Supporting Information

New role of Yb^{3+}—energy reservoir for lanthanide upconversion luminescence

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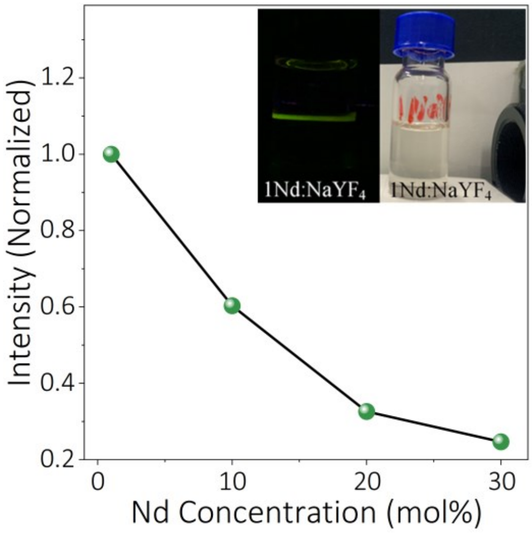

Figure S1. Variation of the integral UC intensity of Nd^{3+} single doped $NaYF_4$ NCs with the Nd^{3+} concentration. The integral intensities are normalized by that of 1 mol% Nd^{3+} doped NCs. Insets are the dark-field and bright-field luminescent images of the most efficient 1 mol% Nd^{3+} doping $NaYF_4$ NCs dispersed in cyclohexane with a density of ~0.07 mmol/mL excited at a pumping power of ~1.7 W with the 800 nm laser diode.

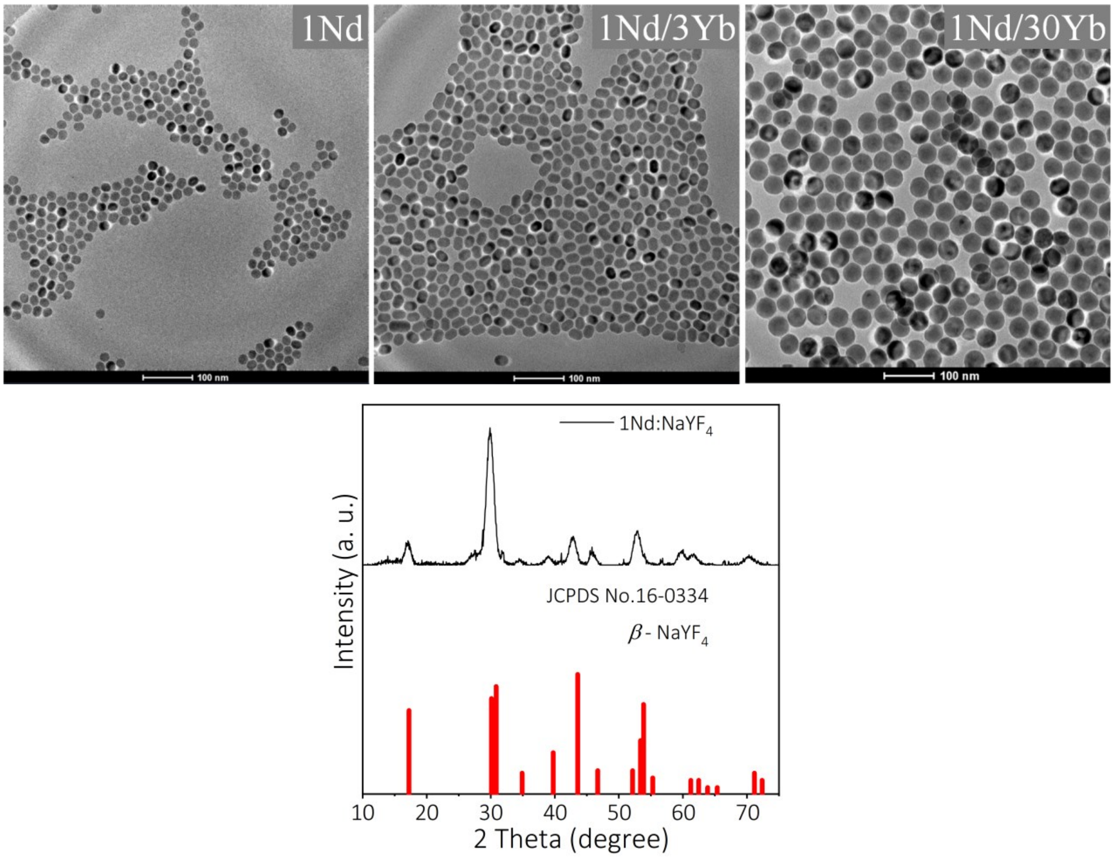

Figure S2. Top: TEM photographs of various Nd^{3+}/Yb^{3+} codoped $NaYF_4$ NCs, scale bars are 100 nm. Bottom: XRD pattern of 1 mol% Nd^{3+}:$NaYF_4$, indicating the hexagonal phase of the formed NCs.

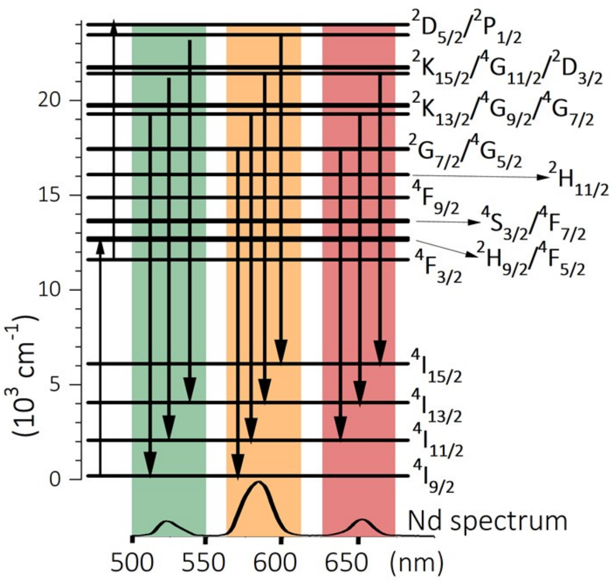

Figure S3. Possible transitions of Nd^{3+} overlapping the observed spectrum (bottom of the figure).

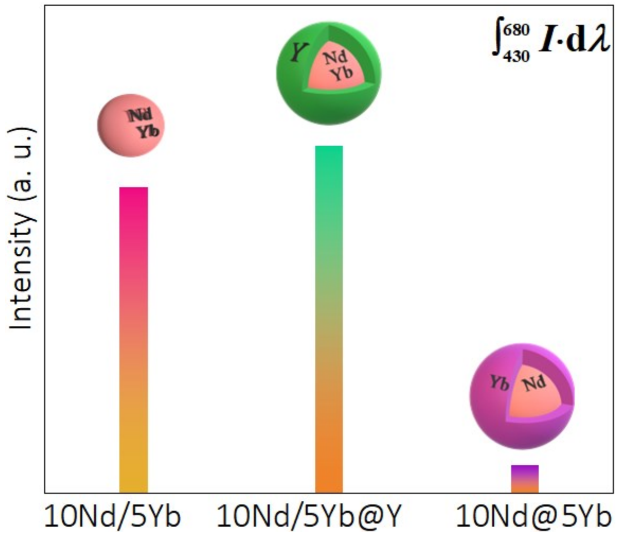

Figure S4. Comparison of the integral UC intensities of $10Nd^{3+}/5Yb^{3+}:NaYF_4$, $10Nd^{3+}/5Yb^{3+}:NaYF_4@NaYF_4$, and $10Nd^{3+}:NaYF_4@5Yb^{3+}:NaYF_4$ NCs.

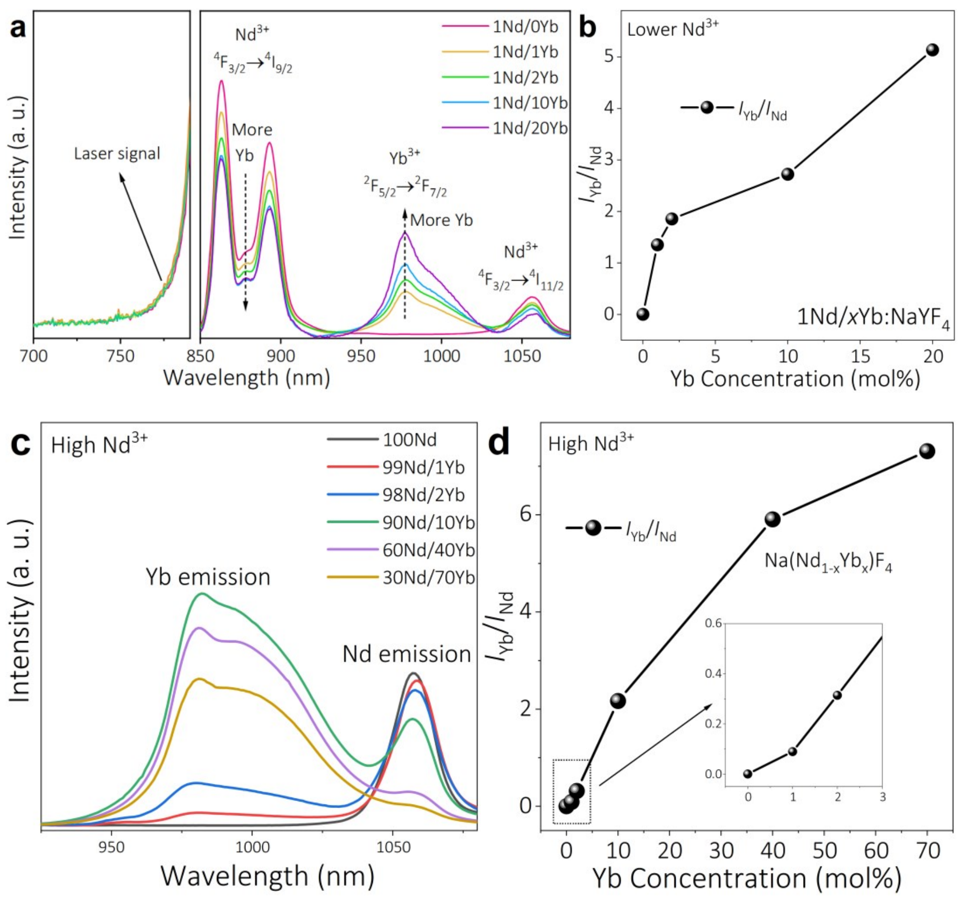

Figure S5. (a) NIR spectra and (b) intensity ratio between the Yb^{3+} emission and the Nd^{3+} emission in low Nd^{3+} doped $NaYF_4$ NCs; (c) NIR spectra and (d) intensity ratio between the Yb^{3+} emission and the Nd^{3+} emission in high Nd^{3+} doped $NaYF_4$ NCs. The gradually increasing intensity ratio with Yb^{3+} concentration in both low Nd^{3+} and high Nd^{3+} doping situations clearly manifest the FET process of Nd^{3+}→Yb^{3+}.

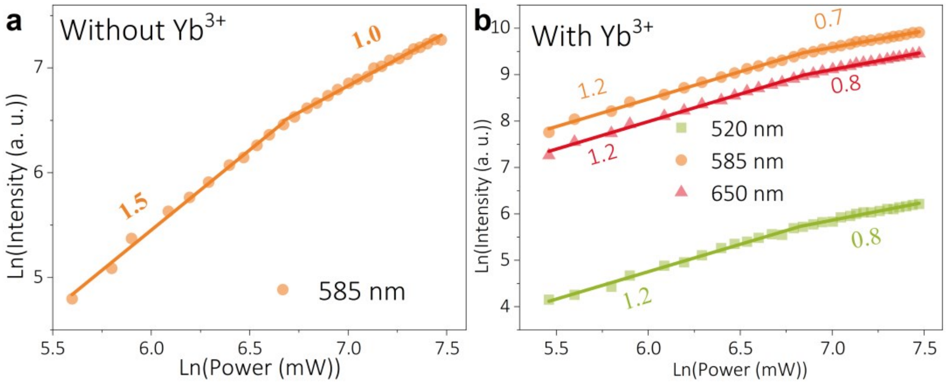

Figure S6. Ln-Ln power dependences of (a) Nd^{3+} doped and (b) Nd^{3+}/ Yb^{3+} codoped $NaYF_4$ NCs.

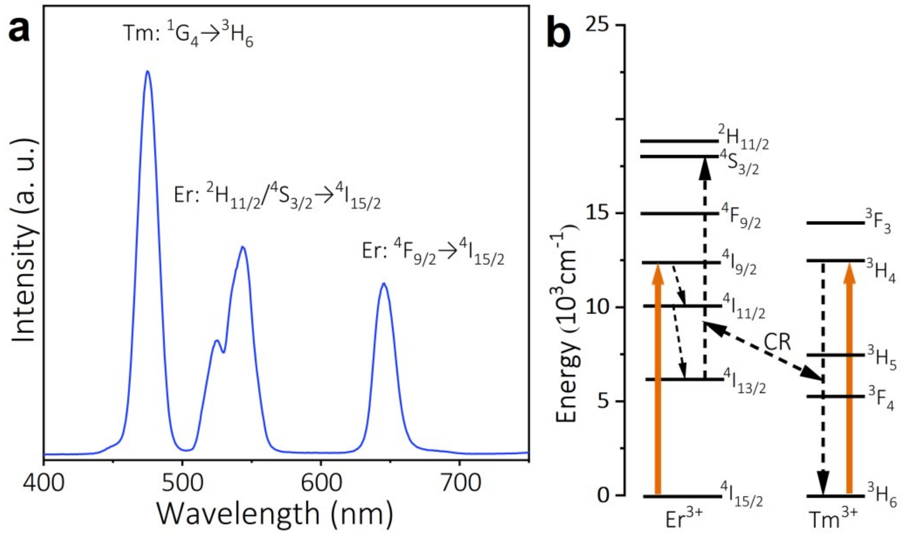

Figure S7. (a) UC spectrum of $0.5Tm^{3+}/10Yb^{3+}$ codoped $NaYF_4$ NCs upon 800 nm excitation. The green and red emission bands of Er^{3+} evidence the existence of the Er^{3+} impurity. (b) Simplified energy-level diagrams depicting the possible cross-relaxation (CR) quenching mechanisms between Er^{3+} and Tm^{3+} under 800 nm excitation.

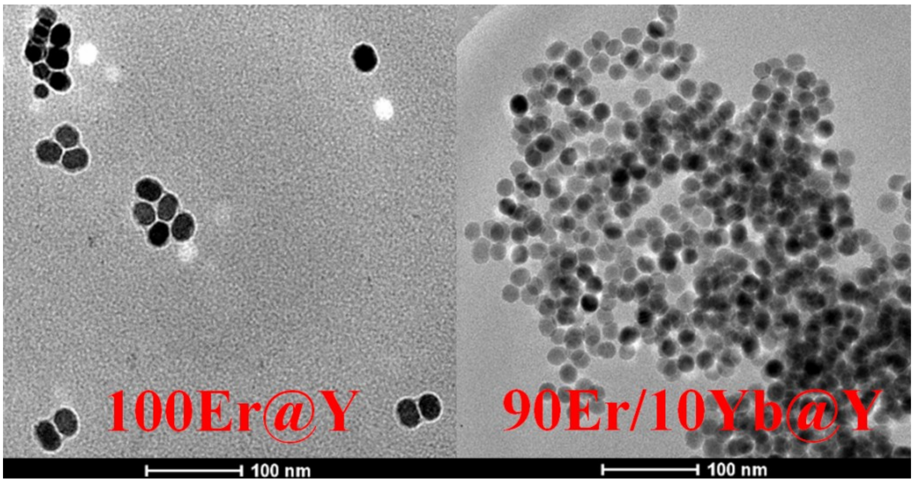

Figure S8. TEM images of $NaErF_4$@$NaYF_4$ and $Na(Er_{0.9}/Yb_{0.1})F_4$@$NaYF_4$ NCs. Scale bars are 100 nm.

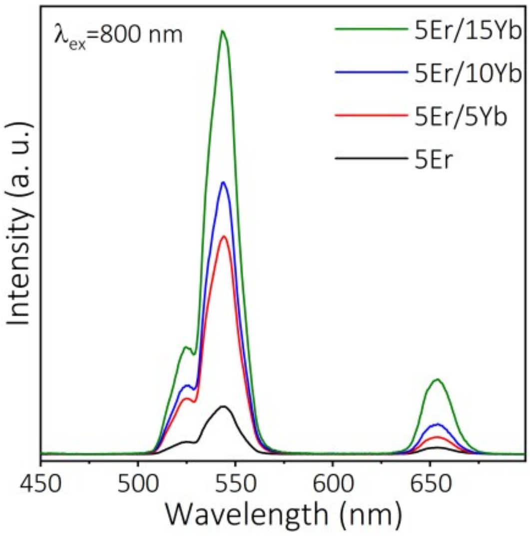

Figure S9. Effects of Yb^{3+} on the UC spectra of Er^{3+} upon 800 nm excitation in low Er^{3+} doped NCs.

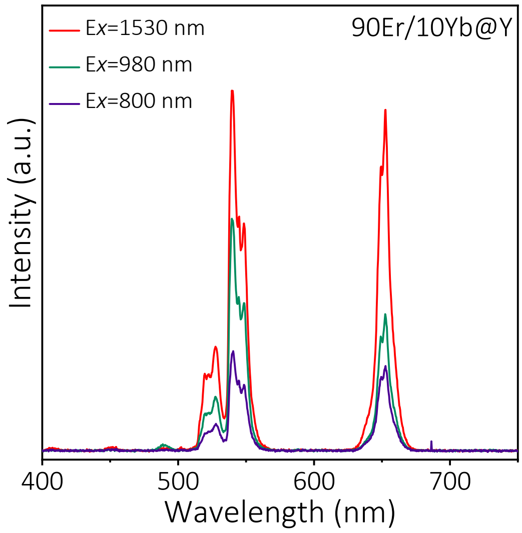

Figure S10. Upconversion spectra of $Na(Er/Yb)F_4@NaYF_4$ nanocrystals upon 800, 980, and 1530 nm excitation using identical excitation intensity.

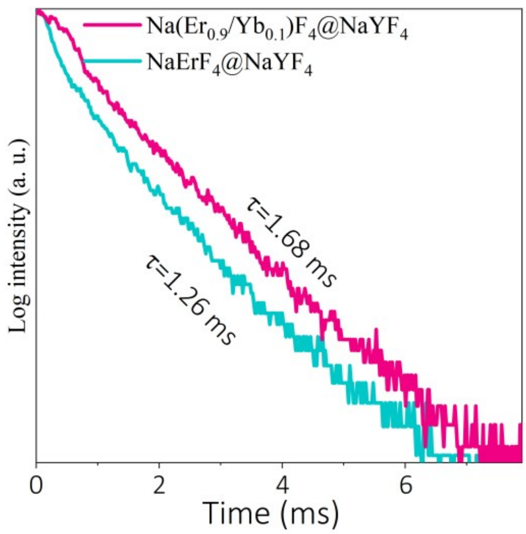

Figure S11. Decay profiles of the Er^{3+} 540 nm emission of $NaErF_4$@$NaYF_4$ core-shell NCs and $Na(Er_{0.9}/Yb_{0.1})F_4$@$NaYF_4$ core-shell NCs upon 1530 nm excitation.

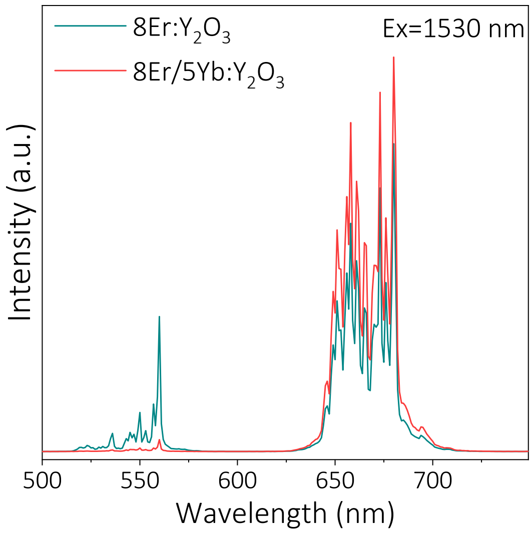

Figure S12. Upconversion spectra of Er^{3+}:Y_2O_3 and Er^{3+}/Yb^{3+}:Y_2O_3 ceramics.

Table S1. Integral intensity of visible light of $Nd^{3+}/Yb^{3+}:NaYF_4$. All intensities were normalized to the value of 1 mol% Nd^{3+} NCs. Those impossible compositions are labeled as NA. Two typical intensities of $1Nd^{3+}$ and $10Nd^{3+}/5Yb^{3+}$ NCs were given in bold font, respectively, corresponding to the most efficient Nd^{3+} single doped and Nd^{3+}/Yb^{3+} co-doped NCs.

	1Nd	10Nd	20Nd	30Nd	40Nd	60Nd	90Nd	100Nd
0Yb	**1.00**	0.64	0.21	0.23	0.24			0.22
1Yb	1.83	2.48	--	--	--			NA
2Yb	2.18	4.96	--	--	--			NA
3Yb	2.30	6.25	--	--	--			NA
5Yb	1.93	**7.06**	4.89	2.87	2.25		1.59	NA
10Yb	1.46	6.13	3.71	3.39	3.58		1.71	NA
20Yb	1.09	5.81	3.21	2.79	2.65		NA	NA
30Yb	0.65	2.58	2.41	1.86	2.21		NA	NA
40Yb	0.41			--		0.91	NA	NA
60Yb	0.29			--		NA	NA	NA
70Yb	--			0.82	NA	NA	NA	NA
80Yb	0.19			NA	NA	NA	NA	NA
99Yb	0.11	NA	NA	NA	NA	NA	NA	NA