RSSI, Vol. 08, N°. 01, Juin 2019, 01-06

Revue des Sciences et Sciences de l'ingénieur
Journal of sciences and engineering sciences

ISSN 2170-0737 EISSN: 2600-7029

https://www.asjp.cerist.dz/en/PresentationRevue/303

Enhancement of the Electromagnetic Interference Shielding Efficiency of Mixtures and Multilayer Films

Merizgui Tahar [*1,2]. Hadjadj Abdechafik [2]. Kious Mecheri [1].

[1]*Laboratoire des Semi-conducteurs et Matériaux Fonctionnels, Université Amar Telidji de Laghouat, BP 37G, Laghouat 03000, Algeria.*

[2]*Laboratoire d'Analyse, de Commande des Systèmes d'Energie et Réseaux électriques, Université Amar Telidji de Laghouat, BP 37G, Laghouat 03000, Algeria.*

Article history
Received: 2018-03-21
Accepted: 2019-02-20

Abstract

The paper aims to measure the EMI shielding efficiency SE of the mixtures of Polyaniline (PAN) and conducting powders such as silver (Ag), graphite, and carbon black. The EMI SE of hydrochloric acid doped Polyaniline containing silver (Ag) powder at room temperature with 70 µm thickness. Chemical doping in PAN mixture samples in this research paper aims to enhance the SE of materials, which indicates of theoretical values received from a good conductor approximation that the used materials and techniques can be commercially applied in shielding application against electromagnetic EM radiation. The theory of EMI SE calculation appears their effects in multilayer films based on conducting polymers. These conducting polymers were discussed in terms of boundary conditions for electric and magnetic fields of an EM plane waves. EMI shielding response displays the monolayer and multilayer films are dependent with the different thickness at high frequencies were compared and shows the theoretically expected results.

Key-words : Conducting polymers; Mixture; Multilayer film; Monolayer film; Electromagnetic interference;

Résumé

L'objectif de ce présent travail est une étude comparative qui consiste à évaluer et améliorer les performances de blindage électromagnétique de plusieurs films multicouches à base de polymères conducteurs tout en prenant en considération l'influence imbriquée des propriétés physique des matériaux utilisés dans ces films (Conductivité, Perméabilité, Permittivité, Epaisseur). Les résultats obtenues permettent d'évaluer l'efficacité de blindage des films multicouches et de faciliter le choix judicieux d'une modélisation adaptée sur une gamme allons de 0.1Hz jusqu'à 10GHz.

Mots-clés : Polymères conducteurs ; Mélange ; Film multicouche ; Film monocouche ; Interférence électromagnétique ;

*Merizgui Tahar. Tel./fax: +213 775424422.
E-mail address: t.merizgui@lagh-univ.dz

1. Introduction

Electromagnetic interference EMI is a most undesirable thing that produced by the explosive growth of electronics and monetization of devices [1-2]. EMI is becoming an alarming issue which can disturb and effect on the performance of electronic appliances and the human health. The EMI shielding efficiency SE in a wide frequency range depends on intrinsic properties of shielding materials (conductivity σ and dielectric constant ε_r), the frequency of the source, and the distance between the source and the shield [3-5]. It is well known that the higher conducting materials such as copper and silver which were used and well suited for contributing to high EMI shielding efficiency (SE) [6-8]. While typical metals have good mechanical properties and are the most common materials for EMI shielding applications but they have the disadvantages for being heavy weight, easy corrosion, and a poor ability for shielding material. Doped polyaniline (PAN) and its alloys with conducting powder are promising materials for EMI shielding application to supplement the disadvantages of conventional metals [9].

Conducting polymers has the advantages for being lightweight, physical flexibility, and a tunable shielding response. For commercial and military applications, the required EMI shielding efficiencies are in between 40 dB and 80 dB. So the conducting polymers become required materials for many shielding applications, and there are many technics to enhance the EMI SE of the materials by using these conducting polymer/metal composites for example or use them as a multilayers film [10]. The SE of multilayer films standing is being consisted of the high H and low L conducting layers with the same thickness as the monolayer material. The SE of H–L–H layers are smaller than that of H–H–H layers at low frequency. Nevertheless, there exist frequency ranges where the SE of H–L–H layers are larger than that of H–H–H layers. The result suggests that the coherent multiple reflections at the internal interfaces of H–L–H layers contribute to increase the SE. We observe that the effect of coherent multiple reflections decrease when the thickness of the layer increases.

In this letter, we preceding a method to measure the EMI SE of PAN alloys and conducting powders (silver, graphite, or carbon black) the measured to the theoretical values calculated from DC conductivity and plane wave theory in far-field region. We obtain that chemical doping and mixing process in PAN system is an indicative enhance of EMI shielding efficiency. The theoretical results of EMI shielding response of multilayer and monolayer films at high-frequency have also presented. The used method gives a good agreement results. Finally, the shielding responses of both monolayer and multilayer films are compared.

2. Theoretical model

The EMI shielding efficiency is defined in terms of the ratio of the power of incident and transmitted EM wave as [10]

$$SE = 10\log(\frac{P_I}{P_T}) = 20\log(\frac{E_I}{E_T}) \qquad (1)$$

Where, P_I (E_I) and P_T (E_T) are the power (electric field) of the incident and transmitted EM waves, respectively. The unit of SE is given in decibels (dB).

The structure of multilayer films is shown in Fig. 1. Here E_j and E'_j are electric fields of the incident and reflected EM waves in the j_{th} layer, respectively. The σ_j, $\varepsilon_{r\,j}$ and d_j are the conductivity, the dielectric constant, and the thickness of the j_{th} layer, respectively.

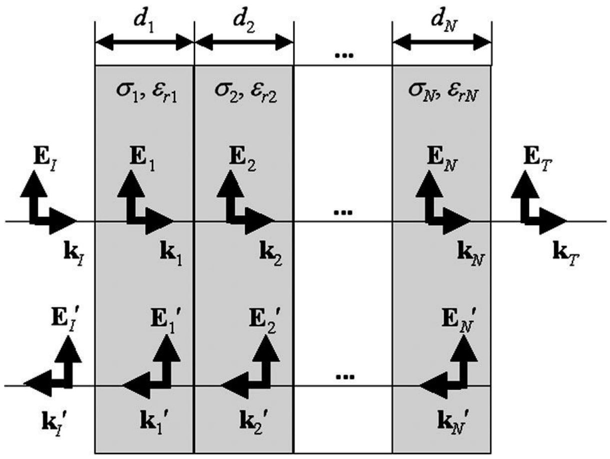

Fig.1: Schematic structure of multilayer films. The direction of wave vectors is normal to layers, and the direction of electric and magnetic fields are parallel to layers, but perpendicular to each other.

Assuming that plane EM waves are normally incident on nonmagnetic layers (i.e., relative magnetic permeability μ_r=1), the relation between the electric fields of the incident, reflected, and transmitted EM waves respectively. The theoretical model of multilayer films can be obtained from the boundary conditions for the electric and magnetic fields of EM waves as follows:

$$\begin{bmatrix} E_I \\ E'_I \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ K_I & -K_I \end{bmatrix}^{-1} A_1 B_1^{-1} A_2 B_2^{-1} ... A_N B_N^{-1} \begin{bmatrix} 1 \\ K_T \end{bmatrix} E_T \qquad (2)$$

Here, matrices A_j and B_j are described as $A_j = \begin{bmatrix} 1 & 1 \\ K_I & -K_j \end{bmatrix}$ and

$$B_j = \begin{bmatrix} \exp(ik_j d_j) & \exp(-ik_j d_j) \\ k\exp(ik_j d_j) & -k_j \exp(-ik_j d_j) \end{bmatrix}$$

Here, k_I and k_T are the wave vectors in the incident and transmitted medium, respectively. The complex wave vector in the j_{th} layer k_j follows the dispersion relation as

$$k_j^2 = \omega^2 \mu_0 \varepsilon_0 \varepsilon_{rj} + i\,\omega\mu_0\sigma_j$$

Where ω is the angular frequency of EM waves, and μ_0 and ε_0 are the magnetic permeability and the electric permittivity of free space, respectively. Thus, the real part k_{j1} and imaginary part k_{j2} (or absorption coefficient) of complex wave vector k_j are given by [10].

$$k_{j1} = (\omega/c)\sqrt{(\left|\varepsilon_{rj}\right|/2)(\sqrt{1+\tan^2\Delta_j} \pm 1}, \quad (3)$$

$$k_{j2} = (\omega/c)\sqrt{(\left|\varepsilon_{rj}\right|/2)(\sqrt{1+\tan^2\Delta_j} \mp 1}, \quad (4)$$

Where, c is the speed of EM wave in free space, and $\tan\Delta_j = \sigma_j / (\omega\,\varepsilon\,\varepsilon_{rj})$ is the loss tangent (or dissipation factor) of the j_{th} layer. Upper and lower signs of Eqs (3) and (4) are applied for positive and negative ε_{rj}, respectively. From Eq. (2), the reflectance $R = |E'_I/E_I|^2$. While, the transmittance $T = |E'_T/E_I|^2$ can be directly calculated. In addition, the absorbance A is obtained by using the relations $A+R+T=1$. The SE of the multilayer (SE_{multi}) can be described as

$SE_{multi} = -10\log T$.

The shielding response of monolayer films is also analyzed by using a similar model to calculate the shielding effectiveness of multilayer (SE_{multi}). The SE of monolayer films (SE_{mono}) can be described as

$$SE_{mono} = 20\log\left|\left(\frac{1}{4n}\right)\left[(1+n)^2\exp(-ikd) - (1-n)^2\exp(ikd)\right]\right| \quad (5)$$

Where the complex index of refraction n is related to the complex wave vector k ($=n\omega/c$). The SE_{mono} is typically expressed as

$$SE_{mono} = SE_A + SE_B + SE_M \quad (6)$$

SE_A, SE_R, and SE_M are the shielding efficiency due to absorption, reflection, and multiple reflections, respectively. Assuming that the shielding material has nonmagnetic properties (magnetic permeability, $\mu_r=1$), the terms in Eq. (6) are explicit expresses as [10]

$$SE_A = 20k_2 d\log e = 8.686k_2 d, \quad (7)$$

$$SE_R = 20\log\left|1+n\right|^2/4\left|n\right|, \quad (8)$$

$$SE_M = 20\log\left|1-\exp(2ikd)(1-n)^2/(1+n)^2\right|, \quad (9)$$

Here, $k=k_1+ik_2$ is the complex wave vector in monolayer films. The relation of $k_1=k_2$ is obtained without regard to the sign of ε_r in a low-frequency range (i.e., tan Δ>>1), while the relations of $k_2=0$ for positive ε_r and $k_1=0$ for negative ε_r are obtained in a high-frequency range (i.e., tan Δ<<1). For positive ε_r, the SE_{mono} shows a constant behavior at low frequency and an oscillating behavior at high frequency described by $SE_{mono}=10\log[P_1+P_2\cos(2\omega\sqrt{\varepsilon_r}d/c)]$ (P_1 and P_2 are constants).

Based on the theory of EMI shielding, the SE increases with increasing σ of the material. The SE of monolayer films described in Eq. (5) is given as follows:

$$SE_{mono} = 10\log\left\{\frac{1}{4}\left[\frac{\sigma}{2\omega\varepsilon_0}\left(\cosh\frac{2d}{\delta} - \cos\frac{2d}{\delta}\right) + 2\sqrt{\frac{\sigma}{2\omega\varepsilon_0}}\left(\sinh\frac{2d}{\delta} - \sin\frac{2d}{\delta}\right) + 2\left(\cosh\frac{2d}{\delta} + \cos\frac{2d}{\delta}\right)\right]\right\} \quad (10)$$

The σ_{dc} of PAN-CSA (*m*-cresol), PAN-ES/graphite, and PAN-ES/CB samples decreases when the temperature decrease. This implies that the charges were localized. The σ_{dc} at room temperature and the thickness of the samples are listed in Table 1 by [10].

Table 1. The DC conductivity and thickness of different samples studied

Sample	σ_{dc} (S/m)	Thick(d) (μm)
PAN-ES/Ag	150	70.5
PAN-ES/graphite	11	123
PAN-ES/CB	9.7	140
PAN-EB/Ag	0.3	70.5
PAN-CSA(*m*-cresol)	120	26
PAN-ES	5	55

3. Results and discussions

To understand better the impact of the thickness of conducting polymers films, the chemical processing of emeraldine base form of polyaniline (PAN-EB) has been reported earlier. Silver (Ag) powder (~0.8 µm diameter) mixed with PAN-EB powder. The mass ratio of Ag powder was ≤ 8% in total mass of alloys samples. The homogeneously mixed PAN-EB with Ag powder dissolved in N-methyl-2-pyrrolidinone (NMP) solvent. EB/Ag free-standing film was prepared by solution casting. The free-standing film of ES/Ag synthesized through 1-mole hydrochloric acid (HCl) doping in EB/Ag film. Using the same procedure, ES/graphite and ES/carbon black films were prepared. The free-standing film of PAN doped with camphor sulfonic acid in an *m*-cresol solvent [PAN-CSA (*m*-cresol)] synthesized as the previously reported method.

The EM1 shielding efficiency was measured by using ASTM D4935-89 technique at room temperature (RT) []. The frequency range for EM1 SE was from 10 MHz to 1GHz to calculate the theoretical SEs. Also the dc conductivity σ_{dc} was measured by using a four-probe method to eliminate contact resistance, and the result used to calculate theoretical EMI SE. The results of this comparison are summarized in the figs. 2-3.

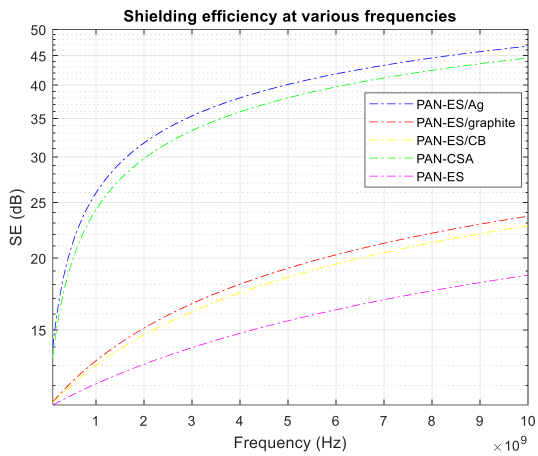

Fig.2: Simulation results of frequency dependence of shielding efficiency.

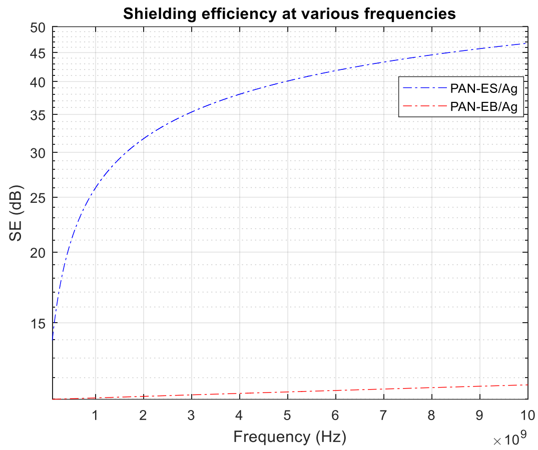

Fig.3: Simulation results of shielding efficiency between PAN-ES/Ag and PAN-EB/Ag samples for theoretical data.

Fig. 2 shows the frequency dependence of the EMI SE of the studied systems. The theoretical SEs are calculated by using the measured σ_{dc} and the EM plane wave theory. The theoretical SEs is approximately in accordance with the experimental values of the other authors [9-10] at the same frequency range. The small deviation of theoretical values from the experimental data is a result of the good conductor approximation. The measured SEs of PAN-ES, PAN-ES/graphite, PAN-CSA (*m*-cresol), and PAN-ES/Ag samples are in the range from 10 to 47 dB, as shown in Fig. 3. The maximum of the SE of PAN-ES/Ag at 47 dB and PAN-ES/graphite at 24 dB, while the PAN-ES about of value 18 dB and PAN-ES/CB about 23 dB more than PAN-CSA 45 dB. The result implies that the mixing process of PAN-ES with conducting powder contribute in the enhancement of the EMI SE.

Fig. 3 shows the comparison between the EMI SE of the doped PAN-ES/Ag and undoped PAN-EB/Ag mixture samples. The SEs of PAN-ES/Ag and PAN-EB/Ag samples are; 47 and; 5 dB, respectively. The room temperature σ_{dc} of those samples are about; 150 and; 0.3 S/cm, the results suggest that the chemical doping enhances not only the σ_{dc} but also EMI SE more than ten times. For PAN-EB/Ag samples, Ag particles are surrounded by insulating PAN-EB material. The free electrons in Ag particles are localized due to the insulating barrier of PAN-EB, and as a result, the σ_{dc} and the SE are relatively low. However, the PAN-ES/Ag samples, background PAN-EB material is changed to a conducting state due to (HCl) doping, which induces the delocalization or percolation path for the conduction of charges. The electronic wave functions are overlapped, and the systems are in an intrinsic metallic state.

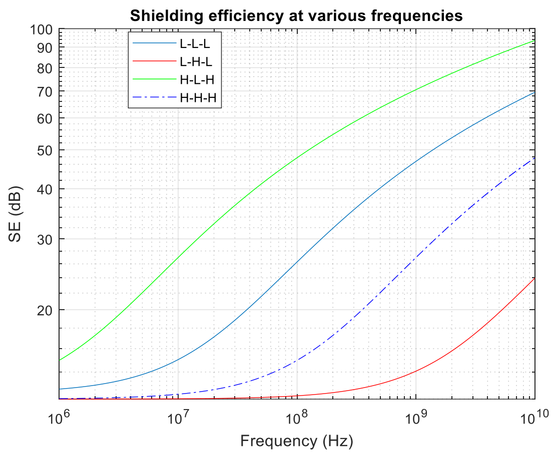

Fig.4: Simulation results of frequency dependence of theoretical shielding efficiency of multilayer films. Inset: H-Layer (σ=150 s/m, ε_r=3000, d=100µm) and L-Layer (σ=10 s/m, ε_r=500, d=100µm).

The high (H) layer denotes a highly conducting layer, which has σ =150 S/cm, ε=30 000, and a thickness of 10, 50, 100 µm. The low (L) layer denotes a low conducting layer, which has σ=10 S/cm, ε= 500, and a thickness of 10, 50, 100 µm. Monolayer and multilayer films are written as H–H–H and H–L–H layers, respectively.

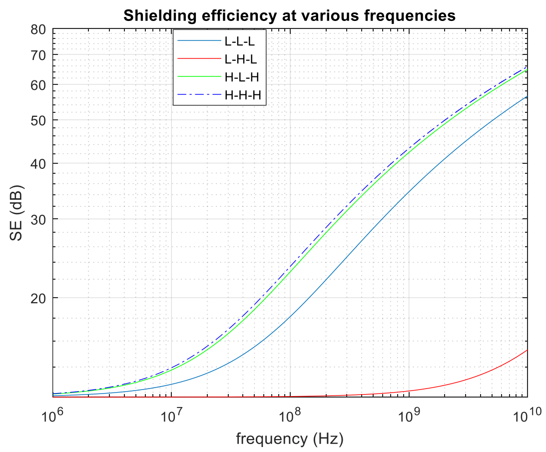

Fig.5: Simulation results of frequency dependence of theoretical shielding efficiency of multilayer films. Inset: H-Layer (σ=150 s/m, ε_r=3000, d=50µm) and L-Layer (σ=10 s/m, ε_r=500, d=50µm).

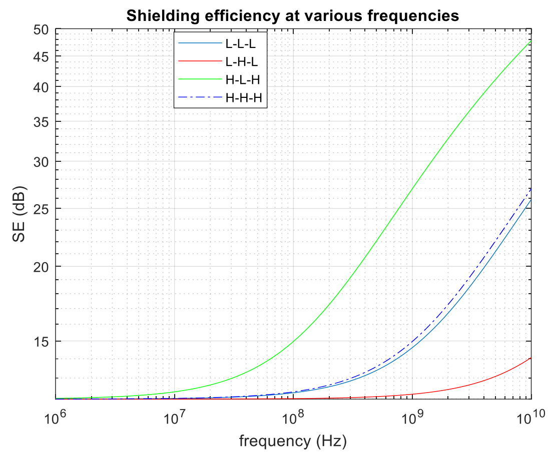

Fig.6: Simulation results of frequency dependence of theoretical shielding efficiency of multilayer films. Inset: H-Layer (σ=150 s/m, ε_r=3000, d=10µm) and L-Layer (σ=10 s/m, ε_r=500, d=10µm).

Fig. 4-5 and 6 show the theoretical EMI SE of multilayer and monolayer films with several thicknesses are tested and compared to each other, the results of theoretical calculation of the 3-layered material using the full formula of Eqs. (7), (8), and (9). Conductivity is an intrinsic parameter of the SE, and the thickness is an extrinsic parameter. As the thickness of material increases, the SE becomes larger due to the increase of absorption mechanism of the EM wave. We assume that the ε_r and σ of conducting materials is independent of frequency. It has been known that a conducting polymer with high and good crystallinity shows Drude metallic response. Previously reported values of the microwave conductivity σ and the microwave dielectric constant ε of doped (PANs) were used to calculate the EMI SE. Otherwise, as the thickness of L-layer in H-L-H multilayer increases, the SE increases patiently.

4. Conclusion

We conclude from the theory of EMI shielding that the SE increases with the conductivity σ, the thickness of the material and through mixing the materials with conducting powders. Similarly, the theoretical SEs calculated by using σ_{dc} and EM plane wave theory is approximately in agreement with the experimental of the other works listed in the paper. The presented results suggest that the thickness of layers is also considered as another factor to optimize the coherent multiple reflections in multilayer films that improve the total shielding effectiveness.

References

[1] Kashi, S., Gupta, R. K., Baum, T., Kao, N., & Bhattacharya, S. N. (2016). Dielectric properties and electromagnetic interference shielding effectiveness of graphene-based biodegradable nanocomposites. Materials & Design, 109, 68-78

[2] Arjmand, M., Chizari, K., Krause, B., Pötschke, P., & Sundararaj, U. (2016). Effect of synthesis catalyst on structure of nitrogen-doped carbon nanotubes and electrical conductivity and electromagnetic interference shielding of their polymeric nanocomposites. Carbon, 98, 358-372.

[3] Hayashida, K., & Matsuoka, Y. (2015). Electromagnetic interference shielding properties of polymer-grafted carbon nanotube composites with high electrical resistance. Carbon, 85, 363-371.

[4] Plueddemann, E. P. (Ed.). (2016). Interfaces in Polymer Matrix Composites: Composite Materials (Vol. 6). Elsevier.

[5] J. D. Jackson, Classical Electrodynamics (Wiley, New York, 1974).

[6] American Society for Testing and Materials. (2010). Standard test method for measuring the electromagnetic shielding effectiveness of planar materials. ASTM International

[7] Manna, K., & Srivastava, S. K. (2017). Fe3O4@ Carbon@ polyaniline trilaminar core–shell composites as superior microwave absorber in shielding of electromagnetic pollution. ACS Sustainable Chemistry & Engineering, 5(11), 10710-10721.

[8] ASTM D4935-89, Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials (1989).

[9] Sasikumar, S. P., Libimol, V. A., George, D. M., Lindo, A. O., Pushkaran, N. K., John, H., & Aanandan, C. K. (2017). Electromagnetic interference shielding efficiency enhancement of the PANI-CSA films at broad band frequencies. Progress In Electromagnetics Research, 57, 163-174.

[10] J. Joo and C. Y. Lee, "High frequency electromagnetic interference shielding response of mixtures and multilayer films based on conducting polymers", J. Appl. Phys. 88, 513(2000); doi: 10.1063/1.373688