

Low frequency magnetic shielding: An integrated solution

Innovative direct coating technique as an alternative to conventional foils

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Many electrically sensitive devices, such as transducers, sensors, detectors, and test instrumentation require protection from electromagnetic interference (EMI). Higher frequency interference is normally shielded using a thin conductive metallization layer. Unfortunately, simple electrically conductive layers (e.g., copper, aluminum) are transparent to low frequency magnetic fields that can cause noise in an electronic device. This low frequency magnetic interference can be emitted from sources such as switches, motors, power supplies, and transformers and is typically a challenging EMI shielding problem. If the accuracy or precision of the underlying circuitry is critical, low-frequency magnetic shielding is required and is normally achieved through the use of specialty ferromagnetic metal alloys with high magnetic permeability (Figure 1). Materials with high magnetic permeability protect sensitive devices from the electrical noise caused by magnetic fields by redirecting the magnetic field through the shielding material and away from the protected device. In the same fashion, devices that emit low frequency magnetic fields can also be

isolated by using materials with high magnetic permeability.

Aside from the permeability, the strength (or flux density) of a magnetic shield must be considered as well. Each material has a magnetic saturation, which determines the magnetic field strength that can be effectively shielded. In strong fields, a magnetic shield can become “full,” after which it will no longer provide effective shielding. Many materials chosen for high magnetic intensity applications have good saturation, but higher saturation often comes with a sacrifice in terms of the absolute permeability that can be achieved. For the purpose of this article, we will focus on applications that are permeability limited, not saturation limited.

REVIEW OF SOLUTIONS

Shielding materials: magnetic properties and grain structure

The most common solution for shielding low frequency EMI is to use a high permeability

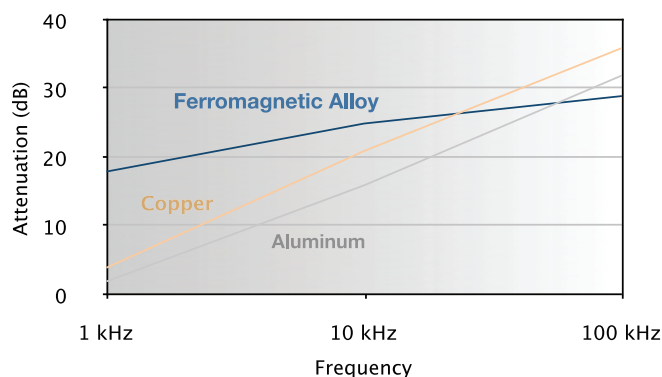


Figure 1. Magnetic shielding ability at different frequencies.

Adapted from: Ott, H.W., Noise Reduction Techniques in Electronic Systems (New York: John Wiley & Sons, © 1976)

magnetic shielding sheet metal or foil. Typical examples of shielding foils include specialty ferromagnetic alloys branded as MuMetal®, Netic®, Finemet® and Metglas®. In many of these alloy foils, the magnetic shielding properties rely on maintaining a large crystalline grain size of around 100 μm or more in the material. Since the materials have an equilibrium state grain size of around 1–10 μm, the large grain structure must be achieved through annealing the metal at high temperatures, often in a tightly controlled atmosphere to control impurities. Other foils have an amorphous, *i.e.*, no crystalline grains, or nano-crystalline structure that is normally achieved through complex manufacturing techniques including rapid solidification and high frequency annealing processes.

Existing shielding solutions

Although specialty foils are very effective EMI shields, they are best suited to shielding simply shaped parts. There are currently a few methods for

creating parts with relatively complex geometries, described in Table 1.

Foil Lay-up and formed foils

Since sheet metal or foils are manufactured flat, materials that resist forming operations, like glassy amorphous alloys, must be cut to shape and must be laid onto flat surfaces to achieve the necessary part shielding. Although these materials have excellent shielding performance, this lay-up approach is a cumbersome method for shielding parts with any contour. Other less brittle shielding materials can also be cut and formed to the shape required. For example, a sensitive transducer measuring a faint analog current might require a “can” of material over the device that will be integrated into the enclosure or onto the circuit board. This shape would need to be cut and stamped from the original sheet metal or foil. Although this process adds cost to the shielding process, it is not, in itself, a particularly challenging operation.

Unfortunately, the forming operation reduces the effectiveness of the shield by introducing deformation into the material—destroying the key material characteristic that generates the high permeability. To restore the defect-free structure, the material must be annealed once more in a high temperature controlled environment to restore shielding effectiveness. This necessity presents a restriction for customers as the forming operation now has to be coupled with an annealing operation, limiting the possible manufacturers, or adding an additional step in the supply chain.

Apart from shielding efficacy, the forming step also sets a practical size limit as complex or small geometries are difficult to produce. As electronic structures and packaging shrinks, discrete, formed shields may not be a viable alternative. Lastly, once the discrete shield is cut, formed, and annealed, it still needs to be integrated into the assembly of the shielded part. This integration requires labor and of-

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	Foil Lay up	Formed Foils	Metal Injection Molding (MIM)	Metal components
Advantages	<ul style="list-style-type: none"> • Excellent shielding properties • Effective for low volume applications and simply shaped parts 	<ul style="list-style-type: none"> • Excellent shielding properties • Suitable for handling modest geometries 	<ul style="list-style-type: none"> • Ability to form more complex shapes where tooling cost is not an issue 	<ul style="list-style-type: none"> • Can be cost effective where weight is not an issue
Drawbacks	<ul style="list-style-type: none"> • Labor intensive = high cost • Sensitive - performance degrades quickly with deformation 	<ul style="list-style-type: none"> • Requires heat treatment after forming to achieve shielding performance • Sensitive - performance degrades quickly with deformation • Integration onto part surface requires manual labor = higher cost 	<ul style="list-style-type: none"> • Requires sintering - shrinkage & porosity • Tooling can be expensive • Lower shielding effectiveness • Effective for small parts only 	<ul style="list-style-type: none"> • Steel parts are very heavy • Al and Mg often do not have sufficient low frequency shielding

Table 1. Existing shielding solutions.

ten relies on adhesives, further adding to the assembly cost and complexity.

Metal injection molding (MIM)

Fine specialty ferromagnetic powders

can now be injection molded with a binder to create complex parts that are effective low frequency magnetic shields. After molding, the parts are thermally or chemically treated and then sintered at

high temperatures to remove the binder. Secondary operations are sometimes required to achieve the final shape. Although this process can make effective shields in relatively complex forms, part shrinkage must be accounted for, as well as mechanical considerations such as part porosity and brittleness. As tooling costs can be high, this method is ultimately best suited for high volume but relatively small parts.

Metal components

Conventional metal components, such as steel stampings and castings, can also be used for low-frequency EMI shielding. Often, this can be a very cost-effective method, but the additional weight can be problematic in some applications. Much thicker steel stock will be required to achieve the same shielding effectiveness as specialty ferromagnetic alloys and in many cases a minimum thickness of steel is required for the forming operations. In many applications where weight is critical, steel is being replaced



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with other materials, such as polymers or aluminum that have little or no low frequency shielding capability. These materials must often be combined with one of the other shielding solutions.

ALTERNATIVE SOLUTION: DIRECT PART COATING

An alternative solution is to apply a high magnetic permeability metal coating directly to the surface of a part (Figure 2). This process is easily adapted to small and complex shield shapes and avoids many of the possible drawbacks of a discrete shield, including the elimination of annealing steps. Coating parts with conductive surfaces is often used for high frequency EMI shielding in electronics applications using techniques such as physical vapor deposition (PVD), conductive paints, and electroless and electrolytic plating. In these cases, the primary requirement is a thin conductive coating. With recent developments in nanocrystalline ferromagnetic coatings, the same concept can now be used for low frequency shielding.

Magnetic properties of nanostructured coatings

In contrast to conventional shielding materials that derive magnetic properties from their large, un-deformed grain structure, a ferromagnetic alloy coating with a very small (nanometer,

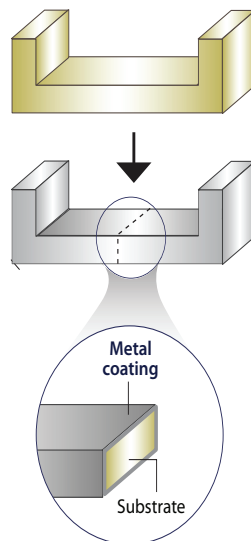


Figure 2. Part directly coated with high magnetic permeability metal.

in fact) grain structure can also achieve high permeability—and therefore similar magnetic shielding performance. Figure 3 illustrates the relationship between coercivity and grain size in a ferromagnetic material. Typically magnetic shielding materials with low coercivity also possess high permeability. Therefore, as shown in the graph in Figure 3, when the grain size of the material is reduced to the nanometer scale, the coercivity is minimized and the permeability is maximized. A similar effect also occurs with very large grain size.

Processing and design benefits and limitations

Although the magnetic shielding characteristics of nanocrystalline ferromagnetic metal coatings are good, the real benefit lies in the processing and design flexibility that this material affords. This material is used most frequently as a coating deposited directly onto part substrates such as metals (e.g., aluminum enclosures), polymers (e.g., thermoplastic formed parts), and composites (e.g., carbon fiber epoxy structures)—a process that avoids any forming operations. The coating can be integrated directly into the part packaging or enclosure, a design option that reduces part count by eliminating the discrete formed shield and related adhesives and labor. Selective coating is possible, allowing shielding performance that can be delivered where it is needed most and avoiding unnecessary added weight. For injection molded polymers in particular, monolithic part integration is now possible because the shielding function can be molded directly into the larger electronics enclosure or part packaging.

Aside from avoiding the forming operation, deformation of these nanocrystalline coatings does not affect the grain size, thus retaining shielding effectiveness and avoiding both a loss in performance and a re-annealing step. However, the long-term operating temperature must be kept under a threshold of approximately 400°F to avoid grain growth back to a larger crystalline equilibrium state. (The exact temperature will vary depending on the alloy composition.)

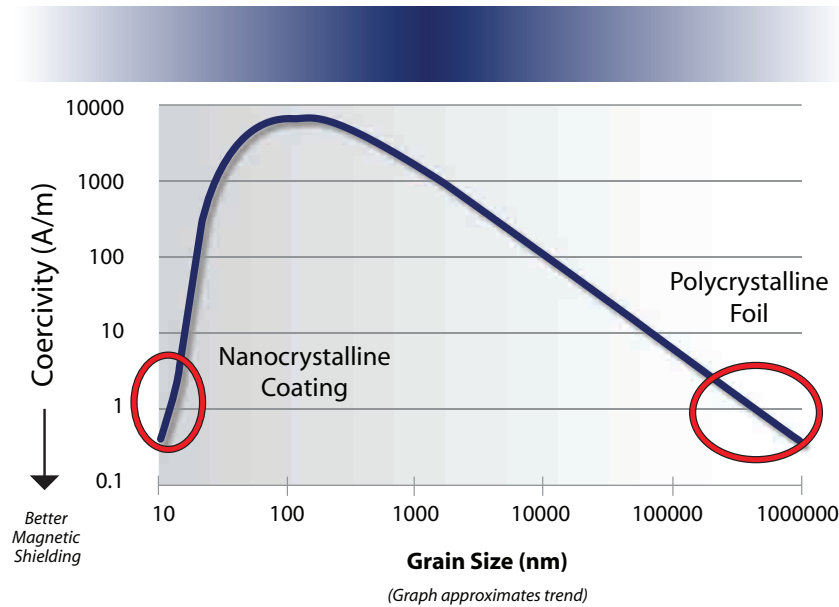


Figure 3. Trend of coercivity vs. grain size
Source: Adapted from G. Herzer, Mat. Sci. Eng., A133 (1991).

As with any solution, this approach has its own drawbacks. The metal coating operation is a secondary operation that adds cost to the part. In addition, the thickness and distribution of metal

in a typical deposition process for nanocrystalline metals is influenced by part geometry. Despite these factors, the application process is industrially scalable, and the metal coating approach

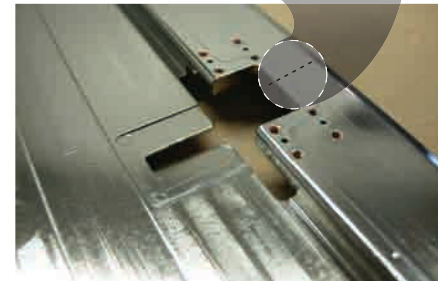
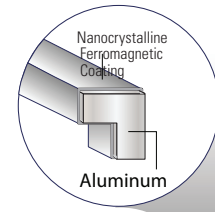


Figure 4. Aluminum housing coated with nanocrystalline ferromagnetic coating.
Source: Integran Technologies Inc.

is effective for applications in which discrete shields are awkward or impractical. An example of a metal part that can benefit from direct part coating is shown in Figure 4 that depicts a complex aluminum machined housing that required shielding. The application

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is weight sensitive and required layups of MuMetal® foils and labor intensive work to bend the foils and to bond them to shield the corners. As an alternative, a nanocrystalline ferromagnetic coating, 50 microns thick was applied. The part has performed well in initial EMI testing, and the majority of the foils could be eliminated, decreasing both weight and cost. The part also benefited from increased surface hardness and an aesthetically pleasing finish.

Polymer parts can also benefit greatly from direct coating solutions (Figure 5). Complex moldings may be coated, a step that also provides additional stiffness, strength, and surface hardness to create multifunctional parts that may be lighter and thinner than die-cast parts. Coating a complex polymer housing with a nanocrystalline metal will add stiffness and strength to the polymer part. Figure 6 shows a polymer housing with the coating applied selectively. This selective application delivers shielding performance where it is required and



Figure 5. Polymer cell phone component selectively coated with nanocrystalline metal shielding.

Source: Integran Technologies Inc.

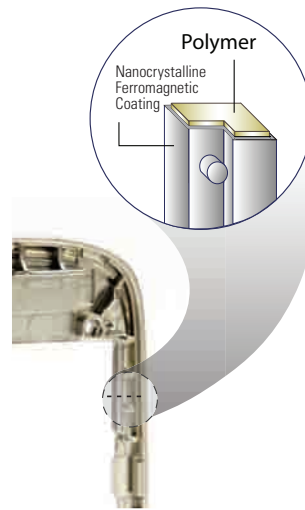


Figure 6. Complex polymer housing coated with nanocrystalline metal shielding.

Source: Integran Technologies Inc.

eliminates unnecessary weight. Using a selective coating process can enable

monolithic integration of discrete parts in an assembly, reducing part cost.

Material property benefits

Another useful property of nanocrystalline coatings is that they have a higher strength and hardness than coarse-grained equivalent material (Table 2). Applied to polymer substrates, the increase in strength can be used to dramatically increase the strength and stiffness of the hybrid part. A relatively weak or flexible polymer enclosure can now become a rigid, durable structural part. The high yield strength and good ductility also make the coating particularly well suited for polymer and composite applications that often undergo a lot of flexing. A lower strength coating would plastically deform with flexion; whereas traditional high strength coatings are normally brittle, a situation that typically leads to failure at low loads.

Nanocrystalline metals can now be made fully dense—i.e., they have no voids or porosity. Having a highly impermeable coating could be beneficial either for keeping liquids or gases from penetrating the surface of a part, as would be the case for protecting a polymer case from chemical attack, or for keeping the part from outgassing into the environment—often a secondary consideration in semiconductor or space applications.

	Nanocrystalline Coating	Polycrystalline Foil
Material Application	<ul style="list-style-type: none"> • Foils (thick and thin) • Coating of polymers • Coating of composites • Coating of metals 	<ul style="list-style-type: none"> • Foils • Stampings
Yield Strength	• > 900 MPa	• ~340 MPa
Hardness	• > 500 VHN	• ~140 VHN
Post Processing	• None, as deposited	• Annealing needed after any deformation
Effect of Deformation	• Difficult to deform because of high Yield Strength	• Significant drop in magnetic properties when deformed

Table 2. Comparison of nanocrystalline coating vs. polycrystalline foil. Source: Integran Technologies Inc.

CONCLUSION

While specialty ferromagnetic foils and sheet metal stock are useful for creating relatively simple geometry discrete magnetic shields, they require forming, annealing, and assembly steps and are not amenable to small or complex parts. Metal injection molding and standard steel parts can also solve many shielding problems but can run into challenges in weight and lower shielding effectiveness. Nanocrystalline ferromagnetic metal coatings offer an alternative solution for directly shielding metal, polymer, or composite parts which can reduce cost by simplifying the supply chain and assembly process. This metal coating process also offers the possibility of creating small or complex shields that were previously impractical with discrete shielding methods. Additional benefits can also be realized by using the superior mechanical properties of nanocrystalline metals to strengthen, stiffen, render impermeable, or add durability to a polymeric part.

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