Quantum Dot - Dye Hybrid Solar Cell

FRET Based Dye-Sensitized Solar Cell

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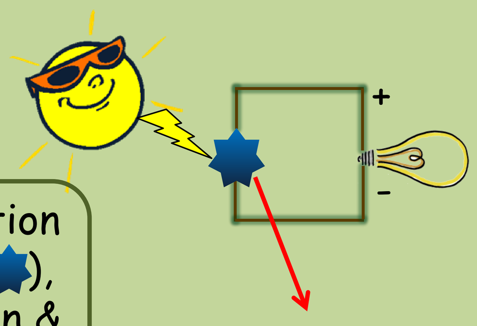
Conventional Dye-Sensitized Solar Cell

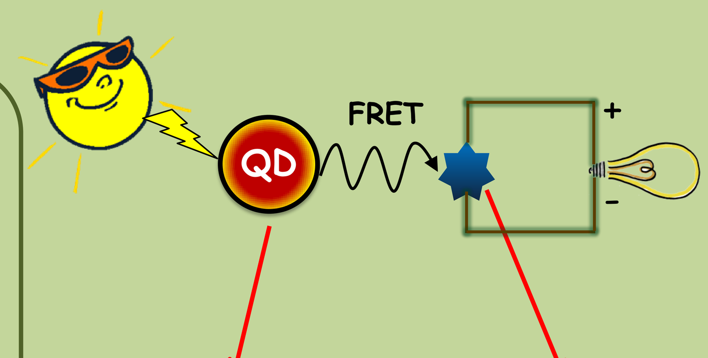
Upon photon absorption by a dye molecule, the charges (electron & hole) are separated



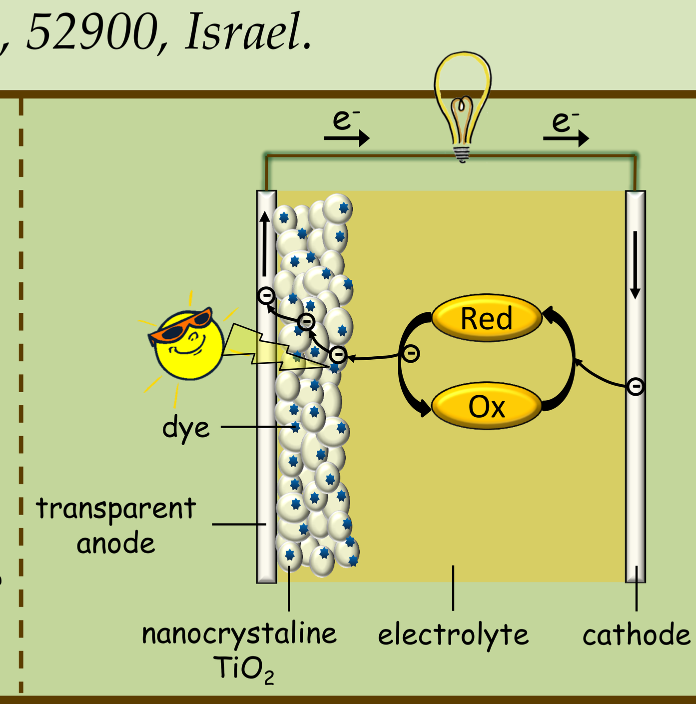
photon absorber and charge separator

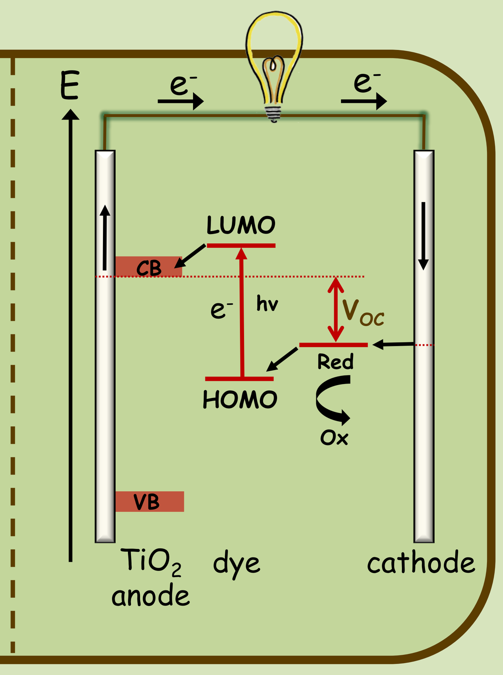
FRET Based Dye-Sensitized Solar Cell

combining advantages of both materials → benefit from wide spectral absorption range by quantum dots (QDs) and efficient charge separation by dye molecules

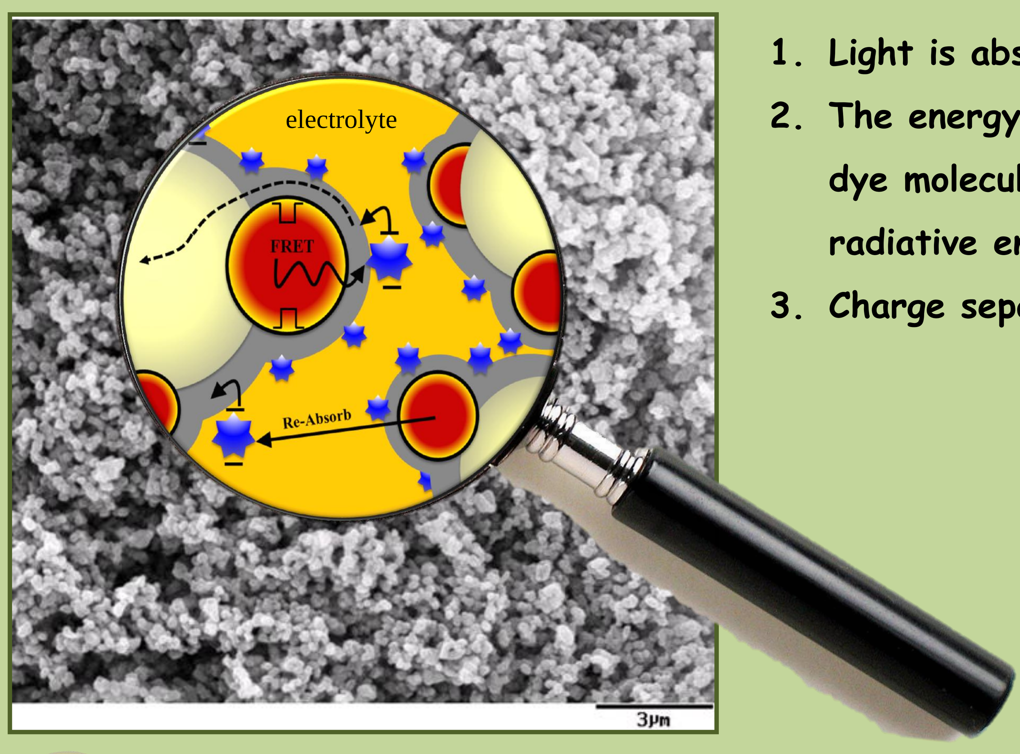


photon absorber (donor) **charge separator (acceptor)**

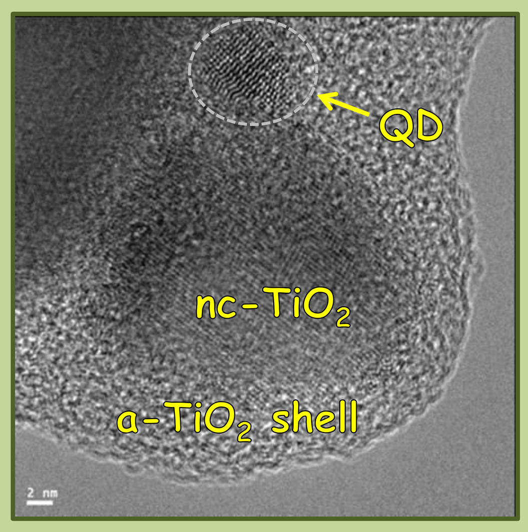




The System



1. Light is absorbed by a QD (donor)
2. The energy is transferred to a nearby dye molecule (acceptor) via a non-radiative energy transfer, FRET
3. Charge separation by a dye molecule

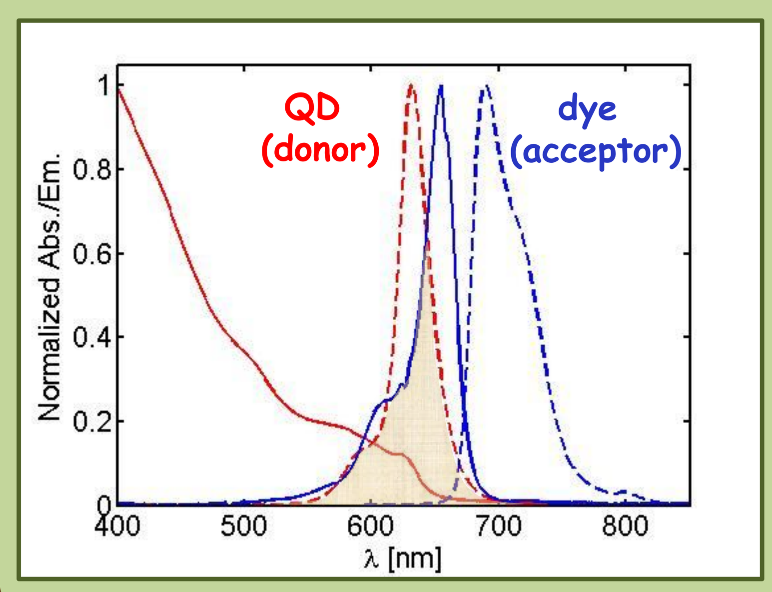


- nanocrystaline (nc) TiO_2
- QD donor (CdSe/CdS/ZnS)
- amorphous (a-) TiO_2 shell
- dye acceptor

Requirements

From the QDs:

- ✓ High spectral **overlapping** (marked area)↔ size tunability
- ✓ High **quantum yield** ↔ graded CdS/ZnS shell
- ✓ **Small** size relative to TiO_2 nano-pores ↔ type-II system
- ✓ **Neutrality** upon illumination ↔ type-I system

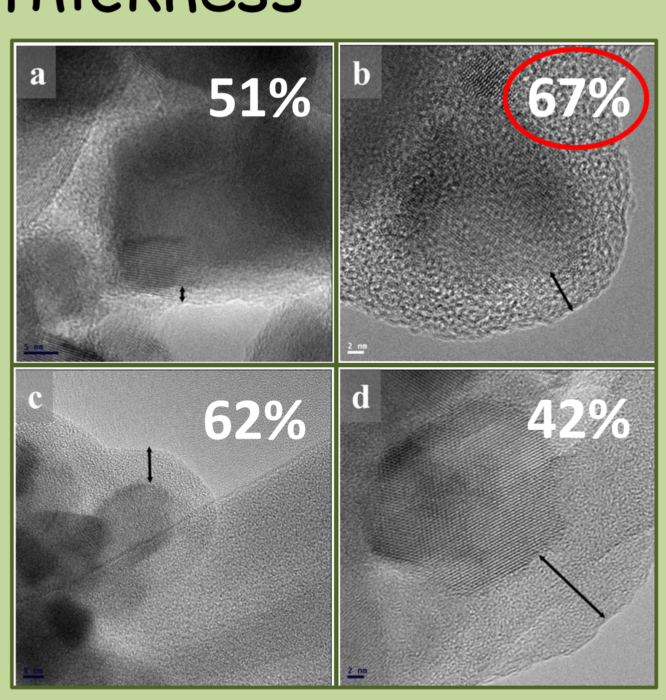


From the dye molecules:

- ✓ Good **charge separation** abilities
- ✓ High **photo-stability**
- ✓ Narrow absorption spectrum, preferentially in the **near-IR**
- ✓ High molar **extinction coefficient** at the donor (QD) emission peak

Varying the amorphous TiO_2 shell thickness

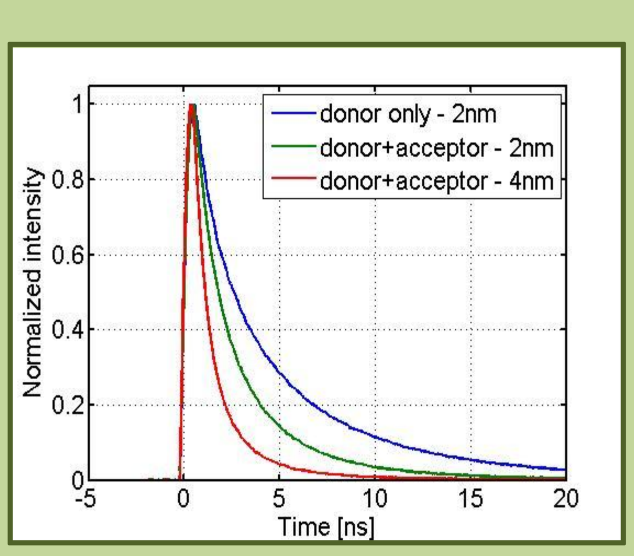
FRET efficiency =



TEM images

First increases, reaching a maximal value of ~70%, then decreases with increasing amorphous shell thickness

Lifetime Measurements



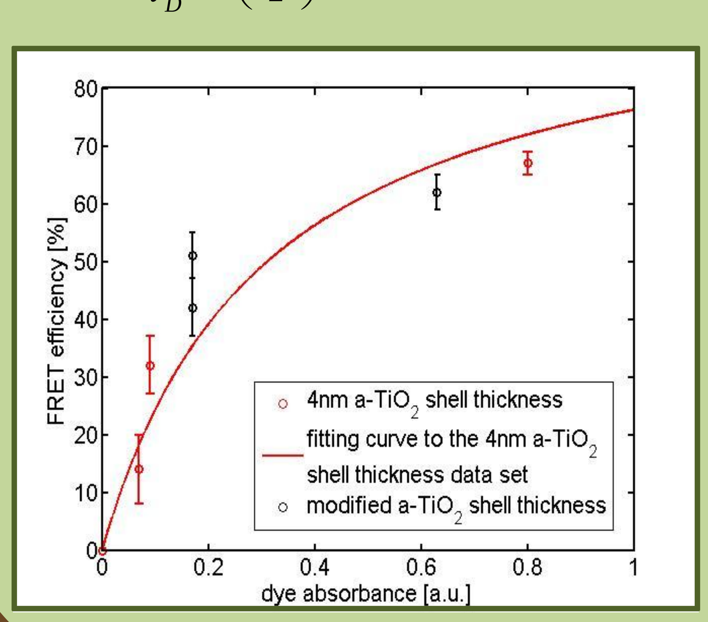
Were measured at the donor (QD) emission wavelength in presence and absence of the acceptor (dye molecules)

FRET efficiency can be calculated

FRET efficiency, E, and FRET rate, K_{FRET} (non-radiative energy transfer)

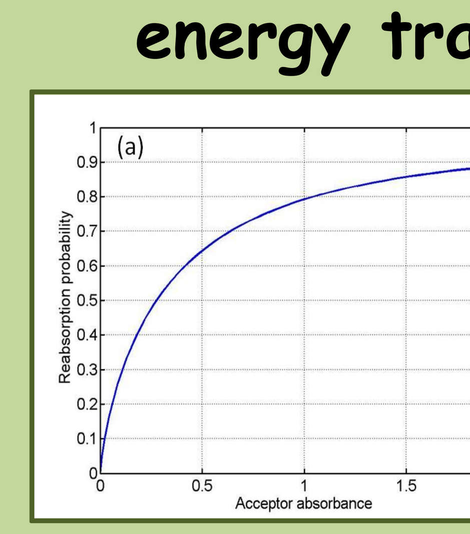
$$E=\frac{K_{FRET}}{K_{FRET}+K_R+K_{NR}}=\frac{1}{1+\frac{(K_R+K_{NR})}{(K_{FRET})}}=\frac{1}{1+\frac{K_D}{K_{FRET}}}$$

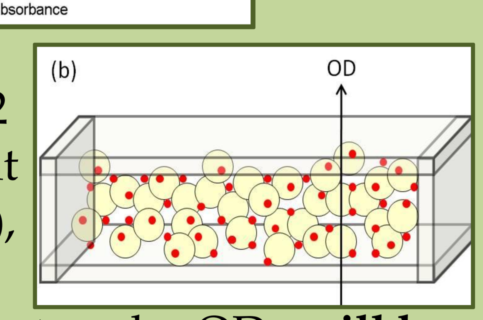
$$K_{FRET}=\frac{C_A \pi R_0^2}{\tau_D}\cdot\left(\frac{R_0}{z}\right)^4$$ For single donor – layer of acceptors



The **dye absorbance**, reflecting its concentration inside the electrode, is probably the main determining factor **controlling the FRET efficiency**

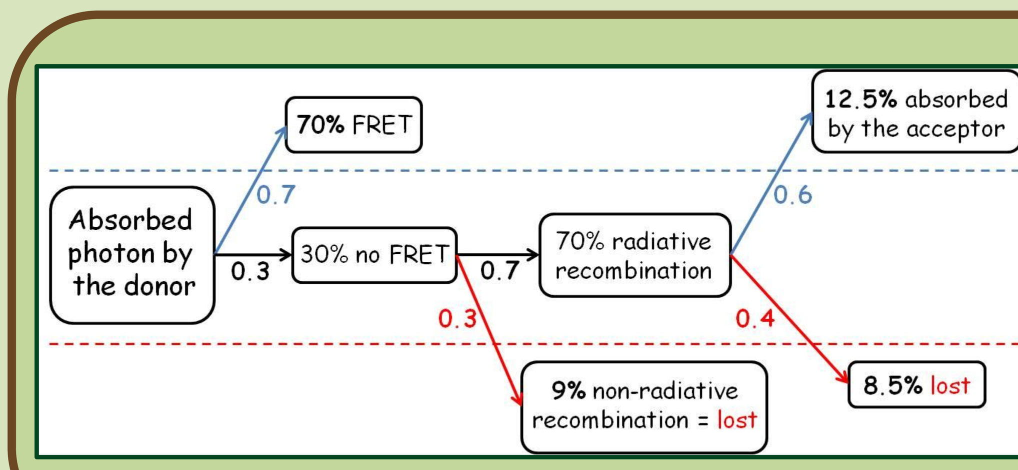
Emission – re-absorption (radiative energy transfer)





For an OD of 2 (1% of the light is transmitted), nearly **90%** of the emitted photons by QDs **will be absorbed** by the dye and contribute to the total current **even in the complete absence of FRET**

Total contribution of QDs to the internal quantum efficiency, IQE



$\Delta IQE = 70\% + 12.5\% \approx 85\%$

FRET emission – re-absorption

Conclusions

1. A new design of dye-sensitized solar cell separates the processes of light absorption and charge separation, enabling us to optimize each of these separately
2. This design opens the way toward the utilization of new materials for both absorber and the charge separator
3. The full cell absorbance is probably the main determining factor controlling the entire cell performance

References

1. S. Buhbut, et al., *ACS Nano*, **2010**, 4 (3), 1293–1298
2. S. Itzhakov, et al., *Adv. Energy Mater.*, **2011**, 4(1), 626-633
3. S. Buhbut, et al., *JPCL*, **2011**, 2 (15), 1917–1924

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