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Electronic Supplementary Information

High-Efficiency Perovskite Nanocrystal Light-Emitting Diodes via Decorating NiO_x on Nanocrystals Surface

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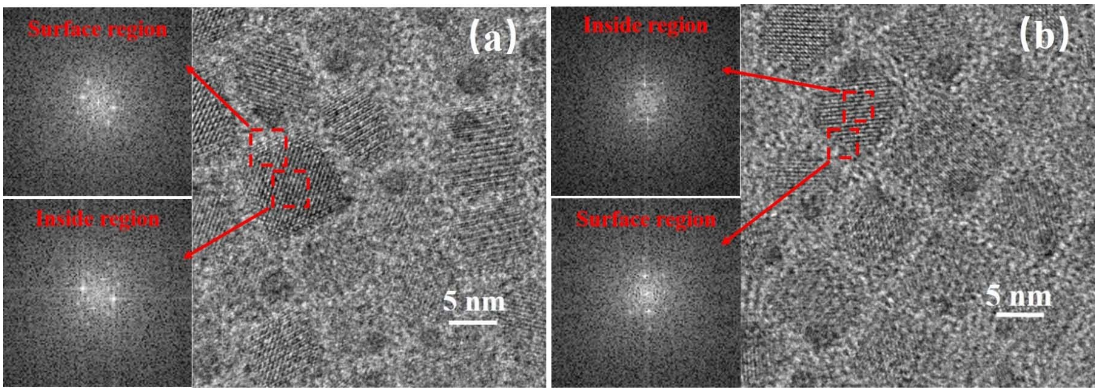

Figure S1 HRTEM images of (a) $CsPbBr_3$-DDAB and (b) $CsPbBr_3$-DDAB-Ni NCs.

Table S1 Interplanar spacing of $CsPbBr_3$-DDAB and CsPbBr3-DDAB-Ni NCs

Pe-QDs		**Interplanar spacing（110）**	**Interplanar spacing（001）**
$CsPbBr_3$-DDAB	Inside	3.94 Å	5.87 Å
	Surface	3.92 Å	5.85 Å
$CsPbBr_3$-DDAB-Ni	Inside	3.92 Å	5.89 Å
	Surface	4.16 Å	5.91 Å

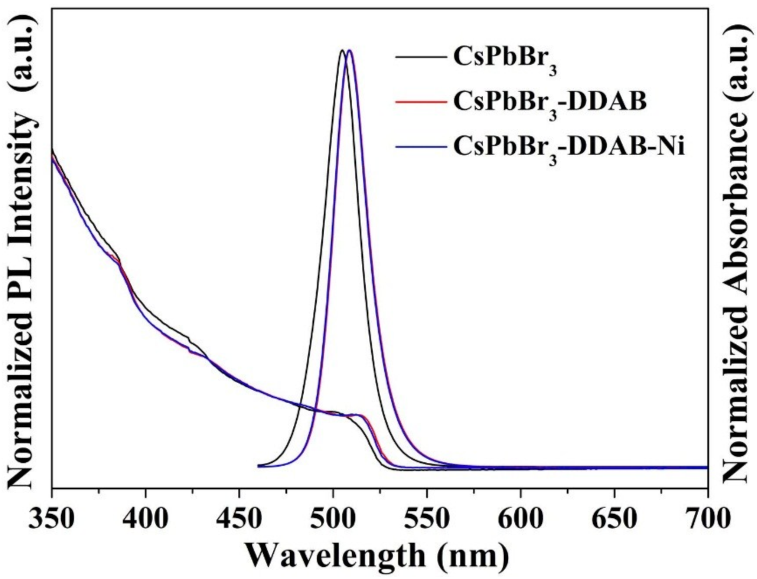

Figure S2 PL (absorbance is 0.5 at 450 nm) and UV-vis absorption spectra of $CsPbBr_3$, $CsPbBr_3$-DDAB, and $CsPbBr_3$-DDAB-Ni NCs.

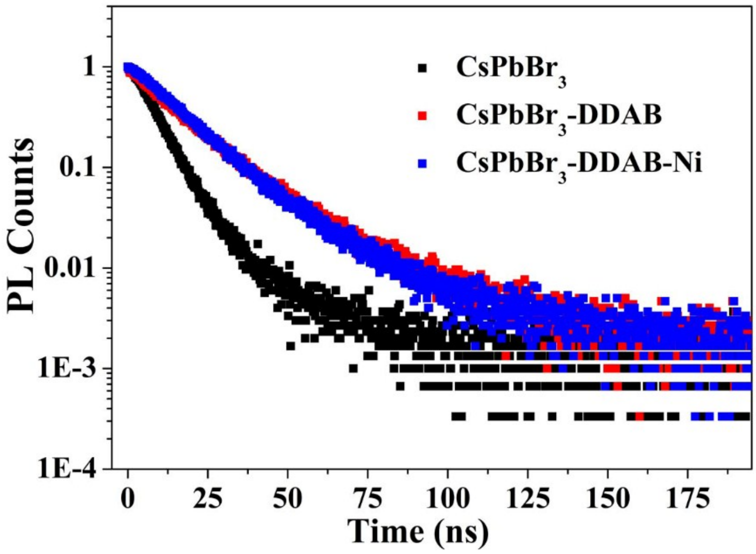

Figure S3 Time-resolved PL decays and the fitted curves for the $CsPbBr_3$, $CsPbBr_3$-DDAB, and $CsPbBr_3$-DDAB-Ni NCs solutions detected with excitation of 450 nm.

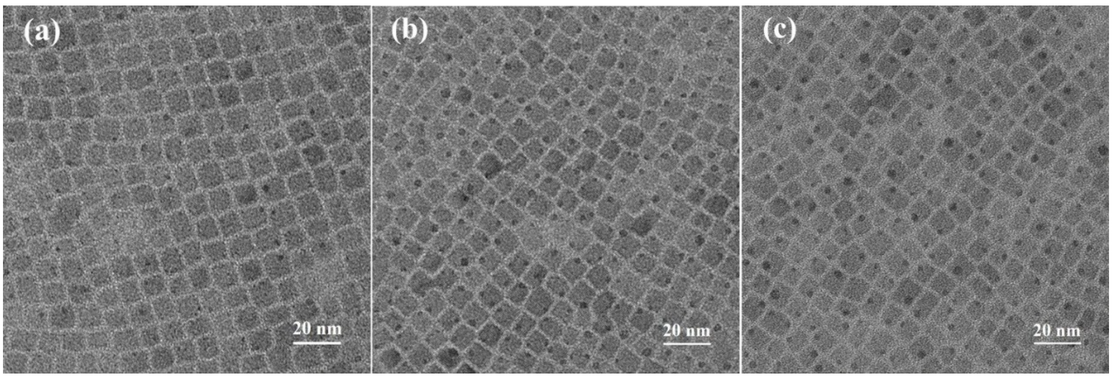

Figure S4 TEM images of (a) $CsPbBr_3$, (b) $CsPbBr_3$-DDAB, and (c) $CsPbBr_3$-DDAB-Ni NCs

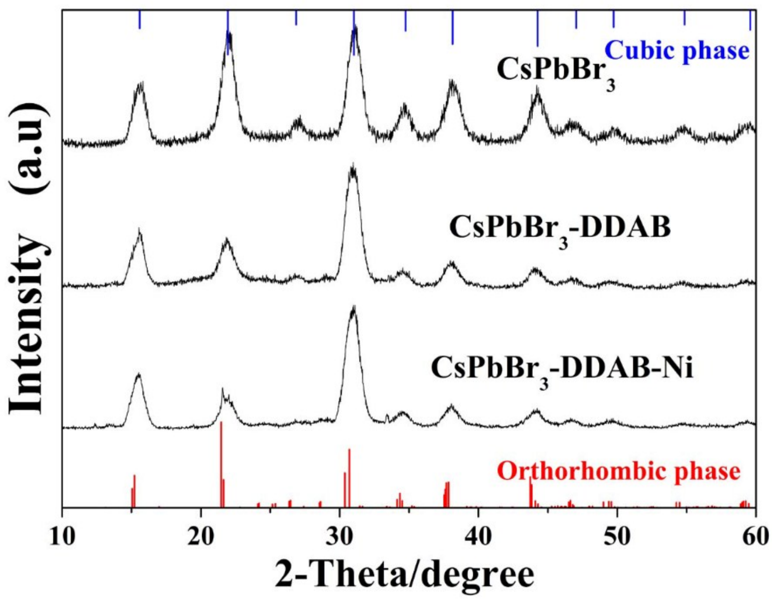

Figure S5 XRD patterns of $CsPbBr_3$, $CsPbBr_3$-DDAB, and $CsPbBr_3$-DDAB-Ni NCs

Figure S6 Optical images of the $CsPbBr_3$-DDAB-Ni NCs under illumination with a 450 nm LED light (175 mW/cm^2).

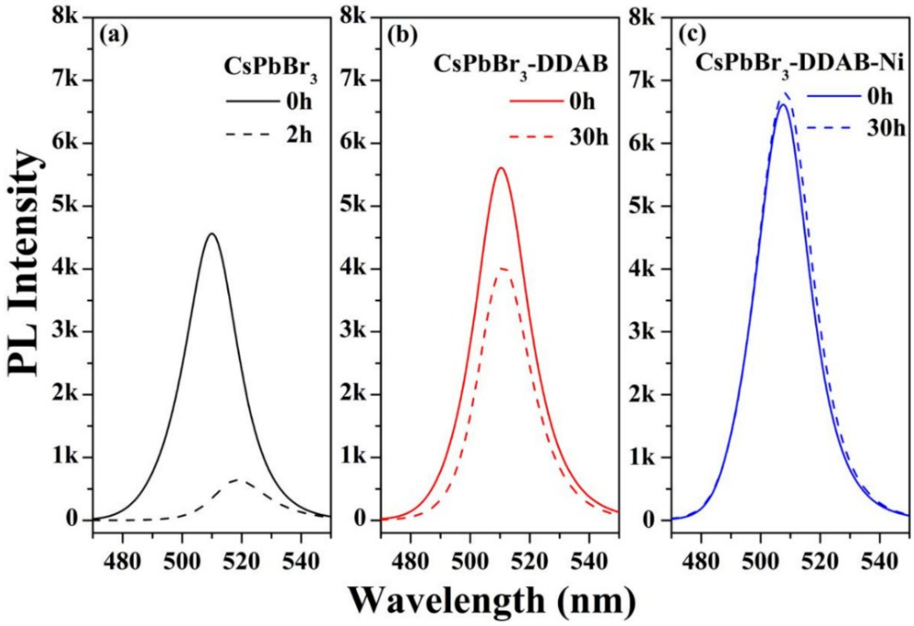

Figure S7 PL spectra of the $CsPbBr_3$, $CsPbBr_3$-DDAB, and $CsPbBr_3$-DDAB-Ni NCs solution as a function of the illumination time with a 450 nm LED light(175 mW/cm^2).

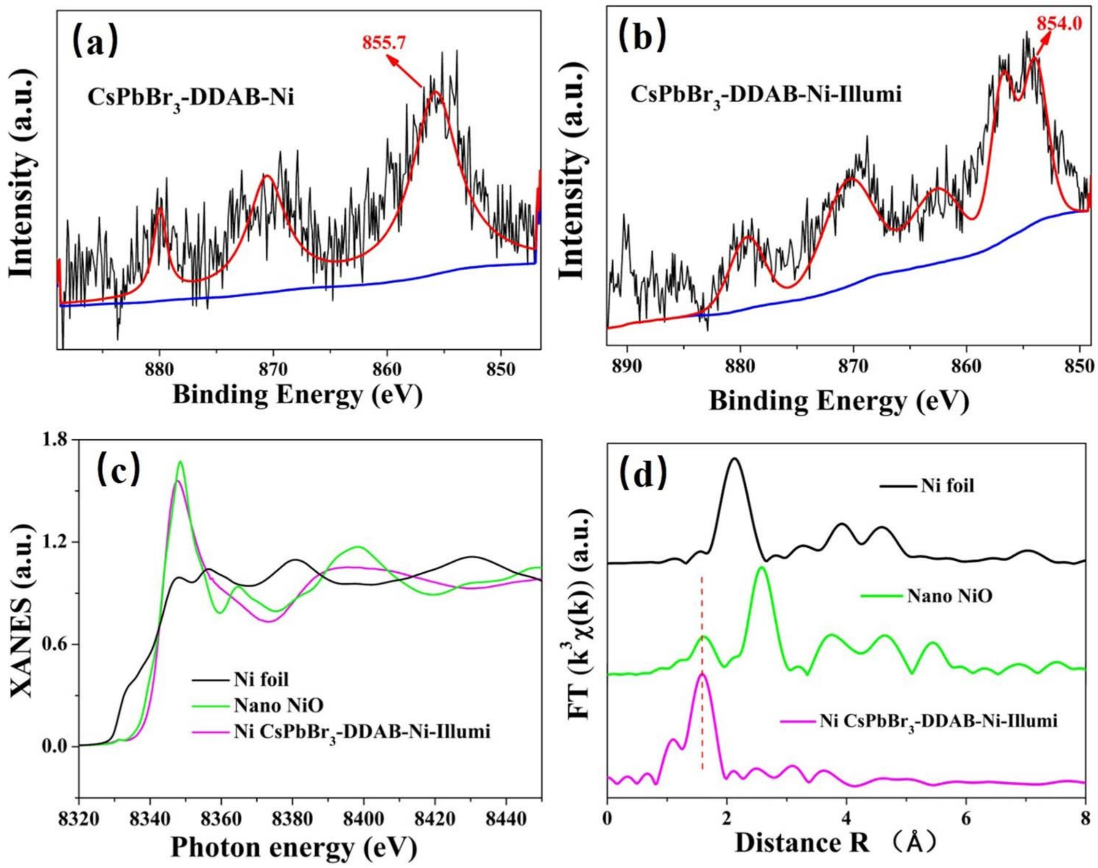

Figure S8 2p XPS spectra of the $CsPbBr_3$-DDAB-Ni NCs (a) before and (b) after light irradiation for 30 hours; (c) Ni K-edge XANES spectra; and (d) Ni K-edge Fourier transformed EXAFS spectra in the R space.

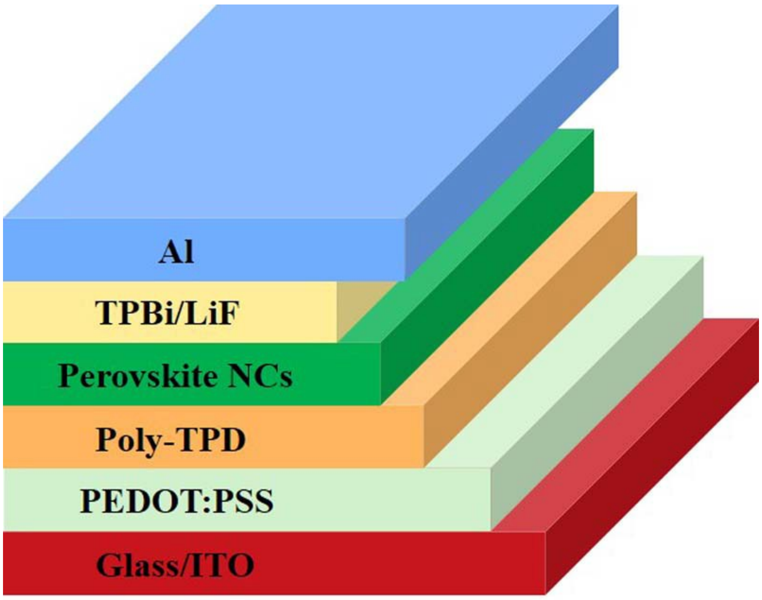

Figure S9 Illustration of the schematic perovskite LED device structure

Table S2 Characteristics of LED devices. L (Luminance), EQE (external quantum efficiency), V_{on} (turn-on voltage), CE (current efficiency)

Pe-QDs	L_{max} (cd m^{-2})	Peak EQE (%)	Turn-on Voltage (V) @ 1cd m^{-2}	CE_{max} (cd A^{-1})
$CsPbBr_3$	451	0.5	5.6	0.9
$CsPbBr_3$-DDAB	416	3.2	4.2	6.1
$CsPbBr_3$-DDAB-Ni	553	6.5	3.0	12.6
$CsPbBr_3$-DDAB-Ni- Illumi	870	9.2	3.0	17.8

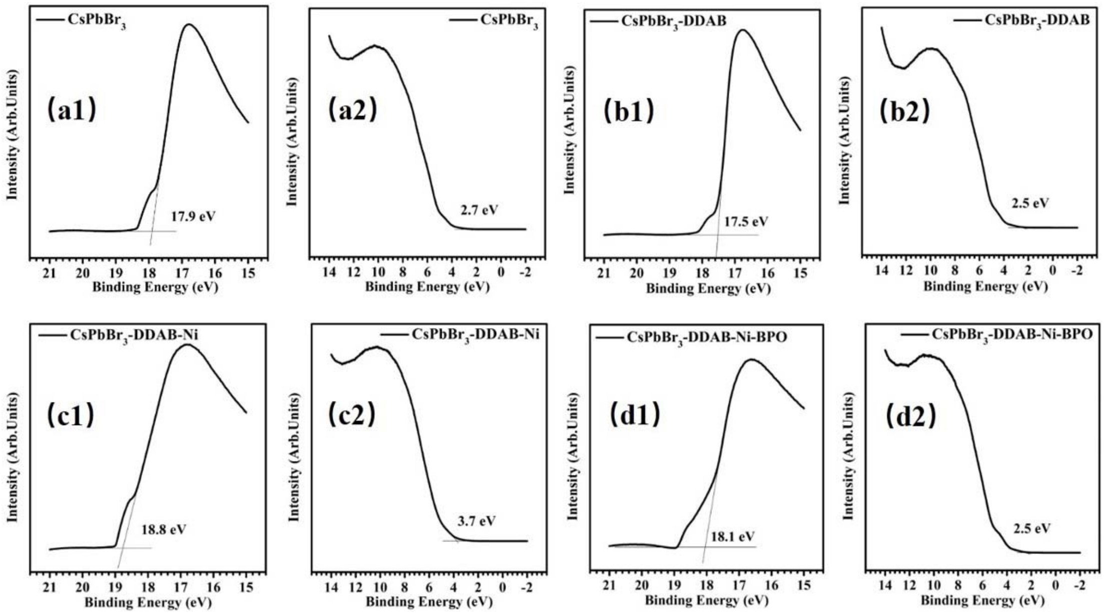

Figure S10 High-binding energy secondary-electron cutoff regions of Pe-NCs and VB-edge region of Pe-NCs.

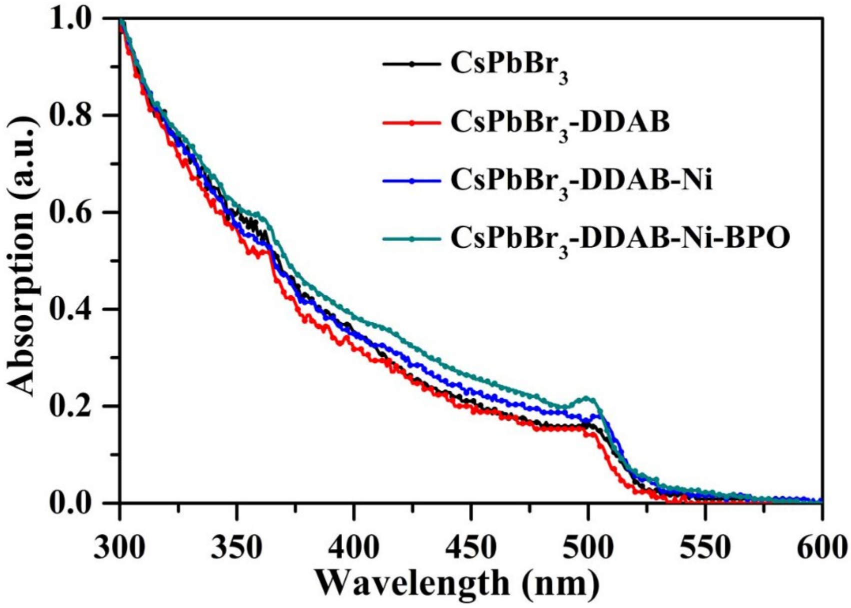

Figure S11 UV-vis absorption spectra of $CsPbBr_3$, $CsPbBr_3$-DDAB, $CsPbBr_3$-DDAB-Ni, and $CsPbBr_3$-DDAB-Ni-BPO films

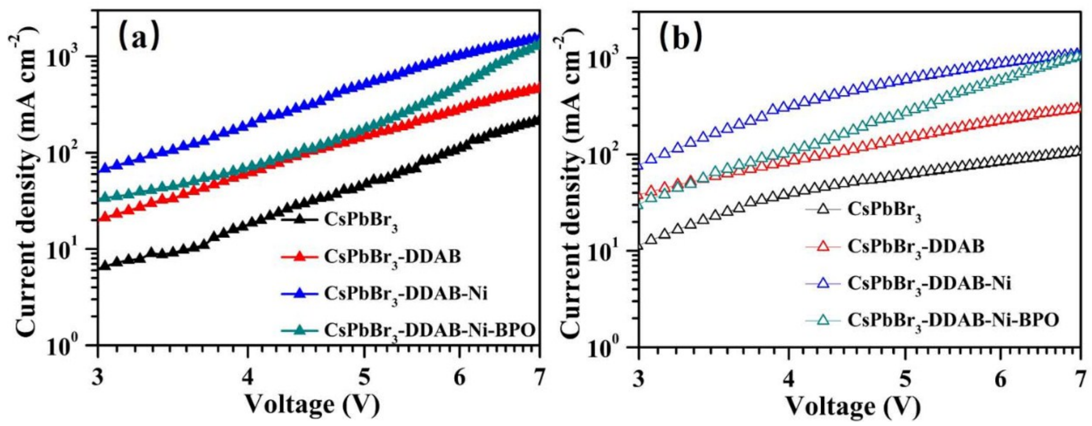

Figure S12 Current density–voltage (J–V) characteristics of (a) electron-only and (b) hole-only Pe-LED devices with $CsPbBr_3$, $CsPbBr_3$-DDAB, $CsPbBr_3$-DDAB-Ni, and $CsPbBr_3$-DDAB-Ni-BPO films.

The mobility was measured by the space charge limited current (SCLC) method by a hole-only device with a structure of ITO/PEDOT: PSS/Poly-TPD/Perovskite NCs/MoO_3/Al or an electron-only device with a structure of ITO/ZnO/Perovskite NCs TPBi/LiF/Al and estimated through the Mott-Gurney equation[1].

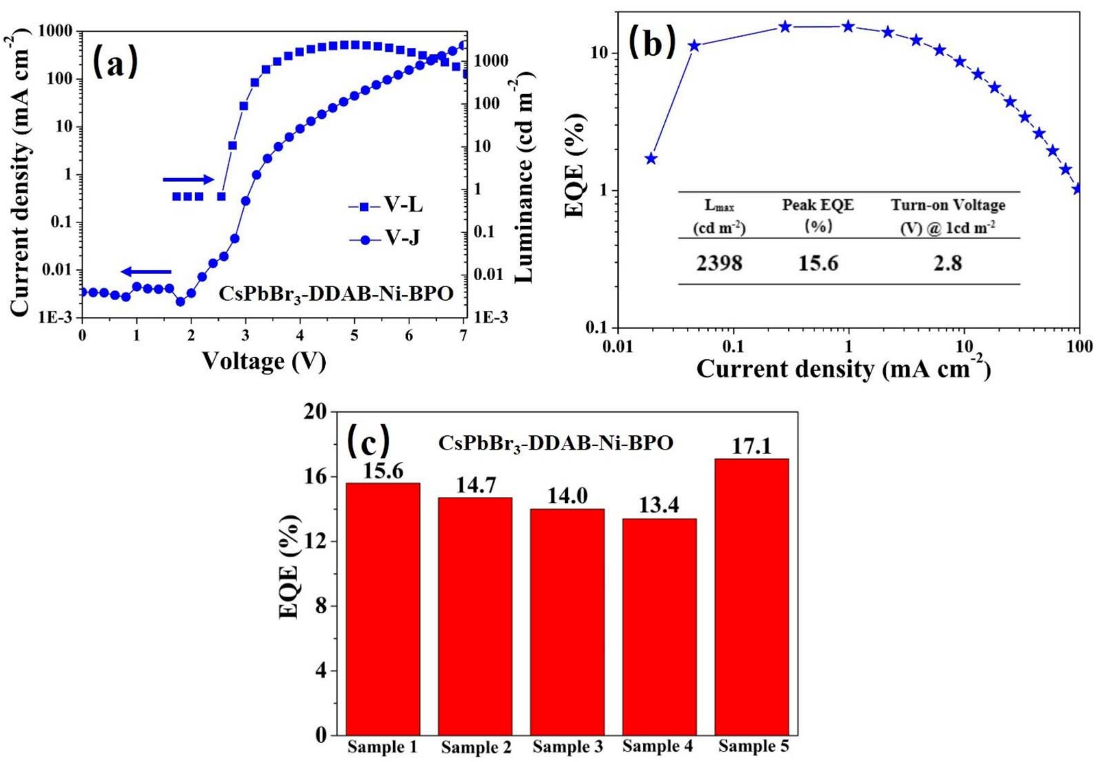

Figure S13 (a) Current density and Luminance versus driving voltage characteristics; (b) EQE versus current density characteristics with inserted table showing characteristics of LED devices; (c) EQE values of LEDs fabricated with different batches of $CsPbBr_3$-DDAB-Ni-BPO NCs.

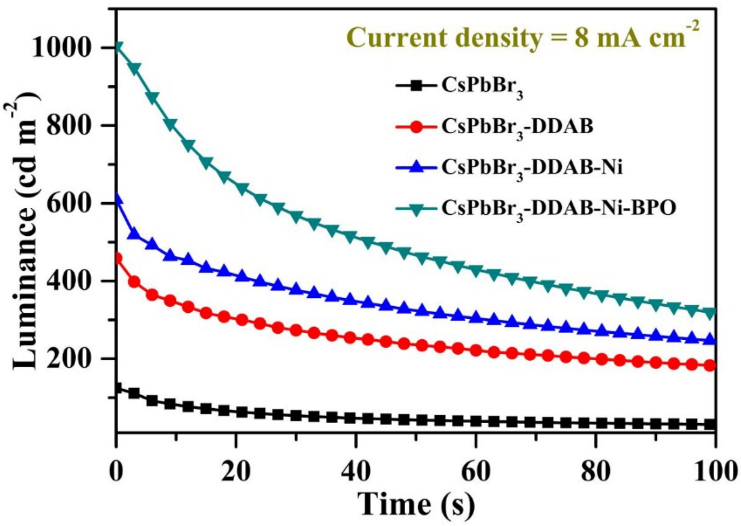

Figure S14 Lifetime measurements of the $CsPbBr_3$-based LED devices.

Table S3. Summary of the performance of LEDs based on $CsPbBr_3$ NCs

Composition and types	V_{ON} (V)	EL (nm)	Max. Luminance (Cd/m^2)	Peak EQE (%)	Max. CE (Cd/A)	Publication Date and Ref
$CsPbBr_3$ NCs	4.2	516	946	0.12	0.43	2015[2]
$CsPbBr_3$ NCs	3.5	516	1377	0.06	0.19	2016[3]
$CsPbBr_3$ NCs	3.0	515	330	3	≈9	2016[4]
$CsPbBr_3$ NCs	3.4	512	15185	6.27	13.3	2016[5]
$CsPbBr_3$ NCs	4.6	515	12090	1.19	3.11	2017[6]
$CsPbBr_3$ NCs	2.9	518	3059	1.1	3.66	2017[7]
$CsPbBr_3$ NCs	2.6	512	1660	8.73	—	2017[8]
$CsPbBr_3$ NCs	2.4	518	4212	0.35	1.38	2017[9]
$CsPbBr_3$ NCs	2.8	516	7085	6.5	18.13	2018[10]
$CsPbBr_3$ NCs	≈7	≈520	≈450	1.43	4.69	2018[11]
$CsPbBr_3$ NCs	2.4	515	55800	11.6	45.5	2018[12]
$CsPbBr_3$ NCs	2.7	508	≈1000	8.08	—	2018[13]
$CsPbBr_3$ NCs	≈3	512	18600	15.17	≈50	2018[14]
$CsPbBr_3$ NCs	2.4	518	76940	16.48	66.7	2018[15]
$CsPbBr_3$ NCs	2.6	517	2270	9.7	31.7	2019[16]
$CsPbBr_3$ NCs	≈3.5	520	≈500	8.2	25.7	2019[17]
$CsPbBr_3$ NCs	**2.8**	**512**	**2114**	**16.8**	**32.4**	**This work**

As we know, the morphologies of emitting layer for perovskite light-emitting diodes (PeLEDs) could be bulk form, thin films and nanocrystals (NCs). In this paper, we focused on studying the device performances of PeLEDs based on NCs. Here, we collected the date about the device performances of $CsPbBr_3$ NCs LEDs, which is shown in the Table S2. To our knowledge, the EQE of 16.8% in our work may be the highest value for the LEDs fabricated with $CsPbBr_3$ NCs. Additionally, the highest EQE of 21.3% has been achieved by using all-inorganic $CsPbBr_{0.6}I_{2.4}$ NCs as emitters[18], which is the record-holder for all-inorganic NCs fabricated in LEDs.

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