Development of flexible materials suitable for shielding electromagnetic waves over a wide range of frequencies

Physical vapor deposition (PVD) may be a cost-effective alternative for improving the shielding effectiveness of plastic housings and metallized woven and nonwoven shielding materials.

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At high frequencies (HF), achieving effective EMC shielding means meeting ever more stringent specifications. Modern electronic devices use ever higher frequencies; in consequence, these devices have created rising demands for:

- Higher shielding properties over a wider frequency range
- Materials with particularly high- or low-loss magnetic hysteresis properties at high frequencies
- Special magnetic permeability properties (μ)
- Special electric permittivity properties (eps)
- Special reflectance and/or absorbent properties

For shielding, an abundance of materials and technologies are now in use. Chemical metallization and plating processes are used especially for smaller and more complexly shaped plastic housings. With the direct stationary physical vapor deposition (PVD) of plastic housings, metal layers can be added directly to simply shaped housings. More complex multi-piece housings necessitate the use of gaskets made from metallic gasketing—metallized yarn or metallized woven or non-woven materials. This metallization can be achieved either by chemical metallization and subsequent plating or through physical vapor deposition of flexible materials. Shielding of larger areas, within buildings, for example, is usually accomplished using chemical or PVD metallized wovens or non-wovens.

NEW MATERIALS FOR EMC APPLICATIONS

Recently, there have been new developments in the area of flexible PVD-coated materials for EMC applications. These materials were developed to improve the shielding properties of substrates coated by PVD while keeping costs to a minimum. In fact, these new techniques are less expensive than the options considered above. However, these new developments are limited by the layer thicknesses that can be achieved without introducing excessive heat. Certain inherent shielding trade-offs are created by this coating process. Layer thickness is controlled by the evaporation rate and by the speed at which the substrate is moved over the evaporation source. Essentially, a slower speed yields a greater layer thickness but exposes the polymer substrate to the higher heat load generated by the thermal radiation from the evaporation source. The challenge arises in improving the shielding effectiveness of PVD-coated materials in spite of the inherent limitations encountered.

SHIELDING MECHANISMS AND POSSIBLE IMPROVEMENTS

The basic principles of electromagnetic shielding, established by Schelkunow in the 1940s, provide a model for future reference. Figure 1 illustrates the diminution of electromagnetic wave intensity as it passes through material.

If a more complex model which utilizes porous, non-flat material is used rather than an ideal plane and a continuous material surface, the effect of wave scattering is introduced. Alternatively, the use of several layers of different metallic materials heightens the effects of the multiple reflection and the absorption inside the material because the number of interfaces has increased. This improved shielding efficiency is demonstrated in Figure 2.

SHIELDING MECHANISMS ACCORDING TO SCHELKUNOW

For a further explanation of this model, the following equation should be used.

$S = -\log(T/Io)$, with $T = Io - (A + R + B)$ yields:

$$S = -\log[1 - (A + R + B)/Io] \qquad (1)$$

The shielding factor (S) may be defined as the negative log of the transmitted-to-incoming intensity of the HF wave (in correspondence to the laws of optics). The transmission (T) is the sum of absorption (A) in the material that forms the housing, the direct reflection (R) at the same material, and the multiple reflection (B) inside this material (wall).

USE OF MULTIPLE LAYERS IMPROVES THE SHIELDING EFFICIENCY

By using a more complex model and several layers of different metallic materials, the effect of the multiple reflections and absorptions within the material caused by the number of interfaces is increased.

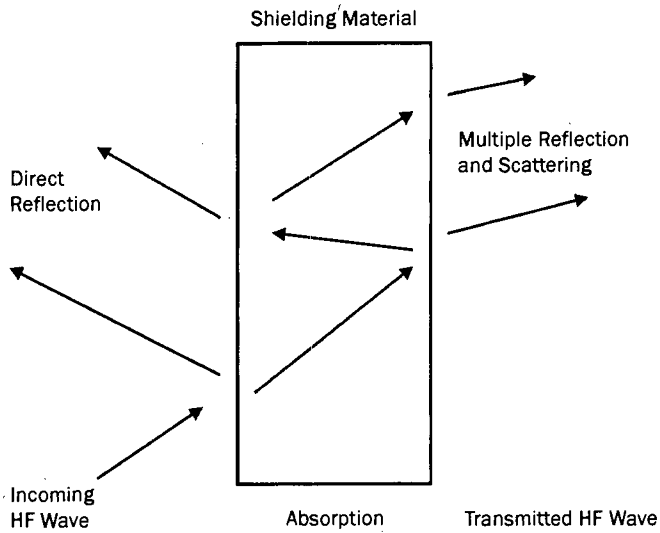

Figure 1. Model of the shielded HF wave. The material might be an electromagnetic device that needs to be shielded.

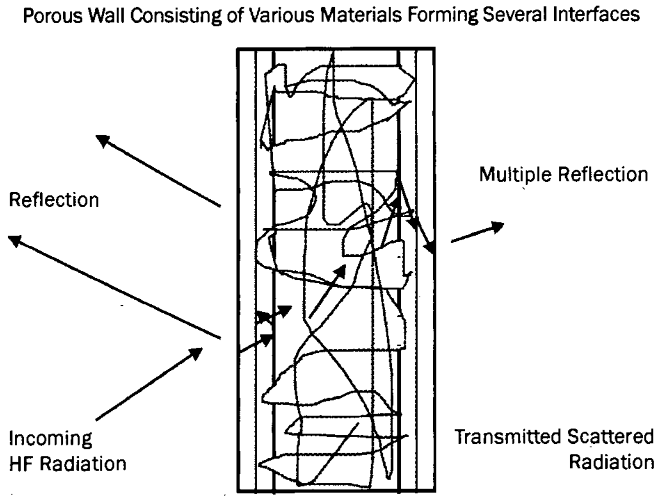

Figure 2. Schematic structure of the shielding material.

This raises the shielding efficiency considerably as is demonstrated in Figure 2:

In Equation 2 the shielding equation as established by Schelkunow has been altered by the addition of multiple reflectance and scattering

$$S = -\log T/Io = -\log[1 - (AB + R + BB + C)/Io] \qquad (2)$$

Now, the transmission (T) is further diminished by the multiple absorption (AB) caused by the wall, by the multiple reflections (BB) at the inner interfaces formed by the sequence of the various metal layers, and finally by the multiple scattering (C) caused by the roughness and porosity of the substrate material.

A comparison of Equations 1 and 2 shows that the introduction of new sources of shielding should improve shielding efficiency. In Table 1 this is done by comparison to film metallized in the same manner.

FABRICATION AND STRUCTURE OF THE NEW HF SHIELDING MATERIAL

The material corresponding to the model introduced above is formed by a triple metal layer on either side of a nonwoven with 65 g/m^2 areal weight. The single layers are produced by the physical vapor deposition of copper, aluminum and copper. Each forms a semicontinuous layer on both sides of the substrate. A metric thickness could not be measured due to the layers' roughness (*i.e.*, the substrate used is uneven and has both a flat and a rough side). Porosity can be determined by measuring the electric resistance of the layers after each PVD process step.

The measurements were always performed on both sides of the substrate. The results emphasize the significant effect of using a rough and porous substrate, rather than metallized Kapton film or even a

Substrate	Designation	Layer Sequence	Process Step #	4-Point Probe Resistance	Eddy Current Resistance	ϕ Shielding dB
			Even numbers: flat side; Uneven numbers: rough side	Ω/sq.	Ω/sq.	Near N, far range F
35 µm Cu metal foil		Reference material		<< 0.1	<< 0.1	N: 20; F: 20
Kapton 50 µm		Cu	1	0.22	0.1	N: 35
			2	0.12		F: 25
Non-woven	MV83/93	Cu	1	1.70	0.99	N: 35
65 g/m²			2	1.72		F: 25
Non-woven	MV28/11/98	Cu	1	3.17	0.36	
			2	10.1		N: 35
		Al-Cu	3	1.42	0.99	F: 25
			4	3.62		
		Cu-Al-Cu	5	1.06	0.64	
			6	2.03		
Non-woven	MV28/11/98	Al	1	2.54	0.55	N: 40; F: 25
65 g/m²			2	6.29		
		Cu-Al	3	1.71	1.1	
			4	2.97		
		Al-Cu-Al	5	1.34	0.76	
			6	2.06		

Table 1. Shielding effectiveness results of physical vapor deposition.

copper metal foil of much greater thickness. Note that the efficiency of the shielding in the frequency range considered is improved significantly by the PVD layer and that it is improved even further by the triple layer on either substrate side.

The following scanning electron microscope image reveals the porous structure of the material.

DISCUSSION OF THE SHIELDING MEASUREMENTS

The shielding measurements were carried out in an absorbing chamber according to VG 95373 T 15. Figure 4 shows the shielding of the non-woven with a triplet metal layer on either substrate side:

For comparison, the same substrate is shown in Figure 5 with a single metal layer (designated MV83/98 in the table above).

CONCLUSION

Heightened shielding efficiency can be attained by introducing additional porous uneven substrate surfaces and multiple metallic layers. These introduce multiple scattering and multiple inner

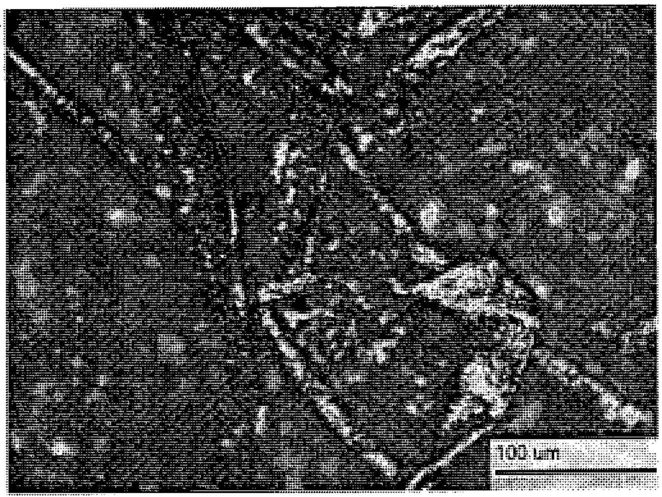

Figure 3. Scanning microscope image of the shielding material.

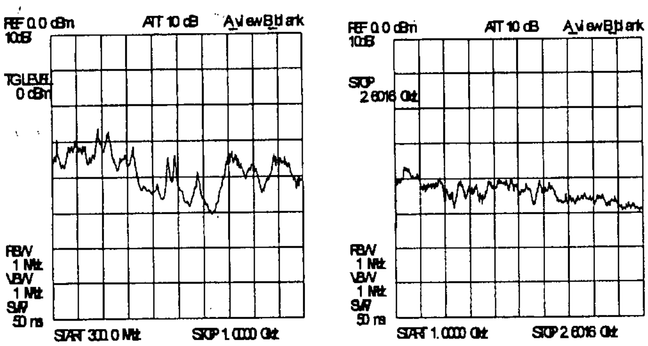

Figure 4. Shielding of a nonwoven with a triplet PVD metal layer Cu-Al-Cu on either side for a) f = 300 MHz–1GHz; b) f = 1 GHz–2.6 GHz.

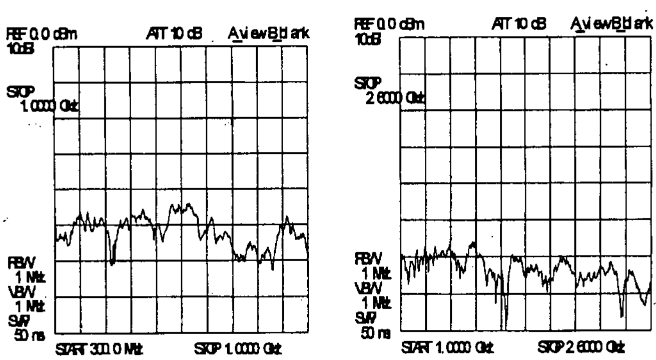

Figure 5. Shielding of a nonwoven with a single PVD metal layer Cu on either side for a) f = 300 MHz–1 GHz; b) f = 1 GHz–2.6 GHz.

reflections which boost shielding efficiency. The substrate used was a nonwoven with a triple PVD metal layer on either side, which improved the damping by 10 to 15 dB over a frequency range of 0.3 to 2.6 GHz. This brings shielding values into a range where direct application might be feasible for shielding carpets or wall papers in safety rooms for data security, EMC housings for larger simple shaped housings, EMC gaskets, and EMC cable shielding.

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