# Effects of CsF/Metal Cathode Interface on Electron Injection in Organic Light-Emitting Diodes Fabricated by Wet-Process

Zenken Kin<sup>1</sup> Kazuo Yoshihara<sup>2</sup> Hirotake Kajii<sup>1</sup> Koutaku Hayashi<sup>2</sup> and Yutaka Ohmori<sup>1</sup>

<sup>1</sup>Center for Advanced Science and Innovation (CASI), Osaka University 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan Phone: +81-6-6879-4213 E-mail: k-zenken@casi.osaka-u.ac.jp

> <sup>2</sup>Graduate School of Kinki University 3-4-1 Kowakae, Higasiosaka. Osaka 577-8502, Japan

#### 1. Introduction

Organic light-emitting diodes (OLEDs) have gained enormous interest because of their potential for applications as full-color flat-panel displays. In fabricating OLEDs, it is important to accomplish high efficient of electron injection to achieve high device performances. Some research groups reported low-work-function metals (Cs, Na, K, Mg, Ca, Ba, and Ce) used as efficient electron injection cathodes in anthracene crystals, or alkali metals used (Na K and Cs) as efficient electron injection cathodes in а poly(N-vinylcarbazole) (PVCz) based OLEDs [1-5]. Tang, et al. adopted a convenient MgAg alloy cathode in a double layer OLEDs [6]. Furthermore, MgAg alloy used as cathode, applied fluoride-metals as buffer-layer, reported efficient electron injection [7]. Oyamada et al. elucidated the mechanism of efficient electron injection cathodes composed of thin layer of Cs, Rb, K, Na, Li, or Ca capped with an aluminum back electrode, and focused on the electron injection mechanism at the interface between the organic layer and the cathode layer [8]. However, detailed electron injection mechanism at the interface between CsF layer and MgAg layer is still ununclear.

In this study, we fabricated the OLEDs with the cathode composed of CsF, MgAg, capped with Ag back electrode. And we focused on the electron injection mechanism at the interface between the CsF and MgAg.

## 2. Experimental Procedure

Organic layers were fabricated by spin coating onto a glass substrate coated with patterned indium-tin-oxide (ITO) electrode. The substrate was degreased with solvents and cleaned in an ultraviolet (UV)-ozone chamber. First, a poly(ethylenedioxythiophene):poly(styrene sulfonic acid) (PEDOT:PSS) hole injection layer was spun over the ITO-coated glass substrate with a 35-nm-thick layer and baked in air at 120 °C for 10 min. The emitting layer which consists of the host PVCz, a dopant Coumarin6 (C6) and an electron-transport material 2,5-Bis(1-naphthyl)-1,3,4-oxadiazole (BND) dissolved were in 1,2-dichloroethane. The content of guest C6 was 2.0 wt%.

The emitting layer was spin-coated to 90-nm thickness. The cathode consisting of CsF/MgAg/Ag was deposited in vacuum at a chamber base pressure of  $< 10^{-6}$  Torr. The thickness of CsF, MgAg and Ag is 1.5 nm, 0~250 nm and 150 nm, respectively. Finally, the device was covered with a glass plate and encapsulated by epoxy resin in an argon gas atmosphere to prevent oxidation of the cathode and the organic layer. The device structure and the molecular structures employed in this study are shown in Fig. 1. The active device area of 4 mm<sup>2</sup> was obtained using shadow mask. The forward bias condition was a positive bias with respect to the CsF/MgAg/Ag cathode. All measurements were carried out at room tempreture in an inert gas atmosphere.

The current-voltage-luminance (I-V-L) characteristics were obtained using a 2000 multimeter (Keithley) and a luminance meter (Minolta, LS-100). The surface morphologies were observed by atomic force microscopy (AFM) (JEOL, JSPM-5200).



Fig. 1. Chemical structure of molecules and a device structure employed in this study.

### 3. Results and discussion

Figure 2 shows the maximum luminance and current efficiency of OLEDs for different thickness of the MgAg layer. In the case of MgAg thickness of more than 1 nm, the maximum luminance and the current efficiency were about  $4,000 \text{ cd/m}^2$  and about 2 cd/A. These devices shown almost similar characteristics when the MgAg thickness was more than 1 nm. However, in the case of MgAg thickness of less than 1nm, the maximum luminance and the current efficiency were decreased. This result suggest that efficient electron injection is accomplished in MgAg thickness is more than 1 nm.



Fig. 2. Dependence of the maximum luminance and current efficiency on the thickness of MgAg layer.

Next, in order to investigate the stability of the CsF and MgAg in air atmosphere, we have examined the characteristics of the devices. Device 1 and device 2 are arranged as follows: device1; after deposited the organic layer and CsF, exposed in air for 3 min, the device is deposited 1 nm –thick MgAg and 150 nm thick Ag, device 2 ; after deposited the organic layer, CsF and 1-nm-thick MgAg, the device is exposed in air for 3 min and deposited Ag.

Figure 3 shows I-V-L characteristics of the device 1 and 2 and with 1-nm-thick device MgAg device (non-air-exposed device). Device 1 exhibited the maximum luminance of 4,100  $cd/m^2$  and the current efficiency of 2.0 cd/A at the current density of 0.3 A/cm<sup>2</sup> and 9 mA/cm<sup>2</sup>. While, non-air-exposed device exhibited the maximum luminance of 4,000  $cd/m^2$  and the current efficiency of 1.8 cd/A at the current density of 0.3 A/cm<sup>2</sup> and 9 mA/cm<sup>2</sup>, Both devices respectively. showed almost similar characteristics of current density-voltage and luminance-voltage behaviors. However, device 2 exhibited the maximum luminance of 510  $cd/m^2$  and the current efficiency of 0.9 cd/A at the current density of 0.9 A/cm<sup>2</sup> and 20  $mA/cm^2$ . Compared with device 1 or non-air-exposed device, the current density and the luminance of device 2 were decreased, and the subthreshold was increased. It indicates CsF layer is little influence of

the oxidation, however, MgAg layer is oxidized. It reveals that deposited CsF is not dissociated to Cs and F, and the electron injection is depended on the interface of CsF layer and MgAg layer thickness of about 1 nm.



Fig. 3. The I-V-L characteristics of the device depending on the air exposure.

Next, we examined the surface morphology of the 1.5 nm-thick CsF layer deposited on the organic layer by using AFM. The stripes morphology of the CsF layer deposited on organic layer was observed. It is considered that the surface morphology of CsF layer is closely related to electron injection mechanism.

## 3. Conclusions

In this study, we investigated the electron injection mechanism at CsF/MgAg interface. Efficient electron injection was accomplished in MgAg thickness was more than 1 nm. It is found that CsF layer is little influence of the oxidation. It is considered that the surface morphology of CsF layer is closely related to electron injection mechanism.

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