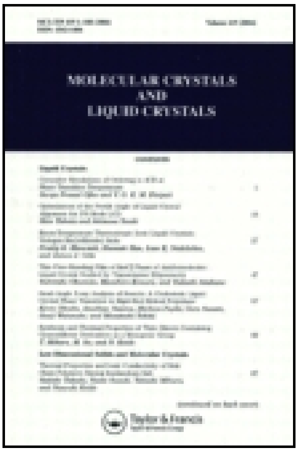

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Effect of Height and Radius(h/r)Ratio of Micro Lens Array Pattern on the Light Extraction of OLEDs

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In this paper we discussed the effect of micro lens array(MLA) pattern fabricated on the glass substrate of organic light emitting diode(OLED) for improvement of light extraction efficiency. The MLA patterns were formed by combination of photolithography and thermal reflow method and its effect on light extraction efficiency form OLED device was examined.

Keywords Organic Light Emtting Diode; OLED; Light extraction efficiency; Micro lens array

Introduction

Organic light emitting diodes(OLEDs) have been regarded as an ideal mobile display due to the low power consumption, excellent color gamut, wide viewing angle, and fast response time. However the power and current efficiencies of OLED panel are still not high enough for the specific applications of OLEDs. Although the internal quantum efficiency of OLED has been fully achieved in the OLED, the light extraction efficiency remains about 20% because the reflective index of the glass substrate is higher than that of air [1]. In order to improve the light extraction efficiency of the OLEDs, the micro lens array (MLA) pattern has been suggested to be fabricated on top of the glass substrate [2, 3, 4]. In this paper various MLA patterns were optically simulated with such parameters as height to radius (h/r) ratios of the micro lens and gap between lenses [5–8]. The effects of MLA pattern on light extraction efficiency were also checked with OLED devices on which MLA pattern was fabricated on the ITO glass side of OLED devices [9–12].

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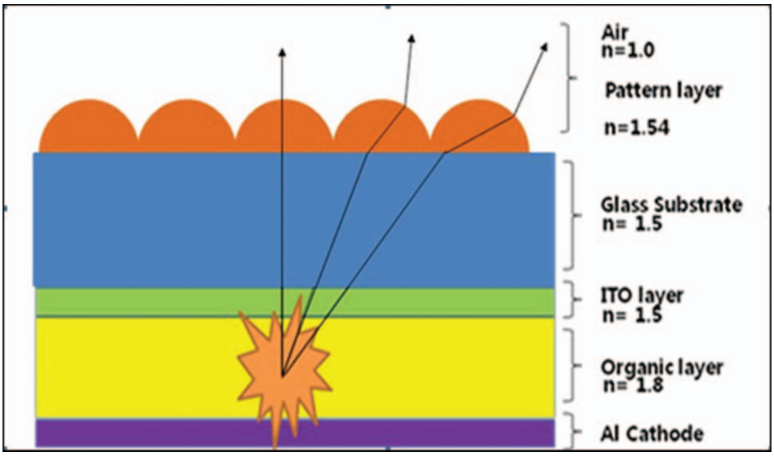

Figure 1. Structure of OLED with MLA pattern on glass substrate.

Experimental

1. Fabrication of MLA Pattern with Commercial Photoresist

The micro lens array(MLA) patterns were made with commercial nega-PR(DNR L-300) and newly synthesized nega-PR(KNU ML-1), respectively. In Figure 1 is shown the schematic diagram of OLED device on which the micro lens array pattern was fabricated on top of the glass substrate with the refractive index values of different layer materials. Figure 2 shows the photomask to generate MLA patterns on top of OLED devices by photolithographic method using UV light source. Figure 3 shows the fabrication process of MLA pattern on the OLED panel. The fabrication process of MLA pattern using a commercial negative photoresist was as following. First a negative type photoresist (DNR-L300, Dongjin Chemical co.) was coated on top of OLED substrate glass. The photoresist (DNR-L300) had a high refractive index of 1.56 and could be cured by UV light with peak at 350–440 nm. The spin coating was conducted by two steps for the uniformity and control of thickness

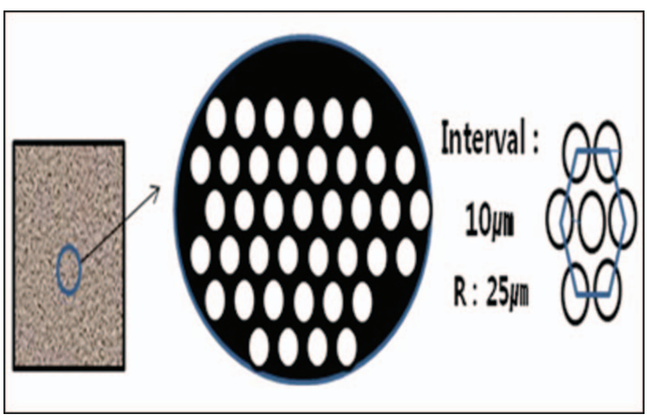

Figure 2. Photo-mask to make MLA patterns.

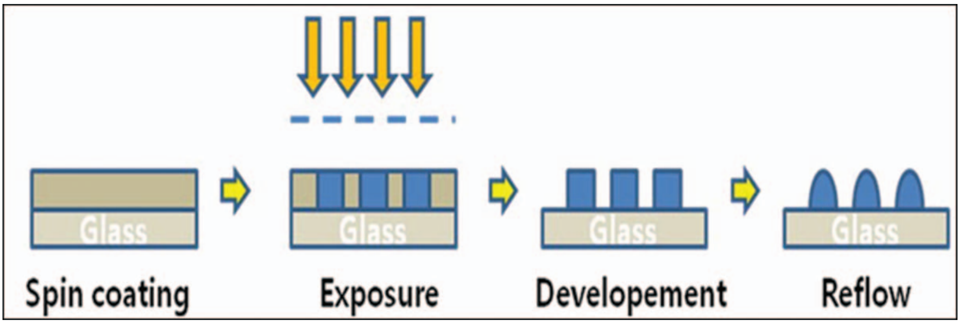

Figure 3. Fabrication process of MLA pattern.

of coated negative photoresist. After coating the photoresist layer, soft baking was carried out at 110°C for 13 minitues. After soft bake the UV exposure was conducted under the condition of 60mJ by using 14mW UV lamp for 50second, followed by post bake at 110°C for 150 second. The development was done with a nega-PR developer CPD-18(TMAH 2.38 wt%) for 60 second to give a MLA pattern with circular column shape. The thermal reflow was conducted in on oven at 150°C for 150 seconds to transform the column shape MLA pattern to micro lens shape.

2. *MLA Patterning with Synthesized Photoresist*

The MLA pattern obtained with the nega-PR(DNR L-300) had slight yellowish color after curing process, so a the new negative PR was synthesized in order to achieve high transparency and good thermal reflow property. First a prepolymer was synthesized by free radical solution polymerization. Benzylmethacrylate(BMA), glycidylmethacrylate(GMA), methymethacrylate(MMA) and 2-hydroxyethyl methacrylate(2-HEMA) comonomers were polymerized in propyleneglycol monomethyl ether acetate(PGMEA) solvent with AIBN initiator at 60°C for 6 hours under nitrogen atmosphere. The prepolymer solution was then precipitated in n-hexane as non-solvent to purify the polymer. The precipitated polymer was filtered and dried. A new negative photoresist solution was made by mixing the photomonomer, oligomer, photoinitiator, surfactant with the synthesized prepolymer dissolved in PGMEA solvent. A typical formulation is shown in Table 1.

Table 1. The formulation of negative photoresist solution (KNU-ML1)

Component	Weight (g)	Contents (wt%)
PhotoInitiator (Iraqure907:ITX = 7.3)	0.120	1.2%
Photo monomer (HEMA)	1.000	10.0%
Photo Oligomer (EB-600)	0.500	5.0%
NS-B	0.150	1.5%
Binder Polymer (BP-1)	6.000	60%
PGMEA	2.230	22.3%
Total	10.00	100%

Table 2. The simulation data of light extraction from OLED by MLA patterns

Radius	code	Height	Gap	h/r ratio	Viewing angle	Luminance (Arb.)
25 μM (D = 50 μM)	A	10 μM	10 μM	0.4	155°	8,150
	B	15 μM	10 μM	0.6	135.7°	9,700
	C	20 μM	10 μM	0.8	117.4°	11,000
	D	25 μM	10 μM	1.0	109.5°	10,500

3. Fabrication of OLEDs with MLA Pattern and Measurement

After fabrication of MLA pattern on the glass substrate, the OLED device was made by using a cluster type OLED fabrication system (Sunicel Plus200 Series). The materials used in OLED were as following; NPB (N,N′-bis(naphthalene-1-yl)-N,N′-diphenyl-benzidine) from Doosan Chemical Co. was used as a hole transport layer. Alq3(Tris(8-hydroxy quinolinato)aluminum) was used as host material in the emitting layer as well as the electron transport layer. C545T(3,3′-dibromo-2,2′-bithiophene-5,5′-diyl)bis(trimethylsilane) was used as a green dopant in the emitting layer. LiF(lithium fluoride 99.99% purity) was used as electron injection layer and the cathode was formed by evaporation of aluminum with 99.99% purity. OLEDs fabricated had a configuration of ITO(150nm)/a-NPD (120 nm)/Alq3:C545T (40 nm)/Alq3 (30 nm)/LiF (1nm)/Al (120 nm). The size of the OLED was 40 mm*40 mm and the active emitting area of the OLEDs was 2 mm*2 mm. Electroluminescence(EL) spectra were measured by using Spectroscan PR 650 (Photo research Inc). Current density-luminescence-voltage(J-V-L) profiles of the OLED devices on which MLA patterns were formed on the outside of ITO glass substrate were obtained by using dc power supply connected to Keithley 2400.

Results and Discussion

The optical simulation data obtained by varying the height to radius (h/r) ratios of micro lens and the gap between the lenses are shown in Table 2 and Figure 4. As the h/r ratio increases the maximum luminance (light extraction) of the OLED device was increased, but the viewing angle became narrow. Therefore the optimum design of micro lens array was determined to be at h/r ratio of 0.8 with micro lens radius of 25 μM and gap of 10 μM. According to the optical simulation result the MLA patterns were fabricated on the glass side of the ITO glass substrate. In Fig. 5 are shown the MLA patterns made by standard

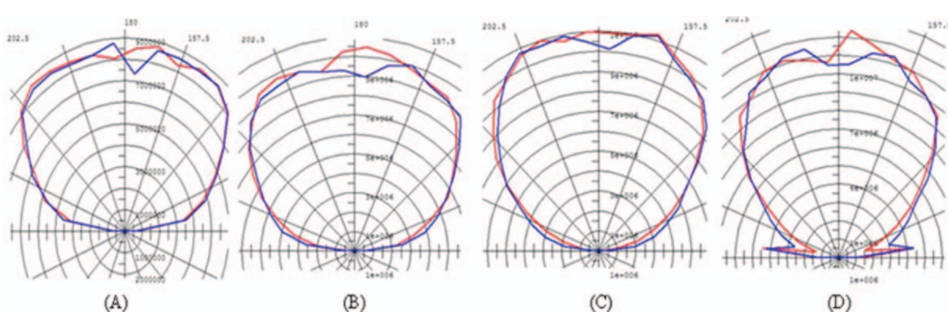

Figure 4. The simulation data of light extraction from OLED with MLA patterns.

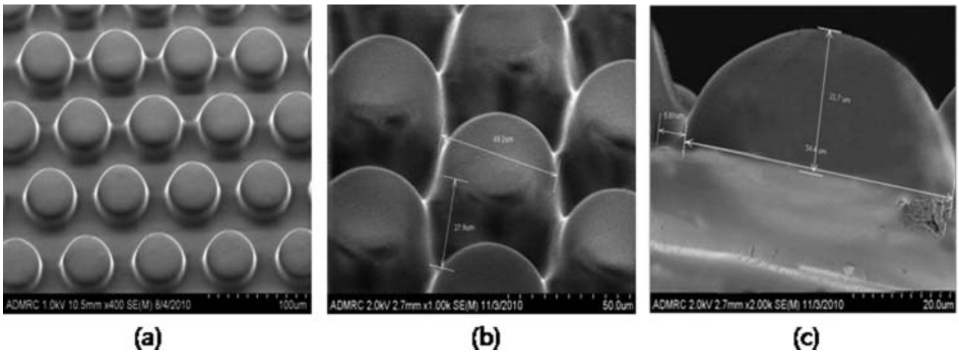

Figure 5. SEM images of the MLA pattern.

photolithography and thermal reflow method. In Fig. 5, (a) and (b) show the MLA pattern before thermal reflow, (c) is the MLA patterns after thermal reflow obtained with newly synthesized nega-PR(KNU ML-1). The MLA made with new nega-PR exhibited smoother surface than commercial one. It was also observed that the height of micro lens decreased to 21 μM after thermal reflow from 27 μM of circular column shape, the diameter increased to 56 μM from 50 μM of circular column and the gap between the micro lens decreased to 6 μM form 10 μM in the case of circular columns.

The OLED device was made by vacuum evaporation of organic materials on top of the ITO layer of the glass behind which the MLA patterns were formed. The performances of OLED devices with and without MLA pattern on the glass substrate are shown in Table 3 and Fig. 6. When the current density of the OLED device was about 15(mA/cm^2), the luminance of the OLED device over 1000 cd/m^2 was observed. The luminance of the OLED device with MLA pattern formed with KNU ML-1 negative photoresist was 42% higher than that of the OLED without MLA pattern and 30% higher than that of the OLED with MLA made by commercial DNR L-300 negative photoresist. The difference between MLAs made with a new nega-PR(KNU ML-1) and commercial sample(DNR L-300) seemed to be due to the transmittance to the visible light. The transmittance of the former was 90.2% but the later was 87.3% when measured at 520nm wave length. The reflective index was nearly same 1.57 and 1.58, respectively. These results indicated that the light extraction in OLED devices depend on the geometry of the MLA pattern as well as property of the MLA materials.

Table 3. The performance of MLA patterned and non-MLA OLED devices.

			OLED Performance	
OLED Devices	MLA h/r Ratio	Current Density (mA/cm^2)	cd/m^2	cd/A
Ref Non-MLA	—	15	707	7.7
MLA (DNR L-300)	0.8		904	9.2
MLA (KNU ML-1)			1094	9.9

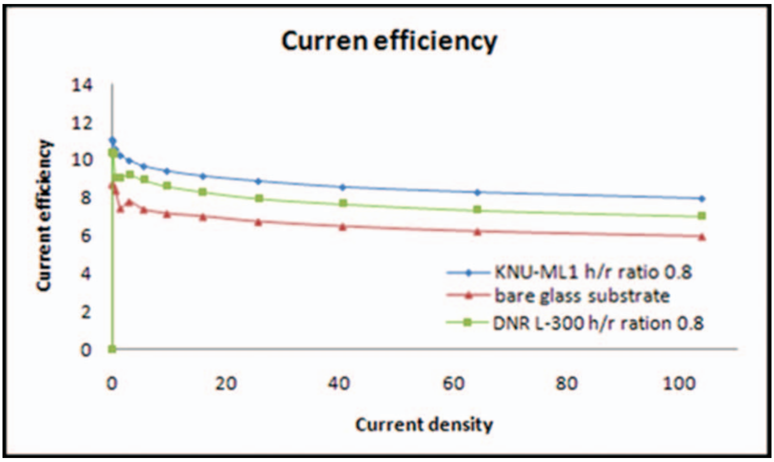

Figure 6. The current efficiency vs current density curves of MLA patterned and non-MLA OLED devices.

Conclusions

In this paper the simulation of light extraction from the micro lens array(MLA)pattern was conducted with the height to radius(h/r) ratios of the micro lens and gap between micro lenses as a major variables. From the simulation the optimum design of micro lens array on the OLED devices was determined to be at h/r ratio of 0.8. The effect of MLA pattern on light extraction efficiency was examined by application of various MLA patterns to the OLED devices. In case of the MLA patterned OLED device, the brightness and the current efficiency of the OLED were improved to 50% and 24% respectively compared to the non-MLA OLED devices.

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