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Supplementary Information

High-Performance Top-Emitting Quantum Dot Light-Emitting Diodes by Balancing Electrical Conductance and Light Outcoupling

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EXPERIMENT

Device structures

TE-QLEDs with a structure of glass/Al (100 nm)/ITO (0, 5, 10, 20, 40, 60 or 80 nm)/PEDOT:PSS (45 nm)/TFB (40 nm)/QDs (20 nm)/ZnMgO:PVP (50 nm)/ITO (100 nm) were fabricated (abbreviations: PEDOT:PSS: poly(3,4-ethylenedioxythiophene) polystyrene sulfonate, TFB: Poly[(9,9-dioctylfluorenyl-2,7-diyl)-co-(4,40-(N-(p-butylphenyl))diphenylamine)], PVP: polyvinylpyrrolidone). CdZnSe/ZnS R-QDs were commercially purchased from Mesolight, Inc.

Device Fabrication.

The glass substrates were cleaned with detergent, deionized water, and isopropanol in an ultrasonic bath for 30 min and then treated in an oven at 60 °C for 30 min. To prepare the bottom reflective electrode, a 100 nm thick Al anode was thermally deposited on the glass substrate under a high vacuum chamber ($< 5 \times 10^{-4}$ Pa). After that, the ITO interfacial modification layer was deposited on the Al electrode by magnetron sputtering under a power of 50 W, a working pressure of 3×10^{-3} Torr, and an Ar flow of 10 sccm. Different deposition durations resulted in a thickness of 5, 10, 20, 40, 60 and 80 nm, respectively. Then all samples were treated in ultraviolet (UV)-ozone for 20 min, followed by the PEDOT:PSS (Clevios AI 4083) HIL was spin-casting over the pre-coated substrates at 3000 rpm for 45 s and annealing at 130 °C for 15 min in the air. Afterward, all the substrates were transferred to a nitrogen atmosphere glovebox to deposit the functional layers for the TE-QLEDs. The TFB (8 mg mL^{-1} in chlorobenzene) HTL was spin-coated over the PEDOT:PSS layer at 3500 rpm for 45 s and baked at 120 °C for 20 min. The QDs (10 mg mL^{-1} in octane) solution was directly spin-coated over the TFB film at 3000 rpm for 45 s as the emitting layer, baked at 100 ℃ for 5 min. For ETL preparation, the $Zn_{0.85}Mg_{0.15}O$ nanoparticles (20 mg mL^{-1} in ethanol) were mixed with PVP (20 mg mL^{-1} in ethanol, average molecular weight: 24 000) to form ZnMgO:PVP hybrid solutions with a weight ratio of 20: 9.6. Then the ZnMgO:PVP solution were spin-coated over the QDs layer at 2000 rpm for 45 s and annealed on at 100 ℃ for 15 min. Then, the samples were transferred to a magnetron sputtering system to deposit the 80 nm ITO cathode (~ 100 Ω sq^{-1}) under a power of 50 W, an Ar flow of 10 sccm, and a working pressure of 3×10^{-3} Torr. Finally, Finally, all the samples are encapsulated by a glass covers.

Device characterization.

The thicknesses of the functional layer were measured by using a Bruker DektakXT Stylus Profiler. The surface morphologies were characterized via atomic force microscopy (AFM, Bruker Multimode 8). The cross-sectional SEM image was obtained on a field-emission scanning electron microscope (FESEM) (Gemini SEM 300). The angular emission pattern of the devices was measured by EVERFINE GO-SPEX 500 from Hangzhou EVERFINE Equipment Co., Ltd. The contact angles were measured by a contact angle meter (JC200C1, Powereach). The current density–voltage (J–V) characteristics were recorded by a programmable source meter (Keithley 2614B). The forward-direction photons emitted from the devices were detected by a calibrated UDT PIN-25D silicon photodiode.

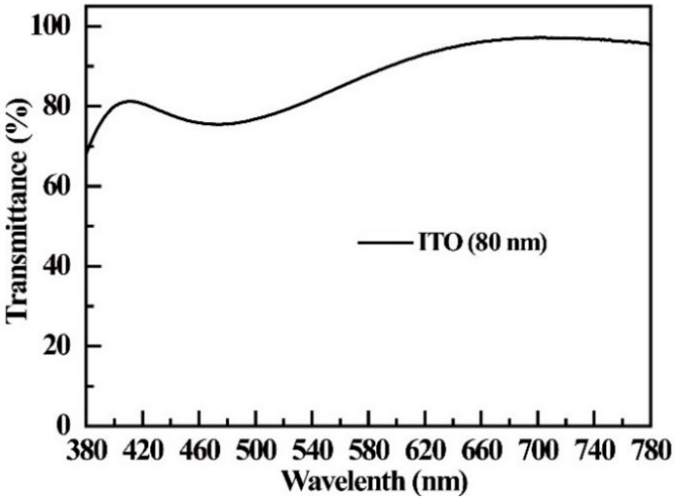

Figure S1 The transmittance of ITO top electrode about 80 nm.

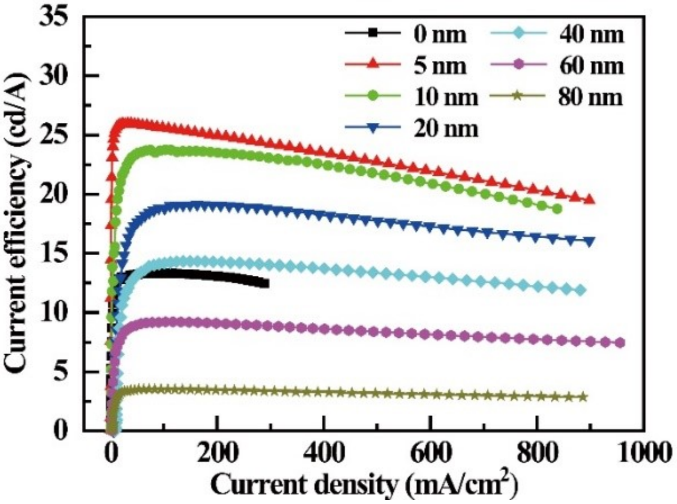

Figure S2 CE–J characteristics of the devices without and with ITO interlayer.

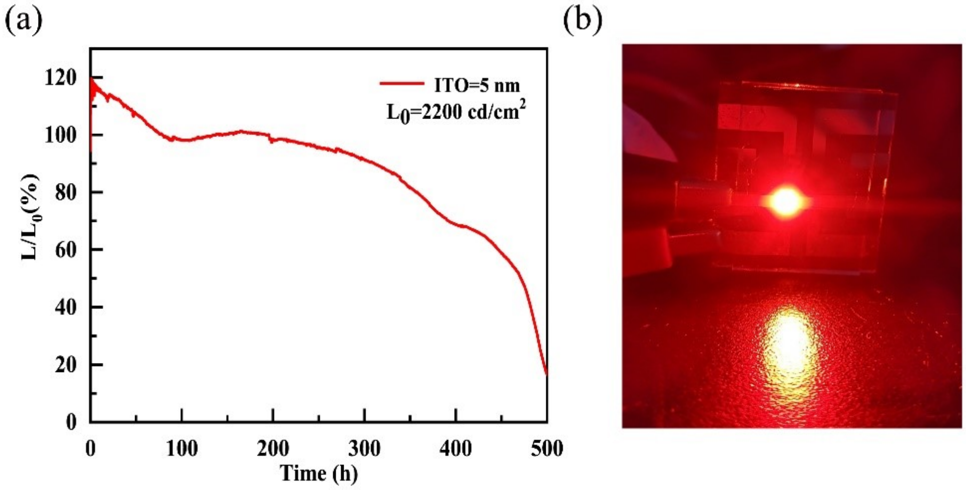

Figure S3 (a) Luminance–time curves of red TE-QLEDs with 5 nm ITO interlayers. (b) The photograph of the red TE-QLEDs.

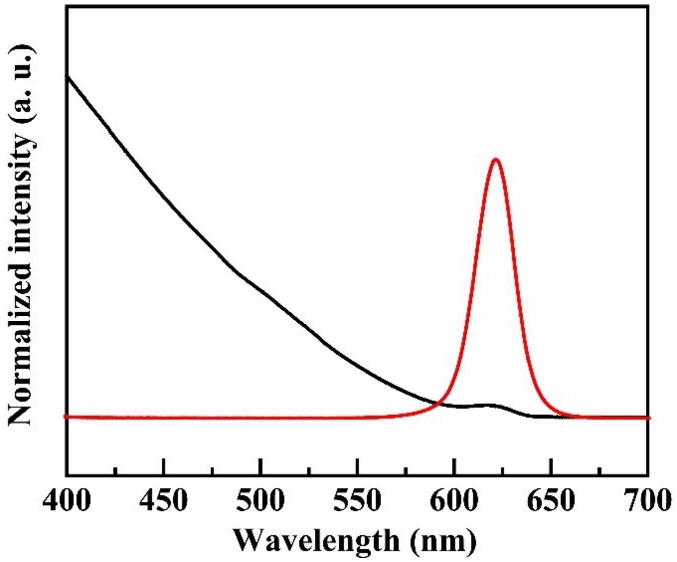

Figure S4 Ultraviolet-visible absorption and normalized photoluminescence spectra of the red QDs.

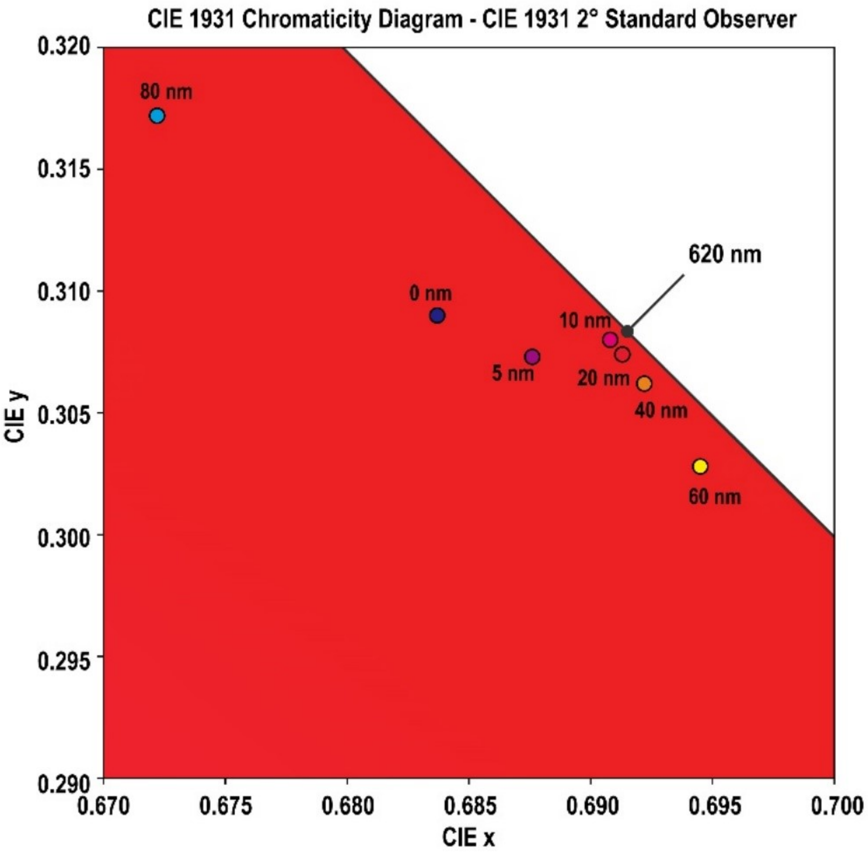

Figure S5 Color coordinates of the TE-QLEDs with different thicknesses of ITO interlayer at CIE 1931 Chromaticity diagram – CIE 1931 2° standard observer.

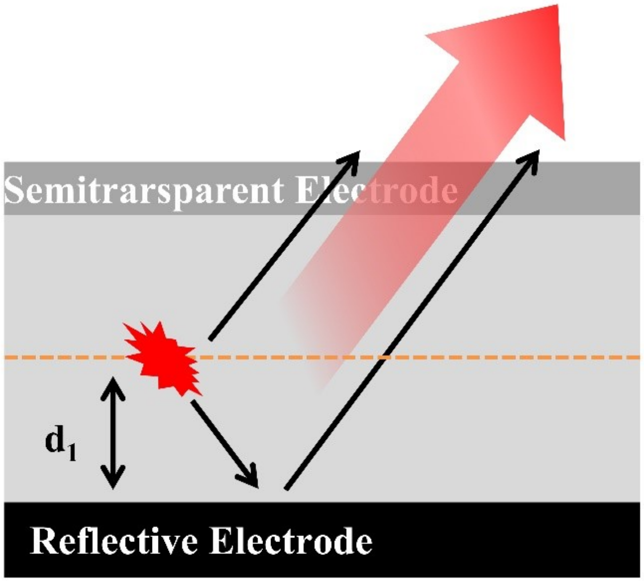

Figure S6 Schematic optical model of the wide-angle interference in the TE-QLEDs.