Efficiency Enhancement of Organic Light Emitting Diode Using TiO_2 Buffer Layer

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Abstract

We have studied the effect of TiO_2 layer deposited by RF magnetron sputtering which is used as an ultra thin hole-injection buffer layer in organic light-emitting diode (OLED). The TiO_2 thin film layer prevents metallic ions from diffusing from the ITO layer to the organic layers and improves the balance of hole and electron injections and the interface characteristics between the electrode and the organic layer. With 2 nm thickness of TiO_2, the quantum efficiency was improved by 45 % compared to the device fabricated without the TiO_2 layer.

1. Introduction

Organic light-emitting diodes (OLEDs) based on both small-molecule and polymer thin films seem to attract much interest as flat panel displays for the next generation. Longer lifetime as well as attainment of high quantum efficiency is one of the most important issues for the applications of OLEDs. Since the first report on the efficient bright emission obtained from a bilayer organic device, considerable progress has been made in improving the material performance and in optimizing the device structure [1, 2, 7]. Insertion of a buffer layer at the interface between an electrode and an organic layer is one of the effective methods to improve the efficiency and the lifetime of the OLEDs, suppressing noisy leakage current, reducing the operating voltage, and enhancing the thermal stability [3, 4, 5, 6]. Not only the unmatched energy barriers but also different mobilities of electron and hole in the OLED structure induce an imbalance in electron and hole concentrations in the emission layer. Therefore, by inserting an insulating hole-injection buffer material between ITO anode and hole transport layer (HTL), excess injected holes from ITO can be blocked out and accordingly the number of electrons and holes can be matched in the emitting layer. In this work, we propose TiO_2 buffer layer by means of material to replace conventionally used buffer layer materials.

2. Experiments

We report on the enhancement of the quantum efficiency in an OLED utilizing 8-hydroxy quinoline aluminum (Alq_3) and diamine derivative (TPD) with insertion of a thin titanium dioxide (TiO_2) film between the ITO anode and the TPD layer. Figure. 1 shows a schematic description of the device used in this study. The device is consisted of an indium tin oxide (ITO)-coated glass, TiO_2 buffer layer (0-3 nm), N,N'-dipheny1-N,N'-bis(3-methylpheny)-1,1'bipheny 1-4,4'-diamine (TPD) hole transporting layer (50 nm), a 8-hydroxyquinoline aluminum (Alq_3) emission layer (50 nm) and aluminum (Al) cathode (150 nm). The TiO_2 layer was deposited onto the ITO-covered glass substrate by RF magnetron sputter. Its average deposition rate was 0.5 Å/s. Organic thin films were subsequently deposited by the conventional vapor deposition techniques at a rate of 0.2 nm/s. The deposition was carried out at a background pressure of less than 10^{-6} torr. Figure. 2 shows an energy bend diagram of the device used in this study. The active device area was 4 mm^2. The current-voltage characteristics and voltage-luminescence characteristics were measured by Keithley 238 Electrometer and Hamamatsu Photonics Photomultiplier, respectively. All measurements were carried out at the room temperature.

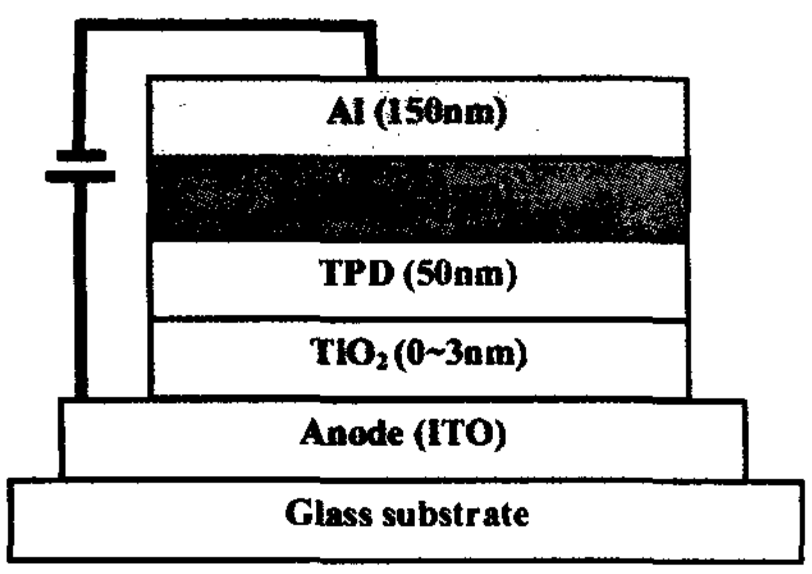


Fig. 1. EL device configuration.

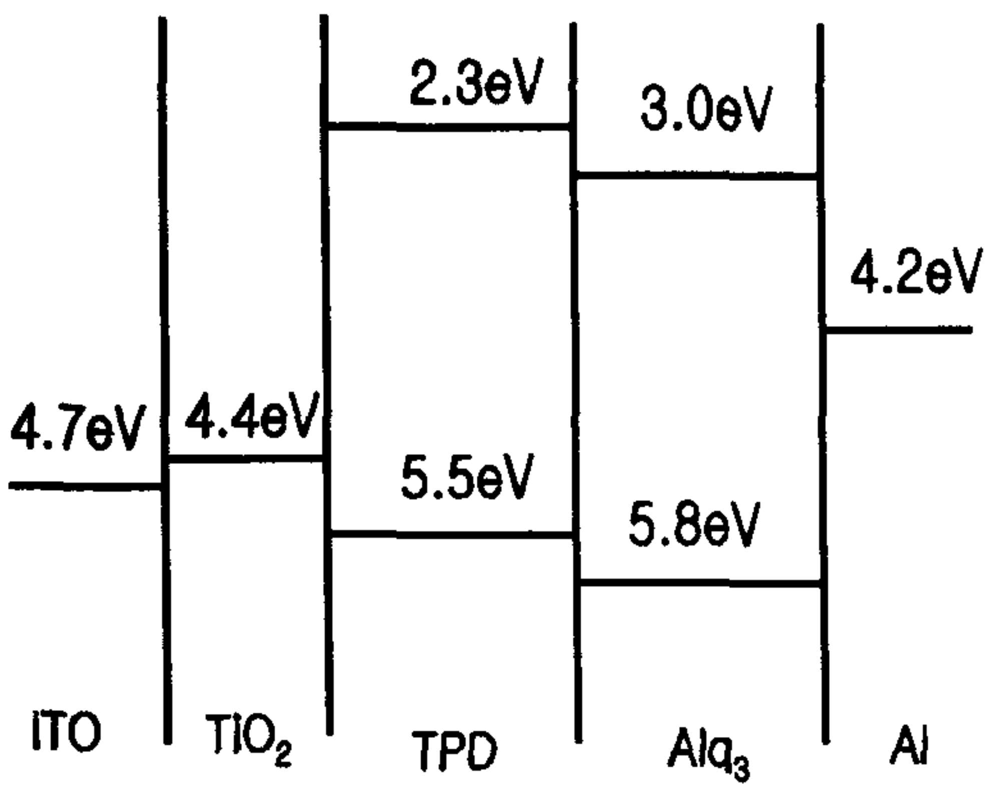


Fig. 2. Energy bend diagram in the fabricated EL device.

3. Results and discussion

Transmittance characteristics of sample with and without TiO_2 layer onto glass are shown in Fig. 3. At the wavelength 550 nm, transmittance characteristic of the glass is 96.624 % and Transmittance characteristics of sample with and without TiO_2 layer onto glass were 85.654 % and 86.982 %, respectively. According to these results, we could verify that TiO_2 buffer layer in OLED structure does not change the amount of emission.

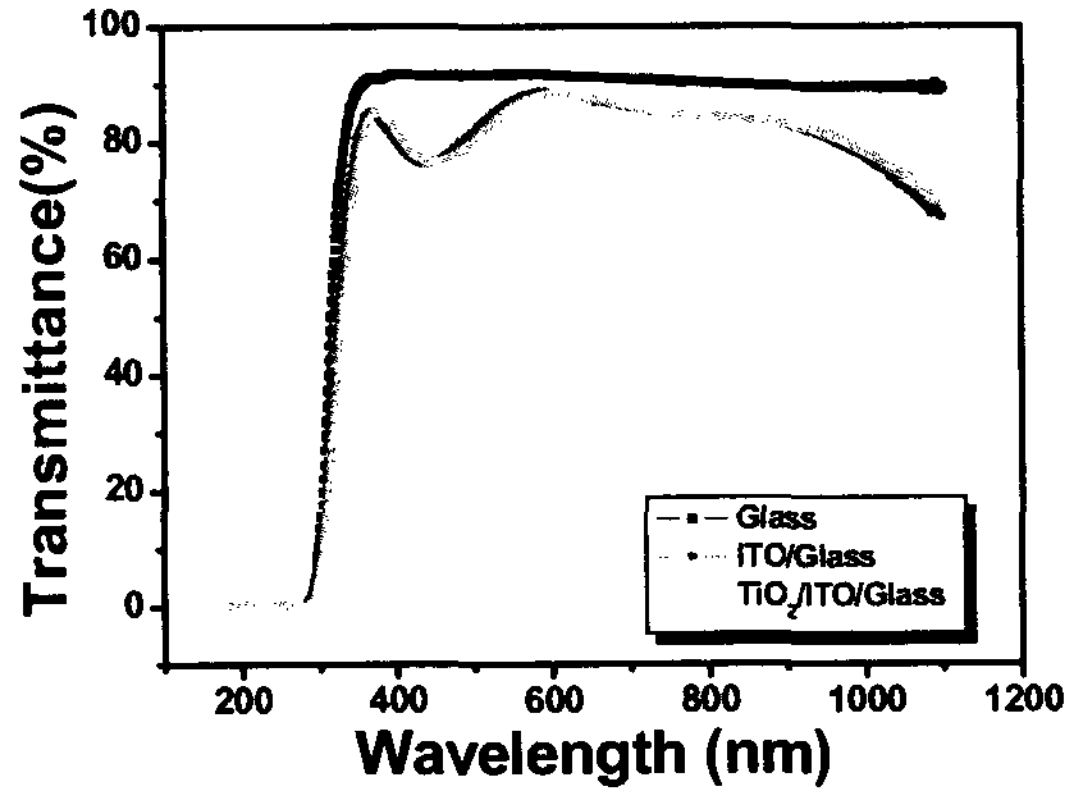
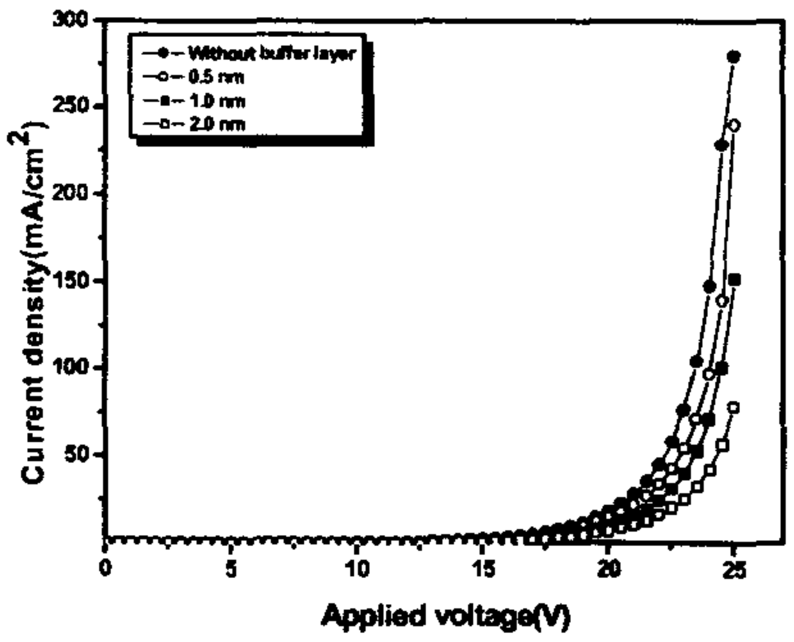
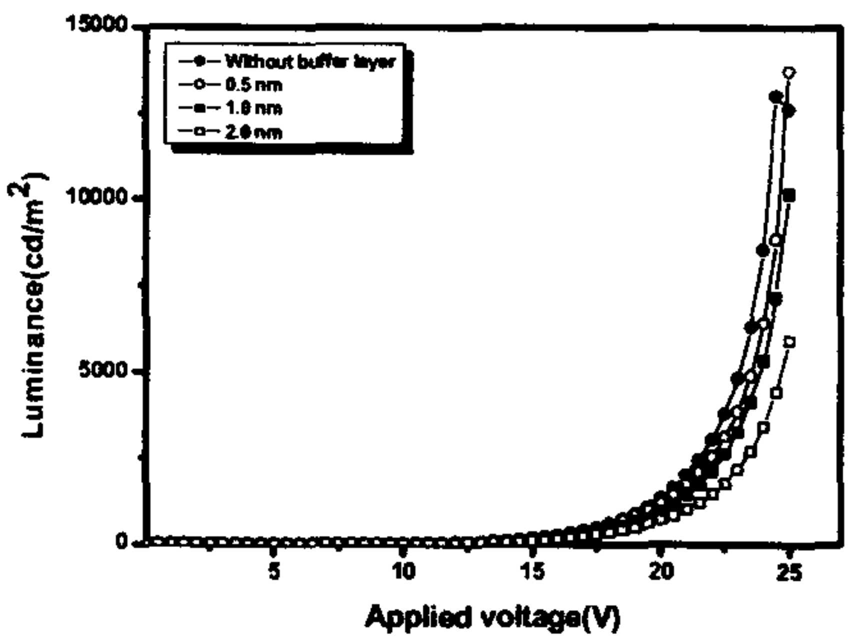


Fig. 3. Transmittance characteristics of sample with and without TiO_2 layer onto glass.

The luminance-current density-voltage (L-J-V) characteristics of the ITO/TiO_2/TPD/Alq_3 /Al devices are shown in Fig. 4. The J-V performance of the fabricated devices is strongly dependent on the presence and the thickness of the TiO_2 buffer layer. When the applied voltage was fixed, the injection current density decreases with the increment of the TiO_2 thickness. The turn-on voltages of the devices without and with the TiO_2 buffer layers of 0.5, 1.0 and 2.0 nm were 10, 9.5, 9.5, and 10 V, respectively.



(a)



(b)

Fig. 4. Current density versus voltage characteristics(a) and luminance versus voltage characteristic(b) of the fabricated devices with different buffer layer thickness.

Figure. 5 shows the luminance-current characteristics of the fabricated devices with various TiO_2 thicknesses. Luminance increased proportionally as the current density increased. The luminance of the devices with 1 nm and 2 nm TiO_2 thickness were larger than the one without TiO_2 layer under the same current density. Figure. 6 shows the current efficiency versus current density for the four different devices. A maximum efficiency of 10.01 cd/A was obtained with the device of 2.0 nm TiO_2 buffer layer. Figure. 7 shows the luminance efficiency versus voltage for the four different devices and as expected, a maximum efficiency of 2.09 lm/W was obtained with the device of 2.0 nm TiO_2 buffer layer. Figue.8 shows luminance efficiency with respect of different buffer layer thickness. The quantum efficiency of the device with 2 nm TiO_2 thickness was improved by 45 % compared to the device without a TiO_2 layer. Figure.9 shows images of atomic force microscopy of the ITO surface without and with the TiO_2 buffer layer. Root mean square (RMS) values of ITO surface without and with the TiO_2 buffer layer were 5.465 nm and 4.641 nm, respectively.

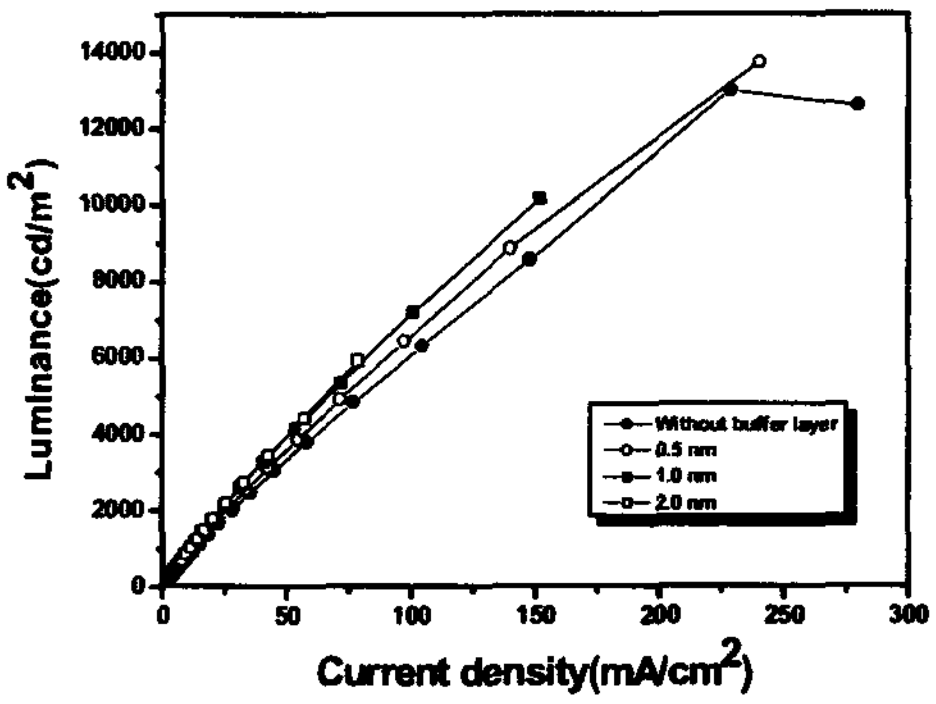


Fig. 5. Luminance versus current density characteristics of the fabricated devices with different buffer layer thickness.

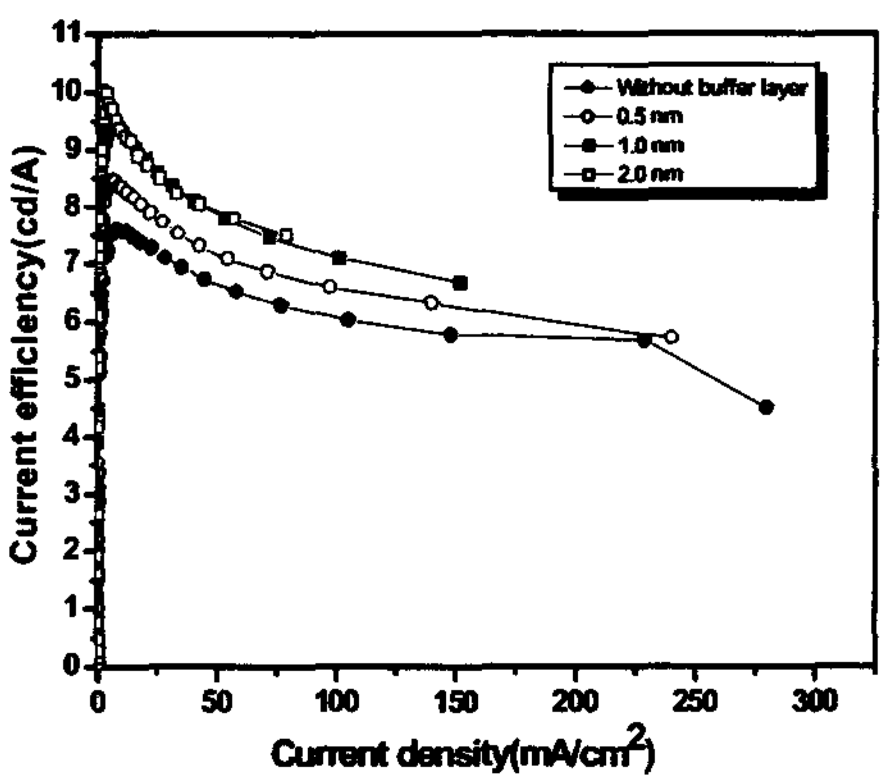


Fig. 6. Current efficiency versus current density characteristics of the fabricated devices with different buffer layer thickness.

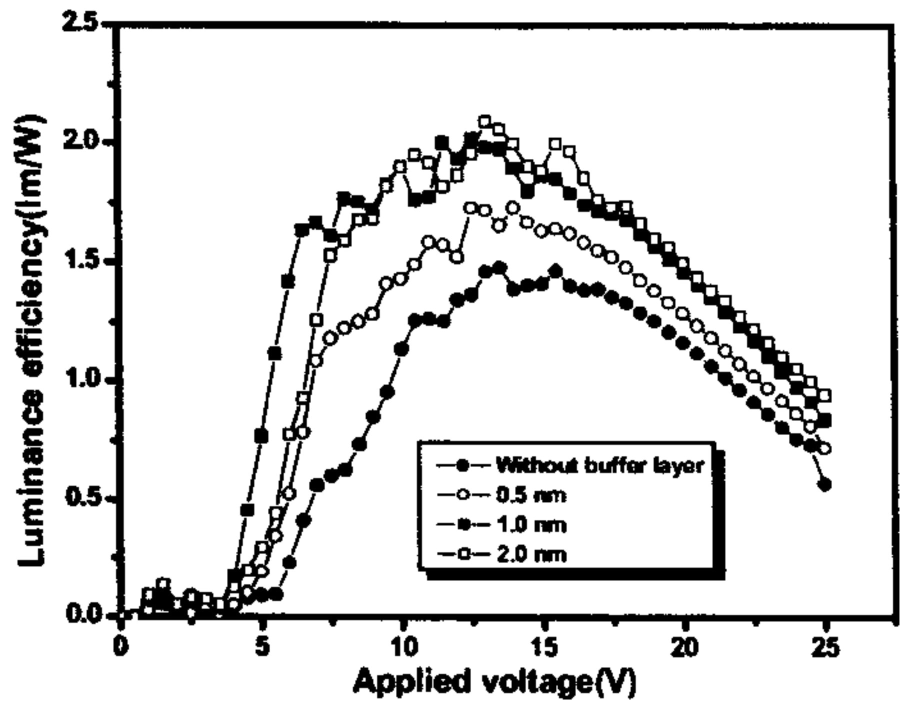


Fig. 7. Luminance efficiency versus voltage characteristics of the fabricated devices with different buffer layer thickness.

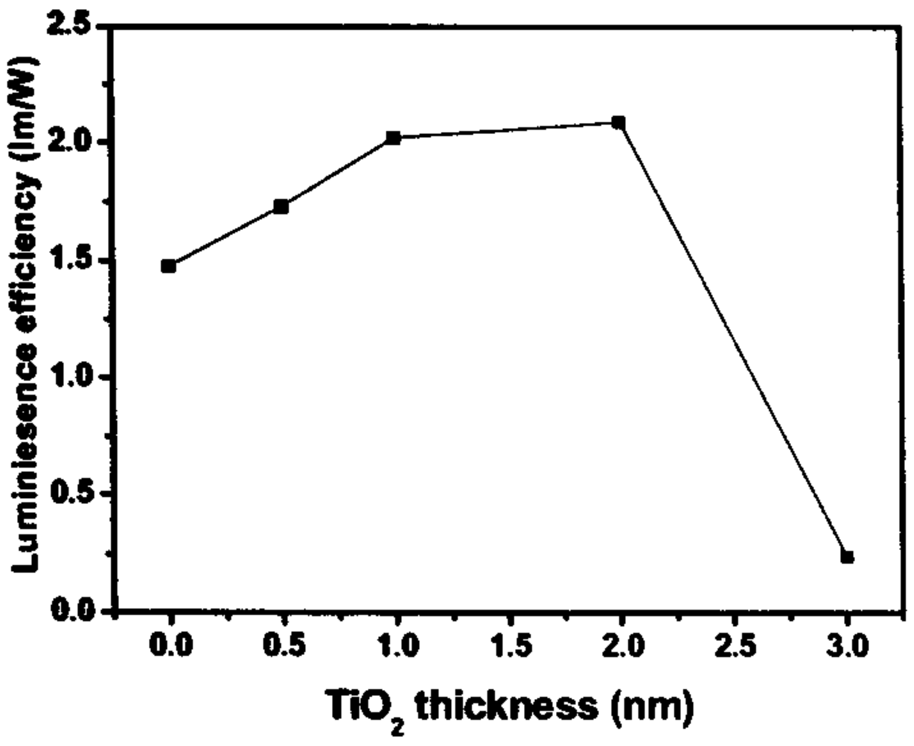
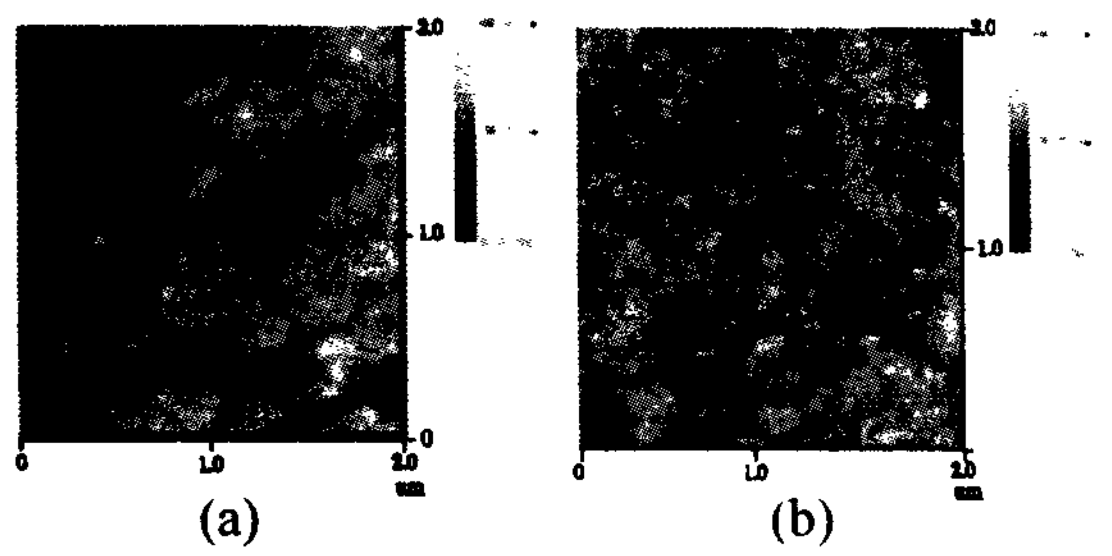


Fig. 8. Luminance efficiency characteristics with respect of different buffer layer thickness.



(a) (b)

Fig. 9. Images of atomic force microscopy of the ITO surface (a) without and (b) with the TiO_2 buffer layer.

We can conjecture that TiO_2 buffer layer may smooth the interface and lead to a more homogeneous adhesion of the hole-transport layer (HTL) to the anode.

4. Conclusions

We have studied the effect of TiO_2 layer deposited by RF magnetron sputtering and used as an ultra thin hole-injection buffer layer in organic light-emitting diode (OLED). The experiment results show that the device efficiency can be enhanced with certain thickness of buffer layer. The quantum efficiency of the device with 2 nm TiO_2 thickness was improved by 45 % compared to the device without a TiO_2 layer.

5. References

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