Dispensing EMI Shielding Materials: An Alternative to Sputtering

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Abstract

Shielding electronic systems against electromagnetic interference (EMI) has become a hot topic. Technological advancements toward 5G standards, wireless charging of mobile electronics, in-package antenna integration, and system-in-package (SiP) adoption are driving the need to apply more effective EMI shielding and isolation to component packages and larger modules. For conformal shielding, EMI shielding materials for exterior package surfaces have mostly been applied with a physical vapor deposition (PVD) process of sputtering, leveraging front-end packaging technologies to back-end packaging applications. However, sputtering technology challenges in scalability and cost along with advancements in dispensable materials are driving considerations for alternative dispensing techniques for EMI shielding.

The authors will discuss development of a spray coating process to apply EMI shielding materials to the exterior surfaces of individual components on strips and larger SiP packages. Using newly developed and enhanced materials and equipment for this industry, a process was demonstrated that provided uniform coating on packages in the sub-10µm thickness range with consistent coating thicknesses around package corners and package sidewalls, producing a top surface-to-sidewall thickness ratio of 1:1. Further investigation showed decreased production costs for applying EMI shielding to component packages by increasing spray-coating productivity and by selectively applying the coating to specific areas of packages. Additionally, low capital-equipment expense and shorter lead times for spray coating equipment improved the ability to scale up production capacity compared to sputtering equipment.

In mobile electronics packaging, several SiP-module manufacturers are challenged to isolate components within the SiP from each other and from their exterior for EMI shielding. Trenches are cut around the interior components and conductive paste is dispensed into the trenches to form smaller Faraday cages within the package. As trench designs become narrower, it becomes imperative to control both the volume and placement accuracy of the material filling the trenches. The latest, advanced jetting products provide control of the volume while the narrow, in-air stream width delivers accurate trench-fill. In a final step, the tops of these paste-filled trenches are connected by applying exterior EMI shield coating. Spraying overcomes challenges faced when using sputtering equipment and harnesses the improvements in both the EMI shielding materials and the equipment for depositing it, so that SiP packages can be manufactured using efficient back-end packaging techniques.

Keywords

EMI Shielding, Sidewall Thickness, Spray Coating, EMI Trench Filling, Jetting, Conductive Paste

I. Introduction - Growth of EMI Shielding

EMI shielding has become a topic of significant interest in recent years. As 5G wireless technology is approaching mass-market acceptance and the future capabilities 5G standards will enable for Internet of Things (IoT) and mission-critical communications, there is a significantly increasing need to effectively shield electronics and components from EMI.

With the upcoming 5G wireless standards, signal frequencies of 600MHz to 6GHz[1] and mmWave bands will become increasingly more common and powerful as the technology is adopted. Some of the proposed uses and implementations include window panels for office buildings or public transportation to help deal with shorter range communications. Other proposed implementations include home and office building repeaters to provide adequate coverage due to 5G frequencies having difficulties passing through walls and other solid objects.[2] All of this activity will lead to an increased prevalence of signals in the 5G frequency range and a higher risk of exposure to EMI in these frequency ranges and their harmonics.

Fortunately, EMI can be shielded on component and System-in-Package (SiP) devices through the application of thin coatings of conductive metal to the exteriors of such devices. Historically, EMI shielding has been applied through placing stamped metal cans around groups of components or by applying EMI shielding tapes to specific components. However, as packages and end devices continue become miniaturized, such shielding methods become prohibitive due to size constraints as well as flexibility to handle diverse, non-orthogonal packaging concepts that are becoming more common in mobile and wearable electronics. Likewise, some leading-edge package designs are moving toward selective coating of only certain areas of a package for the EMI shielding rather than a complete shell over the full exterior of the package. In addition to the external coating for the EMI shielding, new SiP devices are further requiring additional integrated shielding to be built directly into the package to properly isolate individual components from each other in a single package.

Figure 1 – Example SiP Unit with Sputter Coating and Integrated EMI Shielding Structures

II. Sputtering – A Method of Applying EMI Shielding

The predominant method for creating EMI shielding on molded component packages or molded SiP devices has been through sputtering multiple layers of metals over the surface. With sputtering, it has been possible to apply very thin, consistent coatings of pure metal or metal alloys to package surfaces in the 1-7µm thickness range. With the nature of the sputtering process capable of depositing metals at the angstrom level, electrical performance of its coating layer has been effective thus far for typical shielding application.

However, as the need for shielding grows, sputtering has significant inherent drawbacks for it to be established as a scalable method for manufacturers and designers. Initial capital equipment costs for sputtering equipment are very high, with typical equipment running in the one million to five million dollar range depending upon supplier and equipment capabilities. Sputter equipment lines require significant floor space due to its multi-chamber process, and further increases the need for additional real estate with full in-line conveyorized systems. With the inciting of a plasma to sputter material from a sputter target to the substrate, typical sputter chamber environments could reach into the 400C range and therefore cooling of a substrate with a "cold plate" mounting fixture to reduce the experienced temperatures is needed. The sputtering process deposits metal on a given substrate but typically only produces up to 60% thickness coverage on the vertical sidewalls of a three-dimensional package compared to the thickness of the top surface layer. Lastly, due to the nature of sputtering being a line-of-sight deposition process, metal particles cannot be selectively applied or necessarily applied under overhanging structures and topology and therefore can result in significant material wastage in addition to material accumulation inside the chamber walls; hence requires intensive maintenance. It is also necessary to pre-apply masking to substrates if there are specific areas of a given substrate that must remain exposed or do not require EMI shielding.

III. Spray Coating – An Alternative Process to Sputtering

Spray coating is an established conformal coating method commonly used in the automotive and printed circuit board assembly (PCBA) markets to protect substrates from harsh environmental factors including moisture and dust. Using similar spray technologies, thin layers of flux material have also been applied to PCBs prior to ball grid array (BGA) component attachment and reflow. Military applications use spray technology to apply extremely thin coatings to substrates, at times involving highly customized and expensive fluid formulations. Today's EMI spray coating equipment has evolved from these markets and applications, leveraging successful designs to achieve high productivity, long service life, and low capital costs.

Spray coating for EMI shielding started to gain attention in the 2000s as a result of extensive use in industrial and automotive markets and military applications. By 2012, Nordson ASYMTEK began to apply conformal coating expertise to EMI shielding applications using the DispenseJet® 2200 spray valve to coat the top surfaces of semiconductor packages in mass production. However, at that time, sidewall coverage and fluid adhesion to vertical surfaces were significant challenges toward wider adoption of the process. Furthermore, initial formulations of EMI shielding materials, based on conductive silver inks, required moderate to high thicknesses to provide adequate shielding effectiveness and had limited adhesion property than recent formulations.

As discussed in a prior publication[3], the application of tilt spraying with a spray applicator has led to notable improvements in overcoming the prior sidewall coverage limitations from earlier implementations. Recent spray applicator design enhancements have also delivered greater selectivity and refined edge definition in the spray pattern. Such improvements further enabled capabilities of selective patterning or coating coverage desired in various leading-edge packages where full conformal shielding is not required. Sprayed material's adhesion compatibility to different substrates was also required for spray shielding is to be considered as a viable or superior alternative to sputtering.

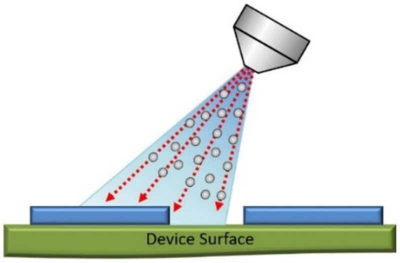


Figure 2 – Tilted Spray Coating Applies Fluid at an Angle to the Top and Sidewalls of Component Surfaces

IV. EMI Spray Shielding Material Improvements

Initially, EMI shielding materials for spray coating were silver-based conductive inks. These modified inks were adopted for mass production in a very limited market segment due to concerns with the material thickness required (≥ 25µm) to achieve adequate shielding performance and lack of ability to adequately coat the vertical sidewalls of the substrates. However, new conductive material formulations have been recently developed to address adequate shielding performance and coverage consistency.

These formulations were initially focused on providing superior conductivity performance compared to conventional materials. As seen in Figure 3 below, shielding performance was improved by up to 80% and allowed reducing from 25µm thick coatings to coatings in the 3-6µm thickness range while achieving comparable shielding performance as sputtering. With these novel EMI shielding material formulations, spraying can now achieve comparable performance and thickness as sputtering.

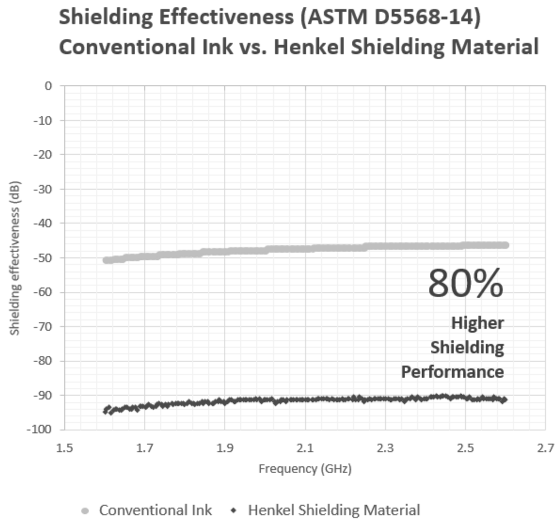


Figure 3 – Shielding Effectivity Comparison Between Henkel Shielding Material and Conventional Silver Ink

Another challenge with conventional spray coating materials was the tendency of the material to "slump" after being sprayed or applied to the sidewalls of the target substrate. These early materials would tend to run down the sides of component packages causing inconsistent thickness and nonuniform coverage on the coated substrates.

New material formulations from Henkel Electronic Materials, such as the commercially available LOCTITE ABLESTIK EMI 8880S, have eliminated slumping. In recent tests with this material, we were able to coat test samples with 100% sidewall thickness as top surface thickness (1:1 ratio). Through adjusting parameters of the spraying process, such as dispense distance from the substrate or motion speed of the spray valve, the coating thickness and resulting sidewall to top surface thickness can be adjusted. Typical sidewall to top surface ratio is greater than 0.7 : 1.

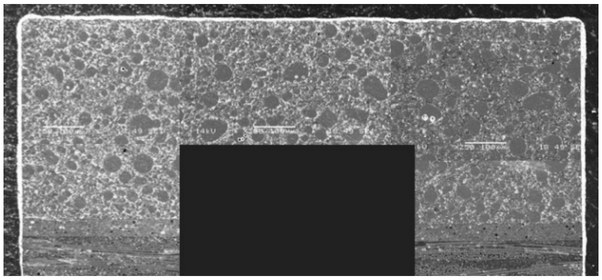
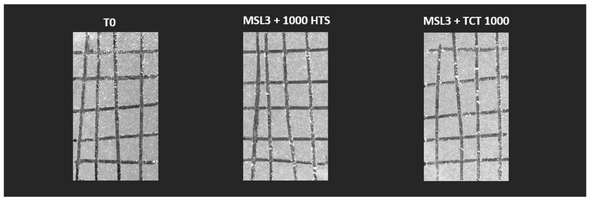


Figure 4 – Spray Shielding Uniformity for Top and Sidewall Surfaces with Henkel EMI 8880S

In addition to improved sidewall coverage, adhesion performance is a critical component to this solution. Industry standards call for a cross-hatch etch and peel test and coatings must adhere with a rating of 4B or 5B to pass (minimal or no loss of material apart from the etched areas). Figure 5 below illustrates a limited set of the test results for the Henkel 8880S material at time zero as well as after accelerated life cycle tests.



- All of the parts tested provide 5B adhesion results at time 0
- No adhesion degradation after MSL3 + 1000hr at 150ºC and after MSL3 + 1000TCTs
- Note:
    - Temperature Cycle -40ºC~125ºC
    - High temperature storage: 150ºC

Figure 5 – Adhesion Testing & Reliability of Henkel 8880S

Furthermore, as illustrated below, new spray shielding materials from Henkel also provide robust adhesion on various substrates commonly used across a wide range of electronics design applications, including polyimide films used in flexible PCBs. As such, spray coating for EMI shielding can further be applied to a broader scope of applications than could previously be considered.

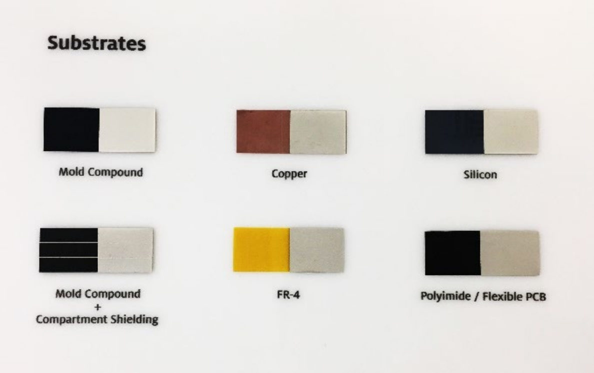


Figure 6 – Substrate Adhesion Flexibility of Spray Shielding Materials

V. Cost Advantages of EMI Spray Coating

As EMI shielding continues to expand into wider markets and applications, manufacturers are paying close attention to the costs for starting EMI shielding production and weighing their options. One of the downsides of sputter coating is the significant cost of the capital equipment and associated floor space and operating cost. A typical sputter coating production line may require floor space on the order of 60m^2. Productivity with such equipment for a package that is 25x25mm can roughly reach 1,500 units per hour (UPH). With the price of the equipment running well over one million dollars, the initial capital expenditure to start a production line and to further add capacity can easily be problematic for contract manufacturers with varying production loading from their end customers.

By comparison, a spray coating process is far more scalable and flexible. A typical spray coating platform will require ~1m^2 in floor space a curing oven. A batch curing oven will typically run ~1m^2 or an inline curing oven can be added for greater automation but at the trade-off of additional floor space. A single batch oven can typically serve curing parts from multiple spray coating platforms. Spray coating equipment with the batch oven can be sourced for well under two hundred thousand dollars, depending upon the configuration. As single spray coater can produce comparable or higher UPH for the same 25x25mm package. With the low cost of the spray coater itself and the ability of the oven to serve multiple coaters, the equipment cost for starting a small coating production and increasing production capacity as loading increases is much more practical.

While the overall cost of ownership is lower for spray, consumable material costs for spray coating will naturally show a higher cost per unit. Sputtering for EMI shielding generally uses pure copper as the core shielding layer and therefore the consumable cost is relatively low. Spray materials for EMI shielding can include different metals including silver as well as other value-add technologies and therefore results in a relatively higher cost compared to sputtering pure copper. However, in large volume manufacturing conditions and with an optimized spray process, the overall cost per unit of spray coating is lower than sputter. As such, optimized spray material consumption can further improve the cost advantage of spray.

Resulting from this study on reducing fluid consumption, there has been further evolution of the spraying and dispense technology for applying the EMI shielding fluid to different substrates. Recently, modifications to the spray coating equipment have resulted in a marked improvement in the overspray conditions and width of the overall spray pattern. Current default spray patterns result in roughly an 8mm wide spray area. The most recent design changes to the spray head have allowed for being able to adjust and control the width of the spray pattern (and therefore over spray condition) from the 8mm width down into the 2mm width range while maintaining target coating thickness and uniformity. Reducing the spray width has been a significant improvement in the process capability as it opens the door for more selective coating to only target areas and therefore significantly reducing material consumption. In at least one case example, this ability to selectively spray-coat target areas of a substrate allowed for reducing the cost of the spray coating process by more than 50% of the cost of the end customer sputter process.

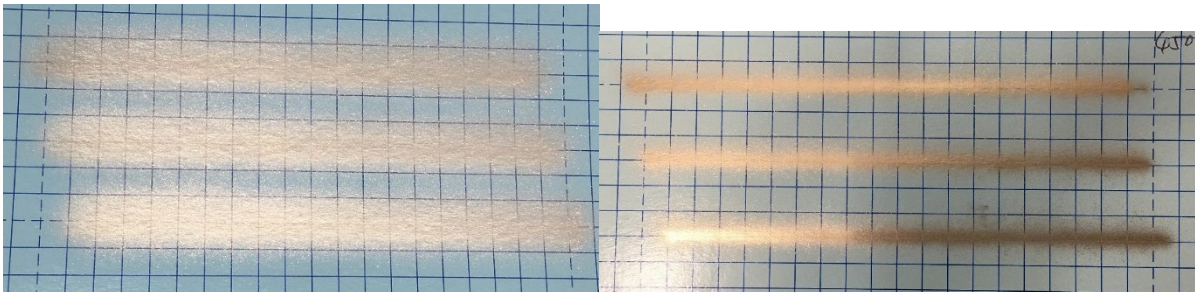


Figure 7 – 8mm-Wide Spray Pattern (Left) versus 2mm-Wide Spray Pattern (Right)

VI. Jet Dispensing for Greater Selectivity

With the desire to further improve on selectively coating or compartment shielding structures, jet dispensing offers and attractive potential solution. Figure 8 shows an example process found in a growing number of SiP devices where an integrated EMI shielding structure creates partitioning within a single package. To fill such a trench, a highly conductive paste, such as Henkel's LOCTITE ABLESTIK EMI 3620FA with optimal rheology is jet dispensed.

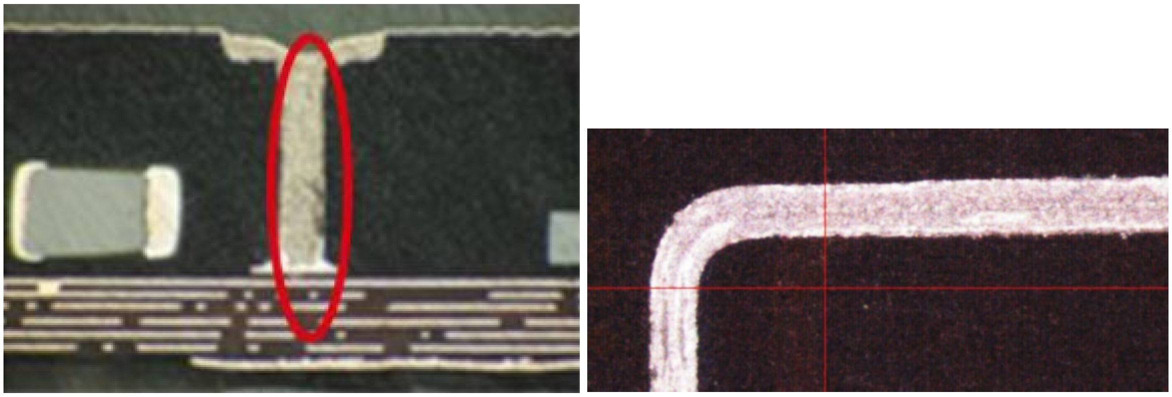


Figure X – Cross-Section Example of a Filled Trench

Jet dispensing offers some significant advantages in terms of process controls as well as productivity compared to auger valve dispensing. In addition to increased productivity, jet dispensing also allows for smaller discrete dots of fluid to be dispensed. Leading-edge technology in jet dispensing with piezo jets, like the Nordson ASYMTEK IntelliJet® with the ReadiSet® Jet cartridge hardware, provide superior control for the in-air stream width of the fluid and better enable further improvements for new trench-fill applications as the SiP packages continue to narrow the trenches and increase the depth to width ratio.

With further improvements in fluid formulation to meet requirements for jetted line thickness, width, and surface adhesion, it is expected that jet dispensing will open the doors for further improving selectivity coverage and enabling new packaging structures. It is also possible that jet dispensing conductive pastes will allow for more additive manufacturing techniques and make possible for new applications such as flexible circuit trace printing or on-package antenna printing.

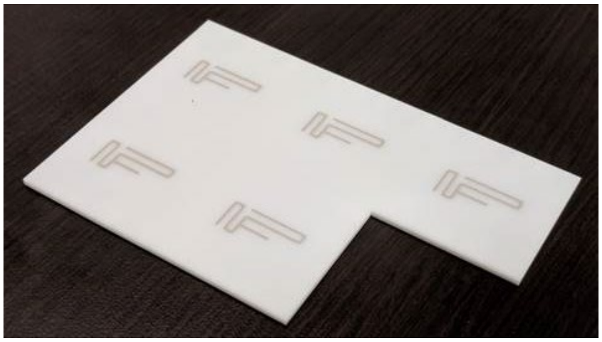


Figure X – Jetted lines of conductive paste; approximately 300µm wide

VII. Conclusion

In conclusion, sprayed EMI shielding has become a viable and attractive alternative to sputter coating. Advancements in material formulations as well as the methods of applying these materials allow for comparable performance and thickness as sputter coating. In addition, spray coating offers far more flexibility for different types of substrates that can be coated as well as allowing for greater selectivity for placement of the shielding material. Through optimizing the spray coating process and patterning, spray can achieve comparable or better cost per unit when compared to sputter coating. Spray coating further offers superior scalability for growing production capacity with low capital investment. Lastly, further innovation in the dispensing of shielding materials is leading the way for highly precise shielded areas and conductive trace creation through jet dispensing.

VIII. References

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IX. Acknowledgements

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