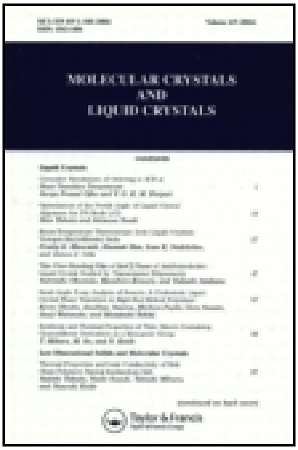


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Electromagnetic Interference (EMI) Shielding Efficiency (SE) Characteristics of the ITO/Ag Multilayer Structure

Jung Hyun Lee [a], Jong Won Jang [a], Sang Ho Sohn [a], Sang Gul Lee [b] & Myung Sub Park [c]

[a] Department of Physics, Kyung pook National University, Daegu, Korea

[b] Korea Basic Science Institute, Deajeon, Korea

[c] Research Center, AVATEC Co., Ltd., Deagu, Korea

Version of record first published: 22 Sep 2010

To cite this article: Jung Hyun Lee, Jong Won Jang, Sang Ho Sohn, Sang Gul Lee & Myung Sub Park (2007): Electromagnetic Interference (EMI) Shielding Efficiency (SE) Characteristics of the ITO/Ag Multilayer Structure, Molecular Crystals and Liquid Crystals, 470:1, 107-120

To link to this article: http://dx.doi.org/10.1080/15421400701493448

Mol. Cryst. Liq. Cryst., Vol. 470, pp. 107–120, 2007

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701493448

Electromagnetic Interference (EMI) Shielding Efficiency (SE) Characteristics of the ITO/Ag Multilayer Structure

Jung Hyun Lee
Jong Won Jang
Sang Ho Sohn
Department of Physics, Kyung pook National University, Daegu, Korea

Sang Gul Lee
Korea Basic Science Institute, Deajeon, Korea

Myung Sub Park
Research Center, AVATEC Co., Ltd., Deagu, Korea

The electromagnetic interference (EMI) shielding efficiency (SE) of multilayered thin films in which indium-tin-oxide (ITO) and Ag were deposited alternately from 3 Layer to 9 Layer on Poly Methly Methacrylate (PMMA) substrates at the room temperature using a RF sputtering. We measured optical and electrical characteristics by UV-spectrometer and 4 point probe method. The measurement of EMI shielding efficiency (SE) in the frequency ranges from 50 MHz to 1.5 GHz was performed by using ASTM D 4935–89 method. We compared the measured EMI SEs with theoretical simulation data. Our EMI SE multi-layers showed relatively low resistivities and high transmittances. In this study, we obtain good optical and electrical characteristics with a minimum transmittance of about 60% at 550 nm wavelength and sheet resistance of $2 \sim 3\,\Omega$/sq., respectively. Measured EMI SEs were over 50 dB and similar to theoretical simulation data.

Keywords: Ag; EMI SE; ITO; PMMA; RF sputtering

INTRODUCTION

Today, we are frequently exposed to EM (Electro-Magnetic) waves like X-ray, microwave of an electric oven, electrical wave of mobile phones

This work was supported by the Regional Innovation Center Program(ADMRC) of the Ministry of commerce, Industry and Energy of Korea.

Address correspondence to Prof. Sang Ho Sohn, Department of Physics, Kyungpook National University, Sangyuk-dong, Buk-gu, Daegu 702-701 Korea (ROK). E-mail: shsohn@mail.knu.ac.kr

and television, etc. Even if we have still no tangible evidences for the danger of EM and thence it is controversial, it is reinforcing to restrict about EM wave radiation of devices such as displays including the mobile display. Thus, EMI technology was being emphasized and EMI shielding materials are becoming of importance in the electronic devices, especially in the display devices.

In this study, we prepared a multi-layered structure of oxide-metal-oxide on the PMMA substrate and investigated their electro-optical characteristics. EMI SE as functions of the film thickness and the number of layers are measured. Also, measured EMI SEs were compared with computational ones.

To begin with, we will introduce the EMI SE formula briefly. As seen in Figure 1, EMI SE is the ratio of output energy to input energy across shielding material and defined as [1,2]

$$SE = 10\log\left[\frac{P_i}{P_0}\right] = 20\log\left[\frac{E_i}{E_0}\right] \tag{1}$$

where $P_i(E_i)$ and $P_0(E_0)$ means the input and the output energy, respectively, and E_i and E_0 do the input and the output electric fields, respectively.

The EMI attenuation by a material occurs by three mechanisms. The first mechanism is the reflection loss by impedance mismatching between the air and the metal layer, which plays a major role in producing loss in EMI SE mechanisms. The second one is penetration or absorption loss. When the electromagnetic wave goes through EMI materials, heat is generated by the ohmic loss. Last one is the multi-reflection loss, it occurs by re-reflection from metal SE film both boundary layers to inside metal layer. Finally, we can describe the EMI SE of monolayer films as [2]

$$SE = SE_A + SE_R + SE_M \tag{2}$$

$$SE = 20\log\left|\frac{1}{4n}\left[(1+n)^2\exp(-ikd) - (1-n)^2\exp(ikd)\right]\right| \tag{3}$$

where the complex index of refraction n is related with the complex wave vector k(=nω/c) and d is the film thickness. In Eqs. (2), (3), each EMI SE mechanism is given by

$$SE_A = 20\,k_2 d\ \log e = 8.686\,k_2 d \tag{4}$$

$$SE_R = 20\ \log\frac{|1+n|^2}{4|n|} \tag{5}$$

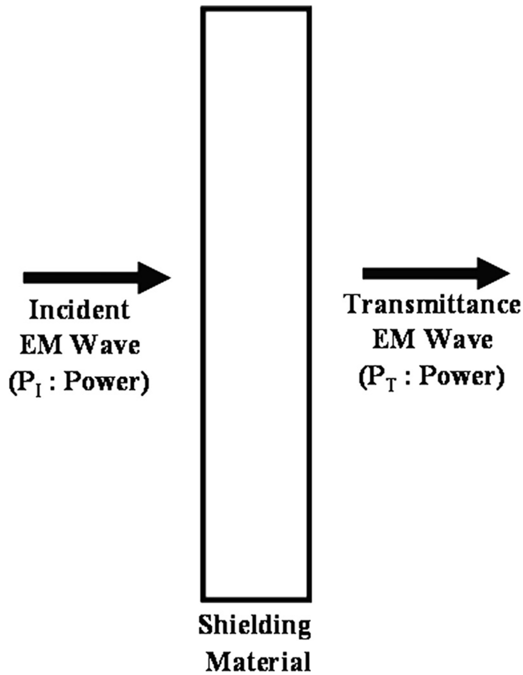


FIGURE 1 Theory of EMI SE.

$$SE_M = 20\ \log\left|1 - \exp(2ikd)\frac{(1-n)^2}{(1+n)^2}\right| \tag{6}$$

where SE_A, SE_R, and SE_M denote the shielding efficiencies due to reflection, absorption, and multiple reflections, respectively [3].

EXPERIMENTAL

The EMI filters were made of the indium-tin oxide (ITO) thin film and the Ag film, deposited alternately from 3 Layer to 9 Layer on poly methyl methacrylate (PMMA) substrate at room temperature using a RF sputtering. A disk-shaped target of 3 inches diameter ITO (In_2O_3: SnO_2 = 90:10 wt%) and Ag 99.99% purity was used in the thin film deposition process. In Figure 2, we wer explaining RF sputtering system for coating EMI SE filter.

Optical transmittance of multi-layered thin films was measured by UV-VIS-NIR spectrometer (Shimazu Co.) in the wavelength range

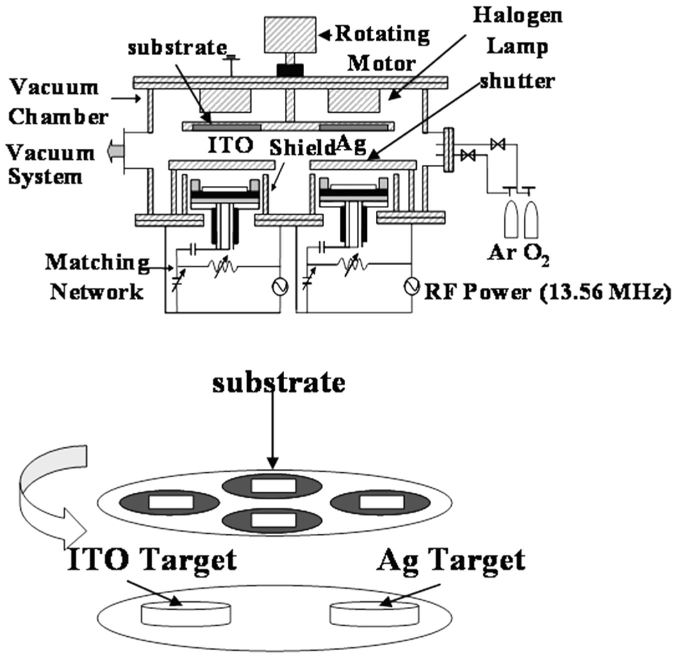
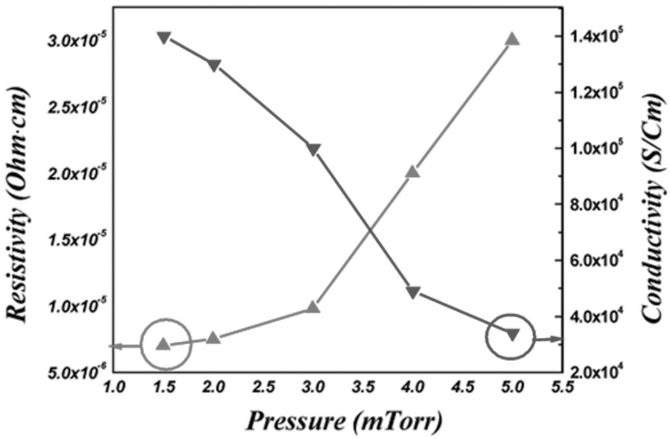


FIGURE 2 RF magnetron sputtering system.

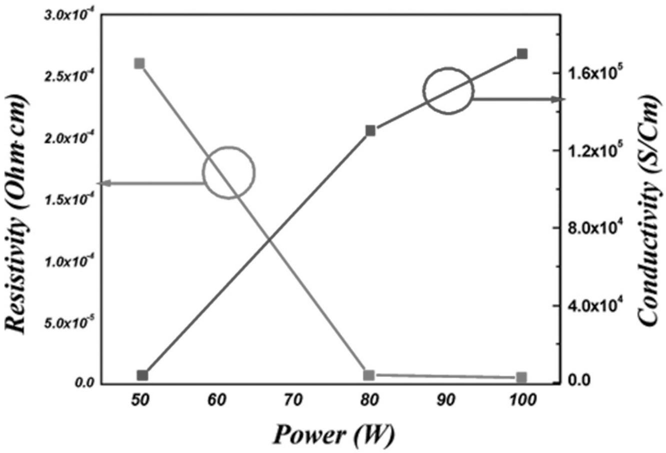
from 300 nm to 1000 nm. The measurement of EMI SE in the frequency ranges from 50 MHz to 1.5 GHz was carried out by using the ASTM D 4935 method [4,5]. Electrical sheet resistance of multi-layers was determined by the 4 point probe method.

RESULTS AND DISCUSSION

First, we optimized coating conditions of ITO and Ag single-layer. As for Ag single-layer, we made experiments with changing value of working pressure from 1.5 mTorr to 5.0 mTorr and one of supplied power from 50 W to 100 W. As seen in Figure 3, Ag thin films have good electrical characteristics when they are deposited at low working pressures or high supplied powers. Figure 4 shows XRD pattern of Ag films according to coating conditions. All samples showed the (1 1 1) XRD peak. It was found that higher supplied power yield better crystallization while working pressures seldom affect it. Second, as for ITO single-layer, we made experiment as changing working pressures from 1.5 mTorr to 5.0 mTorr, supplied power from 80 W to 120 W and ratio of O_2/Ar from 0% to 0.5%.



(a)



(b)

FIGURE 3 Electrical characteristic of Ag films as coating conditions. (a) as working pressure, (b) as supplied power.

Figure 5 shows that the specific resistivity of ITO film become lower and the deposition rates became higher in the low working pressure and in the high supplied power regions.

Figure 6 shows the change of the sheet resistance and transmittance as a function of O_2/Ar ratio. It was found that increasing ratio of O_2/Ar leads to decreasing the transmittance and increasing the sheet resistance.

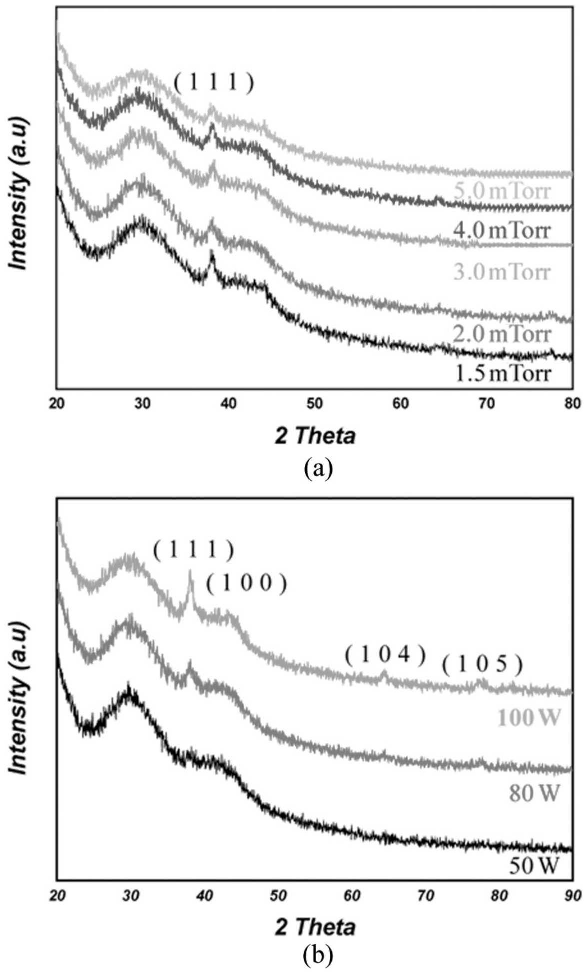


FIGURE 4 The XRD patterns of Ag films as coating condition (a) as working pressure, (b) as supplied power. (See COLOR PLATE IV)

Figure 7 shows XRD pattern of ITO films according to coating conditions. All samples had no XRD peak, denoting a natural result that all ITO films are amorphous since we coated on PMMA at room temperature and we could not perform any heat-treatment of the polymer films. Table 1 shows Ag and ITO coating conditions to be optimized.

We prepared EMI SE multi-layers with optimized single layer coating conditions and measured the transmittance, sheet resistance

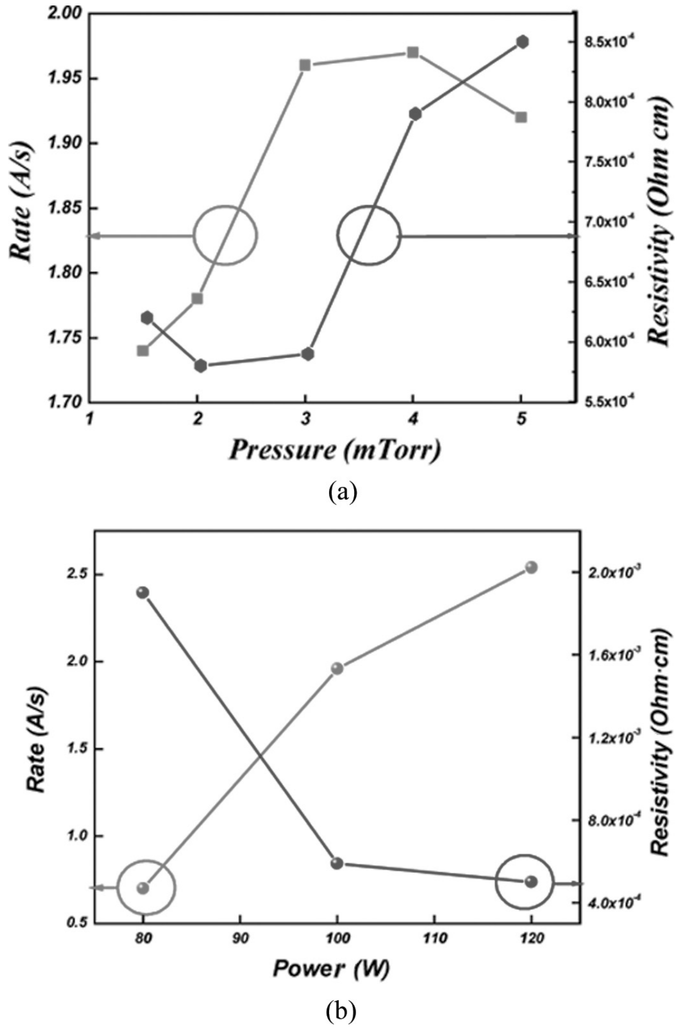


FIGURE 5 Rate and specific resistivity of ITO films as coating condition. (a) as working pressure, (b) as supplied power.

and EMI SE. Figure 8 shows the measured EMI SE and transmittance characteristics of 3 layered EMI SE filters, as functions of the Ag and ITO films thickness. In Figure 8, we can find that the Ag film largely decides EMI SE characteristics while the ITO film decides optical transmittance characteristic.

In Figure 9, the measured and computational EMI SE values are compared in the frequency range from 50 MHz to 1.5 GHz.

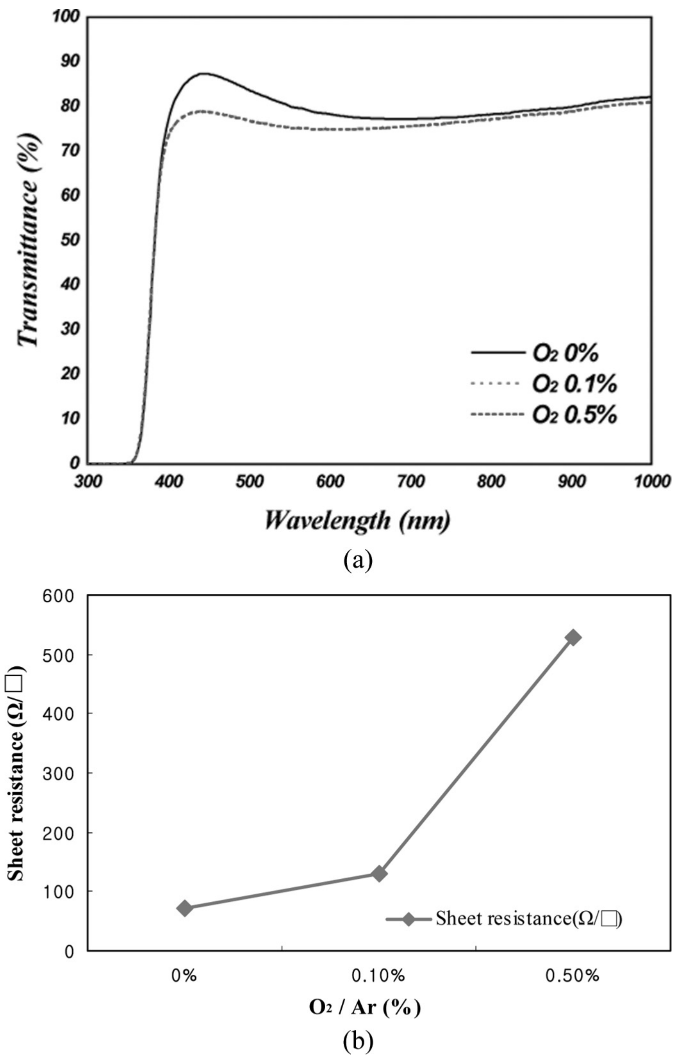


FIGURE 6 Change characteristic of ITO film as ratio of O_2/Ar (a) Transmittance, (b) Sheet resistance. (See COLOR PLATE V)

The computational EMI SE values were obtained by using an Eq. (3). As shown in Figure 9, computational EMI SE values were higher than measured ones, approximately 10 dB.

Figure 10 shows the results of measure transmittance and EMI SE as the number of layer increase 3 layer of air/ITO/Ag/ITO/

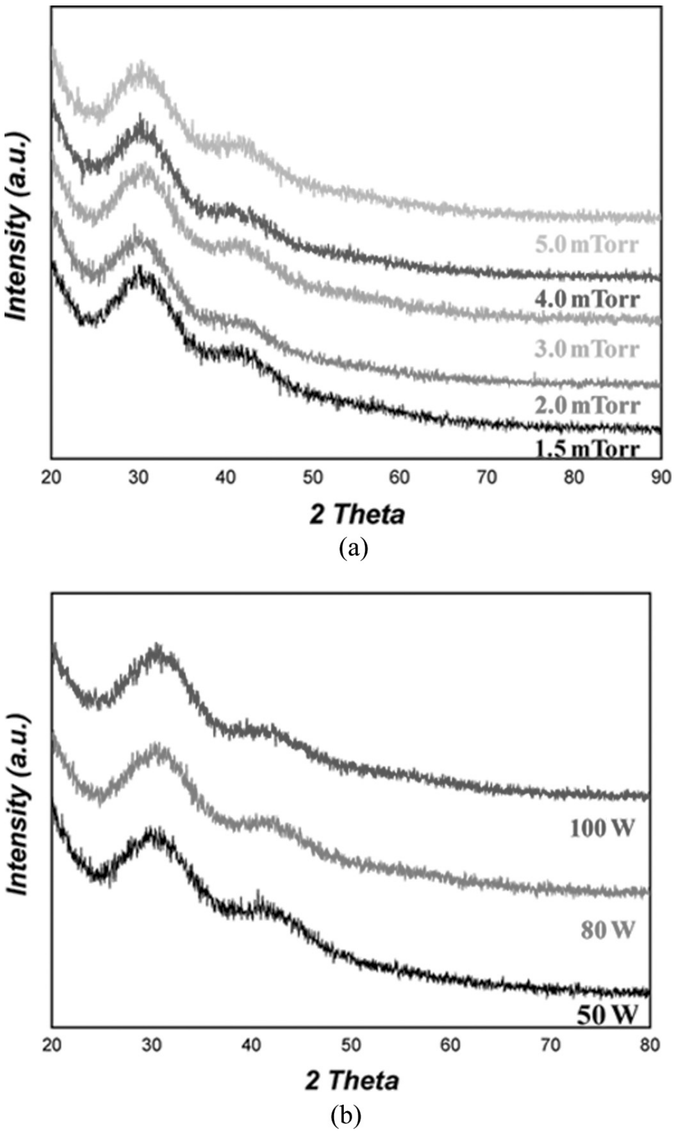


FIGURE 7 The XRD patterns of ITO films as coating condition (a) as working pressure, (b) as supplied power. (See COLOR PLATE VI)

PMMA to 9 layer of air/ITO/Ag/ITO/Ag/ITO/Ag/ITO/Ag/ITO/PMMA. In TEM image of Figure 10, we verified that ITO/Ag were alternately deposited in the our samples. It revealed that as the

TABLE 1 Optimized Coating Conditions

Experiment parameters		Value
Base Pressure		Bellow 3×10^{-5} Torr
Temperature		RT
Anode-ITO Spacing		5 cm, 7 cm
RF Input Power	ITO	100 Watt
	Ag	80 Watt
Working Pressure	ITO	3.0×10^{-3} Torr
	Ag	2.0×10^{-3} Torr
Working Time	ITO	$161 \sim 224$ s/384 s
	Ag	$124 \sim 194$ s

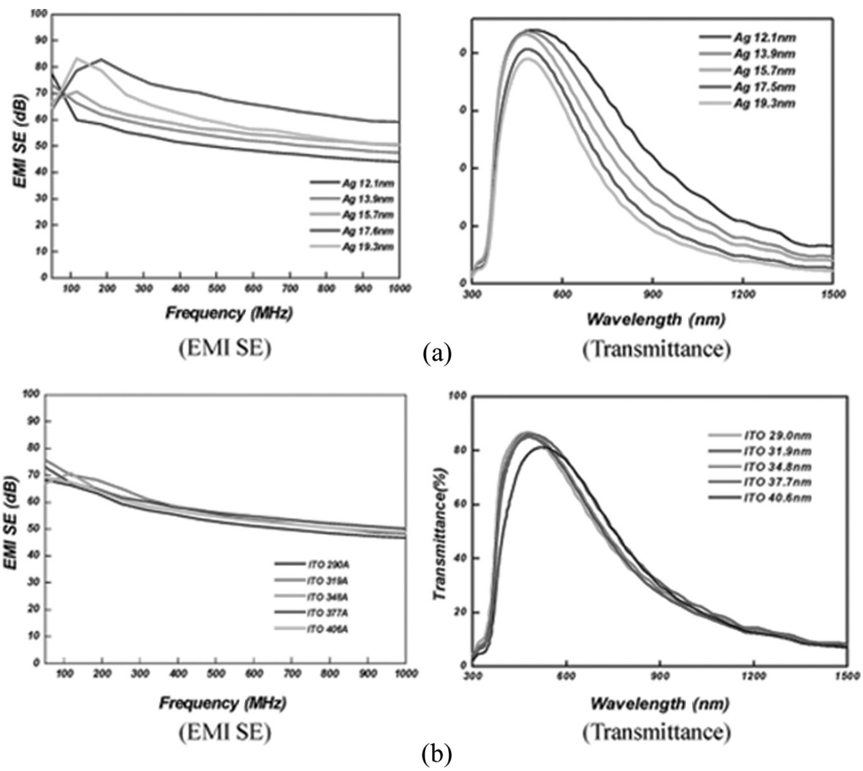


FIGURE 8 Change EMI SE and optical transmittance characteristic of EMI SE filter as film thickness. (a) Ag film thickness, (b) ITO film thickness. (See COLOR PLATE VII)

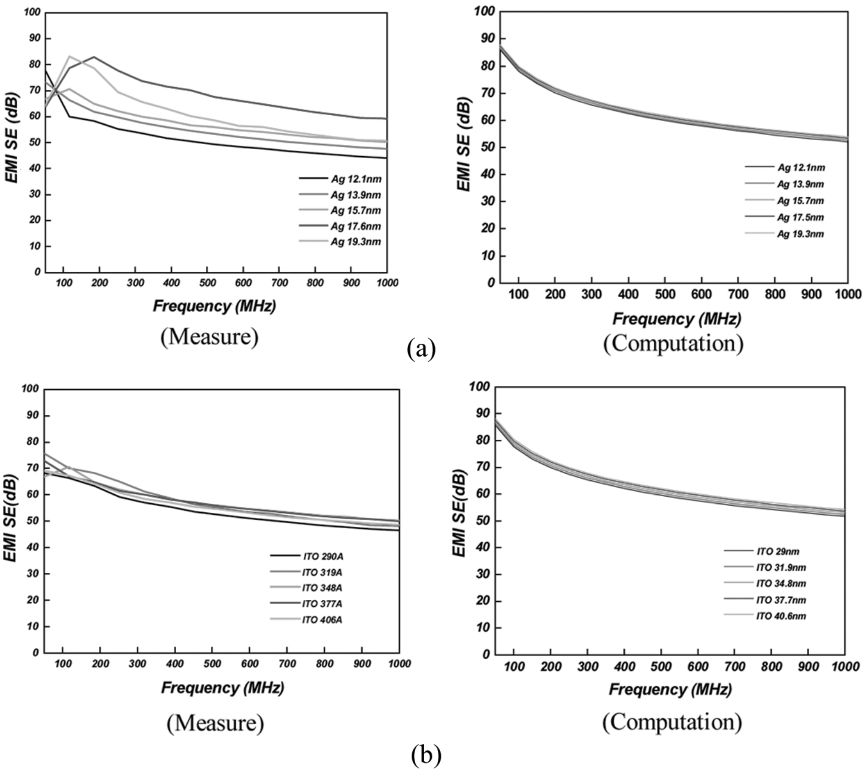


FIGURE 9 Measured and computational EMI SE. (a) as Ag film thickness, (b) as ITO film thickness. (See COLOR PLATE VIII)

number of layer is increasing from 3 to 9, EMI SE increasing from to and optical transmittance and sheet resistance are decreasing from 86.6% to 65.5% at 550 nm wavelength, from 4.3 Ω/sq. to 1 Ω/sq., respectively. Specially, in EMI SE filter of over 5 layer, we could obtain good optical and electrical characteristics with a minimum transmittance of about 60% at 550 nm wavelength and sheet resistance of $1 \sim 3\,\Omega$/sq., respectively.

Figure 11 shows SIMS patterns of EMI SE filter. We could find that our films have diffusion layers containing a little of In, Sn and O composition. We think that this fact will be a reason for EMI SE difference between measured and computational ones as seen in Figure 9.

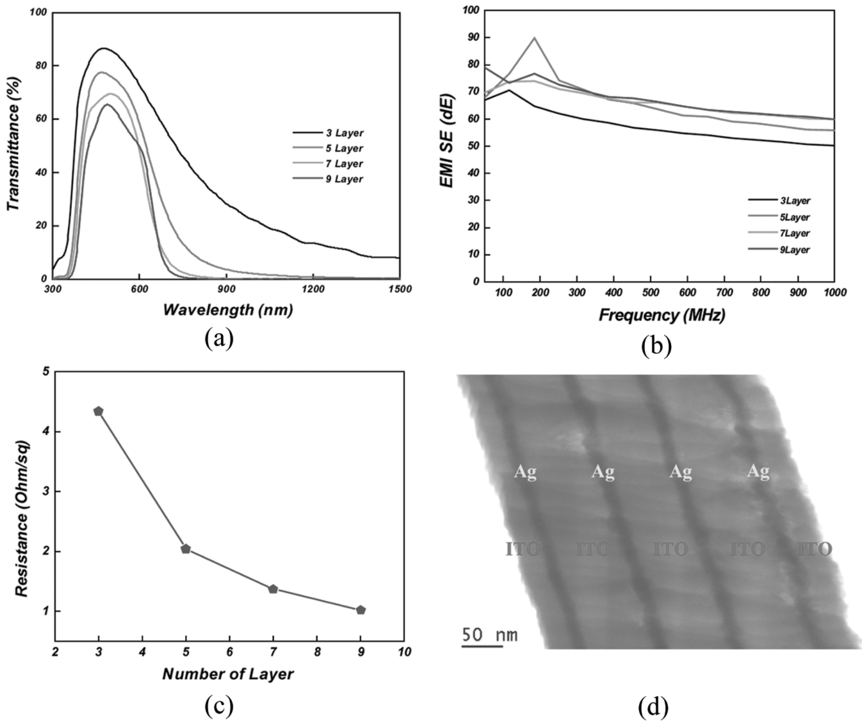


FIGURE 10 Characteristic of EMI SE filter as number of layer. (a) Optical transmittance, (b) EMI SE, (c) Sheet resistance, (d) TEM image. (See COLOR PLATE IX)

Figure 12 is XRD patterns of EMI SE filters. The results reveal that the more increasing number of layer, the more increasing Ag peak, but we couldn't find ITO peak. It suggests that the crystallinity of Ag films can be improved with increasing the Ag film thickness but ITO films could not grow crystallized in this way.

CONCLUSIONS

In this study, we fabricated a multi-layered EMI SE filter with ITO and Ag thin films for a display devices including the mobile display. It was found that the Ag films decide mainly EMI SE characteristics while the ITO films do the optical transmittance. The SIMS results show that EMI SE filters deposited alternately ITO and Ag films have a diffusion layer in the boundary between the ITO and the Ag film. This diffusion layer leads to a decrease in the measured EMI SEs, the compared computation ones. In this study, we could found that

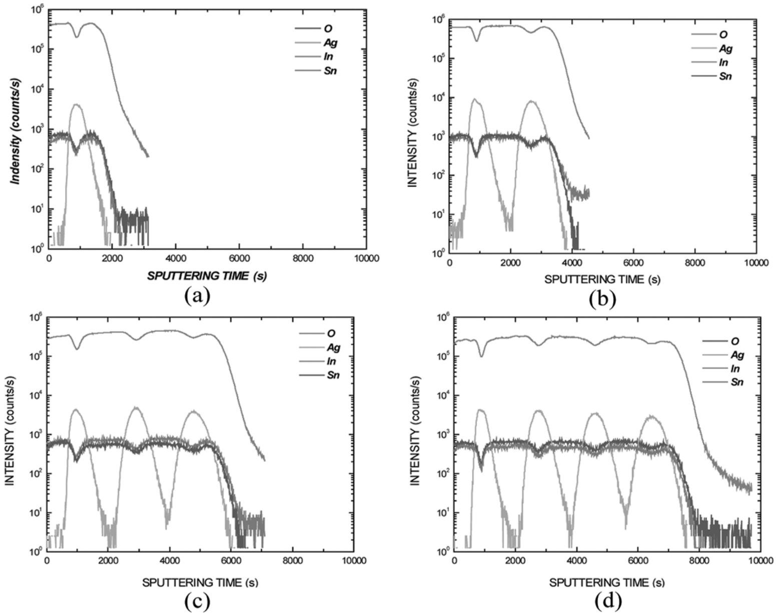


FIGURE 11 Result SIMS of EMI SE multi-layered filter. (a) 3 Layer, (b) 5 Layer, (c) 7 Layer, (d) 9 Layer. (See COLOR PLATE X)

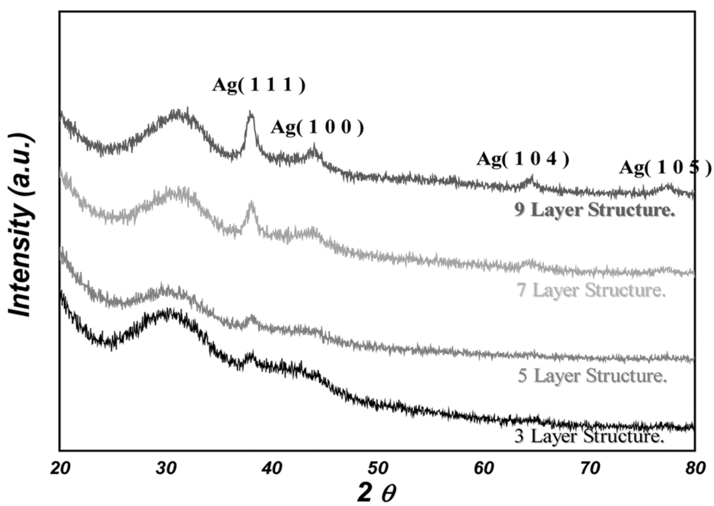


FIGURE 12 XRD pattern of EMI SE multi-layer filter. (See COLOR PLATE XI)

as the number of layer is increasing from 3 to 9, EMI SE increasing from to and optical transmittance and sheet resistance are decreasing from 86.6% to 65.5% at 550 nm wavelength, from 4.3 Ω/sq. to 1 Ω/sq., respectively. Specially, in EMI SE filter of over 5 layer, we could obtain good optical and electrical characteristics with a minimum transmittance of about 60% at 550 nm wavelength and sheet resistance of 1 ~ 3 Ω/sq., respectively.

REFERENCES

[1] Ott, H. W. (1988). *Noise Reduction Techniques in Electronic Systems*, Wiley: New York, 2nd ed.
[2] Hund, E. (1989). *Microwave Communications-Components and Circuits*, McGraw Hill: New York.
[3] Colaneri, N. F. & Shacklette, L. W. (1992). *IEEE Trans. Instrum. Meas.*, *41*, 291.
[4] ASTM D4935–89. (1999). Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials.
[5] Hong, Y. K., Lee, C. Y., Jeong, C. K., Lee, D. E., Kim, K., & Joo, J. (2003). *Rev. Sci. Instum.*, *74*, 1098.