Overview of Techniques for Depositing EMC Shielding Coatings

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Introduction

Modern microelectronics depend on the control of electromagnetic interference. The maximum allowable interference is now set by regulation. In Europe the EMC Directive, 89/336/EEC, came into effect in 1992 and has been mandatory for CE marking of electronic/electrical equipment since January 1, 1996.

Some forms of interference can be controlled with suppression components and good circuit design. Radiated interference is best controlled by enclosing the circuitry in a shielded enclosure.

Metal enclosures generally offer very good shielding. Highly conductive, metals will absorb or reflect electromagnetic waves. Plastics provide the enclosure designer with several advantages over metal. Reductions in weight and cost, coupled with increased flexibility and aesthetic appeal have led to the increased use of plastic. However, being nonconductive, plastics are transparent to electromagnetic waves and hence offer no protection against EMI.

To allow plastics to be used as enclosures for computers, mobile phones, medical equipment and other electronic products, several techniques have been developed over the past few years to make the plastic enclosures conductive. Essentially, there are three routes to making a shielded plastic enclosure: the polymer can be made conductive by adding fillers; thin metal plates or foils can be bonded to the enclosure; or the surface of the enclosure can be coated with a conductive film.

Plastics can be filled with conductive media. Graphite particles or metal flakes are commonly used. However, these materials are difficult to mold and only provide moderate levels of shielding. In recent years, the use of nickel-coated carbon fibers has improved the performance of these materials.

Enclosing the RF components in a metal can or bonding thin metal plates to the plastic enclosure will, in some instances, provide a cost-effective method for shielding. In-mold foiling would provide an even lower cost option, but the process is limited to fairly simple geometries.

By far, the most common means of shielding an enclosure is to apply a conductive film to the surface of the enclosure.

This article will review the major techniques of applying EMI shielding coatings to plastic housings and displays. Processes for vacuum deposition, conductive paint spraying and electroplating will be reviewed. Physical and electrical data on the various coatings are presented.

Techniques for Applying Conductive Coatings to Plastics

It is estimated by this author that some 100 million parts per year are coated in Europe to provide EMI shielding. Over the past 10 to 15 years, three major techniques have been developed to service this market. Table 1 shows the estimated market share for conductive paint spraying, electroplating and physical vapor deposition (PVD) techniques in Europe.

PROCESS	ESTIMATED MARKET SHARE
Spraying	50%
Electroplating	40%
PVD	5%
Others	5%

***Table 1.** Estimated Market Share of EMI Shielding Processes.*

Using these processes, a number of different coatings can be deposited. Designers must ensure that the coating that best fits their requirements is specified. Table 2 shows the criteria that should be considered when evaluating a coating for EMI shielding.

Shielding effectiveness (SE) is a measure of how effective the coating is as a barrier to the transmissions of electromagnetic waves. Shielding effectiveness is usually expressed as:

$$SE = 20 \log (E1/E2) \text{ dB}$$

where E1 and E2 are the incident and transmitted field strengths respectively. Typically, the shielding effectiveness of coatings ranges from 40 to 90 dB. There is good correlation between the conductivity of the coating and the level of shielding: the lower the resistance, the better the shielding properties. Table 3 can be used as a rough guide to deter-

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1 Shielding effectiveness (SE) over the required operating frequency	SE is proportional to the conductivity of the film. High conductivity metals such as silver, copper and aluminum offer the best shielding
2 Compatibility with substrate material	Adhesion Impact on intrinsic properties of the polymer Size and geometry of substrate UL approval Temperature during coating process
3 Environmental stability	Temperature, humidity, sea salt, fire, etc. Product life expectancy Galvanic corrosion
4 Masking requirement	Internal and external areas to be coated Tolerance of masking detail Contact resistance at mating faces
5 Coating appearance	Aesthetic Wear resistant Transparent

Table 2. *Criteria for Evaluation of Coatings for EMI Shielding.*

mine the shielding effectiveness of coatings by measuring their sheet resistance.

It is essential that compatibility of the coating with the chosen substrate material is considered. Problems often occur with poor adhesion and solvent attack of substrate. The long-term stability of the coating under the normal working environment of the equipment also needs to be considered.

As mentioned, there are three main techniques for applying EMI shielding coating: conductive paint spraying, electroplating and physical vapor deposition (PVD). These techniques will be reviewed and the properties of the deposited coatings will be discussed.

Sheet Resistance (Ohms/Square)	SE for Plane Waves (dB)
0.5 - 1.0	< 40
0.1 - 0.5	40 - 50
0.05 - 0.1	50 - 70
<0.05	>70

Table 3. *Correlation of SE to Sheet Resistance of Coatings.*

Application of Conductive Paints

A large number of conductive paints have been developed by various companies for EMI shielding applications. Most of the formulations are based on adding either one or a combination of metal flakes of nickel, copper or silver. Nickel-loaded paints offer the cheapest solution but provide the lowest level of shielding, while silver paints offer the highest degree of shielding at a premium. Table 4 illustrates the typical sheet resistance obtained with coatings containing various pigments.

Although water-based paints are available, solvent-based (MEK, MBK) coatings provide better electrical and physical properties.

Nickel-loaded paints developed some 20 years ago were widely used in the early Eighties. However, their use has declined in recent years as copper and silver pigment technology has developed. With increased usage, the price of silver-loaded paints has fallen significantly in recent years, and now most products are shielded with silver-loaded paints. Silver-plated copper paints are widely used for shielding larger moldings such as computer housings.

All the paints can be applied manually or using robotic spraying equipment. In recent years, the development of robotics and HVLP (high volume low pressure) guns has significantly improved the efficiency of spraying processes.

Paints containing a high solids content tend to settle quickly, so pressure pots and fluid lines must be designed to allow the paint to circulate freely between the paint reservoir and the gun. Right-angled connections should be avoided and the lines left as short as possible to avoid localized settling.

For low-volume applications, suction cup or gravity feed guns are most suitable. Paints should be diluted and mixed thoroughly prior to being added to the gun and should be stirred regularly to ensure solids stay in suspension.

Paints adhere well to most engi-

Pigment	Solids Content (%)	Applied Thickness (µm)	Typical Sheet Resistance (Ohm/Square)
Silver	55-60	10-15	<0.03
Silver	40-45	15-20	<0.05
Silver + silver-plated copper	35-45	20-30	<0.05
Silver-plated copper	35-45	30-40	0.1-0.25
Nickel	60-70	50-70	0.3-0.5

Table 4. *Typical Sheet Resistance Obtained with Specified Coatings.*

neering plastics. However, as with all coatings, moldings should be free from dirt, grease and mold release agents to ensure the best results. Priming is necessary on the thermoset range of plastics (i.e., glass-reinforced polyesters, glass-reinforced phenolics, SMC, DMC and polyurethane foam moldings).

Electroless and Electrolytic Plating

Electroless or autocatalytic plating processes can be used to deposit thin uniform layers of nickel or copper. For shielding applications, a duplex coating of electroless nickel phosphorous alloy (3 – 10% P) is deposited over a layer of pure copper.

The process involves loading parts to be coated onto jigs, which are then totally immersed in a series of tanks containing chemical solutions. There are three essential stages in the plating process: pre-treatment, catalyzing and electroless plating. The first stage involves chemically etching and then neutralizing the surface. The purpose of etching is to create microscopic cavities on the surface of the plastic. These will provide adhesion sites for the electroless metal deposit. Not all plastics can be etched and this limits the use of the process.

Catalysis is achieved by absorption of submicron metallic palladium particles from a diluted solution onto the etched pores in the plastic substrate.

The plating process is completed by immersing the catalyzed plastic part into the electroless plating baths. The palladium then reduces the metal ions in the solution to a metallic deposit on the plastic surface.

Typically 0.5-1.0 μm of electroless nickel phosphorus is deposited over 3-4 μm layer of copper. This provides very high levels of shielding and the coatings are extremely stable, wear- and abrasion-resistant.

One of the main drawbacks of conventional electroless plating is the inability to mask areas that do not require coating. This can now be overcome by applying a spray-on activator. The activator can be applied using normal spraying equipment to selected areas. Then the plating adheres only to the areas covered with the activator. Solvent- and water-based activators are available and allow a wide range of polymers to be coated (Figure 1).

Much thicker layers of nickel and copper can be deposited with conventional electroplating which requires a DC current to flow to achieve metal deposition. In this process, a very thin layer of electroless nickel phosphorus is deposited to make the surface of the polymer conductive. This is followed by an electrolytic deposition of copper to a thickness of between 10-15 μm. Finally a protective/aesthetic layer of nickel and/or chromium is deposited to a thickness of 8-12 μm.

Electrolytic copper nickel coatings can be aesthetically appealing as well as extremely durable and provide very high levels of shielding. There are, however, two main disadvantages of plating for shielding applications: limited range of plastics (best on ABS) which can be plated and the inability to mask off areas. For high-volume applications, masking can be achieved by two-shot molding the parts using platable and unplatable grades of polymer.

Physical Vapor Deposition (PVD) Techniques

Vacuum Evaporation

Thermal evaporation of aluminum is a widely available technique for depositing reflective and aesthetic coatings. Typically, the thickness of aluminum deposited is about 0.1 μm, and to ensure adhesion and environmental stability, the layer is sandwiched between protective lacquer. For EMI shielding application, processes have been developed to deposit films at least 2.0 μm thick. This ensures the conductivity necessary to achieve high levels of shielding and the stability of the coating without the need for top lacquers.

The coating procedure involves aqueous cleaning of parts prior to loading on fixtures which are designed to hold the parts in the vacuum chamber and mask areas that do not need coating. Once the parts are loaded, the chamber is evacuated to a base pressure of below 2×10^{-5} mbar. To improve adhesion, parts can be cleaned in-situ by glow-discharge bombardment prior to deposition of the film.

Coating thickness is built up by evaporating aluminium pins or wire placed on tungsten filaments. Thickness can be controlled to within 0.2 μm by controlling the number of pins or length of wire placed on the filaments. The process provides coatings of very high uniformity and batch-to-batch consistency. Coatings are flexible and adhere well to most engineering polymers. However, adhesion to polycarbonate, acrylics, nylons and glass-filled composites can only be achieved by bead blasting the surface prior to coating.

Magnetron Sputtering

Sputtering is defined as the ejection of surface particles by positive ion

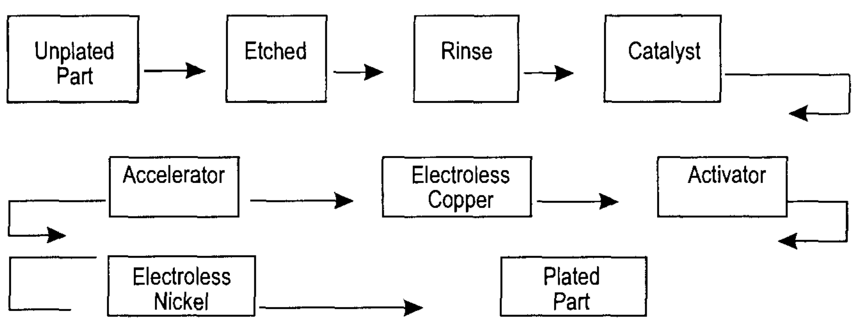

Figure 1. Electroless Plating Process.

bombardment. The ejection of particles occurs as a result of the direct transfer of momentum from the bombarding ions to the atoms of the target. The basic sputtering arrangement is illustrated in Figure 2. The material to be deposited is attached to the cathode and the substrates are placed on the anode or any other separate holder, which can be earthed or biased. To initiate the discharge, the chamber is first evacuated to 10^{-4} - 10^{-5} mbar to remove contamination such as water vapor, and then backfilled with an inert gas, usually argon. Typically, the argon pressure is between 0.5 - 1.0 - 10^{-2} mbar. The plasma is then struck by applying a voltage (500 V - 5000 V) between the cathode and the anode. When sputtering dielectrics, an RF voltage is required. Otherwise the material to be sputtered is connected to the negative terminal of the dc voltage source so that it will be bombarded by positive argon ions from the discharge.

Magnetron sputtering is differentiated from conventional diode sputtering by the use of magnets placed behind the target (Figure 3). The combination of electric and magnetic fields confines the electrons in the discharge to regions close to the target and hence, increases the electron density and therefore the ionization efficiency. This results in higher sputtering rates and a reduction in the substrate heating compared with simple diode sputtering.

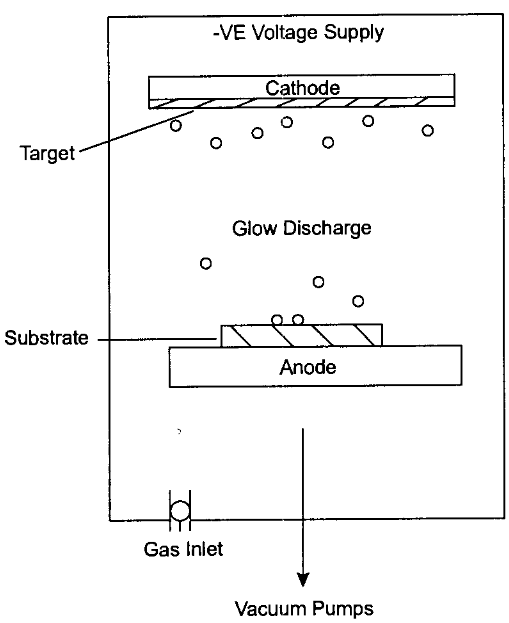

Figure 2. Basic Sputtering Arrangement.

Sputtering can be carried out either as a batch process or as a continuous process, the latter being the ideal design for large surface area substrates (i.e., foil or sheet material). Plants for continuous coatings are designed to either coat from roll to roll or, in the case of non-flexible substrates, "in line." The size of the targets can be varied from a few centimeters to some hundreds of centimeters. Virtually any metal or alloy can be deposited using the process. Silver, copper, aluminum and nickel have been sputtered for EMI shielding application.

The requirements of producing a coating with high conductivity, good adhesion to plastics and corrosion resistance can best be met by producing multilayer coatings. One such coating is a commercially-available multilayer coating of stainless steel and copper. The coatings are deposited in a single cycle using a dual target magnetron sputtering chamber. Figure 4 illustrates the structure of the coatings. The stainless steel base coat provides excellent adhesion to most plastic substrates. The middle layer of 99.9% pure copper provides the shielding. Typically a 1-micron layer of copper is deposited, providing shielding effectiveness in the range of 65-70 dB. The top layer of stainless steel protects the copper from oxidation and environmental degradation.

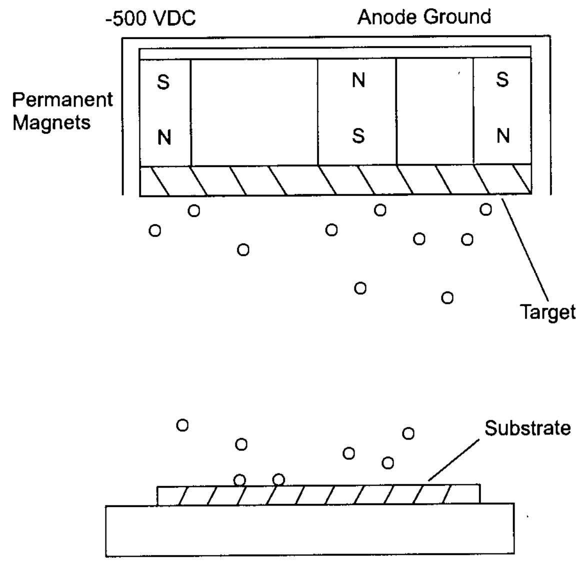

Figure 3. Planar Magnetron Target.

TRANSPARENT CONDUCTIVE COATINGS

There are basically two ways of achieving a transparent coating which is electrically conducting. One is to use a very thin metal and the second is to use a semiconductor. Metal-based coatings are the simplest solution to the problem. The best properties are obtained with high conductivity elements, silver, gold and copper. Of these, silver is preferable from an optical viewpoint because of the absorption of gold and copper in the visible part of the spectrum.

A thin layer of silver 10 nm thick will give a sheet resistivity of about 4 ohms square and good shielding effectiveness. Unfortunately, the visible transmittance through such a thin metal layer is less than 50%, the limited transmittance being caused by reflection at the coating surfaces. It is possible to improve transmittance by additional layers, usually on both

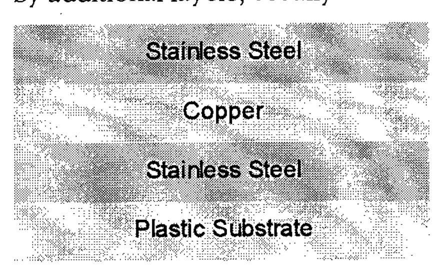

Figure 4. The Structure of RFI Shielding Coatings.

sides of the metal which act to anti-reflect it. High refractive index transparent dielectrics, such as tin oxide, indium tin oxide, indium oxide and titanium oxide give the best improvement in transmittance.

The problem with coatings based on thin metal layers is their limited chemical stability. Even with the oxide over-layers, degradation of the metal can occur in humid and polluted industrial atmospheres. Use of these coatings is normally limited to hermetically sealed multiglazed units, although use in a laminate is possible provided that potential corrosive attack at the rim is considered.

Semiconductors with a band gap wider than 3.0 eV are transparent and can be made conducting by creating a sufficient number of free carrier electrons. Materials known to be useful are all oxides of metals, zinc, cadmium, indium, tin and alloys of these. The doping, to give electrical conductivity, is achieved by the addition of a second element of differing valency. The oxide (SnO_2) has been doped with fluorine and antimony, indium oxide (IN_2O_3) with tin, cadmium oxide with either tin or indium and zinc oxide with aluminum. Of all these combinations, the best properties in terms of electrical conductivity and visible transmittance is given with tin-doped indium oxide, known as indium tin oxide (ITO).

Doped semiconductors and in particular, ITO, can be produced by a wide variety of coating techniques including vacuum deposition by evaporation, electron beam melting and sputtering, and chemical vapor deposition. Probably the most controllable process of producing ITO on large surfaces is that of magnetron sputtering.

The electrical resistivity of good quality ITO is about 200 μohm cm which means that a coating thickness of 0.5 μm is needed to give a sheet resistivity of 4 ohms square. This is ten times thicker than metal oxide, metal-oxide-metal multilayer used for shielding. The implications of this affect cost and optical properties. Thicker films take longer to produce and are therefore more expensive. The thickness of the ITO films are near to the wavelength of visible light, which means they can give rise to interference effects. Slight variations in thickness causes iridescence which is not acceptable to the operator. Therefore, controlled coating systems which can produce very uniform films are necessary.

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Conclusion

Over the past couple of decades, the proliferation of electronic devices has led to the introduction of regulations controlling the emission of electromagnetic waves. It is important that designers consider the EMC compatibility of their products at early stages of design. In many cases, compliance can be achieved by simple modifications to the board layout.

Coatings form an essential part of the design of many electronic products such as mobile phones, computer, medical equipment and military hardware. A number of coating processes have been developed that can provide high levels of EMC shielding.

With ever increasing intricacies and volumes of plastics that require shielding, EMC compatibility will continue to provide coating technologists with challenges to produce consistent, high-volume, low-cost coating solutions.

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