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Effects of nitridation time on top-emission inverted organic light-emitting diodes

Fuh-Shyang Juang, Liang-Wen Ji*, Yu-Sheng Tsai, Chien-Chang Tseng, Teen-Hang Meen

Institute of Electro-Optical and Materials Science, National Formosa University, Yunlin 632, Taiwan, ROC

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Abstract

A top-emission inverted organic light-emitting diode (TEIOLED) was fabricated by using Al/AlN_x layer as the cathode in the device structure of glass/Al/AlN_x/AlQ_3/NPB/MTDATA/Au/Ag, where AlN_x ultra-thin layer was obtained from Al layer under 90 W microwave plasma treatments in Ar and N_2 mixed-gas environment. The N_2/Ar ratio and plasma treatment time were adjusted to obtain the maximum luminance and efficiency of 1206 cd/m^2 and 0.51 cd/A, respectively, both at 17 V. The AlN_x layer surface after plasma treatment was examined by atomic force microscope (AFM) to study the effects of surface roughness on the electroluminescent (EL) characteristics. The thickness of AlN_x layer also affected EL results apparently.

Keywords: A1. Buffer layer; A3. Microcavity; B3. Top-emission inverted organic light-emitting diode

1. Introduction

One of the trends in the organic light-emitting diode (OLED) display industry in recent years is to develop large-screen display. Large-size panel must be driven by thin-film transistor (TFT) to enhance its brightness uniformity, resolution and life time. The conventional OLED has predominantly bottom-emission structure, where emitted light is partially blocked by bottom-layer TFT and data line. To improve aperture ratio and minimize the effect of TFT on active-matrix panel, the research and development of top-emission OLED is inevitable [1,2]. However, it is very common that light is extracted from OLEDs in bottom emission at present. Such bottom-emission OLEDs (BEOLEDs) are formed by depositing a transparent anode, indium–tin-oxide (ITO) film, organic layers, and a metallic cathode sequentially on a transparent substrate. While current is passed from the anode through organic layers to the cathode, light generated in the organic emitting layer is mostly emitted through the anode and the substrate. Top-emission OLED (TEOLED) structure will be very useful since TEOLEDs can emit light through the top electrode, and in the presence of TFT arrays lying under the OLEDs, as is the case of active matrix displays, a higher portion of the emitted light can be utilized compared to the BEOLEDs. One of the approaches to fabricate TEOLEDs is to simply invert the fabrication process of OLEDs, i.e., to deposit the constituting layers of OLEDs in the sequence of a metallic cathode, organic layers, can be referred to as top-emission-inverted OLEDs (TEIOLEDs) [3]. To integrate the process for OLED with other active components in the fabrication of active-matrix panel, including amorphous silicon (α-Si), poly-silicon (poly-Si) or complementary metal oxide semiconductor (CMOS), the whole process may be simplified if the electrode (Al pad) prepared on TFT substrate in the final step of the process is also used as the cathode of OLED. Such OLED device must employ TEIOLEDs structure. But when Al electrode is deposited on the substrate using thermal evaporation, spikes tend to form, which are prone to lead to organic carbonization and puncture the organic thin film after prolonged operation of OLED, causing dark spots on the emitting surface of OLED [4]. Many researchers have proposed inverted

*Corresponding author. Tel.: +886 5 631 5679; fax: +886 5 632 9257.
E-mail address: lwji@seed.net.tw (L.-W. Ji).

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top-emission light-emitting diode by inserting an ultra-thin insulating layer between the organic layer and metal electrode to increase electron injection from cathode, thereby enhancing the luminance efficiency. For example, Li et al. [5], Kurosaka et al. [6], and Kho et al. [3], respectively, inserted a proper buffer layer of Al_2O_3/AlN_x between the organic light-emitting layer and Al cathode to improve the electroluminescence (EL) of OLED. This paper utilized the plasma of $Ar+N_2$ gas mixture to treat Al surface to modify the surface roughness and form an ultra-thin AlN_x insulating layer (or buffer layer) to improve the efficiency of cathode electron injection.

2. Experiments

Our experiment comprised the following steps: first, ultrasonically wash the glass substrate with in sequence acetone, methyl alcohol, and DI water. Deposit cathode metal Al on the glass substrate by evaporation under 3×10^{-6} Torr and then move the substrate to a microwave plasma chamber to undergo plasma treatment of Al surface with the mixture of Ar (70 sccm) and N_2 (10 sccm) under 0.35 Torr and 90 W to form AlN_x as buffer layer. Remove the AlN_x-treated substrate from plasma chamber and place it in organic vacuum evaporator to deposit tris (8-quinolinolato) aluminum (AlQ_3) as green-light emitting layer, NPB as hole transport layer, and m-MTDATA as hole inject layer (HIL). Finally, move the substrate to another chamber to deposit Au/Ag as metal anode by evaporation. The resulting device has a structure of glass/A1 (80 nm)/AlN_x/AlQ_3 (100 nm)/NPB (60 nm) /m-MTDA-TA (50 nm)/Au (5 nm)/Ag (10 nm) as shown in Fig. 1. The light-emitting area of the device was 36 mm^2 as defined by shadow mask. The experiment used KEITHLEY 2400 and SpectraScan PR650 to measure the L–J–V curve of device, atomic force microscope (AFM) and contact angle to observe its surface roughness, and four-point probe to measure the sheet resistance.

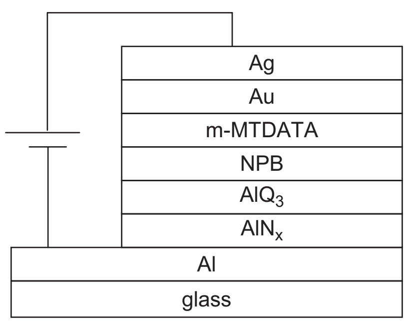

Fig. 1. TEIOLED structure.

3. Results and discussion

AFM was used to observe the surface roughness of Al cathode layer after microwave plasma treatment over different durations. As shown in Fig. 2, it is found that untreated Al electrode surface has many spikes that would cause non-uniform distribution of electric field in the

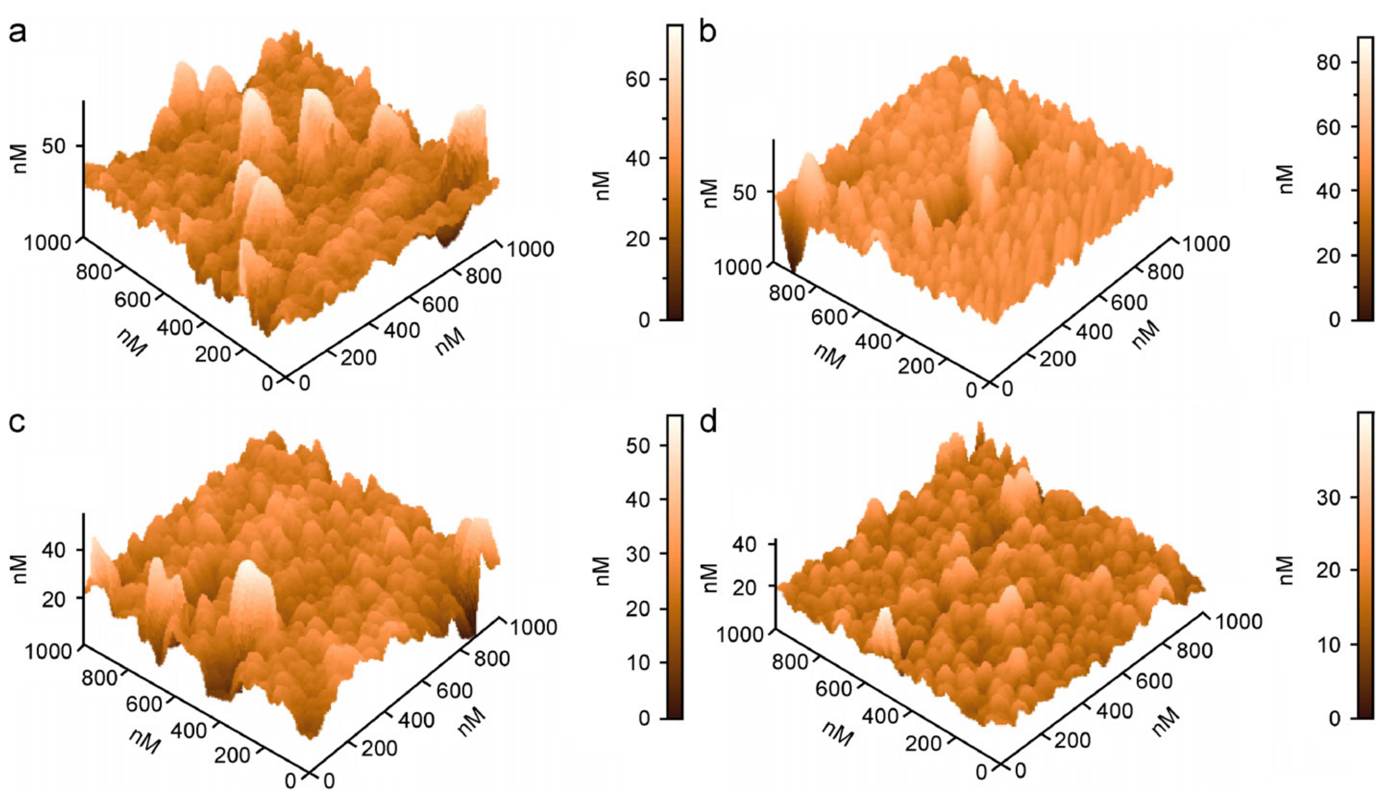

Fig. 2. Plasma-treated surface of Al cathode under AFM: (a) untreated Ra = 5.249 nm, (b) 40 s Ra = 4.112 nm, (c) 60 s Ra = 3.747 nm, and (d) 80 s Ra = 2.551 nm.