

# Organic Photovoltaic Solar Cells: Recent Advancements in Efficiency

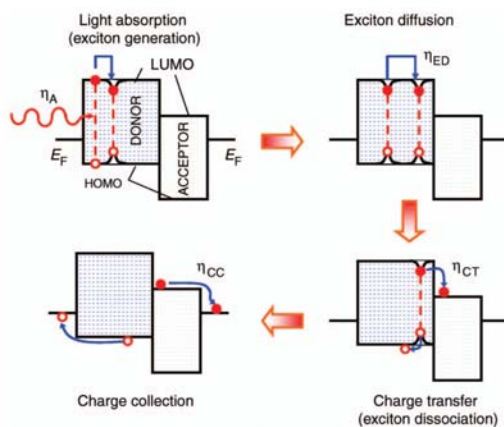
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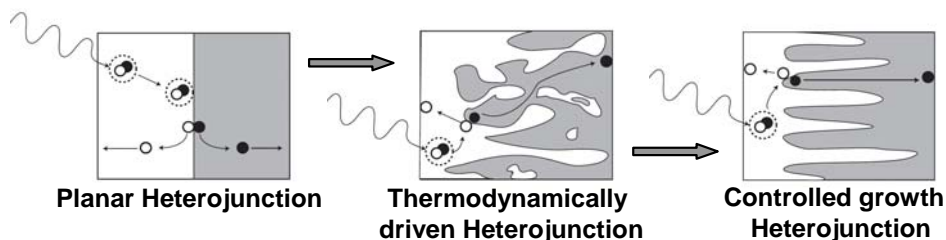
In a society where cheap and clean renewable energy sources are increasingly desirable, solar cells are slowly, but steadily, answering the call. Since the discovery of conducting polymers in the late 1970's, applications of these polymers to fabricate solar cells that convert solar energy into a viable power source have been of great interest. Until recently, however, less than spectacular power conversion efficiencies have been observed for organic or polymeric materials. In 1986, Tang and co-workers achieved a 1% power conversion efficiency with an organic photovoltaic cell based on a small molecular weight organic thin-film photodetector.<sup>1</sup> Since that breakthrough, great strides have been made resulting in a variety of strategies for solar cell improvements based on polymers,<sup>2, 3</sup> quantum dots,<sup>4</sup> dye-sensitized metal-oxides,<sup>5</sup> and multi-crystalline silicon.<sup>6</sup> Due to their cost-effective manufacturing methods and low-cost materials, organic photovoltaic cells, or *OPVs*, need only achieve a power conversion efficiency of about 10% (~ 4% greater than today's most efficient OPVs based on small molecular weight thin-film photodetectors) to become more *economically* efficient than silicon.

Although solar cell technology has been studied for decades, it is only in the past several years that organic photovoltaic cells have emerged as a possible contender in the solar power industry. Conventional silicon photovoltaics, with efficiencies approaching 35%, consist of two or more layers of positively or negatively doped semiconducting materials. Upon absorption of a photon, electrons are promoted from the valence band to the conduction band of the material making up the absorbing layer. Once excited, these electrons are free to form a current. Organic photovoltaic cells work by a slightly different mechanism. As is discussed in a number of reviews on organic solar cells,<sup>7, 8</sup> the absorbing layers are commonly designed using materials consisting largely of carbon atoms arranged in a conjugated system. Once the semiconducting materials are brought into contact with one another, an interface is formed. This interface allows for a one-way transport of either electrons or holes. When these thin-film materials absorb a photon, an exciton (an electrically neutral electron-hole pair) is formed.<sup>9</sup> These excitons are not free to travel throughout the layer, as they can in many inorganic materials. Rather, they must make their way via *exciton diffusion* to the interface of a second thin-film where they undergo a charge transfer (exciton dissociation) into electrons and holes that travel to the cathode and the anode, respectively (Figure 1).



**Figure 1:** Mechanism of photocurrent generation in an organic photovoltaic solar cell.<sup>10</sup>

Although the use of polymeric or small molecular weight organic thin-films affords the opportunity for deposition onto plastic or flexible substrates,<sup>11</sup> a “bound-exciton” system brings with it inherent limitations.<sup>10</sup> Among these is the sensitivity of the thin-films used as absorption media. As is the case with any semiconductor, the electron and/or hole producing layer must be in direct contact with either an anode or a cathode. For OPVs, the deposition of a metal cathode (usually Ag or Al) can cause severe defects at the acceptor/cathode interface thereby limiting the overall efficiency of the cell. Great progress has been made in the development of an *exciton blocking layer* (EBL) to act as an intermediate between the light absorbing layer and the cathode.<sup>12</sup> EBLs not only buffer the sensitive portions of the cell, but when doped with light absorbing materials, also can work to increase the absorption efficiency of the cell. Another challenge facing materials and device scientists is an avoidance of an *exciton diffusion bottleneck*, in which photogenerated excitons are unable to diffuse to a donor/acceptor (DA) interface prior to dissociation. This phenomenon occurs primarily because that the distance an exciton can travel is often much less than the optical absorption length ( $1/\alpha$ ). One way to counter this effect is to employ materials that possess a longer *exciton diffusion length* ( $L_D$ ), which improve internal quantum efficiencies, thereby raising the overall power conversion efficiency.<sup>13</sup> Other strategies include the use of mixed or bulk heterojunctions,<sup>14-17</sup> in which a layer is constructed of a mixture of donor and acceptor materials sandwiched between the two thin films. Such heterojunctions increase the surface area of the DA interface, resulting in an increase in exciton diffusion efficiency. Optimization via the use of *organic vapor phase deposition* (OVPD)<sup>18</sup> of the donor layer has yielded drastic improvements to the power conversion efficiencies of OPVs (Figure 2).<sup>17</sup>



**Figure 2:** Schematics of organic donor-acceptor heterojunctions.<sup>17</sup>

A third and vital factor limiting the efficiencies of OPVs is the inability of the thin-film device to absorb a large enough fraction of the solar spectrum. Typical materials employed in OPVs absorb relatively little of the incoming light, resulting in poor absorption efficiencies. To overcome this limitation, high-efficiency organic photovoltaic cells can be stacked and connected in series, thereby optimizing the absorption of incident light.<sup>19</sup>

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