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The operating voltage behavior of green fluorescent organic light emitting diode with blue common layer structure during laser imaging process

Sang Hee Cho [a], Min Chul Suh [a,*], Jeong Won Kim [b]

[a] Department of Information Display and Advanced Display Research Center, Kyung Hee University, Seoul 130-701, Republic of Korea
[b] Korea Research Institute of Standards and Science, Daejeon 305-340, Republic of Korea

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ABSTRACT

The blue common layer (BCL) approach has become very useful methodology to reduce the process steps which may increase the production yield of active matrix organic light emitting diode (AMOLED) fabrication. From this approach, we can reduce one step (from 5 to 4) for fine metal masking (FMM) method as a current mass-production technology to form a common thick-microcavity structure. Moreover, we can reduce the patterning steps from 5 to 2 if we use a laser induced thermal imaging (LITI) technology for the same structure. Nevertheless, we still prefer to apply the FMM technology for the mass production because there are lots of problematic issues on LITI process such as an operating voltage increase (by 0.5–1.0 V), efficiency drop (by ~10%), shorter lifetime, etc. Here, we report about the fundamental causes of these problems during LITI processes.

1. Introduction

Organic light emitting diode (OLED) technology has been under extensive development in a number of research groups since the discovery of organic electroluminescence in later 1980s [1]. As a result, there have been lots of advances in OLED technology especially for the new materials [2–4] and/or device architectures for better performances such as operating voltage, efficiency, lifetime, etc. [5–10]. Nevertheless, some significant bottlenecks still exist on the path of realization of a large area or high-resolution full color displays based on organic electroluminescence. Especially, the lack of appropriate color patterning technology for high resolution and large area AMOLED fabrication has become the most serious problem to enlarge the market volume of those businesses. The conventional photolithography is difficult to be applied as a color patterning technology of OLEDs because many organic thin films are susceptible to degradation during exposure to wet etchant, developer, stripper, etc. Thus, several alternative patterning methods have been widely demonstrated: the use of excimer laser ablation [11–13], ink-jet printing [14–16], and micro-patterning by cold welding [17,18], etc. Nevertheless, OLEDs have been patterned mostly by deposition through a shadow mask or fine-metal mask (FMM) for mass production. But FMM-related patterning technology has many problems for fabricating high resolution or large-area displays due to a shadow effect originated from the mismatching of glass, mask sagging extent, mask lifetime, cleaning, particle contamination, thermal expansion of masks, etc. In general, the probability of the defect site formation becomes higher if the number of patterning steps is increased regardless of the color patterning technology. Thus, a skip of certain numbers of color patterning steps is directly associated with the improvement of production yield. As a part of these efforts, the blue common layer (BCL) approach has become one of the most useful methodologies for this purpose. Nevertheless, the problem during fabrication of high resolution or large-area displays remains unresolved because we can reduce only one step (from 5 to 4) to form a common thick-microcavity structure. Meanwhile, a laser-induced thermal imaging

* Corresponding author. Tel.: +82 2 961 0694; fax: +82 2 968 6924.
E-mail address: mcsuh@khu.ac.kr (M.C. Suh).

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(LITI) process which is a sort of maskless process provides a much higher patterning accuracy by itself compared to that of FMM technology [19–21]. Moreover, we can reduce the patterning steps from 5 to 2 if we use such common layer approach. However, the operating voltage is rather increased even if one prepares the devices by standard evaporation process. To make matters worse, the operating voltage is even significantly increased when we prepare such devices by standard LITI process.

In general, organic materials as donor and/or receptor layers can be deformed during LITI process because it basically utilizes the thermal energy for patterning. Hence the heat generated during this process may cause a change in the physical property of organic materials, which results in a poor reproducibility as well as serious deterioration of device performance [22]. Associated with this problem, the synthesis of materials for hole transport layer (HTL) as well as emitting layer (EML) with high thermal stability has become very important as reported by Chin [20]. However, it normally takes too long time to obtain totally new material sets because there is no guideline on synthetic parameters of the materials for LITI process [e.g. glass transition temperature (T_g), molecular weight (M_w), surface energy, etc.]. Thus, one of simple approaches to suppress the thermal deformation during LITI process could be to skip a certain number of patterning steps. The representative method for this purpose is also a blue common layer (BCL) approach which was reported by Kim et al. [23]. Therefore, this approach has become very useful not only due to the simplicity by itself, but also due to an exclusion of the patterning of the most vulnerable material to heat. Thus, BCL approach could be a sort of essential way for LITI process. However, the increase of an operating voltage of LITI device could be a serious problem if we apply the BCL approach for the future. Thus, we have investigated about the reason of such a high operating voltage increase of LITI devices after fabrication by BCL structure in this study.

2. Experimental

2.1. Materials

N,*N*′-Di[4-(*N*,*N*′-diphenylamino)phenyl]-*N*,*N*′-diphenylbenzidine (DNTPD) and IDE406 (HTM) as a hole injection layer (HIL) or hole transport layer (HTL), 1,4,5,8,9,11-hexaazatriphenylene–hexacarbonitrile (HAT–CN) as a π-electron acceptor, 9,10-di(2-naphtyl)anthracene (ADN) based materials as a fluorescent green host (FGH) and fluorescent green dopant (FGD), 9-naphthalen-1-yl-10-(4-naphthalen-2-yl-phenyl)-anthracene as a fluorescent blue host (FBH), tris(8-hydroxyquinolinato)aluminum (Alq_3) and LGC 201 as an electron transport layer (ETL), lithium fluoride (LiF) as an electron injection layer (EIL), lithium quinolate (LiQ) as a π-electron donor and/or EIL were purchased from commercial suppliers and used without purification.

2.2. Interface analysis

The changes in electronic structures and the energy level alignment at each interface were investigated using in situ ultraviolet photoelectron spectroscopy (UPS) experiments [24]. The details in fabrication process are like the following. The indium tin oxide (ITO) substrates were mounted in an ultrahigh vacuum system. The DNTPD film (10 nm) was deposited on the ITO coated glass substrate under the condition of 0.5 Å/s deposition rate at 3.6×10^{-8} Torr. This deposition source comprises a quartz crucible wound with tungsten wire for heating. Upon the deposition of the first layer, we investigated the interfacial electronic properties by the UPS. In addition, we also measured UPS spectra after exposing the sample to oxygen for 15 min under the low vacuum condition (~3 Torr). After the measurements of first layer, the DNTPD and FGH (10 nm for each) were successively evaporated as second and third layers and measured by UPS. After the measurement of clean top surfaces of FGH, we also measured the sample prepared under oxygen exposure condition aforementioned. Then, FBH thin films were finally formed by the same method and measured again by UPS. The surface of the FBH layer is not exposed to oxygen according to the standard procedure of LITI. All the film thicknesses were monitored by a quartz crystal microbalance which had been calibrated prior to use. For the rigorous measurement of UPS, the samples were transferred to an analysis chamber without exposing to air before and after the each film deposition. The UPS measurements were performed using a hemispherical electron energy analyzer and a He I ultraviolet source ($\hbar\omega$ = 21.2 eV) without monochromator. UPS spectra were obtained with a sample bias of −10 V for secondary electron cutoff region and highest occupied molecular orbital (HOMO) region spectra, respectively.

2.3. Device fabrication

To fabricate OLED devices, clean glass substrates precoated with ITO layer were used to investigate the bottom emission properties and ITO/silver (Ag)/ITO layers were used to investigate top emission properties. Line patterns of anode materials and organic insulating materials for confinement of the aperture area were formed on glass by photolithography process. The ITO or ITO/Ag/ITO glasses were cleaned by sonification in an isopropyl alcohol and acetone, rinsed in deionized water, and finally irradiated in a UV–ozone chamber. All organic materials were deposited by the vacuum evaporation technique under a pressure of $\sim 1 \times 10^{-7}$ Torr. The deposition rate of organic layers was about 1 Å/s. Then, lithium fluoride (LiF) and aluminum (Al) were deposited in another vacuum deposition system without breaking vacuum for bottom emission devices. Deposition rates of LiF and Al were 0.5 and 5–10 Å/s, respectively. For top emission devices, LiQ and Mg/Ag were deposited in another vacuum deposition system without breaking vacuum. Deposition rates of LiQ and Mg/Ag were 0.5 and 0.1 Å/s, respectively.

2.4. Laser patterning process

HIL and/or HTL were deposited on a glass substrate with reflective anode. Then, HTL and EML was successively deposited on a poly(ethyleneterephthalate) (PET) donor film with a light-to-heat conversion layer (LTHC) and inter-