Supporting Information

Simultaneous Multiple Wavelength Upconversion in a Core-Shell Nanoparticle for Enhanced Near Infrared Light Harvesting in a Dye-Sensitized Solar Cell

Chunze Yuan [a], Guanying Chen [a,b,c], Lin Li [f], Jossana A. Damasco [b], Zhijun Ning [a], Hui Xing [d], Tianmu Zhang [e], Licheng Sun [f], Hao Zeng [d], Alexander N. Cartwright [e], Paras N. Prasad [b*] and Hans Ågren [a*]*

[a] Department of Theoretical Chemistry and Biology, School of Biotechnology, Royal Institute of Technology (KTH), 10691, Stockholm, Sweden

[b] Institute for Lasers, Photonics, and Biophotonics, University of Buffalo, The State University of New York, Buffalo, New York 14260, USA

[c] School of Chemical Engineering and Technology, Harbin Institute of Technology, Harbin 15000, People's Republic of China

[d] Department of Physics, University of Buffalo,The State University of New York at Buffalo, Buffalo, New York 14260, USA

[e] Department of Electrical Engineering, University of Buffalo,The State University of New York at Buffalo, Buffalo, New York 14260, USA

[f] Center of Molecular Devices, Department of Chemistry, School of Chemical Science and Engineering, Royal Institute of Technology (KTH), 10044, Stockholm, Sweden

* Corresponding authors:
E-mail addresses: agren@theochem.kth.se (H. Ågren), Fax: +46 8 55378416; Tel: +46 8 55378590
guanying@buffalo.edu (G. Chen)
pnprasad@buffalo.edu (P.N. Prasad)

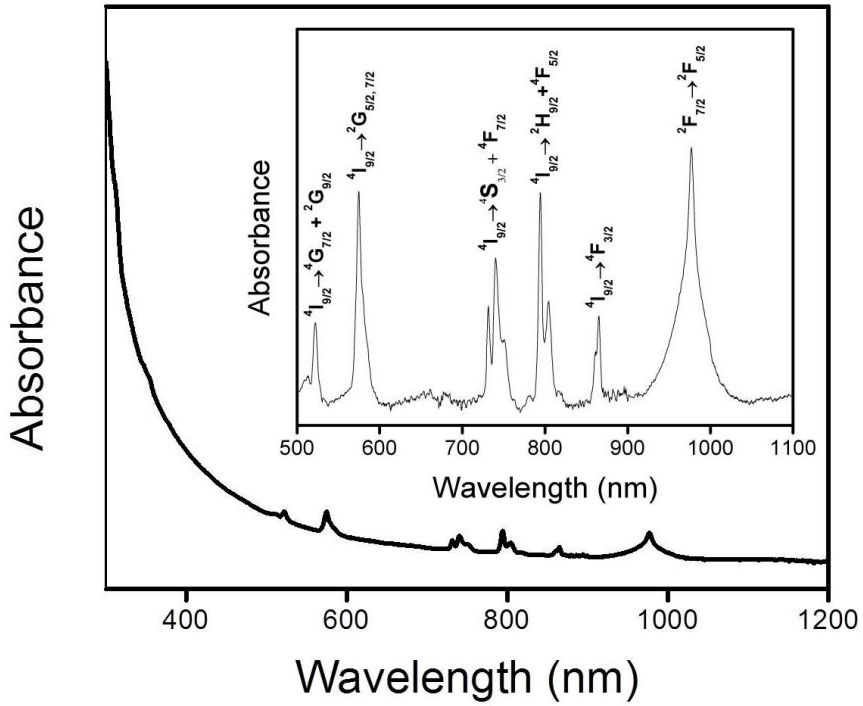

Figure S1. UV-Vis absorption spectrum of UCNPs dispersed in Hexane. Inset is enlarged view of the absorbance in the wavelength of 500-1100 nm.

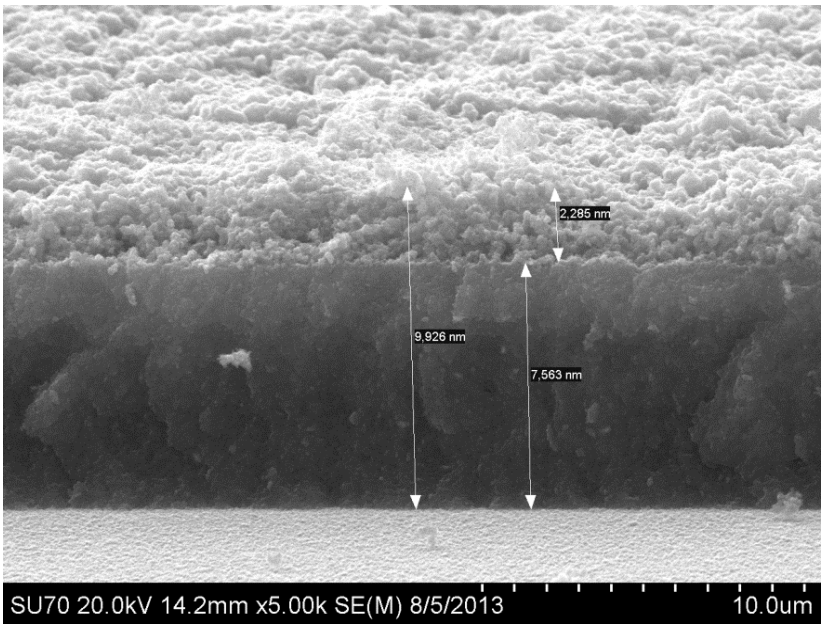

Figure S2. SEM image of cross-section of UCNPs nanoparticles deposited on dye (N719) sensitized TiO_2 film.

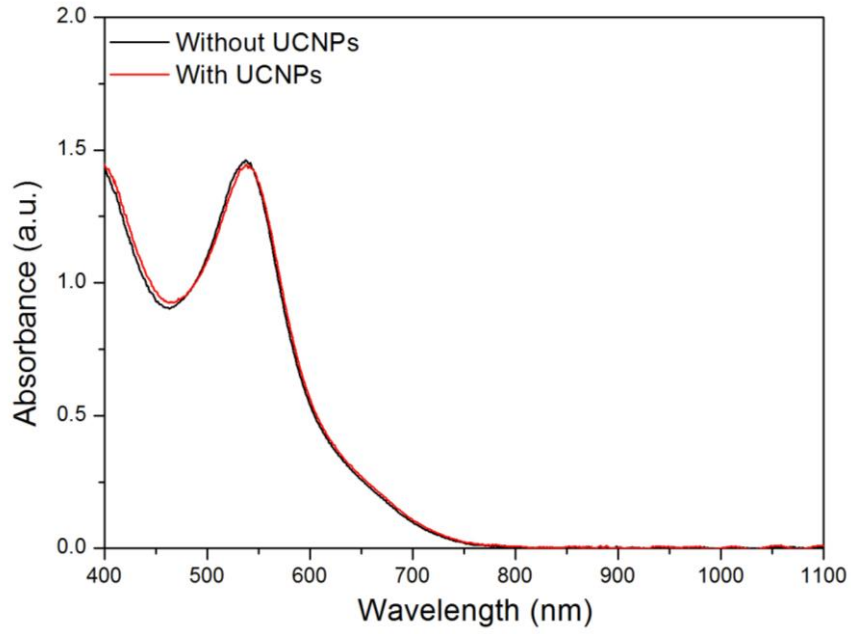

Figure S3. UV-Vis absorption Spectra of N719 on TiO_2 (transparent film type 1) with and without UCNPs.

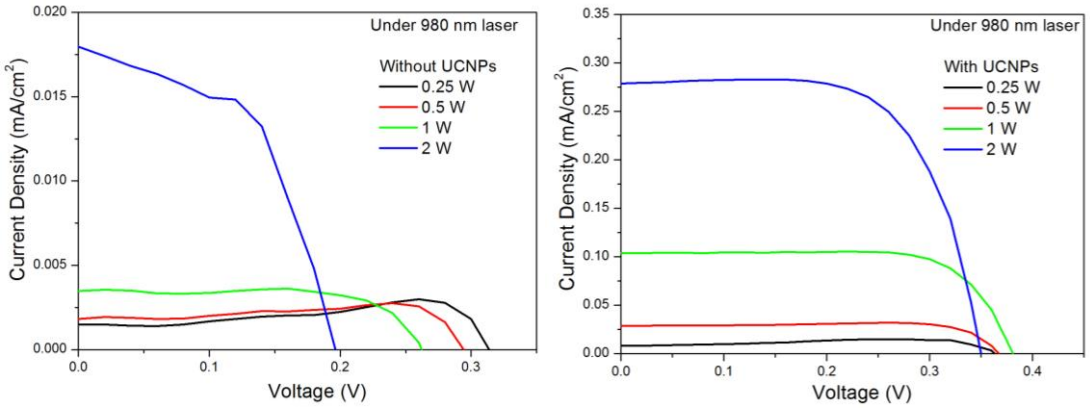

Figure S4. IV-curves of standard solar cell (left figure) and with the addition of UCNPs (right figure) under the illumination of a 980 nm laser with different power (Black line: 0.25 W; Red line: 0.5 W; Green line: 1 W and Blue line: 2 W)

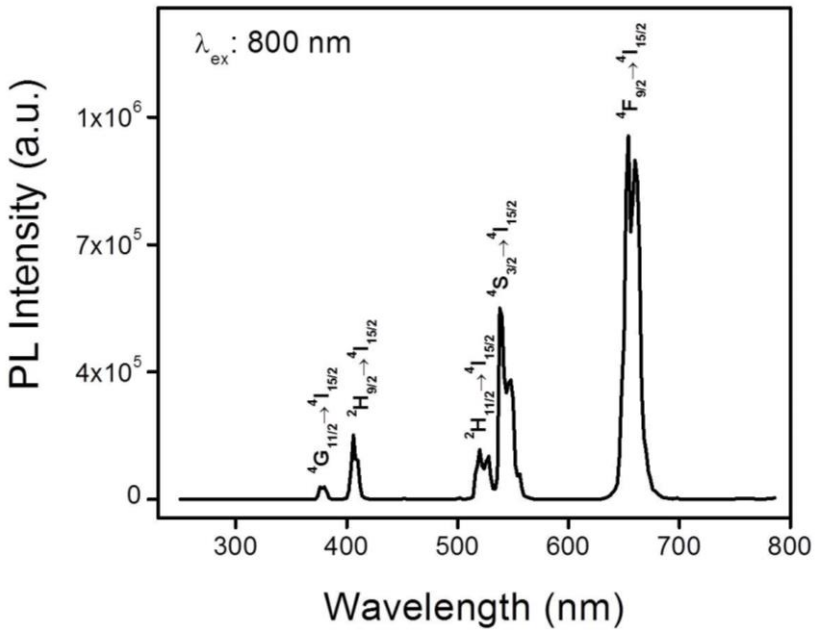

Figure S5. The fluorescence spectra of the UCNPs (0.02 M in hexane) under 800nm laser. The peaks are marked with the energy transitions from the Er^{3+} emission.

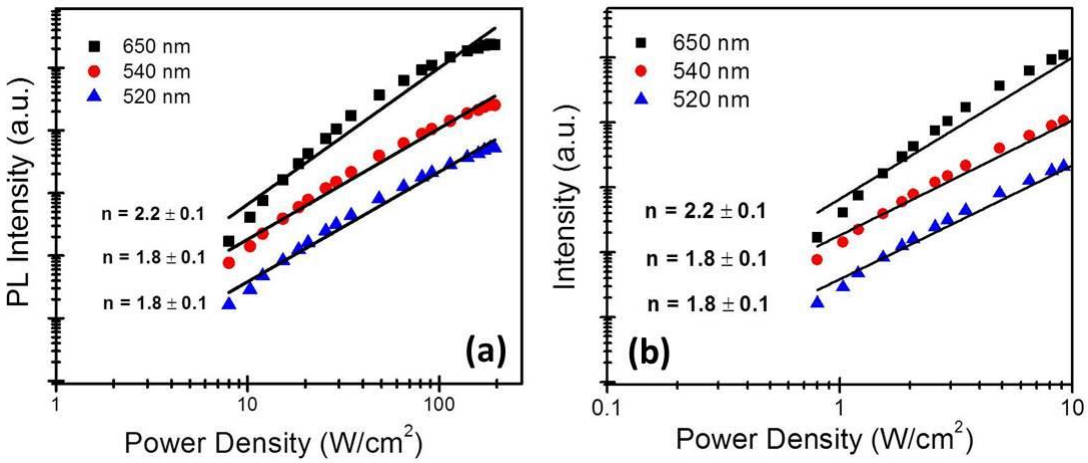

Figure S6. Dependence of the intensity of UC PL peaks at 520, 540 and 650 nm on the power density of excitation at 980 nm (a) and 798 nm (b) for UCNPs.

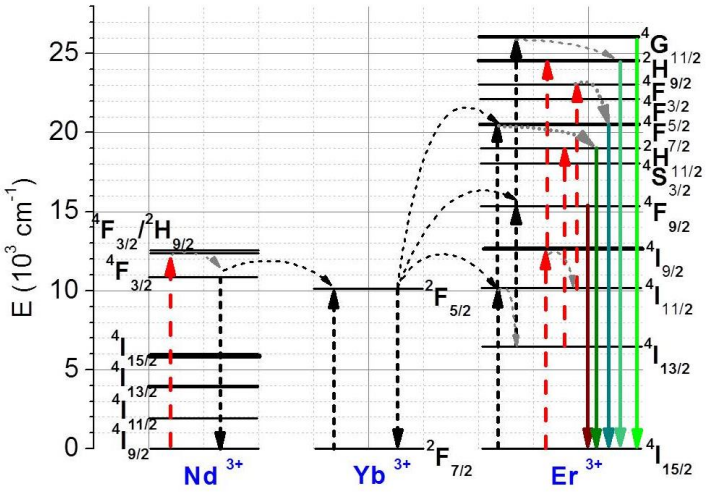

Figure S7. Mechanisms of upconversion emissions in the UCNPs

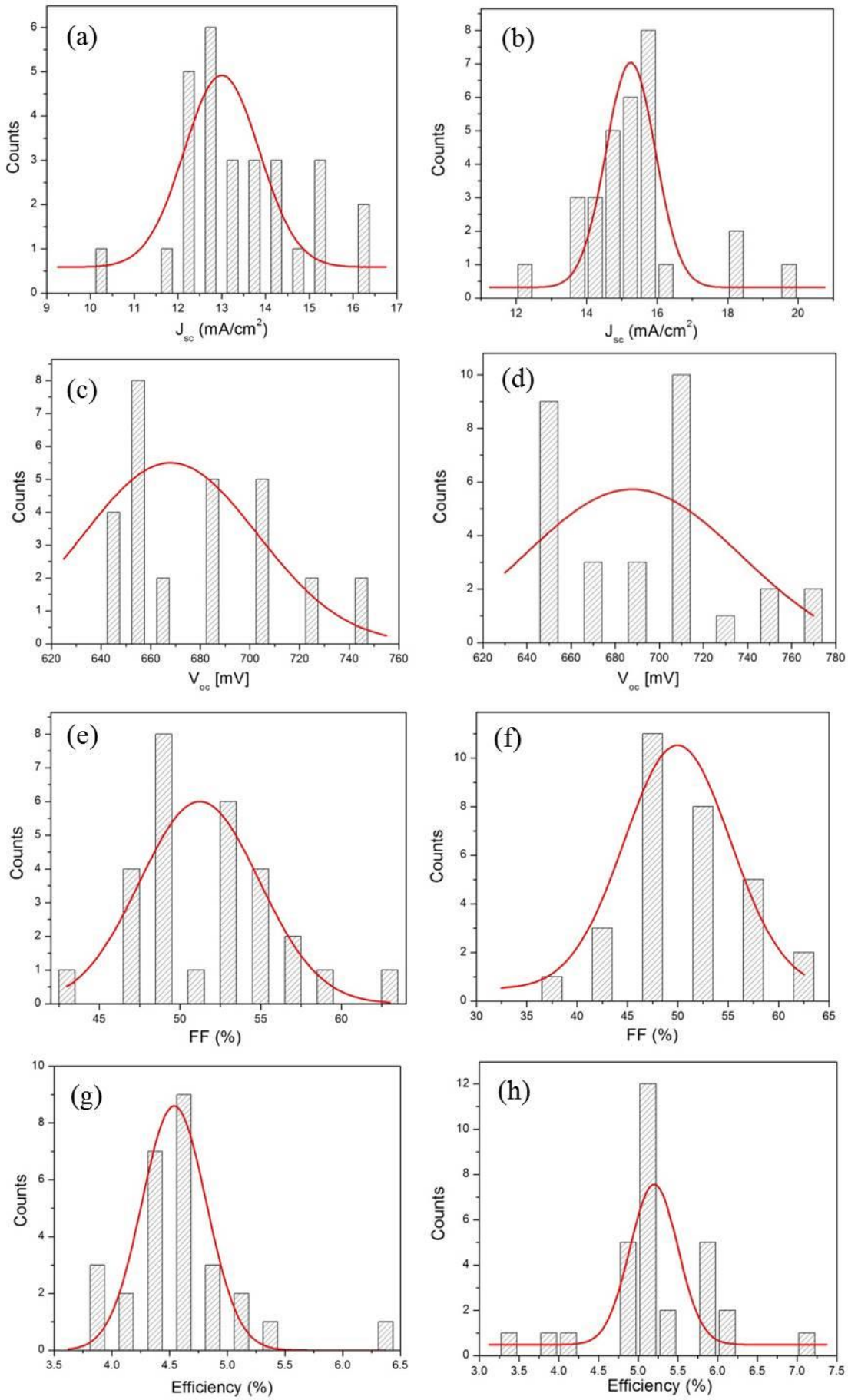
(a)
Counts
J_{sc} (mA/cm^2)
(b)
Counts
J_{sc} (mA/cm^2)
(c)
Counts
V_{oc} [mV]
(d)
Counts
V_{oc} [mV]
(e)
Counts
FF (%)
(f)
Counts
FF (%)
(g)
Counts
Efficiency (%)
(h)
Counts
Efficiency (%)

Figure S8. Histogram of (a) Jsc, (c) Voc, (e) FF and (g) efficiency of 28 samples without the use of UCNPs. Histogram of (b) Jsc, (d) Voc, (f) FF and (h) efficiency of 30 samples with the use of UCNPs for the preparation of 30 min.