Light Extraction and Viewing Angle Characteristics of Nano-structure embedded Top-emitting OLEDs fabricated by Vacuum Deposition Processes

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ABSTRACT

We fabricated the nano-structure applicable for a highly efficient and color stable TEOLED by using thermal evaporation and organic vapor phase deposition, respectively. The nano-structure integrated TEOLEDs showed efficiency increase by 12% (thermal evaporation) and 32% (OVPD), respectively. The Δ(u'v') from normal direction to 30º were 0.06 and 0.03, respectively.

1 INTRODUCTION

Flexible organic light emitting diode (OLED) panels may provide designers innovative designs of displays and lightings.[1] But the performance and the price of the panels are not satisfactory yet. Light extraction can be a key technology as a realization method for OLED with high power efficiency. Many light extraction technologies for bottom-emitting OLEDs have been announced, but those for top-emitting OLEDs (TEOLEDs) are scarcely proposed. Generally, TEOLEDs better fit to display applications,[2] and most flexible AMOLED displays consist of TEOLEDs at this time. However, we don't have any stable light extraction technology for the TEOLEDs except for micro-cavity method. The micro-cavity method has several issues such as viewing angle characteristics and spectrum narrowing. Therefore, by using a highly compatible process with OLED industries, fabrication of a nano-structure that combines the functions of light extraction and scattering are needed to improve optical properties of TEOLEDs. Up to date most of vacuum deposition equipment for OLEDs has been developed to fabricate the planar film, thus embossed structures are difficult to fabricate by those equipment. In this paper, we propose the nano-structure fabrication for a highly efficient and color stable TEOLED by using the vacuum deposition process. We have recently reported the nano-lens fabrication by OVPD. To increase the importance of the nano-structure technology, it is necessary to extend the kinds of the vacuum process from OVPD to thermal evaporation because thermal evaporation is widely used in OLED industries. To our best knowledge, the evaporation process for the nano-structure fabrication is firstly reported in this work. Furthermore, the nano-structure shape dependence on process parameters and the effects of two nano-structures fabricated by thermal evaporation and OVPD, respectively, on TEOLEDs are investigated.

2 EXPERIMENT

We set up the thermal evaporator and the OVPD equipment for the organic nano-structures. The thermal evaporator consists of a vacuum chamber, an inside vaporizer(Ti crucible with heater), a temperature controller, and a vacuum pump. The OVPD equipment consists of a vacuum chamber, an outside vaporizer(Ti crucible with heater), a temperature controller, a vacuum pump, a carrier gas supplier, and line heaters. The base pressure of both system was low 10^{-2} Torr. We examined several organic materials for the nano-structure fabrication. The proper materials for thermal evaporation and OVPD were different. Therefore, the nano-structures of thermal evaporation and OVPD were composed of different organic materials which are easily vaporized in each systems. They were evaporated at 150-200ºC in the thermal evaporation and 300-360ºC in the OVPD. We fabricated TEOLED devices with Al_2O_3 encapsulation for the nano-structure integration. Fig. 1 shows the nao-structure integrated TEOLED devices.

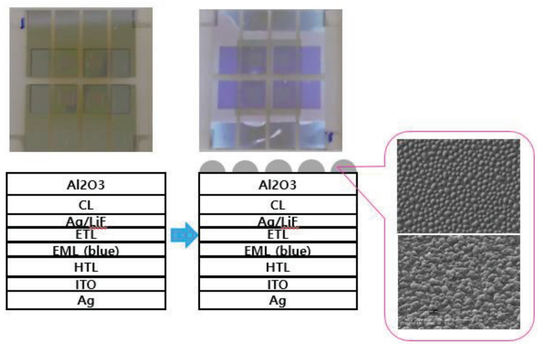


Fig. 1 Schematic diagram of the nano-structure integrated TEOLED

The OLED stack and cathode were deposited by a thermal evaporation method in a high-vacuum chamber below 5 × 10^{-7} Torr, and the Al_2O_3 thin films were deposited by an ALD process. The current-voltage (I-V) characteristics of the OLED devices were measured using a Keithley 238 source-measure unit, and the luminance (L) and electroluminescence (EL) spectra were examined using a Konica Minolta spectroradiometer (Model CS-2000).

3 RESULTS and DISCUSSION

We developed the fabrication processes for the nano-structures on a TEOLED with thermal evaporation method and organic vapor phase deposition (OVPD) method, respectively. We didn't use the post-process and masks that can deteriorate the OLED layers.

The thermal evaporation and OVPD methods are safe and suitable for TEOLED because they are vacuum processes and don't damage the OLED devices. Both are usually used in OLED manufacturing systems up to now. Fig. 2 shows SEM images of nano-structures made by the thermal evaporation and the OVPD processes on a glass, respectively. The nano-structures of thermal evaporation and OVPD were composed of different organic materials which are easily vaporized in vacuum. The OVPD process used nitrogen carrier gas, but the thermal evaporation process did not use any carrier gas. The shape of the nano-structure was irregular and the size was between 150-700 nm in the case of thermal evaporation. The shape of the nano-structure was embossed lens and the size was 200-600 nm in the case of OVPD. Fig. 3 shows SEM images of nano-structures made by the thermal evaporation and the OVPD processes on Al_2O_3 thin films, respectively. The shapes of the nano-structures were

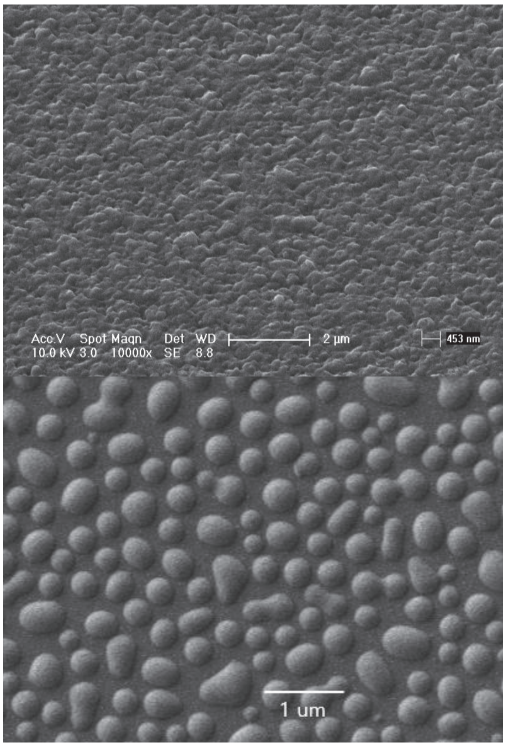


Fig. 2 The nano-structure on glass made by thermal evaporation (upper) and OVPD (lower)

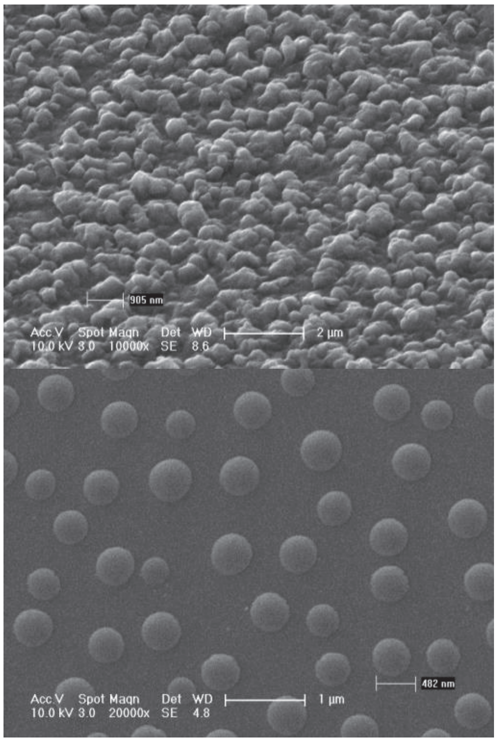


Fig. 3 The nano-structure on Al_2O_3 made by thermal evaporation (upper) and OVPD (lower)

similar to those on the glass, but size of them was enlarged in both cases. The sizes of nano-structures are proper for the light extraction and scattering of visible light in all cases. The We examined various process parameters including evaporation temperature, time, and source/shower head-substrate distance, etc. The size and height can be controlled by evaporation temperature, deposition time, and the source/shower head-substrate. The carrier gas flow rate was also important factor in the case of OVPD. We could fabricate the nano-structures on a glass, ITO, Al_2O_3, silver, and even on several organic layers. In some cases, particular surface treatments changing the surface energy were required. The size and shape changes are supposed to come from surface energy difference of each substrate and organic material, deposition rate of the organic material.

We integrated these nano-structure on TEOLED devices encapsulated with Al_2O_3 thin films (NS-TEOLED), and measured their electro-optical characteristics. Fig. 4 shows J-V-L characteristics of the NS-TEOLEDS. The electrical characteristics including leakage current were scarcely changed in both cases. This indicates that the nano-structure integration process (thermal evaporation and OVPD) didn't damage to OLED devices. Fig. 5 shows current efficiencies of the NS-TEOLEDS. The efficiencies increased by 12% (thermal evaporation: 7.9 → 8.9 cd/A) and 32% (OVPD: 7.1 → 9.4 cd/A) at 1000 nit compared to the reference devices (without nano-structure), respectively.

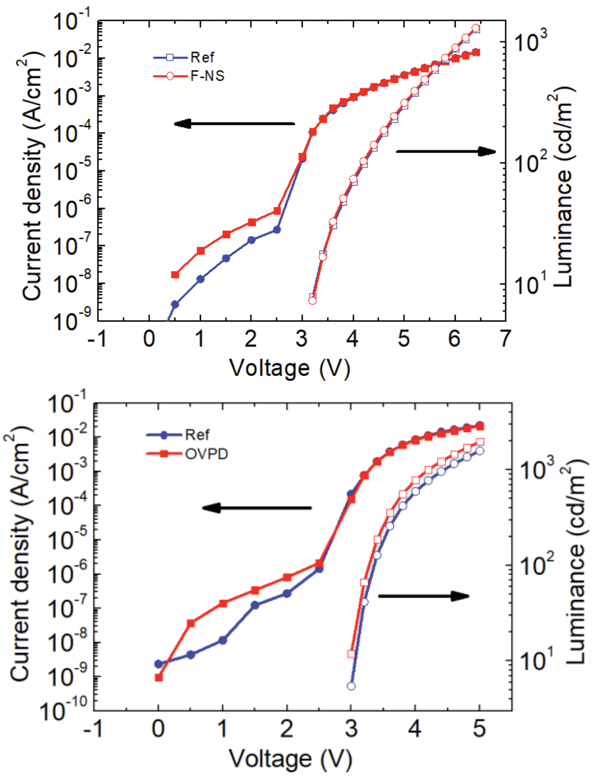


Fig. 4 J-V-L characteristics of NS-TEOLEDs made by thermal evaporation (upper) and OVPD (lower)

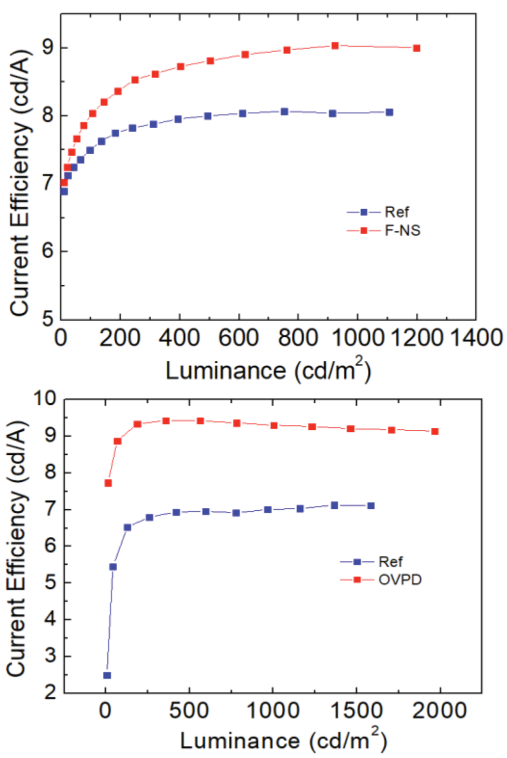


Fig. 5 Current efficiencies of NS-TEOLEDs made by thermal evaporation (upper) and OVPD (lower)

Light extraction enhancement by the nano-structures of the OVPD device was larger than that of the thermal evaporation device, that is, the scattering power of the nano-structures fabricated by OVPD (nano-lens type island structure) were more effective for light extraction than those fabricated by thermal evaporation (continuously roughened surface).

Fig. 6 and 7 show EL spectra changes of the NS-TEOLEDS and reference device (without nano-structures) depending on viewing angle. The peak wavelength shift with viewing angle of the NS-TEOLED was significantly reduced compared to the reference device in both cases, but the OVPD case was more remarkable.

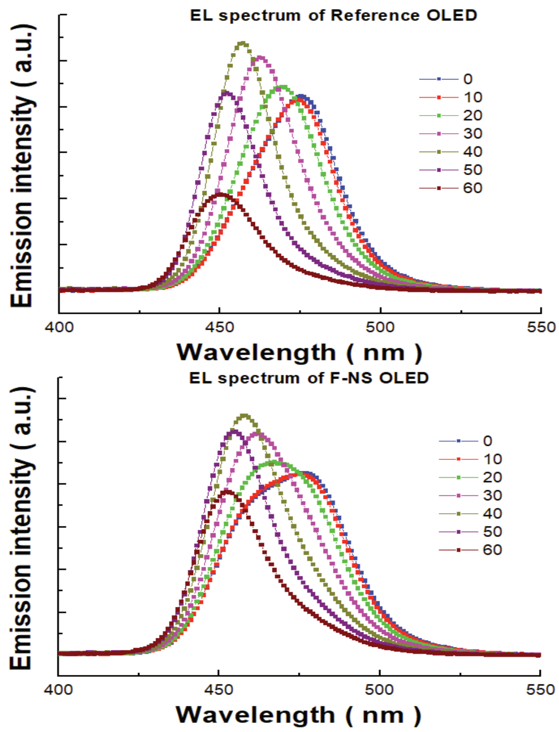
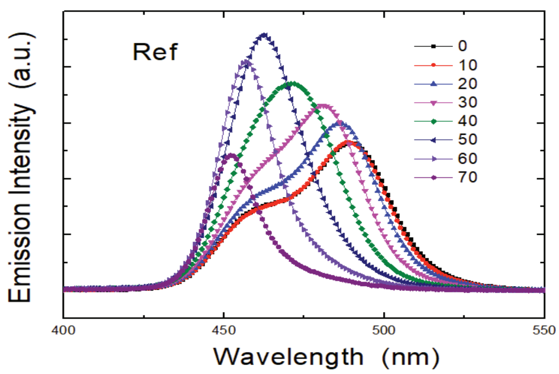


Fig. 6 EL spectra changes with viewing angle of reference TEOLED (upper) and NS-TEOLEDs made by thermal evaporation (lower)



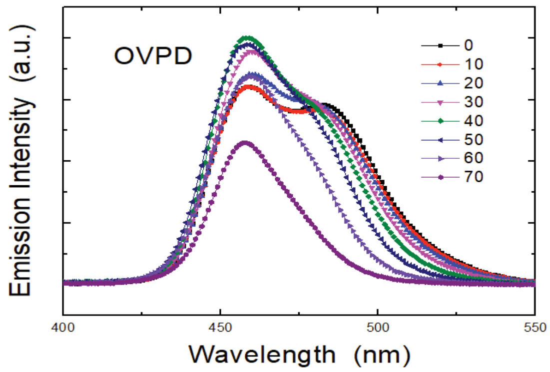


Fig. 7 EL spectra changes with viewing angle of reference TEOLED (upper) and NS-TEOLEDs made by OVPD (lower)

The chromaticity coordinate shifts (Δ(u'v')) from normal direction to 30° were greatly reduced in the nano-structure combined devices (reference: 0.09; thermal evaporation: 0.06; OVPD: 0.03), indicating that nano-structures enhanced the light extraction efficiencies as well as viewing angle characteristics. The nano-lenses by OVPD were more effective for color shift problem than the roughened surface by thermal evaporation due to their scattering power as before.

4 CONCLUSIONS

We successfully fabricated the nano-structures applicable for a highly efficient and color stable TEOLED by using thermal evaporation and OVPD. The manufacturing process for the nano-structures did not damage the OLED devices. The nano-lenses by OVPD were more effective for light extraction and color shift problem than the roughened surface by thermal evaporation due to their scattering power. Most commercial OLED displays are top-emitting type. TEOLEDs are obliged to have relatively strong micro-cavity effect, therefore they have viewing angle problems and limitation of efficiency improvement. Our nano-structures can solve those problems, and will assist the large-size TEOLED display commercialization.

REFERENCES

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