

## Chapter 6

# Hybrid Solar Cells: Materials and Technology

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### ABSTRACT

*Conventional solar cells are usually manufactured from silicon, an inorganic material. This type of solar cell has a high efficiency, up to 40%, but these cells are using very expensive materials of a high purity and energy intensive processing techniques. This chapter is dedicated to a critical presentation of hybrid solar cells. They are a combination of both organic and inorganic nanostructure materials and, therefore, combine the properties and advantages of their components. Unfortunately, so far, the hybrid solar cells have a low conversion efficiency of the sunlight, 6-7% (Kim, et al., 2007).*

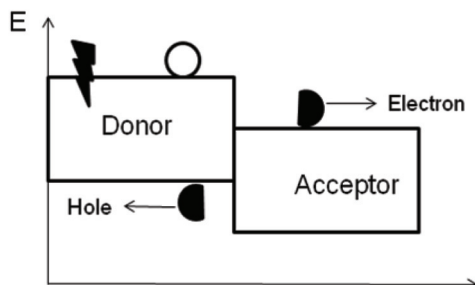
### INTRODUCTION

Hybrid photovoltaic cells, classified as the third and fourth generation solar cells, are a mix of nanostructures of both organic (p-type conjugated polymers, photosensitive dyes, carbon nanotubes, etc.) and inorganic (nanostructures or nanoparticles of TiO<sub>2</sub>, ZnO, PbS, PbSe, CdTe, CuInS<sub>2</sub>, CuInSe<sub>2</sub>, etc.) materials.

One of the materials (organic component) acts as the photon absorber. In contrast to inorganic semiconductors, photo excitation of organic semiconductors results in a strongly bounded electron-hole pair, called an exciton (Ginger & Greenham, 1999b). These electron-hole pairs are only effectively separated at an interface between a p-type (electron-donating) material and n-type (electron-accepting) material represented by the inorganic component of a hybrid solar cell, Figure 1.

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Figure 1. Energy ( $E$ ) diagram at the interface donor/acceptor in a hybrid solar cell



In order to have a favourable charge transfer at the interface, the following condition must be satisfied (Ginger & Greenham, 1999b):  $E_A^A - E_A^D > U_D$ , where  $E_A$  is the electron affinity,  $U$  is the coulombic binding energy of the exciton on the donor and superscript A refers to the acceptor and superscript D refers to the donor. For the exciton binding energy in commonly used organic materials (polymers, oligomers, small molecules, carbon nanotubes) the value ranges from 0.3 eV to 1.4 eV, which is considerably higher than the binding exciton energy for inorganic semiconductor materials, 0.02-0.04 eV (Scheblykin, Yartsev, Pullerits, Gulbinas, & Sundström, 2007). In order to dissociate the exciton in a bulk organic medium, the thermal energy at room temperature ( $\approx 0.025$  eV) is not sufficient, therefore the exciton dissociation is possible only at the interface between the donor and the acceptor materials with favourable HOMO and LUMO energy levels.

The difference between the LUMOs (or conductive band) of the donor and acceptor will compensate the energy required for the dissociation and the transfer of the electron (Saunders & Turner, 2008). After charge separation, the carriers (electrons and holes) are transported to the electrodes through a percolation network.

The exciton generated in polymer has a time scale from one picosecond to one nanosecond

(Shaw, Ruseckas, & Samuel, 2008) and the diffusion length (at average distance an exciton can diffuse through material before its annihilation by recombination) is short in polymers (5-10 nm) (Ginger & Greenham, 1999b). Only the exciton generated within this length close to an acceptor would contribute to the photocurrent of the cells. For this reason, the hybrid solar cells often use a nanostructured interpenetrating network of donor and acceptor materials (bulk heterojunction) with an enhanced interfacial area where the excitons are separated into charge carriers (Saunders & Turner, 2008). The bulk heterojunction concept allows for more interfacial contact between the organic (donor) and inorganic (acceptor) materials than the phase separated bi-layer heterojunction.

Hybrid solar cells have some advantages over the other types of photovoltaics (first and second-generation cells) (Gledhill, Scott, & Gregg, 2005; Huynh, Dittmer, & Alivisatos, 2002; McGehee, 2009; Ong & Levitsky, 2010):

- Hybrid nanocomposite mixtures combine the advantages of both type of materials: the solution processing of organic semiconductors with the high charge-carriers mobility and light absorption at longer wavelengths if inorganic semiconductors;
- The existence of an organic component allows hybrid solar cells to be superior over conventional semiconducting photovoltaics in terms of cost efficiency, scalable wet processing, and the variety of organic materials, lightweight, and flexibility. Moreover, the recent progress in advanced semiconducting nanostructures in combination with polymers and/or organic nanomaterials, such as fullerenes and carbon nanotubes, opens new opportunities to overcome the 8-10% barrier of light conversion efficiency for hybrid solar cells in the near future (Li, et al., 2009; Ong, Euler, & Levitsky, 2010).

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