Top emission organic light emitting diode with transparent cathode, Ba-Ag double layer

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Abstract
We fabricated top emission organic light emitting diode (TEOLED) with transparent metal cathode Barium and Silver bilayer. Very thin Ba/Ag bilayer was deposited on the organic layer by thermal evaporation. This cathode shows high transmittance over 70% in visible range. And the device with a Ba-Ag has a low turn on voltage and good electrical properties.

1. Introduction
TEOLED has favorable attributes with many advantages to improve display performances, which are increasing the aperture ratio, vesting the freedom of pixel and circuit design and lowering power consumption[1-2].

In the OLED, generated light is emitted through the transparent electrode. Generally, Indium tin oxide (ITO) and Indium zinc oxide (IZO) were used as transparent electrodes in information displays. However to get over the certain quality, these materials must be deposited by sputtering method at the high temperature, over 200^{o}C. So during deposition on organic layer, the organic material is damaged by high energetic particles, deteriorating the performances of devices.

Therefore, we have attempted to develop damage free transparent cathode, which is composed with various metal and deposited by a method not inducing any damages. In our earlier work, we fabricated highly transparent cathode using Ca and Ag double layer[3-4]. To improve device properties further, we tested Ba and Ag as a transparent cathode. Barium is a good candidate for the cathode having a low work function, 2.5eV and has been used as electrode for efficient electron injection in polymer OLEDs[5]. But because Ba is very reactive metal with oxygen, the protective layer is required to prevent oxidation of Ba. So Thin Ag is deposited on the Ba layer. Transmittance and sheet resistance were measured in deposited Ba-Ag bilayer. We fabricated top emission device with Ba-Ag transparent cathode.

2. Results
Ba and Ag were deposited on clean glass substrates by thermal evaporation method in high vacuum, below 10^{-6}torr without breaking vacuum. Transmittance, sheet resistance and morphology of Ba-Ag double layer were measured. Figure 1 shows the photograph of Ba-Ag displaying the transmittance and schematic diagram.

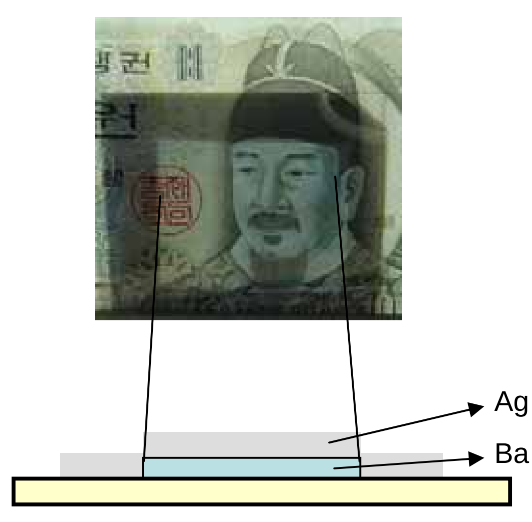


Figure 1 Structure and Photograph of Ba-Ag

Figure 2 represents the transmittance of the Ba-Ag cathodes and Ag single layer. Ag thickness was fixed 80A and 100A. And at the fixed Ag thickness, it is compared with transmittance curves of calculated Ag film and really deposited Ag and Ba-Ag. Ag transmittance was calculated by Macleod method. The calculated transmittance of Ag single layer with 80A thick shows about 64-87% and that is decreased as wavelength increased. But in the case of deposited layer by thermal evaporation, transmittance curve is very different and it is decreased upto 508nm and after this point, it is increased. When Ag is of same thickness, 100A, added Ba layers, 100A and 80A increase the transmittance than Ag mono layer from 34.4% to 55.5% and 73.3% at 500nm, respectively.

This curve is caused by the Ag island growth at the initial stage of Ag film. In this experiment, thickness of Ag film was limited below 100A, which is very thin, so deposited Ag film is not continuous. Figure 2 (a) shows the island growth of Ag with 100A thick. The incident light is not uniformly reflected and transferred and it is scattered at the boundary between islands. However, at the calculation, the transmittance curve of thin Ag film is made on the assumption that Ag film grows continuously without regard to thickness.

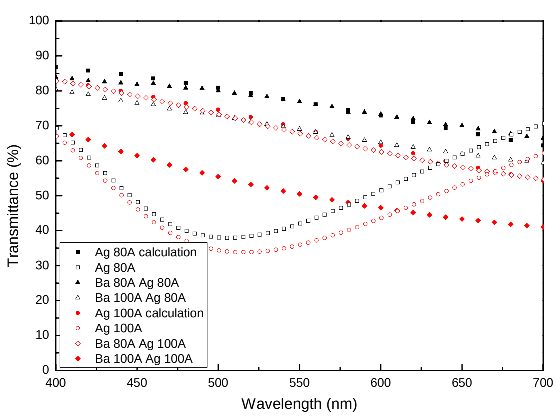
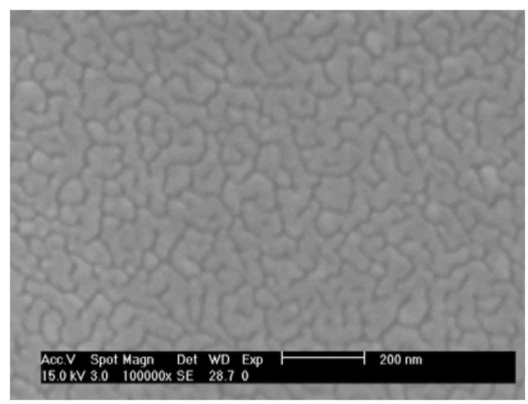


Figure 2 Transmittance of Ag and Ba-Ag

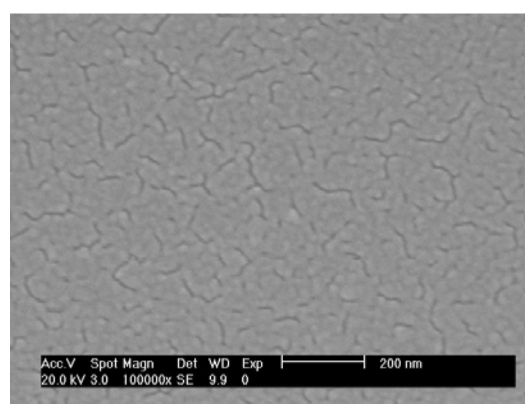
Ba layer which is deposited at first on organic material makes Ag film grow uniform and continuous. Ba makes the transmittance curve of double layer, Ba-Ag become similar or over that to calculated Ag single layer. In the SEM image, figure 2 (b), although the trace of grain boundary leaves, the bulk of serious grains are eliminated.

Here as Ag thickness is increased, transmittance is lowered but curves of transmittance are analogous with each other. Ba layer improves the property of Ag to grow continuous state.

So in the Ba-Ag double layer, Ba makes Ag layer to form continuously and the transmittance of Ba-Ag is mainly dominated by Ag layer. But this Ag growth is not enough to explain that the transmittance of Ba-Ag with thicker thickness is improved than that of Ag mono layer. It is thought that the Ba layer induces interference to increase transmittance.



(a)



(b)

Figure 2 SEM image (a) Ag 100A (b) Ba-Ag (100A-100A)

Ba-Ag double layer represent very good electrical properties. Sheet resistance was measured by four point probe. The sheet resistance of only Ag layer with 100A thick is not detected. As this film is very soft, it is scratched by probe. Ba-Ag double layer has very low sheet resistance. And it is very sensitive to individual layer thickness. Sheet resistance of Ba(100A)-Ag(100A) layer is 8.8 Ω/sq, which is lower value than Ca(100A)-Ag(100A) with 12 Ω/sq in our previous study[4].

Table 1 Sheet resistance of Ba-Ag

Sample(A)	Sheet resistance (Ω/sq)
Ag (100)	-
Ba(80)-Ag(80)	16.5
Ba(100)-Ag(80)	12.2
Ba(80)-Ag(100)	9.4
Ba(100)-Ag(100)	8.8

OLED with Ba-Ag cathode was fabricated. OLED was composed with this structure; glass\Ni\2TNATA\α-NPD\Alq3:C545T(1%)\BCP \Ba-Ag. Where 4,4′,4″-Tris(N-(2-naphthyl)-N-phenyl-amino) - triphenylamine (2TNATA) 4,4 – bis [N-(1-naphtyl)-N-phenyl-amino]biphenyl (α-NPD), Alq_3 (tris-(8-hydroxyquinoline)-aluminum), 9-benzothiazol -2-*yl*-1,1,6,6-tetramethyl-2,3,5,6,7*a*,11*a*-hexahydro-1*H*, 4*H*-11-oxa-3*a*-aza-benzo de anthracen-10-one (C545T) and 2,9-dimethyl-4,7 diphenyl-1,10-phenanthroline (BCP) were used as hole-injecting layer, a hole-transporting layer, a host for the emission layer, a dopant for the EML, and buffer layers, respectively. Ni is used as anode, since it has a high work function 5.1eV and simple as single material. Thicknesses of Ba and Ag were 80A and 80A respectively. All the devices have the emitting area of 0.4x0.6mm^2.

Figure 4 shows current density-brightness-voltage curve of the fabricated device. Maximum efficiency is 4.5cd/A at 5.5V, 997cd/m^2.

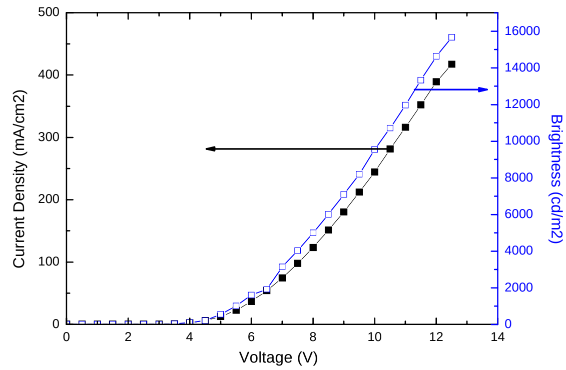


Figure 4 I-V-L characteristics curve of fabricated TEOLED

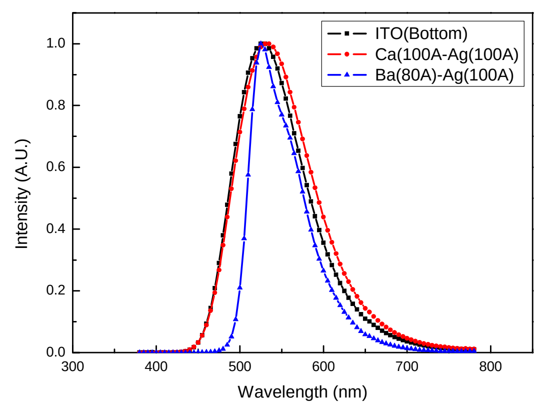


Figure 5 EL Spectra throughout various transparent electrodes, ITO, Ca-Ag and Ba-Ag

Figure 5 represent EL spectrum with 3 type transparent electrode, ITO, Ca-Ag and Ba-Ag. Bottom emission OLED has the same structure except anode and cathode. Anode is used ITO and cathode is LiF-Al. Top emission OLED has different spectrum with that of bottom emission device. Device with Ca-Ag has the spectrum that is similar with bottom emission. But peak is shifted from 530 to 535nm toward long wavelength. And width of peak is larger at the long wavelength region.

But, although the same top emission structure, spectrum of device with Ba-Ag is very different. This device shows narrower spectrum than other devices. It contains two peaks, the main peak at 526nm and the shoulder peak at near 560nm. In this TEOLED, the

Fabry-Perot resonator is formed by the transparent Ba-Ag cathode and reflective Ni anode. This micro-cavity structure makes EL spectrum to become narrow.

3. Conclusion

Transparent cathode is the key technology to realize AMOLED. Our new cathode, Ba-Ag has a good electrical and optical properties and it is formed by damage free process. Double layer, Ba(80Å)-Ag(100Å) shows high transmittance over 70% in visible range and low resistance 9.4Ω/sq. Here thin Ba layer prevents Ag growing as island shape and makes transparency to increase. We fabricated top emission device with reflective anode, Ni and this transparent cathode, Ba-Ag. This device has a low turn on voltage and good electrical properties. Maximum efficiency is 4.5cd/A at 5.5V, 997cd/m^2. Its EL spectrum has two peaks, the main peak at 526nm and the shoulder peak at near 560nm by micro cavity effect.

4. Acknowledgements

This work was supported by the program of Ministry of Commerce, Industry and Energy in Korea.

5. References

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