Organic Solar Cells

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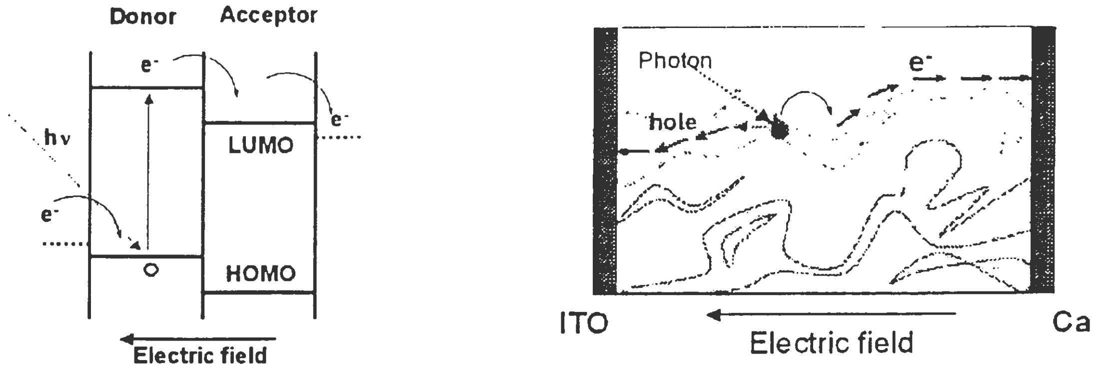
Solar cells are devices used to convert sunlight directly into electrical energy. Solar cells are widely studied because they offer several potential advantages over other sources of electricity: access to an unlimited energy source, maintenance-free operation and environmentally clean power generation. Despite these advantages, the contribution of solar cells to commercial electricity generation is very low. For example, the contribution to the net generation of electricity was just 0.08% in the United States in 1998.[1] This low contribution is due to the energy production costs, which are many times higher than those for conventional (nuclear and fossil fuel) power stations.

Most solar cells are diodes constructed by placing two different semiconducting materials in contact with one another to form a p-n junction. It is well known that the conductivity of a semiconductor can be increased by introducing small amounts of certain impurities called dopants. For example, doping of a Si substrate with a group III element generates a p-type semiconductor, in which holes in the valence band are created by thermal excitation of electrons into low-lying acceptor states. In contrast, doping with a group V element creates an n-type semiconductor in which electrons in the conduction band are created by thermal excitation from filled high-lying states. When a p-type semiconductor is placed in contact with an n-type semiconductor, a p-n junction is created and electron transfer processes cause the formation of an insulating depletion zone and an internal electric field at the interface. Under illumination, two processes result at the p-n junction; 1) light is absorbed, generating electron-hole pairs and 2) electron-hole pairs separate due to the internal electric field.[2,3]

In organic solar cells, charge carriers are generated via π to π^* transitions. Since electron-hole pairs are strongly bound to each other, a charge separation process similar to that in p-n junctions is required to prevent recombination and to promote the flow of current. Such charge separation can be accomplished by placing organic donor and organic acceptor materials in contact with one another. Charge separation results because excited electrons in the donor material transfer to the π^* orbitals of the acceptor material [Figure 1a].[4] Efficient charge separation occurs only at the donor/acceptor (D/A) interface, so a large interface area is required for high photon-to-current efficiency [Figure 1b]. The separated charge carriers are accelerated toward the electrodes by the internal electric field, which is generated by differences in the work functions of the electrodes.

Three different organic solar cell types will be discussed. In system I, poly(2-methosy-5-(2´-ethylhexyloxy)-1,4-phenylene-vinylene), abbreviated MEH-PPV, and a derivative of C_{60} act as the electron donor and the electron acceptor, respectively.[5] MEH-PPV/C_{60} blends are proposed to form a bicontinuous network, which gives the cell a large D/A contact area and thus increases the efficiency of charge separation. Charge separation was monitored by photoluminescence quenching.[6] The photoluminescence intensity of the MEH-PPV was considerably reduced in the composite, which suggests that electron transfer from MEH-PPV to C_{60} is occurring. The short circuit current and



a) b)

Figure 1. a) Electron transfer process in Donor/Acceptor interface.
b) Charge carrier transport process in Donor/Acceptor blend.

photon-to-electron conversion efficiency was two orders of magnitude higher than that of a MEH-PPV single-layer device. The efficiency was also higher than that reported for a polymer blend device.[7]

System II used poly(3-(4-octylphenyl)thiophene), abbreviated POPT, as the electron donor and a cyano derivative of poly(2-methoxy-5-(2′-ethylhexyloxy)-phenylene-vinylene), abbreviated MEH-CN-PPV, as the electron acceptor.[8] The harvesting of solar energy in this system is increased upon thermal annealing of the composite; evidently, thermal annealing causes the POPT to change from a disordered to an ordered structure,[9] and transport of charge to the electrodes is better in the ordered state. Another important experimental parameter is the choice of the electrodes. Different combinations of electrodes create varying internal electric fields and open-circuit voltages. The efficiency of the devices is highest when the open-circuit voltage is maximized.

Hexa(para-n-dodecylphenyl)-substituted-hexa-peri-hexabenzocoronene (HBC-PhC$_{12}$) and perylene diimide were used for system III.[10] One common problem in organic semiconductor materials is low charge-carrier mobility. By using microscopically-ordered HBC-PhC$_{12}$[11] and perylene diimide, a high charge carrier transport efficiency is obtained. Blends of the D/A materials undergo vertical segregation, resulting in a perylene diimide electron-transporting layer and an HBC-PhC$_{12}$, hole-transporting layer. Despite the segregation, interpenetration of the two layers gave good charge separation.

The power conversion efficiencies of organic solar cells are still too low to make them commercially attractive. However, there is considerable room for development. To obtain higher power conversion efficiencies, the structures of the organic materials must be adjusted by making chemical modifications, so that the band gaps of the materials are better matched to the maximum in the solar spectrum, and the materials have higher electron mobilities. Development in these areas will advance the science of organic solar cells.

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