Abstract

An anisotropic conductive adhesive (ACA) bump was produced on a silicon chip for bonding onto a glass substrate. The bumping process and the bonding procedure are described. The constituents of the ACA were investigated with a scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS). The thermal behavior of the ACA was investigated with differential scanning calorimetry (DSC). The spherical conductive nickel particles were deformed after bonding, while the silica filler was not. The reliability of the ACA bonding was tested at 85°C/85% relative humidity. The failure behavior of the ACA bonding was further investigated. A suitable height of the metal bonding pad was recommended.

1. Introduction

Flip chip bonding technology has been applied for high end CPU manufacturing since the 1960s. It is anticipated that more and more ICs will be fabricated with the Flip Chip technology. This trend is mainly ascribed to the characteristics of high I/O, good electrical performance, high reliability, and gang bonding of flip chip technology. Most of the flip chip bonding in production applies solder bumps for interconnection. Several methods are available for the bumping process including dip soldering, stencil printing, and electroplating. These bumping processes all need to expose the IC and the substrate to a temperature well above the melting point of solder during reflow bonding. It is not feasible for certain products such as an LCD (liquid crystal display). In addition, the Pb content of current solder has raised health concerns. A Pb-free bumping process is desirable for foreseeable future
electronic products. Electrical conductive adhesives (ECA) are Pb-free and do not require a high processing temperature. There have been a number of studies investigating ECA.

ECA can be isotropic conductive adhesive (ICA) (1) or anisotropic conductive adhesive (ACA). Both are produced in paste form. The anisotropic type is also produced in film (ACF) (2,3). ACF is being applied in LCD drive IC packaging. Both ICA and ACA are particle filled polymers. The particle fillers include conductive particles and non-conductive particles, the latter added to control the viscosity and rheology of the paste. A variety of conductive particles have been developed. Solid metal particles frequently used are Ni, Ag, Sn and Au (4-12). These particles may be produced in spheres or flakes. In addition to solid metal particles, Ni/Au or Au coated polymer core particles are also available. The polymer matrix can be either thermoplastic or thermosetting materials that exhibit different curing conditions. Epoxy and cyanate ester (4) are the possible polymer matrix materials. The polymer matrix materials and the filler particles exhibit different chemical and physical properties (9,10). Hence a specific curing schedule is generally suggested for each particular conductive adhesive (4,7,9,12). The effect of the rheology of the adhesive, particle size-pitch correlation, and volume fraction of particles on processing has been discussed (13). A disproportional power law relationship was found to exist between resistance and applied force (14). The dependence of resistance on applied force is stronger if the particle size is distributed in size rather than restricted to a narrow range of sizes. Electrical conduction mechanisms have been investigated for ICA (12,15) and ACA (5). These studies found that the electrical resistance of the adhesives is strongly related to the tarnish film on the filler particle and is disproportional to the volume fraction of filler in the adhesive. In order to achieve high volume percentage the smaller particles are desirable. The particle diameter can be as fine as less than 5 mm. A smaller particle size also results in lower resistance (14).

The electrical conduction behavior and material properties of the conductive adhesive have been discussed in the last decade. On the other hand, the failure behavior of the adhesive bonding yet remains to be explored. This present work investigated the bonding and failure behaviors and material characterization of an ACA.

### 2. Experimental

The anisotropic electrical conductive adhesive applied in this study is a commercial adhesive. This adhesive was still under development at the moment of this study. Differential Scanning Calorimetry, DSC, was applied to investigate the thermal properties of the adhesive. The DSC investigation was conducted under argon at a gas flow rate of 20 ml/min. The heating speeds of DSC investigation were 1, 5, 10, 15, 20, 25, and 30 °C/min. Heating was conducted up to 400 °C. The information obtained from DSC studies was the basis for determining bonding conditions. The adhesive, cured after the DSC analysis, was then polished by mounting the adhesive, along with a crucible, for metallographical and elemental investigations with scanning electron microscopy (SEM), energy dispersive x-ray analysis (EDX), and electron probe microanalysis (EPMA).

Bonding experiments were conducted between the silicon chip and the glass substrate. Circuits, bonding pads, and adhesive bumps were produced as follows. The bump pad has a dimension of 500 mm x 500 mm with a pitch of 1000 mm. The width of the circuit line is 300 mm. A chip consists of...
24 bump pads and has a dimension of 10 mm x 10 mm. The circuit and the under bump metallurgy of the adhesive are produced according to the sequence of Figure 1. The bump pad has a structure of Ta/Cu/EN (electroless nickel), while the circuit is made of Ta/Cu/Au. Ta and Cu were produced by sputter deposition. The patterns of circuit and bump pads were produced with the aid of lithography. Electroless nickel was deposited in a solution consisting of 130.5 g/l NiSO₄·H₂O, 30 g/l CH₃COONa·3H₂O, 4.1 g/l C₂H₅(OH)(COOH)₂·H₂O, 2 g/l C₃H₄(OH)(COOH)₂·H₂O, 36 g/l NaH₂PO₂·H₂O, 1 ppm lead acetate, and 1 ppm thiourea. The deposition was performed at pH 4.6 and 70 °C. The electroless gold was deposited from a solution consisting of 2 g/l KAu(CN)₂, 75 g/l NH₄Cl, 50 g/l C₆H₅Na₃O₇·2H₂O, and 10 g/l NaH₂PO₂·H₂O, at pH 7.0 and 92 °C. Cu etching solution was NH₄OH : H₂O₂ = 10 : 10 : 1 (volume ratio), while the Ta etching solution was 25% (vol) HF.

Figure 2 shows the circuit pattern on the glass substrate. The inner end of each circuit line corresponds to the bumping area of each chip (Figure 1). The circuit metallization is composed of Ta/Ta-Cu/Cu/Au. The metallizations were produced by sputter deposition. The Au layer provides the oxidation protection for the underneath Cu layer. The Ta-Cu provides better adhesion between Ta and Cu due to gradient composition and thus gradient coefficient of thermal expansion.

The adhesive was applied on the glass substrate by an injector, as depicted in Figure 3, through a needle with an inner diameter of 1.1 mm. The chip was then flipped onto the glass substrate carefully to align the bump pad on the chip with the pad on the transparent glass substrate. Each glass carries six chips. The chip was thermally pressed on the glass substrate at a force of 65 kg/mm². The thermal compressing was conducted at a heating speed of 15-20 °C/min to a peak temperature of 150 °C.

3. Results and Discussion

The anisotropic conductive adhesive investigated in this study contains Ni as the conductive particle. Figure 4a shows the SEM picture of the adhesive while Figure 4b shows the Ni elemental analysis. The larger particles are Ni and are roughly spherical in shape. The matrix is filled with smaller spherical silica particles.

The thermal behavior of the adhesive, shown in Figure 5, shows that the cross linking reaction of the polymer occurs at around 134.64 °C when the heating speed is 10 °C/min. The measured cross-linking temperature varies with respect to heating speed. It was seen that the maximum measured cross-linking temperature is around 150 °C at the greatest heating speed, 35 °C/min, in this study. The shear strength of the ACA bump was measured to determine the necessary bonding time. The shear strength of the bumps, Figure 6, shows that a maximum strength is achieved when thermal compression was carried out at 150 °C for 25 minutes. Accordingly, the bonding temperature was set up at 150 °C in the later study.

The Ni particle size exhibits wide distribution. It was reported (14) that a large compressing force is needed to achieve successful bonding when the conductive particle has wide size distribution. The large compressive force, 65 kg/mm², applied in this study may cause tremendous size distortion to the Ni particles as seen in Figures 7a and 7b. A larger particle, Figure 7b, was compressed almost flat. The flat surface results in a larger contact area for electrical conduction. On the other hand, the silica particles are hard to compress. It is therefore advisable to have large silica filler particles as they may inhibit the contact between conductive particles and the electrodes as seen in Figure 8a. Furthermore, the filler particles may also affect electrical
Figure 1. The sequence for producing the bonding and electrical circuit patterns on the silicon chip
Figure 2. The bonding and electrical circuit patterns on the glass substrate

conductivity by sitting on top of a conductive particle as seen in Figure 8b. There exists a critical volume fraction of filler beyond which the conductivity drops sharply. However, the filler particle is harder than the metallization layer and the conductive particle. Thus a relatively smaller particle, compared to a conductive particle, may still allow electrical contact if the compressive force is large enough to “embed” the filler particle.

It was reported (16) that the bump height is of importance in the electrical performance of conductive adhesive bonding. The mechanism was not revealed in the paper. In the bonding experiments of this work it was found that the electrical resistivity of some circuits lowers after bonding. The investigation on these lines, Figure 9, shows that the stacking of conductive particles between the spaces of circuit lines results in a short circuit. The stacking phenomenon was not seen to exist for a stacking height of more than two particles. Accordingly it is suggested from this observation that the bump height should be at least twice that of the largest conductive particles, as depicted in Figures 10a and 10b.

The failure of adhesive bonding during humidity testing can be ascribed to humidity absorption of the polymer that causes polymer degradation. The polymer matrix tends to chip off upon grinding after 400 hours of humidity testing at 85°C/85% RH (relative humidity).
Figure 3. (a) The applying of ACA and the flip chip bonding, (b) the sketch of the cross sectional bonding structure

Figure 4. (a) SEM photograph of the ACA, (b) EDS elemental analysis of Ni
Figure 5. DSC profile of the ACA at a heating speed of 10 °C/min.

Figure 6. Shear strength of the ACA bump with respect to compression time
Figure 7. **SEM photograph of a slightly deformed conductive particle, (b) a severely deformed conductive particle**

Figure 8. **(a) A large silica particle inhibits the electrical contact, (b) the interference of a filler particle to electrical contact between conductive particle and bonding pad**

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Humidity absorption results in poor bonding between the ACA and the electroless nickel (EN) bump pad. The top view, Figure 11, shows the delamination phenomenon. The ACA also shows large cracks, left top and right bottom of Figure 11. The cracks will trap humidity and induce further degradation.

The degradation of the polymer matrix results in collapsing of the polymer structure. This further induces delamination of the circuit metallization on the chip and substrate as visualized in Figure 12. The central large particle is the Ni conductive particle. The top and bottom bright lines in contact with the distorted Ni particle are the metallization circuits. Spacing is seen to exist between the metallization and the chip (top) and glass substrate (bottom), indicating that the metallization peels off. A long term, 1000 hours, humidity test further degraded the polymer matrix. Accordingly, the bonding between the adhesive and the glass substrate is lost. Further, the bonding between polymer and the conductive metal particle becomes so weak that the particles may fall off and leave voids and debonding, Figure 13, within the matrix.

4. Conclusions

The bonding conditions needed for the anisotropic conductive adhesive can be established with the aid of thermal investigation and bonding strength evaluation. The conductive nickel particle in the ACA was deformed during the thermal compression bonding of the ACA, while the silica filler was not. The metal bump pad must have a height of at least as twice that of the conductive particle diameter to prevent electrical shorts in circuit line. The degradation of polymer matrix is responsible for the failure of the ACA upon humidity test at 85°C/85% relative humidity.

Acknowledgement

Financial support of this work from the National Science Council of Republic of China under NSC88-2216-E-006-025, NSC89-2216-E-006-003, and NSC88-2216-E-022-02 is gratefully acknowledged.
Figure 10. (a) Sketch of the short circuit behavior resulting from stacking of two conductive particles, (b) adequate thickness of bonding pad to avoid the short circuit due to stacking of particles

Figure 11. The top view of a failed ACA bonding
Figure 12. Humidity test resulted in delamination of circuit metallization

Figure 13. Humidity test resulted in the debonding between polymer matrix and conductive particle
References:


