Development of High Refractive Index Materials Including Nanofiller and Having Light Extraction and Gapfill Property Expected to Be Applied to AR/VR

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ABSTRACT

Organic-inorganic HRI materials 2.3 times improved the luminance of OLED by stacking HRI materials layer which is made by inkjet and exposure process. Moreover HRI materials were embedded into uneven structures by using small filler. These properties are expected to optical control of OLED and application of AR/VR.

1 Introduction

Recently, high refractive index (HRI) materials are needed to achieve high performance in the display fields. OLEDs light conversion efficiency is lower than 20%, because OLED is chemiluminescence and optically isotropic materials. [1][2] Thus, it is important to increase light extraction efficiency to improve energy efficiency. One of approaches to improve is that HRI optical control layer introduces to the OLED device. In general, stacking of different refractive index layer is used for optical control. [3] Particularly, uneven structure is investigated for further improvement of light extraction efficiency for OLED and AR/VR. Therefore, HRI materials are desired to be curable ink solution having gapfilling property to such uneven structure. [4] Here, we report on the HRI materials including inorganic nanoparticles (~10 nm) to increase light extraction efficiency and to achieve gapfill into trench pattern.

2 Experiment

2.1 Improvement of light extraction efficiency

For increasing light extraction efficiency, we optimized photocurable HRI ink including metal oxide nano filler to form HRI optical control layer on the OLED device. The composition consists of zirconia (ZrO_2) particles having HRI property, photo reactive acrylic monomers, and reaction initiators. Liquid monomers or solvents can be selected as a solvent-free or a dilution system, depending on the application such as the necessity of a heating step. We simulated the appropriate thickness of HRI ink layer which stacks on top emission OLED device（Fig.1）

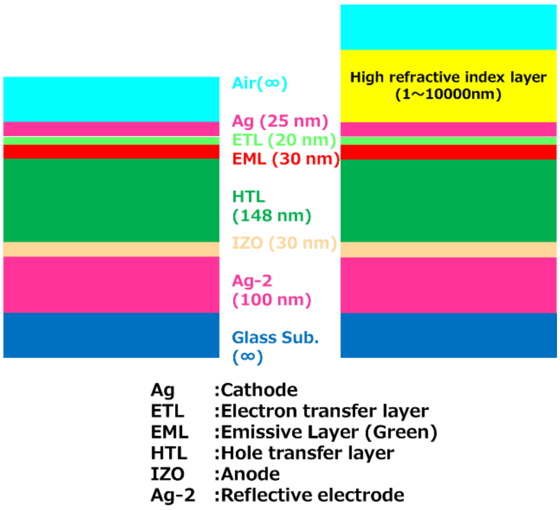


Fig. 1. OLED device models without HRI layer (left) and with HRI layer (right) for the simulation.

Based on the thickness simulation, we made OLED device with structure showed in Fig.2. We print "TOK" characters by inkjet and exposure process of the HRI ink on OLED device and confirm to improve light emission efficiency.

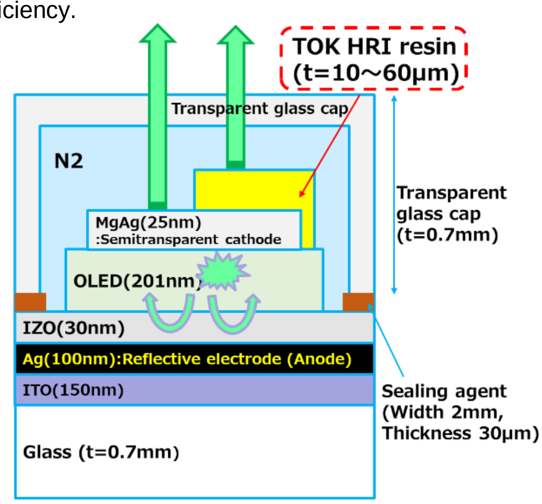


Fig. 2. OLED device structure.

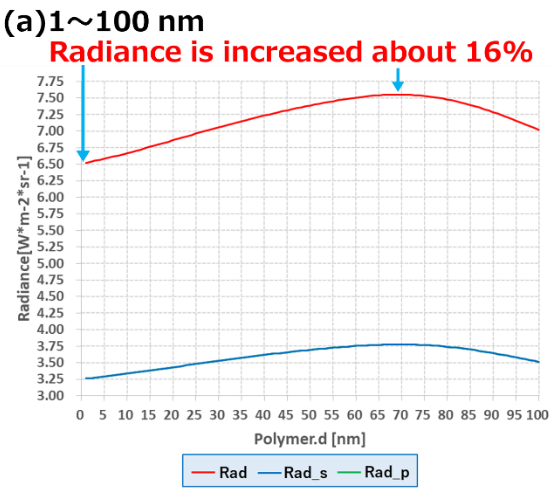
2.2 Gapfill

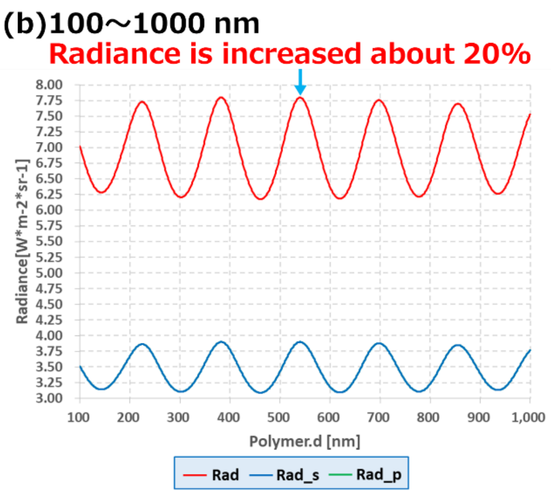
Uneven pattern of display applications is categorized as trench pattern, diffractive optical elements (DOE) and lens shape. [5] Among them, we confirmed gapfill property of HRI ink materials for the trench pattern. In order to fill HRI materials into fine uneven structure, nano filler size is needed small enough for pitch size of trench. We examined ZrO_2 and titania (TiO_2, anatase) nano filler of size about 10 nm for gapfill pattern of lower than 100nm.

3 Results

3.1 Improvement of light extraction efficiency

The simulation of thickness of HRI ink layer is shown in Fig.3. Rad_s (blue line) and Rad_p (green line, overlapped on rad_s) indicate radiation of s-polarized and p-polarized light respectively. Rad (red line) is total radiation, derived from the summation of the two polarized lights. The simulation shows large swinging brightness due to optical interference below 1µm. Film thickness of 5 µm or more is required to obtain stable brightness.





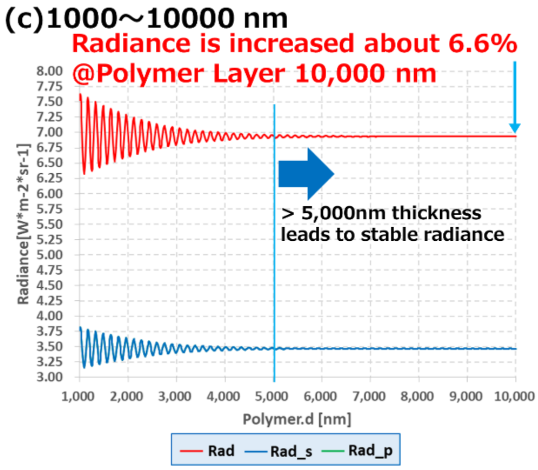


Fig. 3. Simulated radiance of (a) 1~100 nm; (b) 100~1000 nm, (c) 1000~10000 nm thickness of HRI ink layer. (Red line is total radiation. Blue and green line indicate radiation of s-polarized and p-polarized light respectively.)

Fig.4 shows an image of actually emission of the OLED device in which the characters TOK are printed by HRI ink with 10 um thickness. It is found that emission brightness of printed area is higher than that without layer. The current luminance efficiency increased 1.6 times compared to the one without the HRI film.

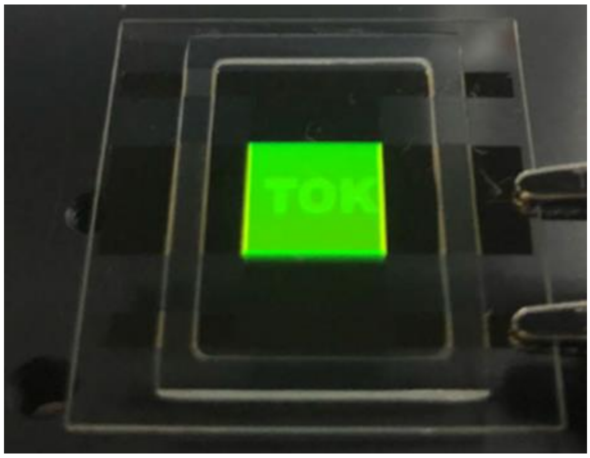


Fig. 4. Emission of the OLED device in which the characters TOK are printed by HRI ink.

We measured luminance with changing film thickness (15 µm, 30 µm, and 60 µm) of HRI material with OLED device of Fig2 structure.(Fig.5) The current luminance efficiency of the 30 µm film thickness was 2.3 times higher than that without the HRI material layer, which was the highest result.

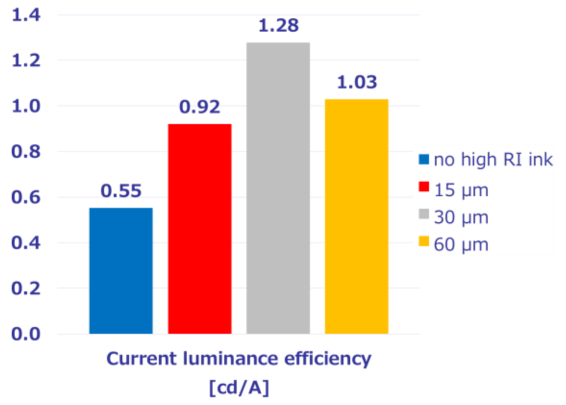


Fig. 5. Current luminance efficiency when changing film thickness of HRI material.

3.2 Gapfill

Fig.6 shows SEM image about gapfill. Both ZrO_2 and TiO_2 nano filler is embedded into trench pattern in Fig.6 (a) and (b), respectively.

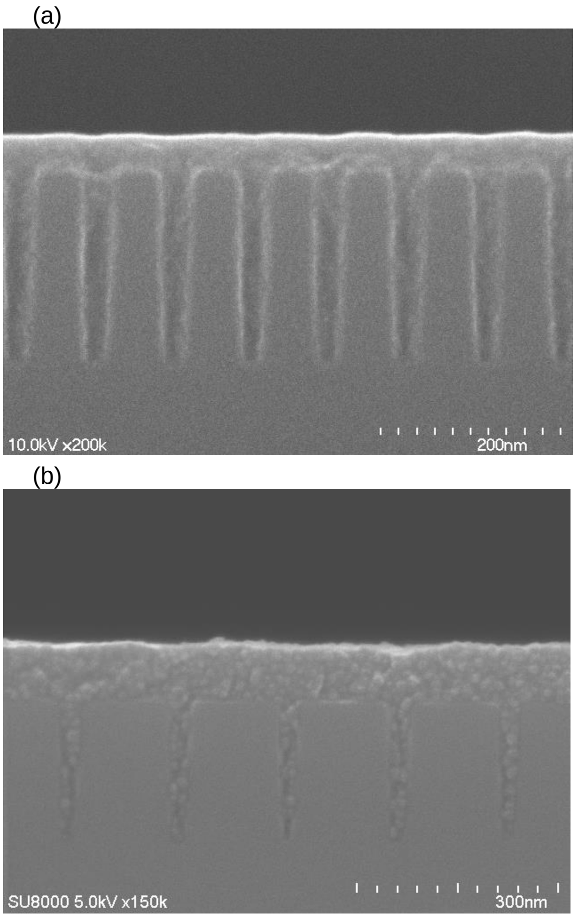


Fig. 6. SEM image about gapfill. (a)ZrO_2 nano filler (b)TiO_2 nano filler

4 Conclusions

HRI materials are used to improve the optical properties of display devices. We reported the case studies of two applications of organic-inorganic hybrid HRI materials using nano filler (~10 nm). The first was to improve the luminance of the OLED. it was confirmed that the light emitting luminance of the device by stacking HRI materials layer which is made inkjet process and exposure process. The second is filling to uneven structures, and by using small filler, we realized filling to nano-sized trench patterns. These properties are expected to optical control of OLED and application of AR/VR.

References

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