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VERTICAL TYPE ORGANIC LIGHT EMITTING TRANSISTOR USING THIN-FILM ZnO

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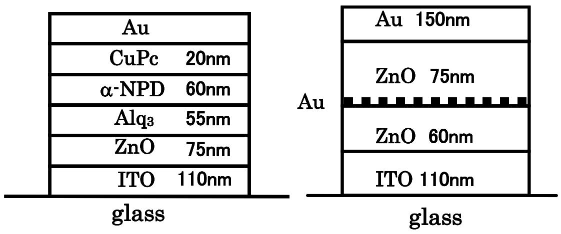
1. Introduction

Display devices using organic materials have much attention for large area, low cost, and ease of processing in recent years. In particular, organic light emitting diodes (OLED) are expected as the display components of mobile electronic devices with excellent stability and high efficiency [1-2]. On the other hand, organic transistors have been great improvements in recent years [3]. However, conventional field-effect transistors (FETs) using organic materials have low-speed, low-power, and relatively high operation voltage mainly due to the low-mobility and high-resistivity of organic materials. It is known that the static induction transistor (SIT) is a promising device because of the high-speed and high-power operation [4-6]. The excellent characteristics of the SIT arise from the vertical structure with a very short distance between the sources and drain electrodes. We have reported that the fabrication and device performance of organic light emitting transistor (OLET) combined with the organic SIT and OLED. The following advantages are expected in the OLET that is low gate voltage, high-speed operation and ease of production. Transparent electrodes are indispensable to realizing organic light emitting diode (OLED) of flat panel displays and sheet displays. It is also well known that a tin doped indium oxide (ITO) [7], tin oxide system [8], and zinc oxide (ZnO) system can be used as a transparent electrode. Although it is a comparatively new material, ZnO has come to be widely used as a wide-gap semi-conducting material, and many researches are made focusing on the deposition by the sputtering method. Because ZnO is relatively low cost and has some unique characteristics, such as high transparency in visible light region, controllability of n- and p-type semi conducting properties by impurity doping. Therefore, ZnO is expected not only to use as a transparent cathode electrode but also to form a p-n junction with organic semiconductors [9]. We propose here to employ ZnO thin film as a transparent electron injection layer in organic display devices. For example, OLET using ZnO layer has vertical type double heterojunction (DHJ) and high performance such as high luminance efficiency and high response time are expected.

In this paper, we describe basic characteristics of OLED using unintentionally doped ZnO thin film as an electron injection layer and the fabrication and characterization of SIT with using ZnO film. Furthermore, we are also presented here about OLET with using ZnO film.

2. Experimentals

Figure 1 (a) and (b) show cross-sectional device structures of OLED and ZnO-SIT, respectively. The OLED has electron injection layer and hole blocking layer of ZnO thin film as shown in Fig.1 (a). The ZnO-SIT has a gate electrode buried into ZnO layer as shown in Fig.1 (b). ZnO thin film layers were fabricated on ITO coated glass substrate using radio frequency (RF) sputtering method. RF sputtering equipment (SHIMADZU HSM-952) was used to deposit ZnO films on ITO coated glass substrate. ZnO target used here was 152.4 mm ϕ, 5mm thickness and the purity was 99.9%. As shown in Fig. 1(a), organic emissive layer is tris (8-hydroxyquinolinolato) aluminum (Alq_3), a hole transfer layer is N, N'-diphenyl-N, N'-di (1-napthyl)- 1, 1'-biphenyl-4, 4' -diamine (α-NPD), CuPc was used as hole injection buffer layer. Au is used for the anode electrode. Au and organic layers are formed by a standard vacuum evaporation technique. The substrate temperature during the vacuum evaporation maintained at room temperature and the background vacuum was approximately 10^{-5} Torr.



(a) (b)

Fig. 1 Cross-sectional structures of (a) OLED (b) ZnO-SIT.

Figure 2 shows a transmittance spectrum of ITO-ZnO thin film and an emission spectrum of Alq_3. Since the strong absorption region of ITO-ZnO thin film does not overlap with the emission peak of Alq_3, ITO-ZnO is a suitable material for the transparent electrode of OLED.

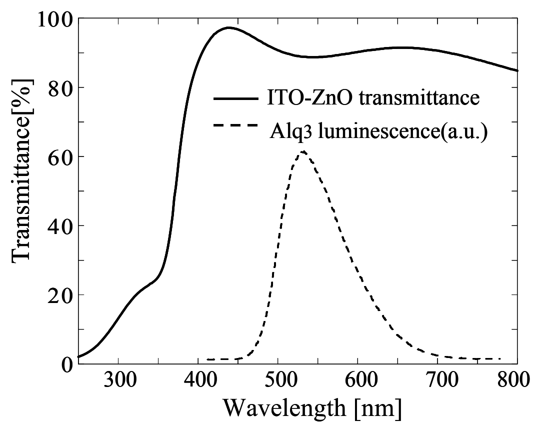


Fig. 2 A transmittance spectrum of an ITO-ZnO thin film and an emission spectrum of Alq_3.

The crystalline structure of the ZnO films was investigated by XRD measurements using PHILIPS X'PERT-PRO equipment with emission and dispersion slit of 1.0 deg. and CuKα. Figure 3 shows X-ray diffraction pattern of ZnO thin film deposited on glass substrate.

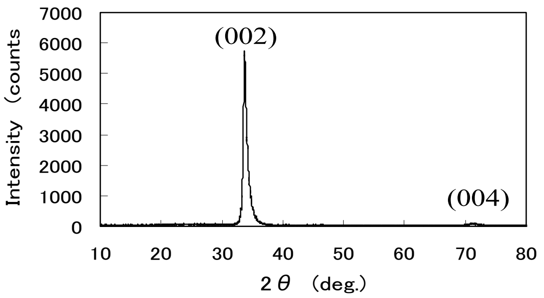


Fig. 3 X-ray diffraction pattern of ZnO thin film deposited on glass substrate.

Figure 4 shows an I-V characteristic of Au(+)/ZnO/ITO(-) of using ZnO thin film fabricated under the above condition.

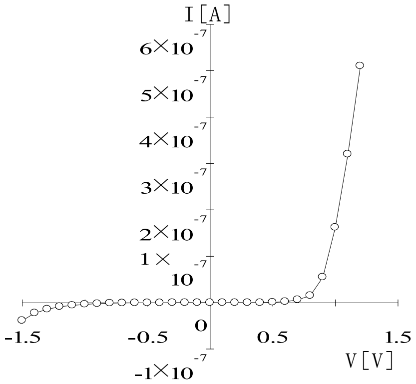


Fig. 4 An I-V characteristic of Au(+)/ZnO/ITO(-)

3. Results and Discussion

The current-luminance (I-L) characteristics of newly developed OLED using ZnO thin film is shown in Fig. 5. The threshold voltage was around 15 V and luminance of 470 cd/m^2 was obtained at 22 V, 7.6 mA/cm^2.

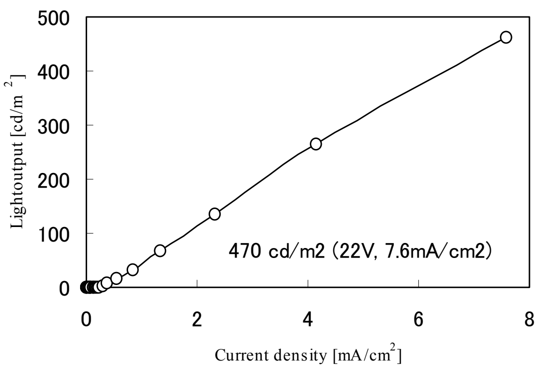


Fig. 5 Current- luminance characteristic of OLED

Figure 6 shows the current-voltage (I-V) characteristics of the ZnO-SIT. The drain-source current (Id) at a constant drain voltage (Vd) decreases with decreasing the gate voltage (Vg). The current between source and drain electrode is controlled by relatively small Vg (0.5 V to –0.5 V) and a typical characteristic of SIT is obtained.

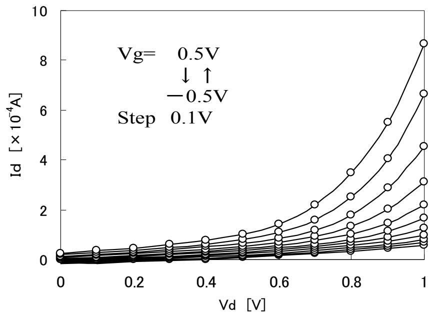


Fig. 6 I-V characteristics of the ZnO-SIT.

Further developments of both ZnO-OLED and ZnO-SIT operating with higher power and speed are expected by optimizing the device structure, such as the thickness of the organic layer and the dimensions of the gate electrode. Figure 7 shows band diagram of our newly OLET with using ZnO-LED and ZnO-SIT. Four candidate devices with different gate electrode position (fig.7) are examined depending on flexible sheet display applications.

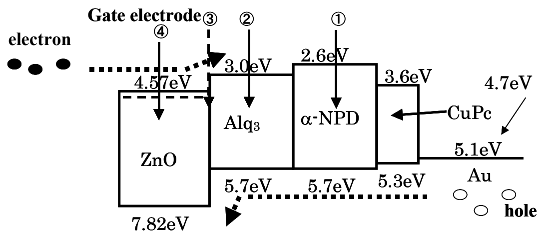


Fig. 7 Band diagram of the ZnO-OLED

4. Conclusions

We have obtained OLED using ZnO thin film as an electron injection layer and investigated basic characteristics of OLED depending on the sputtering condition of ZnO. Excellent light output LED was as high as 470 cd/m^2. Furthermore, we have confirmed the first a typical characteristics of SIT by ZnO-SIT operation. The results obtained here demonstrate that the OLET using ZnO-SIT structure as an electron injection layer is expected as a key element for flexible sheet displays.

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