High Reliable Non-Conductive Adhesives for Flip Chip CSP Applications

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Abstract

Chip Scale Packages have been adapted for mobile phones, DVC, PC cards, PDA's and various others due to the robustness, cost effectiveness, and high reliability of CSP packages. For first level interconnection in CSP, wire bonding with encapsulation, Au stud bump by conductive adhesive, and solder bump interconnection with underfill process are mostly used. Non-conductive adhesives (NCA), widely used in display packaging and fine pitch flip chip packaging technology, are recommended as one of the most suitable interconnection materials for flip chip CSPs. NCA interconnection in flip chip assembly have many advantages such as easier processing, good electrical performance, lower cost, and low temperature processing.

In this paper, we have developed film type NCA materials for flip chip assembly on organic substrate such as FR-4 printed circuit boards (PCBs) or BT resin. NCAs are generally mixture of epoxy polymer resin without any fillers, and have high CTE values like conventional underfill materials used to enhance thermal cycling reliability of solder flip chip assembly on FR-4 boards. In order to reduce thermal and mechanical stress and strain induced by CTE mismatch between a chip and organic substrate, the CTE of NCAs was optimized by filler content. The modified NCA interconnection in flip chip CSP showed highly reliable interconnection when exposed to various environmental tests, such as thermal cycling test (-55 °C/+160 °C, 1000 cycle), high temperature humidity test (85 °C/85%RH, 1000 hours) and high temperature storage test (125 °C, dry condition).

The material properties of NCA such as the curing profile, the thermal expansion, the storage modulus and adhesion were also investigated as a function of filler content.

Flip chip assembly using modified NCA materials with material property optimization such as CTEs and modulus by loading optimized content of non-conductive fillers exhibited good electrical, mechanical and reliability characteristics, that can open wide application of NCA materials for fine pitch first level interconnection in the flip chip CSP applications.

1. Introduction

As the improvement of electronic devices proceeds on, the electronic packaging technology trends move toward lower cost, finer pitch, higher electrical performance, and better reliability in the applications including consumer electronics, mobile communication, computers and telecommunication systems. CSP (Chip Size Package) technology gains popularity as one of chip packaging candidates to meet these trends. Package design, material and process in the CSP has been changed to offer a smaller, miniaturized package with lower cost and high reliability. Fig. 1 shows the typical schematics of chip assembly (first level assembly) and board assembly (second level assembly) in the CSPs.

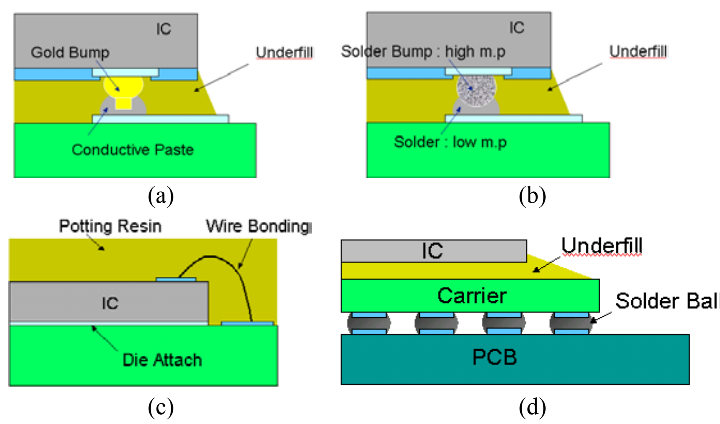


Fig. 1 Schematics of chip assembly by (a) Au stud bump with conductive adhesive, (b) solder bump, (c) wire bonding and board assembly by BGA in the CSP.

Although flip chip assembly using solder balls is in the main stream of flip chip technology, flip chip assembly using conductive adhesives such as isotropic conductive adhesives (ICAs) and anisotropic conductive adhesives (ACAs) has been under development because of their potential advantages compared with soldered bumps. [1] ~ [3] Some advantages of ACA flip chip assembly are (1) lower processing temperature (epoxy curing less than 150 °C compared with 240 °C solder reflowing temperature), (2) finer pitch interconnect (less than 50 μm pitch achieved at chip on glass (COG) technology), (3) lower cost due to less processing steps, and (4) green process (no lead, fluxes, and cleaning solvents).

NCAs, basically materials composed of an adhesive polymer resin and curing agent, have brought much attentions as an alternative for flip-chip-chip on organic boards.

For the full implementation of flip chip using NCAs, it is necessary to provide good reliability data to prove the availability of NCAs flip chip technology. The most commonly observed flip chip failure is occurred during the thermal cycling test, which is due to the thermal expansion mismatch between chips and substrates. Therefore, the problem of CTE mismatch between chips and substrates becomes serious with the NCAs flip chip assembly because of high CTE of NCAs materials. For this reason, we have developed the new NCAs that has underfill-like function. Our previous study showed that low CTE adhesive layer with high filler content had lower shear strain induced by CTE mismatch between the chip and the board under temperature cycling. [4]

The purpose of this study is to investigate the effect of added inorganic fillers on NCAs materials characteristics and reliability for the application in flip chip CSPs.

2. Experiments

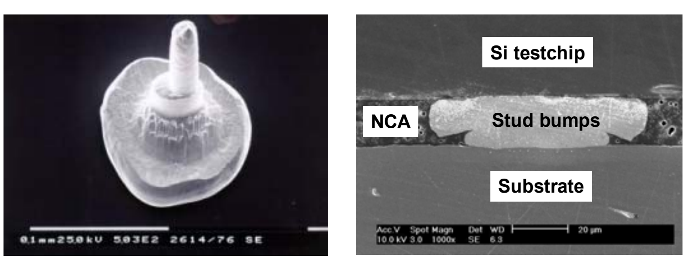
2.1 NCA Materials

Silica fillers of different content were mixed with liquid epoxy to produce NCAs of 0 wt.% ~ 50 wt.% total filler content. Surface modification of fillers was performed to get uniform dispersion of filler inside epoxy matrix of NCA composite. NCAs were formulated by mixing fillers, liquid epoxy resin, and a hardener. The mixtures were stirred and degassed under a vacuum for 3 hours to eliminate the air induced during stirring. The cured NCA samples were prepared by placing the adhesive mixture in a convection oven at 150 ^{o}C for 30 min and cutting with 0.6 mm thick dimension for the thermo-mechanical characterization such as thermo-mechanical analysis (TMA), thermo-gravimetric analysis (TGA). And the uncured NCA adhesives were also prepared to interconnect flip chip on organic substrates.

2.2 Bump formation

It is necessary to form bumps on the I/Os of the chip to be interconnected on the substrate using NCA materials.

At first, the gold stud bumps were formed on each I/O pad of test chips using a modified wire bonding machine. The bump has an acute tail, as shown in Fig. 2 (a), to provide good metal to metal contact during thermal compression. It was previously reported that an acute tail bump was more stable than a flat tail bump. [5]

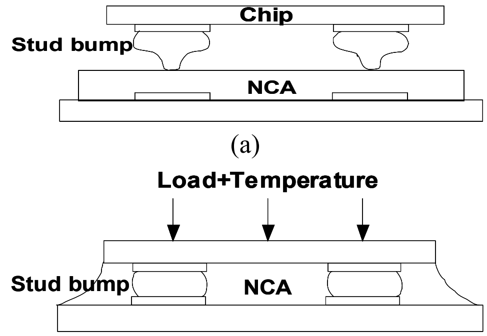


(a) (b)

Fig. 2. Scanning electron microscopy of (a) Au stud bumps formed on Al pads of test chip, (b) flip-chip bonded structure

2-3. Flip Chip Assembly using NCA

The modified NCAs in this study consist of an insulating epoxy thermosetting adhesive and non-conductive fillers. Adhesive flip chip bonding was performed using modified NCA for reliability test.



(b)

Fig. 3. Schematic of flip chip bonding process using NCA (a) NCA application and align, (b) Thermo-compression bonding.

There are three process steps for the NCA flip chip assembly on an organic substrate. First, the gold stud bumps on the chip and the I/O pads on the test substrates were aligned. And then the NCA was dispensed on the substrate to interconnect the chip. Finally, bonding pressure of 30 MPa and temperature of 150 ^{o}C for 5min was applied to bond the chip on the substrate. Thus the chip is electrically connected to the substrate via conductive stud bumps on test-chip as shown in Fig.2 (b). Non-conductive fillers do not contribute the electrical contacts. Fig. 3 shows schematic of flip chip bonding process using NCA.

2-4. Reliability Test

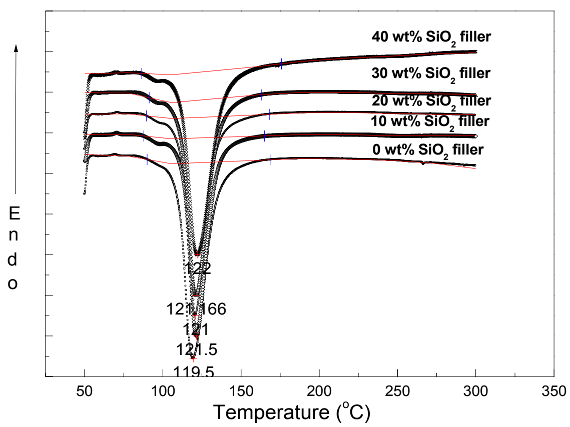
The test chip dimensions 8mm×16mm×0.6mm. It has peripheral-arrayed pads. To investigate the reliability of NCAs flip chip on an organic substrate, contact resistance of a single interconnect is the most important characteristic. The initial contact resistance was measured using a 4-point probe method and after each time interval, in-situ contact resistance was measured during the completion of reliability tests. For the reliability test conditions, 85 ^{o}C/85%RH high humidity and temperature condition for 1000 hours, 125 ^{o}C/dry high temperature/dry condition for 1000 hours, and –55 ^{o}C to 160^{o}C thermal cycling for 1000 cycles condition were adapted.

3. Results and Discussion

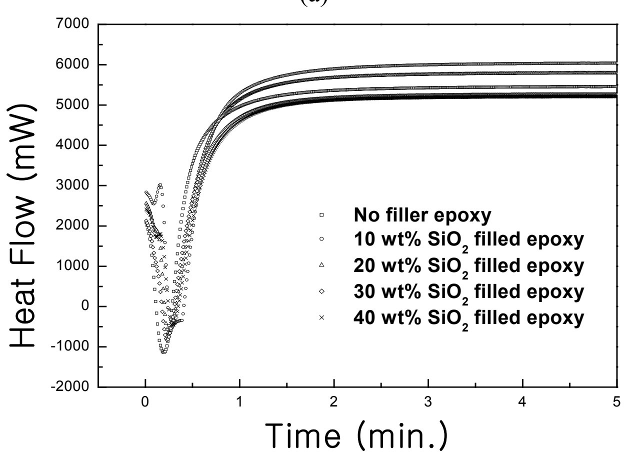
3-1. Material Characterization

3-1-1 DSC results

The DSC curves in Fig. 4 show the effect of filler contents on the curing profiles of NCA composite materials. From the dynamic scan results, similar curing behaviors of different NCA composite materials were observed. However, the increase in the filler content slightly shifted the curing onset temperature and peak temperature to the higher temperature as shown in Fig. 4 (a). For NCA materials with different silica content, isothermal scan was performed. It can be shown that the time to fully cure NCA composite with different silica content was inside 1min.



(a)



(b)

Fig. 4. DSC curves of modified NCA samples with different silica contents. (a) Dynamic scan and (b) Isothermal scan of different silica contents NCA composites.

3-1-2. TMA results

CTEs of NCA composite materials with different filler contents were measured using TMA (TA Instrument). The inflection point of thermal expansion curve is defined as TMA Tg (Tg^{TMA}). This results shows that higher filler content cause the increase in Tg^{TMA} of the cured samples due to stiffening effect of composite materials with the higher interface area between fillers and epoxy resin as discussed in DMA results. The CTE of the NCA composite below the Tg^{TMA}, defined as α1, and the CTE above the Tg^{TMA}, defined as α2, are important parameters in determining the reliability of the NCA flip chip assembly.

Table 1 indicates that the filler content has significant effect on the α1, but no noticeable effect on the α2. From the Tg^{TMA} and the CTE behaviors, higher content of filler is desirable for the reliability improvement of ACA flip chip assembly.

Table 1. Tg^{TMA} and CTE of NCA composites below and above Tg^{TMA}

NCA composite	Tg^{TMA}(°C)	α1 (ppm/°C)	α 2 (ppm/°C)
NCA with 0 wt% filler	112.62	69.9	4500
NCA with 10 wt% filler	116.53	61.9	1400
NCA with 30 wt% filler	119.77	41.3	585
NCA with 30 wt% filler	121.91	38.6	263

3-1-3. TGA result

The thermogravitational analysis was performed to evaluate the decomposition temperature of NCA composites with different content of fillers. The decomposition temperatures of three NCA composites were almost that same at 400 °C due to same epoxy resin used. The filler content in NCA composite doesn't influence on the decomposition temperature. Fig. 5 indicates weight loss increases as the filler content decreases.

Furthermore these decomposition temperatures were also similar to those of commercial underfill materials. The decomposition temperature is one of important properties for reworkable underfill used in flip chip package. [6]

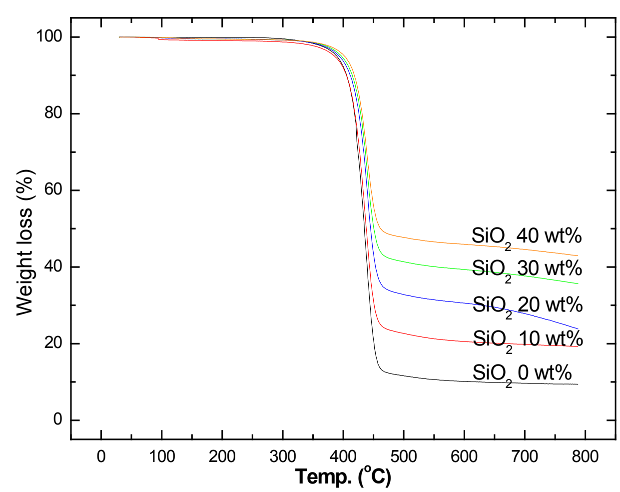


Fig. 5. TGA curves of modified NCA samples with different content fillers

3-1-4. Die shear test results

The NCA bonding adhesion between Si/SiO_2 testchip (3mm×3mm) and FR - 4 substrate was measured through die shear test.

A set of typical die shear force – displacement curves of NCA flip chip bonded test-vehicles is shown in Fig. 6 for modified NCA with different silica content. It can be seen that the shear force of test-vehicles using NCA with higher silica content is smaller than that of test-vehicles using NCA with lower silica content. This is because the modulus of NCA with high silica content is larger than that of NCA with low silica content and the relative fracture toughness of NCA with high silica content is smaller than that of NCA with low silica content.

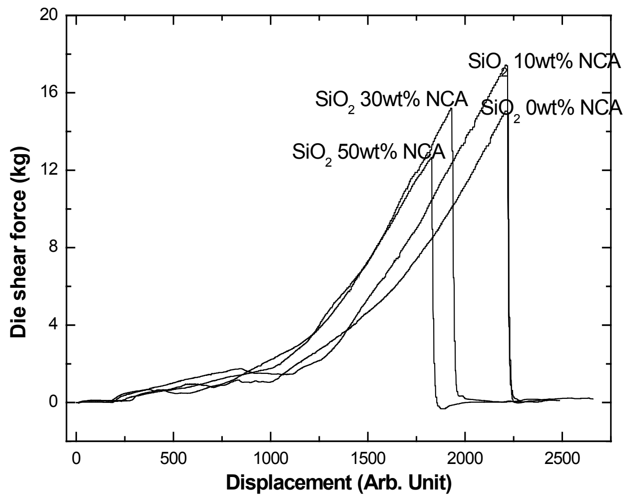


Fig. 6. Die shear force – displacement curves of NCA flip chip bonded test-vehicles

Therefore, by considering modulus & toughness, optimal silica content should be determined for better mechanical property of NCA flip chip assembly.

3-2. Reliability Test Results

From thermo-mechanical properties such as curing kinetics, CTE, thermal stability and adhesion, it can be reported optimum silica filler content filled into epoxy matrix is about 30wt%. Modified NCF including silica 30wt% was used and compared with commercial ACFs for reliability test.

Open occurrence rate was defined as the electrical open probability.

The open occurrence rate variations of flip chip assembly using modified NCA composites during 85 °C /85% relative humidity condition for 1000 hrs were shown in the Fig. 7. The open occurrence rate of modified NCA were in acceptable range of around 10% during 85 °C /85% relative humidity condition for 1000hrs when compared with with other commercial ACF for flip chip applications. No catastrophic failure was observed.

And open occurrence rate of NCA flip chip assembly was stable up to 1000hrs during 125°C/dry condition as shown in Fig. 8.

The comparison of reliability results between the 85 °C /85% relative humidity condition and the 125 °C / dry condition reveal that the increase of open occurrence rate of NCA flip chip assembly is mainly due to the moisture attack on the adhesive layer. This effect of moisture attack on open occurrence rate of NCA joint was predominant in case of high moisture absorption rate epoxy resin.

Fig. 9 shows the open occurrence rate of NCA flip chip assembly during –55°C ~ 160°C thermal shock test. The flip chip assembly using commercial ACF-B could not pass 400cycles, and the assembly using modified NCA and commercial ACF-A could pass 700 cycles. These results of thermal shock test indicate that the thermo-mechanical property of NCA composite has noticeable effect on the reliability of NCA flip chip assembly on an organic substrate. Table 2 shows the CTE values characterized by TMA.

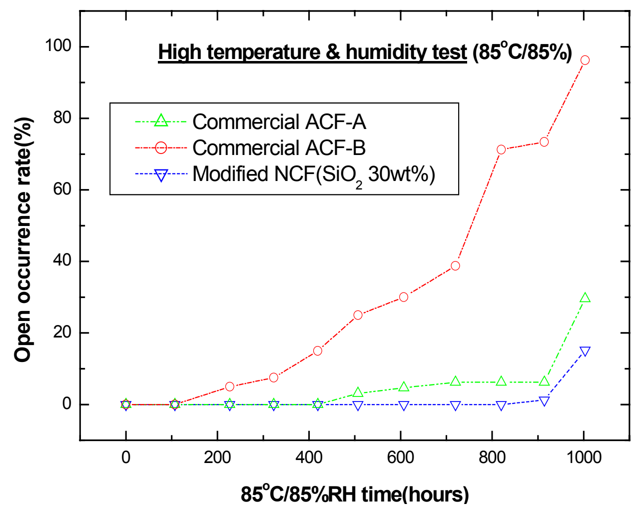


Fig. 7. Open occurrence rate of adhesive flip chip interconnects during 85 °C /85%RH test

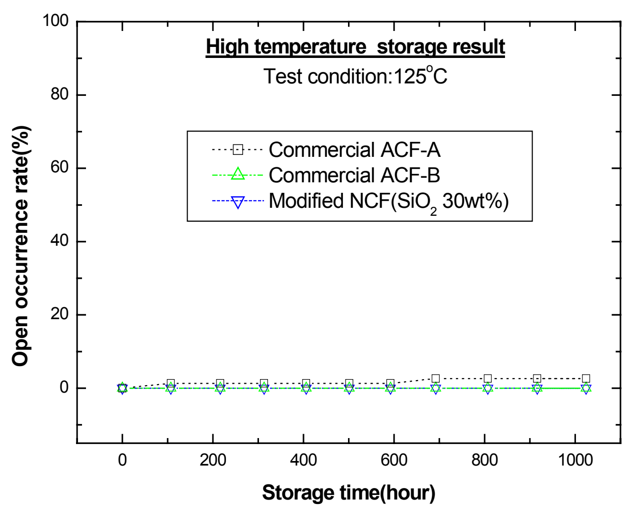


Fig. 8. Open occurrence rate of adhesive flip chip interconnects during 125°C high temperature storage test

Table 2. Tg ^{TMA} and CTE of NCA composites below and above Tg ^{TMA}

NCA composite	Tg^{TMA}(°C)	α1 (ppm/°C)	α 2 (ppm/°C)
Modified NCA	119.77	41.3	585
Commercial ACF-A	113.53	38.5	221
Commercial ACF-B	111.77	74.2	1420

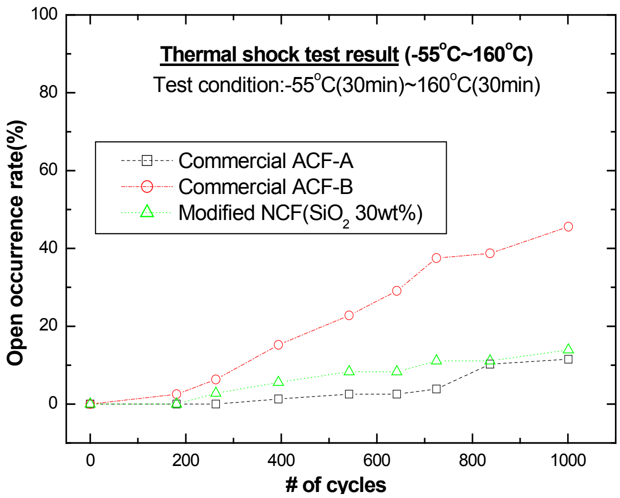


Fig. 9. Open occurrence rate of adhesive flip chip interconnects during –55°C ~ 160°C thermal shock test

From thermal shock test result and CTE data, it can be concluded that low CTE (α1, α2) NCA resulted in a better reliability of NCA flip chip assembly on organic substrate during thermal shock test. But, though two adhesive layers have the similar α1 value, adhesive layer with the lower α2 value results in a better thermal shock resistance.

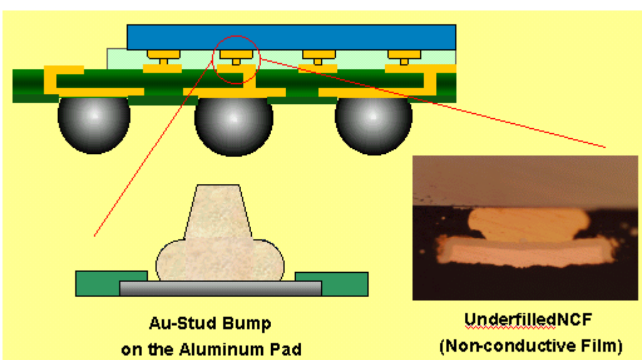


Fig. 10. Schematics of flip chip CSP using NCF and cross-section of NCF interconnection.

Fig. 10 shows the schematic draw of flip chip CSP using NCF as first level interconnection and its cross-section view of Au stud bump joint.

4. Conclusions

In this paper, the effect of non-conducting silica filler of the NCA composite materials on the curing behavior, thermo-mechanical properties, and reliability for the NCA flip chip assembly on an organic substrate was investigated for the application in flip chip CSPs. The content of non-conducting filler is a key factor which controls the basic properties of NCA composite materials such as curing profile, Tg, CTE, modulus, and adhesion and eventually the reliability of NCA flip chip CSPs. The addition of non-conducting filler does not greatly affect the curing kinetics and thermal stability. However, addition of non-conducting filler does noticeably affect CTE, modulus and adhesion.

Therefore, by considering basic material properties, optimum silica content was selected and modified NCA was formulated for reliability test.

These effects of non-conducting filler addition on the NCA material properties were verified by reliability tests. The reliability of NCA flip chip assembly using modified NCA with non-conducting filler is significantly better than that of flip chip assembly using commercial ACF.

Conclusively, the incorporation of non-conductive fillers in the NCA composite material significantly improves the reliability of flip chip CSP using NCAs materials.

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