

# Enhanced performance of the OLED with plasma treated ITO and plasma polymerized thiophene buffer layer

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## Abstract

In this work, indium-tin-oxide (ITO) electrode in organic light emitting device (OLED) was modified by using an O<sub>2</sub> plasma treatment and plasma polymerized thiophene buffer layers were inserted between ITO (anode) and organic layer in order to improve the hole injection efficiency. Furthermore, electron injection to cathode (Al) in the test OLED seemed to be improved due to introduction of quantum well in the cathode. The plasma-polymerized thiophene buffer layer on the O<sub>2</sub> plasma-treated transparent ITO electrode seemed to result in formation of a stable interface and consequently, reduction the hole mobility, which in turn caused enhanced recombination of hole and electron in the emitting layer. Compared with the test device without buffer layer, the turn-on voltage of the test device with the buffer layer was lowered by 1.0 V.

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## 1. Introduction

Organic light-emitting devices (OLEDs) based on organic layers have been extensively studied for potential applications, especially in the field of flat-panel displays [1–4]. Anodes of OLEDs commonly comprised a transparent conducting oxide (TCO). Indium tin oxide (ITO) has been widely used as an attractive anode material because of its high transparency, high conductivity and high work function [5–7]. However, an OLED formed on a bare ITO surface usually shows insufficient hole injection efficiency and unacceptable operation stability. The interface between the electrode and organic layer in OLEDs affects

the charge injection process and consequently result in deterioration of the electrical and luminescent properties. In particular, the morphology and oxygen defects on the ITO surface are known to be important factors for the charge injection efficiency at the interface. Hung et al. [8] managed to deposit a CHF<sub>3</sub> buffer layer on ITO at low frequency. The devices showed superior operation stability, but the influence of the CHF<sub>3</sub> buffer layer on the device efficiency was not reported. In this work, we deposited a plasma polymerized thiophene (ppTh) thin film at radio frequency on ITO, and the effect of ppTh on the device efficiency and stability was investigated. Furthermore, we investigated about the surface treatment of ITO electrode and the growth method of a new buffer layer by using RF plasma-polymerization equipment to improve the efficiency of OLEDs.

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## 2. Experimental details

### 2.1. Fabrication of test devices

The substrates used in this study were ITO coated glasses with ITO film thickness of 2000 Å and sheet resistance of 23 Ω/sq. The as-received substrates were ultrasonically cleaned in deionized water, acetone and methanol, by which most of the surface organic contaminants were removed. After nitrogen blow-drying, the cleaned ITO substrate was then moved into a vacuum chamber. Capacitive-coupled plasma polymerization equipment was used for RF plasma surface treatment of the ITO. A schematic diagram of the plasma-polymerization apparatus used in this experiment is shown in Fig. 1 [9]. A 13.56-MHz RF plasma generator (AUTO ELEC. ST-500) with a matching box was connected to the electrodes. The ppTh was polymerized at the following experimental conditions: 100 W power, 0.1 torr system pressure. A commercial thiophene monomer was used to deposit the ppTh thin film as a buffer layer: Ar gas was introduced into the reaction tube at a flow rate of 10 sccm to generate the RF plasma, and then the thiophene monomer was introduced into the reactor.

In this research, *N,N*-diphenyl-*N,N*-(3-methylphenyl)-1,1-biphenyl-4,4-diamine (TPD), known as a hole transporting material and tris (8-hydroxyquinolino)-aluminum ( $\text{Alq}_3$ ), which is an electron-transporting material were deposited at a base pressure of  $5 \times 10^{-5}$  torr. Deposition rates of the TPD and  $\text{Alq}_3$  were 2 Å/s, respectively, which were measured by using a thickness monitor. Then a 1500 Å thick Al cathode was deposited at the same pressure.

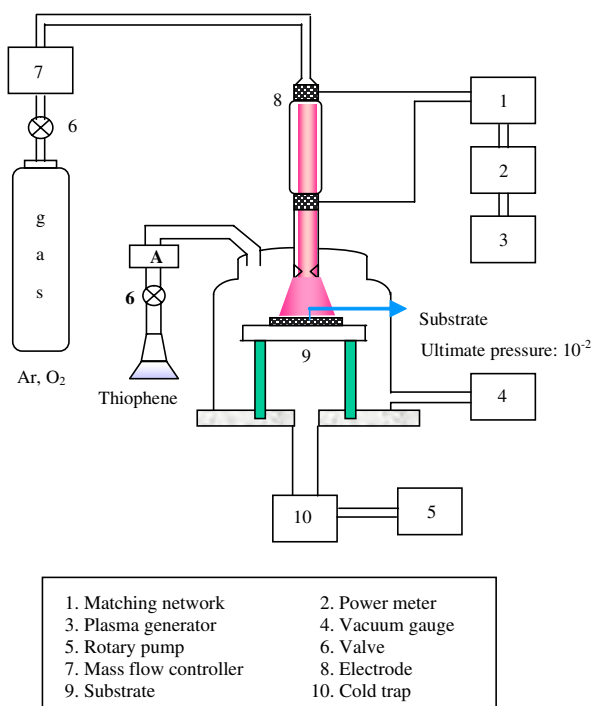


Fig. 1. Schematic diagram of the plasma polymerization apparatus.

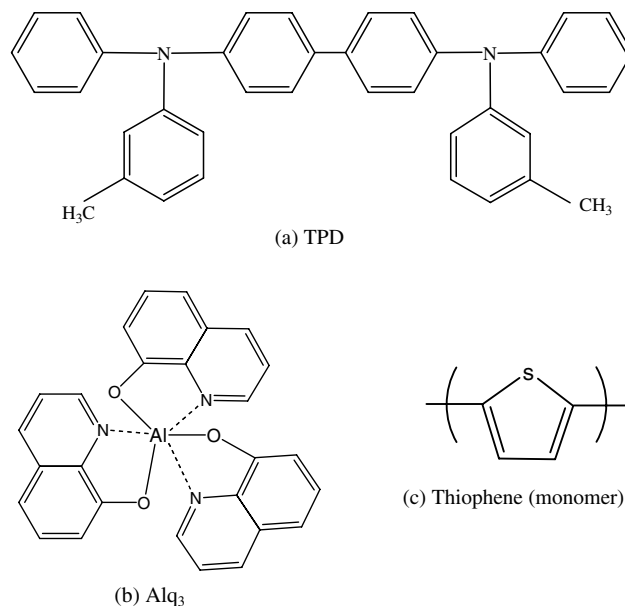


Fig. 2. Molecular structures of the organic materials.

The area of each electrode was  $2 \times 2 \text{ mm}^2$ . Fig. 2 shows the molecular structures of the organic materials.

### 2.2. Current–voltage–luminance measurement

Current and luminance characteristics of the test OLED devices according to applied voltage change were measured by a source measurement unit (SMU; Keithley, model 2400) and luminance meter (TOPCON, BM-8). A personal computer was used for an automated measurement system: the SMU controlled the supply of the source voltage through a GP-IB interface and measured the current. At the same time, the luminance meter measured luminance through a RS-232C interface. The increment of the applied voltage was 0.3 V/0.5 s.

## 3. Results and discussion

### 3.1. Material properties characterization

Since the hole transport layer (HTL) film of the device is directly deposited on the ITO anode, the surface properties of the ITO affect the characteristics of the OLEDs. A high surface roughness of the ITO would cause a structural defect (*i.e.* charge trapping site) at the organic/metal interface and consequently deteriorate the device characteristics. Therefore it is important to optimize the surface conditions of the ITO. We observed atomic force microscopy (AFM) images of the differently treated ITO surface. Fig. 3 shows AFM surface morphologies of the ITO surface as a function of  $\text{O}_2$  plasma treatment time. Roughness is a basic parameter, which indicates the deviation of a surface with respect to a perfect plane. The RMS is defined as

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