Analysis of Undulated Micro-cavity in Organic Light-emitting Diodes

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Abstract – **We investigate the internal physical mechanisms of undulated micro-cavity that controls the emission wavelength in organic light-emitting diodes (OLEDs). Finite-difference-domain method is applied to a previously manufactured OLED design featuring optical structure on a wavy over-coat layer. The emission spectrum of dipole oscillation is calculated with various amplitudes of undulation and emission angles.**

I. INTRODUCTION

Organic light-emitting diodes (OLEDs) exhibit several advantages over other types of flat panel displays, including higher wall plug efficiency, faster response time, and thinner thickness. For full-color active-matrix organic light-emitting diodes (AMOLEDs), the thermal evaporation through a shadow mask is the method chosen by many manufacturers. Since the method has a limitation in terms of the size of substrate, the combination of white OLED with color filters (CFs) has been proposed for television (TV) applications. Samsung Electronics demonstrated a prototype of 40-in AMOLED TV in 2005 [1].

The white OLED with CF has cost advantages due to less usage of electroluminescent (EL) material and higher yield. The disadvantages of this approaches is lower efficiency coming from the absorption by the CF and a narrower color gamut. The first issue is solved by the use of RGBW color system[2]. Moreover, for large displays connected to wall plug power, the energy efficiency may not be important only if it falls below a certain level. However, the narrow color gamut can be more critical issue in the marketplace. The authors reported two optical designs of the AMOLED panel incorporating micro-cavity [3]. The designs enable more than 100% color gamut and 50% higher transmission through the RGB CFs. In spite of experimental success, the design procedure is not fully illustrated in the previous report. It is because the undulated micro-cavity requires two or three dimensional analysis while the first design depends on one dimensional analysis such as transfer matrix method. In general, the two dimensional micro-cavity refers to the cavity formation in two directions. However, the undulated micro-cavity is regarding the optical confinement in one direction with non-flat guiding structure in another direction. From the theoretical viewpoint, such structure is not familiar to most designers. In this paper, we analyzed the wavy micro-cavity using finite-difference-time-domain (FDTD) method. The simulation exhibits how the undulated cavity modifies the emission spectra.

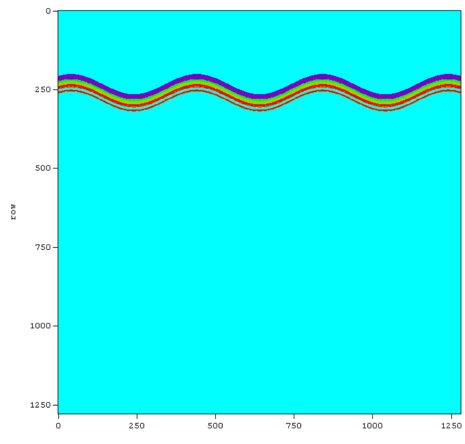

Fig. 1: Permittivity profile of undulated micro-cavity in OLEDs. Period = 5.0 μm, height = 0.6 μm.

II. DEVICE DESIGN

Figure 1 shows the permittivity profile of the device used in the simulation. In this structure, the micro-cavity largely consists of the organic layers sandwiched between distributed Bragg reflector (DBR) and a cathode. From the bottom-most layer, DBR layers are comprised of 70 nm SiN_x, 90 nm SiO_2, 35 nm SiN_x, 90 nm indium zinc oxide (IZO). The organic layers are 120 nm hole transport layer, 50 nm emission layer, 30 nm electron transport layer. Lastly, the thickness of Aluminum cathode is 200 nm on the top. The region below DBR is assumed to be filled with over-coat (OC) layer. The undulation profile of OC layer is made by photolithography and reflow process. The height of undulation is controlled by the ultra-violet (UV) exposure time while the period is determined by the spacing of mask pattern. The other OLED layers are coated on the undulated profile of OC layer.

The main purpose of the undulated micro-cavity is to modify spectrum with the change of undulation profile. For a fixed exposure time, the slope of undulation depends on the period. Since the period of mask pattern can be set to different values for RGB pixels, the resonance frequency of each pixel can be tuned simultaneously by one step photolithography. It

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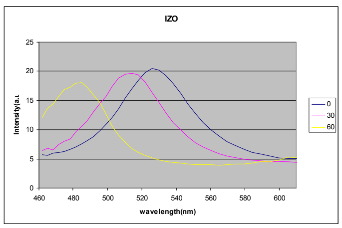
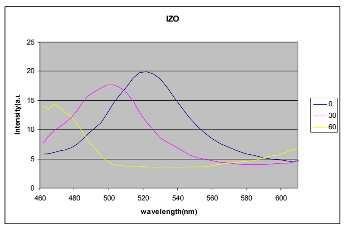
greatly alleviates the processing burden which typically comes with the micro-cavity device for multi-colors.

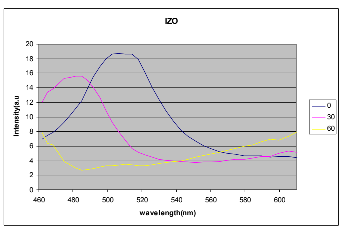
In order to measure the spectrum change, dipole is allowed to oscillate for short time. Since the short pulse acts as a broad band source, it can be a good light source to characterize the frequency response of micro-cavity. The detector apart from the dipole source collects the wave emitted at a certain angle. The Fourier transformed output of the collected wave is divided by the Fourier transformed input to give frequency response at each wavelength. In this way, the spectrum change of micro-cavity can be analyzed.



(a)



(b)



(c)

Fig. 2: Spectrum of dipole emission in undulated micro-cavity with various heights and emission angle; Period = 5.0 μm, height = (a) 0.0 mm, (b) 0.2 μm, and (c) 0.4 μm.

III. SIMULATION AND RESULTS

When the dipole is placed in the middle of the slope of undulation profile, the spectrum shows blue shifts as the height increases as seen in Fig. 2. It agrees well with the experimental results observed in the real device [3]. The dipole is placed in the middle of the slope since the slope region is the brightest part of the device. Thermal evaporation of organic material results in uniform thickness in vertical direction. It means that the thickness normal to the surface is the smallest near the slope. The reduced thickness of organic layers also reduced the electrical resistance in the part, which leads to the current crowding near slope. Therefore, locating dipole in the middle of slope is reasonable to explain the blue shift of the spectrum. Otherwise, the dipole oscillation near peak or valley gives less change to the resonance peak. The resonance peak at normal angle shifts from 525 nm to 510 nm when the height changes from 0.0 μm to 0.4 μm. Since the angle of the slope is roughly 9 degrees at the height of 0.4 μm, the amount of blue shift may be explained by $\cos^2\theta$ dependence. This angle dependency can be ascribed to the layer thinning due to the slated evaporation and oblique resonance condition, each of which has $\cos\theta$ dependency.

IV. CONCLUSION

We investigate the internal physical mechanisms of undulated micro-cavity that controls the emission wavelength in organic light-emitting diodes (OLEDs). Finite-difference-domain method is applied to a previously manufactured OLED design featuring optical structure on a wavy over-coat layer. The emission spectrum shows blue shift of 15 nm when the height of undulation changes from 0.0 μm to 0.4 μm with the period fixed at 5.0 μm. The blue shift is also observed in the experiment and the amount of shift in the simulation complies with $\cos^2\theta$ dependence.

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REFERENCES

[1] K. Chung, J. M. Huh, U. C. Sung, C. C. Chai, J. H. Lee, H. Kim, S. P. Lee, J. C. Goh S. K. Park, C. S. Ko, B. S. Koh, K. J. Shin, J. H. Choi, J.H. Jung, and N.D. Kim, "Development of 40-in. full color AMOLED display," *IMID Symposium Digest 5*, 781 (2005).

[2] B-W. Lee, K. Song, Y. Yang, C. Park, J. Oh, C. Chai, J. Choi, N. Roh, M. Hong, K. Chung, S. Lee, and C. Kim, "Implementation of RGBW color system in TFT-LCDs," *SID Symposium Digest* 35, 111 (2004).

[3] Baek-woon Lee, Young-gu Ju, Young In Hwang, Hae-yeon Lee, Chi Woo Kim, Jin Seok Lee, and Jun Hyung Souk, "Micro-cavity design of bottom-emitting AMOLED with white OLED and RGBW color filters for 100% color gamut", *Journal of the Society for Information Display*, Vol. 17, Issue 2, pp. 151-157 (2009)