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Reliability of adhesive joined thinned chips on flexible substrates under humid conditions

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ABSTRACT

Thin chips are an interesting option for reducing the thickness of an electronics package. In addition to the reduced size, thinned chips are flexible and can dissipate more heat than thicker ones. Joining of the thin chips can be done using several different techniques. Of these, anisotropic conductive adhesives (ACA) are an interesting option as they have several advantages, such as low bonding temperature and capability for high density interconnections. The reliability of ACA flip chip joints under thermal cycling conditions has been found to increase when thinned chips are used. However, the effect of humidity has not been fully explored. In this study the reliability of thinned chips (50 μm) under humid conditions was investigated using thin flexible substrates. Seven test lots were assembled with thinned chips using two different ACA films and liquid crystal polymer (LCP), polyimide (PI) and thin FR-4 substrates. A high humidity and high temperature test was used to study the reliability of the interconnections. A finite element model (FEM) was used to analyse the stresses in the test samples during testing. Several failures occurred during the test and significant differences between the substrates were seen. Additionally, bonding pressure was found to be a critical factor for the reliability under the humid conditions.

1. Introduction

The size of electronics products has been decreasing for many years. In consumer electronics especially, small size has become critical as more and more functionality is needed for smaller portable products. One possibility to decrease the size of an electronics package is to utilize flip chip attachments [1]. Currently mainstream flip chip technology is based on solder bumps [2,3]. However, interest in using electrically conductive adhesives (ECA) for electrical interconnections has increased since they are lead free and can be used with low-cost substrate materials. Anisotropic conductive adhesives (ACA) are ECA materials with a low concentration of conductive particles. They conduct in *z*-direction only after the bonding process.

The volume of a flip chip package can be further reduced by thinning the attached chip. This enables very thin packaging solutions. Another important advantage of thin chips is their flexibility. When silicon chips are thinned below 100 μm, they became pliant [4] and can be used in applications where they need to be bent. Thinning also allows the chips to dissipate more heat [5]. However, thin chips have certain drawbacks. They are more fragile than thicker chips. Additionally, during the thinning and dicing processes a considerable amount of stress may be induced into the chips [5–7].

In many areas of electronics the reliability of the attachments is a key issue. Thermal stresses, especially fluctuation of temperature, are known to be detrimental to many ACA flip chip packages. The reliability of thinned chips under thermal stresses has been investigated in many studies [8–11]. In these studies the thinning of the chips has been found to enhance the reliability of both solder and ACA flip chip interconnections. The reason for this is the pliability of thin chips, which decreases the stresses caused by coefficients of thermal expansion (CTE) mismatches in the package [8].

In addition to various thermal stresses, humid conditions have been found to be damaging to ACA interconnections [12–14]. Under high humidity ACA matrix absorbs water which may cause swelling and deformation. The swelling of the adhesive matrix may be marked [15] and if concurrent with thermal expansion it may cause the conductive particles to lose contact. Absorbed water may also weaken the mechanical properties of the adhesive and therefore cause failures to occur.

Although the reliability of ACA interconnections in humid conditions has been studied widely, there are only a few studies

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Table 1
Properties of the substrates.

	FR-4	LCP	PI
Thickness of base film (μm)	100	50	25
Thickness of solder resist (μm)	–	20	–
Thickness of copper tracks (with Ni/Au) (μm)	19–20	13	18
Double-sided	No	Yes	Yes
T_g (°C)	130–140	205	
CTE (below T_g) (ppm/°C)	10	16	14
Young's modulus (Gpa)	2.0	1.1	3.4
Moisture absorption (wt%)	0.1	0.04	

available on the reliability of thinned chips under humid conditions. In these studies it was seen that the thin structure decreased the reliability as opposed to the results seen under thermal conditions [15–17]. Thin and flexible products would have a wide range of applications, in which they may be subjected to humidity and may even be immersed in water. Consequently it is critical to understand the factors affecting the reliability of thinned chips under humid conditions and how the reliability may be improved.

This study investigates the reliability of thin chips under humid conditions. Seven test lots were assembled with thinned chips using two ACA films and three different flexible substrates (FR-4, polyimide (PI), and liquid crystal polymer (LCP)). To study the reliability of the assembled test lots a constant high humidity and high temperature test was used (85 °C/85% relative humidity, 5,000 h). After testing cross-sections of the test samples were studied with an optical and a scanning electronic microscope (SEM). Additionally, a finite-element model (FEM) was used to compare the stresses in the various structures.

2. Experimental

2.1. Substrates

Three different substrates were used in this study. The thickness and the structure of these substrates varied. However, all of them had copper wiring with nickel–gold coating. Detailed information of the substrates is given in Table 1.

The FR-4 substrate was single-sided and contained only one layer of glass fibre cloth. Due to its thinness this substrate was relatively flexible. The LCP substrate was double-sided. The board had a two-layer structure and had no adhesive layer between the copper and the LCP film. The board had a solder resist on both sides of the board with openings of 6 mm × 6 mm at the bonding sites. The PI board had a three-layer structure, in which the copper tracks were attached to the PI film using a few micrometres of thick adhesive film. The PI board did not have a solder resist.

Table 2
Properties of ACF used.

	ACF1	ACF2
Adhesive type	Epoxy based thermoset	Epoxy based thermoset
Film thickness (μm)	30	30/40
Conductive particle, diameter (μm)	Au coated polymer particle, 5	Au coated polymer particle, 5
Nonconductive particle, diameter (μm)	–	SiO_2, 0.8
T_g (°C)	94	108
CTE (below T_g) (ppm/°C)	91	58
Elastic modulus (MPa)	146	589
Moisture absorption (wt%)	2.0	1.9

Young's moduli and CTE values for the substrates were measured using a Thermo Mechanical Analyser (TMA). In the CTE measurements the length change of the samples was measured as a function of time. The measurements were made using a temperature range from −55 °C to 180 °C and heating rate of 3 °C/min. A stress ramp measurement with the TMA was used to determine the Young's modulus of the materials. Stress was increased at 1 MPa per minute up to 10 MPa. A constant temperature of 85 °C was used across the whole stress ramp. The measured values are given in Table 1. The glass transition temperature (T_g) and moisture absorption shown in Table 1 are from the manufacturer's data sheets.

2.2. Test chips

Silicon chips with a daisy chain interconnection pattern were used in the study. The size of the chips was 5 mm × 5 mm and they had 68 square gold bumps. The size of the bumps was 100 μm × 100 μm and their thickness was 23 μm. The pitch of the peripherally situated bumps was 250 μm. The thickness of the chips was 50 μm.

2.3. Anisotropic conductive films (ACFs)

Test samples were prepared by attaching the test chips to the substrates using commercially available anisotropic conductive adhesive films (ACFs). The thickness of the films was either 30 μm or 40 μm. With LCP and PI substrates an ACF with a thickness of 30 μm was used and with FR-4 an ACF with a thickness of 40 μm. Both ACFs contained gold-coated polymer particles of 5 μm in diameter. ACF2 was similar to ACF1 with the exception of 0.8 μm silica filler particles, which were added to the matrix to lower the coefficient of thermal expansion (CTE).

Similarly to the substrate materials, CTEs and Young's moduli of the ACFs were measured with TMA. Additionally, the T_g values of the ACFs were measured with the TMA. The properties of the ACFs are presented in Table 2.

2.4. Assembly

The test chips were assembled using a Toray FC-1000 flip chip bonder. First, the ACF film was prebonded using light pressure and low temperature. Then a chip was picked by the flip chip bonder. The bumps on the chip and the pads on the substrate were aligned and the chip was bonded to the substrate using a temperature of 50 °C and the final bonding pressure. After this a protective fluoropolymer film of 25 μm was placed between the bonding tool and the chip to protect the tool from excess ACF. The final bonding was done by pressing the tool onto the substrate and heating the ACF through the chip and the substrate. After bonding, the package was cooled to a temperature below the glass transition temperature (T_g) of the ACF while still under pressure.

Bonding time and temperature were chosen according to the ACF manufacturer's recommendation and results from earlier studies with the same materials [18–20]. A bonding pressure of 110 MPa was chosen, since it had been found to give good results for the same adhesive in other studies. This pressure was used with all the substrates. Additionally, with the FR-4 substrate two test lots were assembled using 50 MPa and 80 MPa bonding pressures. Overall seven different test lots were assembled. The test lots are presented in Table 3.

2.5. Humidity testing

The reliability of the test samples was studied using a constant high humidity and high temperature test. The test was performed