Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Supporting Information

Optimizing Charge Balance in Carbon Dots-based LEDs for Enhanced Performance

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Material Characterization:

X-ray diffraction (XRD) measurements.

The samples were dropped on a glass slide while being gently heated to evaporate the solvent as is customary for preparing XRD samples. The XRD patterns were gain on a Bruker D8 Advance working on Cu Kα radiation.

Photoluminescence (PL) measurements.

PL spectra were recorded with a fluorescence spectrofluorometric (Hitachi, F-7000). All the measured sample was dispersed in toluene for the measurements.

Transmission electron microscopy (TEM) measurements.

TEM measurements were performed on a JEOL 2100F operated at 200 kV. the materials were diluted in toluene before being drop-cast onto a 300-mesh copper TEM grid and dried at room temperature before the measurements.

Atomic Force Microscope (AFM) measurements.

The surface morphology and topographic images including the root-mean-square (RMS) roughness were analyzed by an atomic force microscope (AFM, MFP-3D Origin+, MANUFACTURERS). After being dissolved in toluene, the sample was spin-coated onto a silicon chip. In the same manner as CDs-LEDs that were constructed prior to the measurement, the sample was dried to anneal.

UV-visible Absorption measurements.

The measured sample was dispersed in toluene and then test with lambda 950UV/VIS/NIR spectrometer for absorption spectroscopy.

Time-resolved photoluminescence (TRPL) measurements

Time-resolved PL lifetime measurements (HORIBA Instrument Inc., Fluorolog-3) were carried out using a time-correlated single-photon counting (TCSPC) lifetime spectroscopy system with a picosecond pulsed diode laser (EPL-370 nm) as the single wavelength excitation light source. For the measurements, toluene was used to mix together all of the samples.

The PL decay curves were fitted using a two-exponential function Eq. (1):

$$I(t) = A_1 e^{-\frac{t}{\tau_1}} + A_2 e^{-\frac{t}{\tau_2}} \#(1)$$

τ_1, τ_2 represent the decay time constants, and A_1, A_2 represent the normalized amplitudes of each component.

The amplitude weighted average lifetime of the entire photoluminescence decay process was calculated using Eq. 2:

$$\tau = \frac{A_1\tau_1^2 + A_2\tau_2^2}{A_1\tau_1 + A_2\tau_2} \#(2)$$

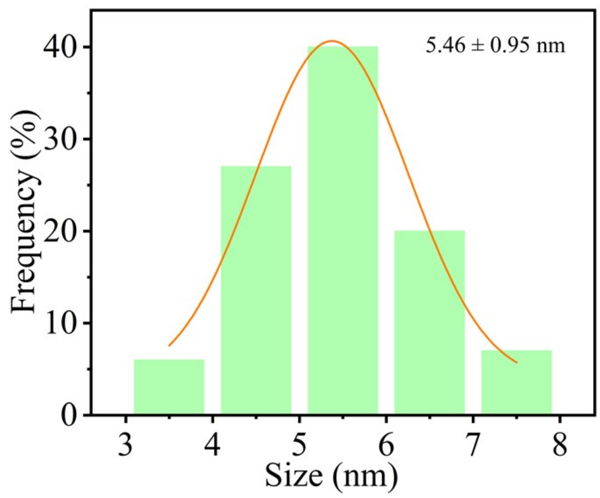

Figure S1. The particle size distribution of CDs

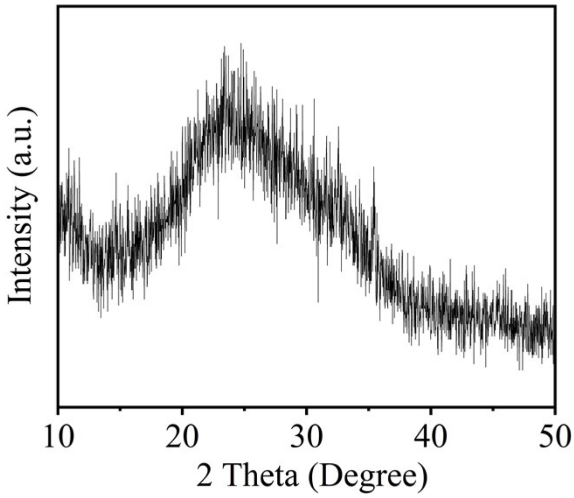

Figure S2. The XRD pattern of the CDs.

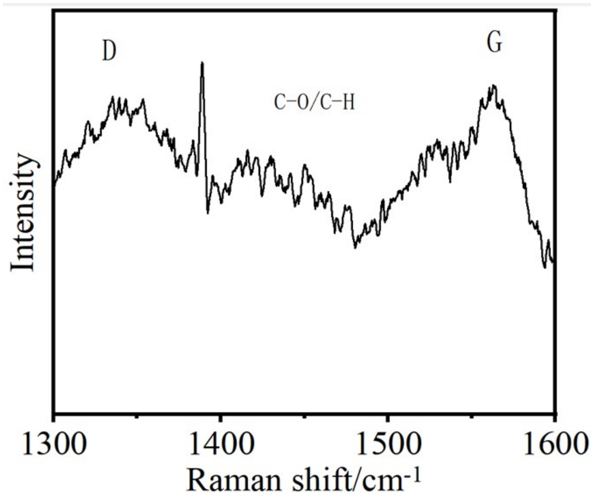

Figure S3. The Raman spectrum of CDs

Table S1.The XPS spectra of CDs quantify Csp^2 and Csp^3.

C 1s chemical state (at. %)	C sp^2	C sp^3
Peak sites	284.4	285.5
Proportion	0.37	0.63

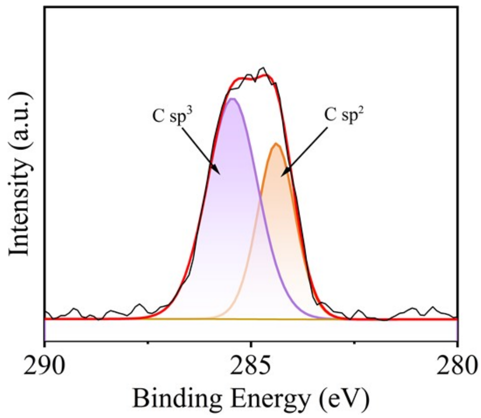

Figure S4. High-resolution C1s XPS spectra.

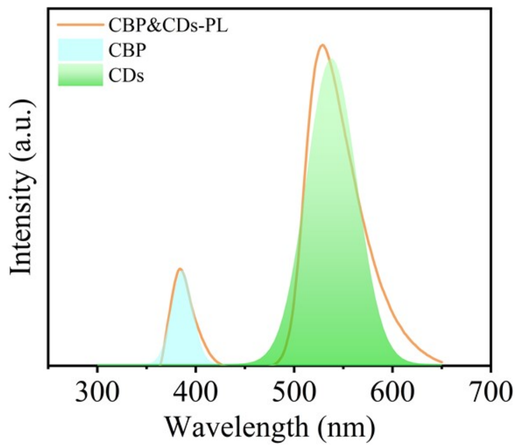

Figure S5. The Peak-splitting fitted spectrum of CBP&CDs (λex = 365 nm)

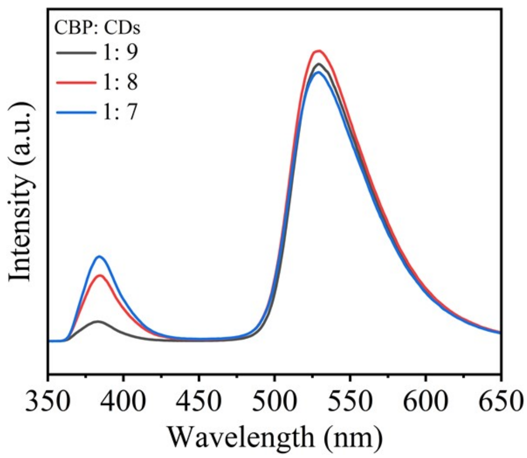

Figure S6. the PL of CBP& CDs with different ratio.

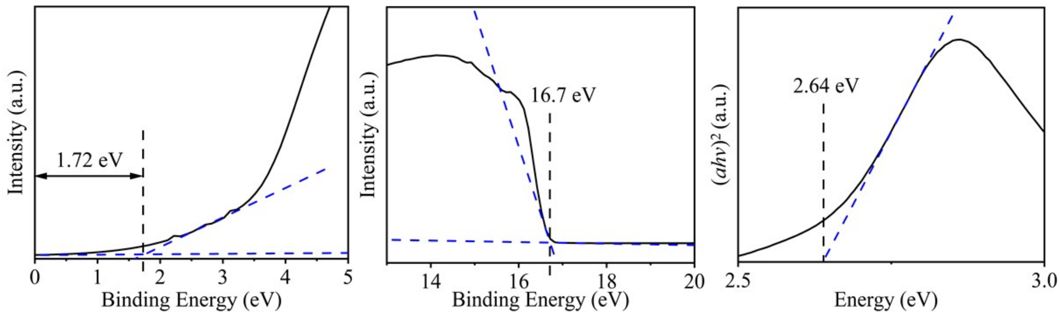

Figure S7. The UPS measurements of the CDs and plots between $(ahv)^2$ and photon energy of Absorption spectra of CDs in toluene solution.

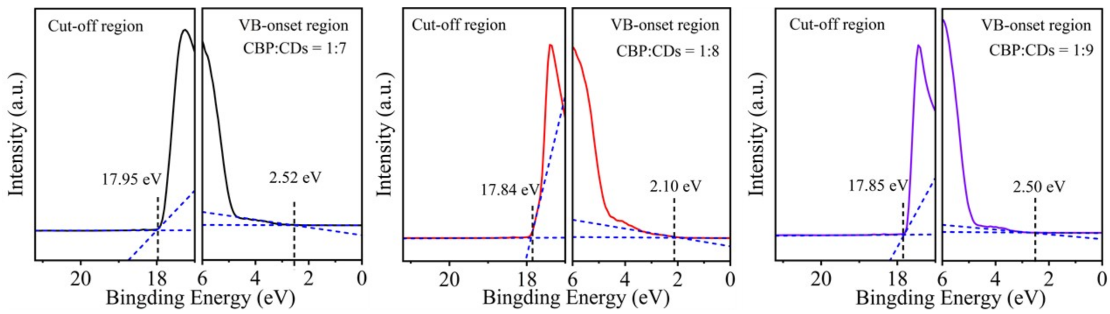

Figure S8. The UPS measurements of the CBP&CDs with different ratio.

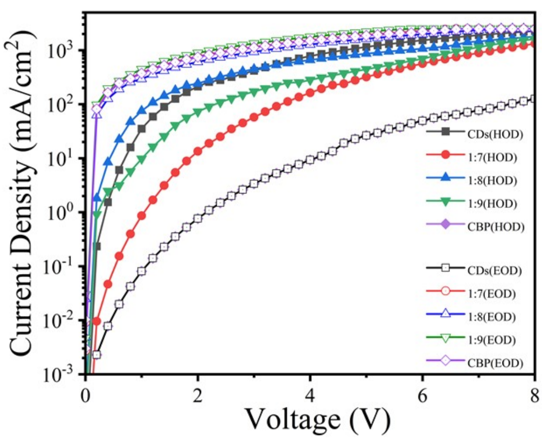

Figure S9. *J-V* characteristic curves of electron-only and hole-only devices of CDs mixed with different host materials.

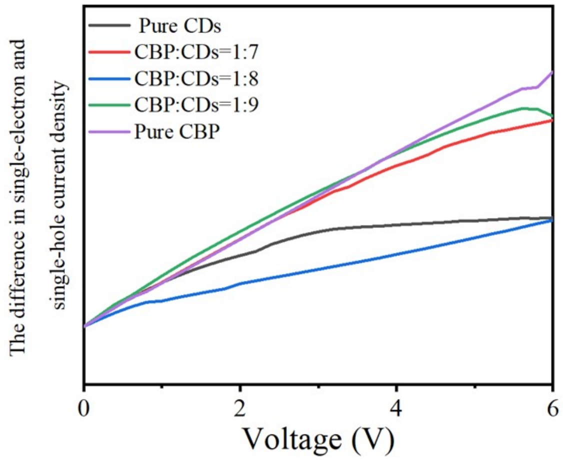

Figure S10. *J-V* characteristic curves of the difference value in electron-only and hole-only devices.

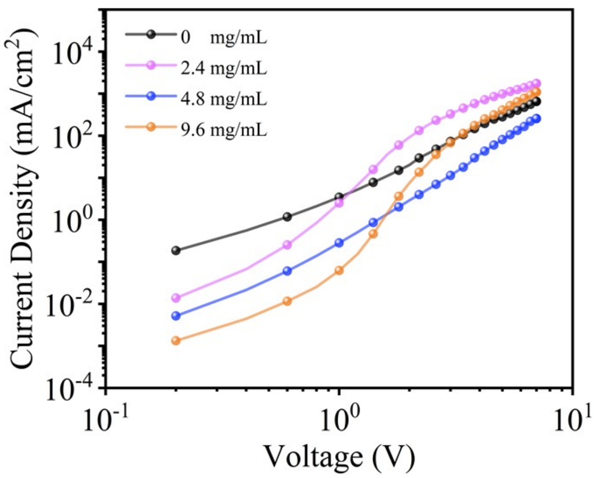

Figure S11. *J-V* characteristic curves of CDs-LEDs with different amount of PVP in ZnMgO.

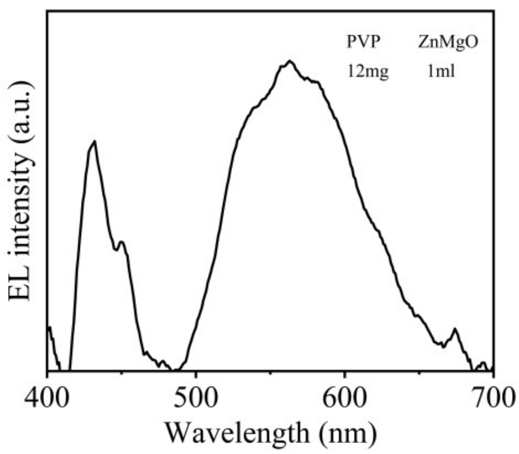

Figure S12. EL spectrum of the device with PVP (12 mg) doped ZnMgO as ETL.

Table S2. The CIE coordinates changes with the variation of the CBP: CDs ratio and the increase of PVP amount in the ETL layer.

Content of PVP (mg/ml)	CBP: CDs	CIE
0	1:7	(0.19, 0.32)
	1:8	(0.21, 0.35)
	1:9	(0.20, 0.30)
2.4	1:7	(0.20, 0.30)
	1:8	(0.22, 0.35)
	1:9	(0.22, 0.31)
4.8	1:7	(0.24, 0.33)
	1:8	(0.24, 0.39)
	1:9	(0.22, 0.33)
9.6	1:7	(0.22, 0.34)
	1:8	(0.31, 0.47)
	1:9	(0.23, 0.37)
12	1:7	(0.21, 0.31)
	1:8	(0.40, 0.45)
	1:9	(0.24, 0.34)

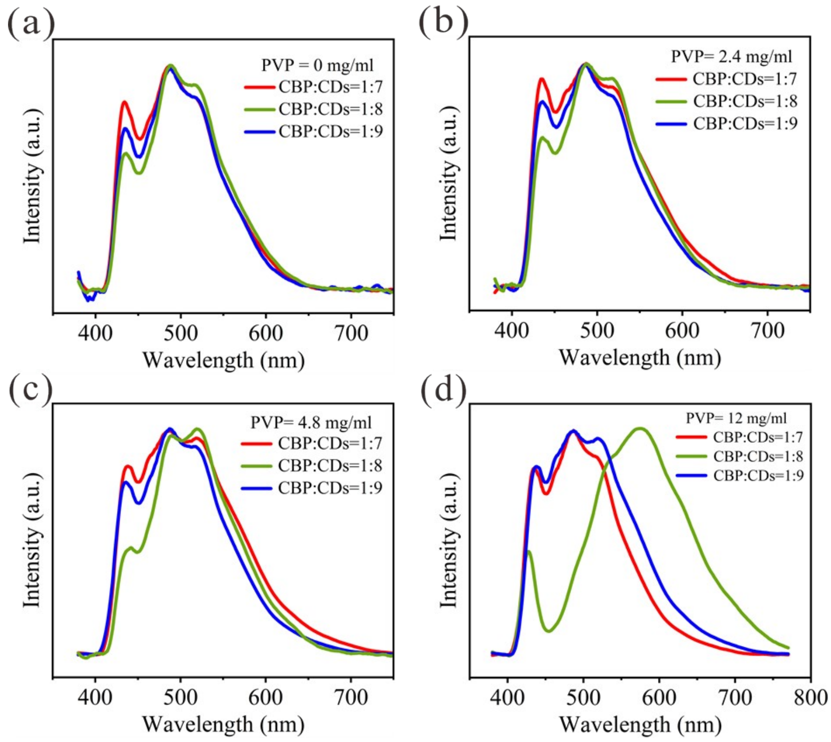

Figure S13. The EL spectra changes with the variation of the CBP: CDs ratio and with the increase in PVP amount in the ETL layer.

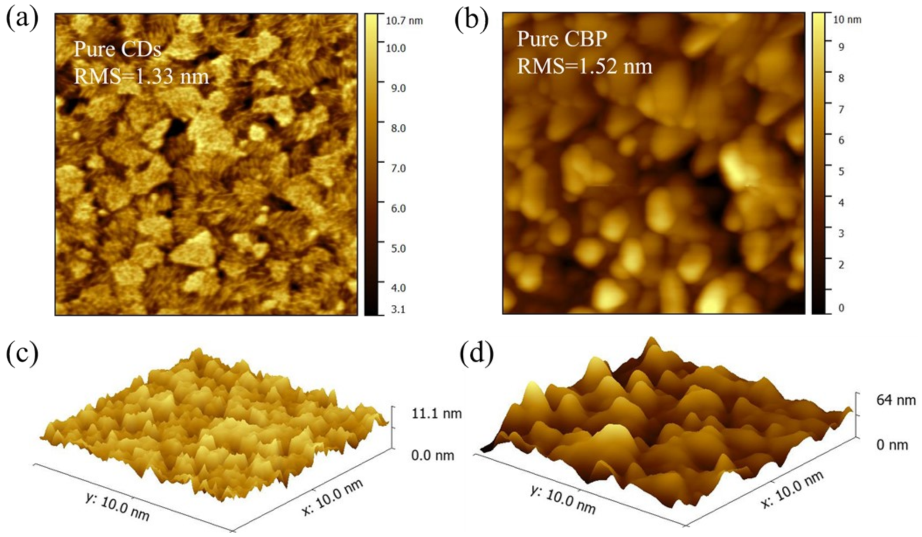

Figure S14. AFM characterization of the emission layer. Height image and pseudo-three-dimensional image of CDs film (a and c) and CBP film (b and d).

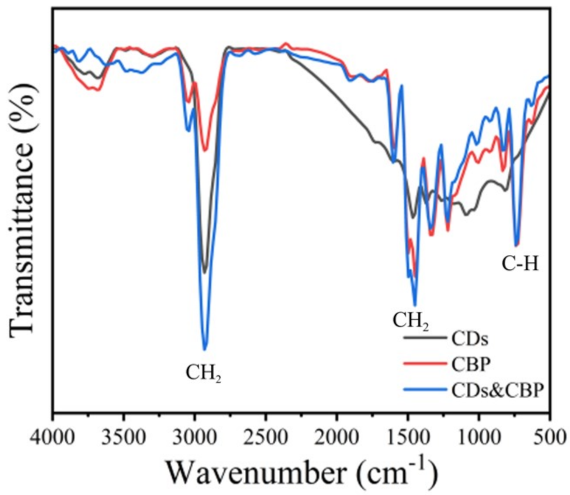

Figure S15 . The FT-IR spectrum of CBP, CBP&CDs, CDs.

Table S3. The fitting parameters of PL decay curves for CDs, CBP, and CBP&CDs

sample	λ_{ex} (nm)	λ_{em} (nm)	A_1	τ_1 (ns)	A_2	τ_2 (ns)	τ_{av} (ns)
CDs	365	528	1.13	2.6	22126.4	9.3	9.29
CBP&CDs	290	528	4.6	2.9	11971.5	10.5	10.49
CBP	365	395	3.3	0.96	6.5	2.3	2.06

Table S4. The structures of different devices and EL peaks are listed.

Device	Device Structure	EL Peak (nm)
1	ITO/PEDOT: PSS/TFB/ZnMgO/Al	440
2	ITO/PEDOT: PSS/TFB/ZnMgO&PVP/Al	440
3	ITO/PEDOT: PSS/TFB/PVK&CDs/ZnMgO&PVP/Al	/
4	ITO/PEDOT: PSS/TFB/TcTa&CDs/ZnMgO&PVP/Al	/
5	ITO/PEDOT: PSS/TFB/CDs/ZnMgO&PVP/Al	530

Table S5. Hall effect testing of ZnMgO and ZnMgO&PVP

Semiconductor hall measurement						
sample	temperature	Resistivity	Mobility	Carrier concentration	Hall coefficient	F factor
ZnMgO	Room temperature	1.54	2.21×10^{3}	1.83×10^{15}	-3.42×10^{3}	5.44×10^{-1}
ZnMgO&PVP	Room temperature	1.07	5.71×10^{2}	1.02×10^{16}	-6.14×10^{2}	9.92×10^{-1}

Table S6. Comparison of the device performance of this work with other CD-LEDs reported previously.

Year	Device structure	Luminance (cd/m^2)	V_{on} (V)	References
2018	ITO/PVK: CDs /TPBi /LiF /Al	569.8	8.5	[42]
2020	ITO/PEDOT: PSS/PVK: CDs /TPBi /Liq /Al	163	3.7	[52]
2021	ITO/PEDOT: PSS/TFB/PVK: CDs /TPBi /Liq /Al	681	7	[53]
2022	ITO/Poly-TPD/CDs/TPBi/Ca/Al	2967	3.3	[20]
2023	ITO/ NiO_X/PEDOT: PSS/O-CDs/TPBi/Ca/Al	6752	3.1	[21]
	ITO/ NiO_X/PEDOT: PSS/Y-CDs/TPBi/Ca/Al	2030	3.6	[21]
	ITO/NiO_X/PEDOT: PSS/Y-CDs: TFB/TPBi/Ca/Al	5726	3.0	[21]
2023	ITO/PEDOT: PSS/TFB/CBP&CDs/ZnMgO&PVP/Al	505	2.5	This work