Fabrication and Evaluation of Microfluidic Organic-Light Emitting Diode Having a Fluorine-Doped Tin Oxide Cathode

Ryuto Ikeda[1], Jun Mizuno[2], and Takashi Kasahara[1].

[1] *Department of Electrical and Electronic Engineering, Hosei University, Tokyo 184, Japan*

[2] *Academy of Innovative Semiconductor and Sustainable Manufacturing, National Cheng Kung University, Tainan 70101, Taiwan*

***Abstract*—We fabricated the microfluidic organic light emitting diode (OLED) having a fluorine-doped tin oxide (FTO) cathode and evaluated its electroluminescence (EL) performances. We found that use of FTO as a cathode improves the EL intensity of the pyrene-based liquid organic semiconductor (1-pyrenebutyric acid 2-ethylhexyl ester (PLQ)). The EL intensities of the microfluidic OLEDs with the PLQ host doped with yellow and red guests were also increased. Furthermore, the turn-on voltage (defined as luminance at 0.01 cd/m^2) of the FTO-based device with PLQ was measured to be 8 V, which is 4 V lower than the indium tin oxide (ITO)-based device with PLQ. Because the FTO has a large surface area and a low work function compared to the ITO, the electron injection from cathode into lowest unoccupied molecular orbital (LUMO) level of emission layer (PLQ) may be facilitated. The proposed microfluidic OLED device is expected to be used for various applications of LOS.**

Keywords—Liquid organic semiconductor, Fluorine-doped tin oxide, Transparent electrode, Microfluidic OLEDs, Electron injection

I. Introduction

Recently, liquid organic semiconductor (LOS), which is fluid at room temperature, has the potential to revolutionize conventional displays. In 2009, Adachi's group at Kyushu University reported liquid organic light-emitting diodes (OLEDs) with LOS as an emitting layer [1]. The first liquid OLED consisted of a simple structure of the liquid carbazole derivative sandwiched between two indium tin oxide (ITO)-coated glass substrates. In 2013, our research group proposed microfluidic OLEDs, which combine liquid OLEDs with microelectromechanical system (MEMS) microfluidic chip. This device enables the integration of liquid OLEDs [2]. In that work, several-micron-thick microchannels sandwiched between the ITO anode and cathode were fabricated, and a greenish-blue electroluminescence (EL) emission of 1-pyrenebutyric acid 2-ethylhexyl ester (PLQ) was clearly observed from the microchannels. ITO is commonly used as a transparent electrode in OLEDs. Furthermore, red and yellow EL emissions were also observed from microfluidic OLEDs containing tetraphenyldibenzoperiflanthene (DBP)-doped PLQ and 2,8-di-*tert*-butyl-5,11-bis(4-*tert*-butylyl-phenyl)-6,12-diphenyltetracene (TBRb)-doped PLQ [2]. However, in comparison with solid-state OLEDs which consist of functional solid layers such as carrier injection/transportation layers, the EL characteristics of the microfluidic OLEDs were still difficult to put to practical use.

Therefore, we have tried to improve the luminance of microfluidic OLEDs. In this study, we fabricated the microfluidic OLEDs having a fluorine-doped tin oxide (FTO). FTO is often used as a cathode in reverse structure OLEDs [4]. We evaluated the EL performances of the microfluidic OLEDs using three different emission layers.

II. Method

Fig. 1 shows a design of the microfluidic OLEDs and chemical structures of PLQ, TBRb, and DBP. A negative photoresist, TMMR S2000LV (Tokyo Ohka Kogyo), was used as a microchannel material. The 2-µm-thick and 1-mm-width microchannel was formed on a cathode. FTO deposited on glass was used for the cathode, and ITO on polyethylene terephthalate (PET) film was used for the anode, which was named the FTO-based device. That device was fabricated by the MEMS process and a vacuum ultraviolet (VUV)-assisted direct bonding technique [3]. We also fabricated the device with an ITO cathode (ITO-based device) instead of a FTO cathode. For both devices, an active area of microchannel is 5 mm^2 (1 mm× 5 mm).

PLQ was used as both a greenish-blue liquid emitter and a host material for fluorescent guests. The PLQ host doped with TBRb (3 wt%) guest was used as yellow emitter. We also prepared a red emitter by doping both TBRb (2 wt%) and DBP (0.5 wt%) into the PLQ host.

III. Results and Discussions

Figs. 2(a)-(c) shows the EL spectra of the FTO and ITO-based devices. It can be seen that the EL intensities of all FTO-based devices with greenish-blue, yellow, and red emitters were higher than those of ITO-based devices. *J-V-L* characteristics of the FTO and ITO-based devices with PLQ are shown in Fig. 3. It was found that the luminance and current density were increased by using the FTO cathode. The luminance of the FTO and ITO-based device at 19 V were 1.9 cd/m^2 and 1.1 cd/m^2, respectively. Furthermore, the turn-on voltage (defined as luminance at 0.01 cd/m^2) of the FTO-based device (8 V) was lower than that of the ITO-based device (12 V).

The surface roughness (R_{ms}) of FTO and ITO was measured by an atomic force microscope (AFM) (SPA-400(SII)). As shown in Fig. 4, R_{ms} of FTO (37 nm) was about 10 times larger than that of ITO (3.9 nm). In addition, a work function value of FTO has been reported to be 4.4 eV, which is approximately 0.4 eV lower than that of ITO (4.8 eV) [4]. Therefore, an electron injection into PLQ was improved because the electron injection barrier height at PLQ/cathode interface was reduced by using the low work function cathode. Besides, it is likely that because FTO has a large surface area compared with ITO, electrons are efficiently injected into the lowest unoccupied molecular orbital (LUMO) level of PLQ. In our previous work, we fabricated a liquid OLED cell having ITO anode and ZnO NPs-coated ITO cathode [6]. In future work, we plan to fabricate the microfluidic OLED having the ZnO NPs-coated FTO cathode.

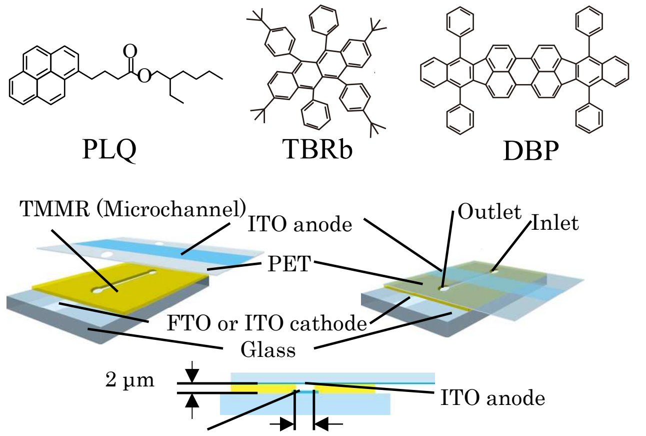

Fig.1 Chemical structures of the PLQ, TBRb, and DBP. Design of micro-fluidic OLEDs.

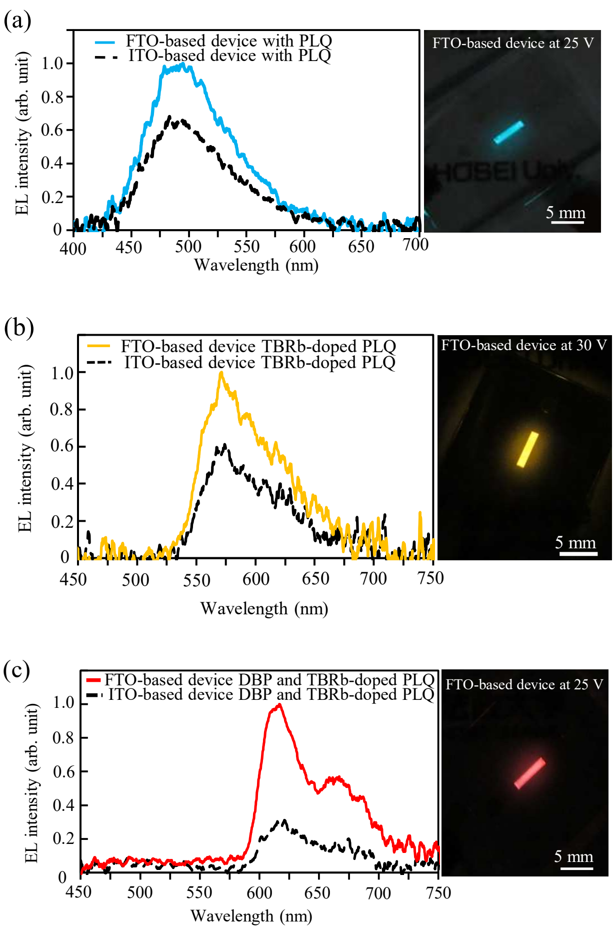

Fig.2 EL spectra and light emission photograph of FTO and ITO-based devices with (a) PLQ at 25 V, TBRb-doped PLQ at 30 V, and (c) TBRb and DBP-doped PLQ at 25 V.

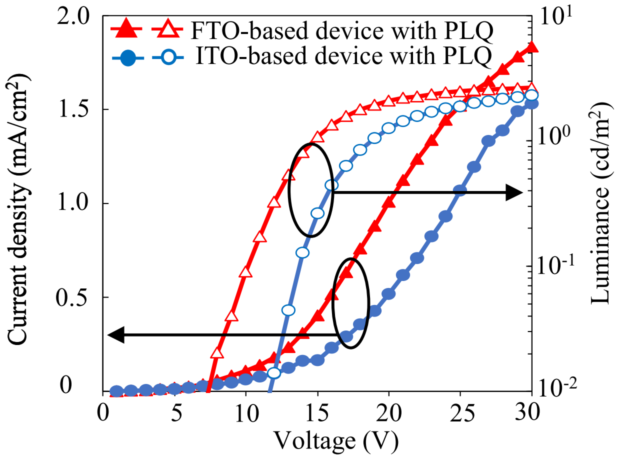

Fig. 3 *J-V-L* characteristics of the FTO and ITO-based devices with PLQ.

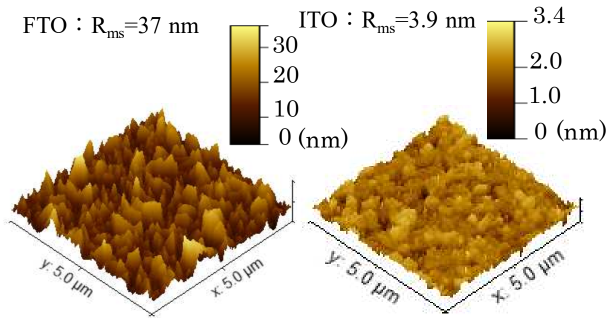

Fig. 4 AFM images of the FTO and ITO electrode.

IV. Conclusions

We have demonstrated that the use of FTO as a cathode improves the EL performance of microfluidic OLEDs.

Acknowledgment

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