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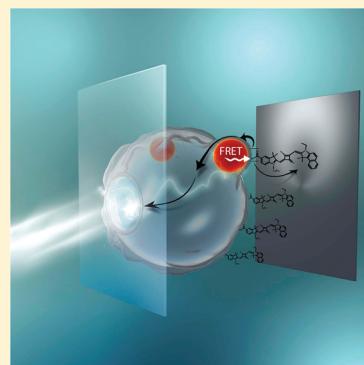
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 Supporting Information

ABSTRACT: The use of Förster resonant energy transfer (FRET) has recently shown promise for significant improvement in various aspects of photoelectrochemical cells. Considering the particular case of semiconductor quantum dot donors, we show that they can enable broadening of the spectral response and increased optical density of the cell, thus increasing the current while potentially decreasing the electrode thickness. Moreover, the use of FRET and the separation of optical and electrical function within the cell provide flexibility in the choice of materials for both the antenna and sensitizer, opening new paths for performance optimization and achievement of long-term cell stability.



Dye-sensitized solar cells (DSSCs) are a promising low-cost alternative to existing crystalline silicon and thin-film photovoltaic technologies.¹ Photoconversion efficiencies higher than 11.5% have been reported for DSSCs based on nanoporous TiO₂ electrodes.² In these cells, titania crystallites are covered with dye molecules, and the mesoporous film architecture is interpenetrated with a liquid electrolyte. The crystallite network is the recipient of injected electrons from optically excited dye molecules and provides a conductive pathway to the transparent back contact. The redox species in the electrolyte transport the holes from the oxidized dyes to the counter electrode.

Semiconductor quantum dot donors can enable broadening of the spectral response and increased optical density of the cell, thus increasing the current while potentially decreasing the electrode thickness.

Despite the current performance, widespread use of DSSCs requires higher efficiencies with preference to a solid version of the redox mediator. Solid mediators seem to be more appropriate for large-scale fabrication and less sensitive to cell sealing. Moreover, the desired photovoltage increase in

DSSCs (>800 mV) is mostly observed in solid mediator based cells.³ The traditional absorbers in DSSCs are ruthenium-based complexes (for example, N719 and N3) that have fairly broad absorption spectra ($\Delta\lambda = 350$ nm) but low molar extinction coefficients ($5000\text{--}20\,000\text{ M}^{-1}\text{ cm}^{-1}$), requiring the use of high-surface-area electrodes.^{2,4} However, most solid electrolytes do not operate well in the thick nanoporous electrodes that provide the necessary surface area. Therefore, a key to improving the efficiency of DSSCs is to increase the sensitizer extinction while extending the spectral response region of the sensitizer to the near-IR region.⁵

Many efforts have been made to increase the absorption extinction coefficient and to widen the spectral response of the photosensitizers. New organic dyes and organometallic complexes were synthesized and optimized for efficient light harvesting.⁶ Dye cocktails or cosensitizers that broaden the absorption spectrum were tested,^{7,8} and bisensitizer layers that lead to a much higher sensitizer surface concentration were developed.⁹ Similar geometries using inorganic semiconductor sensitizers (nanocrystals, quantum dots, thin layers) have been proposed.^{10–17} For example, monodispersed semiconductor quantum dots (QDs) such as CdTe, CdS, CdSe, PbS, and InP have exceptionally high extinction coefficients. The optical and electronic properties of the QDs can be tailored by controlling their size and by engineering of the heterostructures.^{18–21} Surface chemistry permits adjustment of their surface function.^{22–27} In contrast with the

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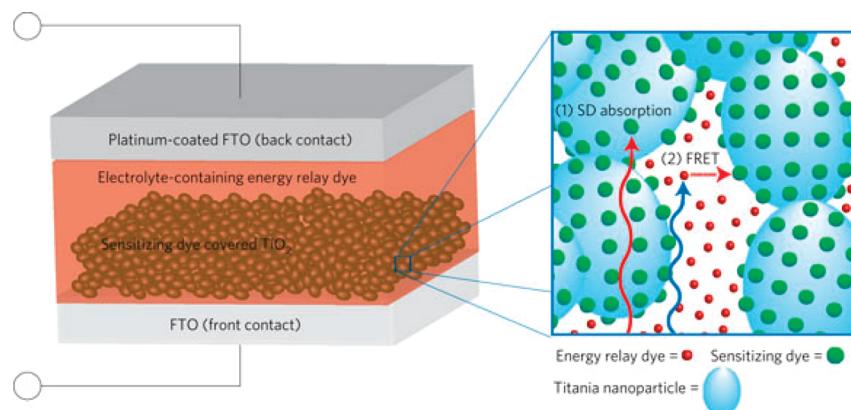


Figure 1. Schematic representation of a DSSC with energy relay dyes (ERDs). The figure shows the typical absorption process for lower-energy (red) photons in the DSSC; light is absorbed by the sensitizing dye (1), transferring an electron into the titania, and a hole is transported to the back contact through the electrolyte. The ERD process is similar, except that higher-energy (blue) photons are first absorbed by the ERD, which undergoes Förster energy transfer (2) to the sensitizing dye. Reprinted with permission from Macmillan Publishers Ltd: adapted from ref 30, copyright 2009, Nature Photonics.

narrow absorption spectra typically exhibited by molecular dyes, QDs absorb from the band edge to higher energies. Indeed, vast progress in QD-sensitized solar cells (QDSSCs) has been observed in the last 2 years, growing rapidly from less than 1% conversion efficiencies to values of around 4–5%.²⁸ Their performance is currently limited by a number of factors, including a limited choice of electrolytes with which QDs are chemically compatible, insufficient passivation of recombination channels (usually attributed to surface traps), and limited QD loading.²⁹

FRET in DSSCs. A new route, based on Förster resonant energy transfer (FRET), was recently proposed in order to both broaden the absorption range in DSSCs as well as to increase the absorber loading.³⁰ FRET is a nonradiative interaction that can occur when a donor chromophore, initially in its electronic excited state, transfers an energy quantum to an acceptor chromophore through nonradiative dipole–dipole coupling (resonant interaction), at distances considerably greater than interatomic separation (usually several nanometers).^{31–33} Light is first absorbed by a donor species, which becomes excited. Before the donor can fluoresce and return to the ground state, its excitation is transferred to a nearby acceptor molecule having slightly lower excitation energy via the exchange of a virtual photon. The donor thus decays to the ground state while the acceptor is excited. The end result is that the acceptor has become excited due to an indirect process, that is, the acceptor effectively captures photons that are not directly absorbed by it (see Figure 3). FRET is an interesting phenomenon because it requires neither physical contact nor charge exchange. This opens up a great number of possibilities for possible donor/acceptor pairings as it avoids many of the problems that may result from direct contact of the two, thus offering relaxed rules for compatibility.

In the first realization of this approach in the context of DSSCs, the high-energy photons were absorbed by an energy relay dye (donor) added to the liquid electrolyte.^{30,34,35} The excited dye transferred its energy via FRET to the sensitizing dye (acceptor) adsorbed to the mesoporous film followed by electron injection and dye regeneration like in conventional dye cells (Figure 1). The fact that two kinds of dyes operate in a cell volume that traditionally utilizes one of them only allows optical density increase for the same thickness of the porous titania. The

feasibility of the concept of using two types of dyes with different functions was recently proven. Nevertheless, this configuration is limited by three factors that require attention, (i) the solubility of the donor in the electrolyte and the hole collection process which determines the maximal donor to acceptor ratio, (ii) the morphology of the donor volume with respect to the acceptor layer and the corresponding distances, and (iii) the competing quenching process of the relay dye, such as by direct photochemistry with the redox species of the liquid electrolyte. Several attempts to overcome these problems by replacing the liquid electrolyte with solid-state p-type semiconductor were recently presented.^{36–39} However, these cells are limited to relatively thin electrodes (~2 μm thick) because the solid electrolyte cannot penetrate deep into the TiO₂ electrode.

The new design, by which the QD antenna is incorporated into the solid titania electrode, inherently provides numerous benefits.

Quantum Dot Antennas in DSSCs. The use of FRET donors in a liquid electrolyte environment is incommensurate with QDs due to their chemical incompatibility. Moreover, it may be desirable to utilize not only the pore volume (occupied by the electrolyte) but also the mesoporous electrode volume for achieving an even higher loading of FRET donors. Thus, incorporation of QD FRET donors inside of the solid electrode is a natural combination. Recently, we presented such a design, which combines the benefits of QDs in terms of their broad absorption spectrum with the chemical stability afforded by the inert solid environment.⁴⁰ In this design, QDs serve as “antennas” (donors), funneling absorbed energy to nearby dye molecules (acceptors) via FRET rather than being used directly as sensitizers. The QDs are incorporated into the nanoporous TiO₂ electrode with complete physical isolation from the redox electrolyte and complete electronic isolation from the electrode, as schematically shown in Figure 2. Similar to molecular dye-based FRET realizations, this allows for separation

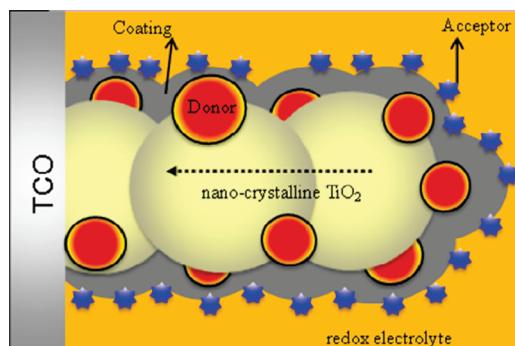


Figure 2. Schematic drawing of a mesoporous TiO₂ electrode covered with donor QDs, coated with an inorganic layer, and sensitized with an acceptor dye.

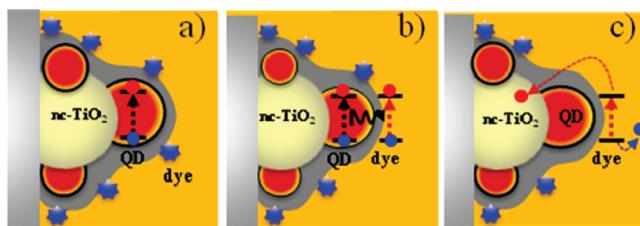


Figure 3. Chain of events following QD excitation in a FRET-based QD-enabled DSSC. (a) Upon illumination, the QD is excited, thus (b) transferring the energy via FRET to an adjacent dye adsorbed to the coating. (c) The dye injects an electron and is recharged by a redox electrolyte.

between the efficient photon absorption by the nanocrystalline QDs and the charge separation (electron injection to the TiO₂ and hole transfer to the electrolyte) by the adjacent dye molecules. It offers a viable alternative to the limitations of carrier injection and collection of both DSSCs and QDSSCs. Most importantly, the new design, by which the QD antenna is incorporated into the solid titania electrode, inherently provides three benefits, (i) high donor to acceptor ratio, (ii) optimal morphology for FRET, where each QD is surrounded by a dye layer in fixed distance, and (iii) isolation of the QD antenna from the electrolyte solution, preventing donor quenching.^{9,41}

As discussed above, quantum dots have not only to be physically isolated from the electrolyte but also electronically isolated from the electrode. Alternatively stated, the QD donor must neither inject charges to the electrode nor be able to accept electrons from it. The main reason for this is that upon charging, a fast nonradiative recombination via an Auger process having a typical lifetime well below 1 ns is opened. Auger recombination can thus compete with the FRET process as well as with the radiative recombination process, which, as will be discussed later, also contributes to the photocurrent of the photovoltaic cell. In practical terms, this means that the QD donor has to be a core/shell heterostructure, the composition of which has to be tailored such that both the electron and hole are confined to the core and passivated by a sufficiently thick larger band gap shell (corresponding to type-I band alignment). One of the prototypical (and thus relatively easily synthesized) systems exhibiting this property is CdSe/CdS/ZnS core/shell/shell QDs.

Before further discussing the properties and photophysics of QD FRET-based DSSCs, let us first present a more detailed description

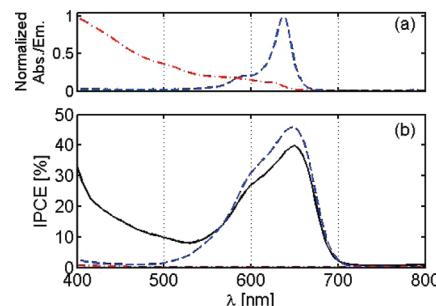


Figure 4. (a) Normalized absorption spectra of QDs (dashed-dotted red curve) and dye molecules (dashed blue curve). (b) IPCE curves of the three solar cells, a cell consisting of QDs only (dashed-dotted red curve), a cell containing only dye molecules (dashed blue curve), and the complete cell including 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.

of a realization of such a system, using CdSe/CdS/ZnS QDs as donors and 5-carboxy-2-[3-[1,3-dihydro-3,3-dimethyl-1-ethyl-2H-indol-2-ylidene)methyl]-2-hydroxy-4-oxo-2-cyclobuten-1-ylidene]-methyl]-3,3-trimethyl-1-octyl-3H-indolium (SQ01) dye molecules as acceptors. In this system, electrodes comprised of 6.5 μ m thick titania films were fabricated using 25 nm TiO₂ nanoparticles (Dyesol-DSC 18 NR-T) together with an additional layer of P-90 titania particles. QDs were deposited on the anode by using an electrophoretic deposition (EPD) technique from a toluene dispersion.⁴² After deposition, the electrode was washed with toluene and dried in air. A thin amorphous TiO₂ coating of the QDs–mesoporous TiO₂ electrodes was made by EPD of stabilized TiO₂ precursor, tetraisopropyl orthotitanate ($Ti(OiC_3H_7)_4$), for 480 s (current 2 mA).^{43,44} Films were dyed for 24 h in 1×10^{-4} M SQ01 with 10 mM chenodeoxylic acid in ethanol. The solar cell was fabricated using an I⁻/I₃⁻ redox electrolyte and a Pt-coated FTO glass as a counter electrode.

In this design, QDs serve as “antennas” (donors), funneling absorbed energy to nearby dye molecules (acceptors) via FRET rather than being used directly as sensitizers.

Figure 4a presents normalized absorption spectra of SQ01 dye and the QDs adsorbed onto the TiO₂ electrode. Figure 4b shows the incident monochromatic photon to current conversion efficiency (IPCE) of the photovoltaic cell sensitized by SQ01 with and without QDs. At the maximum absorption point of the SQ01 sensitized electrode (47% light absorption, dashed blue curve in Figure 4a), IPCE exceeds 45% (dashed blue curve in Figure 4b), giving an internal quantum efficiency (IQE) of 96%. When the donor QDs are embedded in the electrode, the IPCE at short wavelengths (solid black curve in Figure 4b) increases to 33% at 400 nm, 20% at 430 nm, and 15% at 460 nm (corresponding to approximately 50% IQE). This response

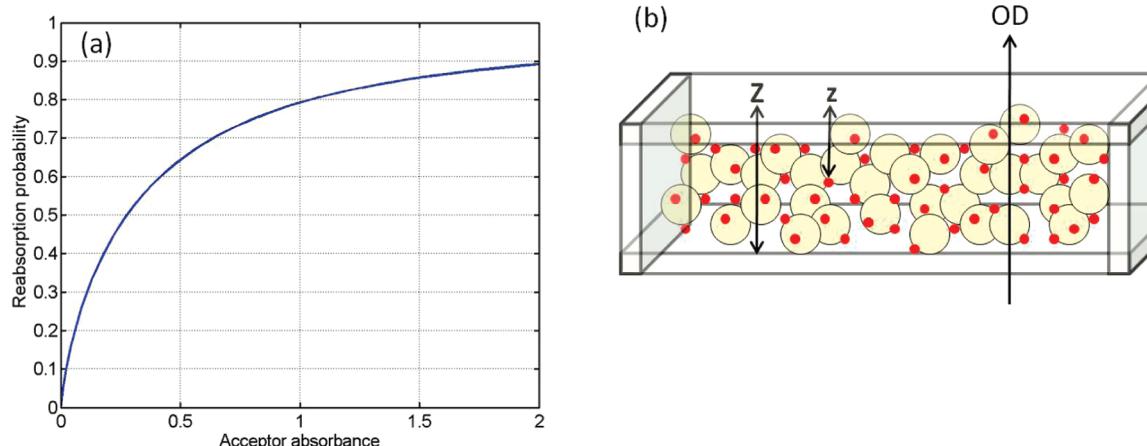


Figure 5. (a) The probability for reabsorption of the donor's emitted light by the acceptor versus the acceptor absorbance (details provided in the Supporting Information S1); (b) schematic representation of the system containing nc-TiO₂ (off-white circles) and QDs (red circles) with some optical density (OD) of the acceptor (dye, not shown). The thickness of the electrode is Z , and the relative height at which a photon was emitted is denoted by z . The amorphous titania coating is not shown.

originates from the relatively strong absorption of QDs in this wavelength range, translated into efficient FRET interaction and charge separation by the dye. The observed increase in photo-generated current is not due to direct injection from QDs to TiO₂. To verify this, a control cell containing QDs but not dye molecules, while keeping all other parameters unchanged, was also measured. The data clearly show no injection of electrons in the visible region between 400 and 800 nm (Figure 4b, dashed-dotted red line), corroborating the hypothesis that the new IPCE band from 400 to 550 nm is caused by energy transfer from QDs to SQ01.

This allows for separation between the efficient photon absorption by the nanocrystalline QDs and the charge separation (electron injection to the TiO₂ and hole transfer to the electrolyte) by the adjacent dye molecules.

Radiative and Nonradiative Energy Transfer. The energy transfer from QDs to dye molecules and thus contribution of QDs to the IPCE in the presence of the dye can be divided into two channels, nonradiative (FRET) and radiative (emission followed by reabsorption). This is also true for organic relay dyes, although there, electrolyte quenching significantly reduces the importance of the radiative channel, at least in liquid electrolytes. As we discuss below, the FRET rate depends on local properties (acceptor density and local geometry), whereas the efficiency of radiative transfer from the donor to the acceptor depends on global parameters of the electrode (the optical density and the whole electrode geometry). The FRET efficiency can be experimentally inferred from lifetime measurements of the donor

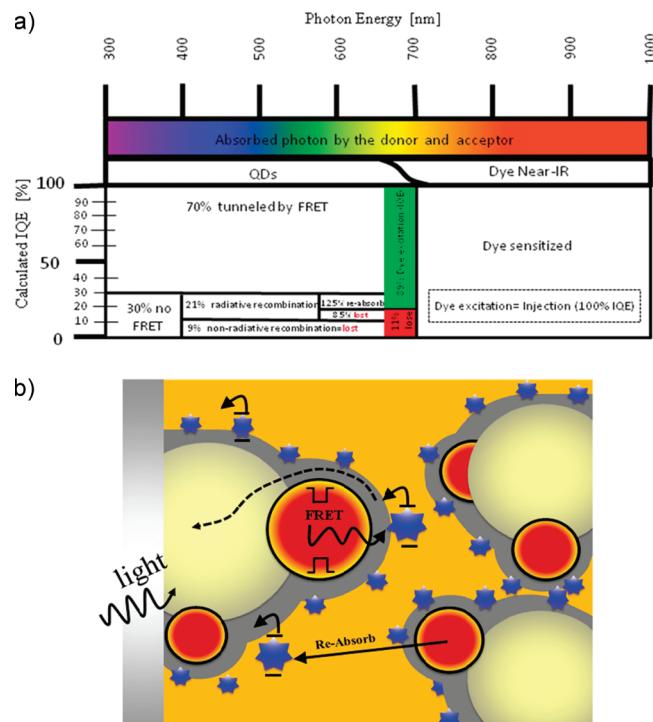


Figure 6. (a) Absorption region of SQ02 dye and of CdSe/CdS/ZnS QDs shown on the y axis; the relative contribution of the dye and QDs to the IQE is shown on the y axis. (b) Schematic representation of the three routes via which a dye molecule can be excited, direct absorption of a photon, the FRET process (nonradiative energy transfer) from QDs, and reabsorption of the photon emitted by the QD (radiative energy transfer).

(QDs) in the absence and presence of an acceptor (dye molecules). A shorter emission lifetime of the donor in the presence of an acceptor corresponds to a higher FRET efficiency. In contrast, the emission-reabsorption process efficiency depends on the quantum yield (QY) of the donor inside of the electrode and the total optical density (OD) of the acceptor at the donor's emission wavelength. The QY determines what

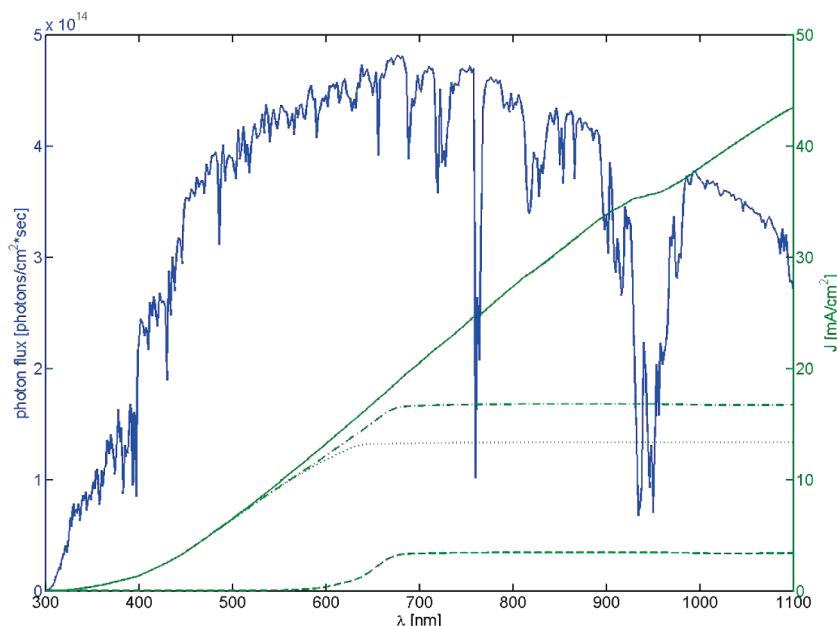


Figure 7. Solar photon flux (left *y* axis) and the accumulated current density of the photovoltaic cell (right *y* axis) as a function of the wavelength. Right *y* axis (green curves): solid line, maximal theoretical; dashed line, relative contribution of SQ02 dye (OD = 1 at the absorption peak); dotted line, relative contribution of CdSe/CdS/ZnS QDs (OD = 0.5 at the first absorption peak); dashed–dotted line, contribution from both the dye and QDs assuming 100% energy-transfer efficiency from QDs to dye molecules. It is assumed that each dye excitation photon contributes to the current.

portion of photons that were not transferred by FRET will be emitted by the donor. Once the photon is emitted, it has a certain probability to be reabsorbed by the acceptor. To quantify the importance of the radiative component, we consider an extremely simple model, depicted in Figure 5a. Depending on the OD of the electrode at the donor emission wavelength, the reabsorption probability of an emitted photon by an acceptor can be calculated from simple geometric considerations, neglecting scattering in the electrode and reabsorption by the QDs.

As can be seen from Figure 5a, for a reasonable OD = 1 of the acceptor, nearly 80% of the photons emitted by excited QDs can be reabsorbed by the acceptor and contribute to the total current. We re-emphasize that the FRET mechanism is more efficient than the slower emission–reabsorption process due to nonradiative decays. Consequently, optimal utilization of the incident photons requires high FRET efficiency and high QY of the donors in order to utilize excitations that do not provide direct energy transfer.

Direct evaluation of the FRET efficiency has, to date, been performed only using QD donors, with maximal achieved FRET efficiencies of nearly 70%⁴⁵ (Figure 6). Taking into account radiative transfer in such an electrode, energy-transfer efficiencies of about 85% are readily achievable. These parameters are comparable to maximal ETEs achieved with dye donors of up to about 90%, which can be mostly attributed to FRET due to the relatively significant quenching of the relay dye by the electrolyte.

In order to increase FRET efficiencies, the following parameters should be optimized: (i) increase of dye (acceptor) concentration, (ii) full spectral overlap (integral) between the emission spectrum of the donor and the absorption spectrum of the acceptor, (iii) shorter distance between the single donor and the layer of acceptors, (iv) higher molar extinction coefficient of the acceptor, and (v) increase of donor QY by decreasing the nonradiative recombination rate. The QY of the donor does not have much influence on the FRET efficiency when using QD

donors in the electrode (in stark contrast to the significant dye quenching by the electrolyte). Yet, even in this case, the nonradiative recombination rate is very important for those photons that were not transferred to acceptors by FRET. As the nonradiative recombination rate is made slower compared to the radiative recombination rate, the photon will have larger probability to be emitted radiatively and absorbed by the acceptor via the radiative energy transfer.

There are a number of requirements from QDs and from dye molecules for an optimal system. The QDs (i) should be engineered from the material and from the size points of view to maximize the overlap between the emission spectrum of QDs (donor) and the absorption spectrum of the dye (acceptor), (ii) maximize the QY of QDs (graded shell), (iii) minimize the overall size of the QD to allow better penetration to the TiO₂ nanopores (potentially by using doped dots), and (iv) provide neutrality of QDs upon illumination by building a high enough barrier for electrons to be injected to the electron conductor (type-I heterojunction). The barrier for the hole can be provided by the amorphous TiO₂ coating. The dye (i) has to be a good charge injector to the electron and hole conductor, (ii) should also have a high molar extinction coefficient at the donor (QD) emission peak, and (iii) should have a relatively narrow absorption peak. Preferentially, the dye should absorb in the near-IR so that the cell can operate within the optimal spectral region determined by the Shockley–Queisser limit.

Maximal Current Densities. Figure 7 shows the photon flux of the sun as a function of the wavelength (blue line, left *y* axis) under AM1.5G conditions. The right *y* axis represents the accumulated current density as a function of the wavelength. The green solid line indicates the theoretical maximum accumulated current density, short-circuit condition, for a solar cell device converting all incident photons below the absorption onset wavelength into electrical current. For example, the maximum short-circuit current density (J_{sc}) for a solar cell with an

absorption onset at 800 nm is 27 mA/cm^2 . The other three green lines are based on the real absorption spectra of SQ02 dye and CdSe/CdS/Zns QDs. The dashed, dotted, and dashed-dotted green lines are for the accumulated current density contributed by the dye only, by the QDs only (that transfer their energy to the dye, but the dye itself does not absorb other photons), and the total contribution from both dye and QDs, respectively. The current densities are calculated assuming that the OD of the dye is 1 at the absorption peak (655 nm), the OD of the QDs is 0.5 at the first excitonic absorption peak (623 nm), and 100% energy transfer efficiency (ETE) from the QDs to the dye molecules. In addition, the number of absorbed photons by the dye, or by the QD, is a portion of the total number of absorbed photons. The maximal current densities that can be reached under these assumptions are 3.4 mA/cm^2 for the dye only, 13.3 mA/cm^2 for QDs only, and 16.7 mA/cm^2 from the total contribution.

From Figure 7, it can be seen that the largest contribution of QDs to the total current is at short wavelengths (until $\sim 550 \text{ nm}$), where QDs have a high OD and where they do not compete with dye molecules on the available photons. If the OD of QDs were increased to 1 at the first excitonic absorption peak, the total current would almost reach the maximal theoretical value (18 mA/cm^2) until the absorption onset of the dye at $\sim 690 \text{ nm}$. Figure 7 represent the current status that is based on the SQ02 dye. A further red shift of both the QD donor and dye absorption can significantly increase the maximal current. For example, a cell with a 50 nm dye absorption band centered at 750 nm and OD = 1 for the QDs should allow currents as high as 26 mA/cm^2 .

Toward a Flat IPCE Spectrum. Further examination of Figure 4, which shows the IPCE data, reveals that even in the case of 100% ETE, the relatively low numbers in the region of $\sim 520\text{--}600 \text{ nm}$ (black line) will still remain. In order to eliminate the valley in the IPCE spectrum, several changes can be made. One way is to increase the OD of QDs in this region. It could be done either by increasing the number of QDs inside of the electrode or by increasing its absorption extinction coefficient. The OD of QDs in the presented system is relatively high, $\sim 10^5\text{--}10^6 \text{ M}^{-1} \text{ cm}^{-1}$ at the discussed region. Further increase by utilizing other materials is a major challenge. The number of QDs can be increased either by working with a thicker electrode, which may lead to more recombination events and thus reduced performance, or by increasing the QD coverage density. The density can probably be increased by working with smaller QDs, which can penetrate deeper to the nanopores of the titania, but this should be balanced with the size-dependent extinction coefficient. Other electrode preparation techniques, such as mixing QDs with the titania paste prior to the deposition on the anode instead of binding QDs at a later stage, may dramatically increase the density of QDs in the electrode. The main barrier of such a technique is the thermal and oxidation stability of QDs during the high-temperature sintering process ($>450^\circ\text{C}$) of the mesoporous titania film.

Another alternative way to eliminate the valley is to use a sensitizing dye with a shoulder in the absorption spectrum, which will compensate for the relatively low OD of the QDs in this region. A third path is to add an organic relay dye to the electrolyte, which will absorb efficiently within this spectral region. This latter option may also aid in reducing the overall electrode thickness, introducing absorbers to all of the available volume (electrode, surface, and pores).

Minimal Thickness of the Mesoporous TiO₂ Film. Now the question that should be answered is, What is the minimal thickness of the TiO₂ electrode that will absorb all of the light

in the QDs band? To answer this question, we calculate the highest possible density of QDs inside of the nanoporous titania. Assuming a QD radius of 3 nm, the maximal concentration that it can reach is on the order of 0.01 M. According to the Beer-Lambert law, the thickness of the medium containing QDs with a molar extinction coefficient of $10^6 \text{ M}^{-1} \text{ cm}^{-1}$ should be $\sim 0.5 \mu\text{m}$ in order to absorb 84% of the light (OD = 0.8) at the first excitonic peak. As shown in Figure 7, an OD of 0.8 should be high enough for the cell to operate close to the maximal theoretical short-circuit current. In addition, the OD of the QDs increases very rapidly for shorter excitation wavelengths starting from $\sim 520 \text{ nm}$. For every micrometer of the TiO₂ electrode, the surface area increases by roughly a factor of 100. Thus, for a 20–30% surface coverage of the TiO₂ by QDs, which should be adequate to allow for charge injection from the dyes to the electrode through the amorphous TiO₂ layer, an electrode thickness of $3\text{--}5 \mu\text{m}$ should sustain a high enough density of QDs. Achievement of such a dense coverage of QDs is not a simple task. Yet, this result exhibits the promise embedded in this geometry, which can potentially reduce in a dramatic manner the required electrode thickness, opening the possibility of use of a solid electrolyte and a concomitant expected increase in open-circuit voltage. We note that a thickness of $3\text{--}5 \mu\text{m}$ provides an OD higher than 1 for dyes with extinction coefficient exceeding $30\,000 \text{ M}^{-1} \text{ cm}^{-1}$, a value well below most narrow band absorbing dyes ($280\,000 \text{ M}^{-1} \text{ cm}^{-1}$ for the SQ01 used in Figure 4).

The promise embedded in this geometry, which can potentially reduce in a dramatic manner the required electrode thickness, opens the possibility of use of a solid electrolyte and a concomitant expected increase in open-circuit voltage.

In summary, the use of FRET-based antennas in DSSCs opens up new design possibilities, significantly increasing the cell spectral response while allowing significant flexibility in the choice of both donor and sensitizer dye. Moreover, the high extinction coefficients of QDs and the more efficient utilization of the electrode volume will permit the use of thinner electrodes toward higher photocurrent, photovoltage, and consequently to increased-efficiency solar cells.

■ ASSOCIATED CONTENT

S Supporting Information. Details of calculations. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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BIOGRAPHIES

Sophia Buhbut completed her undergraduate studies in the Department of Chemistry at Bar Ilan University, Israel (2007). During her M.Sc. and Ph.D., she has been working on development of new DSSCs that integrate the Förster resonance energy transfer (FRET) process. In her research, she developed structures for DSSCs that separate the process of absorbing light from that of carrying electrical charge, aiming for more stable devices. (See http://www.ch.biu.ac.il/php/general/people.php?todo=display_user&user_id=593&l_id=people_bar&status=grad.)

Stella Itzhakov received her B.Sc. in chemical engineering (2004) from the Technion Institute of Technology, Israel, and her M.Sc. in chemistry (2008) from the Weizmann Institute of Science, Israel. She is currently a Ph.D. student at the Weizmann Institute (with Dan Oron and David Cahen). Her main research project focuses on the utilization of semiconductor nanocrystals (quantum dots) as mediators of solar energy in photovoltaic cells. (See <http://www.weizmann.ac.il/physics/idcards/StellaItzhakov0819.html>.)

Dan Oron received his B.Sc. in physics and mathematics from the Hebrew University of Jerusalem (1994), his M.Sc. in physics from Ben-Gurion University on hydrodynamic instability (1998), and his Ph.D. in physics from the Weizmann Institute of Science on ultrafast phenomena (2005). Following postdoctoral studies at the Hebrew University of Jerusalem, he joined the Department of Physics of Complex System at the Weizmann Institute as a senior scientist in 2007. His research focuses on optical properties of colloidal nanocrystals and their utilization in photovoltaic devices and in bioimaging applications. (See <http://www.weizmann.ac.il/complex/DOron/index.html>.)

Arie Zaban earned his B.Sc. in Chemistry (summa cum laude) and a Ph.D. in Electrochemistry (with highest distinction) at Bar Ilan University (1987–1995). After a 2 year postdoctoral stint at the U.S. National Renewable Energy Laboratory (Denver, CO), he was appointed to the senior faculty at Bar Ilan, where he is currently a Full Professor of Chemistry and Director of the Bar Ilan Institute for Nanotechnology and Advanced Materials. His research focuses on the development of new materials and concepts for photovoltaic systems.

(See <http://www.nano.biu.ac.il/index.aspx?id=3400&itemID=2264>.)

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