Enhanced Photovoltaic Performances of Dye-sensitized Solar Cells by A New Photoelectrode Material: Upconversion YbF_3-Ho/TiO_2 Nanoheterostructures

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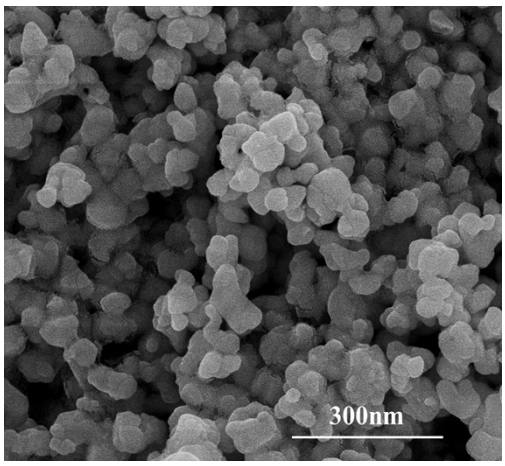

Fig. S1 SEM image of YbF_3-Ho.

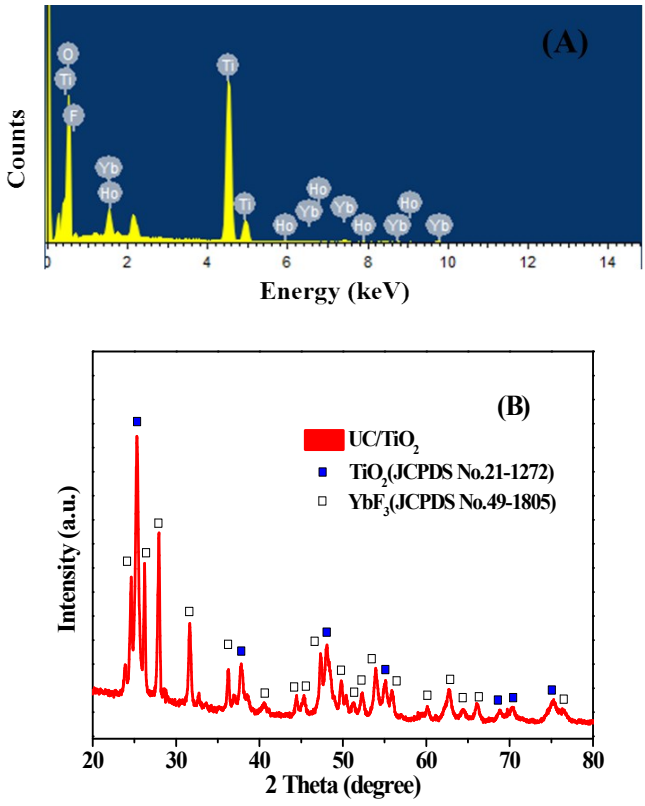

Fig. S2 EDX and XRD analyses of UC/TiO_2 nanoheterostructures.

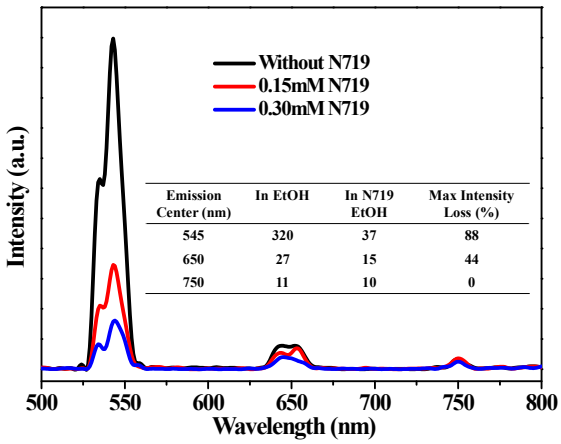

Fig. S3 Upconversion fluorescence spectra of YbF_3-Ho in N719 and EtOH solution.

To investigate the luminescence-mediated energy transfer (LET) process existed between YbF_3-Ho and the N719 sensitizer. We compared the upconversion fluorescence spectra of YbF_3-Ho in absolute EtOH and N719 EtOH solution under 980 nm excitation. As shown in Fig. S3, the upconverted fluorescence of YbF_3-Ho in absolute EtOH shows three characteristic Ho^{3+} emission bands at 545 nm, 650 nm and 750 nm originating from $(^5S_2, {}^5F_4) \rightarrow {}^5I_8$, $^5F_5 \rightarrow {}^5I_8$, $(^5S_2, {}^5F_4) \rightarrow {}^5I_7$, respectively. As the concentration of N719 dye increases, the upconversion fluorescence intensity of green and red emission peaks decrease significantly, which suggest that energy transfer from YbF_3-Ho to N719 dye happened. We calculated the maximum intensity loss of different emission peaks and listed inside of Fig. S3. For the green emission peak, the maximum loss achieves to 88%, while for the red emission peak, there is only 44%. This fact is caused by the absorbance difference of N719 dye in these spectral regions (see Fig. S4). As we can see, the N719 absorption intensity in green spectral area is much more intense than that in red spectral area. Because of the absorption threshold of N719, the emission peak centered at 750 nm does not change much. In other words, the green emission peak is more crucial and efficient for improving the energy transfer efficiency.

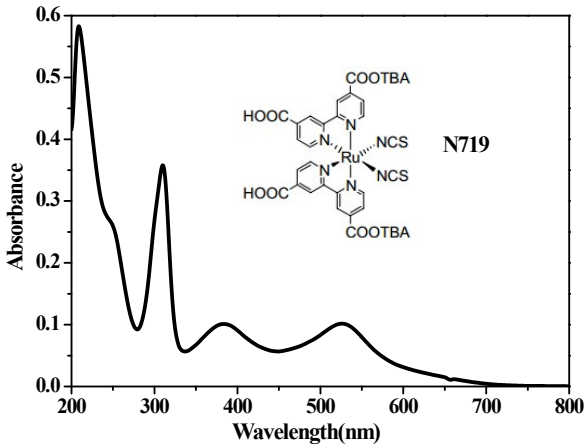

Fig. S4 UV-vis absorption spectrum of N719 in ethanol solution and chemical structure is shown as inset.

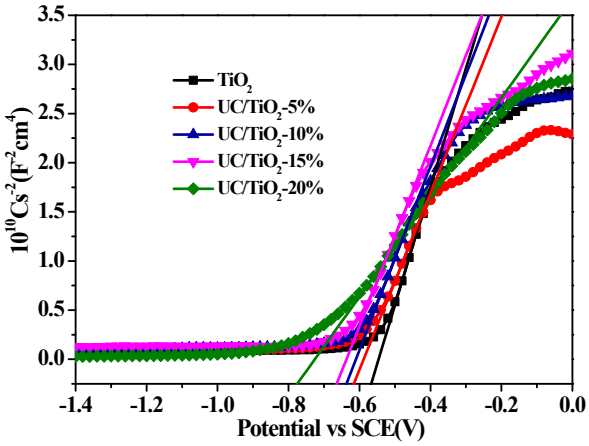

Fig. S5 Mott-Schottky plots of the TiO_2 and UC/TiO_2 photoelectrode films.

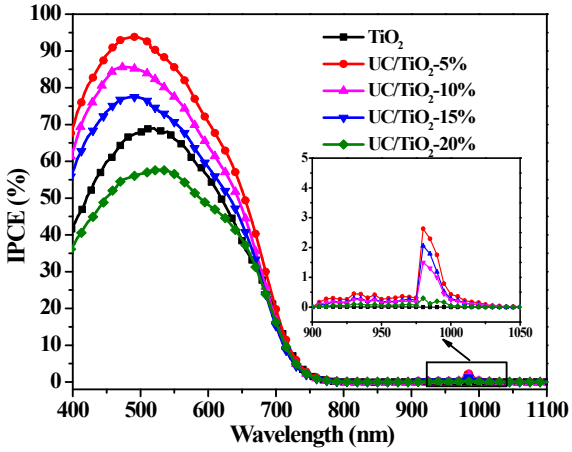

Fig. S6 IPCE spectra of DSSCs with TiO_2 and UC/TiO_2 photoelectrodes.

Table S1 I-V parameters of solar cells composed of TiO_2 and UC/TiO_2 without N719 dye under AM1.5G. The results are based on the average of 6 electrodes for each sample.

Sample	J_{sc} ($mAcm^{-2}$)	Voc (V)	FF	PCE (%)
TiO_2	0.11	0.32	0.56	0.021
5%UC/TiO_2	0.24	0.34	0.55	0.044
10% UC/TiO_2	0.22	0.35	0.54	0.038
15% UC/TiO_2	0.17	0.36	0.55	0.035
20% UC/TiO_2	0.08	0.35	0.54	0.015

Table S2 Resistances simulated based on equivalent circuit.

Sample	R_s (ohm)	R_{ct} (ohm)	R_2 (ohm)
TiO_2	20.76	8.75	14.20
5%UC/TiO_2	19.49	5.35	14.76
10% UC/TiO_2	20.23	7.01	14.73
15% UC/TiO_2	21.49	7.96	14.41
20%UC/TiO_2	20.20	10.02	13.63