A STUDY ON THE DYNAMIC BENDING RELIABILITY OF CHIP-IN-FABRICS(CIF) PACKAGES USING ANISOTROPIC CONDUCTIVE FILMS (ACFS) MATERIALS FOR FLEXIBLE ELECTRONIC APPLICATIONS

Seung-Yoon Jung, and Kyung-Wook Paik
Nano Packaging and Interconnect Lab. (NPIL)
Department of Materials Science and Engineering
Korea Advanced Institute of Science and Technology (KAIST)
Daejeon, South Korea
kwpaik@kaist.ac.kr

ABSTRACT
In this study, flexible Chip-In-Fabric (CIF) assemblies using anisotropic conductive films (ACFs) and cover layer structure were demonstrated. Fabric substrates were fabricated by Cu pattern lamination method with additional Electroless Nickel Immersion Gold (ENIG) metal finish before laminating onto the fabrics. Thermo-compression (T/C) bonding method was used to bond the 50µm-thick Si chip on the fabric substrates using ACFs. After T/C bonding, stable ACFs joint interconnection was formed between chips and substrates. After polymer cover layer structure was applied, the minimum bending radius before chip crack drastically decreased down to 10 mm radius. In addition, a dynamic bending test was performed to evaluate the dynamic bending reliability of the CIF assemblies, and cross-section SEM analysis and digital image correlation (DIC) method were used to analyze the bending test results.

Key words: Cu pattern-Laminated fabric substrates; Chip-in-Fabric; ACFs interconnection; Cover layer structure; Bending property; Dynamic bending test

INTRODUCTION
Smart e-textiles fabrics are considered as one of the substrates for future wearable devices. To fabricate these wearable devices, electronic components should be mechanically attached and electrically interconnected to the fabrics with patterned electrical circuits such as PCBs (Printed Circuit Boards). As a result, Si chip interconnection to fabric substrates are needed. In this regard, Chip-In-Fabric (CIF) interconnection using ACFs is one of the promising interconnection methods for fabric-based wearable devices.

For electrical interconnection, fine-pitch and flexible electrical circuits should be formed on fabrics. In the previous studies, a novel Cu pattern lamination method for fabric substrates has been introduced [1]. Cu foil was firstly attached to the B-stage adhesive films, and patterning process was followed to form electrical circuits on the adhesive films. And then, these metal circuits were laminated onto the fabrics. As a result, fabric substrates with fine-pitch and highly flexible Cu patterns have been successfully demonstrated.

ACFs are well-known film-type adhesive interconnection materials consisting of polymer resin and conductive particles. Compared with other interconnection methods such as soldering and connectors, ACFs can provide stable mechanical and excellent electrical interconnection using low temperature bonding process and flexibility. In addition, recent studies have demonstrated that ACFs interconnection can be a promising solution for flexible chip packages, because ACFs can endure both static and dynamic bending stresses [2-4]. Furthermore, by applying cover layer structure on the flip chip assembled surface, higher flexibility can be obtained [2-3]. Using ACFs materials and the cover layer structure, highly flexible Chip-on-Fabric packages can be realized.

In this study, 500µm-pitch Chip-In-Fabric (CIF) packages with a polymer layer structure were demonstrated using Cu pattern-laminated fabric substrates and ACFs interconnection materials. Fabric substrates were prepared by the Cu pattern lamination method using B-stage adhesive films. Before laminating on the fabric, electroless nickel immersion gold (ENIG) metal finish was performed on the Cu surface to prevent Cu oxidation. And 50 um-thick Si chip was bonded to the Cu pattern of fabric substrates using ACFs and a thermo-compression (T/C) bonding method. And then, the polymer cover layer structure consisting of polyimide and adhesive films was applied to the COF packages to protect the Si chip under bending deformation. First, the effects of the fabric substrates types on the ACFs joint properties such as electrical daisy chain resistance, contact resistance and peel adhesion strength will be investigated. In addition, 4-point bending test was performed to investigate the effects of the fabric substrates types and cover layer structure. Finally, a dynamic bending test was performed to evaluate the dynamic bending properties of CIF packages with the polymer cover layer structure using two types of fabric substrates.

EXPERIMENTAL

A. Materials and Test vehicles

50µm-thick Si chips were designed in a peripheral array format with a size of 10 mm x 10 mm. There were Cu/Ni/Au bumps with a size of 300 µm x 300 µm x 12 µm on the I/O pads having 500 µm pitch.

To fabricate the fabric substrates, 12 um-thick Cu foil, 40µm-thick B-stage adhesive film and commercially available polyester/rayon woven fabrics were used.

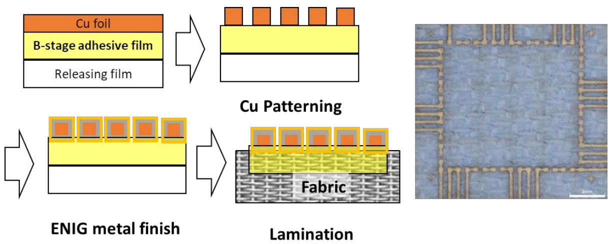


Figure 1. Schematic diagrams of fabric substrates fabrication process and the actual fabric substrate with metal patterns

ACFs were consisted of epoxy-based polymer resin and 20 µm diameter Au/Ni coated polymer balls as conductive particles. ACFs thickness was 30µm, and the conductive particle contents were 20 wt %.

B. Fabric substrates fabrication

Fabric substrates were prepared using Cu pattern lamination method as previously described in Fig. 1.[1] After Cu circuit was formed on the B-stage adhesive film, ENIG metal finish was performed on the Cu electrodes to prevent Cu oxidation, and then ENIG/Cu circuits on the adhesive films were laminated onto the fabrics by a vacuum lamination method. In the fabric substrates, there were one daisy-chain resistance test pattern and 4-point Kelvin structures to measure the continuity of all patterns and single ACFs joint contact resistances.

C. Fabrication of Chip-on-Fabric packages with a polymer cover layer structure

To fabricate flip-chip COF packages, ACFs were laminated onto the thin Si chip and bonded onto fabric substrates using a thermo-compression (T/C) bonding method at 210 ºC for 10 seconds at 1MPa.

After COF bonding, a polymer cover layer was applied using 135µm thick polyimide (PI) cover films and cover adhesive films with various thicknesses. Cover films were laminated onto the surface of the Si chip using a roll laminator, and then vacuum lamination was performed at 110 ºC for 5 minutes at 0.14 MPa nitrogen gas pressure.

D. ACFs joint properties characterization

For electrical property characterization, daisy chain resistances and contact resistances were measured. And 90-degree peel adhesion test was also conducted to measure the adhesion strength of CIF packages by pulling fabric substrates at 10 mm/min. speed.

ACFs joint morphology of CIF packages was observed by optical microscope (OM) and Scanning Electron Microscope (SEM).

E. CIF Bending property evaluation

Static bending property of various CIF packages was evaluated by 4-point bending test as shown in Fig. 2. The minimum bending radius was measured before chip fracture.

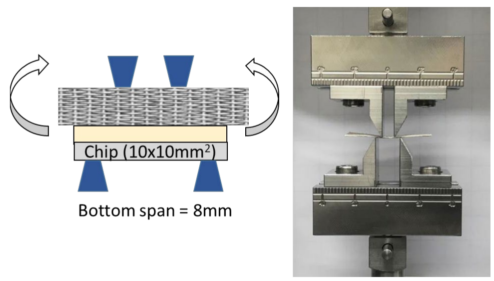


Figure 2. 4-point static bending test of CIF packages

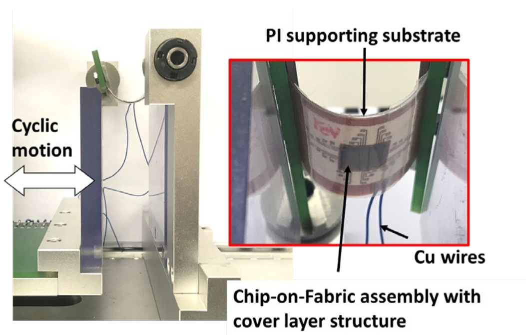


Figure 3. Dynamic bending test setup of CIF packages

And a dynamic bending test was conducted to evaluate the ACFs joint reliability under cyclic bending deformation as shown in Fig. 3. The bending radius was fixed at 12 mm, and the test speed was 60 cycles/min. Two types of the fabric substrates were used in COF packages having the same polymer cover layer structure. During bending tests, in-situ daisy chain resistances were measured at the bent state per every 5 cycles.

Cross-sectional SEM images were observed for failure analysis. Digital image correlation (DIC) method was used to measure the bending strain of the CIF packages [4]. Encapsulated-CIF packages were grinded without any external mold, and then silica speckle was sprayed onto the grinded surface. SEM images of the CIF joints before and after 12 mm rod bending were taken. And the bending strains were calculated by measuring the speckle displacement on the SEM images.

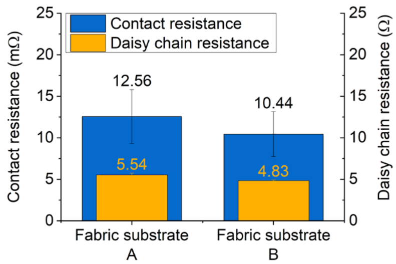


Figure 4. Daisy chain and contact resistances of CIF assembly using various fabric substrates

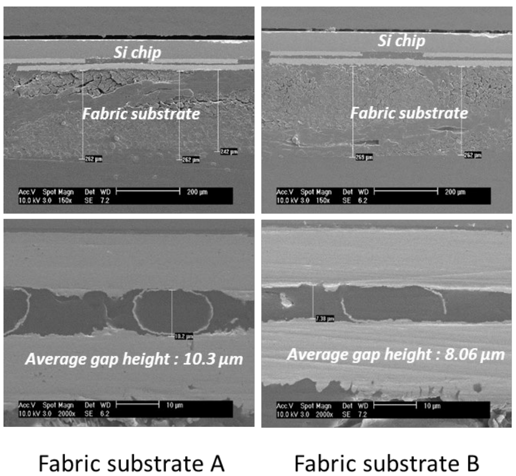


Figure 5. ACFs joint morphology of CIF assembly using two types of fabric substrates

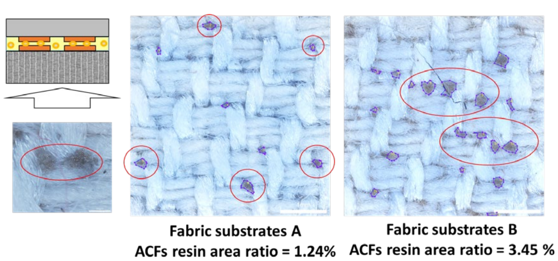


Figure 6. Optical microscope images of the fabrics at the backside of the CIF assembly

RESULTS AND DISCUSSION

F. ACFs joint morphology and electrical properties of CIF joints

Fig. 4 shows the contact and daisy chain resistances of the CIF packages using two types of fabric substrates. Fabric substrates A showed higher resistances than the fabric substrates B. This resistance differences were due to the gap height difference, as shown in cross-section SEM images of Fig. 5.

In addition, ACFs resin was observed at the backside of the fabric substrates as shown in Fig. 6. This suggested that the ACFs resin permeated into the pores of fabric substrates during the T/C bonding process.

When the fabric substrates were fabricated, the resin of the B-stage adhesive films flowed into the fabric materials [1]. Therefore the surface of the resulting fabric substrates had porous structure as shown in Fig. 7. Since the fabric substrates B had more porous surface than substrate A, the ACFs resin permeation may be easier. Since the gap height of the ACFs joint was mainly determined by the ACFs resin flow behavior, the gap height difference can be explained by the degree of ACFs resin permeation into the fabrics.

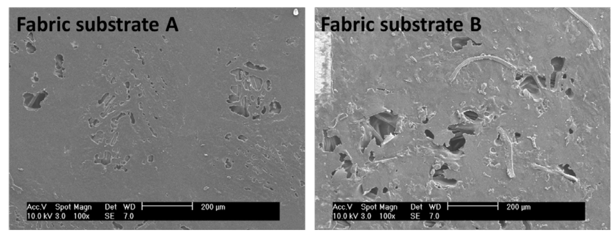


Figure 7. SEM image of the top surface of two fabric substrates

G. Effects of polymer cover layer thickness on the static bending property of the CIF packages

Fig. 8 shows the minimum bending radius of the CIF packages as a function of total cover layer thicknesses. Without cover layer structure, CIF packages showed over 20 mm minimum bending radius. However as the cover layer thickness increased, minimum bending radius gradually decreased down to 7.4 mm for CIF A and 9.5 mm for CIF B.

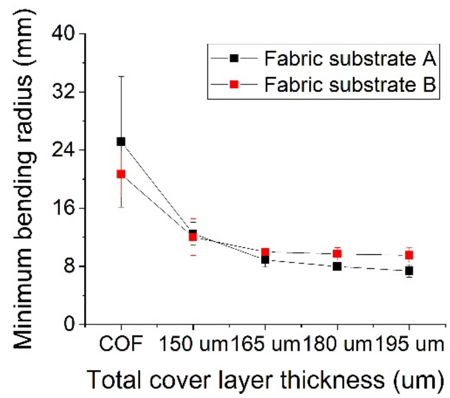
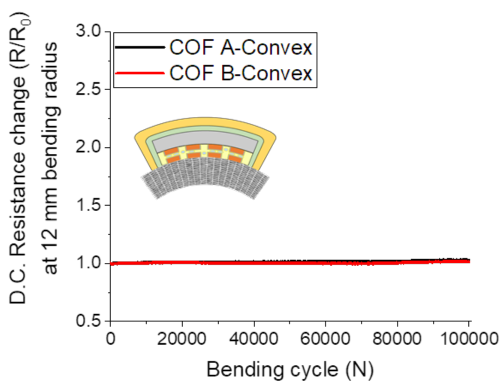


Figure 8. The minimum bending radius of the COF assemblies using various fabric substrates and polymer cover layer thicknesses

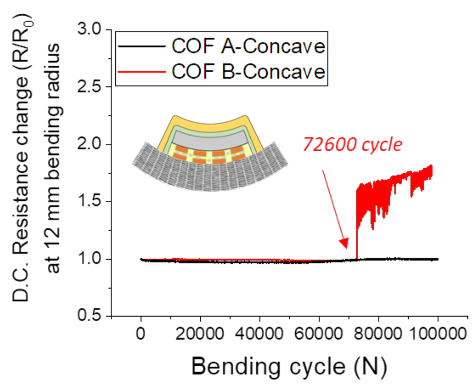
According to the previous studies on the Chip-in-Flex (CIF) packages, cover layer structure on the Si chip reduced the bending stresses on the chip by shifting neutral axis position towards the chip center [2]. As a result, thick cover layer structure led to better bending property of CIF packages. In addition, the encapsulated- CIF A showed better bending properties, which might be presumably due to the lower modulus of the fabric substrate.

H. Dynamic bending fatigue test results

Fig. 9 shows the daisy chain resistance changes with increased bending cycles. For a convex bending, both encapsulated CIF packages showed stable daisy chain resistances up to 100,000 cycles. On the other hand, for a concave bending, encapsulated- CIF B showed about 80% increase of the joint resistance, while encapsulated- CIF A showed no resistance increase.



(a)



(b)

Figure 9. Dynamic bending test results of encapsulated-COF A & B packages at (a) convex and (b) concave bending conditions

Fig. 10 shows the cross-section SEM images of ACFs joint before and after the dynamic bending test for both convex and concave bending conditions. For the convex bending case, no ACFs joint damage was observed. However, for the concave bending condition, ACFs resin delamination was observed for encapsulated CIF B. Because cyclic tensile stress was applied to the ACFs joint, the concave bending test caused ACFs joint damage especially for CIF B.

To analyze the concave bending test results, bending strain on the ACFs joint was measured using SEM-DIC method as shown in Fig. 11. Encapsulated CIF B showed higher bending strain than encapsulated- CIF A, which was consistent with the 4-point static bending test results. As a result, better bending reliability was obtained when the fabric substrates A were used.

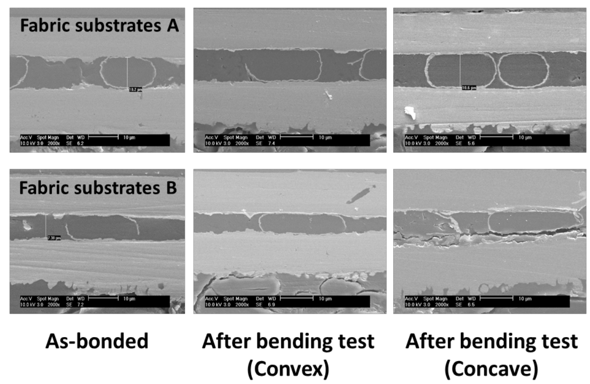


Figure 10. SEM images of ACFs joint after 100,000 cycle dynamic bending test

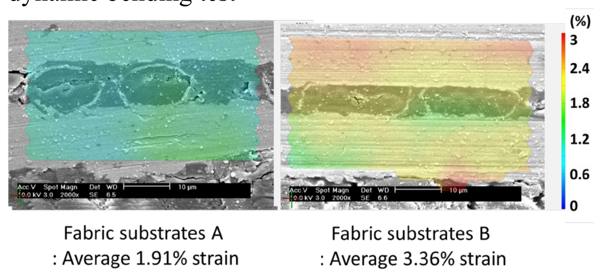


Figure 11. Bending strain mapping results of the two encapsulated-COF packages by the DIC analysis

CONCLUSION

In this study, a novel Chip-In-Fabric assembly was demonstrated using Cu pattern-laminated fabric substrates and ACFs materials. After T/C bonding, ACFs joint was well formed between chip and fabric substrates. During the fabric substrates fabrication, the resin of the B-stage adhesive films permeated into the fabrics, and some part of the fabric substrates had porous structure. Therefore, the amount of ACFs resin permeated into the fabric substrates determined the final ACFs gap height and resulting electrical resistances.

Flexible COF packages were achieved by applying the polymer cover layer structure on top of flip-chip surface. After 195 um-thick cover layer structure was applied, encapsulated-CIF packages A and B showed the minimum bending radius of 7.4 mm and 9.5 mm respectively. In addition, encapsulated-COF packages A showed stable joint resistance after 100,000 cycles of dynamic bending at 12 mm bending radius for both convex and concave bending conditions.

As a result, highly flexible Chip-In-Fabric assemblies were achieved using ACFs materials, fabric substrates A, and 195µm cover layer structure. This encapsulated-CIF packages can be a promising solution for fabric-based wearable devices.

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