

A Highly Efficient Organic Light-Emitting Diode with an Imprinted In-Cell Polarizer for Backlight Applications

Wonsuk Lee, Wonsuk Choi**, **Yong-Woon Lim****, **Yu-Jin Na, and Sin-Doo Lee***

Abstract

A highly efficient organic light-emitting diode (OLED) with an in-cell polarizer made of an imprinted liquid crystalline polymer (LCP) layer doped with dichroic dye molecules is presented. The in-cell polarizer was found to be capable of effectively polarizing the emission light of the OLED and of significantly improving the luminance through the periodic microstructures fabricated using an imprinting method. This type of OLED with an imprinted in-cell polarizer is useful for efficient light source applications in liquid crystal displays (LCDs).

Keywords : organic light-emitting diode, in-cell polarizer, imprinting technique

1. Introduction

OLED devices [1] have attracted much attention as efficient light sources due to their low power consumption and collimated illumination over a large area. In particular, white OLED can be used as a collimated light source in the backlight unit (BLU) of a liquid crystal display (LCD). In this case, polarized light emission from the BLU is inevitably required due to the intrinsic characteristics of the LCD. Thus, numerous researches have been carried out to obtain linearly polarized emission from the OLED by means of the surface treatment of the active layer through a rubbing process [2, 3], photo alignment [4], or the friction transfer method [5, 6]. Such surface treatment, however, does not produce the sufficiently polarized emission required for the BLU applications. Moreover, the damage and contamination of the active layer deteriorate the polarization efficiency. It is thus important to explore the possibility of employing coated polarizers in the OLED device [7-9]. In addition to collimated illumination, the use of a thin polarizer between the substrate and the OLED multilayer can reduce the device thickness of the LCD. Among the various existing thin polarizers, the dye polarizer is widely used for LCD applications. The dye molecule, which shows a high dichroic ratio due to its elongated molecular structure, absorbs the light polarized parallel to the direction of the molecular orientation. For the alignment of dye molecules, some conventional alignment techniques, such as the rubbing process and photo alignment, have been extensively investigated [7-10].

Here, an OLED device to which an in-cell polarizer fabricated using an imprinting technique is attached is presented. It was demonstrated that the imprinted liquid crystalline polymer (LCP) layer doped with azo-dye compounds with a high dichroic ratio is capable of effectively polarizing the light emitted from the OLED. Moreover, the microstructures present in the imprinted in-cell polarizer significantly enhance the luminance efficiency of the OLED due to their high outcoupling efficiency.

2. Experiments

An imprinting technique combined with a host-guest system based on LCP doped with a dichroic dye was utilized to align the LCP molecules. It has been known that the LCP molecules can be aligned through an imprinting technique due to the mechanical stretch of the molecules and the anchoring energy of its microstructures [11, 12]. As a result, the guest material in the host-guest system, dye molecules, could be co-aligned with the LCP during the

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imprinting process. A multifunctional in-cell polarizer with imprinted microstructures was then obtained.

The layer structure of the OLED device and the fabrication processes using an imprinting technique are schematically illustrated in Fig. 1. As shown in such figure, the dye-doped LCP layer, behaving as an in-cell polarizer, was placed between a glass substrate and a transparent indium-zinc oxide (IZO) anode. To fabricate the microstructured LCP layer, an LCP material (RMS03-001C, E. Merck) doped with a dichroic dye (Azo G-472, Hayashibara, Inc.) was spin-coated on the bare glass substrate. The LCP layer was then imprinted using a polydimethylsiloxane (PDMS) stamp that had semi-spherical microstructures fabricated through the conventional photolithography and thermal reflow processes [13]. After the photopolymerization of the LCP layer under ultraviolet irradiation in a nitrogen environment, the PDMS stamp was peeled off, and well-defined LCP microstructures were obtained. To fabricate an OLED device on the microstructured LCP layer, the IZO anode was first sputtered on the polymer layer. Organic multilayers were subsequently deposited in a vacuum. The organic materials used were 4,4',4"-tris[2-naphthylphenylamino] triphenylamine (2-TNATA) as a hole injection layer, 4,4'-bis[N-(naphthyl)-N-phenyl-amino]biphenyl (NPB) as a hole transport layer, and tris-(8-hydroxy-quinoline) aluminum (Alq_3) as an emissive layer and an electron transport layer. A layer of LiF/Al was deposited to form a metallic cathode. The optimized thicknesses of each layer were 60 nm for 2-TNATA, 20 nm for NPB, 60 nm for Alq_3, and 1 nm/200 nm for LiF/Al.

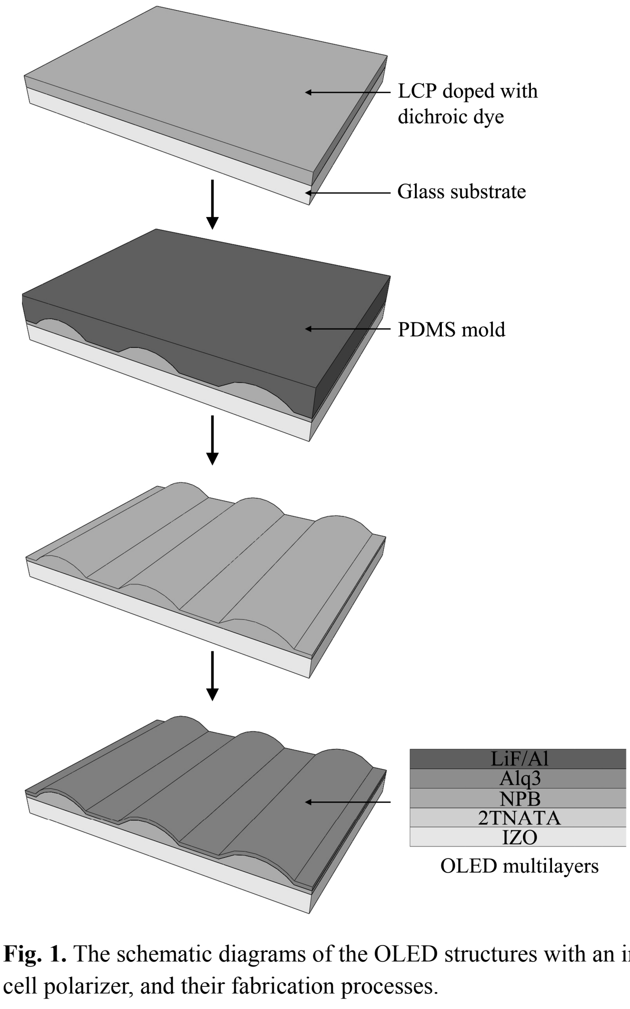

Fig. 1. The schematic diagrams of the OLED structures with an in-cell polarizer, and their fabrication processes.

3. Results and Discussion

Fig. 2 shows an atomic-force microscopic (AFM) image and the surface profile of the imprinted microstructures. As shown in Fig. 2, the microstructures were well replicated from the patterned PDMS stamp to the dye-doped LCP layer. The width, height, and period of the one-dimensional periodic microstructures were determined to be 3 μm, 1.1 μm, and 6 μm, respectively.

The electroluminescence (EL) spectra and the current-voltage-luminance (I-V-L) characteristics were measured to

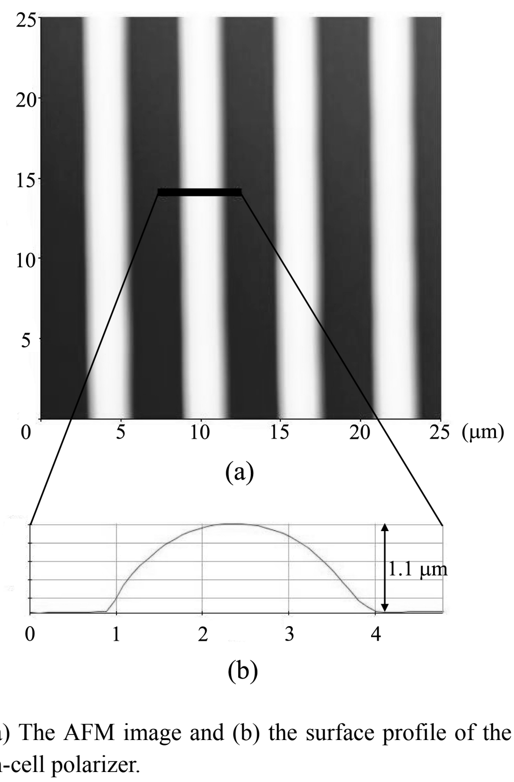

Fig. 2. (a) The AFM image and (b) the surface profile of the imprinted in-cell polarizer.

examine the performance of the OLED device with an in-cell polarizer, using a spectrometer (PR650 Spectra Scan Colorimeter, Photo Research, Inc.) together with a programmable voltage-current source (Keithley model 2400). All the measurements were carried out under ambient conditions.

To evaluate the polarization characteristics of the fabricated OLED devices, a conventional sheet polarizer was attached to the fabricated devices. Fig. 3(a) shows the experimental results measured with a sheet polarizer placed parallel and perpendicular to the optic axis of the in-cell polarizer. It was found that the EL intensity that was measured with the parallel polarizer was much higher than that measured with the perpendicular polarizer. Note that the difference between the two configurations was considerably large, within the range of 500 nm to 580 nm. In Fig. 3(b), the calculated extinction ratio, defined as the intensity measured with the parallel polarizer relative to the intensity measured with the perpendicular polarizer, is shown. The

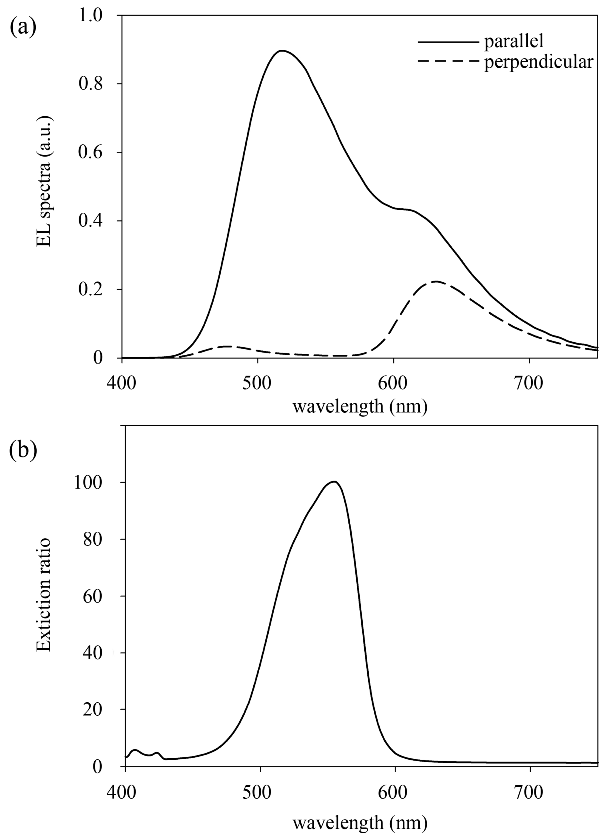

Fig. 3. (a) The EL spectra of the fabricated OLED measured with a sheet polarizer parallel and perpendicular to the optic axis of the fabricated in-cell polarizer. (b) The extinction ratio.

ratio exceeds 50 within the range of 500 nm to 580 nm, which corresponds to the emitting spectra of the fabricated green OLED device. At the wavelength of 555 nm, coinciding with the peak wavelength of the EL emission, the extinction ratio reached about 100. The in-cell polarizer with microstructures can thus be employed for LCD application as long as the extinction ratio is improved within a wide range of the emission spectra through various approaches, such as doping with dyes with a higher dichroic ratio and optimizing the geometrical dimensions of the imprinted microstructures.

Let us now discuss the effect of the LCP microstructures on the luminance characteristic. To examine the geometrical effect of the microstructures on the emission characteristics, two OLED devices were fabricated under the same conditions, except for the presence of the microstructures. Device 1 had a flat structure outside it, to which a conventional sheet polarizer was attached, and device 2 had only an imprinted in-cell polarizer. Fig. 4 shows the I-V-L characteristics of the two OLED devices. As shown in Fig. 4, the luminance of device 2 was two times larger than that of device 1 for the given applied voltage. This improvement came from the increased current density and the enhanced outcoupling of the emitted light. As shown in Fig. 4(b), the measured current density per unit viewing area of device 2 increased by about 50% compared to device 1, for the given applied voltage. This resulted partly from the increase in the effective active area and partly from the change in the electric-field distribution. Geometrically, the surface area covering the curved microstructures was found to be 1.3 times wider than the flat surface, resulting in the increase of the current flow over the whole active area. Moreover, the distortions of the electric field as well as the reduction in the effective thickness of the nonplanar active layer contributed to the increase in current density. Fig. 4(c) shows the luminance for the given current density. The normal direction luminance of device 2 was found to increase by about 20% on average for the given current density. A portion of the light was trapped in the organic layer, the metallic electrode, and the substrate can be extracted outside the device in the presence of the nonplanar microstructures [14-15], leading to the improvement of the light extraction efficiency. The improved luminance efficiency significantly contributes to the higher brightness of the display device.

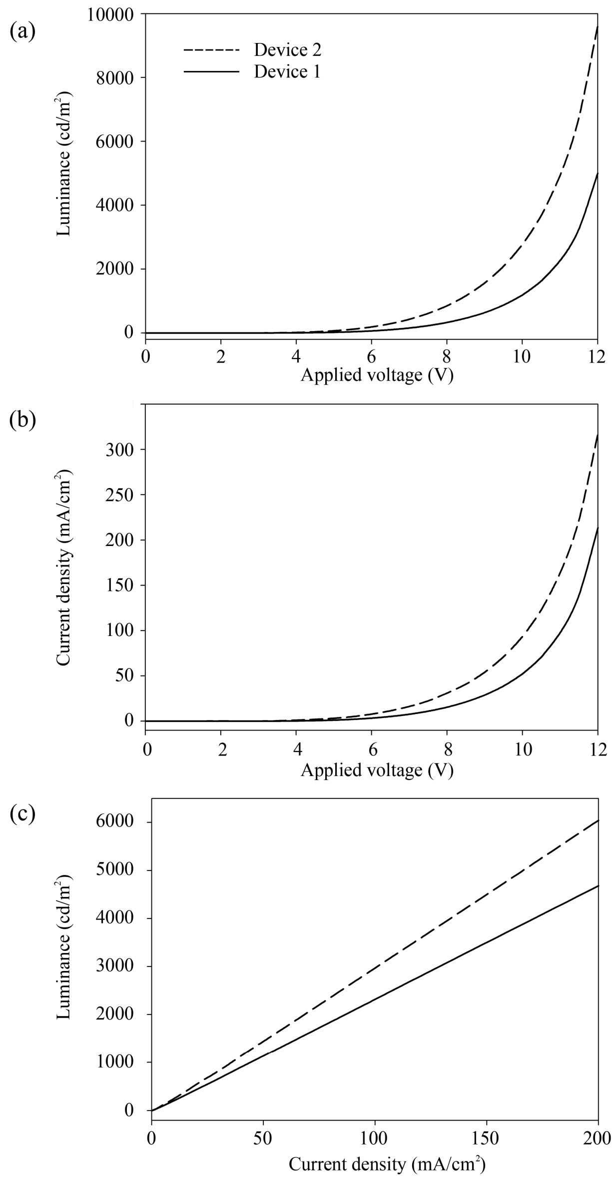

Fig. 4. The I-V-L characteristics of device 1, which had a flat structure outside it, to which a conventional sheet polarizer was attached, and those of device 2, which had only an imprinted in-cell polarizer: (a) Luminance vs. applied voltage, (b) Current density vs. applied voltage, (c) Luminance vs. current density.

4. Conclusions

In this study, an OLED with an imprinted in-cell polarizer was developed based on the dye-doped LCP layer. It was demonstrated that the imprinted in-cell polarizer with microstructures is capable of polarizing the light emitted by the OLED device and of increasing its luminance efficiency. Consequently, the OLED device with such in-cell polarizer is expected to be used for BLU application in LCDs, which requires high brightness as well as polarized emission.

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