Supplementary Information

Enhancing Performance of Inverted Quantum-Dot Light-Emitting Diodes Based on Solution-Processed Hole Transport Layer via Ligand Treatment

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Experimental

Materials~~.~~

For this experiment, chlorobenzene (99%) was purchased from Aladdin. Ethanol (99.7%) and methanol (99.5%) were purchased from Shanghai Lingfeng Chemical Reagent Co., Ltd. Octane (99%) were purchased from Sigma.1,8-diaminooctane (98%) was purchased from TCI (Shanghai) Development Co., Ltd. The red CdSe/ZnS QDs were purchased from Suzhou Xingshuo Nanotech Co., Ltd. The Poly((9,9-dioctylfluorenyl-2,7-diyl)-co-(4,4′-(N-(4-sec-butylphenyl)diphenylamine) (TFB) was purchased from American Dye Source, Inc. Dipyrazino[2,3-f:2',3'-h]quinoxaline-2,3,6,7,10,11-hexacarbonitrile (HAT-CN) was from Luminescence Technology Corp. The ZnO nanoparticles were synthesized by Planck Innovation Technologies Co. Ltd.

QLED device fabrication

The ITO glasses were sequentially cleaned with DI-water, acetone, and ethanol using an ultrasonic cleaner for 20 minutes each. All next steps were carried out in the glove box. The ZnO nanoparticles (20 mg/mL in ethanol) were spin-coated at 3000 rpm for 45 s and annealing at 100 °C for 10 minutes. The QDs (15 mg/mL in octane) was deposited by spinning at 3000 rpm 45 s. For the ligand-treated device, 0.2 mg/mL 1,8-diaminooctane in methanol was dropped on the QD layer and wait 1 minute for ligand treatment. After that, excess ligand was removed by rinsing with methanol. The film was baked at 100 °C for 5 min. The TFB (8 mg/mL in chlorobenzene) was spin-coated onto the QD layer at 3000 rpm for 45 s and the annealing time is 10 minutes. HAT-CN (30 nm) and Al (100 nm) layers were fabricated by heat evaporation. The devices were then packaged using UV glue and encapsulation glass.

Characterizations

To measure UV-vis absorption spectra, a Lambda365 UV-vis spectrometer (PerkinElmer) was used. Steady-state PL spectra and PL QY were obtained using a Quantaurus-QY C11347-12 absolute PL quantum yield spectrometer (Hamamatsu). TRPL characteristics are measured by Fluo Time 300 Fluorescence Lifetime Spectrometer equipped with a 405 nm pulsed laser. SEM images and AFM images were obtained using Zeiss Gemini SEM 300 and Asylum Research mfp-3d, respectively. EL spectra of devices were collected by a fiber optic spectrometer (Ocean Optics USB 2000). The Keithley 2614B power supply and a PIN-25D silicon photodiode were utilized to obtain the current density-luminance-voltage and EQE characteristics. Capacitance-voltage characteristics were measured by Paios System (Fluxim). Lifetime tests were conducted using a lifetime test system with photodiode holders (Guangzhou Crysco Equipment Co., Ltd).

Table S1. Optical properties of QDs.

Method	**PL QY (%)**	**PL peak (nm)**	**FWHM (nm)**
w/o ligand treatment	87.3	628	23.0
/w ligand treatment	87.0	628	22.9

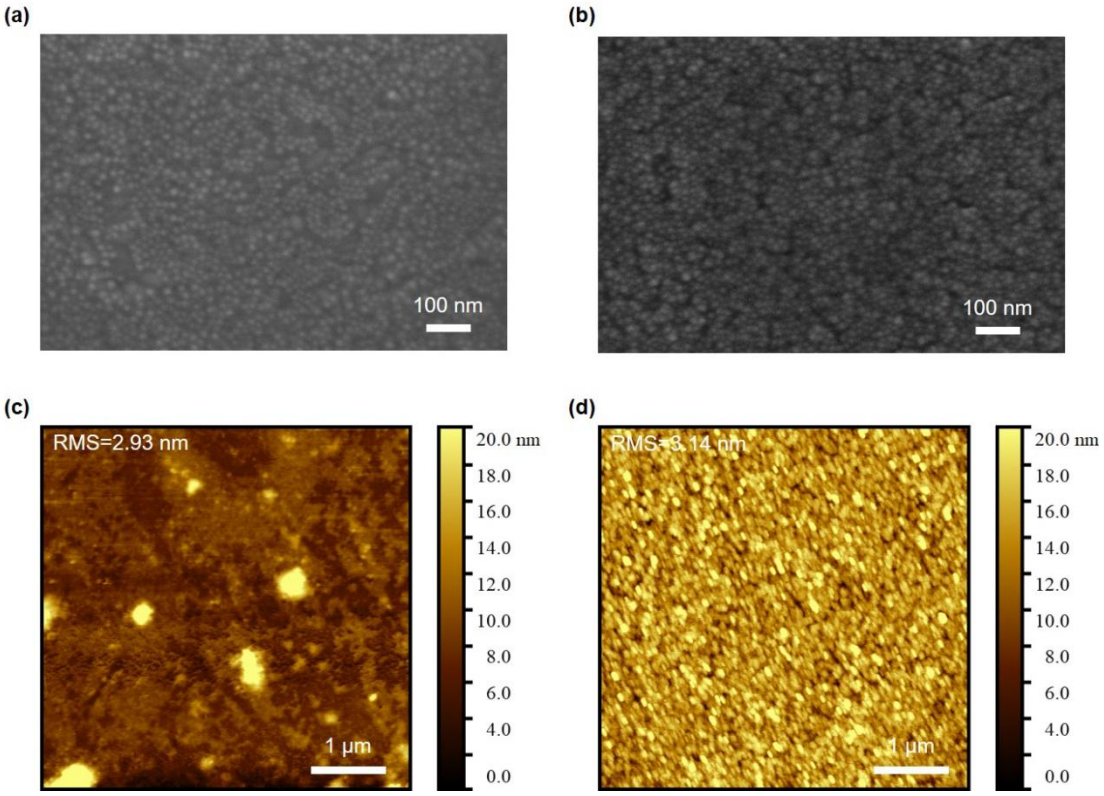

Fig. S1. SEM images of the (a) pristine QD film rinsed with chlorobenzene and (b) ligand-treated QD film rinsed with chlorobenzene. AFM images of the (c) pristine QD film rinsed with chlorobenzene and (d) ligand-treated QD film rinsed with chlorobenzene.

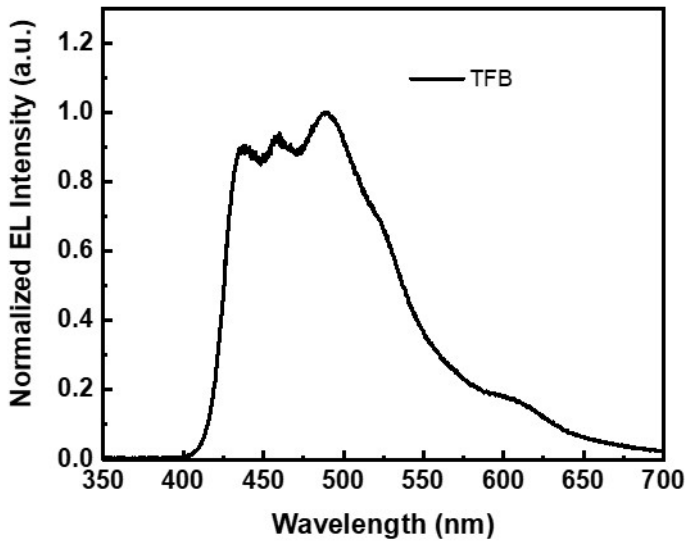

Fig. S2. EL spectrum of TFB. The device structure is ITO/ZnO/TFB/HAT-CN/Al.

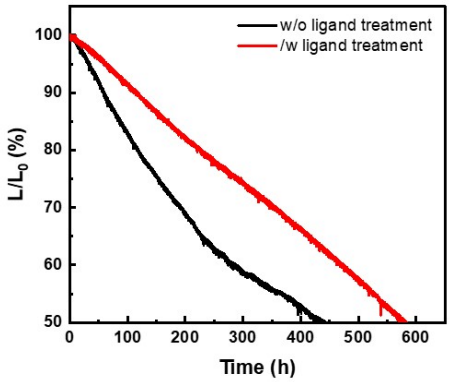

Fig. ~~S2~~S3. The operational T_{50} lifetime under an initial luminance of 1,000 cd/m^2.

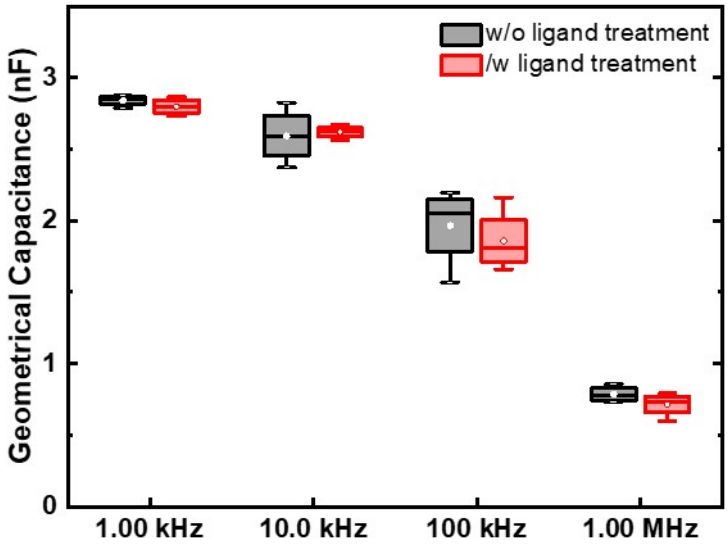

Fig. ~~S3~~S4. The geometrical capacitance of two type devices under different frequencies (4 for each type device).