나노인쇄를 이용하여 성형된 고분자 광결정의 효율 향상

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Output Efficiency of OLEDs with Polymer Photonic Crystals Directly Fabricated by Nanoimprint Lithography

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1. Introduction

Organic light emitting diode (OLED) is a promising device for displays or illuminators because of its characteristics of low power consumption, high contrast, high operation speed, and wide viewing angle. Especially, OLED which consists of thin layers, is drawing much attention because of its possibility as flexible display devices. However, the internally generated light is coupled out of the device into three types of modes: extraction into the air, the glass mode, and the waveguide mode, and the fraction of extraction into the air is limited to only 0.2 [3]. Therefore, improvement of output coupling efficiency of OLED by reducing guided modes is one of the most important issues for practical device application.

There are various efforts to improve output coupling efficiency of OLED [4, 5]. Recently, two-dimensional (2D) slab photonic crystals (PC), originating from semiconductor LED structures, were proposed and applied to OLED [6-10]. However, all of these methods have a problem that the electron beam lithography (EBL) process requires a very expensive cost, consumes long time for fabricating PC patterns, and cannot be applied to large area or flexible substrate which is a next generation display device.

In this study, we directly fabricate the 2D polymer/SiN_x PC by using the room temperature nanoimprint lithography (RT-NIL), which does not require additional processes such as etching or photo but also particular conditions like temperature or pressure specifications. Various electrical and optical characteristics are evaluated for three types of substrates.

2. Experimental

The NIL process of photonic crystal fabrication is carried out as follows. At first, the Silicon mold and 8-inch glass wafer are treated for generation of self-assembly-monolayer (SAM) in order to be easily separated from the resist, after curing. Then, resin is dispensed on a Si mold and cured by UV exposure. The resin consists of monomer, acrylate series, and photo-initiator which enable monomers to be crosslinked by UV. Finally, on separating the mold and glass wafer, we are able to obtain the modified substrate with pillars functioned as photonic crystal.

In addition silicon molds of the two types of design are used in this experiment. Both of the molds have a hexagonal lattice and periodically patterned circular holes whose lattice constant and diameter are 530 and 265 nm. The two molds are distinguished by height of their pillars: one thing is 265 nm, the other thing is 530 nm, in that these holes have different aspect ratio of 1:1 and 1:2, respectively.

As buffering layer, SiN_x layer (two different thicknesses of 500 and 800nm) is deposited on the pillar imprinted substrate at 250°C. Then, OLED devices are integrated on those three types of substrates. And the vertical structure and materials of OLED, horizontal structure of photonic crystal layer and different types of PC substrates we used are depicted in figure 1.

3. Results and discussion

SEM images of the imprinted polymer resin and PC slab are shown in figure 2, and we are able to confirm that the hexagonal lattice pattern of pillar which has about the same dimension as the Si mold was generated.

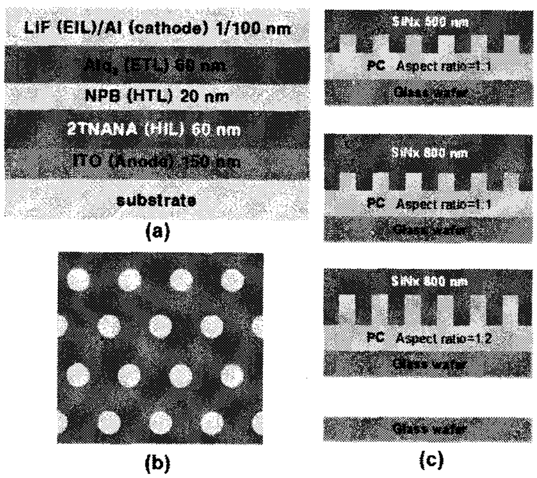

Figure 1. (a) Vertical structure of OLED, (b) Horizontal structure of photonic crystal layer and (c) Various types of substrates: type1,2,3 and reference

As shown in figure 3(a) and (b), the conventional OLED emits lights with a symmetric distribution in all directions, while the PC-OLED produces a pattern with six fold symmetry due to PC effects. In addition, to measure the efficiency from all directions, we used the integrating sphere, which was able to integrate light emitted from all directions. Figure 3 (c) represents electroluminescence (EL) intensity at 1.0 mA and integral value of each device. The EL intensity increased by up to about 50% for type I and II devices (1:1/500 and 1:1/800 substrates). However, in the case of type III (1:2/800), its EL intensity is only 50% compared to that of the reference

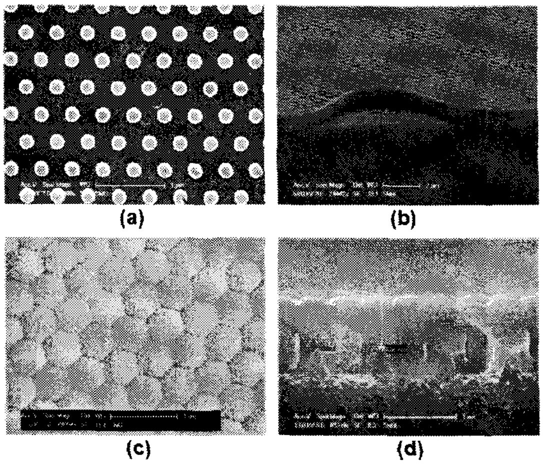

Figure 2. SEM images (a) the PC imprinted on resin, (b) side view of the PC slab, (c) top view of the PC slab and (d) cross-sectional view of the PC slab

and its low intensity is mainly caused by poor filling of SiN_x deposition due to high aspect ratio of PC pillars. To study the far-field radiation profiles, we loaded devices on a rotating jig, and measured luminance in 90±60° at intervals of 10°. Figure 3 (d) show the far-field profiles of the conventional OLED and the PC-OLED (type I) under the same injection current conditions, in terms of the quantum efficiency. As depicted, profile of the conventional OLED is very similar to Lambertian, whereas PC-OLED produces the radiation shape of butterfly, and its area is about one and half times as large as that of the conventional OLED. Therefore, we are able to conclude that the measured EL intensity value is congruous with radiation profile results.

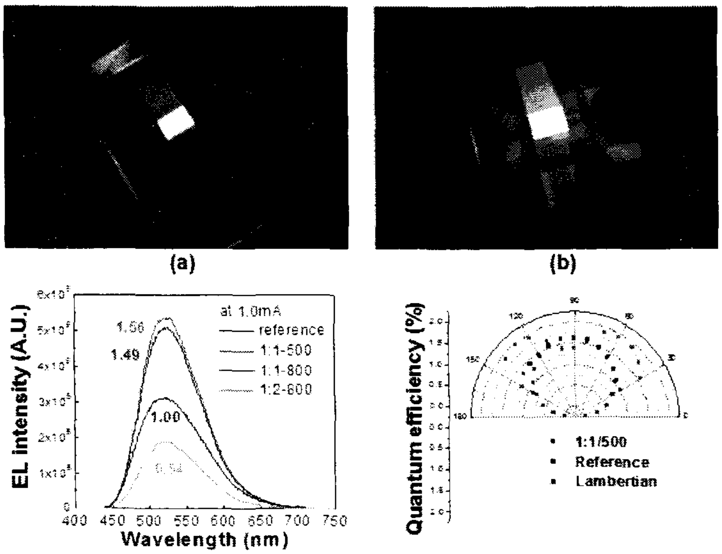

Figure 3. Photographs: (a) Conventional OLED and (b) PC-OLED, Device performances: (c) EL intensity and (d) radiation profiles for type I (1:1/500)substrate

4. Conclusions

It is proposed that 2D polymer/SiNx photonic crystal is directly fabricated by using room temperature nanoimprint lithography, which does not need additional process such as etching or photo but also particular conditions like temperature or pressure. We fabricated PC OLED with the aim of improving the output coupling efficiency, and evaluated device performance for three different types of substrates. In our experiments, in the case of PC-OLED compared with conventional OLED, an enhancement of device efficiency of up to 50% was realized, when we measured the EL intensity by using the integrating sphere which integrates generated light from all direction. From these results, we can conclude that room temperature nanoimprint lithography is a useful method for directly fabricating photonic crystal for enhancement out coupling efficiency of OLEDs.

References

1. C. W. Tang and S. A. Van slyke, *Appl. Phys. Lett.* **51,** 913(1987).
2. Stephen Y. Chou, Peter R. Krauss, and Preston J. Renstrom, *J. Vac. Sci. Techno.* B**14(6),** 4129(1998).
3. C. F. Madigan, M.-H. Lu, and J. C. Sturm, *Appl. Phys. Lett.* **76,** 1650(2000).
4. I. Schnitzer and E. Yablonovitch, *Appl. Phys. Lett.* **63,** 2174(1993).
5. M.-H. Lu and J. C. Sturm, *Appl. Phys. Lett.* **78,** 1927(2001).
6. S. Moller and S. R. Forrest, J. *Appl. Phys. Lett.* **91,** 3324(2002).
7. Shanhui Fan, Pierre R. Villeneuve, and J. D. Joannopoulos, and E. F. Schubert, *Phys. Rev. Lett.* **78,** 3294(1997).
8. Y.-C. Kim, S.-H. Cho, Y. W. Song, Y.-J. Lee, Y.-H. Lee, and Y. R. Do, *Appl. Phys. Lett.* **89,** 173502(2006).
9. Y.-J. Lee, S.-H. Kim, J. Huh, G.-H. Kim, Y.-H. Lee, S.-H. Cho, Y.-C. Kim, and Y. R. DO, *Appl. Phys. Lett.* **82,** 3779(2003).
10. Y. R. Do, Y.-C. Kim, Y.-W. Song, C.-O. Cho, H. Jeon, Y.-J. Lee, S.-H. Kim, and Y.-H. Lee, *Adv. Mater. (Weinheim,Ger.)* **15,** 1214(2003).
11. K. Ishihara, M. Fujita, I. Matsubara, T. Asano, S. Noda, H. Ohata, A. Hirasawa, H. Nakada and N. Shimoji, *Appl. Phys. Lett.* **90,** 111114(2007).