Micro/Nano-Stripe Organic Light Emitting Diodes
Fabricated Using Photolithography and Laser Interference Lithography

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We have demonstrated the fabrication of OLEDs with a micro/nano-patterned pixel defining layer (PDL) using photolithography and laser interference lithography (LIL) techniques. Moreover, we have demonstrated the successful fabrication and operation of micro/nano-stripe OLED pixel sizes of 354 nm and 30 μm. This novel patterning technique scheme holds many merits such as reduced processing, cost, and limitations of resolution, and it is applicable to the fabrication of large-area displays. We discuss the micro/nano-stripe patterning method and device fabrication and analyze the optical and electrical characteristics of micro/nano-stripe OLEDs.

Keywords: Laser Interference Lithography (LIL), Micro/Nano Stripe Organic Light Emitting Diodes, Pixel Defining Layer (PDL).

1. INTRODUCTION

Organic light-emitting diodes (OLEDs) are luminous devices that utilize the electroluminescence (EL) phenomenon when current flows through the organic material. OLEDs have been rapidly investigated during the past two decades owing to their possibilities of low power consumption, high energy efficiency, high-speed operation, and potential applications for large-area flat displays and flexible displays.¹–⁴ OLEDs are an environmentally sound light source that do not produce excessive heat or contain toxic materials. The OLED itself is ultrathin (∼200 nm) and has very low weight, and it can be tailored to many formats.

Advances in the manufacture and processing of micro-OLEDs for full-color displays have increased interest in OLEDs at the nanopixel level. Reducing the pixel size of OLEDs can increase the number of pixels per unit area, which allows production of high-resolution display devices.⁵–⁷ Furthermore, OLEDs have the potential to lead a new generation of high-resolution micro- and nano-displays because they work with high efficiency at low voltages. One of the significant concerns of flat-panel OLEDs in the field is the precise patterning of high-resolution pixelated displays with the maintenance of optimal material characteristics. Consequently, the development of high-resolution and low-cost patterning techniques for large-area displays is needed.⁸⁻⁹

A recent display features pixels with a diamond-shaped pentile structure rather than the general RGB stripe structure. This method can simultaneously raise the resolution and increase the user’s legibility. Therefore, as mentioned above, high-resolution displays as well as pixel shapes and arrangements are required in new technology. A number of pixel patterning methods for OLEDs have been reported. For example, focused ion beam lithography, electron beam lithography, nanoimprint lithography, laser interference lithography, etc., are used in nanosized patterning.⁸⁻¹⁰⁻¹³

LIL is a particularly innovative and efficient way to fabricate one- or two-dimensional periodical patterns in a nanolithography technique; it has many attractive characteristics such as high resolution, low cost, large area fabrication, very high throughput, and easily reconfigurable patterns (different periods, sizes, and pattern shapes).¹²–¹⁴

Previously, conventional nanohole OLEDs were made by shape holes using LIL, but viewing angle problems occurred, and EL characteristics were not addressed in detail.⁷ Here, we demonstrate a solution to the problem of EL characteristics and viewing angles.
through micro/nano-stripe OLEDs. LIL easily fabricates micro/nano-stripe patterns with other methods by using photolithography to fabricate arrays of micropatterns then making nanopatterns through LIL as a one-step development process.

We report the fabrication and EL characteristics of micro/nano-stripe OLEDs. We discuss our process for fabricating micro/nano-stripe OLEDs and analyze the resulting product in this paper.

2. EXPERIMENTAL DETAILS

2.1. Fabrication of Micro/Nano-Stripe-Patterned Pixel Defining Layer

AR N 4240 (Allresist Co., Ltd.), an insulating and negative photoresistor (PR), and a thinner (AR 300-12, Allresist Co., Ltd.) were mixed to create a thin PR for easy patterning. After cleaning the ITO-coated glass, an approximately 200 nm-thick negative PR with a thinner film were spin-cast onto the ITO-coated glass slides at speeds of 500 rpm for 3 s and 4000 rpm for 30 s and to heated 95 °C for 1 min 30 s. UV lithography was then used to produce a pattern of micro-units. UV lithography was employed to obtain the desired micropatterns on the photoresistor. Therefore, the various shapes of the photomask pattern can produce a micropattern of various shapes and arrangements. However, the development process was not necessary during UV lithography. After UV lithography, the photoresistor was continuously treated with LIL immediately. To manufacture nanopatterns or micropatterns using LIL, the PR was exposed to an Ar-ion laser (power = 0.15 mW/cm²) for 30 s. The substrates with the photore sistor were soaked in development solution (AR 300-47) diluted 1:1 at 30 °C for 3 min to develop photoresistance. These processes are schematically shown in Figure 1(a).

Figures 1(b) and (c) present SEM images taken from the side and above the array of micro- and nano-stripes with pitches of ∼60 μm and ∼680 nm, a space line of

![Fig. 1](image_url)

**Fig. 1.** (a) Scheme for patterning micro/nano-stripe OLEDs, SEM images of micro/nano-stripe-patterned PDL structure, ((b) top view, (c) side view), and (d) a cross-sectional view of the micro/nano-stripe OLEDs.

![Fig. 2](image_url)

**Fig. 2.** SEM images of (a) microline-, (b) microsquare- and (c) nanoline-patterned PDL structure.
Fig. 3. (a) Current density–voltage–luminance and (b) current efficiency–luminance characteristics of the conventional, microline, microsquare, nanoline and micro/nano-stripe OLEDs.

The electroluminescence (EL) spectra were collected using a spectroradiometer (Konica Minolta CS-2000). The current density–voltage–luminance (J–V–L) characteristics were obtained using source/measure units (Keithley 238) and the aforementioned spectroradiometer.

### 3. RESULTS AND DISCUSSION

The EL characteristics of the reference, microline, microsquare, nanoline and micro/nano-stripe PDL OLEDs were determined. Their PDL structure calculated fill factors were ∼50% (microline), ∼25% (microsquare), ∼47.3% (nanoline), and ∼21.9% (micro/nano-stripe). Their J–V–L characteristics with PDL substrate and reference are shown in Figure 2(a). The introduction of PDL did not alter the electrical characteristics of our green OLEDs. The measurements show that the J–V–L characteristics are similar in terms of current density in the voltage range of 4 to 6 V. This is interpreted to mean that there is a similar driving voltage for devices owing to the similar electrical interface between the ITO and the HTL.

The current efficiency–luminance characteristics of the reference, microline, microsquare, nanoline and micro/nano-stripe PDL nanosized OLEDs were shown in Figure 3(b). The reference without PDL OLEDs showed a current efficiency of 54 cd/A at 1000 cd/m². Compared to the microline- and microsquare-patterned PDL OLEDs, the efficiency was not changed. The same trend was observed for both efficiency curves of the microline- and microsquare-patterned PDL OLEDs, which may be due to the large emitting area. Conversely, nanoline- and micro/nano-stripe-patterned PDL nanosized OLEDs exhibited less efficient properties than the reference OLEDs because their light emission area is smaller. However, nanosized OLEDs have a more stable current efficiency with a higher luminance at 1000 cd/m².

The introduction of PDL did not alter the electrical characteristics of our green OLEDs. Thus, any change in OLED performance can be interpreted as optical effects due to the PDL. In order to correctly evaluate optical
effects, we measured the luminance as a function of the viewing angle (0° to 60°) in the normalized angular EL spectra at a constant current density of 2 mA/cm² shown in Figure 4. The OLED with microline- and square-patterned-PDL showed almost the same spectrum as the reference. For the planar and micropatterned PDL OLED, spectrum distortion is observed owing to the weak cavity effect. The FWHM changed from 68 nm to 83 nm as the viewing angle decreased from 0° to 60°. Conversely, the FWHMs of the nanoline-patterned PDL OLED and nano/micro-stripe-patterned PDL OLED were from 62 nm to 66 nm and from 65 nm to 72 nm, respectively, as the viewing angle decreased from 0° to 60°. The results from normalized EL spectra clearly showed improved angle dependency as a function of nanopatterns.

We have measured the angular dependence of the reference, microline, microsquare, nanoline, and micro/nano-stripe OLEDs. The observed colors of the emission spectrum were indicated in terms of the chromaticity coordinates \((x, y)\) developed by the Commission Internationale d’Eclairage (CIE) and were used to evaluate the differences in spectra of the reference, microline, microsquare, nanoline, and micro/nano-stripe OLEDs. Figure 5 shows the angular dependences of the CIE color coordinates for the reference, microline, microsquare, nanoline, and micro/nano-stripe OLEDs. The results show that as the viewing angle varies by up to 70° to the normal, the color change ratio of the OLEDs with nanoline- and micro/nano-stripe-patterned PDLs are smaller than that of the reference OLEDs and micro-OLEDs. In Figure 5, we confirmed the angular dependences of the CIE data in which nanosized OLEDs are more stable than the reference OLEDs and micro-OLEDs.

4. CONCLUSION
In summary, the introduction of nano line and micro/nano stripe pattern as pixel define layer was effective in improving the OLEDs for the angle dependency. We have developed a simple procedure to fabricate a better viewing angle and efficient using UV lithography and LIL, micro/nano stripe OLEDs arrays containing up to \(\approx 4.16 \times 10^9\) pixels over areas of 1 cm². Finally, the micro/nano stripe OLEDs have been improved the efficiency and viewing angle compared to the conventional nanohole OLEDs and have the potential for high resolution. In this paper, the micro/nano...
stripe OLEDs provides easy fabrication and possibilities for designing nanoscale lighting devices.

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References and Notes

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