Supporting information

Enhancing Negative Thermal Quenching Effect via Low-valence Doping in Two-dimension Confined Core-shell Upconversion Nanocrystals

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Figure S1-13



Figure S1 TEM image of NaGdF₄ NCs prepared by adding OA and ODE together.



Figure S2 (a)-(f) TEM images of core NCs corresponding to the NaGdF4@xCa/20Yb/2Er: NaGdF4 (x=0, 10, 20, 30, 40, 50) core-shell NCs, respectively. HRTEM images of an individual core (g) and core-shell (h) NCs. (i) STEM image of NaGdF4@20Ca/20Yb/2Er: NaGdF4 core-shell NCs.



Figure S3 XRD (a) and EDS (b) patterns of NaGdF₄@xCa/20Yb/2Er: NaGdF₄ (x=0, 10, 20, 30, 40, 50) core-shell NCs, respectively.



Figure S4 TEM images of 20Yb/2Er: NaGdF₄ (a) and 20Ca/20Yb/2Er: NaGdF₄ (b) NCs. Insets are their corresponding size distributions.



Figure S5 Temperature-dependent UC emission spectra of NaGdF₄@20Ca/20Yb/2Er: NaGdF₄ NCs. Insets are the corresponding integral UC emission intensity enhancement degree.



Figure S6 Luminescence decay curves of Er^{3+} : ${}^{4}F_{9/2} \rightarrow {}^{4}I_{15/2}$ in NaGdF₄@xCa/20Yb/2Er: NaGdF₄ sample under the excitation of a 980 nm laser: (a) x=0 and (b) x=40.



Figure S7 Integral emission intensity enhancement degrees for the $Ho^{3+}(up)$ and Tm^{3+} (down) doped systems.



Figure S8 XPS full spectra of NaGdF₄@xCa/20Yb/2Er: NaGdF₄ (x=0 and 20) NCs.



Figure S9 TSL spectra of the NaGdF4@20Ca/20Yb/2Er: NaGdF4 core-shell NCs.



Figure S10 Temperature-dependent UC emission spectra of NaGdF₄@20Ca/20Yb/2Er:

NaGdF₄@NaGdF₄ (a) and 20Ca/20Yb/2Er: NaGdF₄@NaGdF₄ (b) NCs. Insets are their corresponding integral UC emission intensity enhancement degree. TEM images of NaGdF₄@20Ca/20Yb/2Er: NaGdF₄@NaGdF₄ (c) and 20Ca/20Yb/2Er: NaGdF₄@NaGdF₄ (d) NCs. Insets are their corresponding size distributions.



Figure S11 EDS spectra of NaGdF₄@20Sr/20Yb/2Er: NaGdF₄ NCs (a) and NaGdF₄@10Ba/20Yb/2Er: NaGdF₄ NCs (b), respectively. Insets are their corresponding TEM images. Temperature-dependent UC emission spectra of NaGdF₄@20Sr/20Yb/2Er: NaGdF₄ NCs (c) and NaGdF₄@10Ba/20Yb/2Er: NaGdF₄ NCs (d), respectively. Insets are the corresponding integral UC emission intensity enhancement degree.



Figure S12 Dependence of the Integral UC emission intensity on temperature for different doping conditions. Insets are their corresponding TEM images.



Figure S13 Temperature-dependent UC emission spectra respectively normalized to 545 nm (a) and 660 nm (b) for NaGdF₄@20Yb/2Er: NaGdF₄ NCs.