

# White Light Emission from Microcavity Organic Light-Emitting Diodes with Color-Coverting CdSe/ZnS Quantum Dots

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## 1. Introduction

Organic light-emitting diodes (OLEDs) have attracted a great deal of attention due to their potential applications such as full color or large-area flat panel displays and solid-state lighting [1,2]. For nowadays displays, pure and saturated colors are essential. However, organic emitters exhibited poor color purity because of their very broad spectral bandwidth. To overcome this drawback, the microcavity structure was incorporated into OLEDs so that the light emission can be narrowed to improve color purity [3,4]. Furthermore, the light intensity, tunability of the emission spectra, and luminance efficiency can also be improved significantly [5,6]. In a Fabry-Perot microcavity OLED (MOLED), distributed Bragg reflectors (DBRs) are typically adopted to outcouple the light at resonant wavelength (RW). Therefore, by controlling the thickness of active layers, the adjustment of RW (emission light color) can be achieved.

On the other hand, the chemically-synthesized colloidal semiconductor quantum dots (QDs), or nanocrystals, have been widely used in biomedical, electronic, and optoelectronic applications due to their foremost advantages such as high chemical and optical stabilities, easy tuning of the saturated color emission across the visible to near infrared range, and high processability in hybridizing with organic and inorganic materials. Meanwhile, high quantum yield (QY) and photochemical stability are achieved by surface passivation. For core/shell QDs, free excitons are observed even at room temperature because of their high binding energies, which favors the devices based on excitonic transitions.

In this study, we have modulated the thickness of emission layer (EML) and hole-transporting layer (HTL) to get different RWs corresponding to different Commission Internationale de l'Eclairage (CIE-1931) chromaticity coordinates. A colloidal CdSe/ZnS quantum dot (QD) layer was precoated on the backside of the devices to investigate the light down conversion. In other words, by means of setting the best parameters for EML and HTL, pure white luminescence could be obtained by hybridizing the MOLED and inorganic QDs

## 2. Experimental Details

Firstly, 2-methyl-9,10-di(2-naphthyl)anthracene (MADN) and p-bis (p-N,N-diphenyl-aminostyryl)benzene (DSA-Ph)

were used as the blue emitting host material and the dopant in our device configuration, respectively. At a concentration of 3% w/w of DSA-Ph in MADN, the doped emission layer provided the effective pathway for hole injection from naphthyl-substituted benzidine derivative (NPB), i.e., the hole transport layer (HTL), and thus performed the best electroluminescence (EL) intensity and efficiency [7].

The architecture of the MOLED before adding QD layer is shown in Fig. 1(a). Before the film coating, glass substrates were cleaned by detergent, organic solvents, and ultraviolet (UV)/Ozone treatment, respectively. Subsequently a 20nm-Ag film was evaporated on the glass substrates an appropriate bottom reflector and anode. A thin MoO<sub>3</sub> film with thickness of 5 nm was then coated on Ag anode as a buffer layer and hole-injection layer (HIL). After the deposition of HTL and EML, 10-nm-thick tris (8-hydroxyquinoline) aluminum (Alq<sub>3</sub>) was evaporated as an electron-transporting layer (ETL). Finally, 5-nm-thick LiF and 200-nm-thick Al were evaporated as the cathode. To attach a QD layer onto MOLEDs, the QD-toluene solution (2 wt.%) was blended with PMMA powder (8 wt.%) for more than 24 hours to get the QD-PMMA blends. No aggregation of QDs was observed after the solvent was evaporated. The solution was dropped on the backside of the glass substrate and wiped slightly to make the surface smoother. The QD coating process was completed after the samples were baked on a hot plate for one hour. By adjusting the thicknesses of EML (x nm) and HTL (y nm), a part

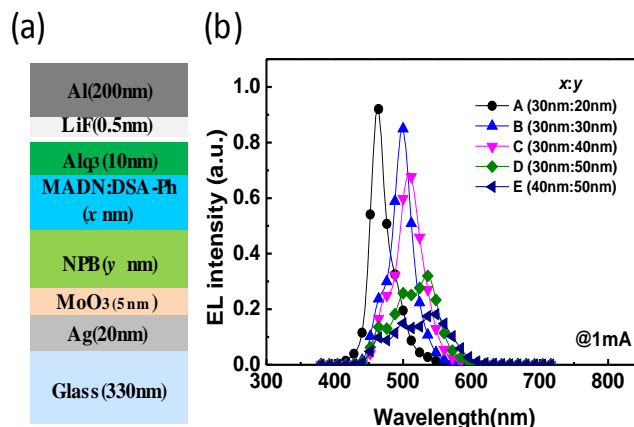


Fig. 1 (a) Schematic of device structure of our MOLEDs and (b) electroluminescence spectra of MOLEDs with different EML and HTL thicknesses.

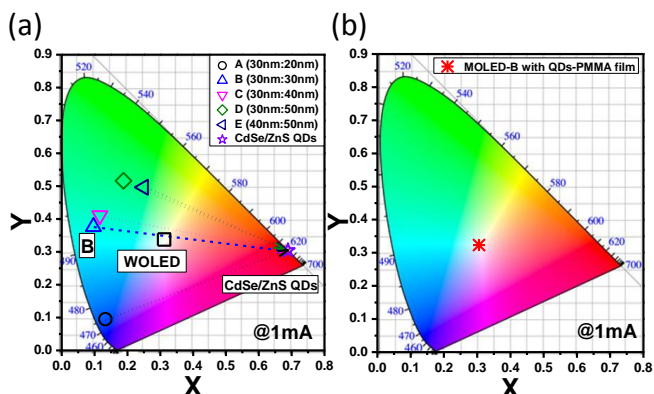


Fig. 2. (a) The CIE chromaticity coordinates of device A,B,C,D,E at 1mA and typical WOLED and CdSe/ZnS QDs emission including the connective line between our device and CdSe/ZnS QDs. (b) The CIE chromaticity coordinates of device B with QDs-PMMA film.

of the modulated RW was down-converted by the QDs to achieve the white light emission. After fabrication, all devices were characterized and preserved in a glove box containing the concentration of oxygen and humidity less than 1 ppm.

### 3. Results and Discussion

Fig. 1(b) shows the electroluminescence (EL) spectra of MOLED-A ( $x=30\text{nm};y=20\text{nm}$ ), -B ( $x=30\text{nm};y=30\text{nm}$ ), -C ( $x=30\text{nm};y=40\text{nm}$ ), -D ( $x=30\text{nm};y=50\text{nm}$ ), and -E ( $x=40\text{nm};y=50\text{nm}$ ) driven at 1 mA. As the thicknesses of HTL and EML were increased, the emission peaks significantly red-shifted. The shift in the emission spectrum turned to be the distinct coordinates on the CIE-1931 chromaticity shown in Fig. 2(a). As shown in Fig 2(a), MOLED-B was obviously the most-likely host emitter to achieve white light emission at coordinates of (0.33, 0.33) after hybridizing with the red-emitting QDs. Indeed, as shown in Fig. 3, the EL spectra of MOLED-B with and without QD layer shows remarkable color down-conversion, and the resulted white light is with coordinates of (0.31, 0.32). The decrease of EL intensity could be attributed to the low quantum yield of QDs blent into PMMA matrix.

The luminance-current density-voltage ( $L$ - $J$ - $V$ ) characteristics are shown in Fig. 4. It clearly demonstrated that the

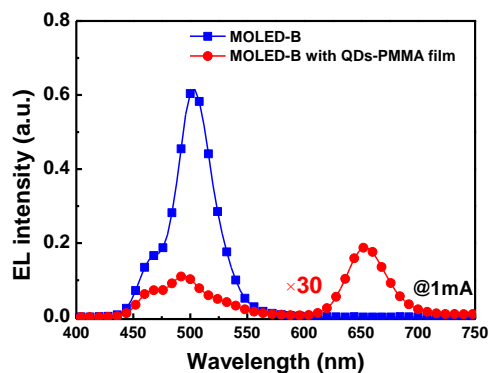


Fig. 3. EL spectra of MOLED-B with and without QD layer at 1 mA.

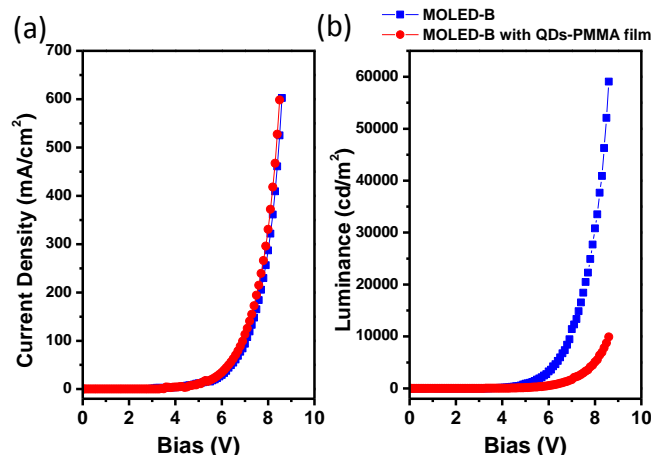


Fig. 4 (a) Current density-voltage ( $J$ - $V$ ) characteristics and (b) luminance-voltage ( $L$ - $V$ ) characteristics for MOLED-B with and without a QD layer.

additional process of QD layer attachment did not have any significant influence on the electrical characteristics of the MOLEDs. The turn-on voltages are about 7 V. The luminance of the fabricated MOLED-B is higher than that of the conventional OLEDs (not shown here) in our experiments. However, the low conversion efficiency may also be attributed to the low quantum yield of QDs in PMMA matrix.

### 4. Conclusions

In conclusion, the MOLEDs with a CdSe/ZnS QD-PMMA composite film were demonstrated. When both of the thicknesses of HTL and EML were 30 nm, the luminance color of QD-attached MOLEDs could be nearly pure white with the CIE chromaticity coordinates of (0.31, 0.32). However, to make the novel devices practical, the quantum yield of the preliminary QD layer has to be improved.

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### References

- [1] C. Rothe and A. Monkman, *Nature Mater.* 5 (2006) 463.
- [2] C. D. Muller, A. Falcou, N. Reckefuss, M. Rojahn, and K. Meerholz, *Nature* 421 (2003) 829.
- [3] A. Dodabalapur, L. J. Rothberg, R. H. Jordan, T. M. Miler, R.E. Slusher, and J. M. Phillips, *J. Appl. Phys.* 80, (1996) 6954.
- [4] C. W. Chen, P. Y. Hsieh, H. H. Chiang, C. L. Lin, H. M. Wu, and C. C. Wu, *Appl. Phys. Lett.* 83, (2003) 5127.
- [5] H. Becker, R. H. Friend, and T. D. Wilkinson, *Appl. Phys. Lett.* 72, (1998) 1266.
- [6] C. L. Lin, H. W. Lin, and C. C. Wu, *Appl. Phys. Lett.* 87 (2005) 021101.
- [7] M. T. Lee, H. H. Chen, C. H. Liao, C. H. Tsai, and C. H. Chen. *Appl. Phys. Lett.* 85, (2004) 3301.