Compound semiconductor nanocrystals as active components in photovoltaic cells

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Abstract: The optical spectrum and band alignment of semiconductor nanoparticles can be tuned by controlling their size, shape and composition. This allows for engineering nanoparticles to have favourable qualities for light harvesting applications. Current synthetic techniques, such as seeded growth and nucleation doping allow for fabrication via colloidal chemistry routes of highly complex nanostructures. These can be used directly as sensitizers, to serve as charge donors or acceptors enabling control of energy band alignment, or to be used as 'stand-alone' devices for photon upconversion. These various possibilities will be discussed, with particular emphasis on the relation between structure and function of the colloidal nanocrystals and the versatility of their design. Particular applications in increasing the open circuit voltage of sensitized cells using photo-induced long lived dipoles either directly built in within the sensitizer or as an add-on to an existing cell will be presented. The potential use of colloidal double quantum dots as broadly tuneable upconversion systems, as well as a specific realization exhibiting a conversion efficiency on the order of 0.1% and saturation intensity of $10^4 W/cm^2$ will be presented, along with design criteria for pushing the performance of these nanoparticles to values relevant for solar energy applications.

Research on the use of colloidal semiconductor nanocrystals (often termed quantum dots, QDs) for light harvesting applications has expanded significantly in the last few years. The relative ease of fabrication of these nanocrystals, as well as the ability to process them by low-temperature solution methods, is an attractive attribute which could turn into a significant advantage if nanocrystal-based cells achieve sufficiently high efficiencies. In other aspects, the ability to tune the QDs band structure via size and composition makes them an ideal test bed for various photophysical studies of new photovoltaic cell designs.

In some of the simplest designs, such as is the case for QD sensitized solar cells, QDs are utilized directly as the active component of the cell. Yet, unlike organic dyes, their energy level structure can be easily manipulated via composition tuning, and they can be tailored so as to impart additional functionalities into the cell. Such is the case of type-II QDs sensitized cells[1]. In a type-II QD, spatial separation of the excited electron from the hole occurs on a picosecond time scale within the QD, facilitating long-range charge separation and inhibiting some recombination pathways. Indeed, type-II sensitized cells are, to date, the highest efficiency cells of this type to have been produced[2].

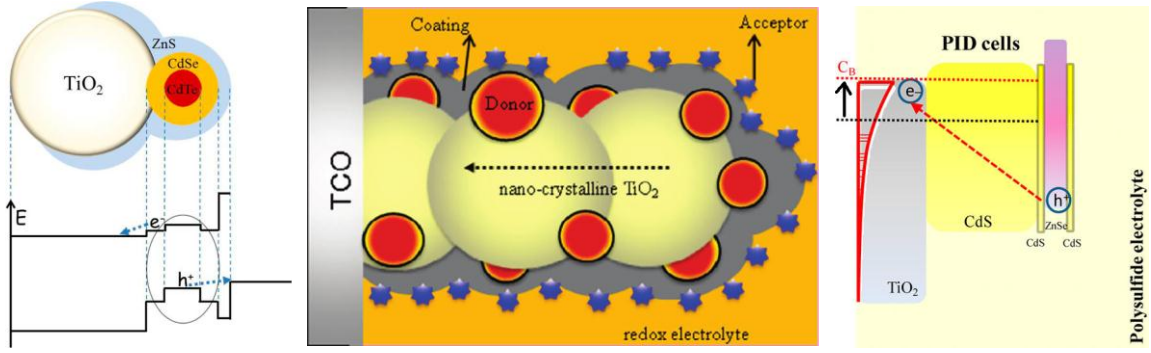

Fig. 1: Schematics of a type-II QD sensitized solar cell (left), of a hybrid QD-dye sensitized FRET cell (middle) and of a photoinduced dipole cell (right).

Yet, the advantages of colloidal QDs can be even more evident in hybrid cells, where the requirements from the QDs are more stringent. One case where this is evident is in FRET-based cells, where two types of absorbers are combined. In this case, QDs are an excellent donor material due to their high quantum yields, excellent surface passivation and photostability and narrow, tunable, emission band[3]. Another example is their use for controlling band alignment within the photovoltaic device via the use of photoinduced dipoles. In the latter case, delicate tuning of the conduction band as well as the carrier lifetime in the valence band (before it is being harvested) is required – a situation where composition tuning in core/shell QDs provides an excellent solution[4].

Finally, QDs can be designed to yield complex spatial structures, enabling new phenomena, such as luminescence upconversion, to occur within a single nanocrystal, potentially expanding the utility of QDs to other uses within the realm of quantum light harvesting[5].

References:

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