probe method.

hand, UV curing of anisotropic conductive adhesives offers several advantages over the conventional epoxy resin, including rapid cure, little to no emission of volatile organic compounds and without affecting other components in the assembly. However, the UV curable ACF materials and technology are not yet matured enough and therefore, this review will mainly focus on the thermal curing induced bonding process.

The procedures for flip chip mounting included several steps: ACF placement, pre-bonding, IC placement and final bonding [7]. Fig. 3 shows the schematic of the typical bonding process. A manual flip-chip bonding machine (Karl Suss 9493 Mauren) can be used to carry out the pre-bonding, i.e. placement of ACF on glass substrate. The typical pre-bonding pressure is 1 MPa, while the temperature and time are 100 °C and 7s respectively. A semi-automatic flip chip bonding machine (Toray SA2000) can be used to perform the final bonding. The substrate pattern and the position of the chip bumps can be aligned automatically by the flip chip bonder. Finally, the chip can be bonded to the substrate by applying heat and pressure simultaneously. For final bonding, the typical pressure and time range are 60-100 MPa and 7-10 s respectively, while the bonding temperature can varied from 150-230 °C. The alignment accuracy can be reached up to ±2 μm.

4. CONTACT RESISTANCE MEASUREMENT

The contact resistance of FCOG assemblies can be measured by using the four-point probe method and the schematic circuitry is shown in Fig. 4. The circuitry has been improved [3] and there was no need to measure the trace resistance before bonding. In the test, 1 mA constant DC current can be applied to the circuit and the voltage was read from the HEWLETT PACKARD multi-meter. Then the contact resistance can be obtained simply by using Ohm's Law, $R = V/I$.

5. EFFECT OF APPLIED BONDING PARAMETERS

Successful bonding involves the selection of proper bonding parameter during which chemical reactions proceed to completion, in order for it to develop its performances [13]. During bonding of ACF joints, applied conditions (temperature and pressure) are the critical bonding parameters for optimal curing conditions of ACF. During component assembly, the epoxy resin is cured to provide mechanical connection and the conducting medium provides electrical connection in the z-direction. The physical, electrical and mechanical properties of the cured conductive adhesives depend to a large extent on the degree of cure of the epoxy composition of the ACF [7]. Therefore, the applied bonding conditions are very critical to develop the ultimate electrical properties of ACF.

5.1. Effect of bonding temperature

The applied bonding temperature directly controls the curing degree of ACF. Therefore the parameter has very strong influence on contact resistance. At low temperature bonding process, the ACF becomes soft and rubbery and this transformation allows the conductive particles to move within the ACF. Therefore, there is a possibility of the conductive particles to squeeze out form the pads interface due to the applied pressure through the soft adhesive. As a result, in some joints, higher and unstable contact resistance and even sometime open joints are found [3]. However, a reliable interconnects should have metal-to-metal contact through out the die pad-to-the deformed particles and deformed particles-to-the Cu pad of the substrate.

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 stable and the contact resistance is relatively low. However, when a very–higher bonding temperature is used, the contact resistance again increased. This may be due to the heat being absorbed by the FCOG packages and acting as a catalyst for oxidation of the metal pads. Metal atoms easily contribute its electrons to oxygen atoms to form metal oxide film. The metal oxide layer acts as a barrier between the metal pad-conductive particle and conductive particle-metal pad, making difficulties for the electrons to flow through this metal pad-conductive particle-metal pad path of the bounding interface. That leads to reduction in number of free electrons on its surface, hence, increases its electrical resistance [13].

5.2. Effect of bonding pressure

Bonding pressure plays an important role on the contact resistance of ACF joints. It is used to compress the conductive particles against the conductive tracks and ACF matrix during the assembly process. The deformation degree of conducting particles during bonding greatly determines the contact area and the electrical characteristics of the interconnection.

When the bonding pressure is too low, the particles may not be able to make contact between the connecting bumps and pads and remain as open joints. As the bonding pressure increases, the contact area also increases due to the deformation of conductive particle, hence the contact resistance decreases. When the pressure applied is greater than the outermost layer of the conductive particle can withstand, the conductive particle may burst open, exposing the polymer sphere, which is an insulator, to the connecting bump and pad. Hence, the conductive property of the particle is lost, leaving it to be an insulator that acts as an obstacle impeding the electrons from trying to flow through the connecting bump and pad. It should be mentioned that this excessive applied bonding pressure induces internal elastic stress build up at the bonding interface. This stress can be released under temperature and humidity tests and resulted in gaps at the interface which lead in a contact resistance increase and open circuits [14]. If the particles are too spread out between adjacent bumps or pads, caused by too much pressure applied, they may also end up contacting each other creating the same effect as short circuiting.

6. INFLUENCE OF BONDING TRACKS (SUBSTRATE AND CHIP)

Both the bonding tracks (substrate and flip chip) structure and materials are importance for the quality and reliability of flip chip joints. Nickel bumps with/without Au flush formed better interconnections than bumpless FCOG packages. Because conductive particles in the Nickel bump FCOG packages are tightly trapped between the bumps and pads and hence provide better connections. The reliability of bumpless chip is also poor. Aluminium oxide is thought to be the main cause of the increased contact resistance after the moisture soak tests. Also, the bumpless FCOG packages gives higher contact resistance values than Ni bump packages, especially with bonding temperatures above 200 °C, the contact resistance doubled. The height of the bumps also can play important role. They control the deformation characteristics, and hence the reliability of the interconnection in the flip-chip assembly. The tall bump height can reduce the potential for electrical failure in ACF interconnects when ACF/bump interfacial fracture is the dominant failure mode. However, high bumped joints showed poor reliability, which could be due to the formation of pores within ACF [15].

7. MISALIGNMENT OF BONDING TRACKS

Misalignment can be caused by placing error, bump height variation and lack of flatness of the bump pads, uneven assembling pressure, and non-uniformity in thickness of ACF. Especially, for such fine-pitch assembly, the conductor pad sizes and conductor spacing are very small. Misalignment will at least decrease the contact area, and thereby increase the resistance. Worse still, there is the possibility of open connections or short-circuits [16].

8. ENVIRONMENTAL EFFECT

The contact resistance of the ACF joints is unstable with environmental change [4]. The ACF joints of flip chip need to subjected through different kind of environment in the real operating field. Therefore the critical issues that can degrade the ACF joints need to be well understood. The typical harsh environments for the ACF are the high temperature and high humidity [17-18]. The effects of those harsh environments are described below.

8.1. Effect of high temperature

For many reason ACF joints of flip chip assembly need to expose in high temperature. Therefore it is also essential to know the degradation issues of ACF joints in such high temperature environments.

At high temperature, contact resistance increases mainly due to the CTE mismatch of the interconnect materials. The contact resistances of ACF joints change with the environmental temperature. Unlike solder joints, the mechanical contact of the conductive particles becomes loose at the higher temperature because of the relatively higher CTE value of the ACF materials. The entrapped (between the chip and substrate) adhesive matrix tries to expand much more than the tiny conductive particles because of the higher coefficient of thermal expansion (CTE), the induced thermal stress will try to lift the bump from the pad and decrease the contact area of the conductive path and eventually, leading to a complete loss of electrical contact. The degradation of electrical performance is also related to the oxide formation on the surface of deformed particles with non-noble metal coating, on the conductive surface of bumps, and the contact conductive surface of substrate metallization.

Most of the reliability of the flip chip on glass (FCOG) assembly was evaluated in terms of the contact resistance change of the specimens measured at room temperature before and after storage in different environments. In these reliability studies, the specimens were removed from the test chamber after a certain interval for measuring the contact resistance at room temperature. When brought to room temperature from the test chamber, the specimens partially acquired the original state. The defects were not necessarily found at room temperature. Therefore, continuous real-time measurements of contact resistance were investigated to identify the defects and getting the actual test results [19].

The contact resistance is also varies on the location of ACF joint in the package. The contact resistance increased from the middle to the corner of the package at high temperature. Because the middle bumps of the chip experienced only the stress developed in the *z*-direction, while the corner bumps experienced the stress developed in all directions and hence greatest cumulative stresses generated at the corner of the interconnections [20]. To avoid higher contact resistance at the corner, it is recommended to use square shaped chip instead of rectangular chip having higher length. Also, ACF with low CTE and high T_g value is essential to make the contact resistance stable, especially at the corner position [19].

8.2. Effect of high humidity

The polymer-based ACF joints are often subjected to high relative humidity environment and are susceptible to moisture absorption, especially at elevated temperatures, which is one of the major reliability concerns for the ACF joints. The absorbed moisture has deleterious effects on the physical properties of ACF and can, therefore, greatly compromise the performance of ACF joints [21].

The contact resistance is increase due to the exposure in high humidity environment. Increasing contact resistance is mainly due to the loss of contact by thermal stress effect and moisture absorption. The formation of metal oxide on top of the metallization of conductive particles is also responsible for increased contact resistance. The combined effect of oxide formation and the hygroscopic swelling also induce corrosion process to increase the contact resistances [22].

9. CONCLUSIONS

The contact resistance of anisotropic conductive adhesives film (ACF) joints is very critical to the success of the reliable packages of flip chip on glass (FCOG). The properties mainly depend on the processing of ACF and structure of bonding tracks. The processing includes the surface cleaning, proper bonding temperature & pressure and suitable operating conditions. They are all critical & it is not possible to look at one property alone to determine suitability. A balance of these properties is obviously needed for minimizing the contact resistance of flip chip on glass packages with ACF. From the recent studies, opportunities & technical challenges are high-lighted also the recommendations are given to address the technical challenges for the flip chip on glass packages.

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