Supplementary Information:

Revisiting the Optimized Doping Ratio in Core/Shell Nanostructured Upconversion Particles

Bin Shen, Shengming Cheng, Yuyang Gu, Danrui Ni, Yilin Gao, Qianqian Su, Wei Feng* and Fuyou Li*

Department of Chemistry and The State Key Laboratory of Molecular Engineering of Polymers and Institute of Biomedicine Science and Collaborative Innovation Center of Chemistry for Energy Materials, Fudan University, Shanghai, 200433, P. R. China

Experimental Section

Materials: All starting materials were obtained from commercial supplies. Rare earth oxides Y_2O_3 (99.999%), Yb_2O_3 (99.999%), Er_2O_3 (99.999%), Lu_2O_3 (99.999%) were purchased from Shanghai Yuelong New Materials Co. Ltd. $Ln(CF_3COO)_3$, $Ca(CF_3COO)_2$ and $LnCl_3$ were prepared as reported in the literature [1-2]. Oleylamine (OM) (>90%), octadecene (ODE) (>90%) and oleic acid (OA) (>90%) were purchased from Sigma-Aldrich. Trifluoroacetic acid (99%), sodium trifluoroacetate (99%) were purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai). All other chemical reagents of analytical grade were used directly without further purification. Nude mice (4 weeks) were purchased from the Second Military Medical University and were housed under standard environmental conditions. Animal procedures were in agreement with the guidelines of the Institutional Animal Care and Use Committee.

***Characterization*:** The size and morphology of RE-UCNPs were characterized at 200 kV at a FEI Tecnai G^2 20 TWIN TEM. The HAADF-STEM images of RE-UCNPs were taken at FEI Tecnai G^2 F20 S-TWIN TEM. Powder X-ray diffraction measurements were performed on a XD-2 diffractometer at a scanning rate of 8 °C/min in the 2θ range from 10 °C to 90 °C (Cu Kα radiation, λ = 1.54056 Å). The upconversion luminescence emission spectra were recorded on a modified Edinburgh LFS-920 instrument. The absolute quantum efficiencies were measured with integrating sphere using barium sulfate as the reference. The excitation source was an external 0–9 W adjustable 980 nm semiconductor laser (Beijing Hi-Tech Optoelectronic Co., China) with an optic fiber accessory. The images of full-color upconversion luminescence were obtained digitally on a Panasonic DMC-LX5 camera.

***Synthesis of β-NaREF$_4$*:** $RE(CH_3COO)_3$ (1 mmol) was dispersed in ODE (11.8g) and OA (7.1 g). The mixture was stirred and heated to 120 °C for 30 min in a 100 mL flask to form an optical transparent solution. Then the solution was cooled down to room temperature and NaOH (0.100 g, 2.5 mmol) and NH_4F (0.148 g, 4 mmol) in methanol (10 mL) were added to the flask dropwisely. The solution was heated to 90 °C, repeatedly degassed and purged with nitrogen for three times. After that the solution was heated to 300 °C and kept for 1 h. Finally the nanoparticles were cooled to room temperature, collected by centrifugation (21036 RCF/8 min) and washed with cyclohexane/ethanol (1:3) for three times. The as-prepared nanoparticles were dispersed in cyclohexane (10 ml).

***Synthesis of β-NaREF$_4$@NaLuF$_4$*:** the as-prepared β-$NaREF_4$ solution (5 mL) and $Lu(CH_3COO)_3$ (1.028 g, 2 mmol) were mixed with OA (11.8 g) and ODE (7.1 g). The mixture was stirred and heated to 120 °C for 30 min in a 100 mL flask to form an optical transparent solution. Then the solution was cooled down to room temperature and NaOH (0.100 g, 2.5 mmol) and NH_4F (0.148 g, 4 mmol) in methanol (10 mL) were added to the flask dropwisely. The solution was heated to 90 °C, repeatedly degassed and purged with nitrogen for three times. After that the solution was heated to 300 °C and kept for 1 h. Finally the nanoparticles were cooled to room temperature, collected by centrifugation (21036 RCF/8 min) and washed with with cyclohexane/ethanol (1:3) for three times. The as-prepared nanoparticles were dispersed in cyclohexane (10 ml).

***Synthesis of α-NaREF$_4$*:** The synthesis of α-$NaYF_4$:Yb,Er and α-$NaYF_4$:Yb,Er@CaF_2 is via co-thermolysis of trifluoroacetates. Typically, $RE(CF_3COO)_3$ (1 mmol) and CF_3COONa (1 mmol, 136 mg) were added into a three-neck flask containing OM (2.6g), OA (2.8g) and ODE (5.0g). The mixture was

then heated to 140 °C under magnetic stirring. After degassed and purged with nitrogen for three times the solution was heated to 300 °C and kept for 0.5 h. The nanoparticles were cooled to room temperature, collected by centrifugation and washed with cyclohexane/ethanol (1:3) for three times. Finally the as-prepared nanoparticles were dispersed in cyclohexane (10 ml).

***Synthesis of α-NaREF$_4$@CaF$_2$*:** the as-prepared α-$NaREF_4$ solution (5 ml) and $Ca(CF_3COO)_2$ (532 mg, 2mmol) was dispersed in OA (5.6 g) and ODE (5.0 g) under magnetic stirring. The mixture was then heated to 140 °C under magnetic stirring. After degassed and purged with nitrogen for three times the solution was heated to 300 °C and kept for 0.5 h. The nanoparticles were collected by centrifugation and washed with cyclohexane/ethanol (1:3) for three times. Finally the as-prepared nanoparticles were dispersed in cyclohexane (10 ml).

***Synthesis of α-NaREF$_4$@CaF$_2$:Yb/Er*:** In a typical synthesis of α-$NaREF_4$@CaF_2:Yb, the as-prepared α-$NaREF_4$ solution (5 ml), $Ca(CF_3COO)_2$ (479 mg, 1.8mmol), CF_3COONa (27 mg, 0.2 mmol) and $Yb(CF_3COO)_3$ (102 mg, 0.2 mmol) were dispersed in OA (5.6 g) and ODE (5.0 g) under magnetic stirring. The mixture was then heated to 140 °C under magnetic stirring. After degassed and purged with nitrogen for three times the solution was heated to 300 °C and kept for 0.5 h. The nanoparticles were collected by centrifugation and washed with cyclohexane/ethanol (1:3) for three times. Finally the as-prepared nanoparticles were dispersed in cyclohexane (10 ml). α-$NaREF_4$@CaF_2:Er was synthesized in a similar procedure with $Ca(CF_3COO)_2$ (507 mg, 1.98 mmol), CF_3COONa (2.7 mg, 0.02 mmol) and $Er(CF_3COO)_3$ (10.1 mg, 0.02 mmol) as precursors.

***Synthesis of water-soluble α-NaREF$_4$@CaF$_2$*:** The water-soluble α-$NaREF_4$@CaF_2 was obtained through acid treatment [3-4]. Typically, the as-synthesized oleate-capped α-$NaREF_4$@CaF_2 UCNPs (10 mg) were dispersed in the acidic ethanol solution (5 mL, pH=1) and ultrasonicated for 3 min to remove the surface ligands. After that, the UCNPs were collected by centrifugation at 21036 RCF for 10 min, and further washed by water/ethanol (1:1) for three times. The as-prepared products were redispersed in distilled water.

***In vivo upconversion imaging*:** Nude mice (~20 g, 4 weeks) were anesthetized with isoflurane and injected intravenously with water-soluble α-$NaREF_4$@CaF_2 solution (200 μL, 2 mg/mL). At 3 hours

post-injection, the upconversion imaging was performed with the upconversion imaging equipment developed by our group.

***Visible UCL signals guided lymphatic vessel resection*:** Nude mice (~20 g) were anesthetized with isoflurane and injected subcutaneously into the forelimb with water-soluble α-$NaREF_4$@CaF_2 solution (200 μL, 2 mg/mL). At 3 hours post-injection, the upconversion imaging was performed with an Olympus SZX2 stereomicroscope. An M-shot MC21 detector in full-color mode was used to record the resection.

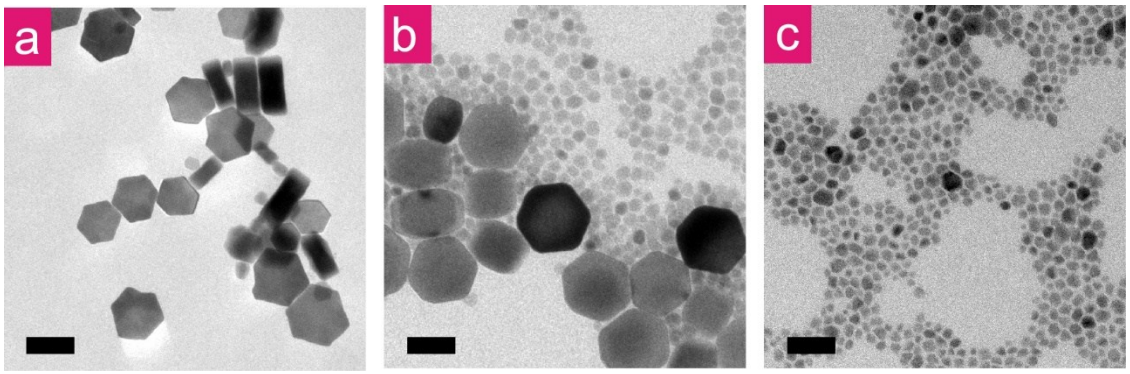

Figure S1. TEM images of the as-prepared β-$NaY_{0.98-x}Yb_xF_4$:2%Er (a) x=0.6; (b) x=0.8; (c) x=0.98. Scale bars: 200 nm in (a) and 50 nm in (b, c).

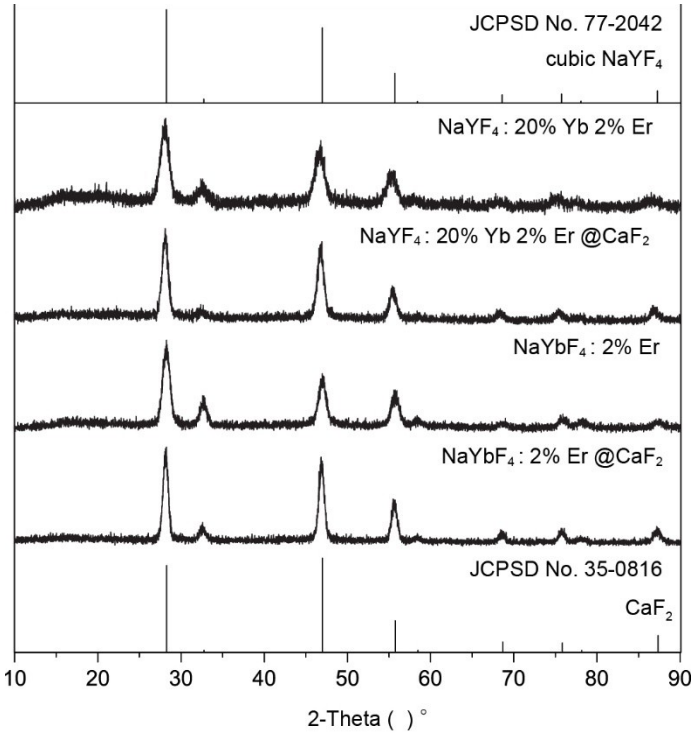

Figure S2 X-ray diffraction patterns of the as-prepared UCNPs.

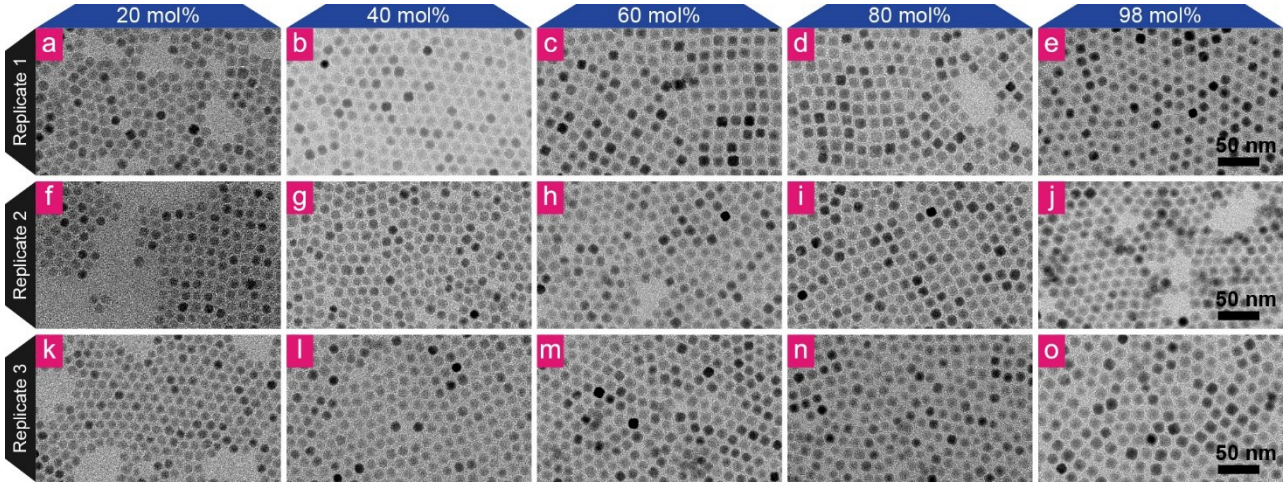

Figure S3 TEM images of three replicates of the as-prepared a-NaY0.98-xYbxF4:2%Er@CaF2 (x= 0.2, 0.4, 0.6, 0.8, 0.98); (a-e) replicate1; (f-j) replicate2; (k-o) replicate3.

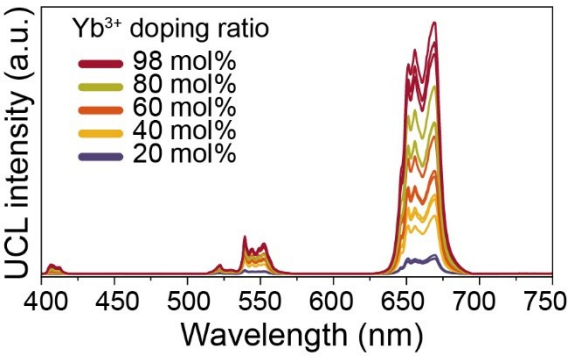

Figure S4 UCL spectra of the corresponding three replicates of a-NaY0.98-xYbxF4:2%Er@CaF_2 (x= 0.2, 0.4, 0.6, 0.8, 0.98) in cyclohexane under the excitation of 980 nm laser (30 W/cm^2)

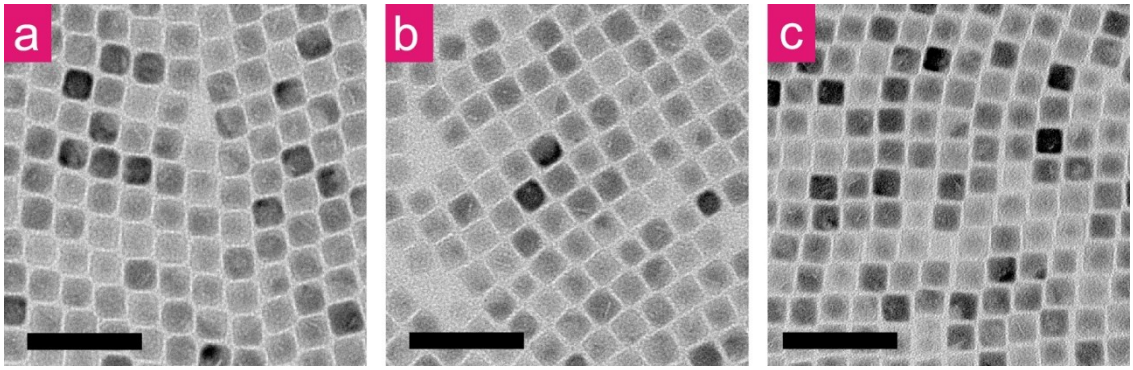

Figure S5 TEM images of α-$NaYbF_4$: Er@CaF_2 with different dopants in the shell. (a) no dopants; (b) 20 mol% Yb; (c) 2 mol% Er. Scale bars: 50 nm.

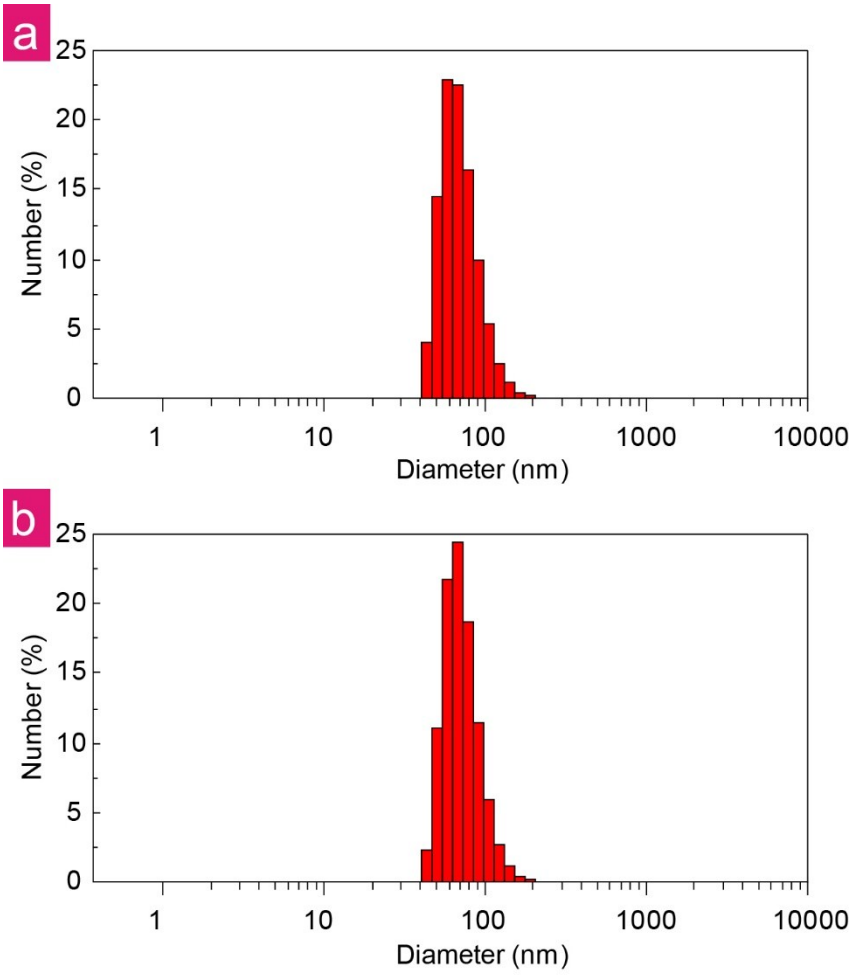

Figure S6 Hydrodynamic diameter distribution of (a) the water-soluble UCNP in water and (b) OA-capped UCNPs in cyclohexane.

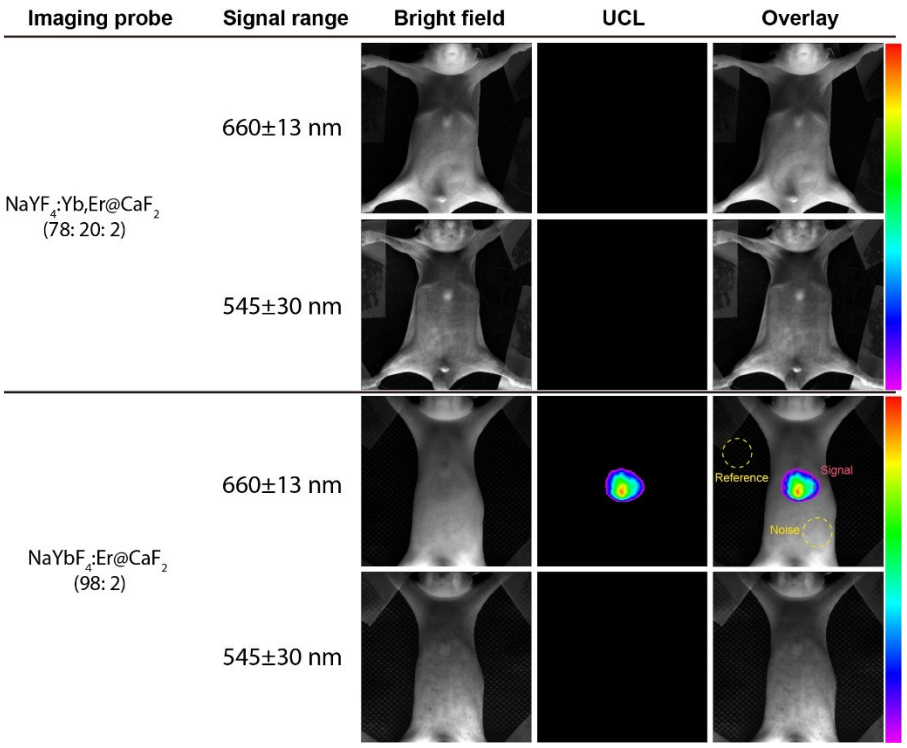

Figure S7 *in vivo* UCL imaging of a nude mouse at 3h post-injection collected in green (545±30 nm) and red (660±13 nm) channel with α-$NaYbF_4$:Er@CaF_2 (98:2) and α-$NaYF_4$:Yb,Er@CaF_2 (78:20:2), respectively.

Reference

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[3] Bogdan, N.; Vetrone, F.; Ozin, G. A.; Capobianco, J. A., *Nano Lett.* **2011**, *11*, 835.
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