Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

Supporting information

Highly Controllable and Reproducible One-step Synthesis of β-$NaYF_4$:Er^{3+}@$NaYbF_4$@$NaYF_4$ Upconversion Nanoparticles for $Sb_2(S,Se)_3$ Solar Cell with Enhanced Efficiency

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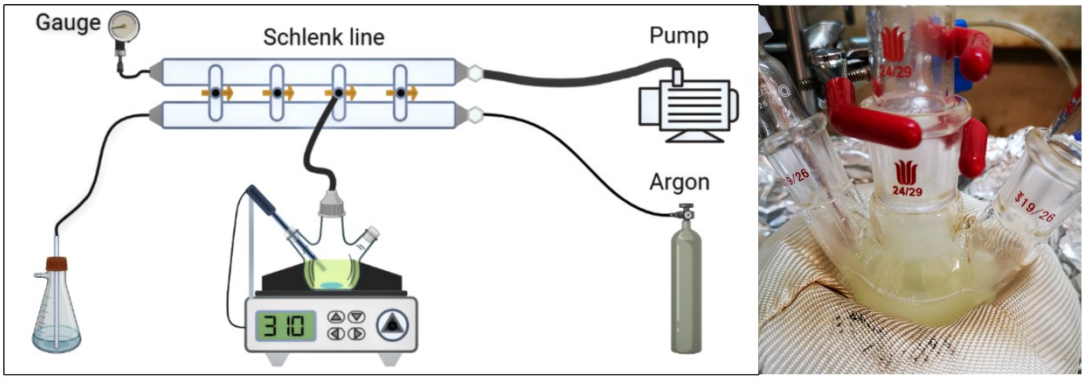

Figure S1. Schematic illustration of experimental setup for synthesizing UCNPs (left) and the digital photo of the product (right).

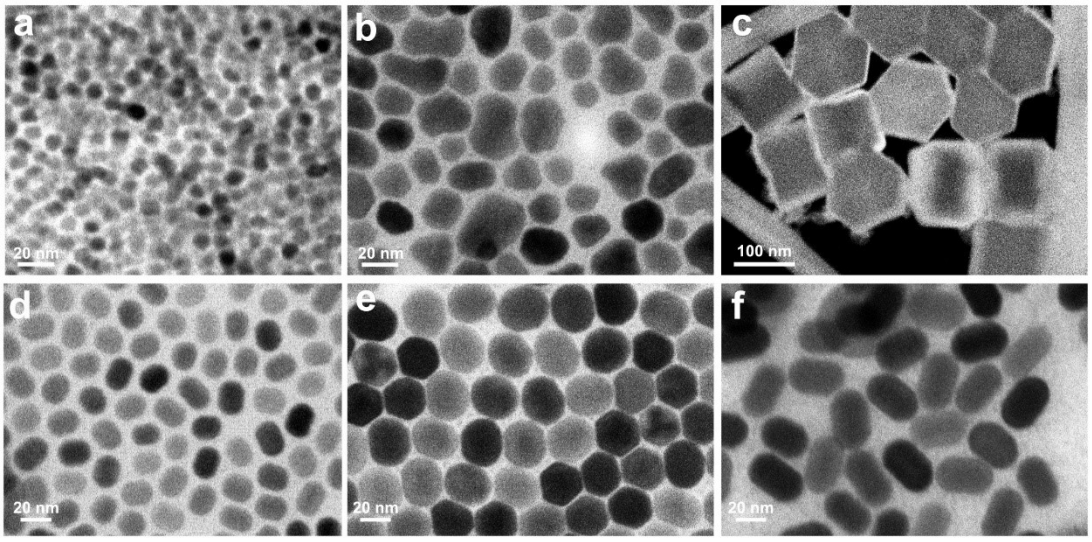

Figure S2. SEM image showing the $NaYF_4$ crystals prepared with temperature profile (a) 1, (b) 2 and (c) 4 as shown in Figure 1b. SEM images of $NaYF_4$ crystals prepared based on temperature profile 3 with growth time of (d) 18 min, (e) 30 min and (f) 45 min.

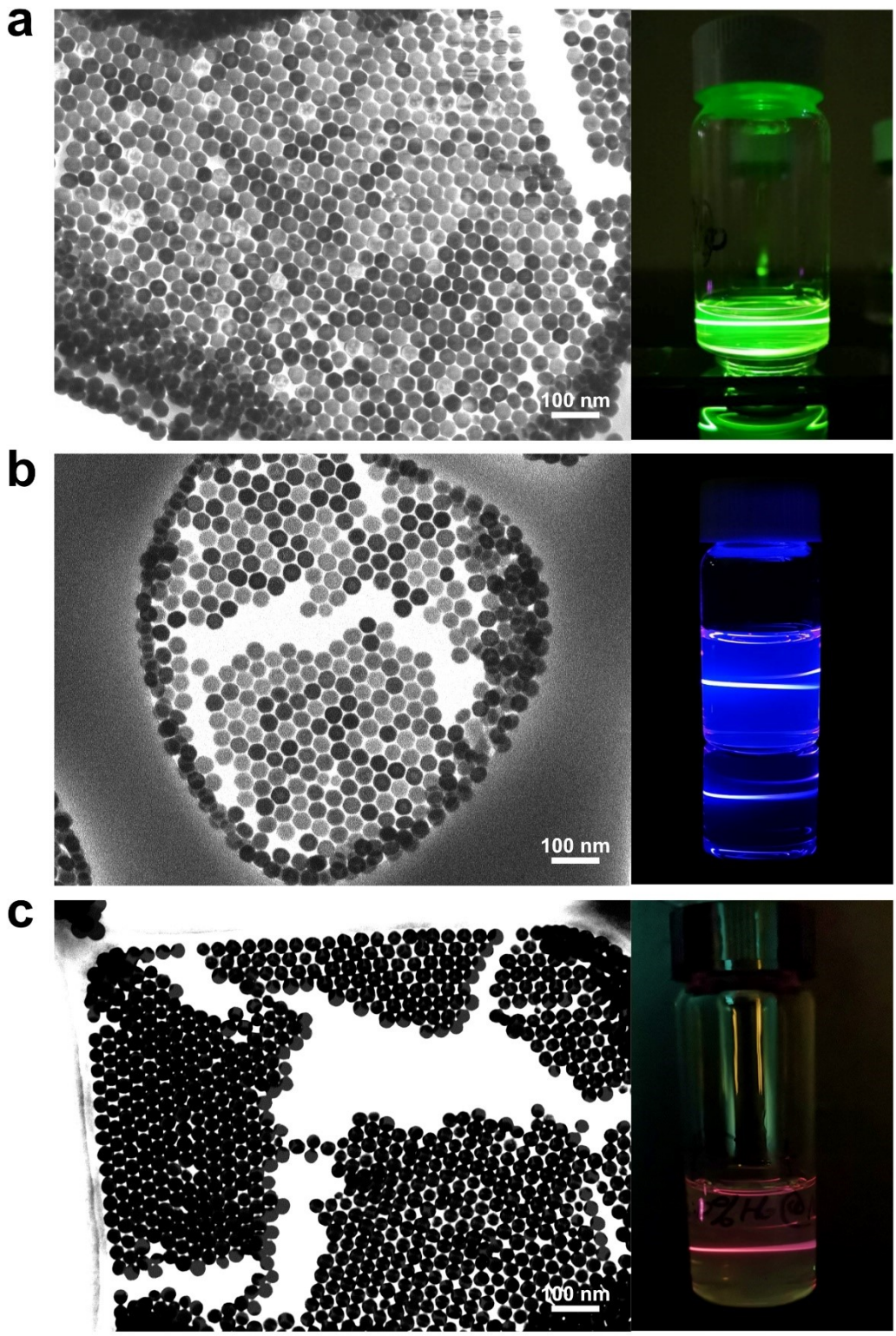

Figure S3. SEM images and corresponding digital photos of emission of (a) $NaYF_4$:10%Er@$NaYbF_4$, (b) $NaYF_4$:10%Tm@$NaYbF_4$ and (c) $NaYF_4$:10%Ho@$NaYbF_4$:40%Ce UCNPs.

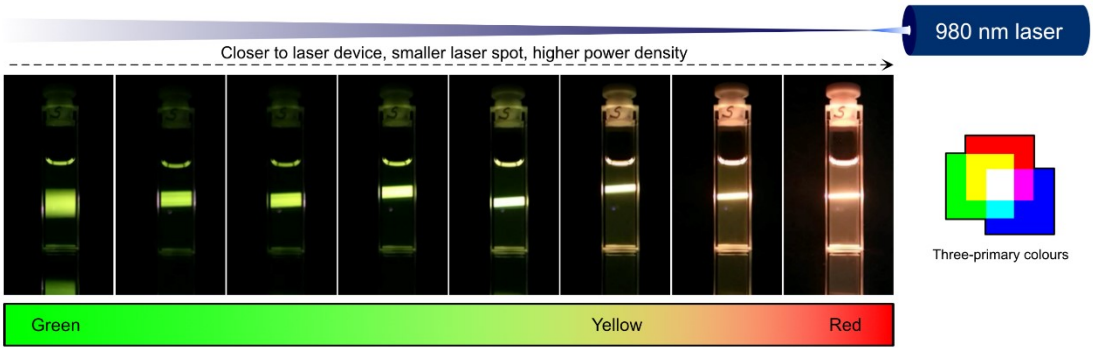

Figure S4. Digital photos showing the emission variation of $NaYF_4$:10%Er@$NaYbF_4$@$NaYF_4$ UCNPs as enhancing the excitation power density by decreasing the distance between sample and laser device (from left to right).

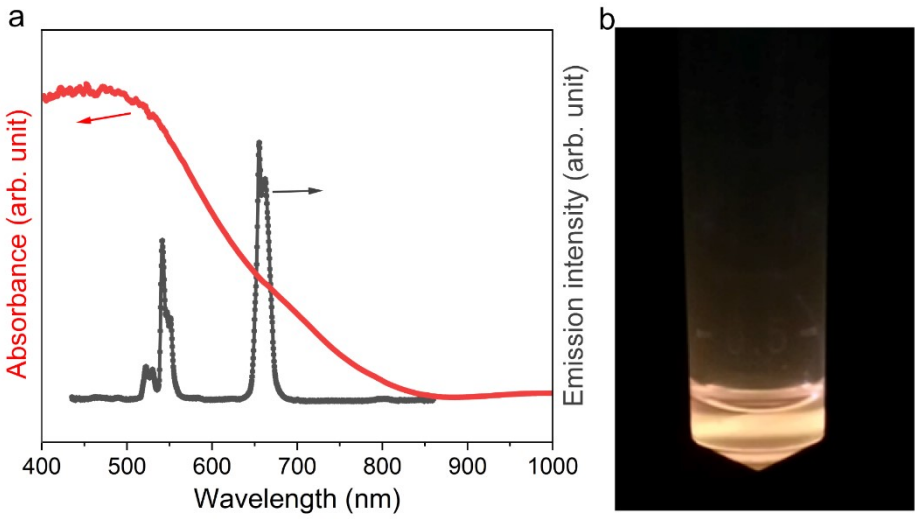

Figure S5. (a) Schematic diagram showing the overlap between the emission of $NaYF_4$:10%Er@$NaYbF_4$@$NaYF_4$ UCNPs and the absorption spectrum of $Sb_2(S,Se)_3$ thin film (Eg = 1.55 eV in this study). (b) Digital photo showing the emission of the mixed solution of Spiro-OMeTAD with UCNPs illuminated by 980 nm laser.

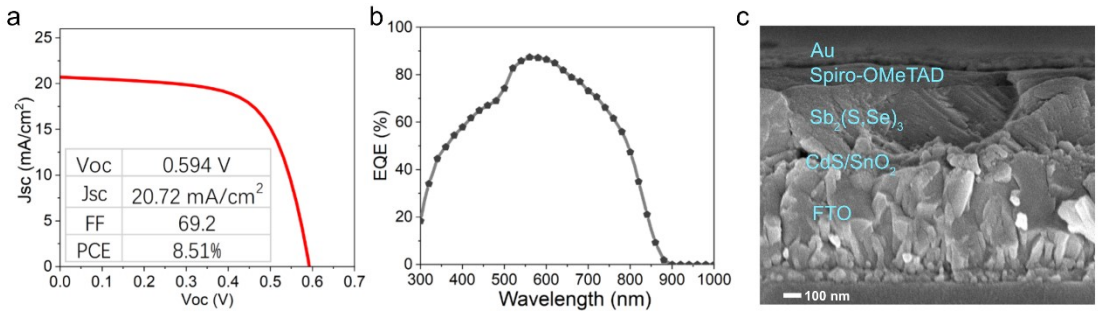

Figure S6. The (a) J-V curve, (b) EQE and the corresponding (c) cross-sectional SEM image of a typical $Sb_2(S,Se)_3$ solar cell without UCNPs.