Supporting Information

Enhanced Emission Efficiency in Doped $CsPbBr_3$ Perovskite Nanocrystals: The Role of Ion Valence

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- **Detailed method for the calculation of the average lifetime, radiative and nonradiative decay rates**:
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- **Figure S3.** The UV-vis absorption spectra and (b) the position of absorption peak and PL peak of Sr^{2+}-doped $CsPbBr_3$ NCs with different Sr^{2+} concentrations.
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- **Figure S5**. The excitation spectra of $CsPbBr_3$, $CsPbBr_3$:Sr^{2+} and $CsPbBr_3$:La^{3+}.
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Detailed method for the calculation of the average lifetime, radiative and nonradiative decay rates: To explore the kinetic luminescence process, we calculated the radiative rate (k_r) of perovskite NCs and its non-radiative decay rate (k_{nr}) by photoluminescence quantum yield (PLQY) and the average lifetime (τ_{ave}) of the samples. The PLQY is the ratio of the number of photons emitted to the number absorbed. Both the radiative recombination and the non-radiative recombination depopulated the excited state. Hence, the PLQY is also defined as the radio of the radiative recombination rate to the total recombination rate, given by

$$PLQY = \frac{k_r}{k_r + k_{nr}} \qquad (I)$$

The lifetime of the excited state is defined by the average time photon spends in the excited state prior to return to the ground state. The average lifetime is the inverse of the total recombination rate, given by

$$\tau_{ave} = \frac{1}{k_r + k_{nr}} \qquad (II)$$

where τ_{avg} is the average time calculated by the fitted date of the time-resolved PL decay.

The average lifetime (τ_{avg}) was calculated as follows:

$$\tau_{avg} = \frac{A_1\tau_1^2 + A_2\tau_2^2 + A_3\tau_3^2 + \ldots}{A_1\tau_1 + A_2\tau_2 + A_3\tau_3 + \ldots} \qquad (III)$$

in which A_1, A_2, A_3, … are the amplitudes of each of a series of components and τ_1, τ_2, τ_3, … are the corresponding lifetime constants.

Therefore, we can calculate the radiative and non-radiative recombination rates:

$$k_r = \frac{PLQY}{\tau_{ave}} \qquad (IV)$$

$$k_{nr} = \frac{1}{\tau_{ave}} - k_r = \frac{1 - PLQY}{\tau_{ave}} \qquad (V)$$

Table S1. The change of X-ray diffraction angle corresponding to (110) and (200) crystal planes in Sr^{2+}-doped $CsPbBr_3$ NCs with different Sr^{2+} concentrations.

Sample	(110)	(200)
CPB	22.94°	30.55°
CPB:0.30%Sr^{2+}	22.96°	30.62°
CPB: 0.69%Sr^{2+}	23.01°	30.65°
CPB:0.97%Sr^{2+}	23.03°	30.65°
CPB:1.12%Sr^{2+}	23.09°	30.66°
CPB:1.50%Sr^{2+}	23.10°	30.66°
CPB:1.76%Sr^{2+}	23.12°	30.75°

Table S2. The Cs:Pb:Sr/La:Br feed ratio and determined ratio by EDS and XPS in undoped and doped samples.

Sample	Feed ratio	Determined ratio by EDS	Determined ratio by XPS
$CsPbBr_3$	Cs:Pb:Br = 1:4:8	Cs:Pb:Br = 1:1.1:3.2	Cs:Pb:Br = 1:0.8:2.2
$CsPbBr_3:Sr^{2+}$	Cs:Pb:Sr:Br = 1:2:2:8	Cs:Pb:Sr:Br = 1:0.9:0.08:3.1	Cs:Pb:Sr:Br = 1:1.1:0.05:3.6
$CsPbBr_3:La^{3+}$	Cs:Pb:La:Br = 1:2.4:1.1:9.6	Cs:Pb:La:Br = 1:0.9:0.09:3.4	Cs:Pb:La:Br = 1:0.8:0.06:3.3

Table S3. The Br/Pb, Br/(Pb+Sr) and Br/(Pb+La) ratios in $CsPbBr_3$, Sr^{2+}-doped $CsPbBr_3$ NCs and La^{3+}-doped $CsPbBr_3$ NCs.

Sample	Determined ratio by EDS	Determined ratio by XPS
$CsPbBr_3$	Br/Pb = 2.91	Br/Pb = 2.75
$CsPbBr_3:Sr^{2+}$	Br/(Pb+Sr) = 3.16	Br/(Pb+Sr) = 3.13
$CsPbBr_3:La^{3+}$	Br/(Pb+La) = 3.43	Br/(Pb+La) = 3.84

Table S3. PLQYs, τ_{ave}, k_r and k_{nr} of $CsPbBr_3$ and Sr^{2+}/La^{3+}-doped $CsPbBr_3$ NCs with different doping concentrations.

Sample	PLQY (%)	τ_{avg} (ns)	k_r (ns^{-1})	k_{nr} (ns^{-1})
CPB	55	19	0.0289	0.0237
CPB:0.30%Sr^{2+}	65	22	0.0295	0.0159
CPB: 0.69%Sr^{2+}	67	23	0.0291	0.0143
CPB:0.97%Sr^{2+}	72	24	0.0300	0.0117
CPB:1.12%Sr^{2+}	79	25	0.0320	0.0080
CPB:1.50%Sr^{2+}	87	26	0.0335	0.0050
CPB:1.76%Sr^{2+}	76	23	0.0330	0.0104
CPB:0.57%La^{3+}	58	20	0.0290	0.0210
CPB:1.24%La^{3+}	70	21	0.0333	0.0143
CPB:1.86%La^{3+}	87	26	0.0334	0.0050
CPB:2.43%La^{3+}	76	24	0.0316	0.0100

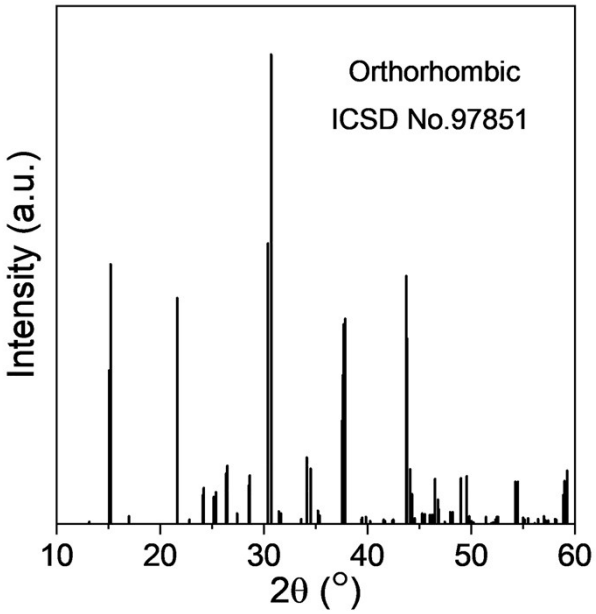

Figure S1. The XRD pattern of orthorhombic phase $CsPbBr_3$.

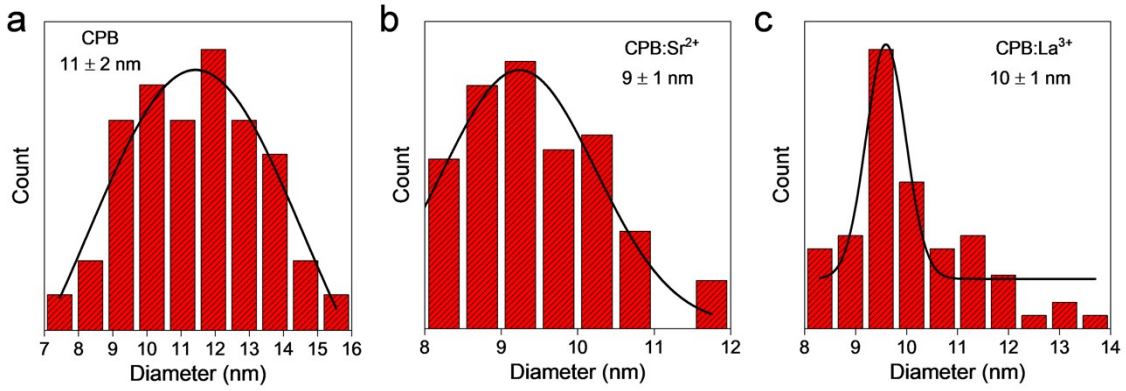

Figure S2. The size distribution statistics of (a) $CsPbBr_3$ NCs, (b) Sr^{2+}-doped $CsPbBr_3$ NCs (1.50% Sr^{2+}) and (c) La^{3+}-doped $CsPbBr_3$ NCs (1.86% La^{3+}).

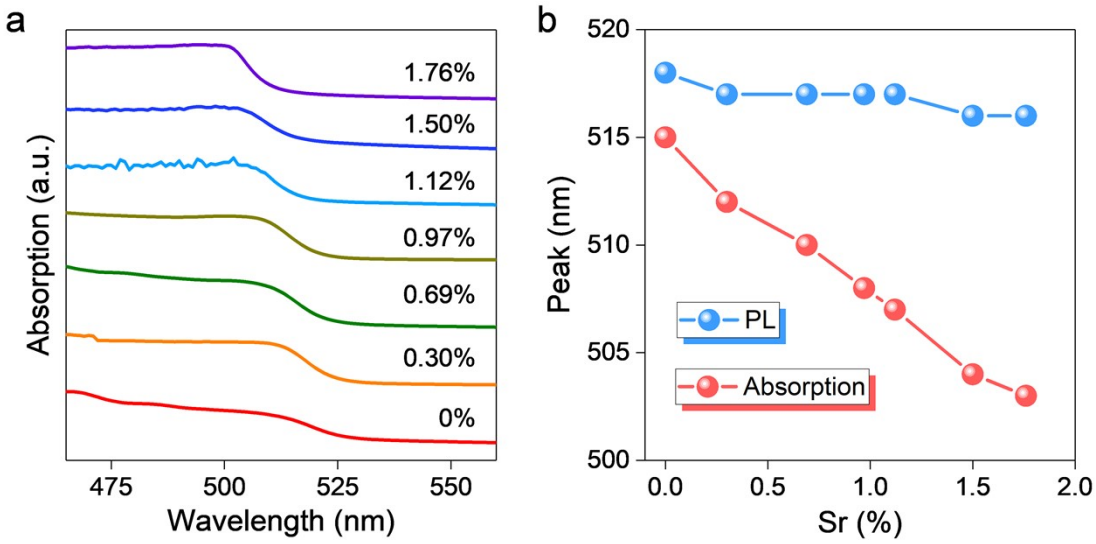

Figure S3. (a) UV-vis absorbance and (b) the position of absorption peak and PL peak of Sr^{2+}-doped $CsPbBr_3$ NCs with different Sr^{2+} ions concentrations.

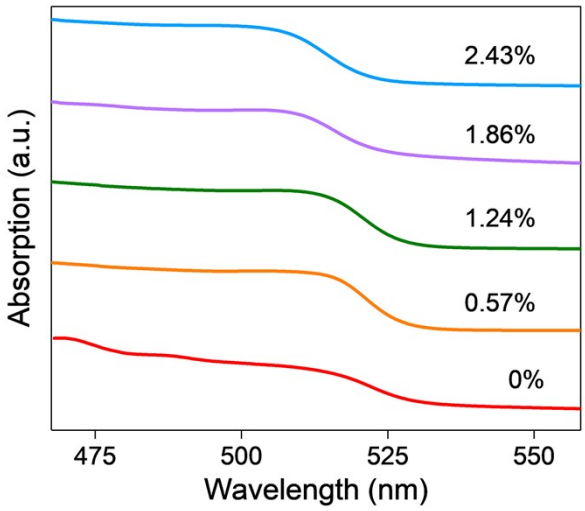

Figure S4. UV-vis absorption spectra of La^{3+}-doped of $CsPbBr_3$ NCs with different La^{3+} ions concentration.

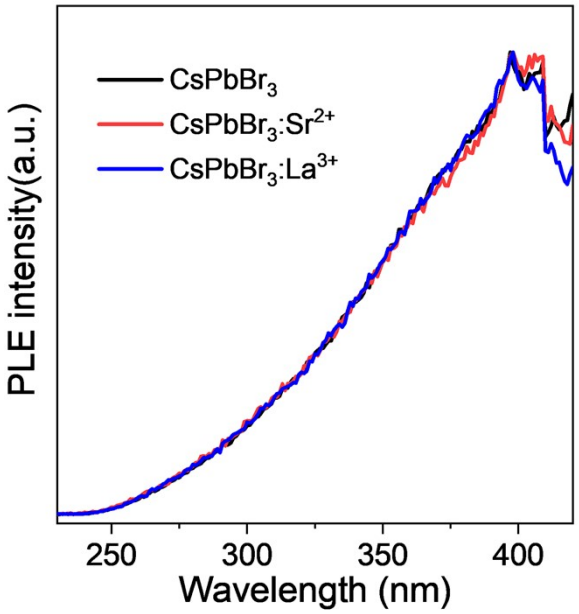

Figure S5. The excitation spectra of $CsPbBr_3$, $CsPbBr_3:Sr^{2+}$ and $CsPbBr_3:La^{3+}$.

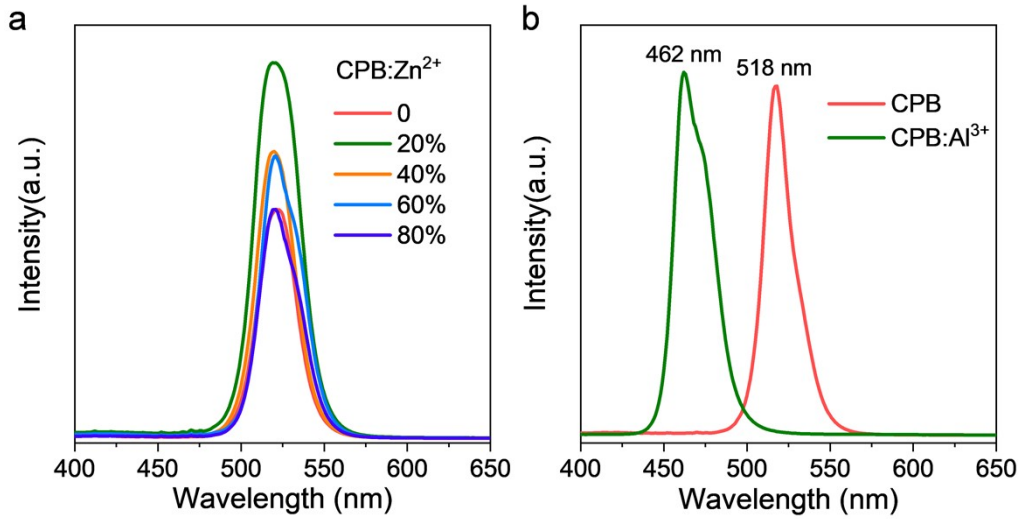

Figure S6. The PL spectra of (a) Zn^{2+} doped $CsPbBr_3$ and (b) Al^{3+} doped $CsPbBr_3$.