Electronic Supplementary Material (ESI) for Nanoscale Horizons.

Supporting Information

Penethylammonium Bromide Interlayer for High-Performance Red Quantum-Dot Light Emitting Diodes

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EXPERIMENTALs

Materials. Chlorobenzene was purchased from Sigma-Aldrich Ltd.. Ethanol, isopropanol, acetone, and octane were purchased from Shanghai Titan Scientific Co. Ltd.. Poly-(ethylenedioxythiophene):polystyrenesulfonate (PEDOT:PSS (AI 4083)) was purchased from Heraeus, Inc.. TFB was purchased from Luminescence Technology Corp.. The red CdSe/ZnS QDs (photoluminescence quantum yield of 96%) and ZnMgO solutions were provided from Mesolight Co., Ltd. (Suzhou). PEABr were obtained from Xi'an Polymer Light Technology Corp.. All chemicals were used as obtained.

Fabrication of QLEDs. The pre-patterned ITO substrates were sequentially cleaned in ethanol, acetone, and isopropanol solution in an ultrasonic bath for 15 min, respectively. Then the substrates were treated with Plasma for 7 min. PEDOT:PSS (AI 4083) was filtered by a 0.22 μm filter and then spin-coated onto the ITO substrates at 3000 rpm for 40 s, following with a thermal annealing at 150 °C for 30 min. Afterwards, the substrates were transferred to the glovebox filled with nitrogen ($O_2 < 1$ ppm, $H_2O < 1$ ppm). TFB (chlorobenzene, 8 mg mL^{-1}) and CdSe/ZnS QDs (octane, 17 mg mL^{-1}) were sequentially spin-coated on the PEDOT:PSS layer at the same speed of 3000 rpm, annealed at 130 °C and 100 °C for 30 and 10 min, respectively. PEABr (isopropanol, 2.5 mg mL^{-1}) was deposited by spin-coating at the different spin-coating rates with a fixed acceleration of 1500 rpm s^{-1} for 40 s and annealed at 50 °C and 80 °C for 10 min depending on the requirements. Later, ZnMgO (ethanol, 25 mg mL^{-1}) was spin-coated on PEABr at 3000 rpm for 40 s, followed by thermal annealing at 50 °C for 20 min. Finally, the samples were transferred to a high-vacuum deposition chamber with a pressure of about 5×10^{-4} Pa for the deposition of the top cathode of Al (100 nm). The active device area was 4 mm^2 defined by the shadow mask and ITO patterns. All the devices were encapsulated in the glove box with ultraviolet-curable resin.

Characterization. Transmission electron microscopy (TEM) image was measured by the HT7700 high-resolution transmission electron microscope (HITACHI), with an accelerating voltage of 120 kV. The current density–voltage–luminance (*J-V-L*) characteristics and the electroluminescence (EL) spectra of the devices were recorded by the M3000 measurement system (McScience). The absorption spectra were measured by UV-3600 spectrophotometer (SHIMADZU). The PL spectra were recorded with the F-4700 fluorescence spectrophotometer (HITACHI) at an excitation wavelength of 420 nm for QDs. The transient photoluminescence spectra were recorded with the C16361-02 spectrofluorometer system (Hamamatsu) at an excitation wavelength of 400 nm. The ZnMgO film surface morphologies were characterized by an atomic force microscopy (AFM) Dimension Icon (Bruker) in the tapping mode. The transient electroluminescence (TREL) properties and the current density-voltage (*J-V*) characteristics of the electron-only devices (EODs) were measured with the all-in-one measurement system Paios 4.3 (Fluxim). All the measurements were operated at ambient atmosphere.

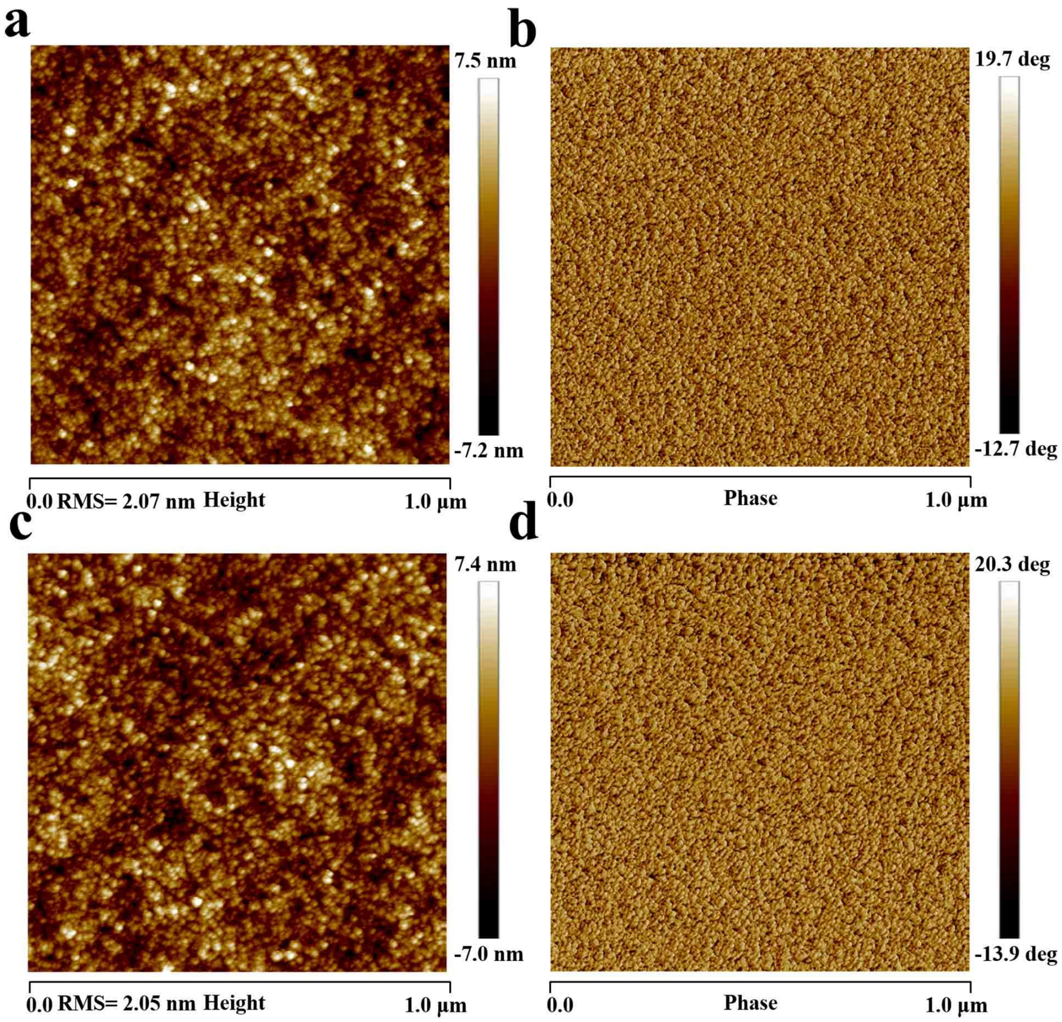

Figure S1. AFM images of ZnMgO film captured in contact (b) and phase mode (b), respectively. AFM images of PEABr/ZnMgO film captured in contact (c) and phase mode (d), respectively.

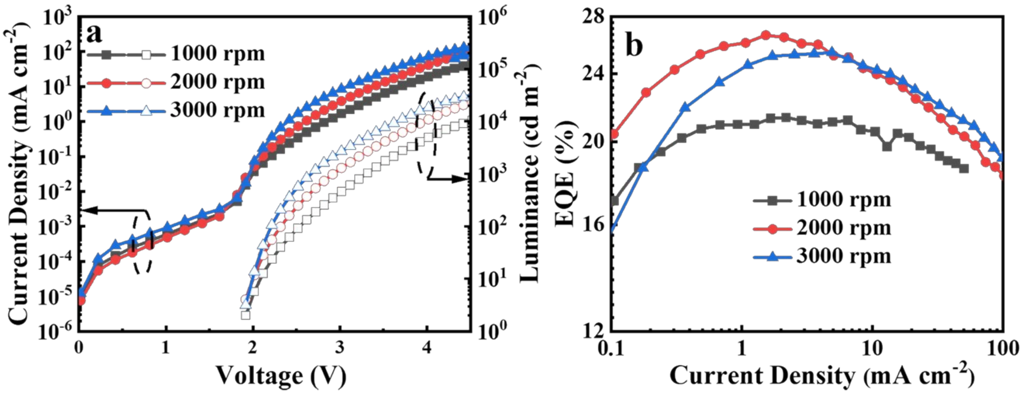

Figure S2. (a) *J-V-L* and (b) EQE curves of the PEABr-based devices with different spin-coating speed of the PEABr layer.

Table S1. Comparison of the electroluminescent performance of the PEABr-based devices with different spin-coating speed of the PEABr layer.

Speed (rpm)	λ_{EL}[a] (nm)	FWHM[b] (nm)	PE[c] (lm W^{-1})	CE[d] (cd A^{-1})	EQE[e] (%)	CIE[f] (x, y)
1000	628	24	27.9	28.1	21.3	(0.69,0.31)
2000	628	24	34.9	40.3	26.6	(0.68,0.31)
3000	628	24	33.1	36.9	25.4	(0.68,0.31)

[a]Peak wavelength. [b]Full-width at half-maximum of the EL spectrum. [c]Maximum power efficiency. [d]Maximum current efficiency. [e]Maximum external quantum efficiency. [f]Commission International de I'Eclairage color coordinates.

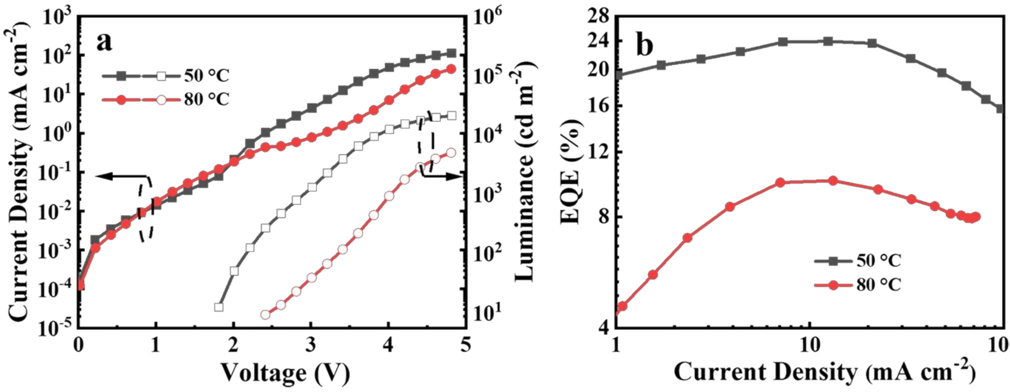

Figure S3. (a) *J-V-L* and (d) EQE curves of the devices with PEABr annealed at 50 ˚C and 80 ˚C, respectively.

Table S2. Comparison of the electroluminescent performance of the devices with PEABr annealed at 50 ˚C and 80 ˚C, respectively.

Temperature (˚C)	λ_{EL}[a] (nm)	FWHM[b] (nm)	PE[c] (lm W^{-1})	CE[d] (cd A^{-1})	EQE[e] (%)	CIE[f] (x, y)
50	628	24	29	31.5	23.9	(0.69,0.31)
80	628	24	13.3	9.9	10	(0.69,0.31)

[a]Peak wavelength. [b]Full-width at half-maximum of the EL spectrum. [c]Maximum power efficiency. [d]Maximum current efficiency. [e]Maximum external quantum efficiency.

[f]Commission International de I'Eclairage color coordinates.

Table S3. Comparison of the electroluminescent performance of the state-of-the-art CdSe/ZnS-based red QLEDs.

Structure	λ_{EL}[a] (nm)	FWHM[b] (nm)	EQE_{col}[c] (%)	EQE_{mod}[d] (%)	Ref.
ITO/PEDOT:PSS/ PVK/QD:TAPC/ZnO/Al	628	28	11.8	15.7	[1]
ITO/ZnO (LZO)/ QD/TCTA/NPB/HAT-CN/Ag	621	24	12.6	16.4	[2]
ITO/rGO/PEDOT:PSS/PVK/ QDs/ ZnO/Al	630	21	7.9	17.3	[3]
ITO/PEDOT:PSS/TFB/ QDs/ZnO/Al	628	20	14.3	17.4	[4]
ITO/PEDOT:PSS/TFB/ QDs/ZnMgO/Ag	630	N.A.	16.5	19	[5]
ITO/ZnO/PEIE/QDs/PVK/ PEDOT:PSS/Al	624	32	20.7	N.A.	[6]
ITO/PEDOT:PSS/TFB (PVK, PTAA, Poly-TPD/QD/ZnO (ZnMgO)/Ag	618	N.A.	6.5	21.1	[7]
ITO/PEDOT:PSS/TFB-PVK/ QDs/ZnMgO/Ag	628	N.A.	17.6	22.7	[8]
ITO/PEDOT:PSS/TFB/ QDs/PEABr/ZnMgO/Al	628	24	20.1	27.6	This Work

[a]Peak wavelength. [b]Full-width at half-maximum of the EL spectrum. [c]Maximum external quantum efficiency of the control device. [d]Maximum external quantum efficiency of the modified device. N.A.: not available.