Built-in Quantum Dot Antennas in Dye-Sensitized Solar Cells

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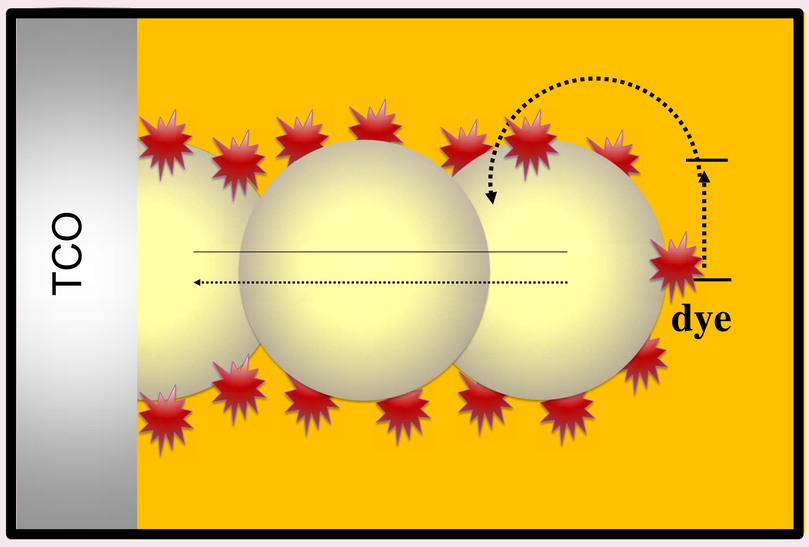
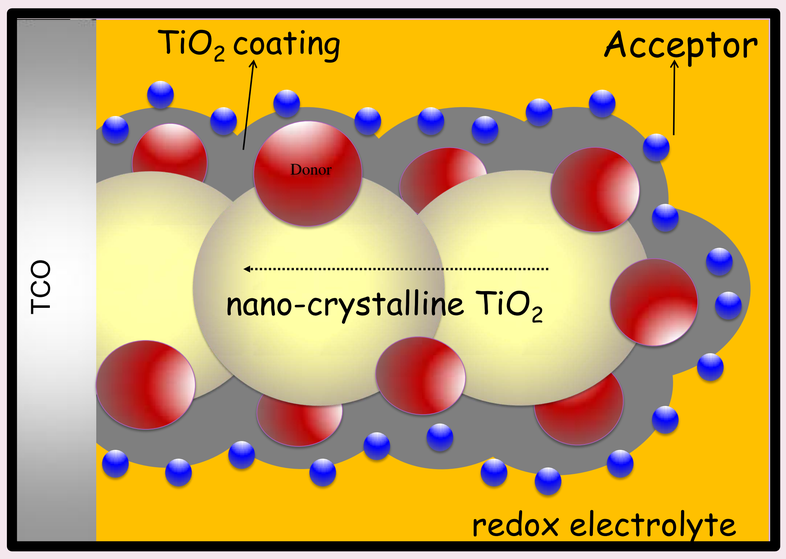
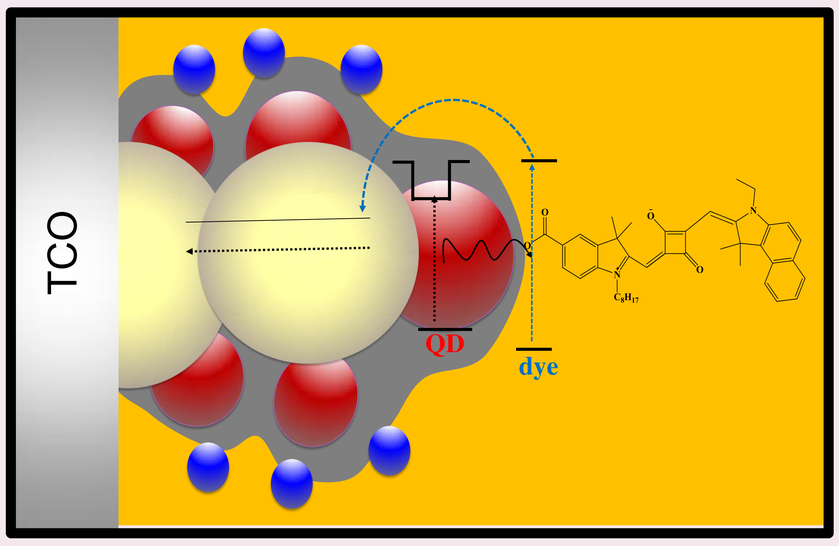
A new design of dye-sensitized solar cells involves colloidal semiconductor quantum dots that serve as antennas, funneling absorbed light to the charge separating dye molecules via nonradiative energy transfer. The colloidal quantum dot donors are incorporated into the solid titania electrode resulting in high energy transfer efficiency and significant improvement of the cell stability. This design practically separates the processes of light absorption and charge carrier injection, enabling us to optimize each of these separately. IPCE measurements show a full coverage of the visible spectrum despite the use of a red absorbing dye, limited only by the efficiency of charge injection from the dye to the titania electrode. Time resolved luminescence measurements clearly relate this to Förster resonance energy transfer from the QDs to the dye. The presented design introduces new degrees of freedom in the utilization of quantum dot sensitizers for PV cells. In particular, it opens the way towards the utilization of new materials whose band offsets do not allow direct charge injection.

Dye Sensitized Solar Cell.

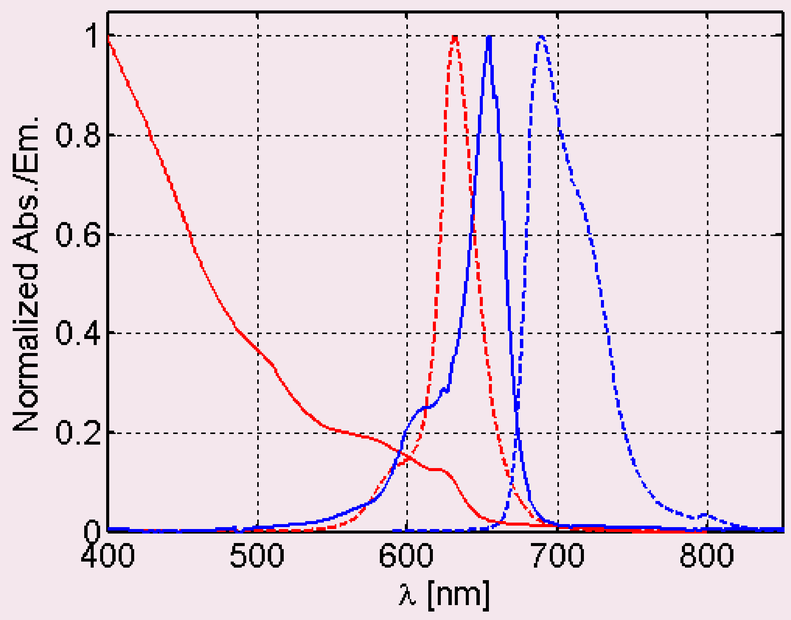


Antenna in Dye Sensitized Solar Cell.



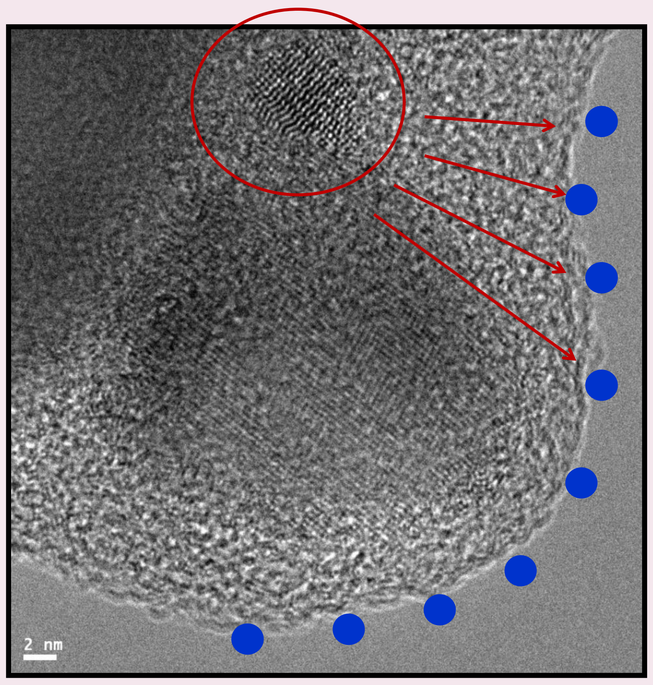


Spectral Overlap (in FRET)



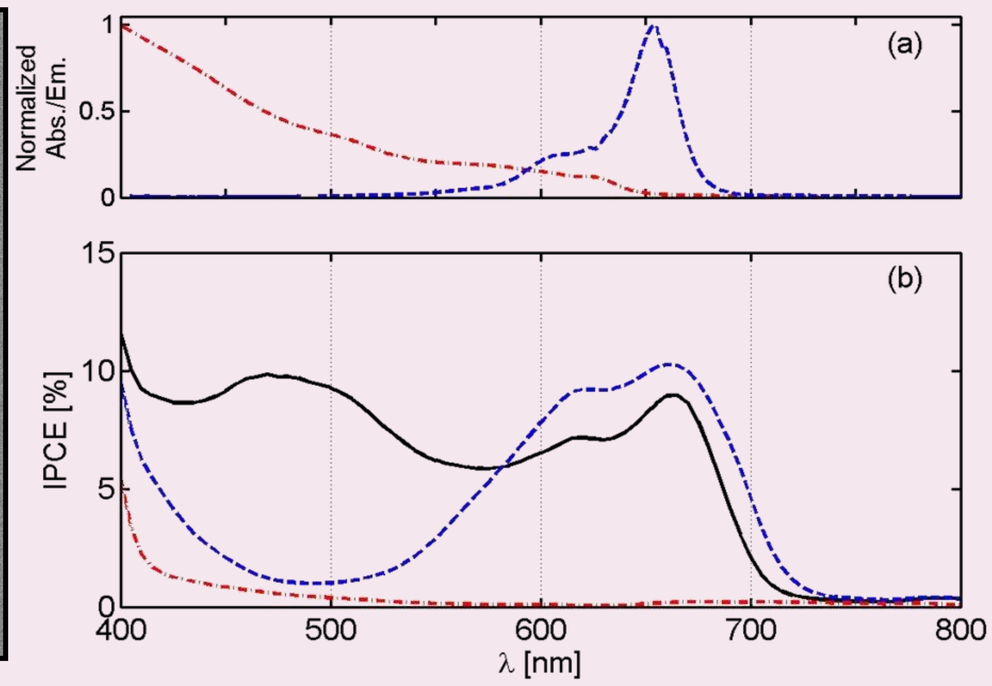
Absorption and emission spectra of CdSe/CdS/ZnS core/shell/shell quantum dots and SQ02 dye molecules . There is a large overlap between emission spectrum of the QDs and absorption spectrum of dye molecules.

HR-TEM



HR-TEM image showing wurtzite structure of CdSe/CdS/ZnS QD bound to the nc-TiO_2 and fully covered by an amorphous TiO_2 coating

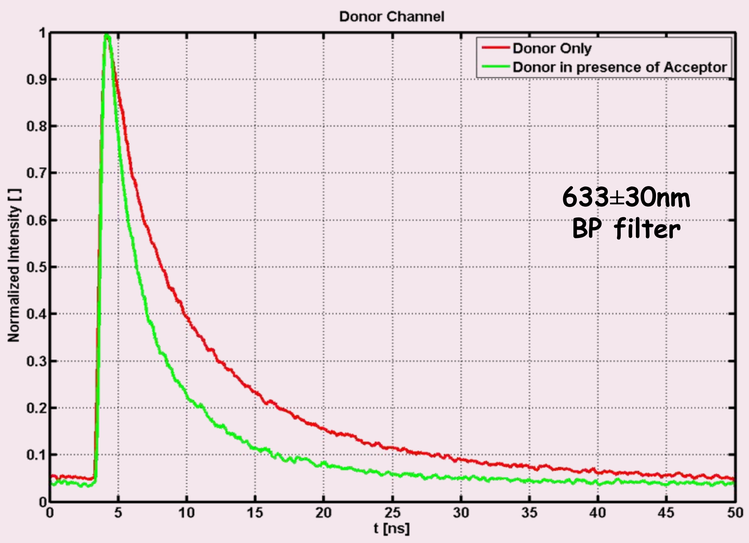
IPCE curves



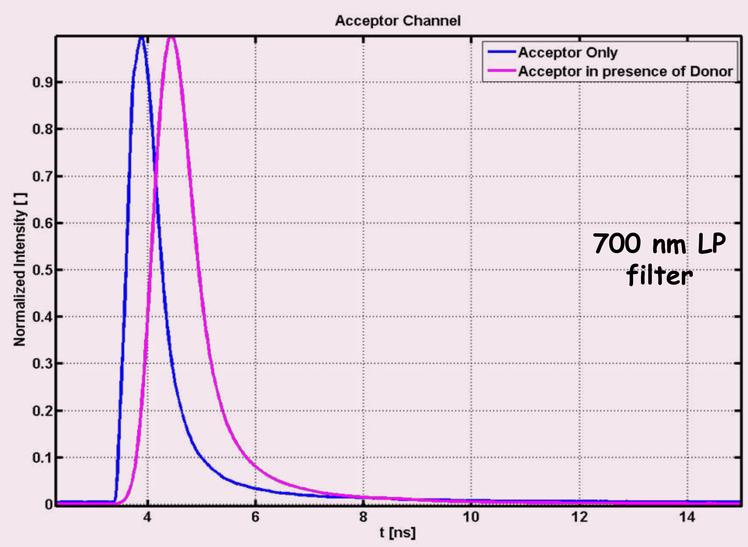
A cell consisting of QDs only (dashdotted red curve); a cell containing only dye molecules (dashed blue curve); the complete cell including the QD antenna layer and the dye molecules (solid black curve).

The IPCE curves reveal significant contribution of the QDs to the spectral response of the cell but only in the presence of the dye.

Lifetime measurements

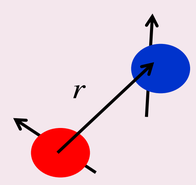


The red curve represents the lifetime of a donor only, while the green curve was measured in presence of an acceptor.

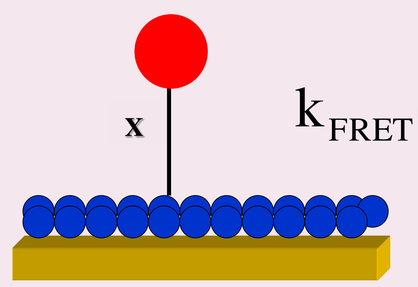


The blue curve represents the lifetime of an acceptor only, while the pink curve was measured in the presence of a donor.

FRET rate in different dimensions



$$k_{FRET}(r) = \frac{1}{\tau_0}\frac{R_0^6}{r^6}$$



$$k_{FRET}(r) = C_A\frac{1}{\tau_0}\frac{R_0^6}{X^4}$$