EMI Shielding for System in Package Using Spray Coating and Silver Particle-Free Ink

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Abstract

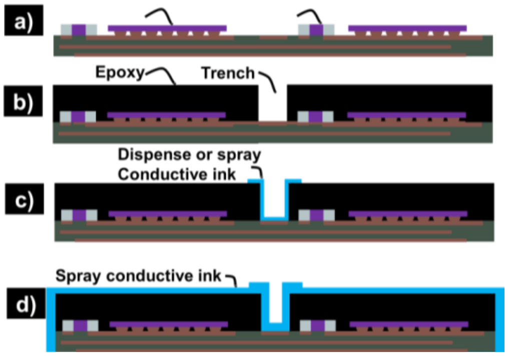
There is a constant drive to pack electronics into smaller spaces. Recently, smart watches have been major drivers of further miniaturization and spurred System in Package "SIP" innovations. SIP enables several integrated circuits (ICs) along with larger capacitors/inductors to be housed in one package. Many of these ICs operate at radio frequencies and the proximity increases electromagnetic interference (EMI). The traditional solution of soldering a "metal can" is not feasible. Compartmental shielding of the package is necessary and sputtered metal has typically been utilized to provide the shield.

The traditional sputtering method is a Physical Vapor Deposition process (PVD) that involves vaporizing a metal and depositing it onto the surfaces of the components. PVD is currently the most commonly used method to apply the EMI shield and it requires a complex, multi-step process. New materials and application methods are required to increase performance and reduce costs associated with producing an effective EMI shield. The EMI shield layer must be applied in a uniform layer on the package surfaces and into the trenches between compartments.

This paper demonstrates the capability of **EMI-207**, metal-complex conductive ink, which sets the standard for the paradigm of particle-free conductive inks, combined with widely adopted spray application for conformal and compartmental EMI shielding performance parameters including coating thickness uniformity, EMI shielding effectiveness, adhesion, process cost will be compared and analyzed between this approach and other silver inks and application methods. Results of these analyses will be presented along with performance improvement and cost reduction potential of this technique for high-volume manufacturing.

Introduction

The need for ICs to operate at RF frequencies in close proximity necessitates compartmental shielding. In this paper, we report on conductive coating **EMI-207**, an emerging cost-effective material approach which involves dispensing/spraying silver ink to form a compartmental shield as shown in Figure 1.



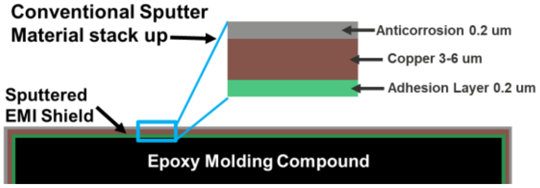


Figure 1. New approach using **EMI-207** as compartmental shielding for SIP.

Figure 2. Typical sputtering process and materials for shielding. [4]

The traditional shielding application method is a Physical Vapor Deposition (PVD) process that involves vaporizing a metal and depositing it onto the surfaces of the components; see Figure 2. Sputtering is currently the most used PVD method for applying the EMI shield and it requires a complex, multi-step process, including: 1) de-gassing; 2) plasma pre-treatment; 3) deposition of an adhesion layer; 4) deposition of the EMI shield layer and 5) deposition of an anti-corrosion layer. This process is performed in costly equipment that occupies a large floor space. The space required is typically in the range of 12.5 to 35 m^2 and the capital cost is in the range of $3M to $8M USD. Sputtering has other technical limitations, including: non-uniform coating of sidewalls and trenches, maintenance costs, material waste, and slow throughput. A common concern about the switch from sputtered copper to silver ink is that the cost of silver would be prohibitive. However, since the amount of metal on each chip is so small, for example 3 um thickness, the silver cost per chip amounts to only a fraction of a cent. The cost and footprint of sputtering equipment can dwarf the costs of these materials.

The primary benefits of spray coating include low capital cost (< $0.5M USD), simple production processes and high throughput with minimal maintenance. Typically, conductive inks are made from metal flakes and/or nanoparticles. In this paper, **EMI-207** particle-free silver ink is introduced that is particularly qualified for shielding applications. **EMI-207** has fundamental conductivity, process, and reliability advantages manifesting in excellent shielding (70 dB) across relevant frequencies, minimal material usage, fast curing time (<5 minutes), and lower material cost. Table 1 highlights the pros and cons of sputtering versus spray coating particle-based and particle free ink [1] [2] [3].

Table 1. Comparison of conformal EMI Shielding technologies.

Coating Method	Sputtering	Spray coat	Spray Coat
Material	Copper/Anti-Corrosion	Silver Particle Ink	Silver Particle-Free Ink
Capital Investment	High	Low	Low
Equipment Footprint	High	Low	Low
Maintenance	High	Low	Low
Throughput	Moderate	High	High
Ability to coat 3D, complex structures	Ok (Requires substrate treatment)	Good	Good
Process Temp	Varies	High (>150°C, >30min)	Low (120-160°C, <20min)
Materials Cost	Very Low	Moderate	Low

A key benefit of **EMI-207** is that its resistivity is very low at 3.2 µOhm-cm (2X bulk silver). As shown in Figure 3, the final microstructure of the particle free silver film is dense and connected. This is because particle free formulations do not rely on nanoparticle sintering nor contain dispersants/ligands that result in voids and poorly connected particles. Resistivity and low porosity is a key factor in shielding performance. Low resistivity means less silver thickness can be used for adequate shielding, resulting in less material usage. This also increases equipment lifetime and reduces costs. Shielding results of 60 to 85 dB at 1GHz will be presented in the results section.

Another benefit is that **EMI-207** is homogenous so no mixing is required, and it can be stored at room temperature during the coating process. Particle based dispersions often need to be both cooled (or frozen) and mixed inside of the spray coating tool. Compared to nanoparticles, the cost of particle free ink is lower because the **EMI-207** formulation is simple to produce in large quantity with near 100% yield. Moreover, the total cost of ownership of particle-free inks is lowered by having higher utilization (less sedimentation), reduced printing maintenance, and prolonged print times.

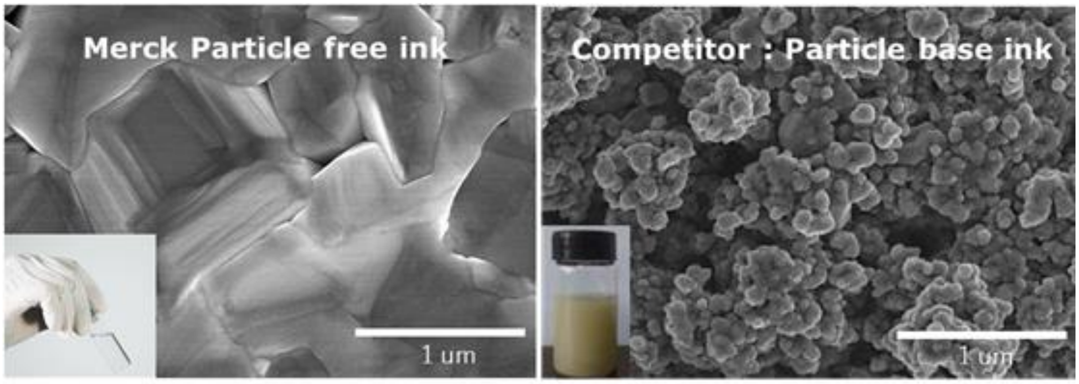


Figure 3. Microstructure of (left) **EMI-207** particle free ink; (right) particle-based silver ink.

Spray Coating Process

The process of coating components with a spray coating system and **EMI-207** is for the most part dictated by the customer. However, a typical process is depicted in Figure 4 and details are described below:

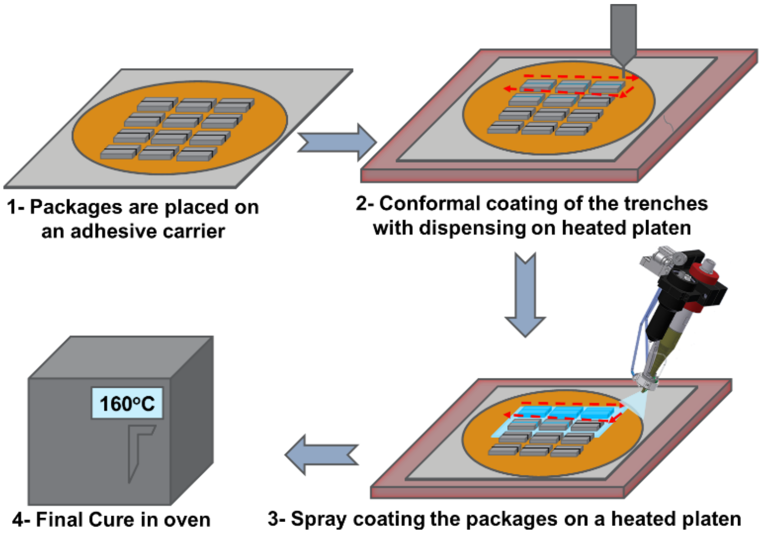


Figure 4. Spray coating process

1. **Preparation** – chip preparation and cleanliness are essential for good adhesion of the film to the chip surface. The chips will be cleaned with a common solvent to take off any residues or dust from the surface of the chips. The chips will then go through a dehydration bake step to evaporate the solvent. Customers often perform their own preparation process including UV ozone treatment or plasma cleaning.
2. **Placement** - the components are placed on an adhesive Kapton sheet. The minimum spacing of the components should be equal or greater than the component thickness.
3. **Load into coating system** - the Kapton sheets will be transferred to a heated platen >100°C surface temperature on the chip at the coating station.
4. **Coating** - the particle free conductive ink is sprayed onto the chips. At a 100°C surface temperature on the chips, the volatile solvent system will evaporate near instantly and the chemical reaction creates a thin silver film on the surface of the EMC. Within seconds the components will visually appear silver as the material deposits. Multiple layers are applied to achieve the desired film thickness without any waiting time between layers. To ensure maximum shielding effectiveness, the target film thickness is between 1-3 µm.
5. **Final cure** - the trays of coated chips are transferred to a thermal oven. Package level components are typically cured at 140-160°C for 5-20 minutes in an oven. It is worth noting that the particle free silver ink is already dried and cured on the spray coating

platen at 100°C. The final oven cure only boosts the resistivity marginally (from 5µOhm-cm to 4µOhm-cm).

Shielding Effectiveness

Theoretical Shielding -Infinite Conductive sheet

The shielding plot of Figure 10 assumes an infinite sheet of silver being struck by a plane wave. In practice, the shielding for enclosures will be lower than in this theoretical model because of the 3D nature of the enclosure - and grounding is paramount. The formulas for the theoretical reflection and absorption terms are given below [5]:

$$\text{Shielding Effectiveness} = \textbf{Reflection} + \textbf{Absorption} \qquad (1)$$

$$\boldsymbol{S.E.(dB)} = 20\log\frac{\eta_o}{4\eta_s} + 20\log e^{\frac{t}{\delta}} \qquad (2)$$

η_o is the intrinsic impedance of free space and η_s is the impedance of the metal, t is the thickness and δ is the skin depth.

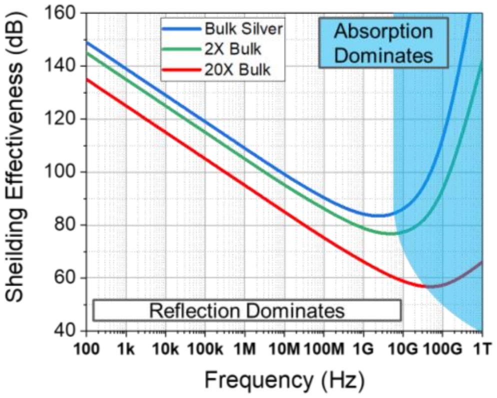


Figure 5. Theoretical shielding of 1um thick layer versus resistivity

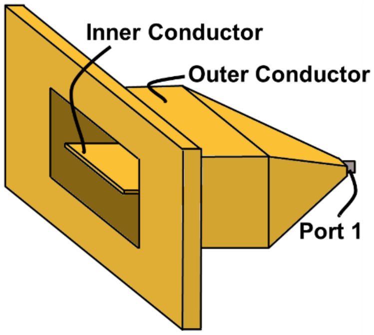


Figure 6. KEC method, electric field measurement, half structure [6]

Using these equations, the shielding is plotted in Figure 5 for a 1 um thick film of material with 1X, 2X and 20X bulk silver resistivity (1.6, 3.2 and 32 µOhm-cm respectively). Note that there is a minimum in the theoretical curve around 1 to 10 GHz when neither the reflection or absorption terms dominate. Coincidentally this is often in the range of many common bands, such as LTE, Bluetooth, GPS. The 1 GHz region is often cited for shielding effectiveness data. Since **EMI-207** offers better resistivity in the range of 2-3X bulk silver, less material is necessary to provide >60dB of shielding at 1 GHz. For comparison, particle-based inks typically have 8-20X bulk resistivity of silver and require 5 to 15um thick films to provide 60dB at 1GHz.

Measured Shielidng - Kansei Electronic Center (KEC) Method

The KEC method is a near field measurement of shielding effectiveness of a thin film. The method can be used in transverse electric (TE) or magnetic modes. The TE mode is of most interest and the symmetrical half section TE port is shown below [6]: The ports are then connected to a network analyzer with amplifiers to measure the transmission. The transmission is compared with and without the shielding material sandwiched between the two structures as shown in Figure 6. In this KEC test, the shielding is below the noise floor of the instrument until about 100MHz. At 100MHz the films provide ~90dB of shielding, which drops down to 75dB of shielding for the 1um thick film at 1GHz. These films are estimated to be near 50% bulk and agree with the theoretical shielding in the previous section.

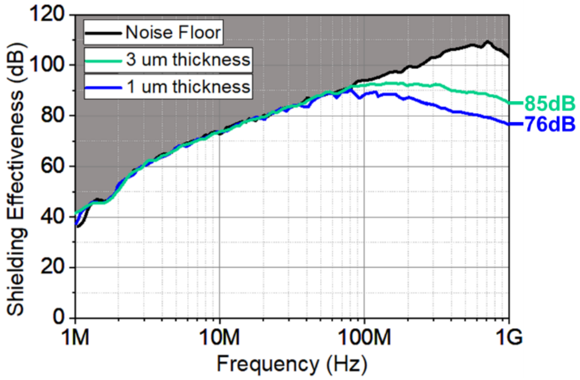


Figure 7. Shielding Effectiveness of **EMI-207** with KEC method

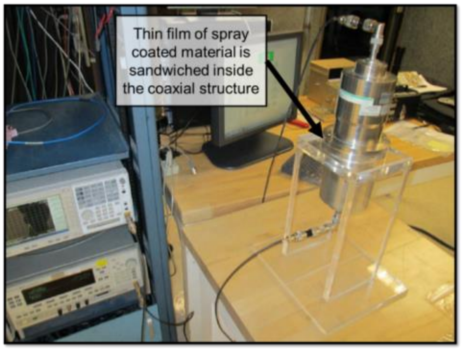


Figure 8. ASTM 4935 Coaxial measurement setup

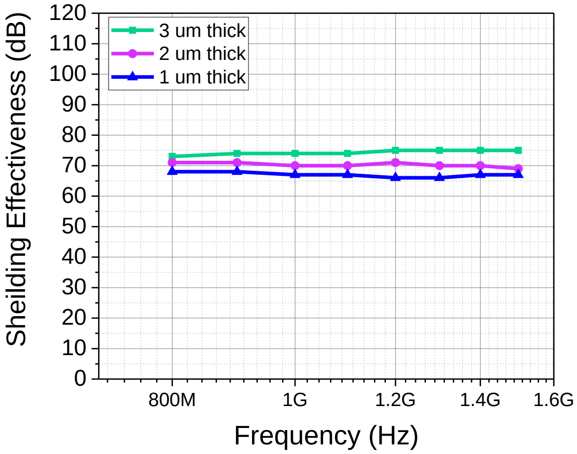


Figure 9. Shielding effectiveness of **EMI-207** (using ASTM4935 testing standard)

Measured Shielidng – Coaxial Method

The coaxial method is similar to the KEC method except symmetrical coaxial structures are used to sandwich the conductive film. The coaxial method is generally used for higher frequency measurement. The smaller the size of the coax, the higher the frequency band that can be measured. **EMI-207** was tested at Parker Chomerics test facility in Massachusetts using the ASTM 4935 standard Figure 8. The films were spray coated with 1, 2 and 3 um dry (final) thicknesses. The measured results show excellent shielding performance beyond 1GHz. Figure 9 shows that there is a dependence on thickness from about 68 dB to 75 dB of shielding for the 1um and 3um thick films respectively. The values are worse than the KEC results at 1GHZ, however these samples have some differences in coating process which may be the reason. Regardless, even the 1um thick film is showing >65dB of shielding, which is excellent.

Measured Shielidng – 3D Epoxy molding structure

In order to measure the shielding on a 3D epoxy mold compound (EMC) package a test structure must be made as shown in Figure 10a. A broad band radiating structure encapsulated with epoxy molding compound is coated with **EMI-207** in Figure 10b. The structure is measured with and without the applied shield in an isolated chamber. From Figure 11 the shielding for a 1um coating is showing better than 60dB of isolation in this configuration up to 1 GHz. It is important to note that ground connection plays a large role in shielding. The 3D nature of the structure and the ground connection may be the reason the shielding is ~60dB from this measurement in comparison to the 76 dB shielding from the KEC method using a thin sheet. However, 60dB of shielding for a 1um thick coating is still excellent performance.

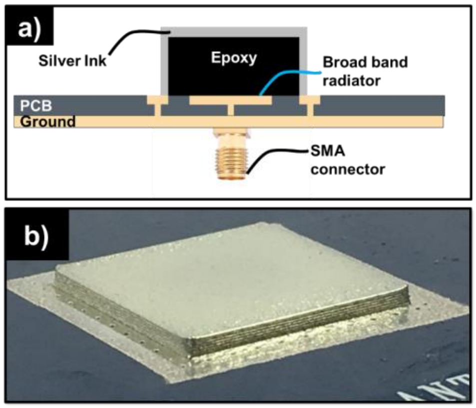


Figure 10. a) 3D EMC test structure (b) **EMI-207** coating on EMC ready for shielding test

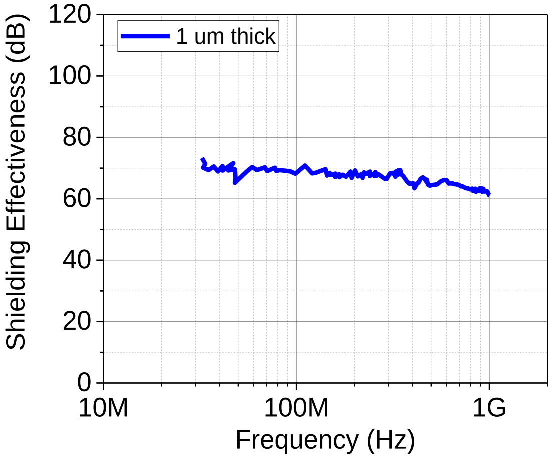


Figure 11. Testing of broad band radiator encapsulated in EMC and shielded with **EMI-207.**

Adhesion and Reliability testing

It is essential to have good adhesion to the surface of the EMC because missing metal will harm the shielding performance. **EMI-207** has been tested with ASTM D3359 Cross Hatch Adhesion Test on EMC chips and shows 5B adhesion, Figure 12. Samples are tested for 1,000 hours in an 85% humidity chamber at 85°C. A set of these samples is shown in Figure 13 and maintains 5B adhesion, conductivity, and visual appearance.

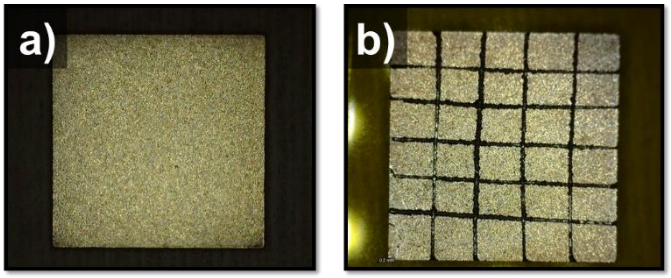


Figure 12. a) top view of EMC component (b) After ASTM tape test

Figure 14 shows the resistivity over time at 85% humidity chamber at 85°C. There is actually an initial drop in resistivity at the 0-100 hours but between 100-hours and 1,000-hours there is no further change in resistivity. Thermal cycling of EMI-207 shows similar stablity and reliability.

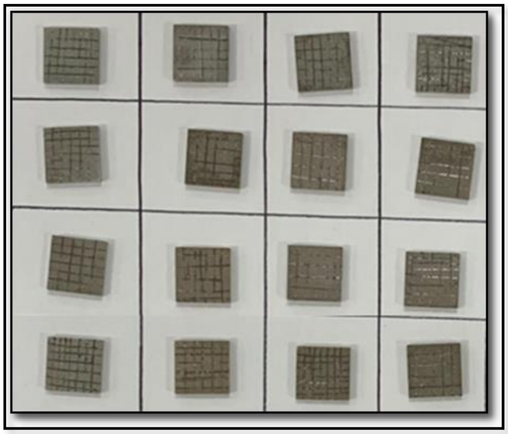


Figure 13. EMC samples after 1000 hours at 85°C/85% humidity chamber and ASTM tape test

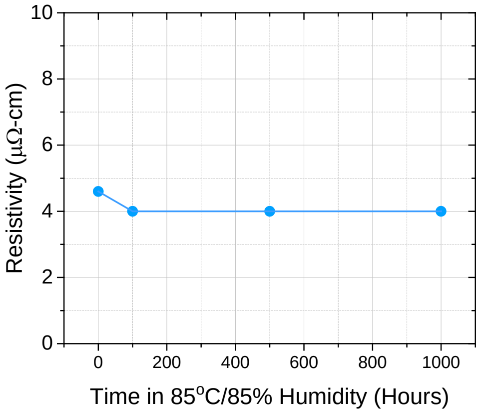


Figure 14. Resistivity over 1000 hours in 85°C/85% humidity

Bar Code Scanning

Laser etched bar codes and serial numbers are written on the packages which are used by pick and place machines. Codes must be clearly read after silver ink is spray coated and cured. Film quality, thickness, and surface roughness of the conductive ink is important for bar code scanning to ensure the bar codes on the packages are readable subsequent to silver film application. Figure 15 shows the bar code on the chip (a) before, and (b) and after coating. These bar codes are typically etched 15-20 um deep into the packaging, and flake-based inks that are deposited 10 um thick for example can cause issues with bar code reading. Since particle free ink uniformly coats the EMC, bar code reading has been successfully tested even at coated thickness greater than 3um.

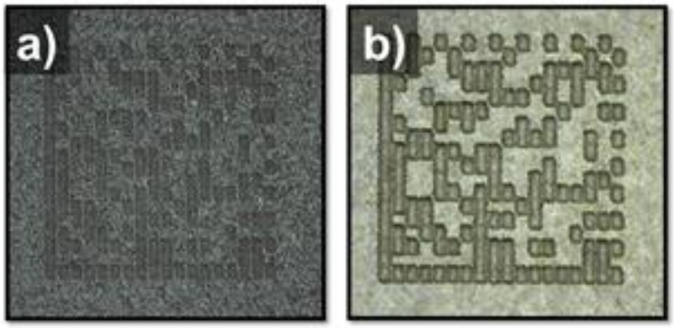


Figure 15. Bar code scanning

Film Thickness and Coverage

A problem with all top down coating techniques, sputtering and spray coating, is that the top horizontal surface being coated thicker than the vertical sidewalls. This problem is overcome with the coating system platform that has a rotating and tilting spray head that can spray at up to a 45° angle. From the images of the coatings below the sidewalls and the tops are uniformly coated with 3 um of silver metal in Figure 16.

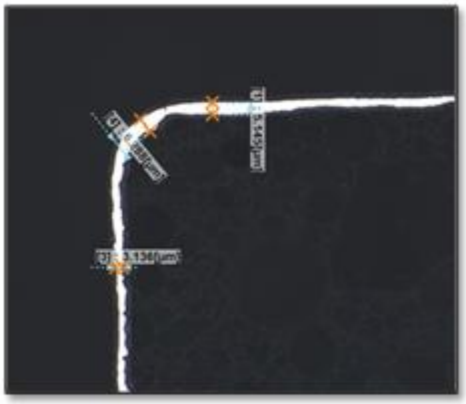


Figure 16. Film thickness on the chip

Conclusions

System in Package "SIP" presents several challenging manufacturing problems including compartmental shielding. This paper presents a novel approach to solving the problem by using **EMI-207**, a highly conductive particle free ink along with uniform coating provided by the coating system platform that includes both spray coating and dispensing technology. This is a cost-effective solution because of the high throughput and lower equipment costs compared to conventional sputter coating. Particle free ink can provide between 2.5X to 4X bulk silver resistivity with excellent shielding >60dB at 1GHz with only 1-3um of thickness. This is less than half the thickness required from particle-based formulations which are less conductive. Pilot scale testing has shown that nozzle-free ultrasonic spray technology which uses a tilted spray head to better facilitate coating non-orthogonal parts, coats the sidewalls and top of the chips uniformly with 3 um thickness. The ink is able to successfully infill trenches in the EMC to isolate the SIP compartments. The ink provides excellent adhesion to epoxy molding compound and passes environmental testing including 1,000 hours at 85% humidity and 85°C temperature.

References

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