Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 158-159

A-3-5

Lifetime property of flexible organic light emitting diodes with plasma polymer barrier layers

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1. Introduction

Organic light emitting diodes (OLEDs) were considered as a promising flat panel display, because of their advantages such as wide view angle, low operating voltage, low cost, and possibility of flexible full color display [1-2]. The flexible OLEDs (FOLEDs) using plastic substrate provide ability to conform, bend or roll a display into any shape [3-10]. For the purpose of reducing moisture permeability through plastic substrates, it is attempted to insert a barrier layer between the OLEDs and the plastic substrates. In order to improve properties of the flexible substrate, P. E. Burrows *et al.* utilized a transparent barrier stack of an alternative organic-inorganic multiplayer on a plastic substrate [8]. An application of plasma polymerized films in OLED devices to improve lifetime of OLEDs has been reported [11]. Because of the highly cross-linked network structure, plasma polymerized thin films are pinhole free, mechanically and chemically stable, and strongly adhere to underlying layers [12].

In this work, we report that, in the fabrication of the FOLEDs, insertion of a plasma polymer barrier layer between FOLEDs and the plastic substrate improved lifetimes of FOLEDs. The plasma polymer barrier layer was deposited by PECVD using para-xylene as the precursor, and was referred to as plasma polymerized para-xylene (PPpX).

2. General Instructions

In our experiments, polyethylene terephthalate (PET) was used as the plastic substrate. The PPpX barrier layer was deposited by PECVD at 0.2 torr. The deposition plasma power was varied in the range of 30-90 W.

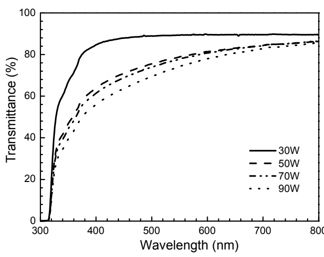


Figure 1. Transmission spectra of the PP*p*X films on PET substrates deposited with various plasma power.

Figure 1 shows the transmission spectra of PPpX films on PET substrates deposited at various plasma deposition power between 30 W and 90 W. The thickness of PPpX barrier film was fixed at 75 nm. Transmittance of PPpX in blue light range decreased as the plasma power increased. The PPpX deposited at plasma power of 30 W showed a similar transmittance spectra to that of the PET substrate.

The indium-tin-oxide (ITO) anode was deposited with sputtering power of 50 W for 15 min, and thickness of ITO was 150 nm. Before deposition of organic layers, the ITO surface was treated by O_2 plasma at 2×10^{-1} torr for 60 sec. N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-diphenyl-4, 4'-diamin (TPD), tris-(8-hydroxyquinoline) aluminum (Alq_3), and Al were used as the hole transport layer (HTL), the emitting layer (EML), and the cathode, respectively. TPD and Alq_3 of 60 nm and 40 nm thickness, respectively, were deposited at the deposition rates of 1.0-1.5 Å/s on ITO. The Al cathode layer was deposited to the thickness of 100 nm at the deposition rates of 10 Å/s by thermal evaporation.

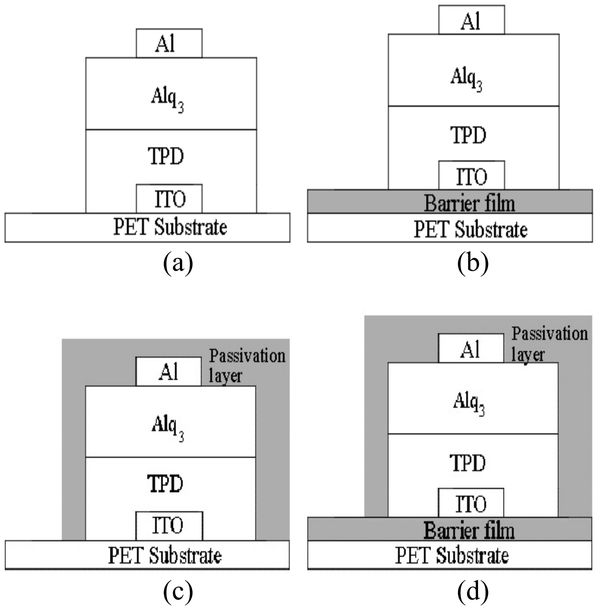
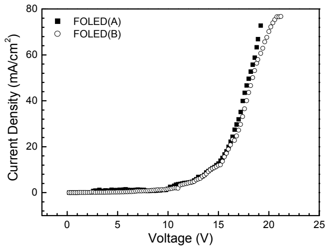


Figure 2. Structures of FOLED(A) (a), FOLED(B) (b), FOLED(C) (c), and FOLED(D) (d).

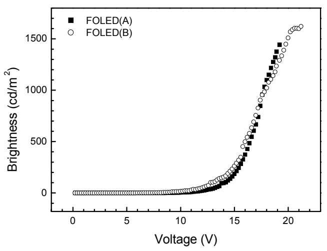
Figures 2(a) and 2(b) show structures of the FOLED without a barrier layer (FOLED(A)) and the FOLED with a barrier layer (FOLED(B)). The PPpX barrier layer (75 nm) was deposited with plasma power of 30 W at deposition pressure of 0.2 torr for 10 min. In addition to a barrier layer, which was needed to prevent moisture penetration through the PET substrate, a passivation layer was also applied to our FOLEDs to prevent moisture penetration from surrounding ambient into FOLEDs. Use of the plasma polymer layer as an OLED passivation layer was previously reported [11]. Figures 2(c) and 2(d) show structures of the passivated FOLED(A) (FOLED(C)) and the passivated FOLED(B) (FOLED(D)). The thickness of PPpX passivation layer was 300 nm.

3. Results and discussion

Figures 3(a) and 3(b) show the current density-voltage (J-V) and brightness-voltage (B-V) characteristics of FOLED(A) and FOLED(B). The FOLED(B) showed similar J-V and B-V characteristics to those of the FOLED(A).



(a)



(b)

Figure 3. Current density versus applied voltage (a) and brightness versus applied voltage (b) for both FOLED(A) and FOLED(B).

The lifetimes of FOLEDs were measured at initial brightness of ~100 cd/m^2, and dc constant current of ~6.5 mA/cm^2 in air at room temperature. Figure 4 shows degradation characteristics of our FOLEDs. The lifetime of FOLED(A) was 1,429 s while the FOLED(B) was 3,022 s, twice larger than that of the FOLED(A). It is thought that the PPpX barrier layer reduced the penetration of moisture and/or oxygen through the PET substrate into FOLEDs, increasing lifetime of FOLED(B).

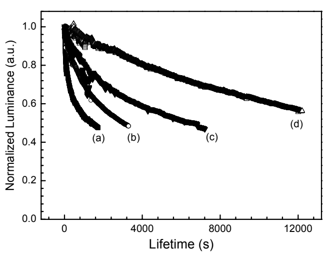


Figure 4. Lifetime characteristics of FOLED(A) (a), FOLED(B) (b), FOLED(C) (c), and FOLED(D) (d).

It is known that plasma polymers have very low density of pinholes due to the highly cross-linked network structure and adhere well to underlying layers due to the activation of the growing surface by plasma at the beginning of and/or during the PECVD deposition process [12]. To investigate the effect of the PPpX barrier layer more closely, it is needed to reduce, as much as possible, the water and/or oxygen penetration from the surrounding ambient into our FOLEDs. For this purpose, we passivated FOLED(A) and FOLED(B) using PPpX as a passivation layer this time. The PPpX passivation layer was deposited with plasma power of 30 W at deposition pressure of 0.2 torr. The thickness of passivation layer was 300 nm. With PPpX passivation layers, lifetimes of both FOLED(A) and FOLED(B) were improved by more than 4 times, as shown previously [11]. The FOLED(C) and the FOLED(D) showed lifetimes of 6,690 s and 12,577 s, respectively. The above results show that the PPpX layer reduces water and/or oxygen penetration through PET substrate into FOLEDs whether FOLEDs are passivated or not, playing a role of a barrier layer.

4. Conclusions

In summary, the PPpX film was used as a barrier layer between FOLEDs and PET substrates. The lifetime of barrier-FOLED was two times longer than that of the control-FOLED. With PPpX passivation layers, lifetimes of both control-FOLEDs and barrier-FOLEDs were improved by more than 4 times. These results show that PECVD deposited PPpX layers can be used as barrier layers for FOLEDs on plastic substrates as well as passivation layers for general OLEDs.

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