MICROWAVE ABSORBING STRUCTURE WITH CONDUCTING POLYMER FSS COATING

W. J. Lee*, J. W. Lee, C. G. Kim***
***KAIST(Korea Advanced Institute of Science and Technology)**
****DPI solutions**

Keywords: *Harmful electromagnetic(EM) wave , EM absorbing composites, conducting polymer*

Abstract

Harmful electromagnetic(EM) waves from various sources, such as mobile phone, portable music player, hair dryer, wireless devices are considered as the serious environmental pollution of the day. The superfluous electromagnetic waves are widely known as the cause of EMI(electromagnetic interference) problems in electrical devices as well as the source of disease in human body.

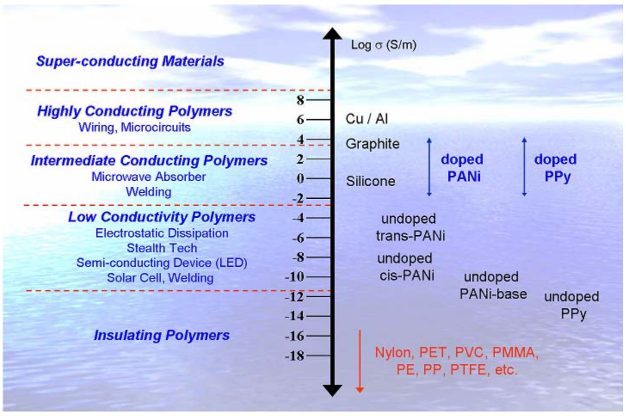
Recently, many kinds of precautions and legislations are developed to verify and prevent the harms from EM waves on the human body but just avoidance and shielding with conductive materials cannot be the basic solution. Only the development of extensive EM wave absorbing medium could be the essential measures on the problems. The "conducting polymers" have the possibility to be the solution.

In this study, EM wave absorbing material and structure based on the intrinsic conducting polymer was suggested and the absorbing characteristics were verified to make the EM protective composites.

1 Introduction

The term, "Plastic age" can be the representative of these days. The plastic material is basic foundation of the industry and has various advantages, such as low price, accessibility, applicability, etc. As the plastics are generally considered as "electric insulator" with low electrical conductivity but if the degree of conductivity could be controlled, it could be adapted widely as the most effective EM wave absorbing materials & structures.

Conventional metallic materials, such as copper, steel, metallic powders have high conductivity and good accessibility but the conductivity cannot be controlled. It means highly conductive materials can be used as shielding or reflective medium to the incident EM waves.



The intrinsic conducting polymers which have wide range of electric conductivity could be adopted as EM wave absorbing material. The advantages of intrinsic conducting polymers are :

- Electric conductivity control
- Simple and effective surface coating
- Coating thickness control
- Compatibility with other polymers
- Transparency

2 Conducting polymer (CP)

2.1 preparation of CP paste

The conducting polymer(CP) paste based on PEDOT(poly(ethylenedioxy)thiophene) with binding material was synthesized. The wt% of PEDOT was limited under 0.4 wt% and the viscosity of the mixture with solvent, PEDOT and binder was about 5000 cps.

For the application for the EM wave shielding and absorption, measurement of the specific conductivity of material is very important. The first experiment was conducted to know the electric conductivity of this CP paste. The specific conductivity (specific resistance) of material could be calculated by surface resistance and coating thickness. 2 glass plate specimens coated by CP paste with different thickness (#1, #2) was prepared and thickness and surface resistance in each specimen was measured. Surface coating was done by bar-coater. Figure 1 shows the CP coated specimens and coating thickness of CP was measured by 3D surface profiling system. The relative coating thickness is illustrated.

The specimen # 1 with CP coating (0.3 um) had specific conductivity of 1300 S/m with surface resistance 2500 ohm/sq. and # 2 (0.75 um, 1000 ohm/sq.) showed same specific conductivity. It means the conductivity of CP paste is defined as 1300 S/m.

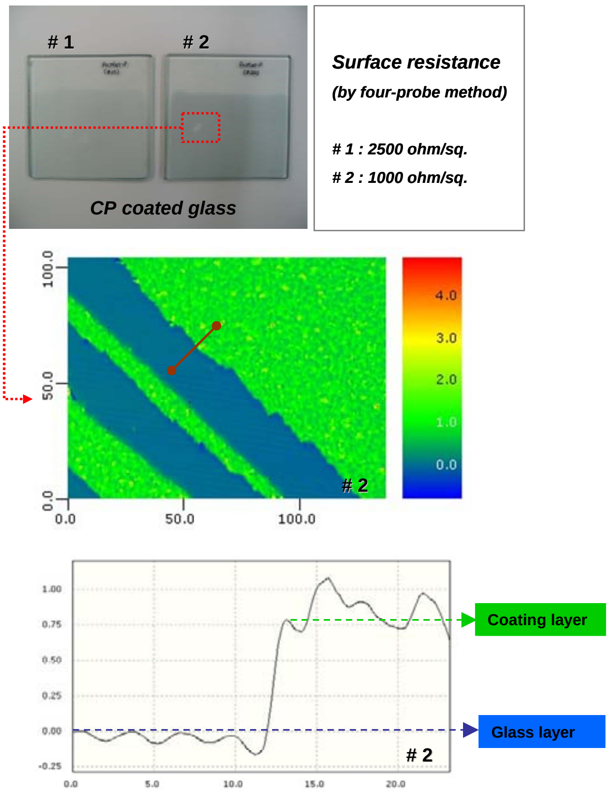


Fig. 1. Thickness of CP coating and surface resistance

After having set the specific conductivity of CP paste, the possibility of conductivity control was verified. As the wt% of CP increased from 0.0 to 0.4, the specific conductivity of CP paste increased up to 1300 S/m(0.4 wt% PEDOT, cured state). So the surface resistance of CP coated layer could be controlled by CP pasted itself as well as coating thickness.

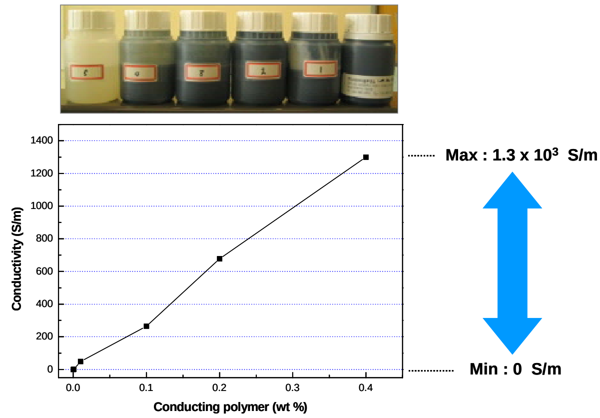


Fig. 2. Controllable conductivity range of CP paste

2.2 Cure process

For the applications, cure monitoring of the synthesized CP paste was conducted. Curing condition was set as 130 °C. In fig. 3, mixture of solvent, PEDOT and binder were coated on the surface of glass / epoxy composite substrate. During the cure process, solvent was removed and thermosetting binder was set, finally conducting network was formed with PEDOT. Considering the wt% of PEDOT and binder in the solvent, if the coating thickness of CP paste was 18 um, the coating thickness of PEDOT and binder would be about 0.72 um, relatively.

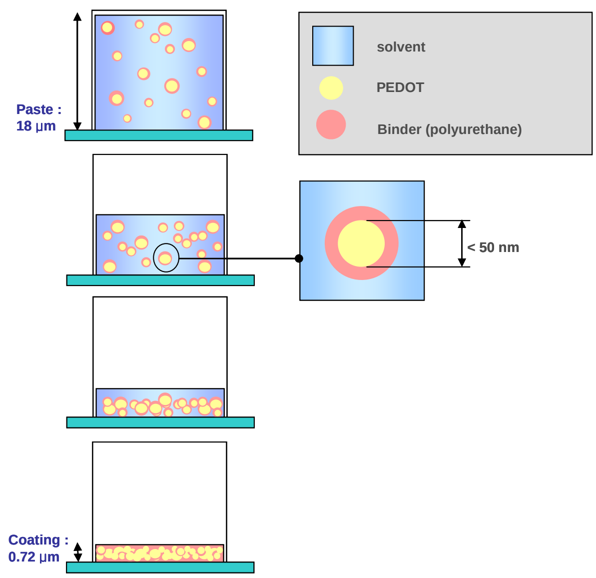


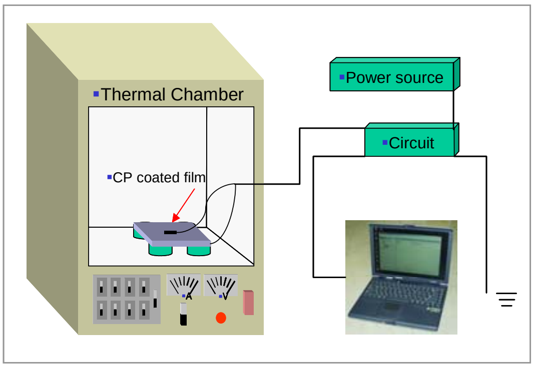
Fig. 3. Coating process of CP paste

The bar-coating method was adopted and the thickness of CP paste was set by the no. of bar which had tiny specific gap between substrate and bar. With the selection of bar with specific gap, the final coating thickness could be controlled.

Coating process was done in the room temperature and curing was conducted under 130°C and cure monitoring of CP paste was performed. The CP paste itself had high electric resistance but during cure process, the solvent was removed and PEDOT with binder made conducting network.

Figure 4 shows the cure monitoring of CP paste coated on the specific square size substrate. After coating, two electrodes were connected in each end of specimen and it was put in the thermal chamber. The variation of electric resistance was measured. At the beginning, the resistance of CP paste changed and fluctuated but it was set up within 30 min.

After cure was set up during initial 30 minutes, the resistance was fixed at specific level and maintained more than 18 hours. Based on this result, curing time was set up as 30 minutes and electric stability of CP paste in the curing temperature was confirmed.



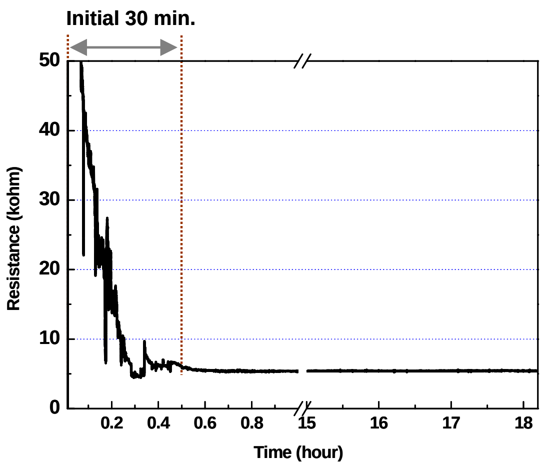


Fig. 4. Cure monitoring of CP paste

2.3 Printing process

The possibility of CP printing and patterning with screen printing method based on the developed CP paste was conducted. As the basic purpose of patterning with specific unit cell, such as rectangle, circle, triangle, mesh and fractal patterns was microwave absorption, the basic rectangular pattern was designed and patterned on the transparent PP(polypropylene) film as an example in figure 5.

Transparency of CP coating and patterning was measured with UV-spectrometer. As coating thickness decreases from 5.1 um to 0.8 um, surface resistance increases from 150 to 1000 ohm/sq. and transparency increases up to 94.1 %, relatively.

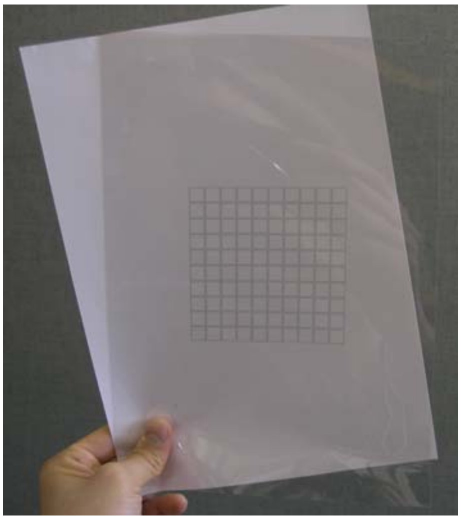


Fig. 5. Mesh type patterning with CP paste

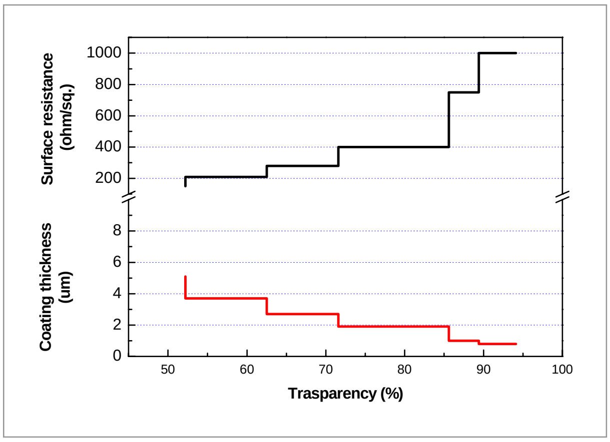


Fig. 6. Transparency and surface resistance of CP with coating thickness

3 EM characteristics of CP coating

3.1 S-parameters

The verification of EM wave reflection and transmission characteristics were conducted on the CP coated specimens. As the DC conductivity of the CP paste and surface resistance of CP coating were verified, the EM characteristics to the plane wave(far field condition) need to be understood.

The CP paste was coated uniformly on the acryl plate (150 x 150 x 1.85 mm) with the thickness of 0.006 um in the fig. 7. With the measurement of S-parameters (S_{11}, S_{21}), the reflection and transmission characteristics of the specimen were verified.

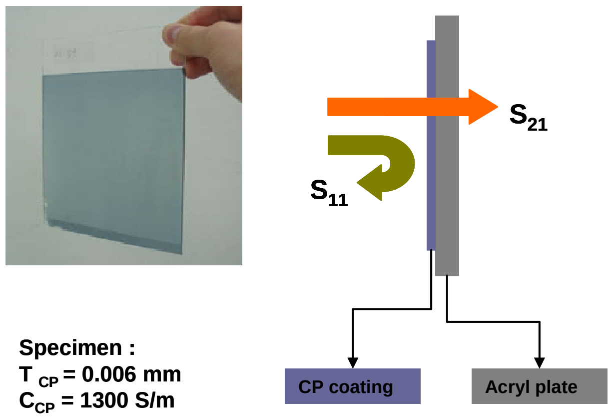
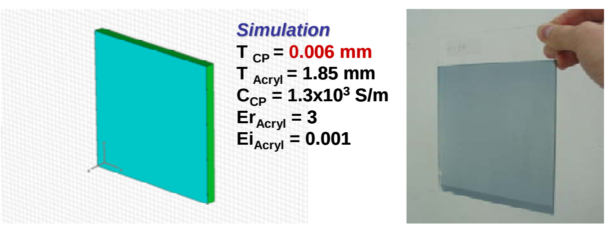
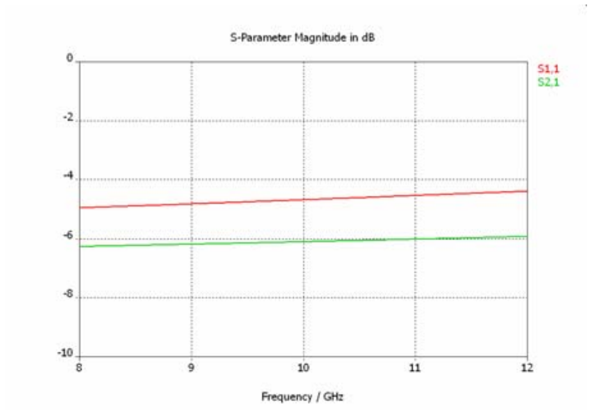


Fig. 7. S-parameters of CP coated acryl plate

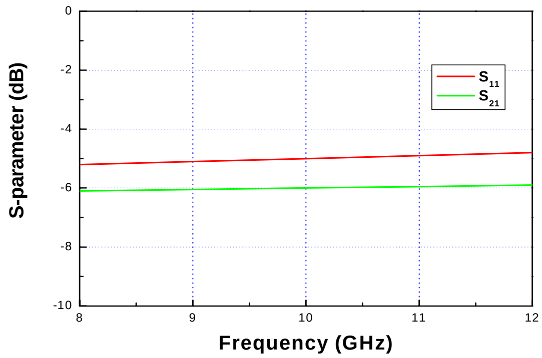
The commercial wireless communication band was relatively at the early stage of GHz range, but newly developed commercial frequency band increased up to tens of GHz in consideration of the amount of wireless data and communication speed. The target frequency range was set as 8.2 ~ 12.4 Ghz (X-band).

Figure 8 shows the s-parameters of CP coated acryl plate. With the aid of EM field simulation tool, the verified parameters were applied in this simulation. The simulation result based on the verified parameters was similar with experimental result.





(a) simulation result



(b) experiment result

Fig. 8. S-parameters : simulation & experiment

3.2 EM wave absorption

Based on the EM characteristics of CP paste, rectangular pattern was designed and printed on the glass / epoxy composite substrate in fig. 9. The unit cell of rectangular CP printing was 6 x 6 mm, and the patterned layer was inserted between two glass / epoxy composite layer. The thickness of front layer was 1.5 mm and rear layer was 2.4 mm. The backside of rear layer was covered with thin aluminum layer as PEC to prevent the transmission of EM wave(S_{21}). Total thickness of EM wave absorbing structure was about 3.9 mm.

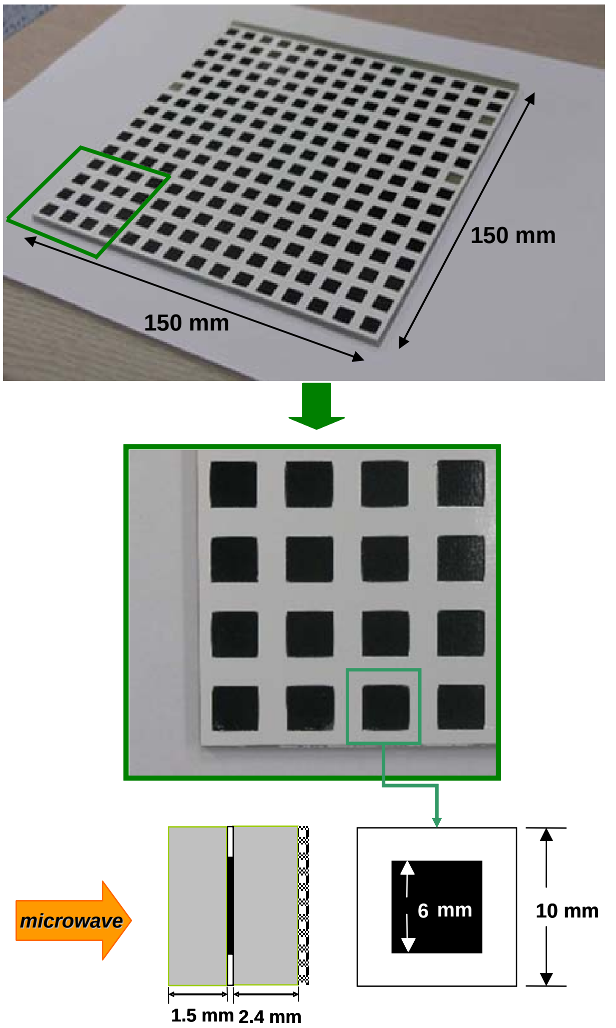


Fig. 9. EM wave absorbing structure with CP printing

With the various parameters, such as thickness of glass / epoxy composite layers, conductivity of CP paste, coating thickness, pattern size, pattern array, etc. the target EM wave absorbing characteristics was set up to cover the X-band range. Total absorbing bandwidth designed to cover X-band was about 9 GHz (about 7 ~ 16 GHz).

Based on the designed parameters, EM wave absorbing specimen was fabricated and the characteristics were measured. In the fig. 10, more than 90% absorbing characteristics were confirmed in the whole X-band range and the designed result and measured result were very similar in the target frequency range.

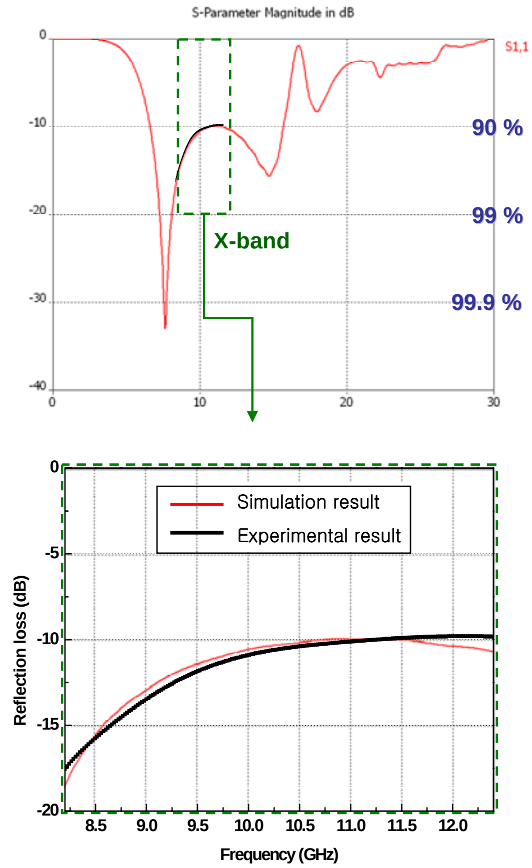


Fig. 10. EM wave absorbing characteristics

The EM wave absorbing characteristics of the specimens with CP patterning on the glass / epoxy composite was verified. Considering the absorbing bandwidth, thickness, simple fabrication process, controllability and structural applications, the CP pattern printing could be the one of the most effective method to design and fabricate the EM wave absorbing structure with composite material as well as various kinds of materials.

4 Conclusion

In this study, PEDOT based CP paste was synthesized and the EM characteristics was verified for the application of harmful EM wave absorbing structures.

- PEDOT with binder was mixed and CP paste was developed.
- Specific electric conductivity was verified.

- Conductivity could be controlled with the wt% of PEDOT.
- CP Coating process was verified and also the coating thickness could be controlled by bar-coating method.
- CP paste cure monitoring was conducted : 130°C, 30 min.
- Pattern printing was tried and the transparency of CP coating was verified.

Based on the EM characteristics of CP paste, plane EM wave absorbing structure was designed, fabricated and measured. In the X-band frequency range, -10 dB (90 % absorption) was measured and very effective wide-band absorbing characteristics were verified from 7 to 16 GHz under -10 dB compared with previous researches.

- Rectangular pattern was designed and EM wave absorbing specimen was fabricated with CP printing method on the glass / epoxy composite structure.
- Effective ultra wide-band EM wave absorbing characteristics was confirmed with simple CP coating technology.

References

[1] B. A. Munk, *"Frequency Selective Surfaces: Theory and Design"*. A Wiley-Interscience Publication, 2000.

[2] S. C. Kim, *"Polymer engineering"*. HEE JUNG DANG, 1994.

[3] J. A. Bossard, D. H. Werner, T. S. Meyer, and R. P. Drupp, "Reconfigurable infrared frequency selective surfaces," *proceedings of the 2004 IEEE, Antennas and Propagation International Symposium*, Vol. II, pp. 1911~1914, 2004.

[4] Qiang Gao, Yan Yin, Dun-Bao Yan, and Nai-Chang Yuan, "A novel radar absorbing material based on EBG structure," *Microwave and optical technology letters*, Vol. 47, no. 3, pp. 228~230, 2005.

[5] Kwanghee Lee, Shinuk Cho, Sung Heum Park, A. J. Heeger, Chan-Woo Lee, Suck-Hyun Lee, *Nature*, Vol. 441/4. pp. 65~68, 2006.

[6] R. S. Biscaro, E. L. Nohara, G. G. Peixoto, "Performance evaluation of conducting polymer paints as radar absorbing materials," *Proceedings of IMOC*, pp. 355-358, 2003.

[7] Iribarren J. I., Armelin E., Liesa F., Casanovas J., Alemán C., "On the use of conducting polymers to improve the resistance against corrosion of paints based on polyurethane resins," *Materials and corrosion*, Vol. 57, no. 9, pp. 683-688, 2006.

[8] B. Chambers, "Optimum Design of a Salisbury Screen Radar Absorber," *Electronics Letters*, Vol. 30, No. 16, pp. 1353-1354, 1994.

[9] J. Kern, D. H. Werner, "A Genetic algorithm Approach to the Design of Ultra-Thin Electromagnetic Bandgap Absorbers," *Microwave and Optical Technology Letters*, Vol. 38, No.1, pp. 61-64, 2003.

[10] S. E. Lee, Design and Fabrication of Radar Absorbing Structures Including Frequency Selective Fabric Composites, *Ph.D. Thesis, KAIST*, 2006.