Optical Simulation for Transparent and Top Emission PLEDs to Optimize the Metal/ITO Cathode

***Yao-Chou Tsai*[a]*, Chen-Chun Chen*[a]*, Kou-Chen Liu*[a]*, Yung-Ting Chang*[b] *,and Jiun-Haw Lee*[b]**

[a]Graduate Institute of Electro-Optical Engineering, Chang Gung University, Kwei-Shan, Tao-Yuan, Taiwan, 333, R.O.C

[b] Graduate Institute of Electro-Optical Engineering, National Taiwan University, Taipei, Taiwan, R.O.C.

Phone: 886-3-2118800 ext : 3152 , E-mail: jacobliu@mail.cgu.edu.tw

Abstract

A simulation method has been purposed in this paper to optimize the stack structure of metal/ITO cathode for full transparent or top emission devices. The result demonstrates that the complexity of the two proper layers thicknesses design is reduced. Finally, the experiment data also strain the simulation result.

1. Objectives and Background

Full transparent or top-emitting PLEDs attract great interesting due to its application for helmet-mounted display or integration with silicon-based driver display. To get high efficiency full transparent or top-emitting PLEDs, cathode design is one of key issue. Carrier balance and light output-coupling have to be considered at the same time. Typically, thermal deposited thin semi-transparent metal as cathode is used to satisfy this requirement, but transmittance is dramatic decreasing as the metal thickness increasing. Therefore, many group reported using transparent conduct oxide (TCO) stacked with a thin metal as a cathode for full transparent and top-emitting devices [1]. In this paper we study the PLEDs performance using TCO stacked with an ultra-thin metal (1, 3, 5 nm) which is enough to resist the sputtering damage and has very high transmittance > 85. The ultra-thin Ag, Au, and Al metal were chosen for their optical property analysis [2]. Difference metal thickness from 1 to 20nm and changing indium tin oxide (ITO) thickness which serves as capping layer for optical property are simulated to understand how the thickness variations influence the optical performance. The trend of simulation results are consistence of our experimental results.

2. Experiment

The experiment has been done for comparing with the result of simulation, we prepared top emission PLEDs. Polymer layers were deposited by spin coater onto a glass substrate coated with a patterned indium-tin-oxide (ITO) electrode. A hole injection layer PEDOT:PSS was spin coated onto ITO glass substrate and baked in atmosphere at 120℃ for 15min. Next, the active luminescent polymer film PFO was spin coated onto PEDOT:PSS layer, and baked in glove box at 120℃ for 30 min. Thereafter, the samples were transferred into thermal evaporation chamber that evaporated Ag interlayer (1nm). Then, the ITO cathode was deposited by dc-sputtering 50 W at room temperature (~ 120 nm). Then the reference device passivated with glass lid that a thin UV-curable resin was applied from a syringe around the edge of the glass adhesively and exposed to UV light 120 seconds. Measurements were carried out at room temperature under atmosphere.

2. Results and discussion

Fig. 1 shows simulated electroluminescence (EL) intensities of devices (metal 3 nm/ITO 120 nm) with different metals of silver (Ag), gold (Au), and aluminum (Al). The device with silver film shows better optical performance than that of the other two devices. From Fig. 2, the transmittance data (the transmittance of Ag and Au is very similar) of different metal seem simply consistent with the result of Fig. 1. From this result, the silver film is thought to be the better choice for the ultra-thin metal film than the other metals when only the optical property is considered. Therefore, the optimum thickness of Ag and ITO were analyzed in Fig. 3. The ITO thickness is fixed at 120 nm, and the Ag thicknesses are changed from 0 to 20 nm. The EL intensity is slightly decreased in the range of 1~5 nm-thick, and sharply drop as the silver film is thicker than 10 nm. This result implies that the proper thickness of the Ag film is around 1~5 nm.

The experiment has also been proceeded base on the simulation result. Figure 4 shows the experiment data of the full transparent devices with different Ag thicknesses. The experiment data shows the similar tendency of optical property to the simulation result. It indicates that this simulation method is reliable to analyze the optical characteristic for the devices. Such thin Ag film causes the high sheet resistance. Therefore, adding additional ITO layer onto Ag layer can attain the lower sheet resistance. Furthermore, ITO layer acted as a capping layer helps index matching. Figure 5 shows the EL spectrum of devices with various thicknesses of ITO and the thickness of Ag is fixed at 5 nm. The devices with different ITO thicknesses perform the similar shape of spectrum but the peak wavelength of the emission spectrum shifts slightly. In addition, the EL intensity varies with different ITO thicknesses in three regions. At the first region, the intensity decreases with the increasing ITO thickness in the range from 40nm to 120nm. Then, it increases in the range from 120nm to 180nm. At the last region, the intensity decreases again in the range of 200nm to 300nm. For the particular application of full transparent PLEDs which integrated with Si-based driver, the top emission PLEDs will be took into account. The major difference between full transparent and top emission PLEDs is that a strong reflective metal layer is arranged underlying the bottom ITO anode. Figure 6 is the EL spectrum of top emission devices with various thicknesses of ITO. It exhibits that the EL intensity and the peak wavelength changes periodically as a function of ITO thickness. The shape of emission spectrum get narrower and peak intensity get larger in the range of ITO thickness from 40nm to 100nm. Then, it becomes broader and smaller until 180nm. After that, it gets narrower and larger again. However, the peak wavelength firstly blue shift when ITO thickness changes from 40nm to 60nm, then, it become red- shift over the range from 60nm to 160nm, after 160nm, it become blue-shift again until 200nm. This result is explained by the strong microcavity effect [3]. From these simulation results, it can be understood that the silver layer is the proper candidate for the ultra-thin metal material, and its thickness should be controlled in the range of 1~5 nm. Furthermore, the thickness of the capping ITO layer should be well designed to obtain the high EL intensity and color purity of devices, especially for the top emission case due to the strong microcavity effect.

Fig. 7 shows optical images of the electroluminescence with time for all devices. We can clearly find the dark spots were formed with increasing time in Fig. 7(a). The non-encapsulated device shown the moisture or oxygen permeation progress through the edge structure and the performance was poor when the device was stored in air condition. The device was glass encapsulated shown no dark spots formation after 100 hours in Fig. 7(b).

3. Impact

In this paper, the experiment results of an ultra-thin metal/ITO cathode for the transparent or top emission PLEDs were verified by simulation method. The EL spectrum and intensity of simulation results match quite well to the experiment data. We believe that the further extension of the simulation work will help us not only to shorten the experiment frequency but also to strength the design capability in the future.

4. Acknowledgements

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5. References

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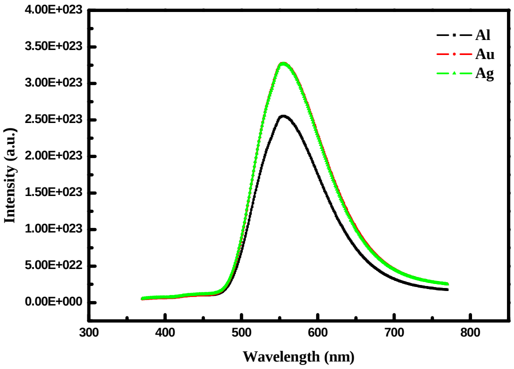

Fig.1. Simulation results of EL intensity for PLEDs with different metal layers of Au, Al, and Ag.

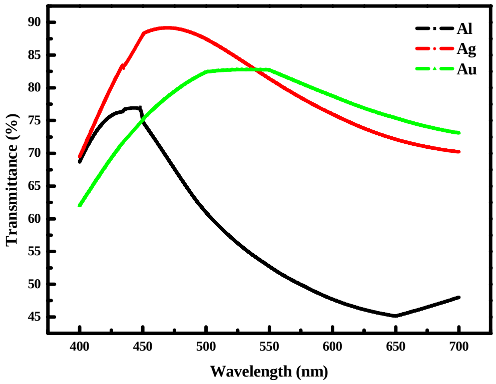

Fig.2. Simulated transmittance of devices with Al and Ag films.

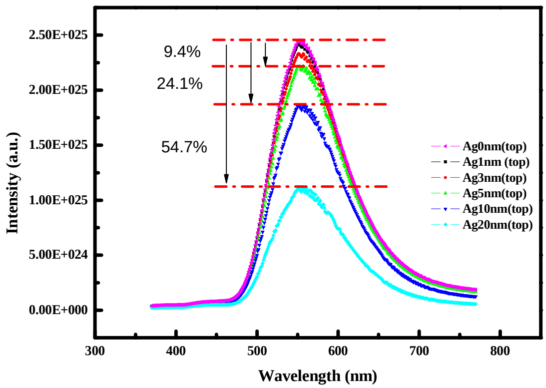

Fig.3. Simulation results of EL intensity for PLEDs with different thicknesses of Ag.

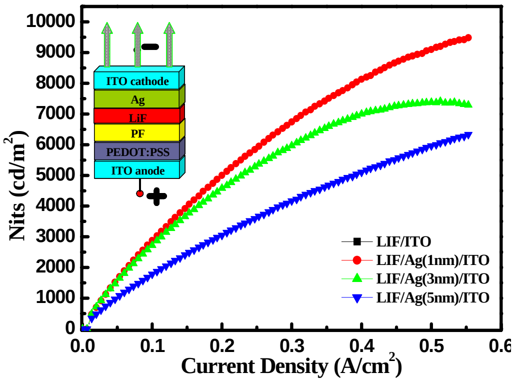

Fig.4. L-I characteristics and efficiency of TEPLEDs which were measured from top side.

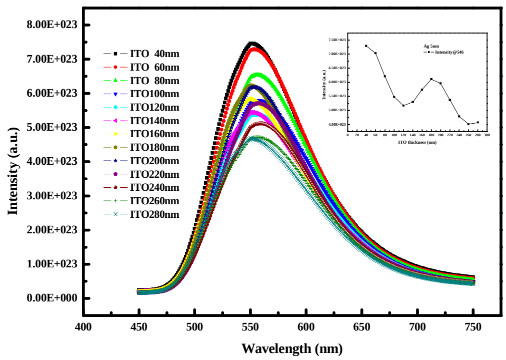

Fig. 5. Simulated EL intensity of transparent PLEDs with various thicknesses of ITO.

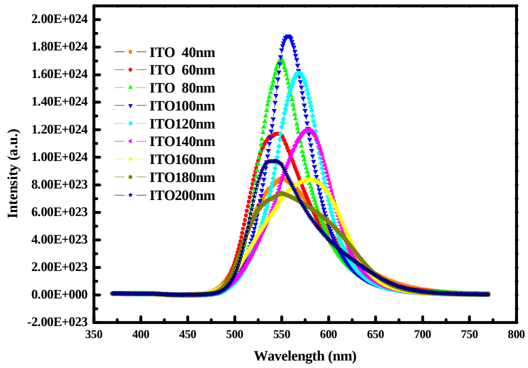

Fig. 6. Simulated EL intensity of top emission PLEDs with various thicknesses of ITO.

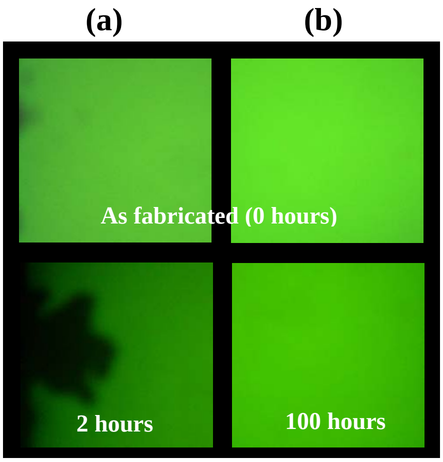

Fig.7.Photographs of the emitting areas of the devices
(a) non- encapsulated device,
(b) encapsulated with glass lid (reference device)