# Optical Effect due to Thickness Variation of Electron Injection Layer in Organic Light-emitting Diodes

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Organic light-emitting diodes (OLEDs) are attractive because of possible application in display with low-operating voltage, low-power consumption, self-emission and capability of multicolor emission by the selection of emissive materials. To investigated the optical effects, we studied the electrical and optical characteristics due to thickness variation of electron injection materials LiF on organic light-emitting diodes in the ITO (indium-tin-oxide)/N,N'-diphenyl-N,N'-bis(3-methyphenyl)-1,1'-biphenyl-4,4'-diamine(TPD)/tris(8-hydroxyquinoline) aluminum ($Alq_3$)/LiF layer/Al device. We maintained the thicknesses of TPD and $Alq_3$ layers at 40 nm and 60 nm, respectively. The deposition rates of TPD and $Alq_3$ were in the 1.5 Å/s under a base pressure of $5 \times 10^{-6}$ Torr. It was found that luminance and luminous efficiency of the device with 0.7 nm LiF layer improve 25 times and 7 times than the device without the LiF layer, respectively.

*Keywords* : OLEDs, Current density, Luminance, LiF layer, Thickness variation, Luminance efficiency

## 1. INTRODUCTION

OLEDs have drawn significant attention because of its possible application in display with low operating voltage, low-power consumption, self-emission and capability of multicolor emission[1-3]. The first report on organic electroluminescence (EL) was published by Pope, Kallmann and Magnante in a DC mode in 1963 with single crystal of anthracene[4]. But there was not much progress in the 1960s and 1970s because of limited size, difficulty of single crystal growth and high driving voltage. Tang and VanSlyke in Kodak Company reported double-layered organic electroluminescent diodes, which combined modern thin film deposition techniques with suitable materials and structure to give moderately low bias voltages and attractive luminance efficiency in 1987[5].

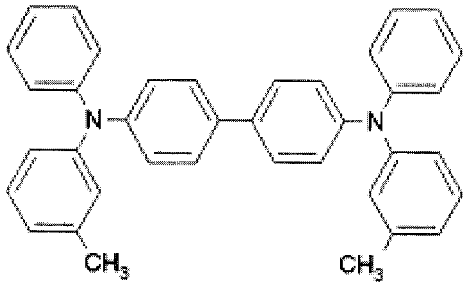
In 1990, Friend *et al.* in Cambridge University first reported green polymer light-emitting diodes using polyphenylenevinylene (PPV)[6]. Since then, significant progress has been made to obtain highly efficient and stable light-emitting diodes[7-9].

Recently, OLEDs have been studied as a potential next generation lighting device. In such an application, optical characteristics such as luminance and efficiency become very important[8,10].

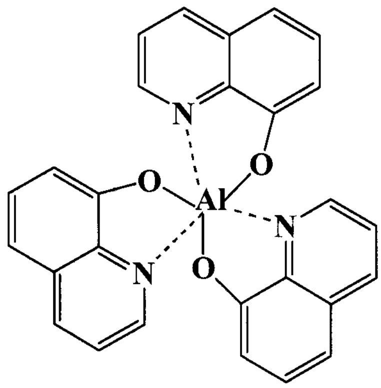
The efficiency of an OLEDs are determined by negative and positive charge balance radiative decay of exitons, and light extraction. In this paper, with a goal of achieving improved optical characteristics in the light emission, we investigated the effect of different thickness of LiF layer used as a electron injection material which promotes recombination of holes and electrons in the light emitting layer.

## 2. EXPERIMENTAL

The ITO (indium-tin-oxide) glass, having a sheet resistance of 15 Ω/□ with ITO thickness of 170 nm, was prepared. A 5 mm wide ITO strip line was patterned by selective etching using a vapor etchant which is a mixture




(a) TPD




(b) $Alq_3$

Fig. 1. Molecular structures of organic materials.

of hydrochloric acid (HCl) and nitric acid ($HNO_3$) at room temperature. The distance between ITO layer and the etchant was set to be approximately 10 mm. The patterned ITO glass was cleaned ultrasonically in chloroform, after which the ITO glass was heated at 80 °C for 1 hour in a solution made with deionized water, ammonia water and hydrogen peroxide at a volume ratio of 5:1:1. We sonicated the substrate again in chloroform, methyl alcohol, and in deionized water for 20 minutes at 50 °C, respectively. After sonication, the substrate was dried by heater.

In our experiments, we used TPD as a hole transport material, $Alq_3$ as an electron transport and emissive material, and LiF as a electron-injection material. Figure 1 shows molecular structures of TPD and $Alq_3$ material.

The deposition rates of TPD and $Alq_3$ were in the 1.5 Å/s under a base pressure of $5x10^{-6}$ Torr. Based on the confirmed TPD:$Alq_3$ optimal thickness ratio of 4:6, we maintained the thicknesses of TPD and $Alq_3$ layers at 40 nm and 60 nm respectively[9,11].

The thickness of LiF layer was made to be 0.5, 0.7, and 1.0 nm. Two device structures were made: one is ITO/TPD/$Alq_3$/Al as a reference, while the other is ITO/TPD/$Alq_3$/LiF/Al to investigate the effects of electron injection material. The deposition rate of Al was 0.1 Å/s up to 5 nm, and 10 Å/s for 5~100 nm under a base pressure of $5 \times 10^{-6}$ Torr.

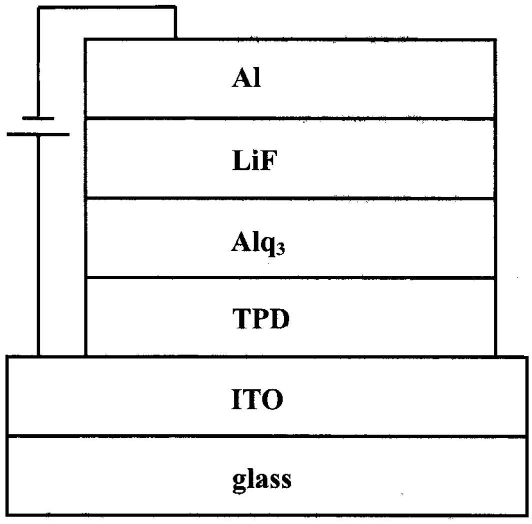



Fig. 2. Device structure of organic light-emitting diode.

Figure 2 shows a device structure of ITO/TPD/$Alq_3$/LiF/Al to investigate the influence of the LiF electron-injection layer. We measured current-voltage characteristics and luminance of the device with a thickness variation of LiF layer in ITO /TPD/$Alq_3$/LiF/ Al device structure.

## 3. RESULTS AND DISCUSSION

Figure 3 shows current density characteristics as a function of voltage for several thicknesses of the LiF layer in ITO/TPD/$Alq_3$/LiF/Al devices. The current density increases as the applied voltage increases and starts to 6 V or higher applied voltage. We confirmed that the negative differential resistance region is about 5 V. The devices of with the LiF layer and device of without the LiF layer similar to current density characteristics. The device with 0.7 nm LiF layer is the highest current density.

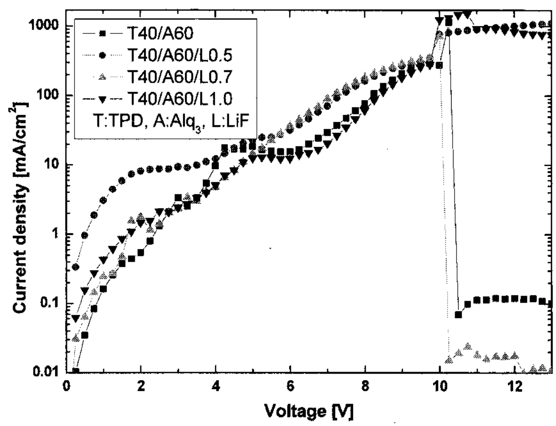



Fig. 3. Current density characteristics as a function of voltage.

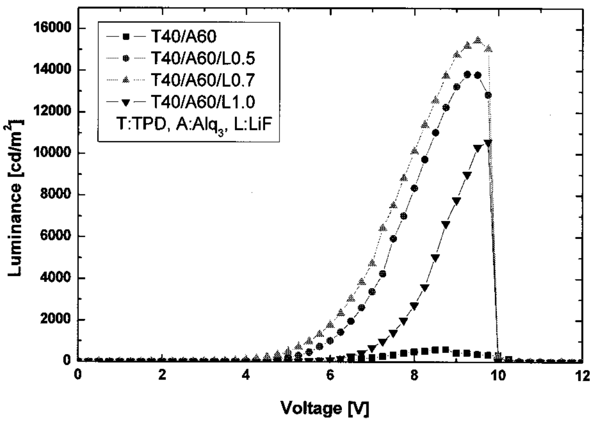



Fig. 4. Luminance characteristics as a function of voltage.

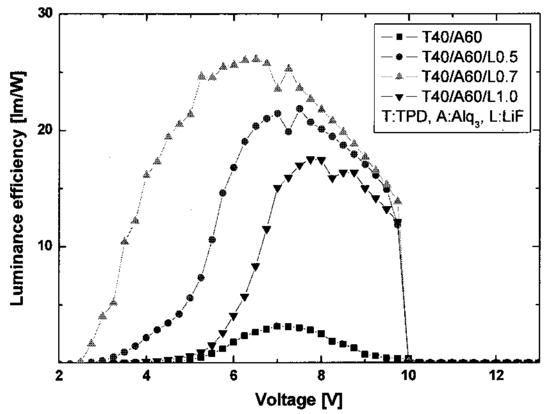



Fig. 5. Luminance efficiency characteristics as a function of voltage.

Figure 4 shows the luminance of the OLED device as a function of thickness of the LiF layer. The luminance starts to increase at 4 V and reaches a maximum value at around 9 ~ 10 V. Then, the luminance is decrease sharply, because of the device destroyed. Luminance reached at maximum with electron injection LiF layer of 0.7 nm which is the factor of 25 improvements from that of the OLED device without the LiF layer.

Figure 5 shows the luminance efficiency of the device. The luminance efficiency begins to increase at around 3 V and reaches to the maximum value at around 6 ~ 8 V. Luminance efficiency of the device with 0.7 nm LiF layer improves 700 % than the device without the LiF layer. This huge improvement in luminance efficiency suggests that the LiF layer efficiently carries out electron injection and consequently recombination of holes and electrons in the emitting layer is substantially increased.

We obtained that the operating voltage of maximum luminance efficiency decreases 1 V compare the device of 0.7 nm LiF layer with the device without the LiF layer. We confirmed that the device of LiF layer is decreased operating voltage by contribute of injected electron in ITO/TPD/$Alq_3$/LiF/Al device structure.

When the LiF layer thickness gets thicker than 0.7 nm, both luminance and luminance efficiency starts drop sharply suggesting that the thicker LiF layer impede electron injection. To investigate the effect of the LiF layer on the electrical characteristics and luminous efficiency, we fabricated ITO/TPD/$Alq_3$/LiF/Al device structure. It was found that the device with 0.7 nm LiF layer showed 7 times improvement in the luminance efficiency compared with the device without the LiF layer.

## 4. CONCLUSION

To investigate the effect of the LiF layer on the electrical characteristics and luminous efficiency, we fabricated ITO/TPD/$Alq_3$/LiF/Al device structure. It was found that the device with 0.7 nm LiF layer showed 25 times improvement in the luminance and 7 times improvement in the luminance efficiency compared with the device without the LiF layer. The operating voltage of maximum luminance efficiency decreases approximately 1 V the device with 0.7 nm LiF layer. We confirmed that the device with 0.7 nm LiF layer is decreased operating voltage in ITO/TPD/$Alq_3$/LiF/Al device structure.

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