TRANSDUCERS & EUROSENSORS '07
The 14th International Conference on Solid-State Sensors, Actuators and Microsystems, Lyon, France, June 10-14, 2007

MICROLENS ARRAY FILM WITH FULL FILL FACTOR FOR ENHANCING OUTCOUPLING EFFICIENCY FROM OLED LIGHTING

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Abstract: This paper reports a microlens array (MLA) film with full fill factor and presents its application to organic light emitting diode (OLED) for improving outcoupling efficiency. Gapless MLA film having high sag ratio is proposed and fabricated by simple micromachining process including trench formation and conformal vapor phase deposition of polymer. As applying MLA film to OLED panel, the outcoupling efficiency increased by maximum 48%. High-sag MLA optical film with full fill factor is expected to give remarkable optical efficiency to various display or lighting applications of the flat panel light sources including OLED.

Key words: Microlens array, MLA film, full fill factor, high-sag, OLED, outcoupling efficiency

1. INTRODUCTION

Recently, microlens array (MLA) has been attracting more attention for various applications in the field of displays, lighting devices, optical sensors, optical communication, etc. MLA film composing convex refractive lenses has versatile optical functions to increase the luminous flux from backlight of display and some lighting devices, to control viewing angles, or to raise sensitivity of the image sensor [1]. It can be easily replicated on an optical film substrate using a stamper fabricated by micromachining technology including thermal reflow of polymers and electroplating process. It is known that the replication process is most cost-effective for mass production of MLA film.

Especially, MLA film can be applied to organic light-emitting diodes (OLED) to enhance the light extraction or outcoupling efficiency [2-3]. Even though OLED is regarded as a potential candidate for the next-generation light source, MLA technology has been researched because the internal reflection loss due to planar light source of OLED, thus the shape and fill factor of MLA became critical issues to optimize the light extraction. However, conventional MLA has a limitation to increase overall light outcoupling efficiency because there is some gap area between adjacent microlenses of which conceptual drawing as shown in Fig. 1(A). In this study, we newly proposed and fabricated MLA film with full fill factor as shown in Fig. 1(B). In addition, to prevent from suppression of outcoupling efficiency due to the loss of sag-height during gap-filling, MLA maintaining high sag-height was also verified by simple micromachining process. And then, we applied the MLA film to OLED panel and measured the outcoupling efficiency.

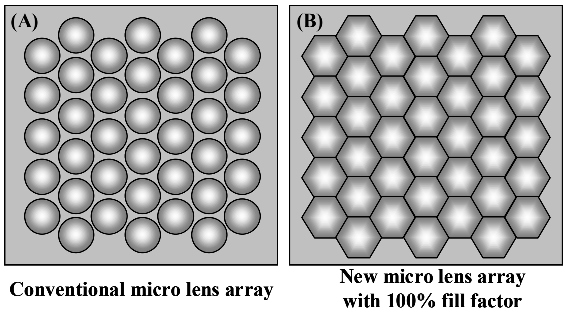

Fig. 1 The conceptual drawing of conventional microlens array (A) and proposed microlens array (MLA) having hexagonal arrangement with 100% fill factor (B)

2. HIGH-SAG MLA FILM WITH 100% FILL FACTOR

Compared with conventional MLA film with some gaps between the microlenses, MLA with 100% fill factor is depicted in Fig. 1(B). Hex-

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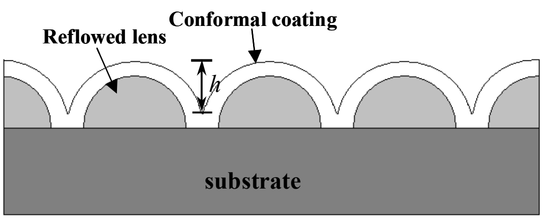
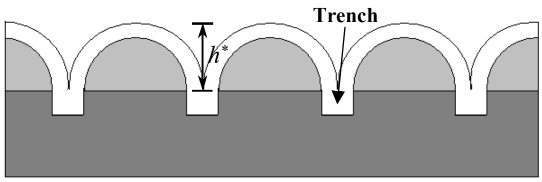
agonal arrangement of the microlenses can obtain the maximum fill factor effectively. Figure 2 shows the proposal for the master mold of MLA with full fill factor maintaining large sag height. By filling the gaps between isolated hemispherical microstructures using conformal coating techniques, full fill factor can be achieved as depicted in Fig. 2(A). Vapor phase deposition is adopted as conformal coating, thus morphology of the coated surface is very smooth not to deteriorate light efficiency as compared with electroplating technique [4]. Furthermore, the radius of curvature of microlens is precisely controlled through the management of deposition thickness. However, there is a drawback that this process leads to the loss of sag-height of microlens.



(A) Master mold of MLA with 100% fill factor by conformal coating



(B) Master mold of MLA with higher sag height by applying trench to substrate for increasing outcoupling efficiency (h > h)*

Fig. 2 Proposal of MLA for full fill factor maintaining large sag-height

Therefore, simple process to maintain high sag ratio of gapless, that is, full fill factor microlens array is proposed as shown in Fig. 2(B). Formation of trench between lenses prevents the loss of the sag-height during the gap filling process. As the sag-height of microlens influences the light extraction efficiency, the control of the sag-height is an important process. In the design of MLA, the depth of the trench and the thickness of conformal deposition for controlling fill factor and sag-height should be considered together with the pitch of lens array and the radius of curvature of microlens. With this approach, gapless MLA film having large sag-height approaching hemisphere can be achieved.

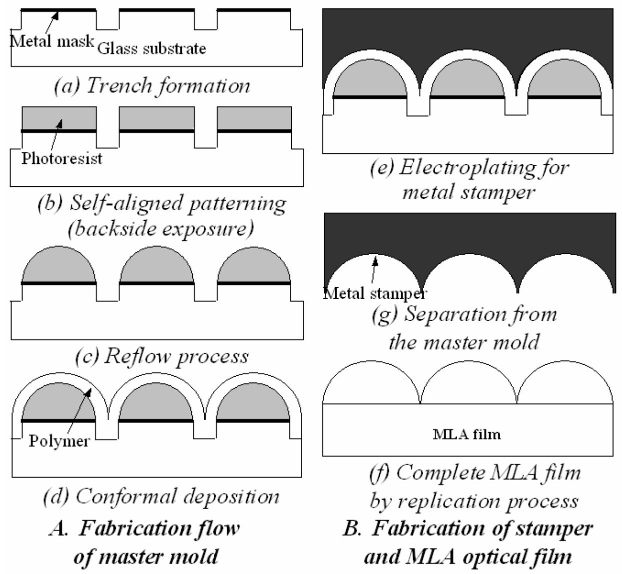


Fig. 3 Schematic fabrication flow of the MLA film with high-sag and full fill factor

Figure 3 shows a schematic fabrication flow of the proposed MLA film. The three main fabrication steps are a master mold fabrication, a stamper fabrication, and replication process, respectively. For a master mold, trenches in a glass wafer are recessed by dry etching process first. Next thick photoresist is patterned on the top surfaces of mesas using self-aligning by backside exposure. The photoresist patterns on the mesas are reflowed to transform them into the shape of hemispheres. Last, gap area existed between the hemispheres on the mesas is filled through conformal polymer deposition.

Subsequently, metal stamper for replicating the MLA is fabricated by electroplating of nickel on the master mold coated with thin gold layer as a seed metal.

Finally, the replica of MLA is made by ultraviolet (UV) stamping process on a transparent polyethylene terephthalate (PET) film. Figure 4 shows scanning electron microscopic (SEM) images of completed hexagonal MLA film. Fabricated MLA has large sag-height nearly approaching hemisphere. The pitch of MLA is 15 μm and the fill factor is 100%. The refractive index of microlenses made from UV-settable resin is 1.54.

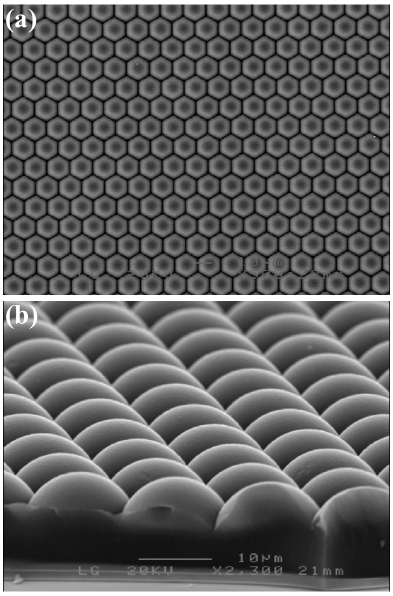


Fig. 4 SEM images of fabricated MLA film by UV replication process using a micromachined stamper

3. APPLICATION TO OLED LIGHTING

Among various applications, we applied the fabricated MLA film to bottom emission OLED and experimented to obtain maximum outcoupling efficiency. High light extraction efficiency of OLED is desirable, but most of generated light in the active region of OLED is lost through total internal reflection due to the mismatch of the refractive index between air and the bottom glass of OLED. Outcoupling efficiency can be defined as the ratio of luminance of OLED lighting passing through the MLA film to that of light extracted from a flat surface of bare panel without MLA.

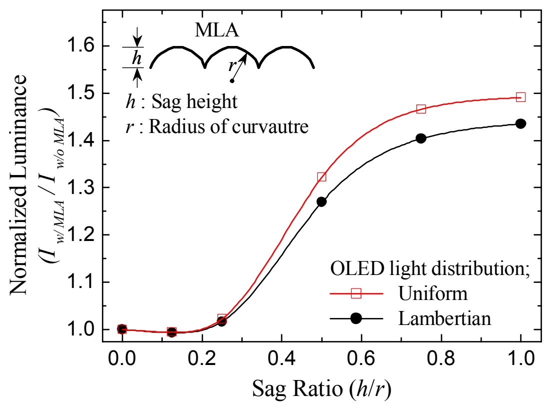
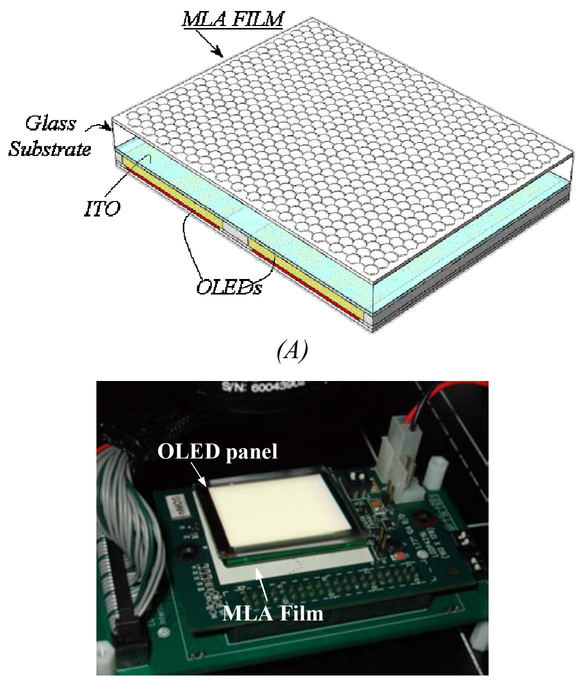


Fig. 5 Simulation results of outcoupling efficiency with respect to the sag ratio of microlens using LightTools®

Figure 5 shows simulation results of outcoupling efficiency with respect to the sag ratio of MLA. Sag ratio is defined as a ratio of the sag-height h to the radius of curvature r of the microlens. From the results, the outcoupling efficiency increases along with the sag ratio. As expected, total luminance flux is also enhanced as the sag ratio increases from the simulation.

Figure 6 shows pictures of the MLA film attached on the glass of a bottom emission white OLED panel. The panel size is 1.77 inch in diagonal. Normal brightness of full white light emitted from the test panel was measured using PR-650 spectra colorimeter. Figure 7 shows measurement results of the outcoupling efficiency depending on the sag ratio of MLA. From the result, OLED panels with the MLA film show higher brightness than the panel without the MLA film. Moreover, higher sag ratio increases the outcoupling efficiency dramatically. In case of the MLA film with the sag ratio of 86%, the luminance increased by up to 48%.

Figure 8 shows spectral flux as a function of wavelength. In this measurement, the values of luminance from the OLED panel were compared before and after attaching the MLA film with the sag ratio of 86% in an integrating-sphere system.



(B)

Fig. 6 Schematic drawing of MLA film attached on the glass of bottom emission white OLED (A) and the picture of 1.77-inch test panel for measuring luminance (B).

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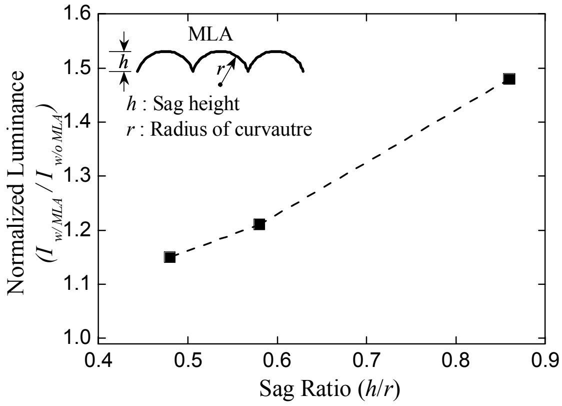

Fig. 7 Measured outcoupling efficiency according to the sag ratio of MLA

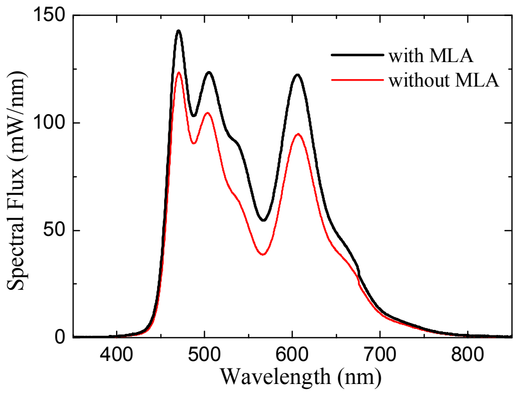

Fig. 8 Spectral flux of OLED panel with and without the MLA film measured by integrating-sphere system at full white light

The improvement in total luminous flux was observed up to 31.3% when the MLA film was applied to OLED lighting as shown in table 1. Figure 9 demonstrates brightness comparison of each OLED panel with MLA and that without MLA. The OLED panels with MLA looked brighter than conventional counterparts at both orange and blue color lighting modules.

4. CONCLUSIONS

We proposed and fabricated high-sag MLA film with full fill factor by simple micro-machining process including conformal vapor deposition followed by trench formation at the master mold fabrication step. And the outcoupling efficiency of OLED lighting modules applying the MLA film was measured. The maximum improvement of luminance efficiency was 48%. It can be expected that the MLA film with both high sag and full fill factor give remarkable improvement in optical efficiency to various display or lighting applications including OLED. Also, the MLA film using roll-to-roll replication process can promise large area, high throughput, and mass production with lowest cost up to date.

Table 1. Measured total luminous flux and chromaticity

OLED Panel	Luminous Flux (lms)	Chromaticity	
		x	*y*
Without MLA	4813.6	0.342	0.373
With MLA	6321.8	0.349	0.386

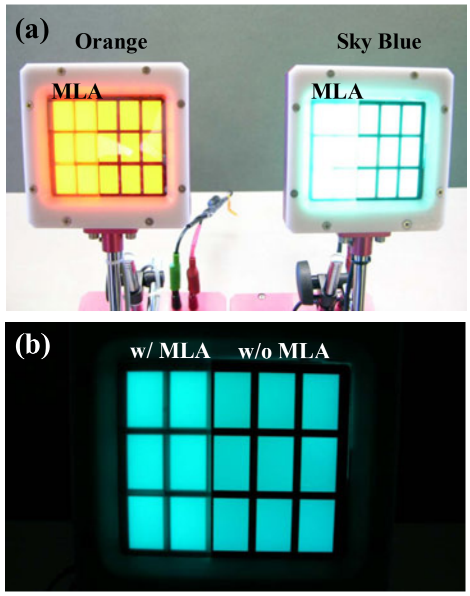

Fig. 9 Demonstration pictures of each OLED panel with and without MLA at different color lighting modules

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