Electrically Conductive Polymer Composite Dispensing Process for EMI Shielding Structure

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Abstract

Electro Magnetic Interference (EMI) shielding structure with low cost and high performance is proposed. Conductive polymer composite is formulated with metal based filler and silicone polymer and solvent. The liquid composite material can be easily dispensed through the low pressure injection nozzle and cured to the conformal structure with high aspect ratio. High electro conductive polymer composite dispensing process is developed to build a conformal structure for the EMI shielding of PBA(Printed Board Assembly). In order to increase electrical conductivity of composite material, Ag coated copper is adopted for conductive filler material and dendrite structure is applied to reduce content ratio of the conductive filler in the composite material. An EMI shielding structure is designed to cover the exposed surface of the chip package and modified for the shielding module containing chips and electrical elements on the PBA. The wall thickness of shielding layer is under 0.6mm and aspect ratio is lower than 2.0. The conformal structure is fabricated by dispensing process with side slot nozzle and viscoelastic behavior of composite material maintains the vertical thin wall structure. EMI shielding performance is verified by measurement of chip level EMI shielding test procedure developed in this study.

Introduction

Electro Magnetic Interference (EMI) shielding has been a major technical issue especially in consumer electronics devices due to the drastic increase of packing density of chip assembly. Metal based shielding structure like stainless steel Shield Can is currently widely used even though it is expensive and requires complicated fabrication process and multiple vent holes for convection cooling and dispensing sealing agent for chip under filling [1]. Conductive polymer composite has been widely investigated because of simple fabrication and application for the flexible device [2]. As a filler material, silver is widely adopted for the conductive composite due to high electrical conductivity and anti-oxidation characteristics. Alternatively, carbon based conductive fillers like single walled and multi walled carbon nanotubes and graphene have been studied to replace metallic fillers [3] [4]. The carbon based filler has lower electrical conductivity than metal fillers and needs high percentage of the composite. Kwon et al [5] synthesized flexible adhesive shields made of micro scale silver flakes (Ag flakes), multi-walled carbon nanotubes decorated with nano scale silver particles (nAg-MWNTs) and nitrile butadiene rubber (NBR) for high conductivity. In this study, silver coated copper is adopted for high conductivity and low material cost.

Chip Level EMI Shielding Structure

Figure 1 shows a cross section of EMI shielding in a chip package. A conventional Shield Can consists of frame and cover and the thickness is about 0.2 mm. The frame is attached to Printed Circuit Board (PCB) by mounting device and heat treatment at more than 240℃. The proposed conformal shielding structure is shown in Figure 1. Insulation layer is placed at the side of the chip package in order to insulate shielding layer from BGA(Ball Grid Array) underneath the package. Thin shielding layer is coated on the outer surface of the chip package to obtain compact and high density of the chip package on the PBA.

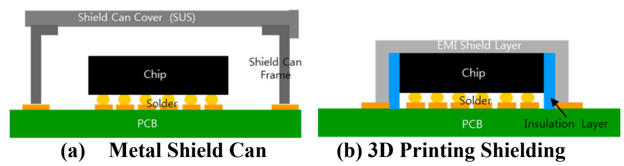

Figure 1. EMI Shielding Structure for a Chip Package

Shielding Mechanism

Electromagnetic wave propagation through a material can be described using power coefficients of transmissivity (T), reflectivity (R) and absorptivity (A) as shown in Eq. (1) [6]. The coefficients T and R can be measured using a network analyzer, and A can be obtained using Eq. (2) [7]

$$T + R + A = 1 \quad (1)$$

$$T = \frac{P_T}{P_I} = |S_{21}|^2,\ R = \frac{P_R}{P_I} = |S_{11}|^2,\ A = \frac{P_A}{P_I} \quad (2)$$

Where P_I is the incident power, P_T is the transmitted power, P_R is the reflected power and P_A is the absorbed power of electromagnetic wave. S_{21} and S_{11} are the S parameters from the network analyzer. S_{21} was obtained by the intensity ratio of transmitted to incident electromagnetic waves. S_{11} was determined by the intensity ratio of reflected to incident electromagnetic wave. A total shielding effectiveness (SE_{Total}) is defined by sum of reflective shielding effectiveness (SE_R) and absorptive shielding effectiveness (SE_A) as shown in Eq. (3) [5]

$$SE_{Total} = -10\log(1-R) - 10\log\left(\frac{T}{1-R}\right) = SE_R + SE_A \quad (3)$$

SE_{Total} can be modelled using Eq. (4) for materials with $t/\delta \geq 1.3$ (electrically thick materials) [8]

$$SE_{Total} = 20\log(\frac{Z_o \delta \sigma}{2\sqrt{2}}) + 8.68\frac{t}{\delta} \quad \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \quad (4)$$

where t is the thickness of the shield material, δ is the skin depth, Z_0 is the impedance of free space (120π), σ is the electrical conductivity, f is the frequency of electromagnetic wave, μ is the magnetic permeability of the shield. This equation shows a logarithmic relationship between the conductivity and shielding effectiveness

Conductive Polymer Composite

Selection of filler material and connecting structure between the filler particles are the key factors for high electrical conductivity of conductive polymer composite. Silver and carbon based conductive filler are considered for filler material and fabricated to a film type sample to measure the shielding effectiveness and electrical conductivity. The shielding effectiveness is evaluated by a measurement system consist of two port network analyzer and a coaxial holder designed according to ASTM D4935-10 and the electrical conductivity is acquired by four point probe method.

As a filler material, MWCNT (Multi-Walled Carbon Nanotube) and graphene and Ag coated Cu and spherical Ag flake are formulated for the composite material and fabricated to the films for measuring the electrical conductivity and shielding effectiveness as shown in Figure3. Carbon based materials have low electrical conductivities under 1.0×10^2 S/m and the shielding effectiveness are under 20dB. In order to increase the electrical conductivity, weight percent of CNT and graphene is increased in the conductive polymer composite material but viscosity of composite material becomes too high for dispensing process.

Silver is widely adopted as a filler material for liquid conductive composite material. However, silver is very high priced material and needs too high weight percent of the composite for the high electrical conductivity.

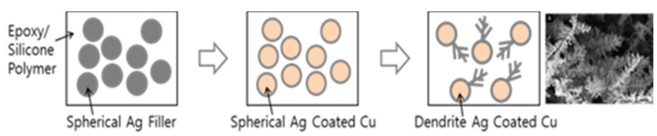

Figure 2. Dendrite Ag Coated Cu dispersion with Silicone

Silver coated copper is selected for a filler material to lower the cost of material in this study. A dendrite structure electrically connecting spherical Ag coated Cu flake each other is applied to reduce filler content ratio as shown in Figure 2. Silicone polymer is formulated with filler and cured by heat. The specific solvent material is added to decrease viscosity for dispensing process. The formulation of composite material is optimized for the EMI shielding. In case of metal, Stainless steel alloy applied to the conventional Shield Can is measured to 1.0×10^5S/m and 60dB. Ag paste filler is measured to 1.0×10^6 S/m higher than stainless steel. The silver coated copper filler has conductivity between 10^4S/m and 10^5S/m and shielding effectiveness is about 50dB. The shielding effectiveness of material can be predicted by Eq.(4). Figure 3 shows that calculated result is in accordance with the measured. The skin depth of silver coated copper filler composite is 0.05 millimeter at 30MHz. The skin depth has a maximum value at the lowest frequency in predetermined range (30MHz ~ 1GHz). The thickness of shielding layer should be more than 0.2 millimeter. Magnetic permeability is very low and the absorption of EMI is negligible.

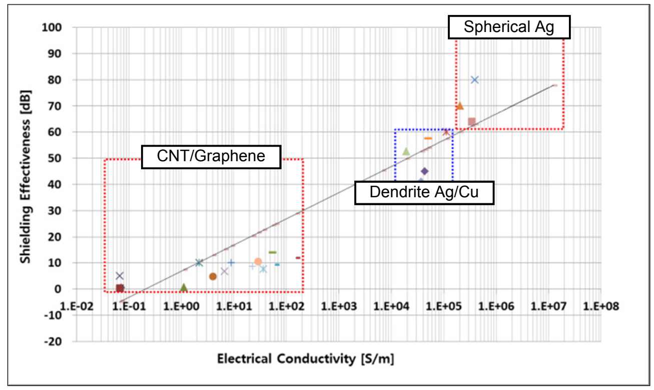

Figure 3. Shielding Effectiveness vs Electrical Conductivity

Dispensing Process

A dispensing process has been developed for fabricating the suggested structure as show in Figure 4. Different from the conventional nozzle, a specific nozzle with narrow side slot is designed to build a vertical thin wall layer for the chip package. Fluidic impedance matching between the bottom opening and side slot is carefully considered and dimensions of nozzle are optimized for the extrusion process at side direction of nozzle. High viscosity and thixotropic characteristics of the composite material is required to maintain the thin wall structure before curing process. The measured viscosity of composite material is about 200,000 centipoises and thixotropic index is more than 5.0. Figure 5 shows the result of building structure. The wall thickness of shielding layer is under 0.2mm and the height of the wall is more than 1.0mm.

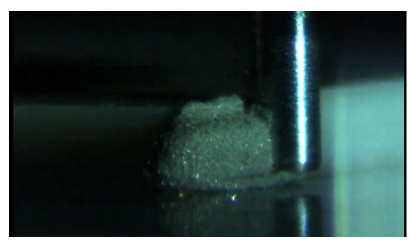

Figure 4. Dispensing Process with Side Slot Nozzle

The shielding layer on the top surface of the chip package is coated by the conventional dispensing process and the viscosity of the composite material is less than 2000 centipoises.

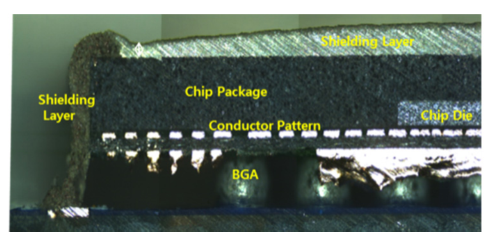

Figure 5. Cross Sectional view of Build Structure

The insulation layer is eliminated because there is no capillary flow at the gap of chip package and PCB due to the high viscosity of the composite material.

Shielding Effectiveness Measurement

EMI shielding performance is evaluated by shielding effectiveness and the experimental apparatus for the suggested the shielding structure is shown in Figure 6. The two kinds of PCB including antenna are designed to generate electrical field (P_z) and magnetic field (M_x, M_y). Figure6 shows that source signal is applied by network analyzer and the frequency of signal is scanned from 30MHz to 1GHz. The transmitted waves into the shielding structure are measured by sensors in TEM (Transverse Electromagnetic Cell). The shielding performance is evaluated by insertion loss (S_{21}). The S_{21} is obtained by the intensity ratio of transmitted to incident electromagnetic waves and the Shielding Effectiveness (SE) is defined by Eq.(5).

$$SE(S_{21}) = S_{21}(Without\ \ Sample) - S_{21}(with\ \ Sample) \quad (5)$$

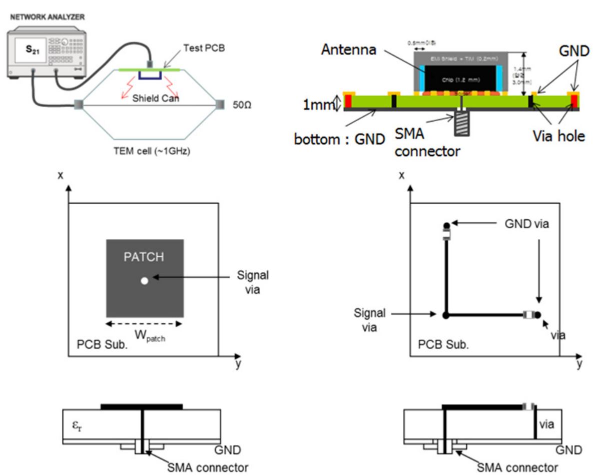

Figure 6. Antenna Design and Measurement apparatus for the EMI Shielding

The Shielding Effectiveness of the suggested shielding structure is more than 70 dB and better than a conventional Shield Can structure of 52 dB as shown in Figure 7. The conventional metal Shield Can has openings and holes because of cooling path or dispenser approaching path for under filling of the chip components.

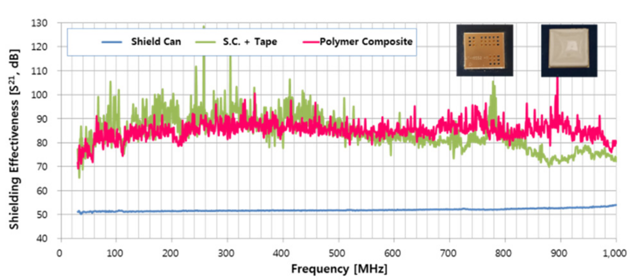

Figure 7. Shielding Performance of Suggested Structure

Conductive EMI shielding tape is attached on the metal Shield Can in order to cover the openings and holes, the shielding effectiveness is increased same as the suggested structure. Consequently, EMI shielding performance of the proposed structure is better than that of the conventional Shield Can.

EMI Shielding for Printed Board Assembly

The suggested EMI shielding structure is modified for the PBA of electronic devices as shown in Figure 8. A conventional Shield Can covers a predefined the module of the PBA and the module should be isolated from the other one by another Shield Can because radiative emission of electron magnetic wave from the module causes to a malfunction of the other module. The suggested shielding structure built by dispensing conductive polymer composite material should replace the Shield Can in same geometry as shown in Figure 8. The fabrication process is composed of five steps. The side shielding dam dispensing for wall structure of the shielding structure is the key process of the suggested fabrication scheme. Thin and high aspect ratio of shielding dam should be realized for a high density PBA. The aspect ratio of dam is under 2.0 but lower than that of chip level structure because there is no predefined the wall of the chip.

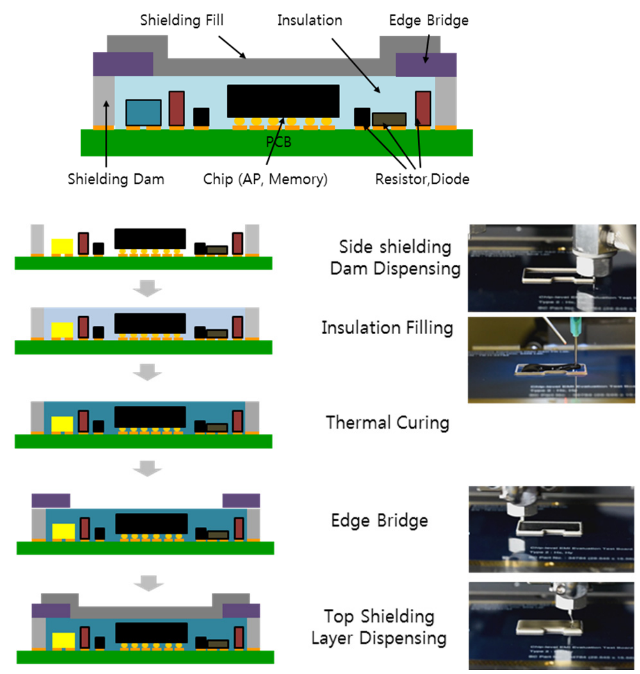

Figure 8. Shielding Structure and Fabrication Process for PBA

Simulation for Dispensing Process

The specific dispensing tip is designed for the side dam of the proposed shield structure as shown in Figure 9. The liquid conductive composite material is extruded from nozzle opening area. The material from side opening forms the upper part of dam and the other material from the bottom opening forms lower part of the dam.

Figure 9. Dispensing Nozzle Tip Structure

The dam with high aspect ratio structure is required to be a side wall of EMI shielding structure in high density PBA. The height of dam should be more than 1.2 mm for the active and passive components mounted on PBA and the width of dam is under the 0.6 mm. The aspect ratio of dam is determined to be more than 2.0. The composite material before thermal curing shows viscoelastic behavior due to the characteristics of polymer with high viscosity and thixotropy.

Discharging behavior at the nozzle opening is analyzed to determine the dimensions of nozzle opening like width and length of side opening, inner diameter of nozzle. Viscoelastic characteristics of material is governed by power law as shown in Eq.(5)

$$\eta(\gamma) = K \cdot (\lambda \cdot \gamma)^{n-1} \qquad (5)$$

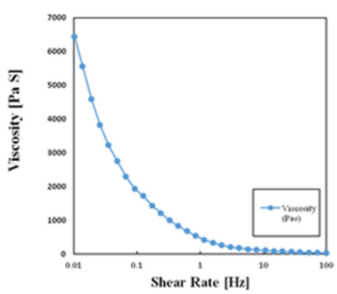

Figure 10. Measured Viscosity

Where η is viscosity [Pa s], γ is shear rate [s^{-1}]. The constants are obtained by curve fitting from viscosity and shear rate curve measured from dynamic viscometer as shown in Figure 10. The obtained results is K = 450, λ = 0.97, n = 0.41. The result shows a shear-thinning characteristic of material. It means that viscosity decreases when shear rate increases. The behavior of extruded conductive material is calculated by commercial viscoelastic simulation CAE S/W: Polyflow®. The Figure11 shows the calculated result of material behavior at dispensing nozzle opening. An inner diameter of nozzle is 0.6mm and a length of side opening is 1.3mm and width is 0.3mm. A flow rate is 13 mg/s and horizontal velocity of nozzle for building dam is 10 mm/s. The viscosity of material can be predicted by the velocity profile of flow in the nozzle and in the extruded dam. The high velocity region in the center of nozzle causes the low viscosity by shear thinning and the characteristic of flow is similar as viscous flow of Newtonian fluid. The low velocity region at the extrude dam results in high viscosity and high thixotropy. The extruded dam with high aspect ratio can be maintained without curing due to the elastic characteristic in the high viscosity region.

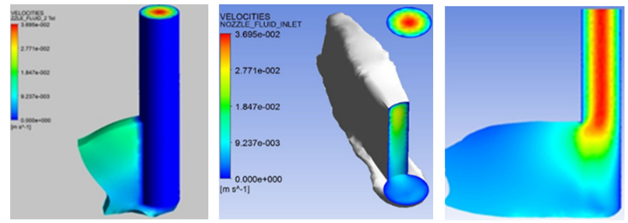

Figure 11. Material Extrusion Behavior at Nozzle Opening

The flow simulation for dispensing process is verified by experimental result as shown in Figure 12. Extrusion Phenomena is captured by high speed camera. The simulation result for dispensing process is well coincident with captured image. Because the target parameter is aspect ratio of dam structure, the cross section of dam is taken by picture.

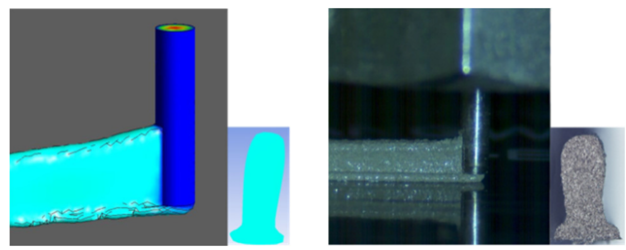

Figure 12. Comparison Simulation and Experimental Result

The calculation predicts that the height is 0.46mm and the width at the bottom is 0.46mm but measured height of dam is 0.55mm and the height is 1.15mm and the width is 0.55mm. The difference is results from the heat due to the flashlight during the high speed camera capturing. The heat increases the temperature of extruded material and causes to the decrease of viscosity. Without high speed camera capturing, the difference between simulation and dispensing result decreases.

A balance between flow resistance between side opening and bottom opening is critical for dispensing because the dam with high aspect ratio can be acquired in case of uniform flow at optimized side opening of nozzle. Figure13 shows the unbalanced result at nozzle opening. The width of side opening is 0.5 mm and height is 1.2 mm. The bottom of dam is not built because the width of dam is too large and the flow resistance is too small. The material is extruded at the side opening and the flow at the bottom opening is too small. Consequently, the High aspect ratio of dam is not accomplished

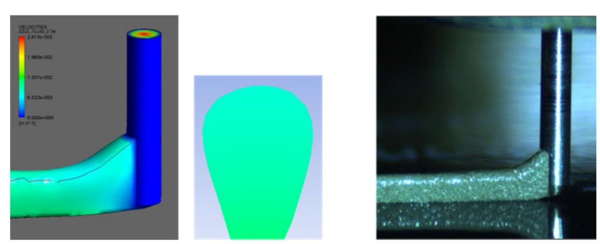

Figure 13. Dispensing at Unbalanced Nozzle Opening

For estimation of dispensing process parameter, aspect ratio of dam is calculated at various parameters like nozzle speed, width of side opening, flow rate of dispensing process as shown in Figure14. The nozzle diameter and the gap between the nozzle and substrate are fixed due to the requirement of dispensing process. The width is the most sensitive of the considered parameters and inverse proportional to the aspect ratio. But width should be more than 0.3 mm due to a restriction of nozzle manufacturing.

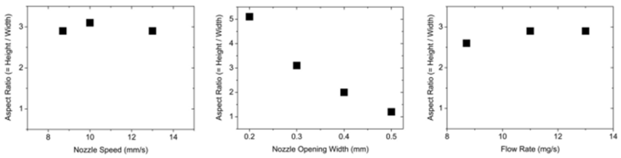

Figure14. Aspect Ratio due to Nozzle Parameter

Conclusion

Conformal thin layered EMI shielding structure with low cost and high shielding performance is introduced. The dendrite silver coated copper is adopted for a conductive filler of the composite material and formulated with silicone polymer. Thin wall thickness of shielding layer with high aspect ratio has been realized by viscoelastic characteristic of liquid conductive composite material and dispensing process with narrow side slot nozzle. The EMI shielding performance is superior to the conventional metal Shield Can because of conformal structure without opening and the high electrical conductivity of conductive composite material.

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Author Biography

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