**Electronic Supplementary Information**

# Plasmon Enhanced Up-conversion Nanoparticles in Perovskite Solar Cells for Effective Utilization of Near Infrared Light

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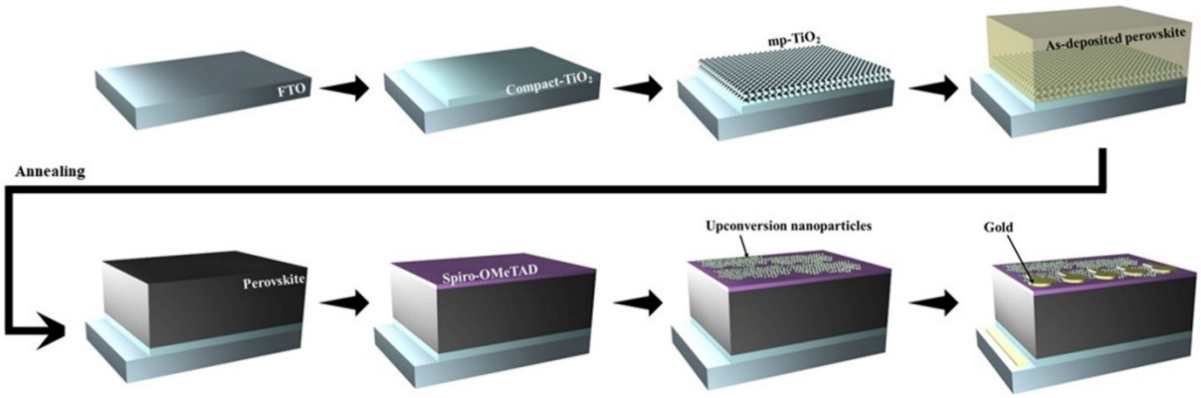


**Fig. S1.** Fabrication process of UCNPs-incorporated perovskite solar cells (PSCs). The PSCs were fabricated by using a conventional one-step process with anti-solvent method, and the UCNPs were transferred by dry transfer method. The PSC has a structure consisting of fluorine-doped tin oxide (FTO)/compact $TiO_2$ (c-$TiO_2$)/mesoporous $TiO_2$(mp-$TiO_2$)/perovskite;$(MAPbI_3)_{0.85}(FAPbI_3)_{0.15}$/spiro-OMeTAD/UCNPs/Au.

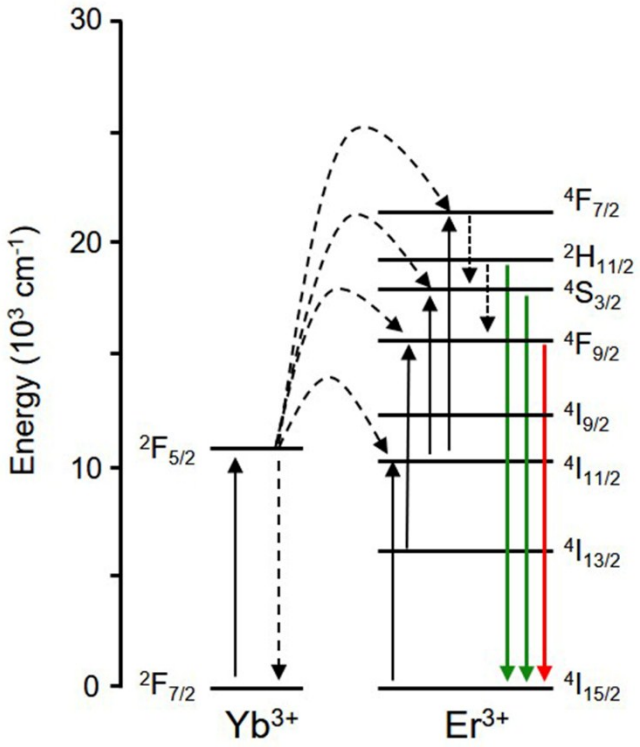


**Fig. S2.** Mechanism of the $NaYF_4$:$Yb^{3+}$,$Er^{3+}$ for up-conversion luminescence.

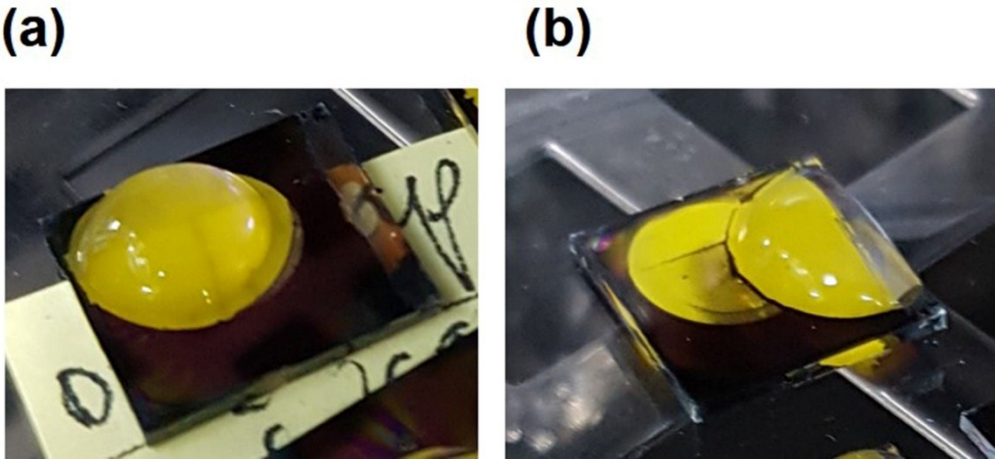


**Fig. S3.** Photographs showing the decomposed spiro-OMeTAD (HTL)/perovskite film when the UCNPs solution was dropped on the HTL: (a) color change immediately after dropping the UCNPs solution; (b) the perovskite film was rapidly decomposed along the moving trajectory of UCNPs solution.

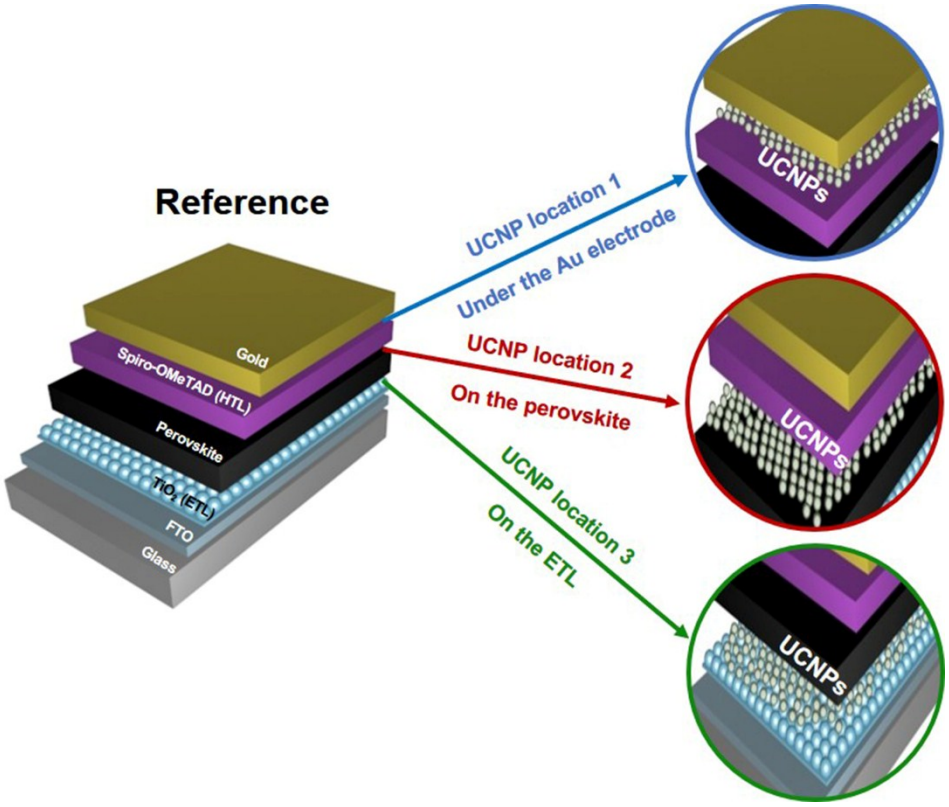


**Fig. S4.** Schematic illustration to show the transferred UCNPs at different locations within a perovskite solar cell.

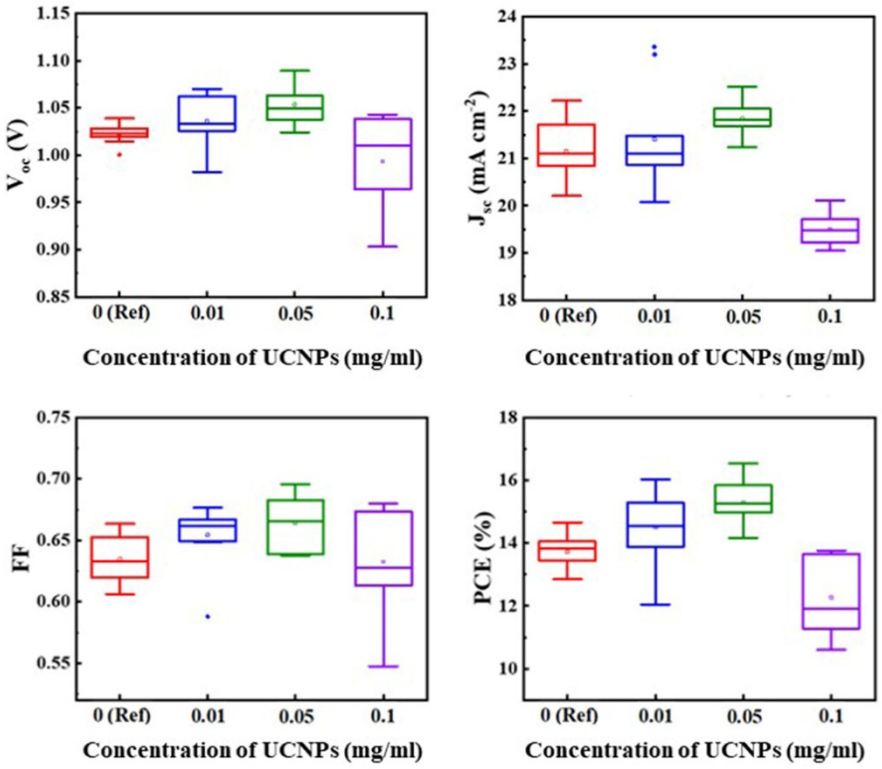


**Fig. S5.** Statistical distribution of PV parameters *vs.* concentration of UCNPs in solution. PV parameters of reference PSC (without UCNPs) are also included for comparison.

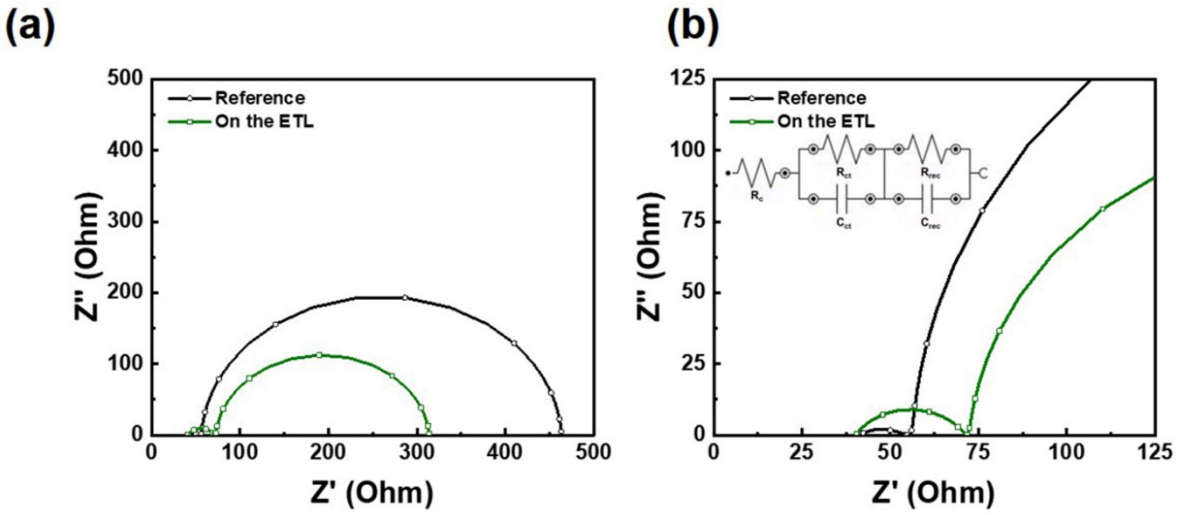


**Fig. S6.** (a) Comparison of Nyquist plots of two PSCs without UCNPs (reference) *vs.* with UCNPs on ETL. (b) The magnified Nyquist plots in the high-frequency region. The inset represents the equivalent circuit utilized to fit the Nyquist plot.

**Table S1.** Recombination resistance ($R_{rec}$) and charge transport resistance ($R_{ct}$) of PSCs obtained by fitting the Nyquist plots to the equivalent circuit.

| | **Reference** | **On the ETL** |
|---|---|---|
| **Recombination resistance, $R_{rec}$ (Ω)** | 408 | 242 |
| **Charge transport resistance, $R_{ct}$ (Ω)** | 19.9 | 34.4 |