Preliminary results on the electromagnetic shielding effectiveness of organic fabrics silver coated by high voltage anodic plasma

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This paper reports preliminary results of the shielding efficiency (SE) obtained for silver coated temperature sensitive organic fabrics. Thin metallic films (Ag) have been deposited in vacuum at room temperature onto organic mesh using the high voltage anodic plasma method. The electromagnetic shielding effectiveness of the silver coated mesh was measured in the frequency range of 0.3 MHz – 4 GHz by ASTM ES7-83 standard test method. It was observed that even for such an open structure of the substrate, increasing the thickness of the coating is reflected in an increase of the SE. It was also found that the shielding efficiency increases with the number of coated sheets, but not proportionally to their number. Another finding was that the SE of a single thick coated sheet was higher than that of a stack of sheets coated with thinner films having a total thickness equal to the single thick coated sheet. This was attributed to the lower surface conductivity of the thinner silver coatings.

(Received November 14, 2014; accepted September 9, 2015)

Keywords: thin films, anodic plasma, electromagnetic shielding

1. Introduction

Nowadays, the electromagnetic interference (EMI) in electronic instruments, military electronic devices and radar and antenna systems is a well-known problem. Electromagnetic Interference (EMI) is an unwanted electromagnetic wave emission that could interfere to an electronic device, perturbing (conducted, spurious, or radiated signals) the original signal that can cause unacceptable degradation in system or equipment performance [1]. There is a critical need for reducing EMIs by developing effective and practical electromagnetic shields (in the case of perturbing radiation) and selective noise filtering systems (in the case of inductive disturbances). According to the Federal Communications Commission (FCC) radiated EMI is most often measured in the frequency range from 30 MHz and less than 10 GHz but conducted is measured in the frequency range from 1 KHz to 30 MHz [2].

Requirements for materials with electromagnetic field shielding capabilities are of current interest for various reasons of which environmental and human health protection are representative. These new materials are used as electromagnetic shields against the unwanted electromagnetic radiation emitted by different sources in several fields of application ranging from navigation and radio location to medical diagnostic and physiotherapy equipment. Organic materials have intrinsic properties that make them very valuable: flexibility, light-weight, mechanical stability, etc; because of this, they are excellent for imparting additional functionalities like screening of the electromagnetic field [3].

2. Experimental

2.1. Silver coatings on organic materials

Sheets of commercially available mesh (7x7 holes/cm^2) were silver coated on one side using the high voltage anodic plasma method - an anodic discharge obtained using DC voltage of the order of kV and low current (a few Amperes). Full details of the method are presented elsewhere [4-7] while in Table 1 the main deposition process parameters are listed. It was demonstrated that this technique makes possible the production of thin coatings at very low temperature (room temperature) and under high vacuum conditions (about 10^{-5} Torr) without the use of buffer gases.

Table 1. Process parameters used for silver coating of mesh, where: If = filament current; Id, Ud = discharge current and voltage.

Sample	Silver plasma parameters				Coating thickness (nm)	Coating time (min)
	Chamber base pressure (Torr)	If (A)	Id (A)	Ud (V)		
Mesh 1	1.5×10^{-5}	54	1.6	50	50	10
Mesh 2	1.5×10^{-5}	54	1.6	50	150	30

The silver atoms and the energetic silver ions resulted in the plasma enter the first few atomic layers of the substrate and form an adherent film, as evidenced by SEM (Fig. 1).

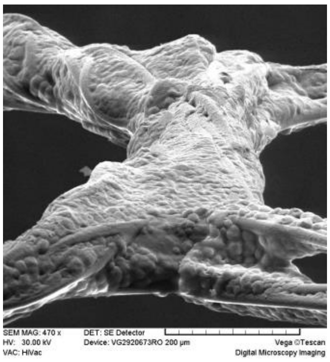

Fig 1. Scanning Electron Microscope image of the silver coated fiber

2.2. Shielding efficiency measurements

The SE measurements were performed in the frequency range 0.3 – 4000 MHz using the “ASTM ES7-83 coaxial transmission line method for planar materials”. The experimental test setup is schematically presented in Fig. 2 and consists of a network analyzer which is able to measure the incident, transmitted and reflected powers of a planar sample and a coaxial TEM cell as sample holder [8].

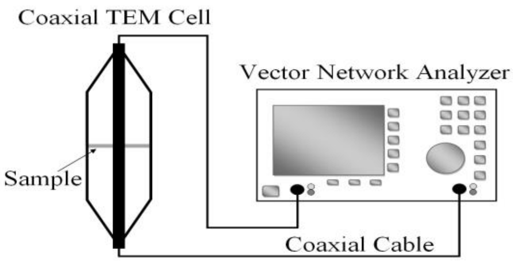

Fig. 2. Schematically representation of the shielding efficiency test set-up.

In order to determine the SE value of the investigated sample, a signal is applied from one side of the TEM cell while on the other side the power of the transmitted signal is measured in both cases: without sample as a reference measurement (P_i) and through the sample (P_t). The SE value is given by the ratio of the two transmitted signal powers. Thus, SE in decibels is given by the following formula:

$$SE_{dB} = 10 \cdot \log\left(\frac{P_i}{P_t}\right) \quad (1)$$

The above formula is obtained using a measurement chain consisting in a signal source and a receptor (oscilloscope or spectrum analyzer). When using a vector network analyzer the information obtained is about the transmission coefficient defined by the formula:

$$S_{21(dB)} = 10 \cdot \log\left(\frac{P_t}{P_i}\right) \quad (2)$$

In the present investigation, the measurements were performed using a vector network analyzer so, taking into account the equations 1 and 2 it can be seen that the measured parameter (S_{21}) gives the negative shielding efficiency:

$$S_{21(dB)} = -SE_{dB} \quad (3)$$

In order to fit into the sample holder of the SE measurement device, discs of 10 cm outer diameter and 3 cm inner diameter were cut from the coated fabrics. In order to ensure good electrical contact between tested mesh and sample holder, the inner and outer edges of the mesh were supplementary coated with a conductive silver layer.

Measurements of SE with increasing film thickness for one and also for multiple meshes were undertaken in this study.

3. Results and discussions

Before presenting and discussing the results it has to be underlined that the organic material used as substrate for metallization has an highly open structure that reflects in lower SE values than the continuous ones [9]. Two sets of experiments were performed:

- for the investigation of silver layer thickness effect on the shielding properties of the fabric;
- to study the effect of superposing multiple coated mesh sheets on the shielding efficiency.

In order to asses the importance of the coating thickness single sheet of fabric coated with 50 nm (black line) and 150 nm (red line) silver layer were analyzed from the shielding efficiency point of view and the obtained results are presented in Fig. 3. It was observed that for the 50 nm silver coating no electromagnetic shielding effect is produced, the SE value being almost zero in the frequency range used. The absence of the screening effect is most probably caused by low reflection of the electromagnetic waves combined with a low absorption into the thin silver layer. Increasing the thickness of the silver layer to 150 nm a minimum value of 7 dB for SE is obtained. This value is equivalent to an attenuation of about 90% and it is comparable with the values obtained for woven fabrics made of cotton doubled by silver wires [10]. Also, analyzing the SE dependence on frequency, two different behaviors can be observed in the case of 150 nm thick silver coating. In the frequency range 0.3 – 1500 MHz the SE value presents a continuous decrease from 27 dB @

0.3 MHz to 10 dB @ 1.5 GHz while for the 1.5 – 4 GHz range a minimum of 7 dB in SE is obtained along a set of 4 points of higher values of 17 dB @ 2.05 GHz, 16 dB @ 2.1 GHz, 12 dB @ 3.05 GHz and 14 dB @ 3.3 GHz.

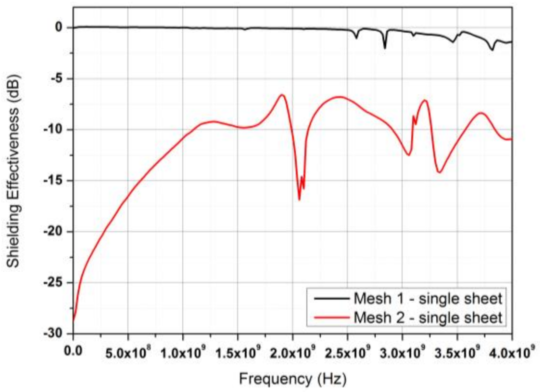

Fig. 3. Shielding Effectiveness (SE) of 50 nm (black line) and 150 nm (red line) silver coated single mesh

The SE of stacks of coated meshes was measured in the same set-up configuration. A comparison between SE obtained using a single mesh with stacks consisting of 2, respectively 3 superposed sheets is presented in Figs. 4 (for 50 nm silver coating case) and 5 (for 150 nm silver coating case).

On addition of more sheets, the SE increases but the increase is not proportional to the number of sheets. It can also be noted that the addition of sheets results in smoothing of the spectrum of the emergent radiation.

The behavior of increasing of the SE value with the number of sheets in the stack is observed also in the case of 150 nm thickness silver coatings. It can be observed from Fig. 5 that the minimum shielding efficiency increases from 7 dB for a single sheet to 21 dB for two sheets stack and 26 dB for three sheets stack, respectively. Also, the same trend of the SE – Frequency dependency may be observed in the two, respectively three sheets stacks as for the single sheet case. In the range of frequencies bellow 1.5 GHZ the shielding efficiency decreases continuously while in the 1.5 – 4 GHz the shielding efficiency is almost constant but presenting some local minimum points. An interesting observation is that contrary to the case of 50 nm silver coated stacks these local minimum SE points become less pronounced by increasing the sheets number. This different behavior of the SE may be attributed to the mismatch in superposing the holes of the meshes and this is the reason why we took into account, while investigating the effect of superposing multiple coated meshes, only the minimum value of the SE.

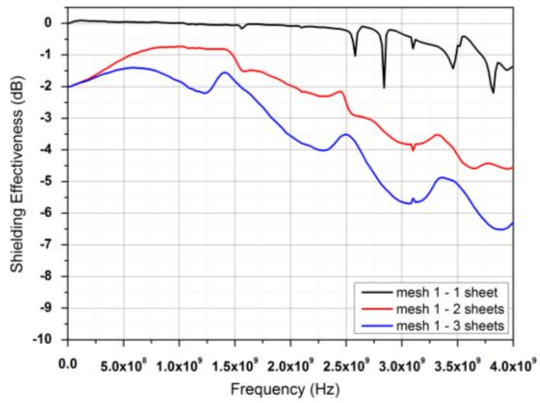

Fig. 4. Comparison of the shielding efficiency between 1 (black line), 2 (red line) and 3 (blue line) superposed 50 nm coated fabrics

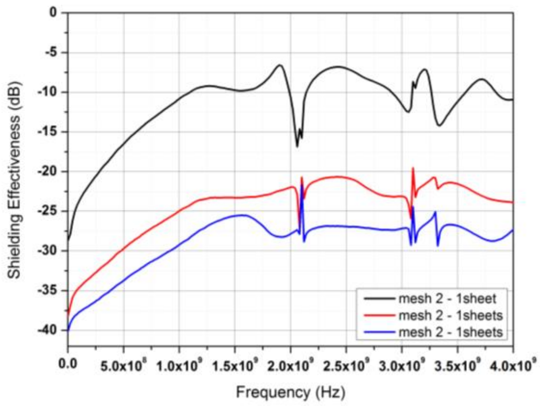

Fig. 5. Comparison of the shielding efficiency between 1 (black line), 2 (red line) and 3 (blue line) superposed 150 nm coated fabrics

Another observation that cannot be neglected is that the shielding efficiency of a single thick coated sheet was higher than that of a stack of sheets coated with thinner films having a total thickness equal to the single thick coated sheet, as presented in Fig. 6.

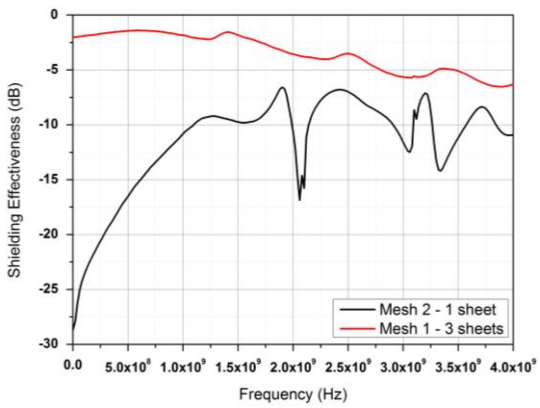

Fig. 6. Shielding Effectiveness of single 150 nm silver coated mesh (black line) and a stack of three 50 nm silver coated meshes

This result is probably due to the smaller surface conductivity of the thinner films.

Moreover, a different behavior in the SE – frequency dependence was observed by comparing the results obtained for a single silver layer of 150 nm and a stack of three superposed sheets of 50 nm silver coating. In the low frequency region (< 1.5 GHz) the SE decreases with frequency, this being attributed to the geometry of the holes in the single mesh which differed from that of the stack.

4. Summary and conclusions

The present paper reports the results of shielding efficiency (SE) obtained for 50 nm and 150 nm silver coated single and multiple organic meshes. An SE value of 7 dB was obtained with an 150 nm silver coating. This is a reasonable value for the open structure type of mesh used as substrate. Increasing the number of coated sheets results in an increase of shielding efficiency due to multiple reflections on the coating surfaces and a simultaneous smoothing of the electromagnetic spectrum.

Acknowledgements

The authors from NILPRP acknowledge the financing of the research by UEFISCDI under the NUCLEU program project PN No.09.39.01.03. Authors would like also to acknowledge the by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132397.

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