Advanced Permeation Properties of Solvent-free Multi-Layer Encapsulation of thin films on Ethylene Terephthalate(PET)

Jin-Woo Han*, Hee-Jin Kang*, Jong-Yeon Kim, Jong-Hwan Kim, Jung-Min Han, Hyun-Chan Moon[1], Kwang-Bum Park[1],Hwi-Woon Kim[2] and Dae-Shik Seo

Department of Electrical and Electronics Engineering, Yonsei University, 134 Shinchon-Dong, Seodaemun-Gu, Seoul 120 - 749, Korea

[1]NANO mechatronics Research Center, Korea Electronics Technology Institute, 68 Yatap-dong, Bundang-gu, Seongnam-si, Gyeonggi-do 463-816, Korea

[2]Bang Joo Opical Co., Ltd., 455-6, Masan-ri, Jinwi-myeon, Pyeongtaek, Gyeonggi-do

Phone: (+82)2-2123-4617, E-mail: dsseo@yonsei.ac.kr

Abstract

In this paper, the inorganic multi-layer encapsulation of thin film was newly adopted to protect the organic layer from moisture and oxygen. Using the electron beam, Sputter, inorganic multi-layer thin-film encapsulation was deposited onto the Ethylene Terephthalate(PET) and their interface properties between inorganic and organic layer were investigated. In this investigation, the SiON SiO_2 and parylene layer showed the most suitable properties. Under these conditions, the water vapor transmission rate (WVTR) for PET can be reduced from level of 0.57 g/㎡/day (bare substrate) to $1*10^{-5}$ g/㎡/day after application of a SiON and SiO_2 layer. These results indicate that the PET/SiO_2/SiON/Parylene barrier coatings have high potential for flexible organic light-emitting diode(OLED) applications.

1. Introduction

Organic Light Emitting Diodes (OLED) is a device which applied electric field to organic materials to replace electric energy with light energy. When a voltage is applied across the electrodes, holes are injected from the anode and electrons from the cathode. These carriers migrate through the organic layer until they meet and recombine to form an exciton. Relaxation occurs after it turns from the excited into the ground states, causing emission of light. OLED has many advantages of low voltage operation, self-radiation, light weight, thin thickness, wide view angle and fast response time comparing with existing liquid crystal display (LCD)'s weakness. Therefore, it draws attention as a promising display and has already been developed for manufactured goods. Above all things, field of material has been making rapid progresses[1-13]. Differently with LCD, OLED needs more thin film transistors (TFT's) per one pixel. The top emitting method has been preferred to use to overcome this weakness rather than the bottom emitting method.

The existing bottom emitting method is easy to protect device from oxide and moisture because light is not emitted on the anode surface. But the top emitting method needs care about the transmittance when the encapsulation layer is on the anode and damage of organic layer when the encapsulation layer is deposited.

Thus in the method of the multi-layer, encapsulation and metal can that are mainly used before, it is difficult to apply to the top emitting OLED due to the damage of the organic emitting layer which is caused by a organic solvent in the former case and is blocked light in the latter case. Therefore, we developed the encapsulation layer which has a high transmittance without organic solvent.

2. Experimental

In this paper, 200 ㎛ thick PET film is deposited in the order of Parylene/SiO_2/SiON to find the permeability of the multi-layer thin film after washing in SC-1 solvent for about 300 sec and blowing with N_2. Parylene is deposited by evaporation and solid-state parylene dimer is evaporated at 150 °C in this process. The evaporated dimer is decomposed into the monomer in the thermal-decomposing region at a high temperature (700 °C) and then is flowed into the chamber. So it gets deposited on the surface of devices forming polymer.

Following the deposition of parylene, SiO_2 is deposited by electron beam in the condition of Table 1. Though a high-temperature deposition enhances a density of thin film and reduces defects of the surface so that the permeation is improved, the organic emitting layer can be damaged by a high temperature in the deposition process onto the electrode of devices, not onto the substrate of OLED. This is why a low-temperature fabrication process is chosen to minimize the damage of organic emitting layer. In addition, the deposition is also performed faster than other deposition methods of the encapsulation layer to prevent damage which is caused by a high temperature of substrate in a slow and long-time deposition.

Table 1. Deposited conditions used to fabricate SiO_2 water barrier films.

Parameters	Conditions
Deposition rate	7-8nm
Temperature	30℃
Thickness	500nm

SiON is deposited using the sputter in the condition of Table 2. The permeation is measured using PERMATRAN-W 3/33, MA of MOCON Inc. and the roughness of surface is measured using AFM. The deposed thickness of thin film is measured using Alpha Step and the transmittance of thin film is measured using Spectra Inc.

Table 2. Deposited conditions used to fabricate SiON water barrier films.

gas	ratio
O_2	12 sccm
Ar	1.2 sccm

3. Result and discussion

The encapsulation with high transmittance is essential to make a high efficient flexible OLED. In the existing bottom emitting method, organic and inorganic multi-layer structure is a mainstream. This kind of method can enhance the permeation easily. However the top emitting method, not the bottom emitting normally used, is difficult to apply to cathode of OLED exposed to air directly because of disadvantages which can be damaged by effects of the organic solvent when organic deposition and need high-temperature fabrication processes.

In order to solve these issues, the thin film fabrication processes without the organic solvent should be developed. Moreover, the transmittance of the encapsulation layer is raised as an important issue because light pass through there. As shown in Fig. 1, the transmittance of parylene 5 ㎛ is 90%. It shows that it doesn't have any problems to apply to the encapsulation layer of devices.

In the case of the organic encapsulation, it has lower transmittance comparing with the inorganic. Thus the inorganic encapsulation is essential to shut out oxygen and moisture perfectly. To deposit the inorganic encapsulation layer in the several methods, the electron-beam and the sputter are available in atmosphere. The sputter is superior in the characteristics of the thin film. However, plasma particles can effect on the organic thin film. SiO_2 is deposited using the electron-beam to settle these problems.

SiO_2 has good transmittance and abilities that can be deposited in many manners and bad permeation. In the other hand, SiN_2 has good permeation and bad transmittance. In this study, the optimized ratio between oxygen and nitrogen is experimented with SiON thin film.

Figure 2 and Figure 3 show the transmittance of SiON thin film and the AFM image of SiON surface. The transmittance performs best when adding 10% of oxygen. Though it is not as good as SiO_2 thin film, it is difficult to find difference within naked eyes. In addition, as shown in Fig 3, the surface of SiON thin film is generated considerably sleekly. In the end, the permeation of the completed encapsulation layer measured by Ca-test approached about $1*10^{-5}$ g/㎡/day. This is an approximate value to goal of OLED, $1*10^{-6}$ g/㎡/day.

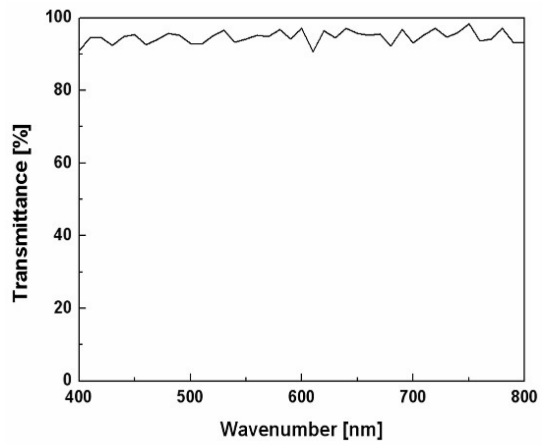

Fig. 1. Transmittance of parylene 5 µm.

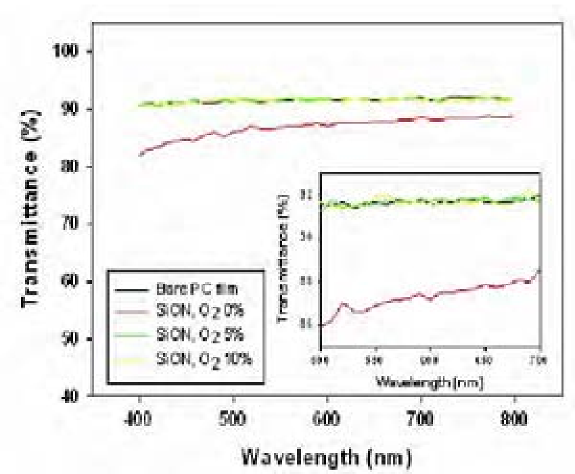

Fig. 2. Transmittance of SiON according to O_2 ratio.

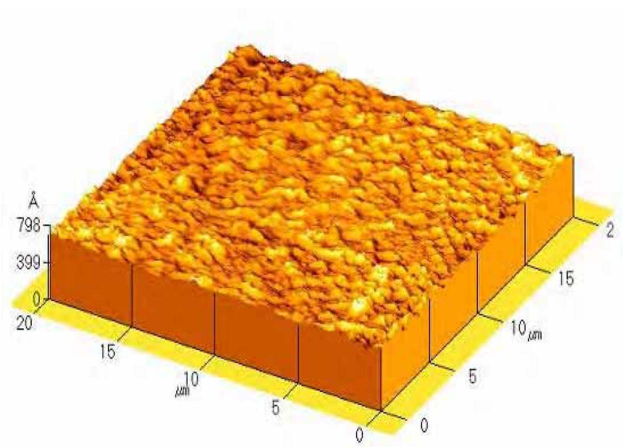

Fig. 3. AFM image of SiON surface.

4. Conclusion

In this paper, we research solvent-free multi-layer encapsulation of thin films on the PET substrates to make a high efficient and long lifetime flexible OLED. As a result, the performance is enhanced up to $1*10^{-5}$ g/㎡/day that this is hard to achieve through a single layer. Though this is not enough to satisfy a required value, outstanding performance is achieved by simple process using solvent-free method. Therefore, this is supposed to be very suitable to the top-emitting OLED that couldn't take the existing encapsulation layer.

5. Acknowledgement

This work is supported by National Research Laboratory program (M1-0412-00-0008) and by the Ministry of Information & Communications of Korea under the Information Technology Research Center (ITRC) Program.

7. References

[1] Anna B. Chang, Mark A. Rothman: Appl. Phys. Lett., **Vol. 83**, p. 413, (2003).

[2] C. W. Tang and S. A. VanSlyke: Appl. Phys. Lett, **Vol. 51**, p. 913, (1987).

[3] H. Lifka, H. A. vanEsch and M. Rosink: Proceedings of the SID 2004 International Symposium, p. 1384, (2004).

[4] D. J. Sekelik, E. V. Stepanov, S. Nazarenko and A. Hiltner: Journal of Polymer Science: Part B, Polymer Physics, **Vol. 37**, p. 847, (1999).

[5] D.S. Wuu, W.C. Lo, L.S. Chang and R.H. Horng: Thin Solid Films **Vol. 468**, p. 105, (2004).

[6] A. Gruniger, Ph. Rudolf and von Rohr: Thin Solid Films **Vol. 459**, p. 308, (2004).

[7] A.P. Roberts, B.M. Henry, A.P. Sutton, C.R.M. Grovenor, G.A.D. Briggs, T. Miyamoto, A. Kano, Y. Tsukahara, M. Yanaka, J. Member: Sci. **Vol. 208,** p. 75, (2002).

[8] Z. Suo, E. Y. Ma, H. Gleskova and S. Wagner: Appl. Phys. Lett., **Vol. 74**, p. 1177, (1999).

[9] C. W. Tang and S. A. VanSlyke: Appl. Phys. Lett, **Vol. 51**, p. 913, (1987).

[10] C. J. Lee, R. B. Pode, D. G. Moon, and J. I. Han: Thin Solid Film, **Vol. 467**, p. 201, (2004).

[11] S. H. Kwon, S. Y. Paik, O. J. Kwon, and J. S. Yoo: Appl. Phy. Lett, **Vol. 79**, p. 4450, (2001).

[12] A. B. Chang, M. A. Rothman, S. Y. Mao, R. H. Hewitt, M. S. Weaver, J. A. Silvernail, M. Haek, J, J. Brown, X. Chu, L. Moro, T. Krajewski and N.

Rutherford: Appl. Phys. Lett, **Vol. 83**, p. 413, (2003).

[13] C. J. Lee, D. G. Moon and J. I. Han: SID 04 Digest, **Vol. 1005,** (2004).