Supporting Information

Surface ligand engineering of pure-red perovskite nanocrystals with enhanced stability by diphenylammonium halide molecules

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Table S1. Resistivity and conductivity of the pristine, DPAI-, and DPABr-modified NC films.

Perovskite NC film	**Resistivity (ρ, Ω·cm)**	**Conductivity (σ, S·cm^{-1})**
pristine	6.44×10^6	1.55×10^{-7}
DPAI-modified	3.26×10^5	3.07×10^{-6}
DPABr-modified	4.27×10^5	2.34×10^{-6}

The band gap of the $CsPbBr_xI_{3-x}$ NC films was determined using the Tauc plot method, as expressed in the following equation (1):

$$(\alpha h\nu)^{\frac{1}{n}} = B(h\nu - E_g) \qquad (1)$$

where α is the absorption coefficient, *hv* represents the photon energy, *B* is a proportionality constant, and E_g is the bandgap. The parameter *n* corresponds to the type of semiconductor; for the direct-gap $CsPbBr_xI_{3-x}$ NCs, $n = 1/2$.

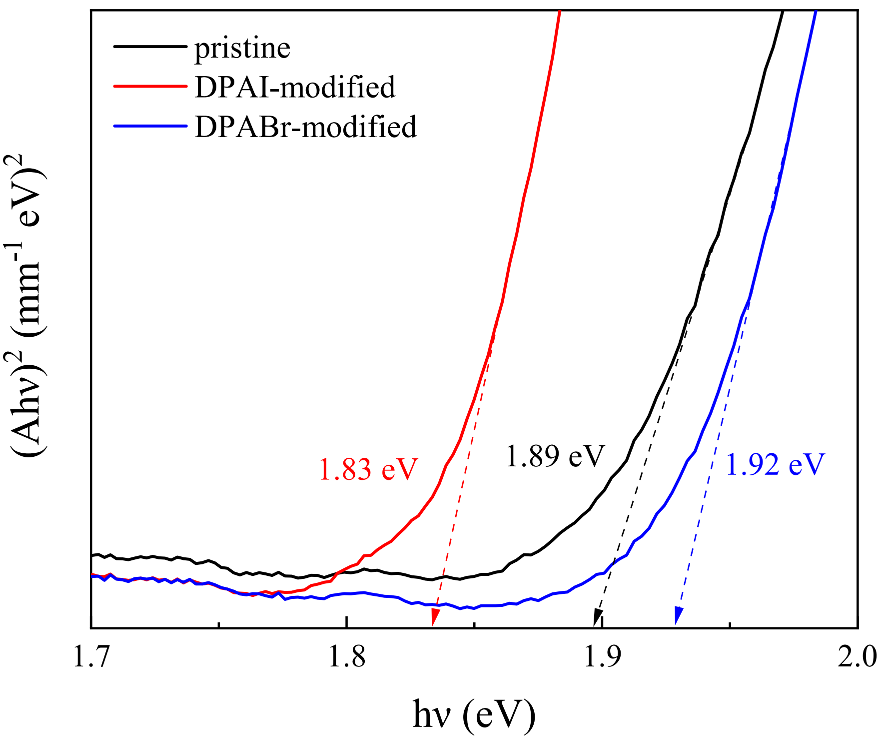

Fig. S1 Tauc plot of the pristine, DPAI-, and DPABr-modified NCs.

The PL decay curves of the $CsPbBr_xI_{3-x}$ NC films were analyzed using a bi-exponential decay model, as described by the following equation (2):

$$f(t) = A_1 \exp\left(-\frac{t}{\tau_1}\right) + A_2 \exp\left(-\frac{t}{\tau_2}\right) \quad (2)$$

where A_1 and A_2 are the amplitudes corresponding to the decay components with lifetimes τ_1 and τ_2, respectively. The τ_{avg} was calculated using the weighted contribution of each component, as described by the following equation (3):

$$\tau_{ave} = \frac{A_1\tau_1^2 + A_2\tau_2^2}{A_1\tau_1 + A_2\tau_2} \quad (3)$$

Table S2. Carrier lifetime parameters of TR-PL decay curves of the pristine, DPAI-, and DPABr-modified NCs.

Sample	**τ_1 (ns)**	**A_1 (%)**	**τ_2 (ns)**	**A_2 (%)**	**τ_{avg} (ns)**
pristine	4.07	19.15	14.38	80.85	8.76
DPAI-modified	6.23	21.72	15.87	78.28	10.22
DPABr-modified	5.11	23.02	16.85	76.98	10.94

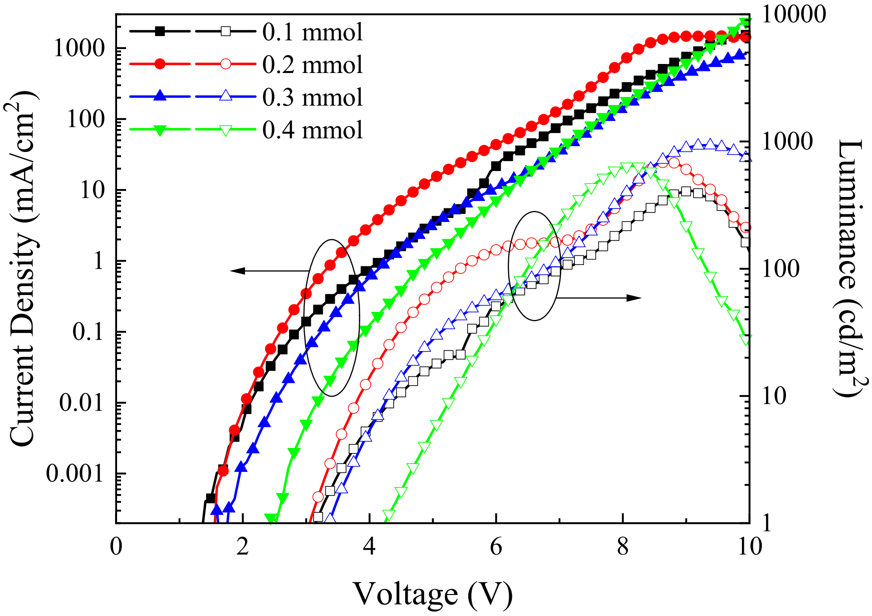

Fig. S2 *J*–*V*–*L* curves of DPAI-modified PeLEDs using different molar concentrations of DPAI from 0.1 to 0.4 mmol.

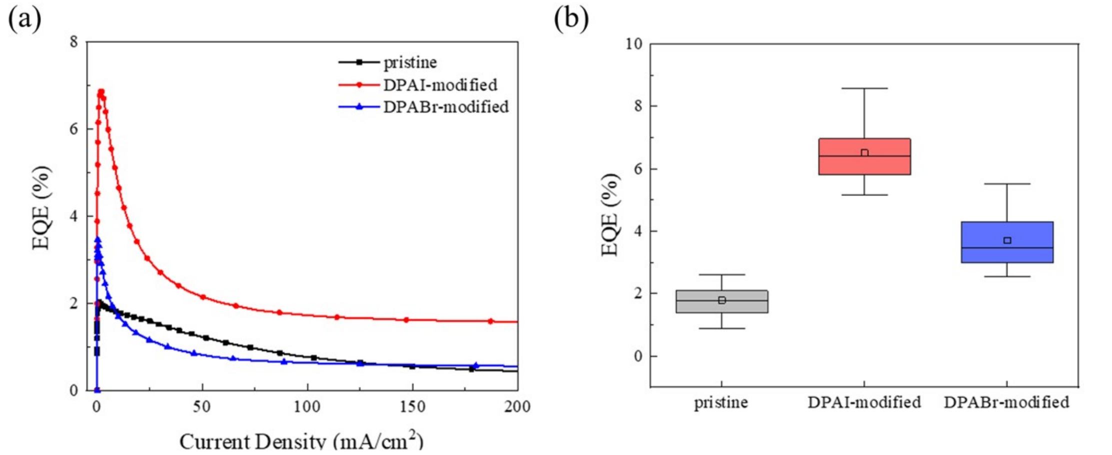

Fig. S3 (a) EQE–*J* curves and (b) EQE statistical distribution of the pristine, DPAI-, and DPABr-modified devices.

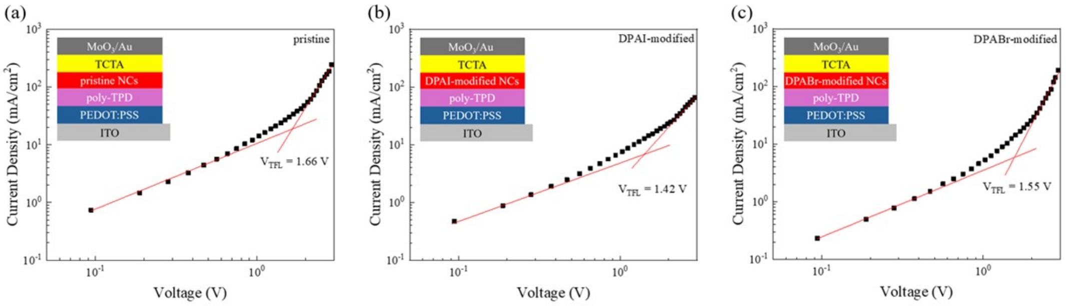

Fig. S4 SCLC characteristics for the (a) pristine, (b) DPAI-, and (c) DPABr-modified devices. The insets show the structure of the hole-only devices based on different perovskite NCs.

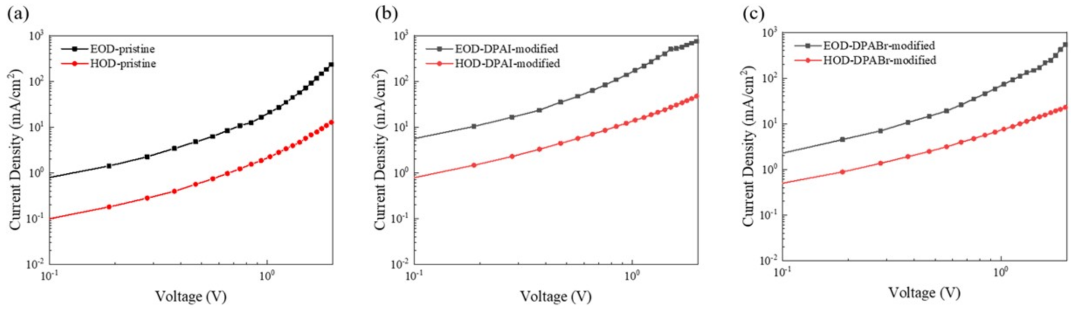

Fig. S5 *J*–*V* characteristics of the electron-only and hole-only devices based on the (a) pristine, (b) DPAI-, and (c) DPABr-modified NCs.

Table S3. An overview of the performance for red PeLEDs from previous literature and our work.

Year	perovskite	EL (nm)	L_{max} (cd/m^2)	EQE (%)	T_{50} stability	Refs.
2018	$CsPbI_3$ with IDA	688	748	5.02	–	[1]
2018	$CsPb(Br/I)_3$ with An-HI	645	794	14.1	180 min @ 100 cd/m^2	[2]
	$CsPb(Br/I)_3$ with OAM-I	653	500	21.3	5 min @ 100 cd/m^2	
2020	$CsPbBr_xI_{3−x}$ with TrDAI	637	255	6.36	540 s @ 4.1 V	[3]
2020	$CsPbBr_xI_{3−x}$ with KBr	637	2,671	3.55	50 s @ 100 cd/m^2	[4]
2021	$CsPbBr_xI_{3−x}$ with In^{3+}	639	423	11.2	–	[5]
2021	KI-exchanged $CsPbI_3$	640	870	23	10 h @ 200 cd/m^2	[6]
2021	β-$CsPbI_3$ with PMA	689	618	17.8	317 h @ 30 mA/cm^2	[7]
2022	$CsPb(I_xBr_{1−x})_3$	642	–	24.4	20 h @ 200 cd/m^2	[8]
2023	$CsPb(Br/I)_3$ with benzenesulfonate	640	1510	23.5	97 min @ 100 cd/m^2	[9]
2023	$CsPbI_{3-x}Br_x$	637	2653	21.8	70 min @ 150 cd/m^2	[10]

2024	$PEA_2Cs_{n-1}Pb_n(Br/I)_{3n+1}$ Br/I ratio = 0.38	668	3024	30.08	47.7 h @ 140 cd/m^2	[11]
	$PEA_2Cs_{n-1}Pb_n(Br/I)_{3n+1}$ Br/I ratio = 0.60	656	2401	32.14	60 h @ 250 cd/m^2	
	$PEA_2Cs_{n-1}Pb_n(Br/I)_{3n+1}$ Br/I ratio = 0.66	648	1231	29.04	43.7 h @ 270 cd/m^2	
2024	$CsPbBr_xI_{3-x}$	636	1621	21.2	240 min @ 130 cd/m^2	[12]
2024	$CsPbI_3$ with TOP	685	906	21.23	40 min @ 100 cd/m^2	[13]
2025	$CsPbBr_xI_{3-x}$ with DPAI	665	913	6.9	800 s @ 5 V	This work
	$CsPbBr_xI_{3-x}$ with DPABr	654	562	3.5	488 s @ 5 V	

Table S4. Carrier mobility and μ_e/μ_h ratio of the pristine, DPAI-, and DPABr-modified electron-only and hole-only devices.

Sample	**Electron Mobility (cm^2/Vs)**	**Hole Mobility (cm^2/Vs)**	**μ_e/μ_h Ratio**
pristine	1.69×10^{-4}	2.95×10^{-5}	5.73
DPAI-modified	4.64×10^{-4}	1.25×10^{-4}	3.71
DPABr-modified	2.92×10^{-4}	5.96×10^{-5}	4.90

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