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Characterization of the Multi-Layer Encapsulation of Thin Films on Ethylene Terephthalate (PET)

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In this paper, the inorganic-organic thin film encapsulation layer was newly adopted to protect the organic layer from moisture and oxygen. Using the electron beam, sputter and spin-coater system, the various kinds of inorganic and organic thin-films were deposited onto the Ethylene Terephthalate (PET) and their interface properties between organic and inorganic layer were investigated. In this investigation, the SiON and Polyimide (PI) layer showed the most suitable properties Under these conditions, the WVTR for PET can be reduced from a level of $0.57 g/m^2/day$ *(bare substrate) to* $1*10^{-5} g/m^2/day$ *after application of a SiON and PI layer. These results indicate that the SiON/PI/SiON/PI/PET barrier coatings have high potential for flexible organic light-emitting diode (OLED) applications.*

Keywords: encapsulation; multi-layer; PI; SiON

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INTRODUCTION

The OLED which has been commercialized by Pioneer at 1997 has very unique properties such as low consuming power level and high contrast, which makes OLED to be very good candidate display system for next generation [1–4]. Especially, most valuable point of OLED is that the OLED can be fabricated onto plastic film substrate such as PET and Polyacryl (PC). This unique fabrication process gives good chance to use for flexible organic light emitting diode (FOLED).

However, one major drawback of through all known plastic film substrate is the high permeation rate to oxygen and water vapor, because materials for OLED are very sensitive to oxygen and water vapor. It is known that long lived OLEDs require a moisture barrier which transmits $< 10^{-5}\,g/m^2{\cdot}day$ and a oxygen barrier of $10^{-3}\,cc/m^2{\cdot}day$ [5,6]. In order to solve this problem, a barrier layer which protects the penetration of oxygen and water can be coated on polymer sheet substrate [7–9]. In this case, buffer layer need also flexibility and chemical resistance.

Multi-coated film has very high feasibility for using buffer and/or barrier layer for FOLED because of its unique process and material properties. Multi-coated film shows excellent homogeneous and conformal coverage without pinhole or micro crack, result in low permeation rate for oxygen and water vapor [10–13]. There were few reports of Multi-coated film to apply in OLED devices. L.Ke *et al.* reported that OLED performance was improved by insertion of 3 nm thick parylene layer between ITO and HTL [14]. However, there were no reports for barrier characteristics of parylene, which was directed coated on plastic substrate, until now.

EXPERIMENTAL

In this study, to measure the water vapor transmission rate (WVTR) of multi-layer inorganic thin films, for 300 sec, 200-μm PET substrates

TABLE 1 Deposited Conditions Used to Fabricate SiO_2 Water Barrier Films

Parameter	Condition
Deposition rate	5–6 nm/sec
Temperature	110°C
Thickness	200 nm

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TABLE 2 Deposited Conditions Used to Fabricate SiON Water Barrier Films

Layer	Deposition temperature
Ar	12 sccm
O_2	0.5 sccm

were cleaned with solution mixed in the ratio of 1:1:5 (H_2O_2: NH_3: H_2O), and blown with N_2 gas. SiO_2 were evaporated on them by electron beam under the conditions of 110°C. The thickness of the SiO_2 thin films were approximately 200 nm with the evaporation speed of 5–6nm/sec (Table 1).

For 20 min at 100 w, the 200 nm thickness of SiON was evaporated with Sputter injected Ar and O_2 in the ratio of Table 2 at the $3.0*10^{-3}$ torr of process pressure. Organic layer was composed of PI and Poly Acrlyic, and coated with spin coater under the condition of spread 500 rpm, spin 3000 rpm. After that, curing was done at 110°C for 2 hours. Repeating these process one more, we made multi-layer.

The WVTR was measured by PERMATRAN-W 3/33, MA (MOCON Co.), but Calsium test was used when could not measure the WVTR with it. Calsium was evaporated by thermal evaporation for Calsium

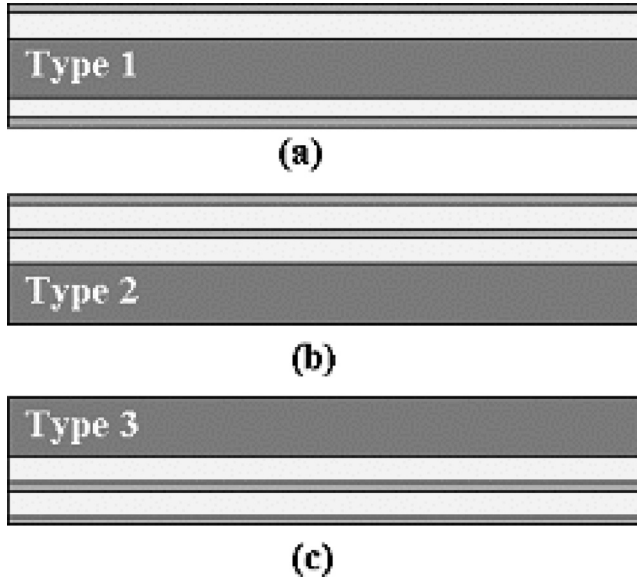

FIGURE 1 Structure of Type-1, Type-2, Type-3.

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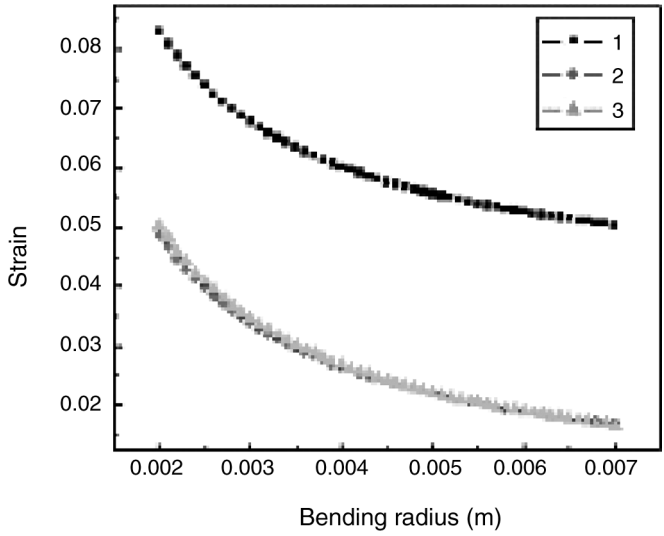

FIGURE 2 Strain of Type-1, Type-2, Type-3.

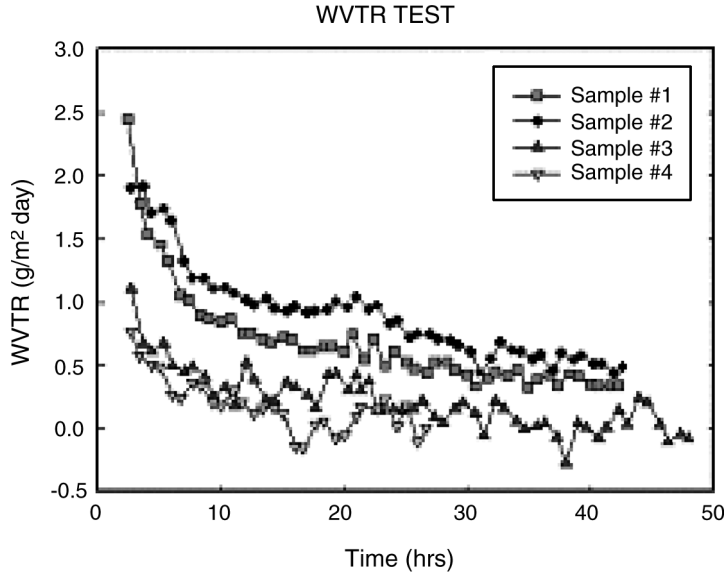

FIGURE 3 AFM image of surface of Type-1.

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Test. Furthermore, the roughness of surface was measured AFM, and Alpha Step was used for the thickness of evaporation.

The encapsulation of high WVTR is essential to manufacture high efficiency FOLED device, but these encapsulation materials are almost inorganic. This fact indicates that minimizing the stress of surface, no cracks must be occurred for FOLED.

We used three types of models to minimize the stress that is occurred when evaporating a multi-layer. Figure 1 shows three different models that were used in this experiment.

RESULTS AND DISCUSSION

Among three models, the stress of Type 2 is lower than others in simulation results [8,11,13]. So, Type 2 was selected as the model for the

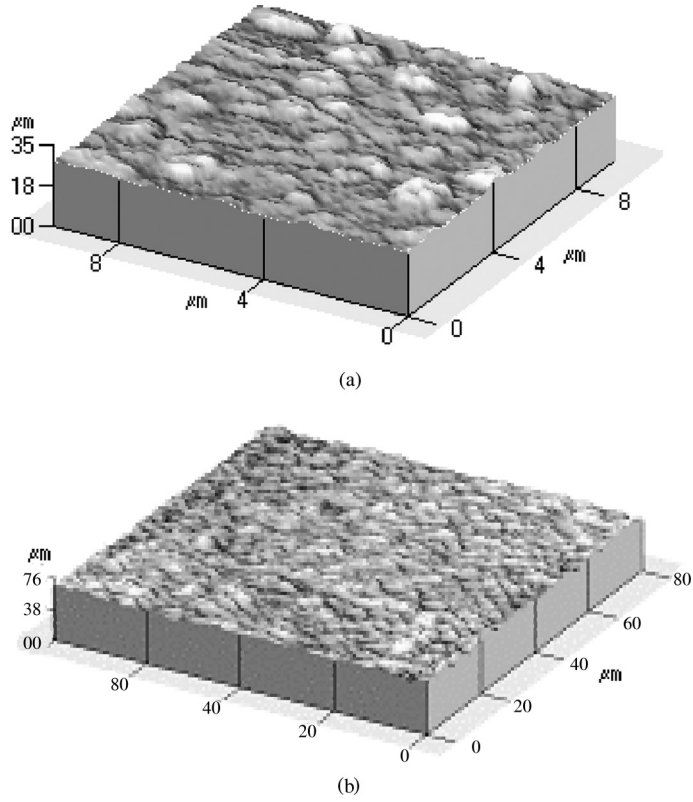

FIGURE 4 AFM image of surface of inorganic film.

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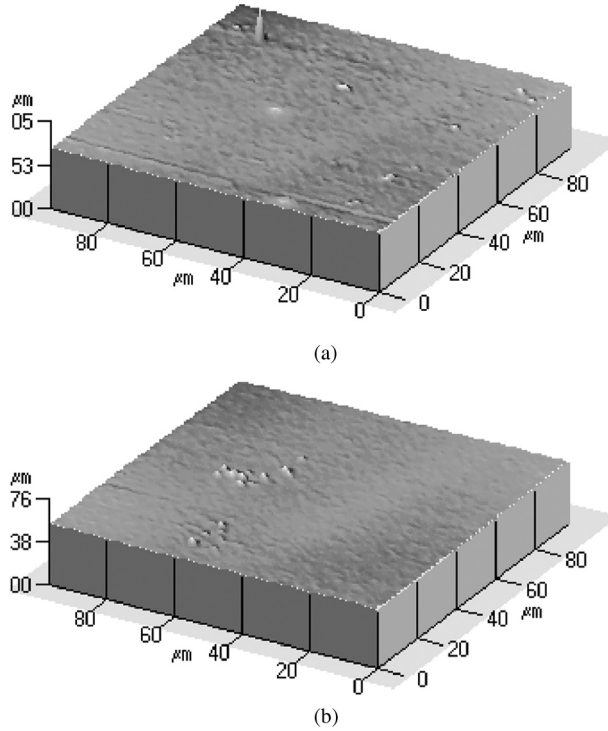

FIGURE 5 AFM image of surface of organic film.

measurement of WVTR, and four types of model were manufactured using SiO_2, SiON as organic layer and PI, PC as inorganic layer.

Figure 3 shows that the kind of inorganic layer affected WVTR more than that of organic layer. The WVTR of model using SiON as inorganic layer was lower than the $1*10^{-3}g/m^2/day$ of minimum value that can be measured with MOCON in both PI and PC.

Figure 4 shows AFM photographs on the surface of SiO_2andSiON. As shown in Figure 4, the surface of SiO_2 thin film evaporated at high temperature was rougher than that of SiON. However, after coating on a organic layer, the photographs of surface are almost same, as shown in Figure 5. So, the roughness of surface is not an important factor which affected the difference of WVTR.

The WVTR of SiON thin film is higher that that of SiO_2 thin film because the density of surface rises due to the addition of N [12,13].

From the result of samples, the WVTR of type2 evaporated SiO_2 in Sputter was $-0.081\,g/m^2/day$, It is lower than the value measured by

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MOCO. This result indicates that the value of WVTR can apply to manufacture long lifetime FOLED device.

CONCLUSIONS

The development of encapsulation technique needs to make high efficiency and long lifetime flexible OLED devices. In this paper, SiO_2 evaporated at high temperature, SiON deposited in sputter, and PI, PC as organic layer were used.

In SiO_2 evaporated at high temperature, the WVTR was $0.05\,g/m^2/day$, but the value was not suitable to OLED devices for common use. However, in SiON thin film, the value of WVTR was suitable to them. Because the multi-layer thin film using SiON can improve WVTR, it is suitable as the encapsulation of FOLED devices.

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