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Fabrication of active light-emitting device combined with ZnO transistors

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1. Introduction

Organic light-emitting diodes (OLEDs) have much attention for flexible, low cost, and ease of processing such as a vacuum evaporation technique, and OLEDs are adopted as the display components of mobile phone and car electronic equipment in recent years [1]. In particular, OLEDs combined with flexible transistors and organic light-emitting transistors (OLETs) have attracted considerable attention in this field [2][3].

On the other hand, zinc oxide (ZnO) is a transparent material and its electrical property varies from conductive to insulating depending on the growth conditions. Since ZnO film is able to deposit on a plastic substrate, ZnO transparent field-effect transistor (FET) [4] is attractive for flexible display applications.

To expand the effective light-emitting area of active matrix displays, we propose new type active light-emitting devices as shown in Fig. 1. Moreover this device has a superior structure to reduce the sputtering damage to organic layer and the oxidation of emitting layer by oxygen in air. The light-emitting devices proposed here are suitable for the display element because these ZnO layers between light-emitting layer work high-transparent electron injection layer, electrode, and active layer of FET. The ZnO works as the active channel, and Al-doped ZnO (AZO) is used as the source/drain electrode [5]. Therefore the aperture ratio increases and light-emitting occurs efficiently.

In this paper, we describe the basic characteristics of transparent FET using thin-film ZnO.

2. Experimental details

Figure 1 shows the device structure combined with OLED and thin-film ZnO FET. An OLED is fabricated on the transparent FET. A transparent ZnO FET has an indium–tin-oxide (ITO) gate and a silicon nitride (SiN) gate insulator fabricated by plasma-enhanced chemical vapor deposition (PECVD). These transparent materials are expected to be promising components of high-efficiency light-emitting devices.

ZnO films were deposited by radio frequency (rf) magnetron sputtering using ZnO target. In this study, we have optimized these growth conditions of ZnO (semiconductor layer) and AZO (electrode and electron injection) to obtain high performances of FET and OLED.

The fabrication process is as follows. First, a SiN gate

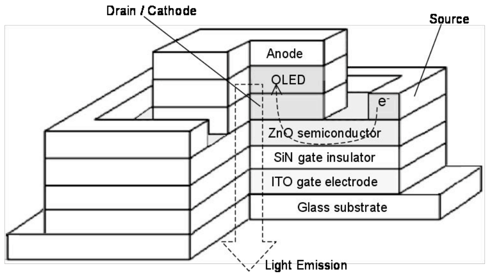


Fig.1 Structure of OLET using thin-film ZnO films.

insulator was deposited on ITO/glass substrate by PECVD. Second, a ZnO active channel layer was deposited. The thickness of the ZnO film was approximately 200 nm. Third, a AZO electrodes were deposited by rf sputtering on ZnO semiconductor layer. The AZO electrode works as a electron injection layer and hole blocking layer for OLED. The deposition parameters of ZnO and AZO are shown in Table 1.

Since ZnO, ITO, AZO layers have high transparency in the visible region, the OLED has a potential for high efficiency displays. Moreover this structure offers long channel width by fabricating the channel surrounding the OLED region. It has considerable promise as a driving transistor OLED.

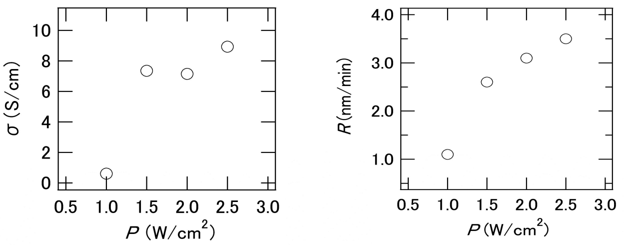
All electrical measurements were performed in vacuum at room temperature, and the measurements were carried out in the dark.

Table 1. Deposition parameters of ZnO and AZO.

Layer	Semiconductor	Electrode
Target	ZnO	AZO (ZnO : Al 2.0 wt%)
Base pressure	2.0×10^{-3} Pa	2.0×10^{-3} Pa
Sputter gas	Ar : 10 sccm	Ar : 10 sccm
Presputter	300 sec	300 sec
Working pressure	0.8 Pa	2.0 Pa
rf power	2.5 W/cm^2	1.0 – 2.5 W/cm^2
Substrate temperature	R. T.	R. T.

3. Results and discussion

There is a correlation between rf power and resistivity and the AZO film deposited at low rf power is low conductivity as shown in Fig. 2. The conductivity of ZnO film depends on carrier concentration such as the concentration of ion implantation, Zn vacancies and oxygen rich. Additionally, the grain boundary was also a critical factor in the electrical characteristics. The low leakage current less than 10 pA between V = -50 V and 50 V was obtained and this



(a) (b)

Fig. 2 (a) sheet resistance and (b) deposition rate as a functional of rf power.

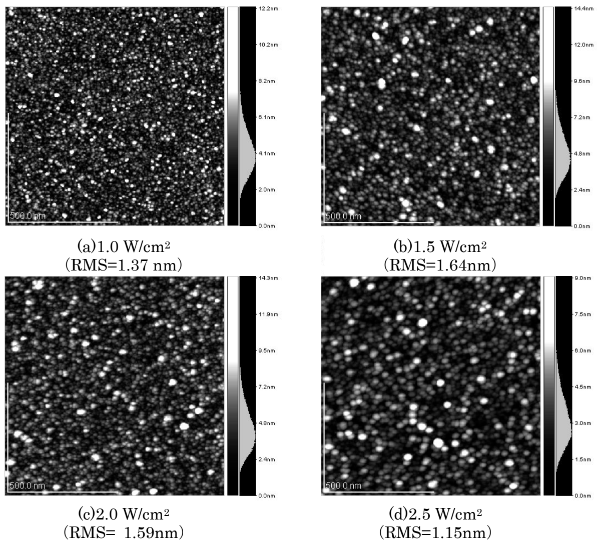
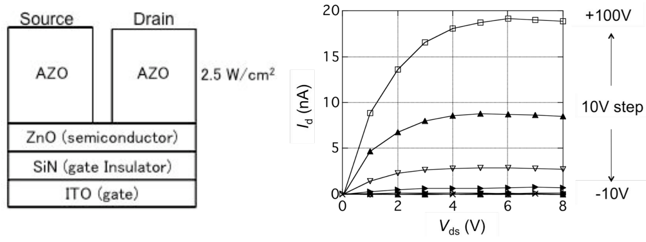
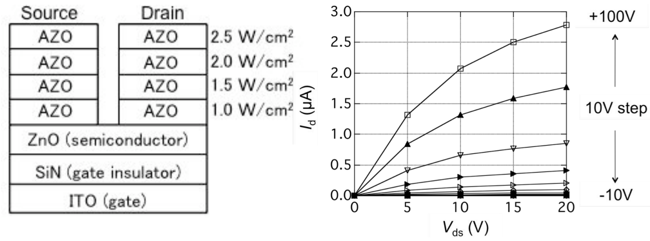


Fig. 3 Surface AFM morphologies of AZO films deposited at different rf power densities, (a)1.0 W/cm^2, (b)1.5 W/cm^2, (c)2.0 W/cm^2, (d)2.5 W/cm^2.



(a) (b)

Fig.4 (a) Schematic of ZnO FET using AZO electrode deposited by uniform power deposition method and (b) I_d-V_{ds} characteristics of ZnO FET.



(a) (b)

Fig. 5 (a) Schematic of ZnO FET using AZO electrode deposited by stepped power deposition method and (b) I_d-V_{ds} characteristics of ZnO FET.

on current of the ZnO FET is sufficient to drive OLED.

In order to reduce the plasma damage, we have tried a new sputtering method for fabricating the AZO electrode. Figure 5 (a) shows the schematic of the stepped power deposition method of rf sputter. First, AZO deposited by rf power of 1.0 W/cm^2. It is necessary to deposit first AZO layer at sufficiently low rf power to avoid the plasma damage. Then the rf power increases from 1.5 to 2.5 W/cm^2 in 4 steps. And the each deposition rate was 0.02 nm/s, 0.03 nm/s, 0.05 nm/s, and 0.06 nm/s. These layers have high transparency in these deposition region.

Figure 3 shows the atomic-force-microscope (AFM) topographic images at different rf power density. These results show that the conductivity of AZO film increases as the AZO grain size increases. These changes should be related to grain size, grain boundary and crystallization.

Figure 4 and 5 show the static characteristics of ZnO transparent FET. We compare the static characteristics of ZnO FET with AZO electrode deposited by conventional sputter and stepped power deposition. These results show the typical static characteristics of FETs and I_{ds} at V_g of 20 V is two orders larger than that of FET with AZO deposited by the conventional sputtering. These improvements are derived from low-damage and high-conductivity AZO films obtained by the new deposition method.

4. Conclusions

In this paper, we report on the electrical properties of transparent ZnO FET with sputtering AZO electrode fabricated by the stepped power deposition method. The low-temperature and low-damage sputtering method improves the on current in two orders magnitude. These experimental results indicate that an OLET using transparent ZnO thin films on a plastic substrate should be realized by optimizing the device design and the fabrication process.

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