Design of Color Filter based on Metallic Nanostructure and Color Conversion Material for White OLED Display

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Keywords: Metallic Nanostructure, Color Filter, White OLED, Color Conversion Material (CCM)

ABSTRACT

We have designed and optimized the geometric parameters of metallic nanostructure with color conversion material as a color filter for white OLED display to enhance the optical efficiency. Optical intensity of red and green light in white OLED was increased by 73.0% and 29.1%, respectively after applying metallic nanostructure with quantum-dot materials.

1 INTRODUCTION

Metallic nanostructure has been considered as a color filter due to its characteristic of selective filtering in the visible spectrum range when it has periodic structural array. When periodical metallic nanostructural arrays are illuminated with light, complex mechanisms are involved in transmittance including localized surface plasmon resonance (LSPR), Wood's anomalies and Bloch wave surface plasmon polaritons [1]. By these mechanisms, metallic nanostructure can result in extraordinary optical transmission to be used as a color filter. So far, it has been studied to design and fabricate the optimum structure by controlling the geometric parameters such as shape, period and radius to realize best performance as a color filter in the visible spectral range [2-5]. However, it still shows a relatively lower optical transmittance and wider range of full width at half maximum (FWHD) compared to those of conventional pigment-based color filter. Meanwhile, a color conversion material (CCM) such as quantum dots (QD) is also studied to convert the unnecessary light to the necessary light at white organic light emitting diodes (WOLED) after matching the color range for the enhancement of optical efficiency in OLED or LCD displays. In previous report, new approach to improve the optical efficiency of white OLED display was proposed by applying the patterned QD film dispersed in photoresist (PR) [6].

The object of this research is to realize both performances of higher optical efficiency and color filtering function by applying metallic nanostructure and color conversion material together with white OLED, as shown in Fig. 1. White light can be firstly converted to the necessary color by color conversion material and secondly transmited through the metallic nanostructure. In this proposed structure, the reflected light from the metallic nanostructure such as blue light in the green and red color ranges can be recycled again in the color conversion material to enhance the intensity of green or red light. Therefore, we have proposed and designed new type of color filters based on metallic nanostructure and color conversion material for the white OLED display in this study.

2 DESIGN AND RESULT

We adjusted the various geometric parameters of metallic nanostructure such as period, radius, and shape to find the optimum structure with the consideration of color conversion material and white OLED display. Since the additional dielectric overlay with the same refractive index as that of substrate can result in the enhancement of spectral response in metallic nanostructure film [2], the thickness of additional layer was also considered as a variable parameter. Then, two metals of aluminum (Al) and silver (Ag) are considered and optimized as metallic nanostructure. Quantum dot was selected as the color conversion material, consisting of the patterned red QD film of 2 μm thickness and 30 wt% QDs with the peak wavelength of 620nm in red color and 20 wt%, 540 nm in green color, respectively. Figure 2 shows geometric parameters on metallic nanostructure (Fig, 2(a)) and type of structure (Fig, 2(b)) considered in this study. For the optimizing simulation tools, the finite-difference time-domain (FDTD) method and the LightTools software were basically conducted and analyzed, which was proposed and modified previously in our group [7]. The simulation process for the design and analysis of metallic nanostructure consists of three steps. First, the spectrum of white OLED with color conversion material was computed by LightTools to identify the target spectrum range which is related to the metallic nanostructure. Secondly, optimum metallic nanostructures were designed by adjusting the variable geometric parameters such as period, radius, and shape of structure as well as the thickness of additional layer using the FDTD method with the consideration of higher transmittance of necessary light and higher reflectance of unnecessary light. Lastly, the display characteristics with the application of white OLED device were simulated by LightTools. Figure 3 shows simulation results on the transmittance as a function of three parameters of metallic nanostructure, consisting of the period (Fig. 3(a)), the radius (Fig. 3(b)), and the thickness of additional layer (Fig. 3(c)). Based on the transmittance tendency on the geometric parameters of metallic nanostructure, we can decide the optimum structure for both the case for the red and green color ranges as well as the material of metal, Al and Ag.

Figure 4 shows the transmittance result on the optimized aluminum metallic nanostructure (Fig. 4(a)) and final optical intensity of white OLED applied with aluminum metallic nanostructure and color conversion material (Fig. 4(b)). In red color range, the metal nanostructure was optimized with the period of 300 nm, the radius of 130 nm and the thickness of additional layer of 50 nm. The shape of nanostructure was selected as dot-type. In green color range, the period of 300 nm, the radius of 93 nm, the thickness of additional layer of 110 nm and hole-type were selected as the optimum structure. Figure 4(b) also includes the spectrum of reference (conventional color filter) and the optimum structure with color conversion materials designed in this study based on white OLED display. With aluminum based nanostructure, final optical efficiency in the red and green range increases 73.0% and 29.1% compared to the reference, respectively. In case of silver metallic nanostructure, the structure of red color range was optimized with the period of 320 nm, the radius of 100 nm without additional layer as dot-type. In green color range, the period of 200 nm, the radius of 70 nm, and the thickness of additional layer of 120nm and hole-type were adopted as the optimized parameters. Final optical intensity in the red and green range increased 70.1% and 37.6% compared to the reference, respectively.

3 SUMMARY

A metallic nanostructure with color conversion material of quantum dots has been proposed and designed as a color filter for white OLED display. The proposed metallic nanostructure was optimized for the color conversion material of patterned quantum dot film. It showed an advantage for not only enhancement of optical efficiency but also introduction of new efficient color filter compare to the case of pigment-based color filter in the white OLED display. Actually, this enhancement comes from the fact that the unnecessary blue and green light from white OLED is effectively recycled to the color conversion material of patterned QD film by being reflected on the metallic nanostructure of color filter. Since our proposed white OLED structure with both patterned QD film and aluminum metallic nanostructure resulted in the enhanced optical intensity of 73.0% and 29.1% at red and green color range, respectively, the proposed new color filter configuration has high potential to be applied to many optoelectronic devices as well as the white OLED display.

ACKNOWLEDGMENTS

This work was supported by the research grant funded by LG Display.

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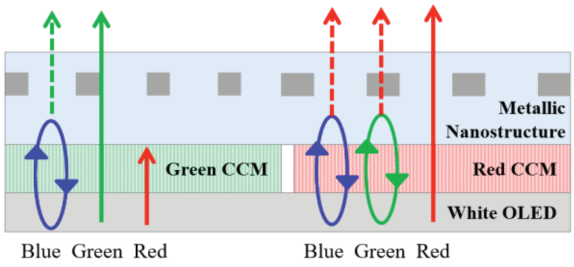

Fig. 1 Schematic illustration of the proposed new type of color filter consisting of metallic nanostructure and color conversion material with white OLED.

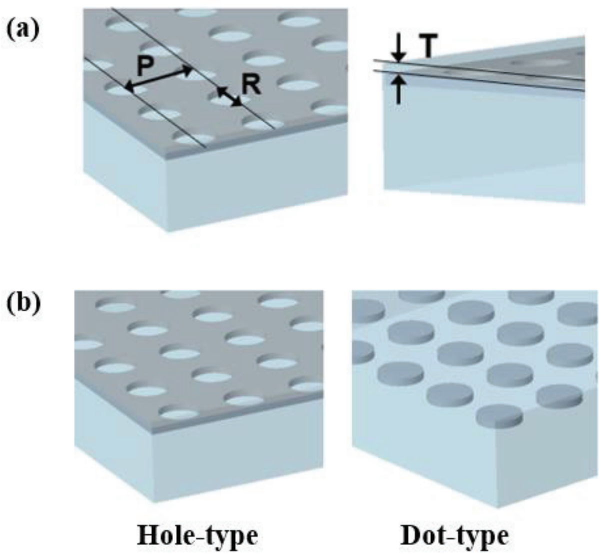

Fig. 2 Geometric parameters of metallic nanostructure

(a) Schematics on geometric parameters of the metallic nanostructure, P is period, R is radius and T is thickness of additional layer (b) two types of nanostructure of hole-type and dot-type,

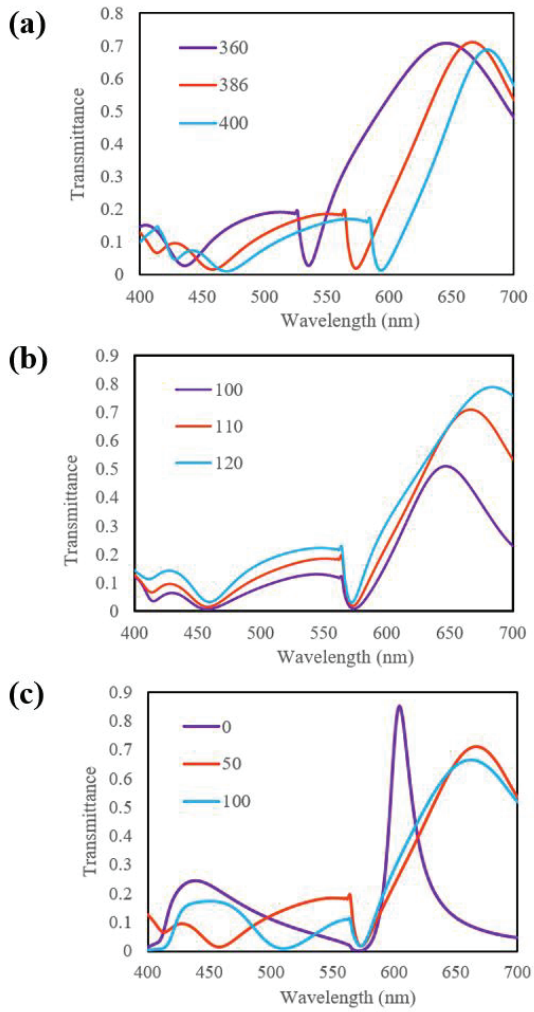

Fig. 3 Simulation results on transmittance

the simulation results on the transmittance as a function of geometric parameters of the metallic nanostructure including (a) the period at constant R,T (b) the radius at constant P,T and (c) the thickness of additional layer at constant P,R.

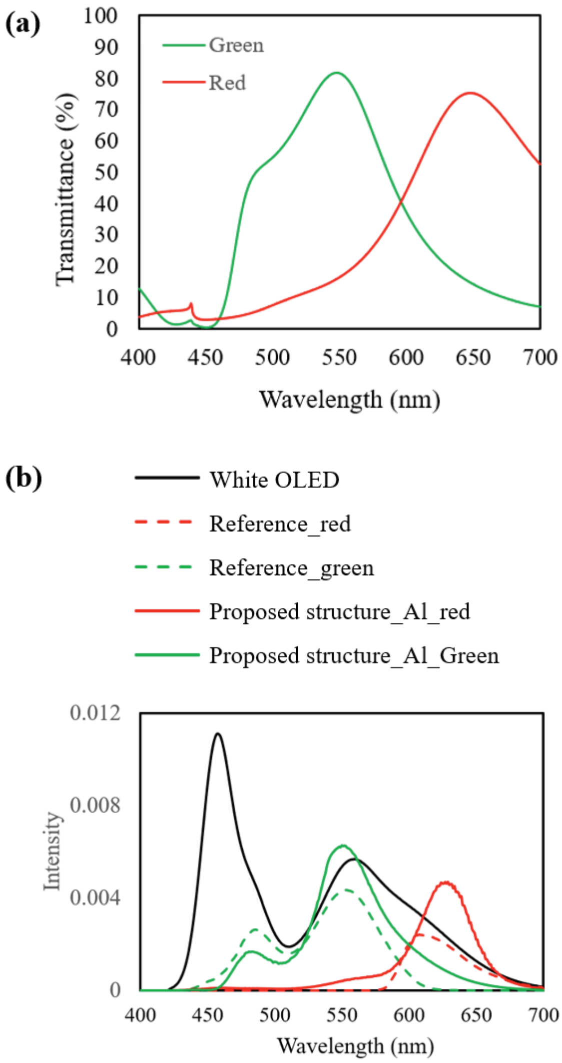

Fig. 4 Optical performance of metallic nanostructure based on aluminum

(a) Transmittance of optimized aluminum metallic nanostructure, and (b) final optical intensity of white OLED applied with aluminum metallic nanostructure and color conversion material (conventional color filters are also indicated as reference).