

# Studies on the Electromagnetic Interference Shielding Effectiveness of Metallized PVAc-AgNO<sub>3</sub> Films

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## Abstract

In this study, the electromagnetic interference (EMI) Shielding effectiveness (SE) and the characterization of conductive PVAc-AgNO<sub>3</sub> chelate films are investigated. By adding metal salts AgNO<sub>3</sub> into PVAc matrix, metal chelate polymer with Ag<sup>+</sup> ions attached to the function groups of PVAc as the complex structure were prepared. Then the films of the metal chelate polymer were cast and reduced, the silver atoms generated and implanted on the surfaces of the metal chelate films. The SE values of the conductive metal chelate films were measured by far field transmission line method, with frequency ranging from 150KHz-1GHz. The best SE (30dB) was reached by AgNO<sub>3</sub> concentration (w%=15) of the metal chelate films ( $R_s=5\ \Omega/\text{cm}^2$ ), a higher SE (35dB) was even attained by double layers films ( $R_s=1\ \Omega/\text{cm}^2$ ) with AgNO<sub>3</sub> concentration w%=30. As confirmed by x-ray and SEM analyses, the conducting network that formed by silver atoms on the surfaces of the reduced films was the dominant path for electron propagation.

**Key Words:** EMI, Metal Chelate, Conductivity, Surface Resistivity, PVAc.

## 1. Introduction

Electromagnetic interference (EMI), such as radio noise, electronic noise, radio-frequency interference can be regarded as an invisible electronic pollution. The electromagnetic field produced by EMI may cause abnormal operation of computer, electronic devices and instruments. In order to eliminate the harmful effects of EMI, one practical method is to enclose the electronic devices completely within metal case so that no electromagnetic wave can be transmitted in or out. However, with the substantial progress in the preparation and processing methods, the conductive polymers have become important materials used instead of metals to provide effective EMI prevention in the electronic industries [1,2].

The electrical conductivity of polymer is usually enhanced by blending conductive fillers (such as metal particles, metal flakes and carbon particles, etc.) into the substrate to form composite conductive polymer [3,4], or by synthesizing intrinsically conductive polymer with conjugated double bonds structure [7,8]. However, the composite has weakened mechanical strength due to the non-uniform distribution of fillers while the intrinsic one has high cost of preparation and unstable conductivity. A novel metal chelate polymer has been developed [9-11], the conductivity of the metal chelate films is excellent and stable. Previous studies showed the surface resistivity ( $R_s$ ) of the chelate films of nylon4-CuCl<sub>2</sub> [10], PAI-AgNO<sub>3</sub> [9], and PVAc-AgNO<sub>3</sub> [11] can be lowered to  $10^0(\Omega/\text{cm}^2)$  when treated with reducing agent SBH solution. Following the line of research, the shielding effectiveness (SE) of the PVAc-AgNO<sub>3</sub> chelate films is studied and reported in this paper. The SE values of various AgNO<sub>3</sub> concentration of the PVAc-AgNO<sub>3</sub> chelate films is measured by the coaxial transmission line test method. The result shows the SE values and the conductivity of the films increase with the AgNO<sub>3</sub> concentration. The surface resistivity of the films with AgNO<sub>3</sub> concentration (w%=15) is lowered to  $5(\Omega/\text{cm}^2)$ , and the SE values of this film reaches 30 dB. The SE value is further improved when multi-layers of the conductive film are used.

As revealed by x-ray and SEM analysis, the better uniformity of the silver metal layer deposits on the surface of the film the higher conductivity and SE value result. This demonstrates the cross-linkage of silver atoms provides a more effective pathway for the electrons to migrate along than the charge transfer mechanism within the Ag<sup>+</sup> ions coordinated to the chelate of the polymers. Furthermore, it is the metal chelate structure of the polymer enabling the reduced silver atoms to adhere firmly on the surface of the films.

## 2. Experimental

### 2.1. Preparation and characterization of PVAc metal chelate film

The chelate solutions of the PVAc metal mixtures were prepared by introducing the AgNO<sub>3</sub> solution into a 20wt% PVAc formic acid solution according to the predetermined weight ratios (w%) of the AgNO<sub>3</sub> to the PVAc. Having stirred 10 minutes at room temperature, the mixture solutions were put into a microwave oven (600W) for microwave reaction under 30% power for 10 seconds. The temperature of the mixture solutions was raised to about 50-60°C and stirred cooling to room temperature. Then cast the mixture solutions on the clean PET plates and dried by an electrical oven with forced air circulation at 80°C for 25 minutes, the formed PVAc-AgNO<sub>3</sub> chelate films were reduced by 500ml of the 1wt% sodium borohydride solution (SBH) at 50°C for a suitable time [9-12]. The reduced PVAc-AgNO<sub>3</sub> chelate films were then washed by distilled water, dried by an air blower and stored in a desiccator filled with N<sub>2</sub> gas.

### 2.2. The measurement for EMI Shielding Effectiveness

In this investigation, the shielding effectiveness (SE) was measured by the coaxial transmission line test method specified by ASTM ES-7-83, and the set-up is shown in Figure 1. The CoAX88 shielding effectiveness measurement unit is used

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to determine the SE of planner shielding substances under free space (far-field) conditions [14]. A HM5012 spectrum analyzer is connected to the CoAX88 unit and the software SW5012 is used to calibrate the system. The SE was measured in the range from 150KHz to 1GHz in which the measurement limit for this spectrum analyzer was 50 dB.

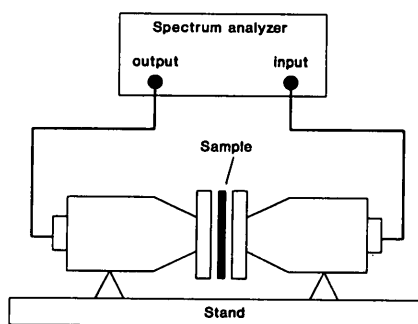


Figure 1. Set up for electromagnetic shielding effectiveness measurement

The SE is given by equation (1), where P is the energy field, E is the electrical field, and H is the magnetic field strength [13],

$$SE = 10 \log(P_{in}/P_{out}) = 20 \log(E_{in}/E_{out}) = 20 \log(H_{in}/H_{out}) \quad (1)$$

In this set-up, the SE was obtained by comparing the signals with and without the shielding. The reduced PVAc-AgNO<sub>3</sub> chelate films being tested were cut into circles of diameter 133mm. Each circular film was measured three times to get the average SE value.

### 3. Discussion

The common frequency range of EMI extends from 10Hz to 100GHz. Electronic devices, such as computer components, are susceptible to EMI frequency from 450KHz to 1GHz, and are more sensitive to the RFI of frequency from 500KHz to 10MHz.

Table 1 shows the conductivity of the reduced PVAc-AgNO<sub>3</sub> chelate films

increases with the AgNO<sub>3</sub> concentration (w%). The Rs of the films prepared from w%=3 AgNO<sub>3</sub> solution is 1×10<sup>3</sup>Ω/cm<sup>2</sup> and that from w%=30 AgNO<sub>3</sub> solution is lowered to 1Ω/cm<sup>2</sup>.

Table 1. Effects of AgNO<sub>3</sub> concentration (w%)<sup>a</sup> on reduced PVAc metal chelate films<sup>b</sup>

AgNO <sub>3</sub> <sup>a</sup> (w%)	Rs (Ω/cm <sup>2</sup> ) (before NaBH <sub>4</sub> treatment)	Rs (Ω/cm <sup>2</sup> ) (after NaBH <sub>4</sub> treatment) <sup>b</sup>
3	6.25 x 10 <sup>8</sup>	1.01 x 10 <sup>3</sup>
5	1.50 x 10 <sup>7</sup>	5.02 x 10 <sup>2</sup>
10	3.50 x 10 <sup>6</sup>	1.00 x 10 <sup>2</sup>
15	1.00 x 10 <sup>4</sup>	5.00 x 10 <sup>0</sup>
20	1.50 x 10 <sup>3</sup>	1.00 x 10 <sup>0</sup>
30	1.00 x 10 <sup>3</sup>	1.00 x 10 <sup>0</sup>

a: based on the PVAc weight.

b: films reduced by concentration of 1wt% of NaBH<sub>4</sub> solution at 50°C

Since Figure 2 indicates the SE of the films increases as Rs decreases, and the EMI shielding capacity of the films is also proportional to the conductivity of the films. All the reduced films tested have similar shielding effectiveness to EMI frequency from 150KHz to 1GHz, and the relationship between the Rs and SE value satisfies equation (2),

$$SE=20\log(1+Z_0/2R_s) \tag{2}$$

where Z<sub>0</sub> is the impedance of a free space (377Ω). Form EMI frequency from 10MHz to 1000MHz, the SE value of the reduced PVAc-AgNO<sub>3</sub> chelate films (w%=30, Rs=1 Ω/cm<sup>2</sup>) reached 33dB, and if two layers of the films were used, the SE value could be increased to 35dB. In general, the intensity of the electromagnetic wave will be decreased when it encounters conductive solid shielding. It was revealed by x-ray analysis that contrast silver atoms were found on the reduced film surface. The results of x-ray analysis are summarized in Table 2. As the double layered film has higher SE value than the single one, so both the reflection and absorption contributed to the EMI attenuation.

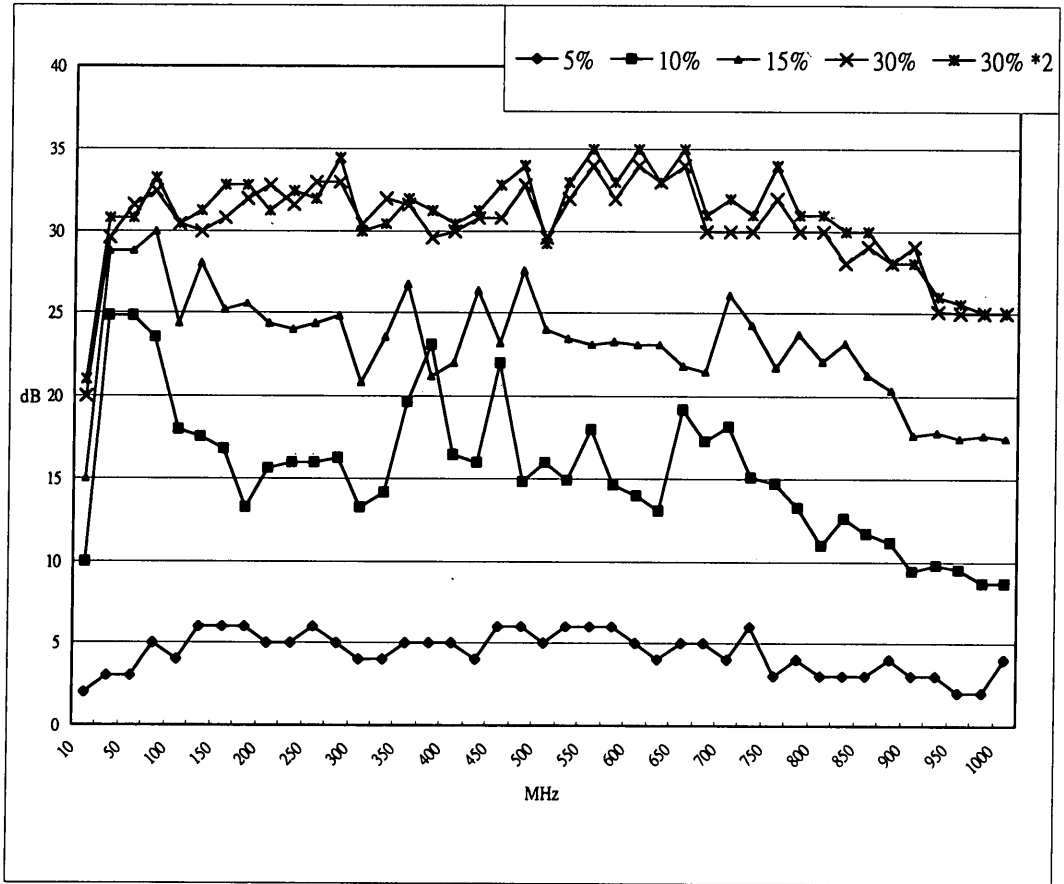
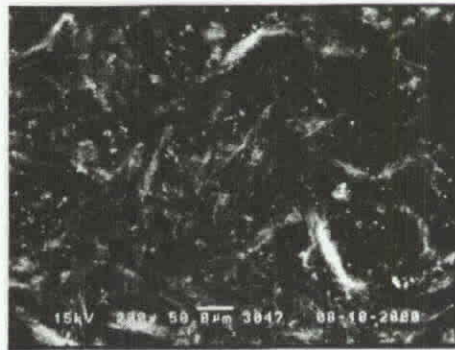


Figure 2. Shielding effectiveness of reduced PVAc-AgNO<sub>3</sub> chelate films.

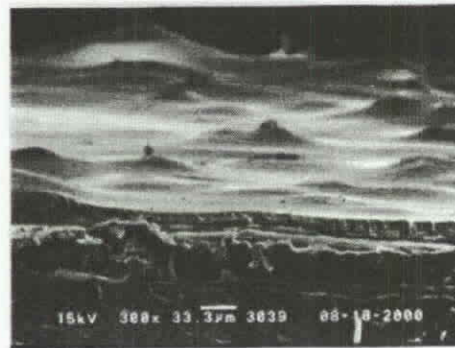
Table 2. Diffraction angles ( $2\theta$ ) and plane distances ( $d$ ) corresponding to peaks observed in X-ray analysis for reduced PVAc-AgNO<sub>3</sub> (w%=30) chelate film

Peaks	Coating layer		Pure Ag reference	
	$2\theta$	$d$	$2\theta$	$d$
1	38.0	2.359	38.12	2.359
2	44.12	2.051	44.27	2.043
3	64.58	1.442	64.42	1.445
4	77.54	1.230	77.47	1.230

Figure 3 shows the scanning electron microscope (SEM) photographs of PVAc-AgNO<sub>3</sub> (w%=30) chelate films with thickness 0.1mm. In Figure 3(a) shows the surface appearance of the film reduced by SBH solution. It is apparent the silver metal was generated and cross-linked to form an excellent conductive network on the film surface. Electrons could be effectively transferred along the network and the Rs was lowered to 10<sup>0</sup>Ω/cm<sup>2</sup>. Figure 3(b) shows the cross-section of the film in Figure 3(a). A thin silver layer can be seen deposited on the film surface.



(a)



(b)

Figure3. Scanning electron microscope<sup>a</sup> photographs showing variation of the surface of PVAc-AgNO<sub>3</sub> (w%=30) chelate films. (a) After SBH treatment (b) After SBH treatment (cross-section)

a: A TOPCON SM-300 scanning electron microscope (SEM) was used to inspect

the surface films.

The conducting mechanism of the reduced film is thus confirmed to be electron transfer via silver layer on the film surface. As the silver atoms distribute densely and closely together on the surface of the reduced film, a continuous conducting network is formed, enabling the reduced film to have a higher conductivity than the unreduced one.

## 4. Conclusion

The conductive PVAc-AgNO<sub>3</sub> chelate films resemble metal materials in having effective reflection and attenuation to the electromagnetic wave. The higher conductivity of the chelate films the greater EMI shielding effectiveness results. When the surface resistivity is lowered to 1  $\Omega/\text{cm}^2$ , the attained SE value is 33dB, enabling the films to be used as effective EMI shielding materials. Increasing the thickness of the film, such as using double layers, may also increase the absorption of electromagnetic waves and attenuate the emission of electromagnetic radiation, resulting in a higher SE value.

## References

1. J. Regan, *J. Polym. Plastic Technol.*, 18(1), 47 (1982).
2. R. M. Gresham, *Plating Surface Finishing*, 75(2), 63 (1988).
3. D. M. Bigg, *Polym. Compos*, 4(1), 40 (1983).
4. P. B. Jana, A. K. Mallick, and K. De, *IEEE Trans. Electromagnetic Compatibility*, 34(4), 478 (1991).
5. P. B. Jana, A. K. Mallick, and K. De, *Composites*, 22(6), 451 (1991).
6. Y. Ramadin, S. A. Jawad, S. M. Musameh, M. Ahmad, A. M. Zihlif, A. Paesano, E. Martuscelli, and G. Ragosta, *Polymer International*, 34(2), 145 (1994).
7. T. Makela, S. Pienimaa, T. Taka, S. Jussila and H. Isotalo, *Synthetic Metals*, 85,



1335 (1997).

8. J. Joo and A. J. Epstein, *Appl. Phys. Lett.*, 65, 2278 (1994).
  9. C. J. Huang, C. C. Yen, and T. C. Chang, *J. Appl. Polym. Sci*, 42, 2269 (1991).
  10. C. C. Yen, C. J. Huang, and T. C. Chang, *J. Appl. Polym. Sci*, 42, 439 (1991).
  11. C. J. Huang, *CICChE, Annual Meeting and Conferences*, 143 (1999).
  12. C. C. Yen, C. J. Huang, and T. C. Chang, *J. Appl. Polym. Sci*, 46, 1677 (1991).
  13. X. C. Luo, D. D. L. Chung, *Composites: Part B*, 30, 227 (1999).
  14. *Emergency Standard Test Methods for Electromagnetic Interference Shielding Effectiveness of Planer Materials (ES7-83)*, ASTM, Philadelphia (1983).
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# 金屬化聚醋酸乙烯酯導電薄膜 電磁輻射干擾遮蔽效能的研究

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## 摘 要

金屬化聚醋酸乙烯酯(PVAc)金屬螯物薄膜的導電性佳，表面電阻( $R_s$ )可達  $10^0 \Omega/\text{cm}^2$  以下，並且具有優良的機械性質及穩定性。本論文進行聚醋酸乙烯酯-硝酸銀(PVAc-AgNO<sub>3</sub>)導電薄膜的電磁輻射干擾(EMI)遮蔽效能的研究。本研究以遠場狀態(far field condition)進行實驗，將薄膜遮蔽材料裝置於兩遮蔽室中間，由發射體一方發射頻率 150KHz 至 1GHz 的電磁波訊號，而在另一方接受器上測得有遮蔽及無遮蔽時的電磁波訊號強度，利用關係式  $SE=10\log_{10}(P_{in}/P_{out})$  計算遮蔽材料的遮蔽效能(SE，單位 dB)。經由實驗得知薄膜的導電度愈高其 SE 值愈高，AgNO<sub>3</sub> 15%的導電薄膜( $R_s=5 \Omega/\text{cm}^2$ )其 SE 值為 30dB，AgNO<sub>3</sub> 30%的導電薄膜( $R_s=1 \Omega/\text{cm}^2$ )其 SE 值可達 33dB。若使用雙層薄膜，其 SE 值更可提高至 35dB，為一種具實用性的 EMI 遮蔽材料。另外本文亦進行薄膜的 X-ray 及 SEM 分析，結果確定導電薄膜表面有金屬銀層形成，這穩定的銀金屬層是薄膜呈現優良 EMI 遮蔽效能及導電性的原因。

**關鍵字**：聚醋酸乙烯酯，導電薄膜，電磁輻射干擾，EMI