Supporting Information

CsPbBr$_3$ and Cs$_4$PbBr$_6$ Perovskite Light-Emitting Diodes using Thermally Evaporated Host-Dopant System

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Supporting Note

   We showed optical properties of perovskites deposited by single-source evaporation and host-dopant system. Also, we showed the device performances according to deposition method and electron transport layer. LEDs fabricated with single-source evaporation show different performance depending on the thickness of perovskite layer, and LEDs fabricated with host-dopant system show different performances according to the percentage of dopant, and electron transport layer.
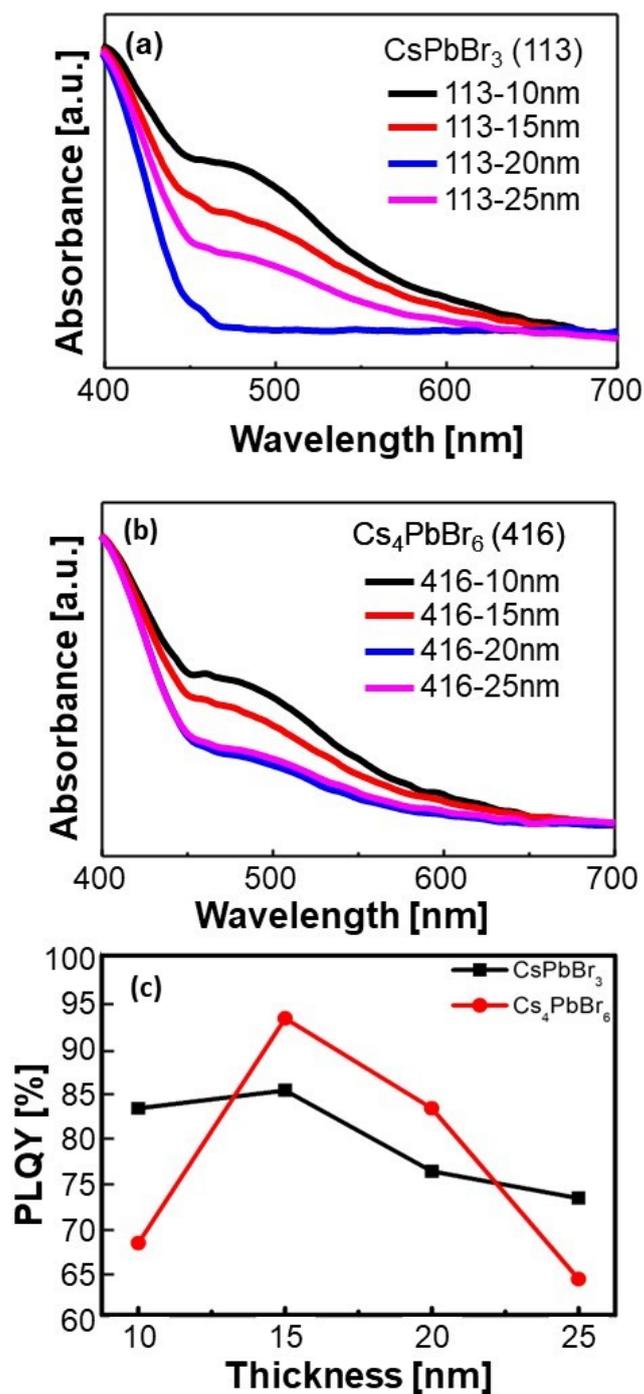
Figure S1. (a) Absorption of $CsPbBr_3$ (113 structure) perovskite films with different thicknesses. (b) Absorption of Cs_4PbBr_6 (416 structure) perovskite films with different thicknesses. (c) PLQY with different thicknesses of $CsPbBr_3$ and Cs_4PbBr_6 perovskite films.
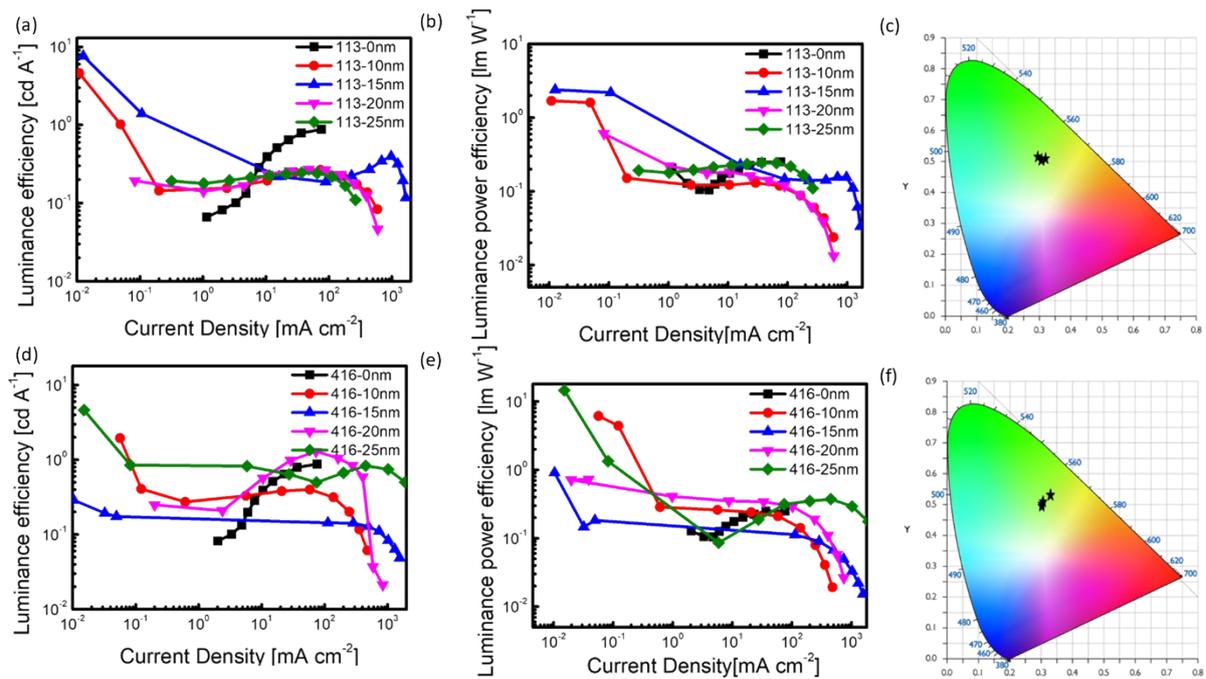
Figure S2. (a) Luminance efficiency as a function of current density, (b) Luminance-power efficiency as a function of current density, and (c) CIE chromaticity diagram of the CsPbBr$_3$ (113 structure) PeLEDs. (d) Luminance efficiency as a function of current density, (e) Luminance-power efficiency as a function of current density, and (f) CIE chromaticity diagram of the Cs$_4$PbBr$_6$ (416 structure) PeLEDs.

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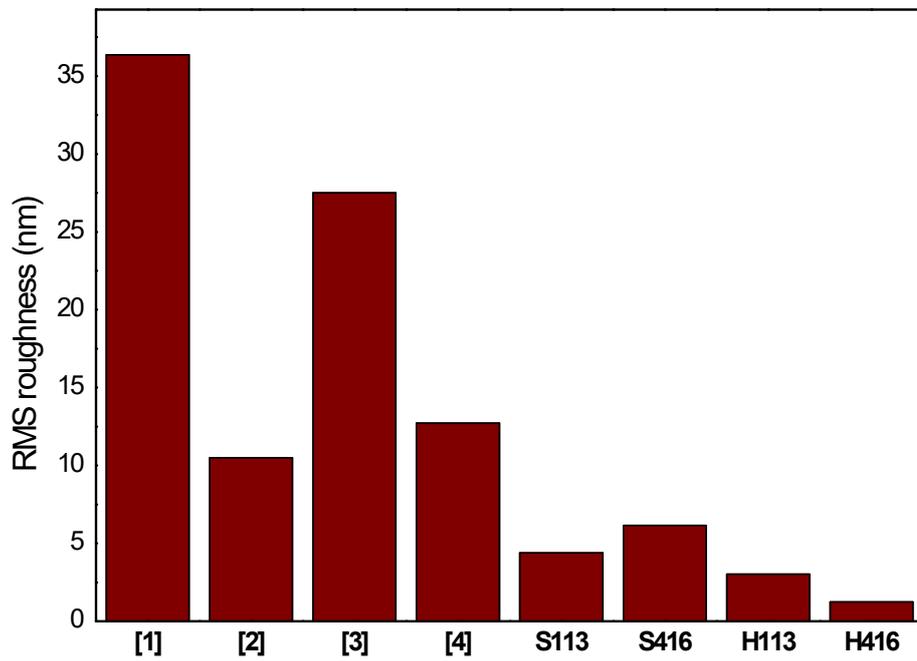
Figure S3. The bar graph that compared root mean square (RMS) roughness of pristine perovskite film. S is single-source evaporation, and H is host-dopant system. 113 is $CsPbBr_3$, and 416 is Cs_4PbBr_6.
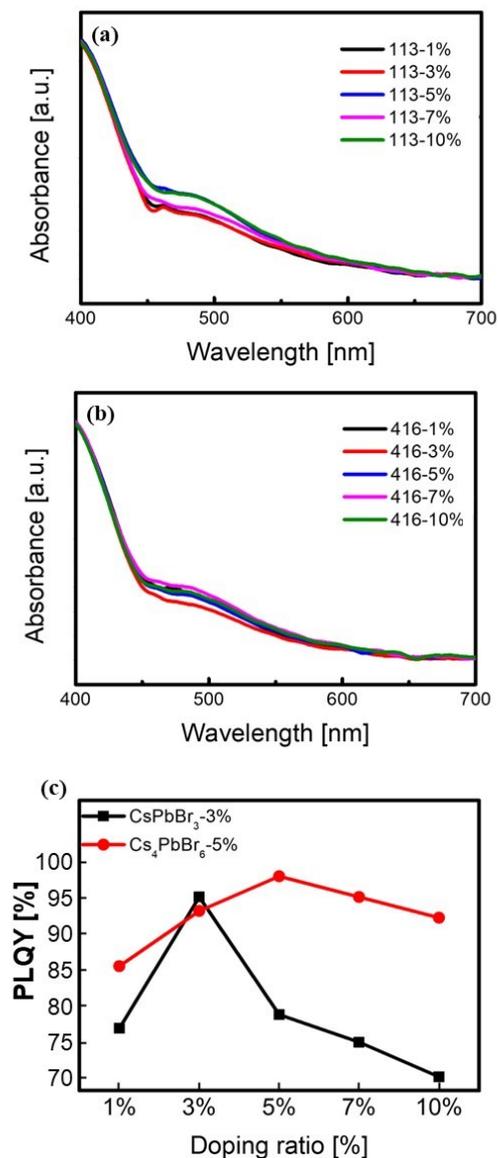
Figure S4 (a) Absorption of doped-CsPbBr$_3$ (113 structure) perovskite films with different doping ratios. (b) Absorption of doped-Cs$_4$PbBr$_6$ (416 structure) perovskite films with different doping ratios. (c) PLQY with different doping ratios of doped-CsPbBr$_3$ and -Cs$_4$PbBr$_6$ perovskite films.
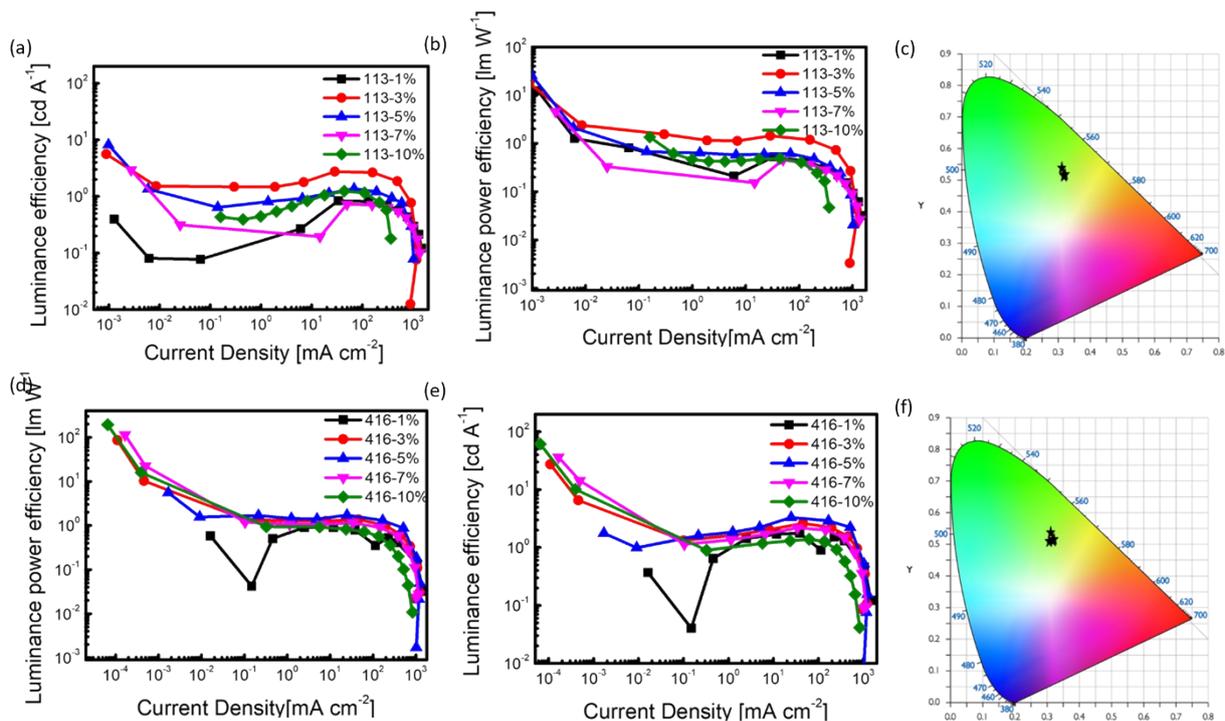
Figure S5. (a) Luminance efficiency as a function of current density, (b) Luminance-power efficiency as a function of current density, and (c) CIE chromaticity diagram of the doped-CsPbBr$_3$ (113 structure) PeLEDs. (d) Luminance efficiency as a function of current density, (e) Luminance-power efficiency as a function of current density, and (f) CIE chromaticity diagram of the doped-Cs$_4$PbBr$_6$ (416 structure) PeLEDs.
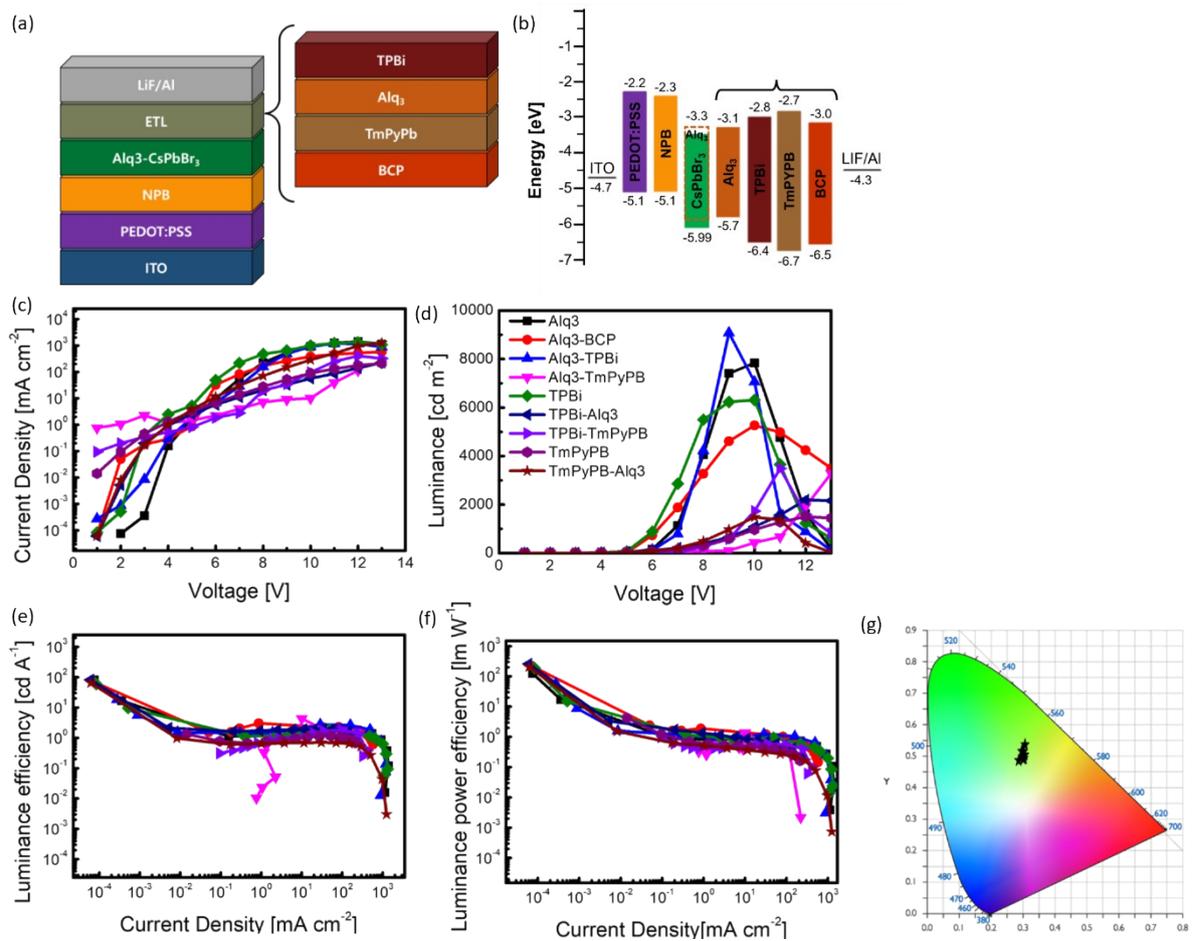
Figure S6. (a) Device structure of 3% doped-CsPbBr$_3$ PeLED. (b) Energy diagram of 3% doped-CsPbBr$_3$ PeLED. (c) Current density as a function of driving voltage. (d) Luminance as a function of driving voltage. (e) Luminance efficiency as a function of current density. (f) Luminance-power efficiency as a function of current density. (g) CIE chromaticity diagram of the 3% doped-CsPbBr$_3$ PeLEDs.
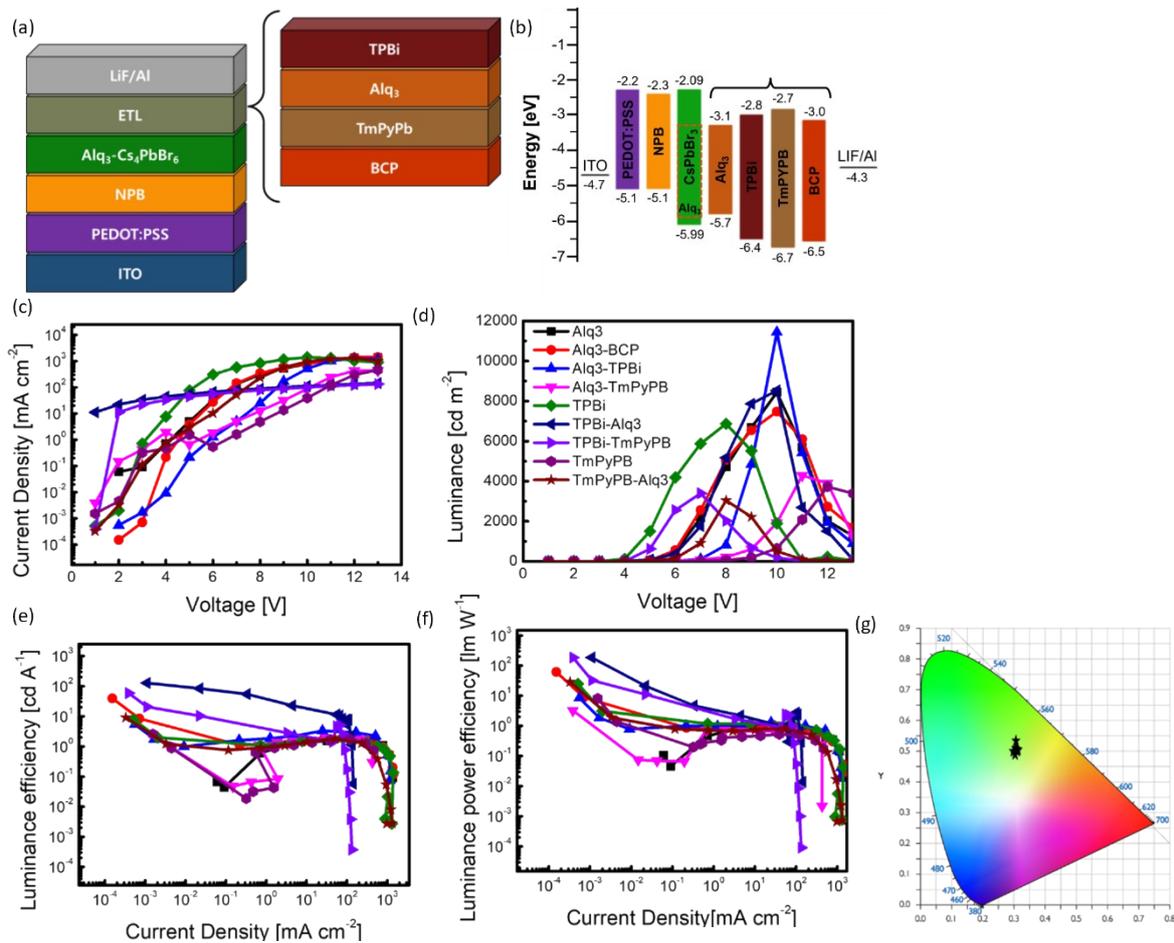
Figure S7. (a) Device structure of 5% doped-Cs_4PbBr_6 PeLED. (b) Energy diagram of 5% doped-Cs_4PbBr_6 PeLED. (c) Current density as a function of driving voltage. (d) Luminance as a function of driving voltage. (e) Luminance efficiency as a function of current density. (f) Luminance-power efficiency as a function of current density. (g) CIE chromaticity diagram of the 5% doped-Cs_4PbBr_6 PeLEDs.
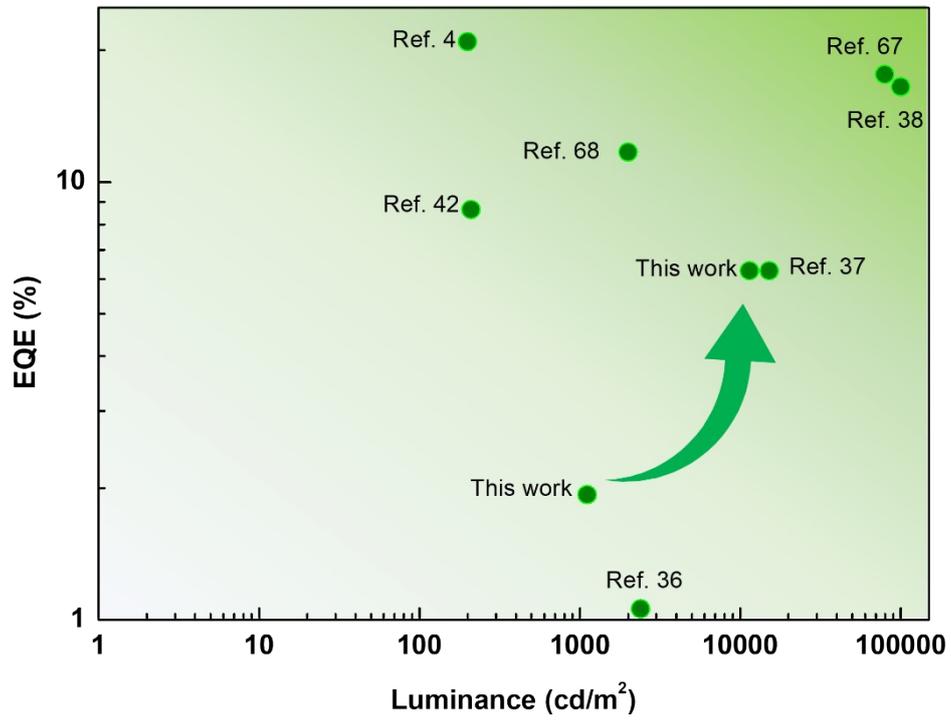
Figure S8. Comparing performance of PeLED fabricated with spin-coating and thermal evaporation by EQE and luminance.

Table S1. Absorption, PL peak wavelength, and PLQY corresponding to the different thicknesses of $CsPbBr_3$ and Cs_4PbBr_6 films.

Perovskite	Absorbance [nm]	Peak [nm]	PLQY [%]
$CsPbBr_3$ 10nm	530	539	83
$CsPbBr_3$ 15nm	533	543	85
$CsPbBr_3$ 20nm	520	539	76
$CsPbBr_3$ 25nm	520	529	73
Cs_4PbBr_6 10nm	530	537	68
Cs_4PbBr_6 15nm	525	534	93
Cs_4PbBr_6 20nm	522	533	83
Cs_4PbBr_6 25nm	531	540	64

Table S2. Absorption, PL peak wavelength, FWHM, and PLQY corresponding to different doping ratios of $CsPbBr_3$ and Cs_4PbBr_6 films.

Perovskite	Absorbance [nm]	Peak [nm]	PLQY [%]
$CsPbBr_3$ 1%	525	537	77
$CsPbBr_3$ 3%	530	541	96
$CsPbBr_3$ 5%	538	549	79
$CsPbBr_3$ 7%	533	545	75
$CsPbBr_3$ 10%	540	548	70
Cs_4PbBr_6 1%	530	540	86
Cs_4PbBr_6 3%	529	537	94
Cs_4PbBr_6 5%	525	533	99
Cs_4PbBr_6 7%	533	541	96
Cs_4PbBr_6 10%	520	527	93

Table S3. Characteristics of 3% doped-CsPbBr$_3$ PeLED.

Device	V_{on} [V]	Luminance^{max} [cd m^{-2}]	Luminance Efficiency^{max} [cd A^{-1}]	Power Efficiency^{max} [lm W^{-2}]
Alq$_3$	4.4	7840	1.37	0.71
Alq$_3$–BCP	4.3	5265	1.74	1.02
Alq$_3$–TmPyPb	4.9	3286	1.07	0.56
Alq$_3$–TPBi	3.4	9083	2.73	1.43
TmPyPb	4.4	1502	0.75	0.4
TmPyPb–Alq$_3$	4.3	1486	0.65	0.42
TPBi	3.8	6312	1.8	1.15
TPBi–Alq$_3$	3.9	2195	1.73	1.14
TPBi–TmPyPb	5.3	3488	0.67	0.42

Turn-on voltages at 10 cd m^{-2}

Table S4. Characteristics of 5% doped-Cs_4PbBr_6 PeLED.

Device	V_{on} [V]	Luminance^{max} [cd m^{-2}]	Luminance Efficiency^{max} [cd A^{-1}]	Power Efficiency^{max} [lm W^{-2}]
Alq_3	4.8	5440	0.51	0.44
Alq_3–BCP	4.6	7474	0.54	0.57
Alq_3–TmPyPB	5.2	4292	0.9	0.64
Alq_3–TPBi	3.4	11440	3.29	1.72
TmPyPB	6.1	3729	0.63	0.52
TmPyPB–Alq_3	4.5	3038	0.75	0.52
TPBi	3.8	6866	0.83	0.72
TPBi–Alq_3	3.5	8532	1.13	1.01
TPBi–TmPyPB	4.2	3401	0.77	0.26

Turn-on voltages at 10 cd m^{-2}

Reference

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