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Highly efficient White Organic Light Emitting Devices with a Binary Random Phase Array

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Abstract

We proposed a binary random phase array (BRPA) to improve the light extraction efficiency and suppress the angle dependent color difference of white organic light emitting devices (WOLEDs). We demonstrate that BRPAs generate diffuse-type diffraction, and that the diffraction properties can be controlled by employing diffraction optics to modify the structural parameters of the BRPA. Our measurement of dependence of light extraction performance on the parameters of the BRPA applied to the OLED surface shows that the light extraction features arise from the scattering properties of the BRPA.

1. Introduction

White organic light emitting diodes (WOLEDs) have shown potential as next generation lightings. While the high internal quantum efficiency of the WOLED is demonstrated [1], the light extraction efficiency is low because the light is trapped by total internal reflections at the interfaces of the layers with different refractive indices: an organic layer (n = 1.7-2.0), a glass substrate (n = 1.5), and air (n = 1.0). Furthermore, since the emitted light interferes with the reflected light by a metal electrode, the angular intensity distribution of emission depends closely on wavelength. This results in the angular dependent color change, which is undesirable when we apply WOLEDs to general lightings.

Here we propose a binary random phase array (BRPA) to improve the light extraction efficiency and suppress the angular dependent color change. We demonstrate that the BRPA generates diffuse-type diffraction, and the diffraction angle and the diffraction efficiency can be controlled independently by the design parameters [2]. The dependence of light extraction performance on the parameters of a BRPA applied to the WOLED clarifies that the light extraction effects are caused by the scattering properties of the BRPA.

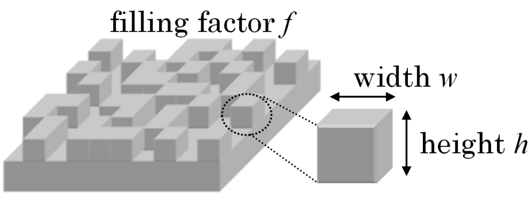

Fig1 A schematic of a BRPA.

2. Design rules and characteristic of BRPAs

A BRPA is a binary random structure where transparent units with a size comparable to the wavelength are randomly arranged on a regular grid, as depicted in Figure 1(a). The design parameters of the BRPA are width w, height h, and filling factor f.

To confirm that the optical characteristic of the BRPA is consistent with diffraction optics, we focus on the transmission profiles of the BRPA. According to scalar diffraction theory, the diffraction profiles of the randomly arranged apertures are approximated to that of the individual aperture [3]. Since the BRPA is equivalent to the randomly arranged square phase masks, the diffraction profiles of the BRPA should similar to that of the single square aperture. Figure 2(a) shows the transmission profiles of a He-Ne laser at normal incidence through the BRPA with (w, h, f) = (1.0μm, 0.6 μm, 0.5). The diffuse-type diffraction and the zeroth-order component can be seen in the profile. The diffuse-type diffraction agrees with the calculated profiles of the single aperture with the width of 1.0 μm as shown in Fig. 2(b). We also confirmed that the diffraction angle can be changed in accordance with the width w of the BRPA, which agrees with the theory.

Next, we investigate the parameter dependency of

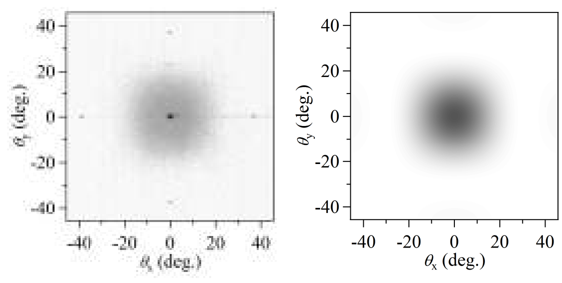

Fig2 (a) Measured and (b) calculated profiles of transmitted light diffracted by a BRPA.

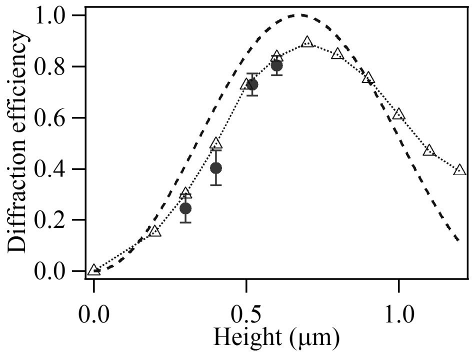

Fig3 Measured and calculated diffraction efficiencies of the BRPA for various heights with (w, f) = (0.6 μm, 0.5).

diffraction efficiency of the BRPA. According to scalar diffraction theory, the diffraction efficiency changes with the optical length. Thus, the diffraction efficiency of the BRPA should be controlled with the height h. To obtain the diffraction efficiency from the measured transmission profile, we separate the zero-order and the diffusing component by fitting the profile with a function predicted by the theory. Figure 3 shows the measured (closed circle) and calculated diffraction efficiency from scalar diffraction theory (dashed line) and B-BPM [4] (open triangles) for various heights with (w, f) = (0.6 μm, 0.5). The prediction using B-BPM shows better agreement with the measurement. Since the width w and the height h of the BRPA can

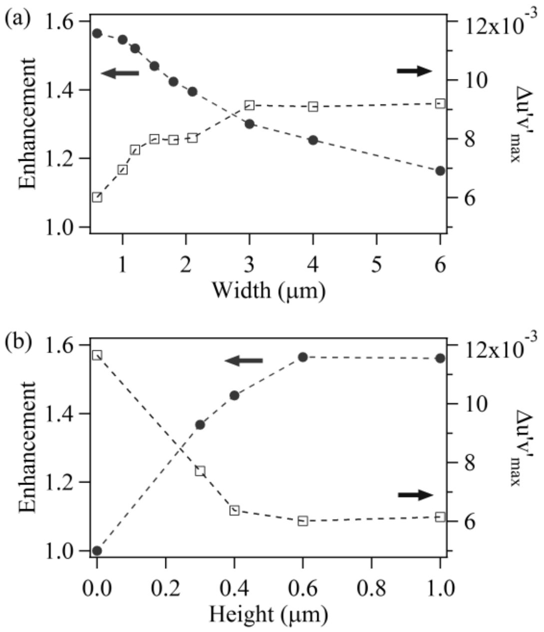

Fig4 Enhancement of measured extraction efficiencies (left axis) and color differences (right axis) (a) with variation in width with (h, f) = (0.6 μm, 0.5) and (b) with variation in height with (w, f) = (0.6 μm, 0.5).

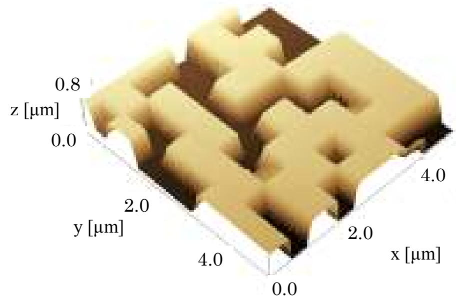

Fig5 AFM image of the imprinted BRPA.

be changed independently, we can realize desired combination of the diffraction efficiency and the diffraction angle of the BPRA.

3. Light extraction performance of WOLED with BRPA

We investigate the effect of the diffraction efficiency and the diffraction angle on the light extraction efficiency and color difference of WOLEDs by applying the BRPA to the surface of the glass substrate of the WOLED. Figure 4(a) and (b) show the enhancement of extraction and the maximum color difference $\Delta u'v'_{max}$ for various widths with (h, f) = (0.6μm, 0.5) and for various heights with (w, f) = (0.6μm, 0.5), respectively. These results indicate that the wider angle scattering at smaller width w and the higher diffraction efficiency at larger height h contribute the improvement of light extraction and the suppression of the angler dependent color difference.

4. Preparation of BRPA by nanoimprint lithography

To provide the BRPA at low-cost, we are developing a nanoimprint lithography (NIL) process. Our NIL process was carried out in three steps: (i) An UV curing resist was coated on a PET film; (ii) a mold was pressed to the film; and (iii) UV light was irradiated to the resist through a PET film. Figure 5 shows the height of the imprinted BRPA. We confirm that the structure of the BRPA on the PET film is successfully imprinted and shows the same light extraction performance.

5. Conclusions

We developed a BRPA to improve the light extraction performance of WOLEDs. We showed that the light scattering properties of the BRPA can be controlled by the design parameters. We demonstrate the improvement of light extraction applying the BRPA on the surface of WOLEDs. The BRPA is also suitable for the light extraction of a waveguide mode trapped in the organic layer of WOLEDs.

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