Novel Nanofiber Anisotropic Conductive Films (ACFs) with coupled conductive particles for Ultra Fine Pitch Electronic Packaging Applications

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ABSTRACT

Nanofiber ACFs composed of adhesive resins, conductive particles, and nanofibers were demonstrated for less than 20 um ultra fine pitch COF and COG packages. Conductive particles containing PAN nanofibers were fabricated using an electrospinning method, and then nafofiber ACFs were successfully fabricated by laminating nanofibers and Nonconductive films(NCFs) together. Nanofiber ACFs show excellent electrical conduction and 100% electrical insulation ratio at the 20 um pitch COF applications, because nanofiber coated conductive particles have excellent electrical insulation and limited movement during ACF assembly. The novel nanofiber ACFs break the technical limitation of ACFs technology at ultra fine pitch interconnection, and also provide various new applications such as solder ball containing nanofiber ACFs.

1 INTRODUCTION

Recently, electronic packages have become finer pitch to satisfy the needs of electronics that have higher functions, lower power consumption as well as higher density [1-3]. The most promising technology of fine pitch electronic packaging is adhesive interconnection using conductive adhesive materials (e.g. anisotropic conductive films, ACFs) [4-5]. The ACFs are composed of conductive fillers and curable polymer resins thereby providing electrical path and adhesion between components. The adhesives have been widely used in display modules, especially in forms of chip-on-glass (COG), chip-on-film (COF), film-on-board (FOB), and flip-on-glass (FOG) because they have advantages such as finer pitch capability, lower process temperature (below 200 ^{o}C), and simpler process (no underfill) [6]. However, the use of ACFs for ultra fine pitch packages, below 30 um pitches, has been limited because of their unstable insulation electrical properties. During ACF bonding process, polymer resins having conductive fillers flow to fill out bonding area. As a result, the fillers may not be captured in fine pitch interconnections causing open circuit, or the fillers may be agglomerated between fine patterns due to the filler movement resulting in an electrical short circuit as shown in Fig. 1. Although many researchers have been conducted to solve these problems, it is difficult to completely solve the problems by controlling resin viscosity.[7]. In addition, insulation layer coating on conductive fillers can not completely solve the problem in ultra fine pitch applications.

In this study, novel nanofiber ACFs are investigated to obtain stable electrical performances in ultra fine pitch applications. Nano polymer fibers have outstanding characteristics such as large surface area to volume ratio and excellent mechanical strength [8]. And electrospinning is one of the effective methods to produce polymer nanofibers which can be applied in filters, sensors, nanocomposite materials, and biomaterials [9-13]. Fig. 2 shows the electrospinning set up. When an electrical potential is applied between a polymer droplet of a syringe needle and a target, the charged droplet results in a shape of Taylor cone and a jet of the electrospinning starts to form nanofibers at above the critical voltage (critical voltage means the electric force that overcomes the surface tension of the droplet) [14].

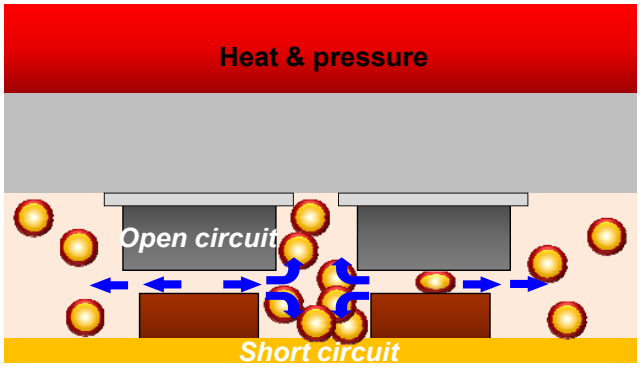
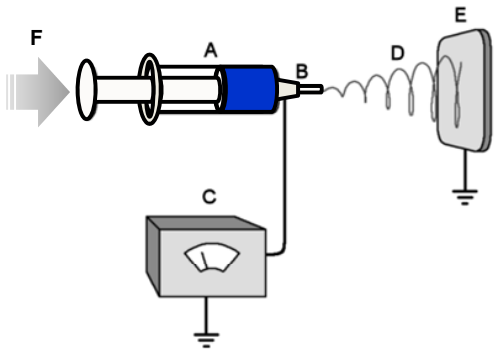


Fig. 1. Issues in ultra fine pitch electronic packages using conventional ACFs



A: syringe, **B:** needle, **C:** high voltage power supply, **D:** nanofibers, **E:** collector units, and **F:** pump

Fig. 2. Electrospinning set up for polymer nanofiber formation

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In this study, nanofiber ACFs are suggested and demonstrated as shown in Fig. 3. Nanofiber ACFs that have randomly distributed nanofibers containing conductive particles in non-conductive film (NCF) resin. There are specific requirements in nanofiber. (1) Nanofibers should be thermally stable at bonding temperature without decomposition or melting. (2) Nanofiber polymer coated on the conductive particles must be easily broken under the interconnection area to provide stable conduction (e.g. chip bump-conductive particle-substrate electrode of COF structures), whereas their initial nanofiber structures should be maintained to guarantee good electrical insulation property.

Considering these requirements, Polyacrilonitrile (PAN) was selected as a polymer material. Among electrospinning parameters, PAN concentration directly affects the PAN nanofiber diameter [15]. Therefore, prior to demonstration of nanofiber ACFs, the optimal PAN concentration was studied. Then, the structural effects of different PAN nanofiber ACFs on electrical properties of COF packages were investigated.

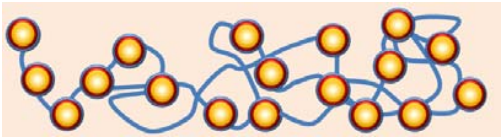


Fig. 3. Nanofiber ACFs of randomly distributed nanofibers containing conductive particles in NCF resin

2 EXPERIMENTS

2.1. Materials

Polyacrylonitrile (PAN, Mw = 150000), N,N-Dimethylformamide (DMF), and conductive particles, metal coated polymer balls of 3 um diameter were used for an electrospinning method. Adhesive materials, anisotropic conductive film (ACF) having conductive particles of 3 um diameter by 23 wt% and (nonconductive film) NCF were prepared. Both ACF and NCF adhesives contained thermosetting, thermoplastic epoxy, and curing agent.

2.2. Fabrication of nanofiber ACFs

In electrospinning process, voltage of 8 kV was applied between the syringe containing PAN solution and the target, and the solution was pumped at 1 uL/min at the same time. The needle diameter was 200 um and working distance was 15 cm. Nanofibers were fabricated by electrospinning the polymer solution composed of 10 wt% of PAN solution with 20 wt% of conductive particles. The fabrication procedures of nanofiber ACFs were described in Fig. 4. Nanofiber ACFs were made by laminating NCFs on both sides of PAN nanofibers having conductive particles, then they were laminated in a vacuum laminator at 75 ^{o}C for 1 min under 80 psi.

2.3. Characterization of electrical properties of nanofiber ACFs

The electrical properties of nanofiber ACFs were analyzed in ultra fine pitch COF packages having 20 um pitch whose pattern space is only 7 um. The chip and substrate have four Kelvin structures for the bump contact resistance measurement and four insulation patterns for the insulation resistance measurement between 24 nearby bumps as shown in Fig. 5 (a) and (b).

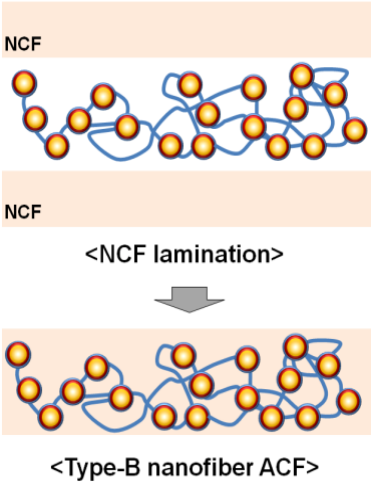
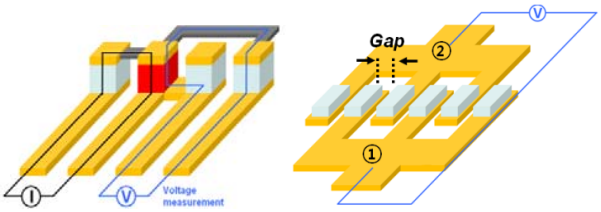


Fig. 4. Fabrication procedures of nanofiber ACFs



(a) (b)

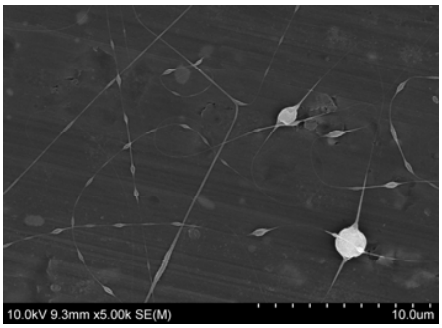
Fig. 5. Electrical test patterns of fine pitch COF packages (a) contact resistance pattern and (b) insulation resistance pattern

3 RESULTS AND DISCUSSION

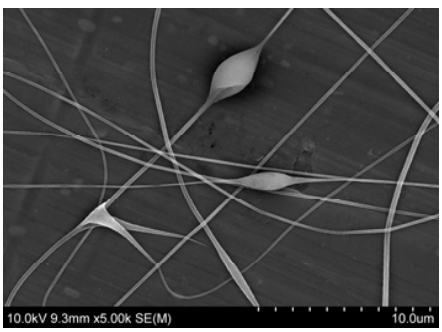
3.1. PAN nanofiber formation by electrospinning

There are many affecting factors on nanofiber morphology such as polymer solution concentration (viscosity), applied voltage, pump rate of polymer solution, needle diameter, working distance from needle to target, solution conductivity and so on. Generally, PAN nanofiber diameter increases and nanofiber morphology becomes uniform as the polymer concentration increases in electrospinning process [15]. As shown in Fig. 6, the PAN nanofiber morphology became uniform and beads were disappeared as PAN content increased from 4 wt% to 10 wt%. About 430 nm diameter of bead-less uniform PAN nanofibers (Type-A nanofiber) could be produced. Fig. 7 shows the PAN nanofibers containing conductive particles inside the fibers (Type-B nanofibers) and the average fiber diameter was about 450 nm.

It is expected that the conductive particles captured by nanofibers cannot easily flow out from bonding area, because the nanostructures can effectively limit the particle flow ability at increased temperature. Moreover, very thin polymer layer covering conductive particles, below 200 nm, can be easily broken at a joint area under bonding pressure. Therefore, conductive particles can provide stable electrical conduction between chip bumps and FPC electrodes, and enhanced electrical insulation between bumps.



(a)



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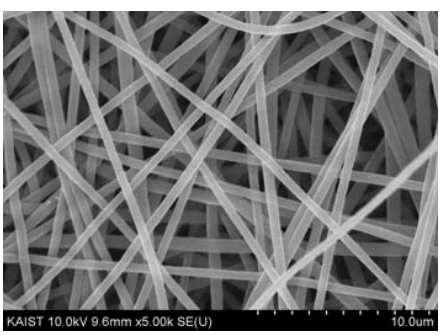


(c)

Fig. 6. PAN Nanofiber morphology as a function of PAN concentration of (a) 4 wt%, (b) 7 wt%, and (c) 10 wt%

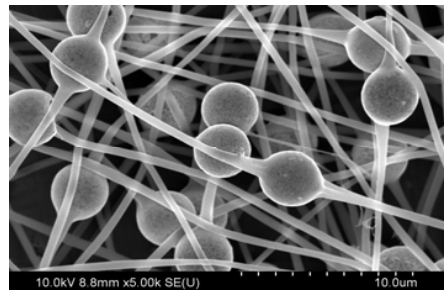


Fig. 7. Nanofiber morphology of PAN nanofibers containing conductive particles

3.2. Demonstration of nanofiber ACFs

The cross-sectional SEM image of nanofiber shown in Fig. 8 proves that metal coated polymer balls of 3 um diameter were well coated with PAN nanofibers. The coating layer was much thinner than particle diameter.

To investigate the effects of PAN nanofiber thickness and nanofiber structure on electrical performances, nanofiber ACFs were fabricated. As explained in the 2.2, adhesive films were laminated on top and bottom side of nanofibers, and then the cross-sectional morphology of ACFs was observed. Conventional ACF and nanofiber ACFs were quenched in a liquid nitrogen and broken to observe the morphology. As shown in Fig. 9 (a), the conductive particles of conventional ACF were found at a whole adhesive area. However, the conductive particles coated with PAN nanofibers ACF were located in the middle of the ACF resin. It can be expected that nanofiber ACFs may show excellent electrical performances in ultra fine pitch COF packages.

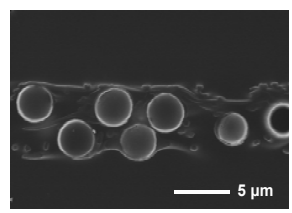
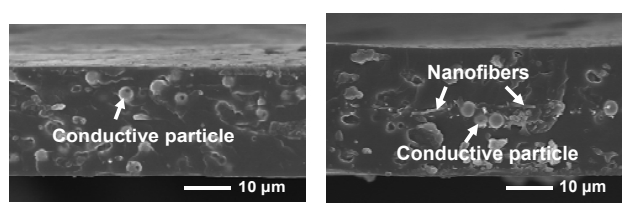


Fig. 8. Cross-sectional SEM images of nanofiber



(a) (b)

Fig. 9. Cross-sectional SEM images of (a) Conventional ACF and (b) nanofiber ACF

Nanofiber effects on electrical properties of fine pitch COF packages were investigated in terms of bump contact resistances and insulation resistances. The bump contact resistances of conventional ACF and nanofiber ACFs were $4.31 \pm 0.46 m\Omega$ and $4.45 \pm 0.5 m\Omega$ respectively. It was found that the thin PAN polymer layer coated on conductive particles of

nanofiber ACF didn't obstruct the electrical conduction between bumps and metal electrodes. More than 10^8 Ω insulated circuit ratio of conventional and nanofiber ACFs are 70% and 100% respectively. Nanofiber ACF showed excellent insulation property, because the PAN nanofiber covered conductive particles have excellent insulation-ability between particles as well as reducing particle's movement. As a summary, nanofiber ACFs whose conductive particles covered with nanofiber is the best promising candidate for highly reliable fine pitch COF package applications.

In addition, not only metal coated polymer balls, but also solder balls like Sn58Bi solder balls can be also used as conductive particles. Fig. 10 shows the electrospun PAN nanofibers with Sn58Bi particles. It was observed that the Sn58Bi solder balls covered with nanofibers were successfully wetted between bumps and metal electrodes, and showed stable electrical performances in terms of contact resistances and insulation resistances.

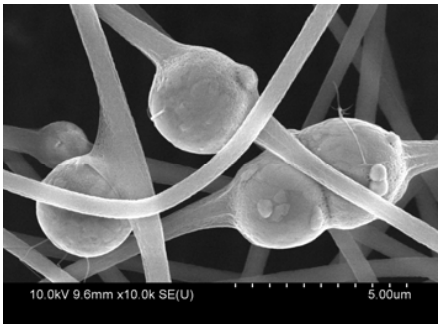


Fig. 10. Sn-Bi solder coated with PAN nanofiber

4 CONCLUSION

Nanofiber ACFs for ultra fine pitch COF packages were demonstrated. Electrospinning method was adapted to make PAN nanofibers. When voltage was applied from the needle of a syringe having 10 wt% of PAN solution to the target, the uniform nanofibers were formed. Nanofiber ACFs were fabricated by laminating NCF on top and bottom side of nanofiber in vacuum laminator at 75 ^{o}C. Nanofiber ACFs showed stable contact resistances with 4 mΩ that was similar values to that of conventional ACF. In addition, nanofiber ACFs also showed 100% insulation property compared with 70% insulation circuit ratio of conventional ACFs at 20 um pitch COF, because nanofiber coated conductive particles were electrically insulated and limited particle movement during ACF assembly. In addition, Sn58Bi solder could be also coated with PAN nanofibers using an electrospinning method, and it also showed stable electrical performances in terms of contact resistances and insulation resistances.

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