Supporting Information

White Light-Emitting Diodes Based on Blue and Green Quantum Confined $CsPbBr_3$ Perovskite Quantum Dots and Red CdSe Quantum Dots Without Ion Exchange Issue

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Keywords: perovskite quantum dots, quantum confinement, color engineering, anion exchange, photoluminescence

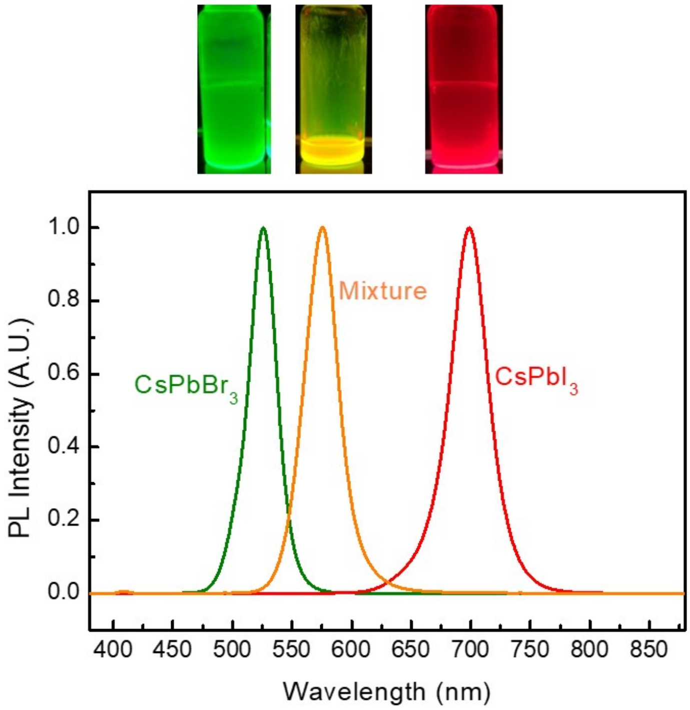

Figure S1 The photograph images and PL spectra of perovskite QD solutions. $CsPbBr_3$ and $CsPbI_3$ QD solutions were mixed and a new emission peak occurred.

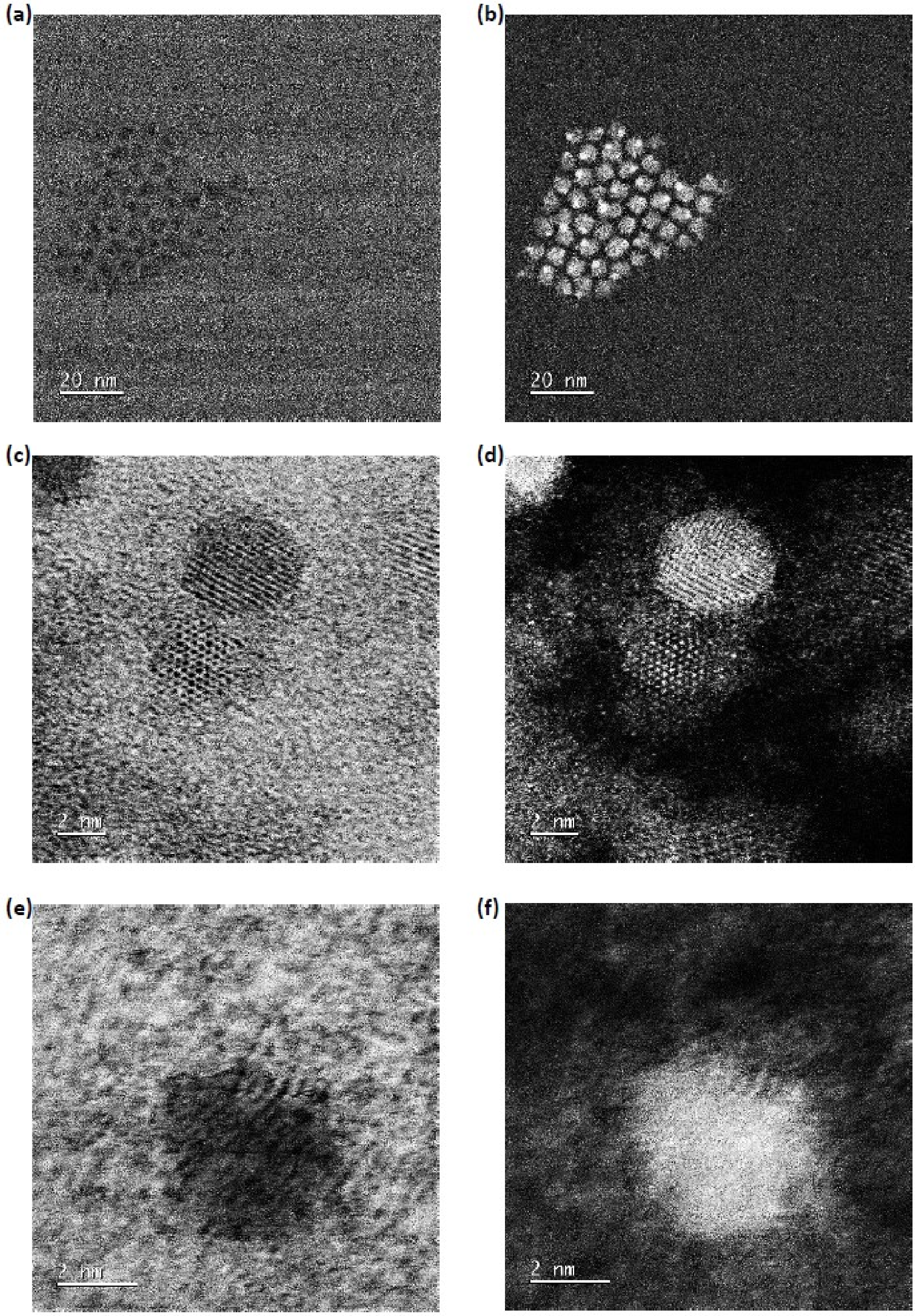

Figure S2 (a,c,e) Bright-field TEM images and (b,d,f) HAADF-STEM images of the $CsPbBr_3$ QDs prepared at 80 ^{o}C reaction temperature. (a,b), (c,d), and (e,f) are pairs of bright-field TEM images and HAADF-STEM images at the same position on the lacey-carbon grids.

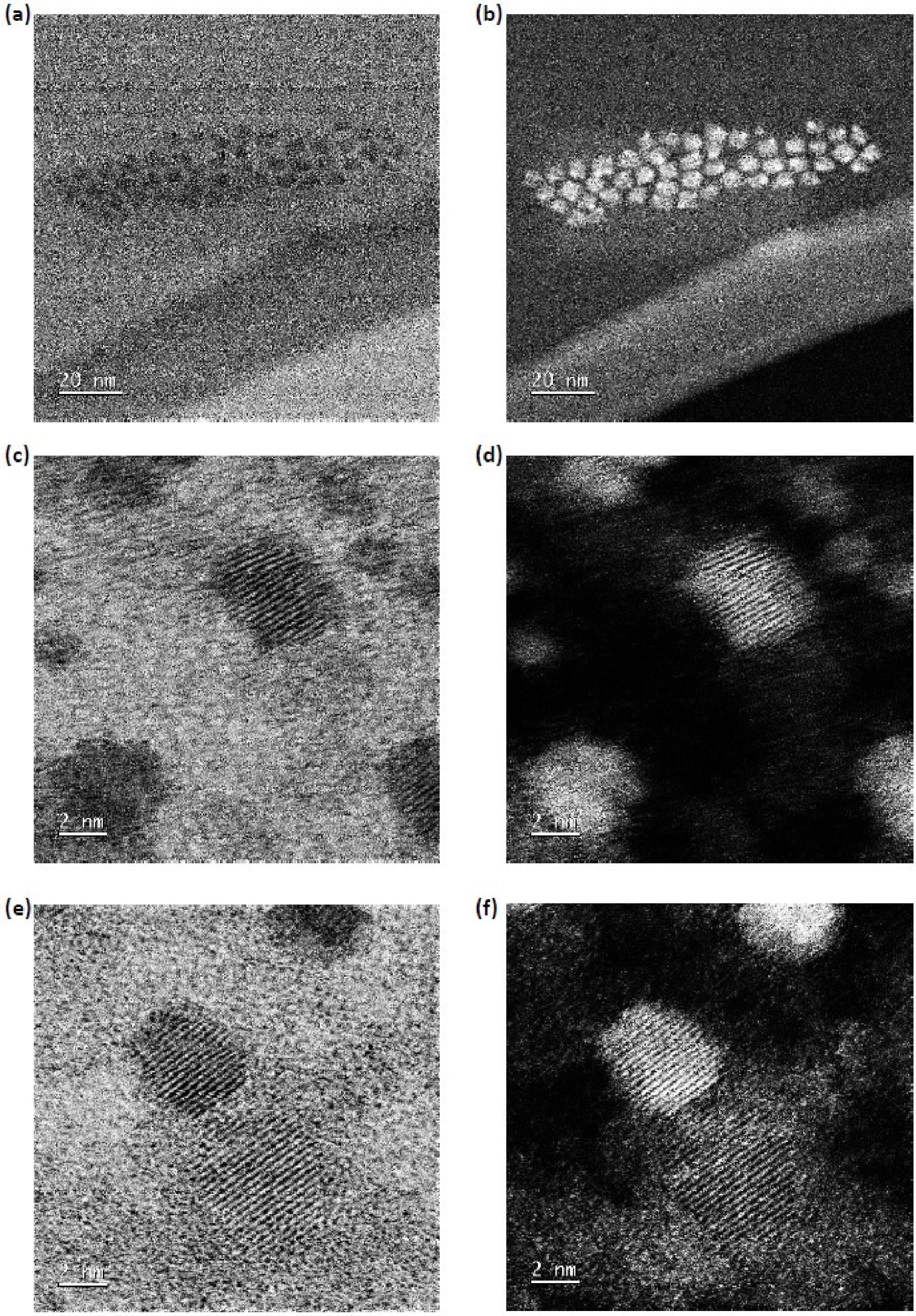

Figure S3 (a,c,e) Bright-field TEM images and (b,d,f) HAADF-STEM images of the $CsPbBr_3$ QDs prepared at 140 ^oC reaction temperature. (a,b), (c,d), and (e,f) are pairs of bright-field TEM images and HAADF-STEM images at the same position on the lacey-carbon grids.

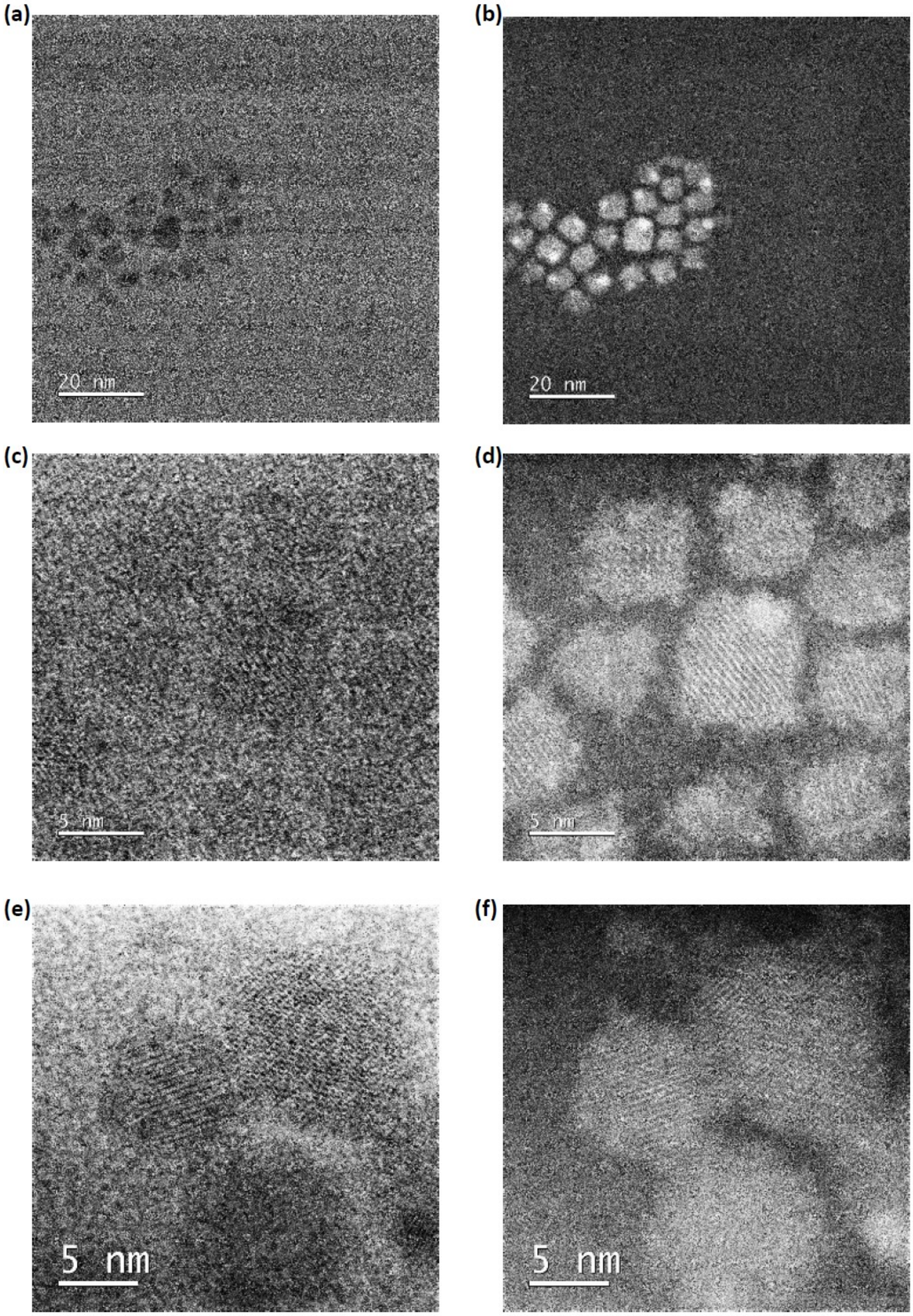

Figure S4 (a,c,e) Bright-field TEM images and (b,d,f) HAADF-STEM images of the $CsPbBr_3$ QDs prepared at 160 ^oC reaction temperature. (a,b), (c,d), and (e,f) are pairs of bright-field TEM images and HAADF-STEM images at the same position on the lacey-carbon grids.

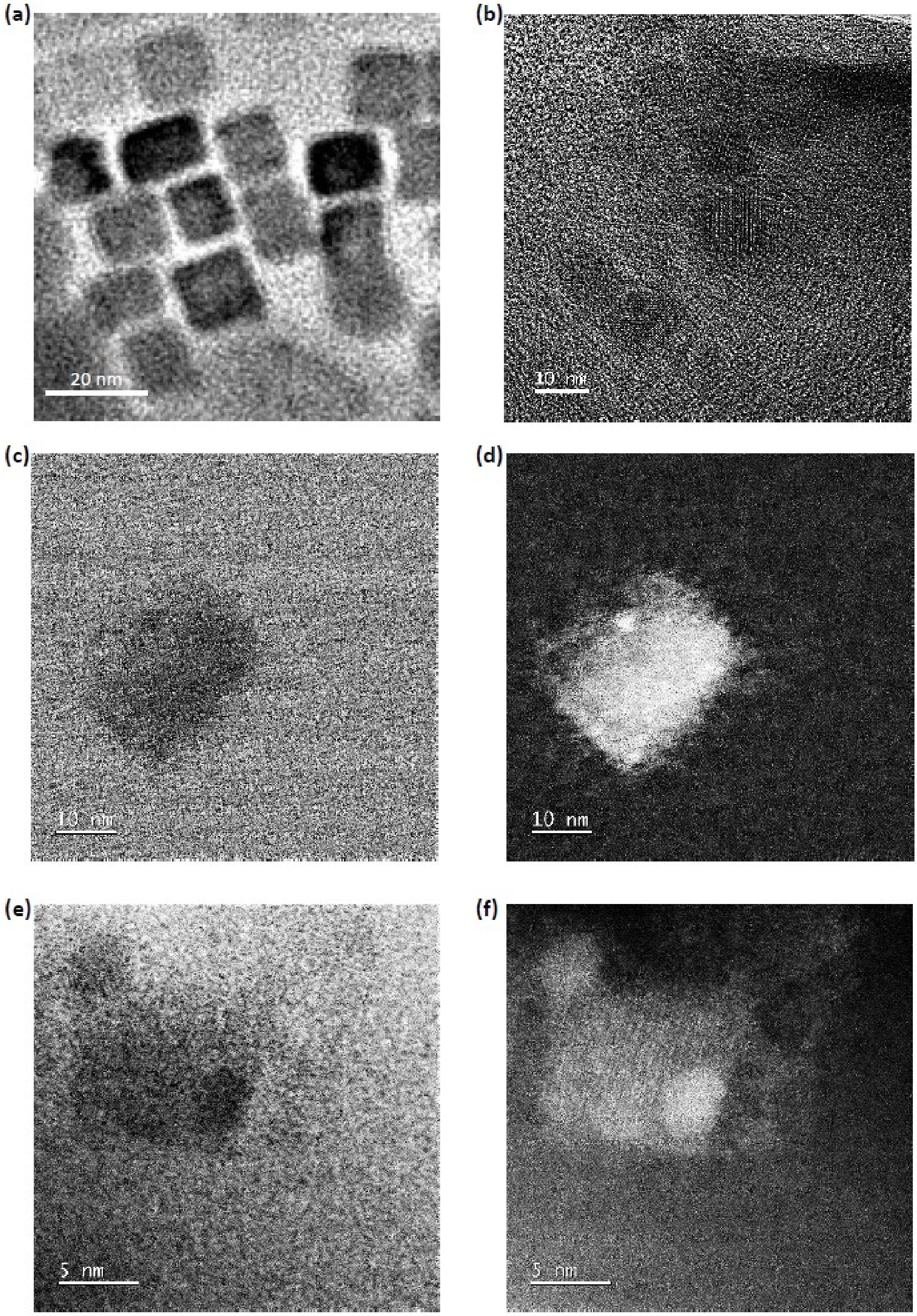

Figure S5 (a,c,e) Bright-field TEM images and (b,d,f) HAADF-STEM images of the $CsPbBr_3$ QDs prepared at 180 ^{o}C reaction temperature. (a,b), (c,d), and (e,f) are pairs of bright-field TEM images and HAADF-STEM images at the same position on the lacey-carbon grids.

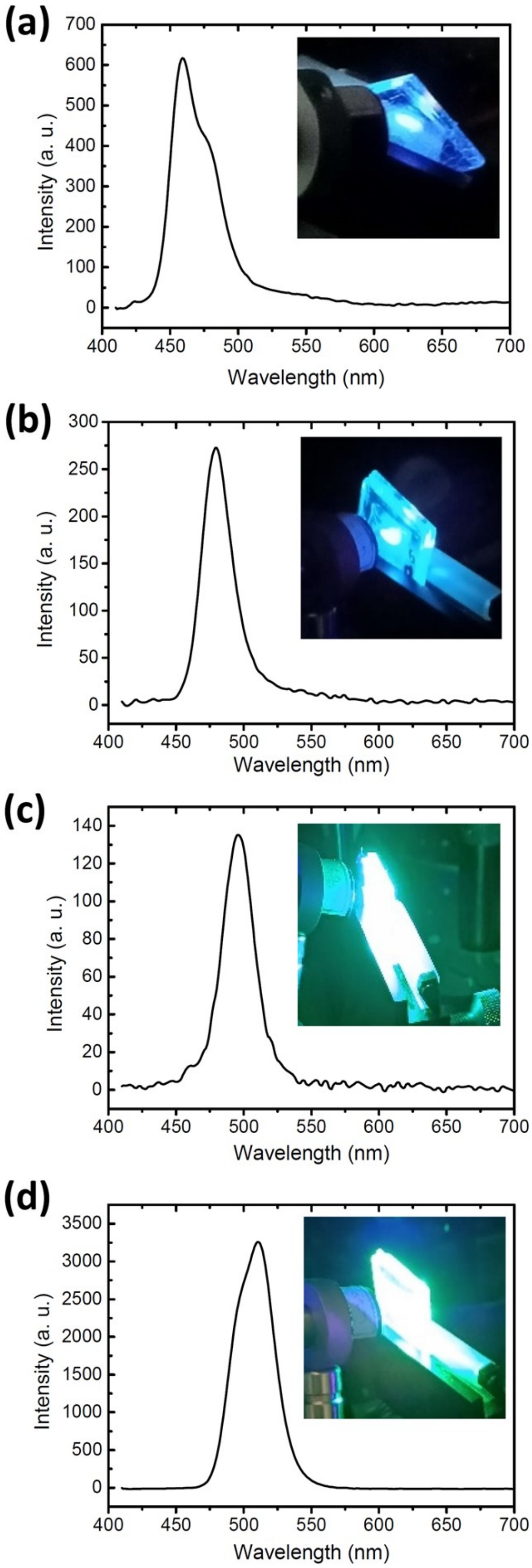

Figure S6 The PL spectra and photograph images of the QD-PCL composite films, (a) Film-459, (b) Film-479, (c) Film-496, and (d) Film-511.

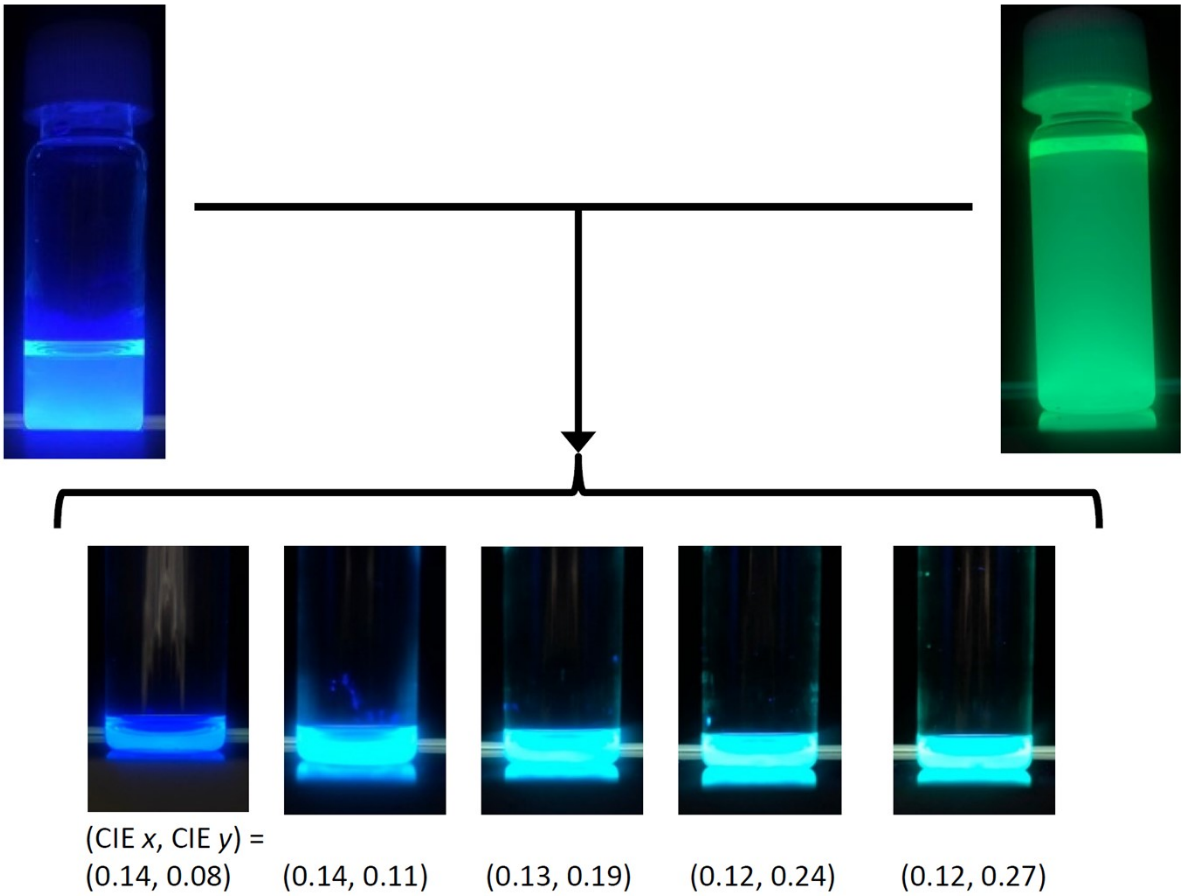

Figure S7 The photograph images showing the changes in color and CIE coordinates after adding QD-515 into QD 460.

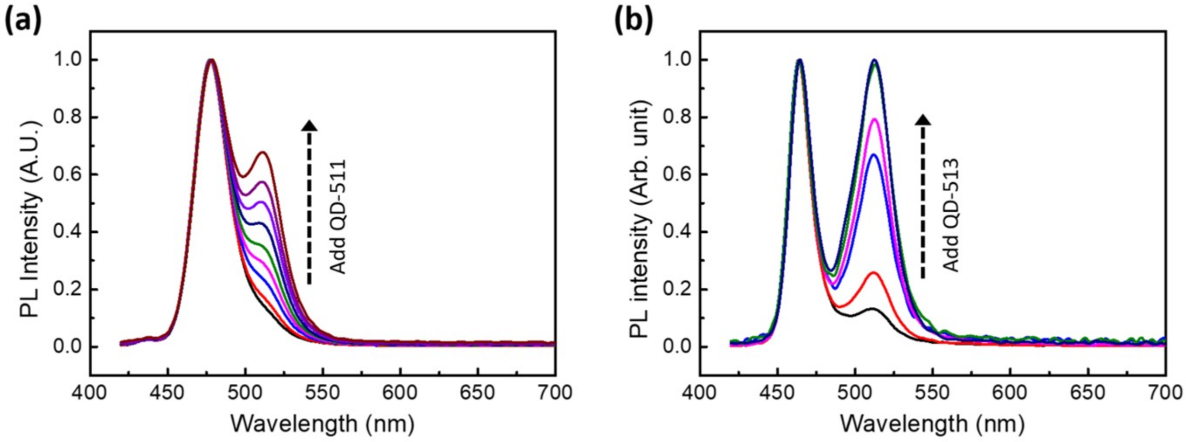

Figure S8 PL spectra of the mixtures of (a) QD-478 & QD-511 and (b) QD-464 & QD-513 with various amount of QD-511 and QD-513 added.

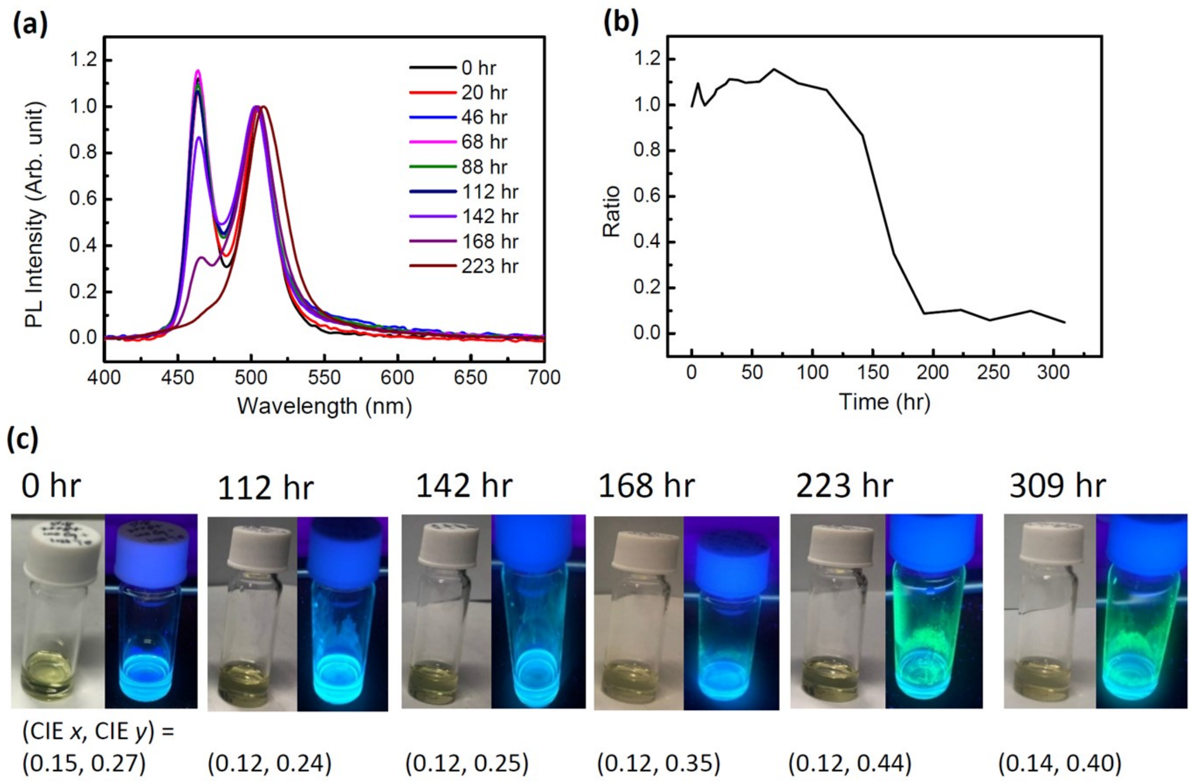

Figure S9 (a) The PL spectra, (b) peak intensity ratio, and (c) photograph images of the mixture (QD-464 & QD-505) sealed under N_2.

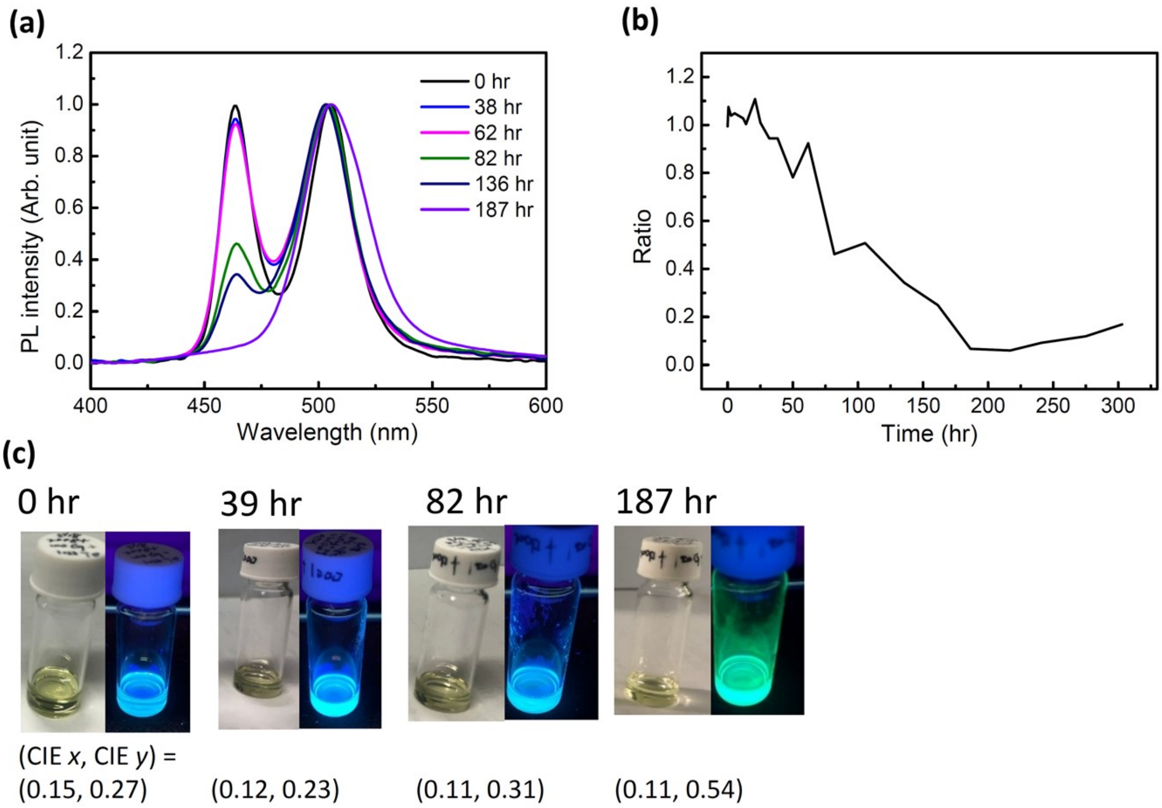

Figure S10 (a) The PL spectra, (b) peak intensity ratio, and (c) photograph images of the mixture (QD-464 & QD-505) sealed under air.

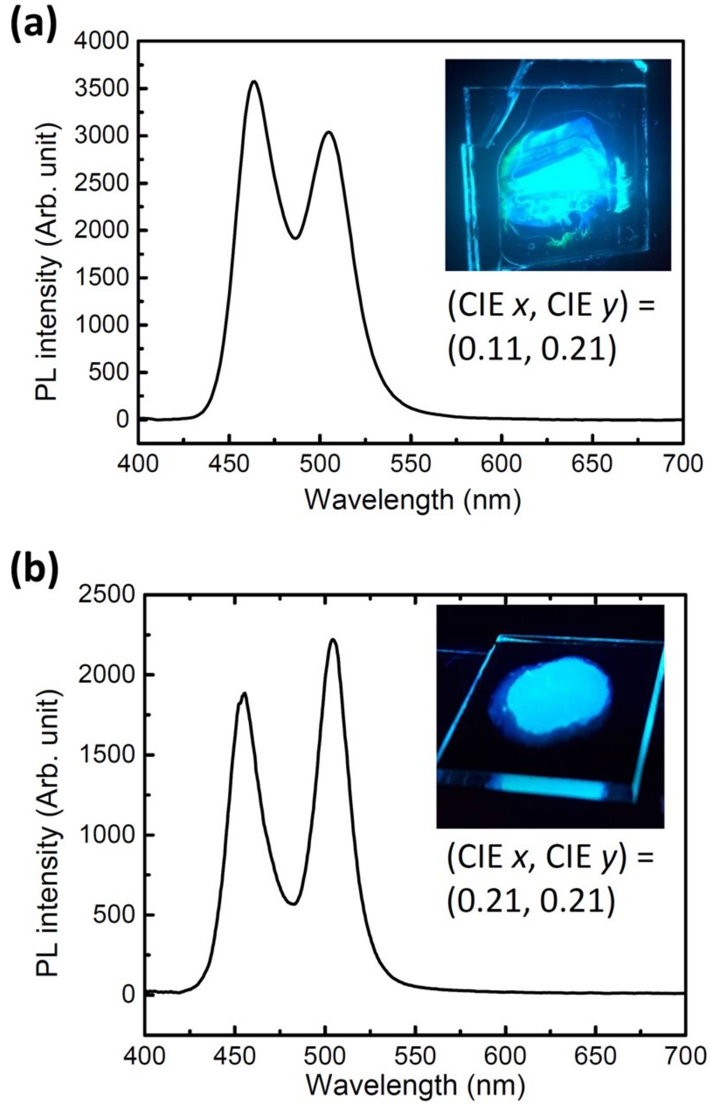

Figure S11 The PL spectra and photograph images of the QD-PCL composite films, (a) Film-464&505, and (b) Film-455&504.

Figure S12 The photograph of CdSe QD solution.

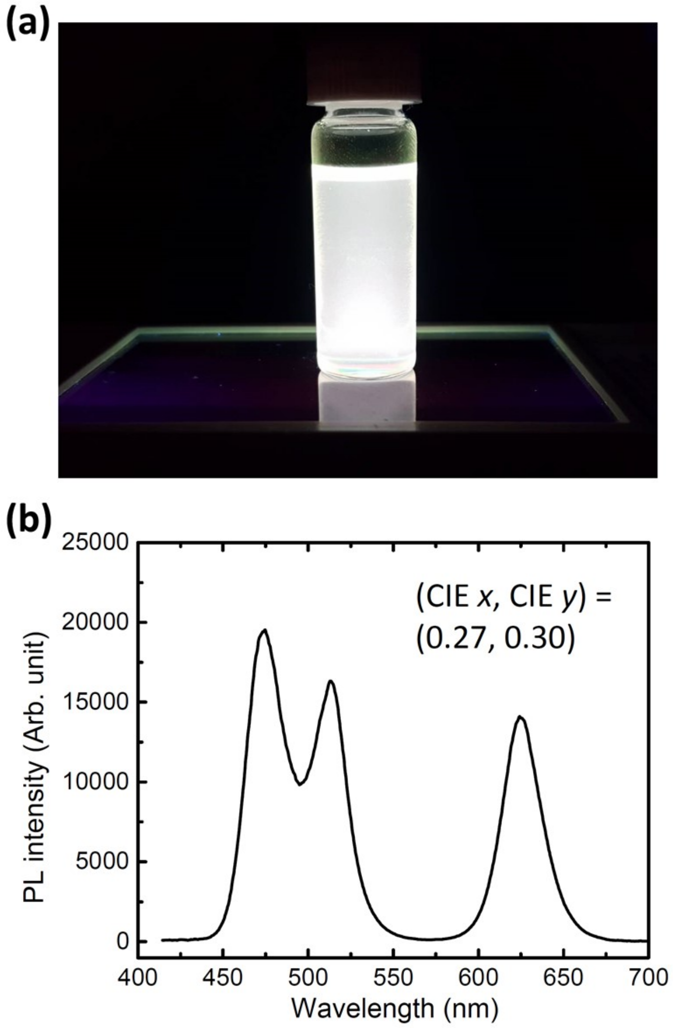

Figure S13 The photograph image, PL spectrum, and CIE coordinates of the ternary mixture solutions consisting of QD-475, QD-513, and CdSe-625.

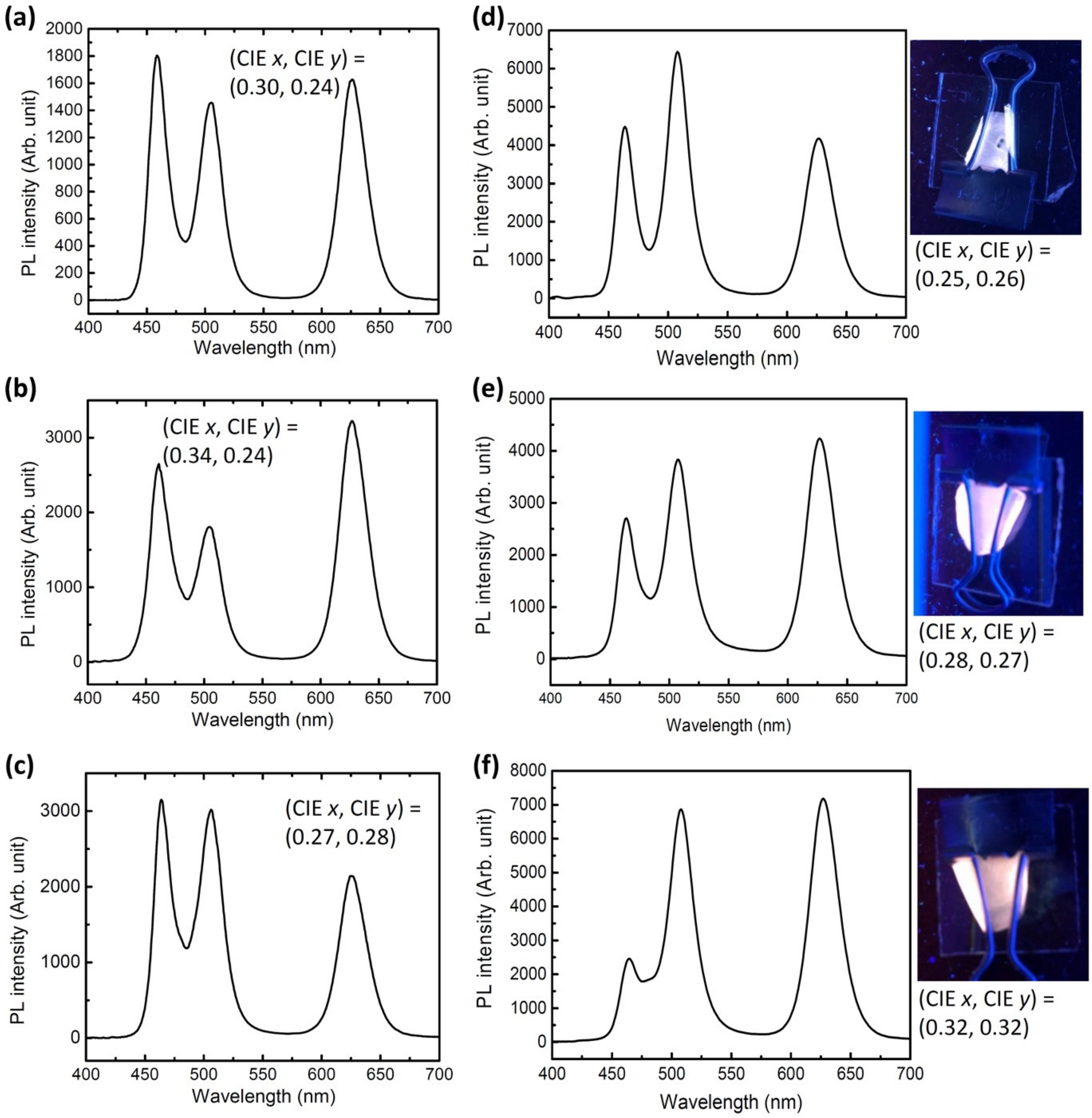

Figure S14 The PL spectrum, photograph images and CIE coordinates of six QD-PCL composite films with three emission peaks. QDs with different emission peak wavelengths can be used to generate white light.

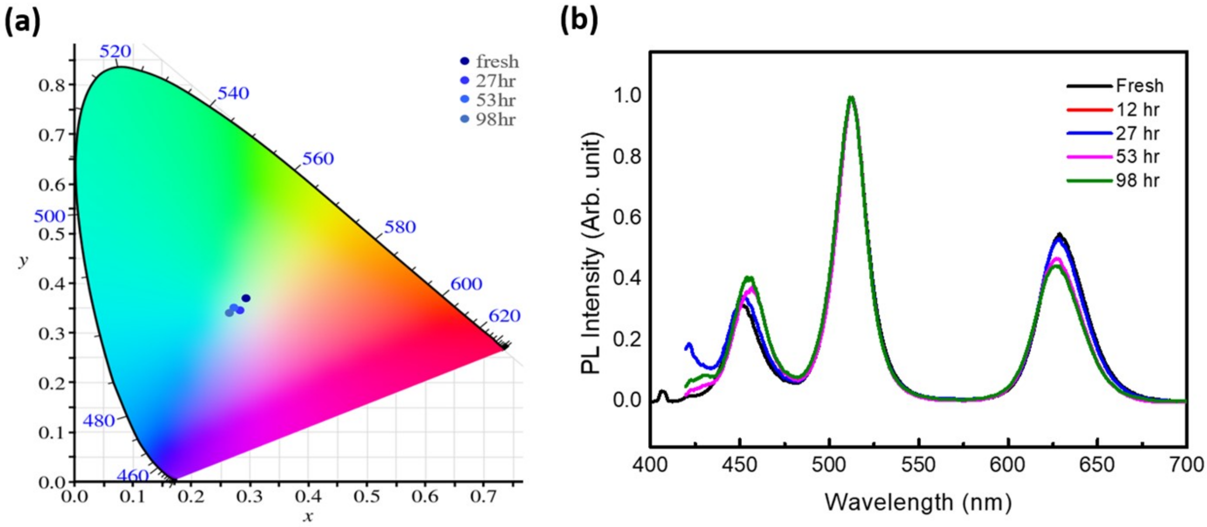

Figure S15 Stability test. (a) The CIE coordinates and (b) PL spectra of a QD-PCL composite film.

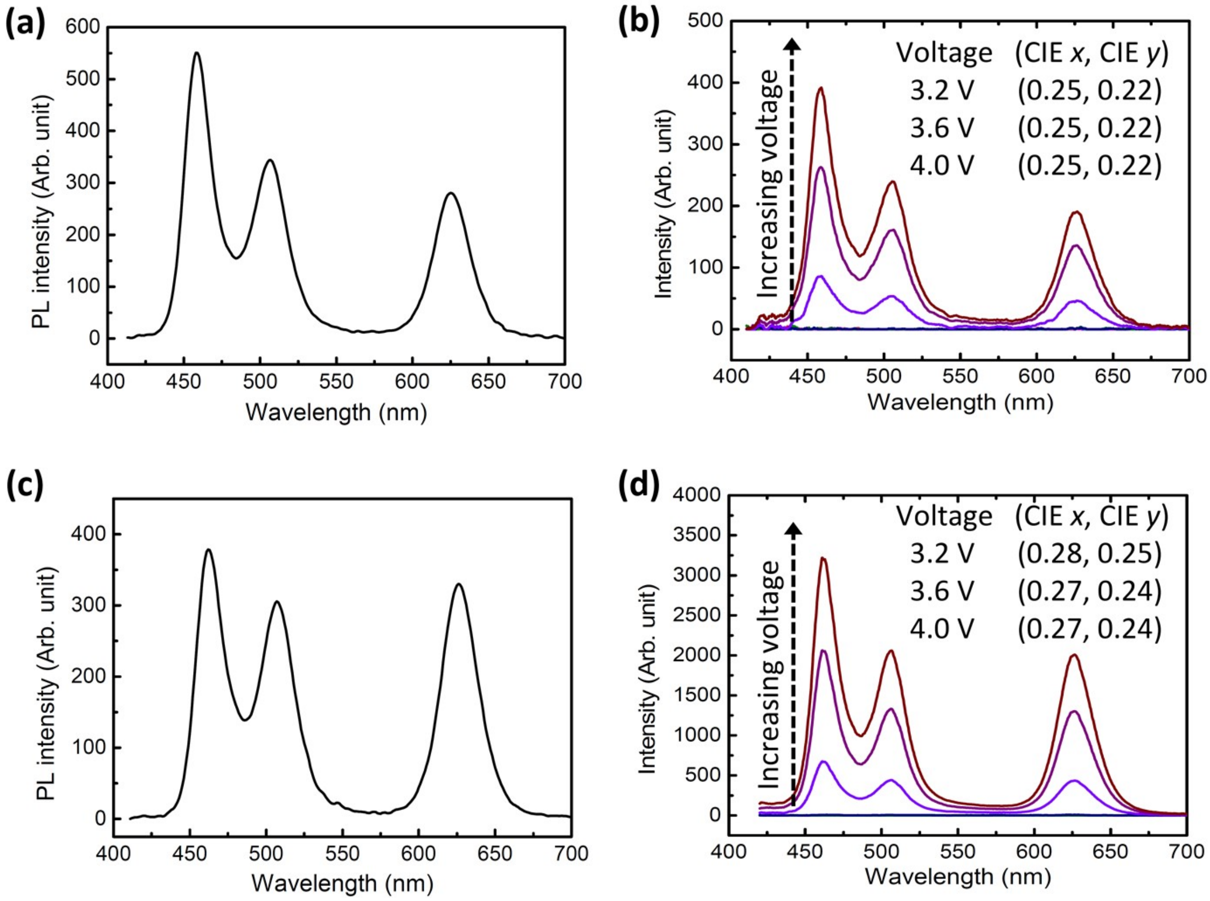

Figure S16 Two more white LEDs. (a,c) the PL spectra of the QD-PCL composite films, and (b,d) the corresponding EL spectra.

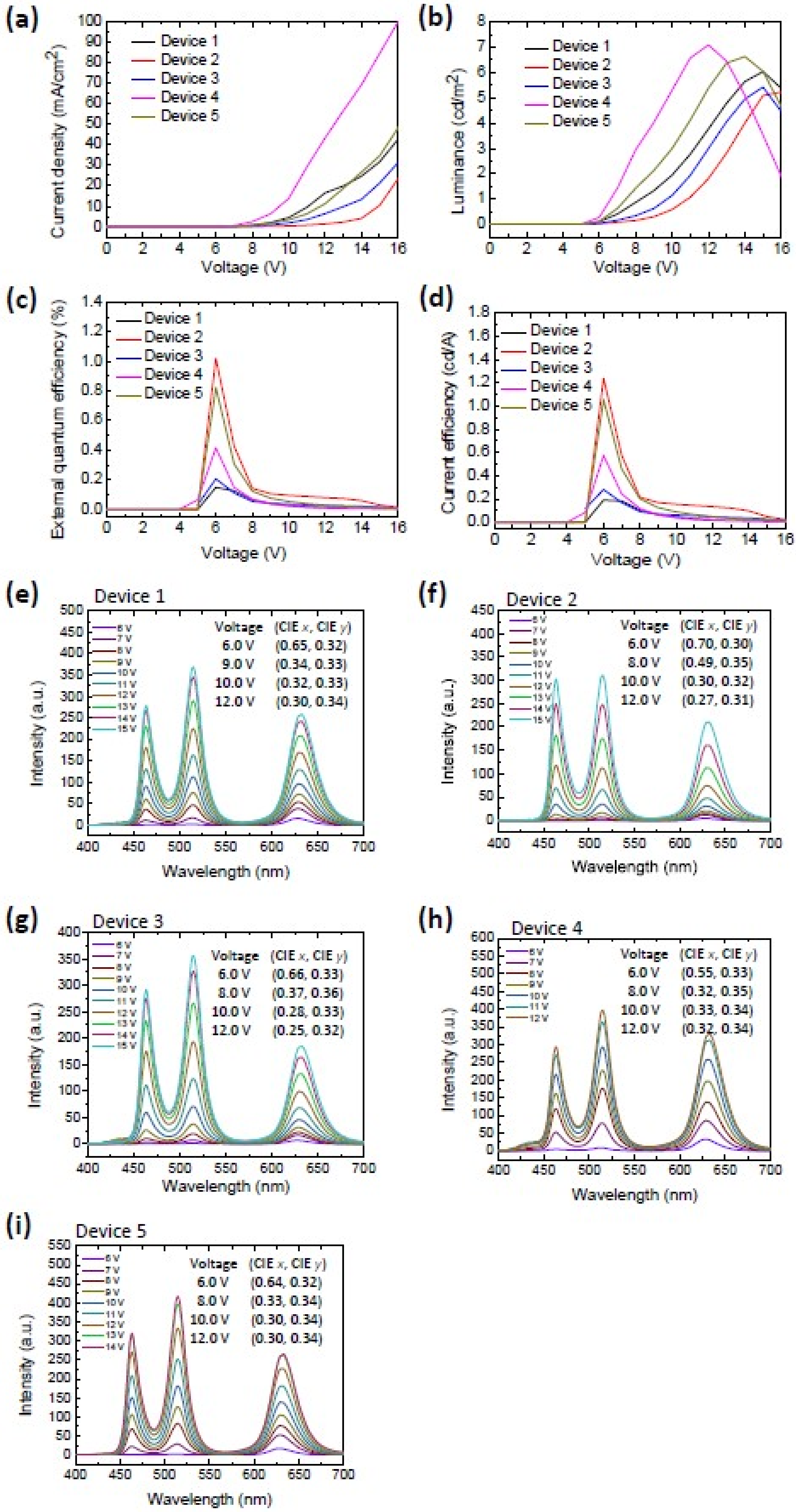

Figure S17 The device performance of the QD LEDs.

Table S1 Summary of the performance of white LEDs with an emissive layer

Type	Emissive layer	Maximum Luminance (cd/m^2)	Maximum EQE (%)	Maximum current efficiency (cd/A)	CIE chromaticity coordinates	Reference
perovskite material with self-trapped exciton	$Cs_2(Ag_{0.60}Na_{0.40})InCl_6$	~50	NA	0.11	NA	1
	$(C_6H_5C_2H_4NH_3)_2PbCl_2Br_2$	70	NA	NA	(0.22, 0.32)	2
	$(C_{18}H_{35}NH_3)_2SnBr_4$	350	0.1	NA	NA	3
	$CsCu_2I_3/Cs_3Cu_2I_5$	352.3	0.053	0.11	(0.327, 0.348)	4
	$CsCu_2I_3/Cs_3Cu_2I_5$	145	0.15	NA	(0.32, 0.33)	5
	α/δ-$CsPbI_3$	12200	6.5	12.23	(0.35, 0.43)	6
	$CsCu_2I_3/Cs_3Cu_2I_5$	1570	3.1	NA	(0.44, 0.53)	7
ion doped perovskite material	Sm^{3+}-doped $CsPbCl_3$	938	1.2	NA	(0.32, 0.31)	8
A perovskite material mixed with other emitting material	$MAPb(Br_{0.6}Cl_{0.4})_3$:(TPA-T-DCV-Ph)	14	10^{-3}	10^{-3}	(0.30, 0.49)	9
	$MAPb(Br_{0.6}Cl_{0.4})_3$: rhodamine 6G	2	10^{-3}	10^{-3}	(0.33, 0.40)	10
	$CsPbBr_xCl_{3-x}$: MEH-PPV	~120	NA	NA	(0.33, 0.34)	11
	$CsPbBr_{1.5}I_{1.5}$:HFSO	~1200	NA	0.48	(0.28, 0.33)	12

References

[1] J. Luo, X. Wang, S. Li, J. Liu, Y. Guo, G. Niu, L. Yao, Y. Fu, L. Gao, Q. Dong, C. Zhao, M. Leng, F. Ma, W. Liang, L. Wang, S. Jin, J. Han, L. Zhang, J. Etheridge, J. Wang, Y. Yan, E. H. Sargent, J. Tang, Nature, 2018, 563, 541.

[2] P. Cai, X. Wang, H. J. Seo, X. Yan, Appl. Phys. Lett., 2018, 112, 153901.

[3] X. Zhang, C. Wang, Y. Zhang, X. Zhang, S. Wang, M. Lu, H. Cui, S. V. Kershaw, W. W. Yu, A. L. Rogach, ACS Energy Lett., 2019, 4, 242–248.

[4] S. Liu, Y. Yue, X. Zhang, C. Wang, G. Yang, D. Zhu, J. Mater. Chem. C, 2020, 8, 8374–8379.

[5] Z. Ma, Z. Shi, D. Yang, Y. Li, F. Zhang, L. Wang, X. Chen, D. Wu, Y. Tian, Y. Zhang, L. Zhang, X. Li, C. Shan, Adv. Mater., 2021, 33, e2001367.

[6] J. Chen, J. Wang, X. Xu, J. Li, J. Song, S. Lan, S. Liu, B. Cai, B. Han, J. T. Precht, D. Ginger, H. Zeng, Nat. Photonics, 2021, 15, 238–244.

[7] H. Chen, L. Zhu, C. Xue, P. Liu, X. Du, K. Wen, H. Zhang, L. Xu, C. Xiang, C. Lin, M. Qin, J. Zhang, T. Jiang, C. Yi, L. Cheng, C. Zhang, P. Yang, M. Niu, W. Xu, J. Lai, Nat. Commun., 2021, 12, 1421.

[8] R. Sun, P. Lu, D. Zhou, W. Xu, N. Ding, H. Shao, Y. Zhang, D. Li, N. Wang, X. Zhuang, B. Dong, X. Bai, H. Song, ACS Energy Lett., 2020, 5, 2131.

[9] C. Y. Chang, A. N. Solodukhin, S. Y. Liao, K. P. O. Mahesh, C. L. Hsu, S. A. Ponomarenko, Y. N. Luponosov, Y. C. Chao, J. Mater. Chem. C, 2019, 7, 8634.

[10] C. Y. Chang, W. L. Hong, P. H. Lo, T. H. Wen, S. F. Horng, C. L. Hsu, Y. C. Chao, J. Mater. Chem. C, 2020, 8, 12951.

[11] E. P. Yao, Z. Yang, L. Meng, P. Sun, S. Dong, Y. Yang, Y. Yang, Adv. Mater., 2017, 29, 1606859.

[12] C. Y. Huang, S. J. Huang, M. H. M. Liu, Org. Electron., 2017, 44, 6–10.