Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information for

Three-primary-color up-conversion luminescence from single tri-sensitized $NaYF_4$ nanocrystals

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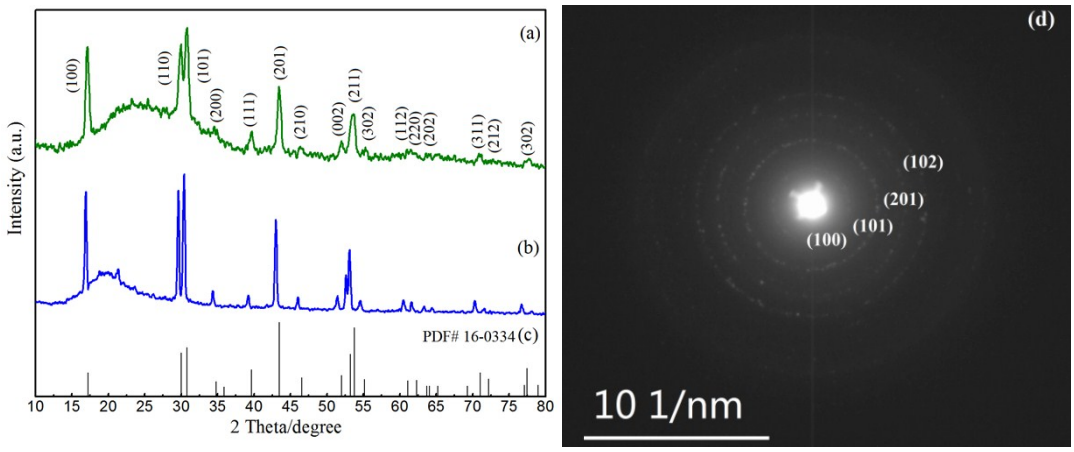


Figure S1. XRD patterns of (a) $NaYF_4$: Nd, Yb, Tm and (b) $NaYF_4$: Nd, Yb, Tm@ $NaYF_4$: Nd samples, which suggest the crystal structure of β-$NaYF_4$. (c) stander cards of β-$NaYF_4$ (PDF# 16-0334). (d) Electron diffraction of as-prepared C-S1-S2-S3-S4 UC nanoparticles indicates the β-$NaYF_4$ crystals.

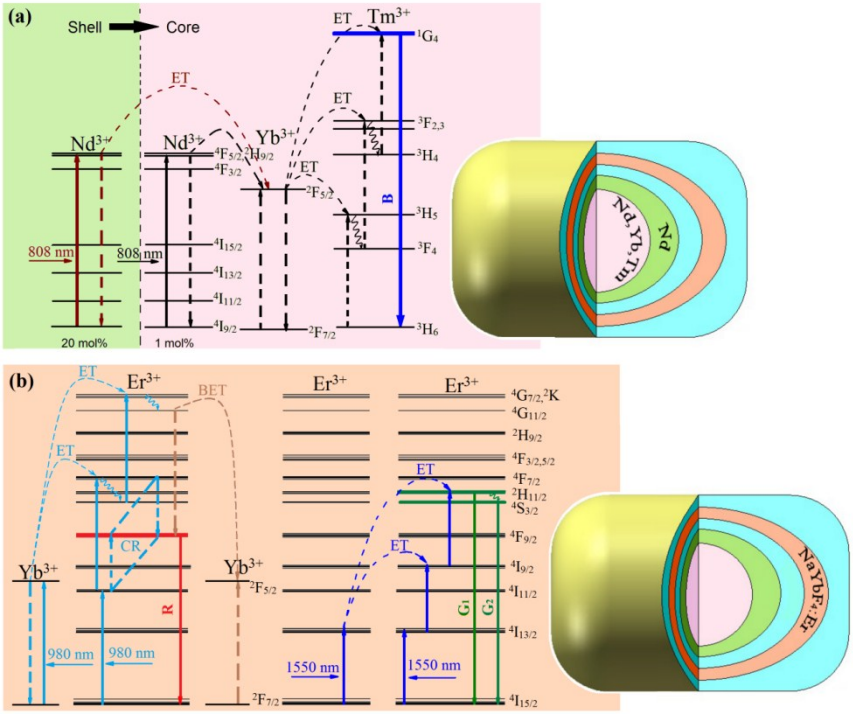


Figure S2. UC luminescence mechanisms of $NaYF_4$-based core-shell nanoparticles. (a) The C and S1 layers exhibit blue emission ($^1G_4 \rightarrow {}^3H_6$) via energy transfer (ET) processes of $Nd^{3+} \rightarrow Yb^{3+} \rightarrow Tm^{3+}$ under 808 nm excitation. (b) The S3 layer of $NaYbF_4$: Er^{3+} presents individual red (marked as R), and green (marked as G1, G2) luminescence. Cross relaxation (CR) between Er^{3+} ions and back energy transfer (BET) from $Er^{3+} \rightarrow Yb^{3+}$ ions lead to red emission excited at 980 nm. While at 1550 nm excitation, continuous absorption of three photons or ET processes between Er^{3+} ions produce green emission.

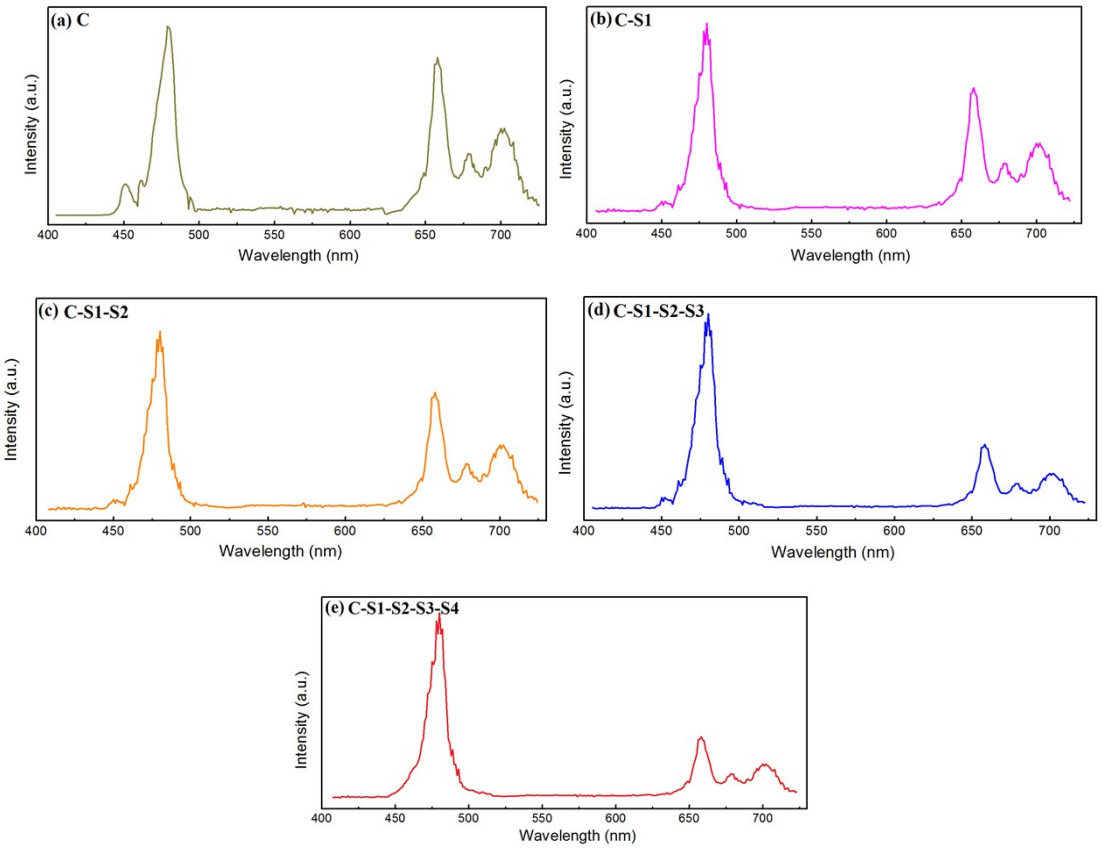
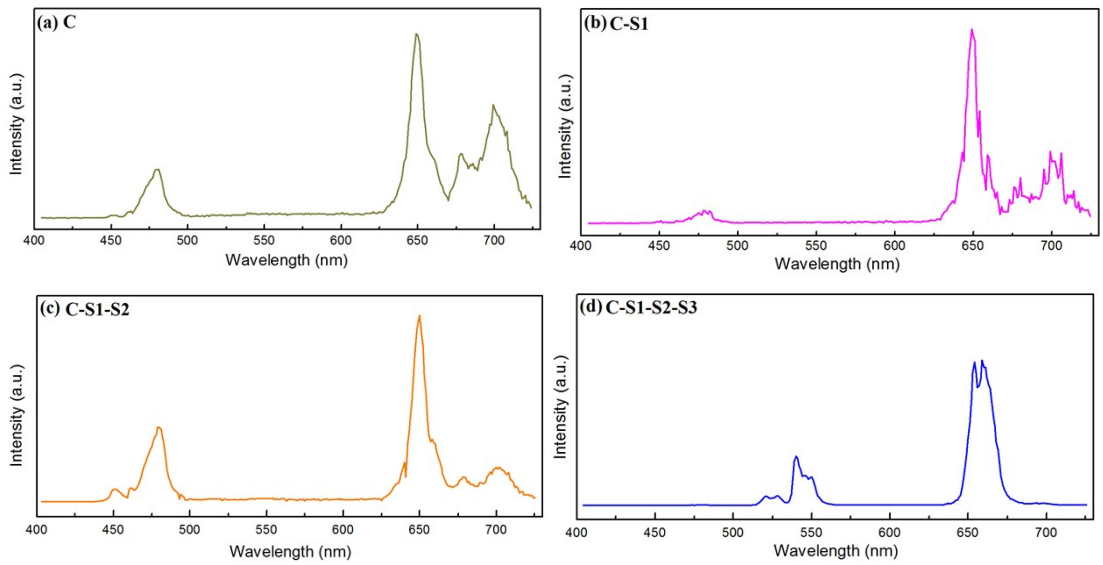


Figure S3. UC luminescence spectra of (a) C, (b) C-S1, (c) C-S1-S2, (d) C-S1-S2-S3, (e) C-S1-S2-S3-S4 UC nanoparticles under 808 nm excitation. The blue emission is enhanced with the shell coating at excitation of 808 nm.



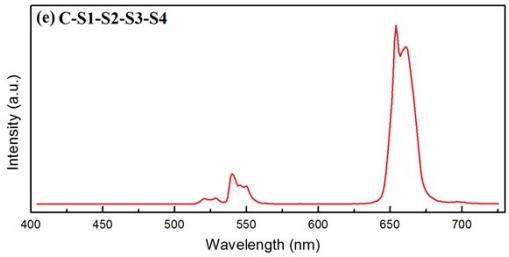


Figure S4. UC luminescence spectra of (a) C, (b) C-S1, (c) C-S1-S2, (d) C-S1-S2-S3, (e) C-S1-S2-S3-S4 UC nanoparticles under 980 nm excitation. The blue emission is suppressed with the shell coating at excitation of 980 nm.

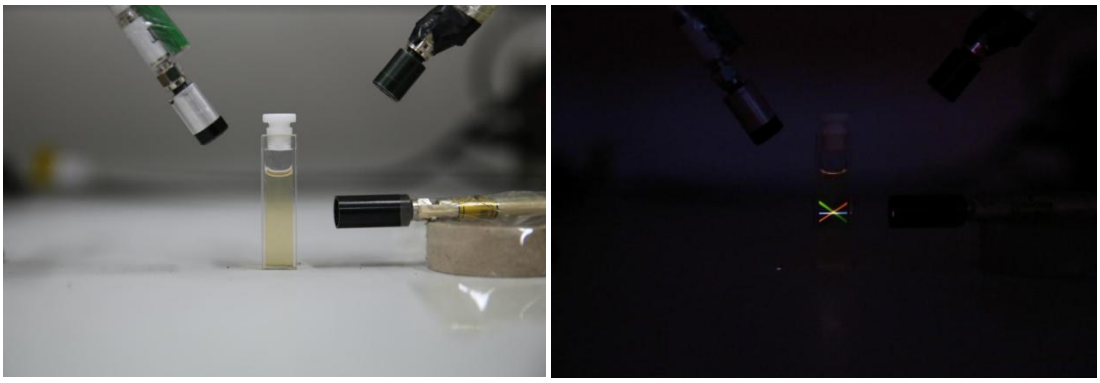


Figure S5. Photographs of three-primary-color luminescence from as-prepared multilayer β-$NaYF_4$ nanoparticles. (Canon EOS 5D Mark III, Tv=1:10, Len: EF24-70mm f/2.8L II USM, Av= 2.8)

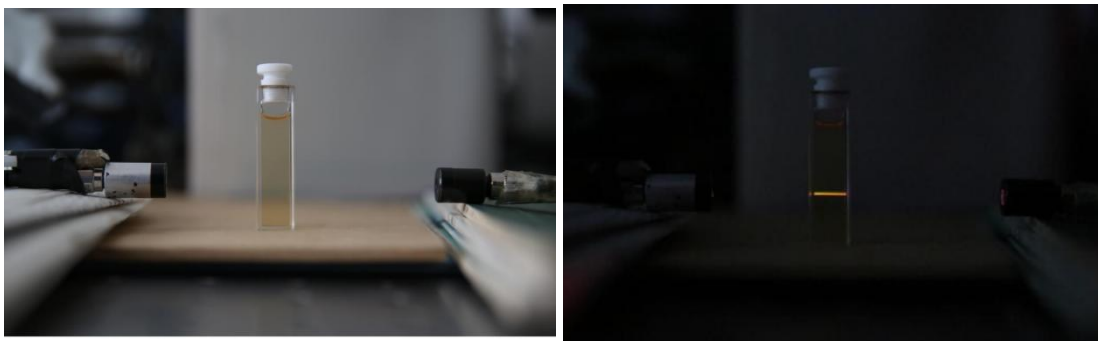


Figure S6. An example of camera images that demonstrates tunable UC luminescence measurement of multilayer β-$NaYF_4$ nanoparticles. (Canon EOS 5D Mark III, Tv=1:10, Len: EF24-70mm f/2.8L II USM, Av= 2.8).

Video.mp4