

# Organic Solar Cells

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Oscar Monge Villora, Jack Thomas Parley and Pablo Ribera Manzano  
Universitat Politècnica de Catalunya, ETSETB,  
Barcelona

## I. INTRODUCTION

Conventional solar cells were invented in the 1950s and first commercialized in the 1960s for use in space programs. Since then there have been rapid advances in the efficiency and reliability of these cells, along with a substantial decrease in their fabrication costs. As a result the photovoltaic industry has been growing rapidly.

Nevertheless the price of solar electricity is still greater than the price of electricity from the electrical grid in industrialized countries. For this reason there is an increasing amount of research devoted to potentially less expensive types of solar cells such as those based on organic dyes and polymers.

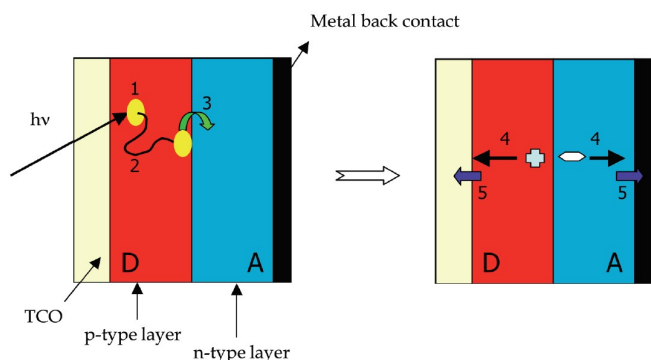
They have attracted much attention during the last decade due to their potential for fabricating light-weight, large-area, customised, flexible and low-cost solar panels. One of the other great promises of organic electronics is that synthetic chemists can produce compounds matching the opto-electronic properties desired.

As we will explain in the following section, a fundamental difference between solar cells based on organic materials and conventional inorganic photovoltaic (IPV) cells is that light absorption results in the formation of excitons in molecular materials, rather than in free electrons and holes. Due to this fundamental difference the processes involved in the conversion of photons into electrical energy are not the same as those occurring in IPV cells.

## II. ORGANIC SOLAR CELLS

In general, for a successful organic photovoltaic cell five important processes have to be optimized to obtain a high conversion efficiency of solar energy into electrical energy:

1. Absorption of light and generation of excitons
2. Diffusion of excitons to an active interface
3. Charge separation
4. Charge transport
5. Charge collection



Illumination of a donor material through a transparent electrode (ITO) results in the formation of an exciton. Subsequently, the exciton is transported by diffusion to the interface between the donor material and an acceptor material. Electron is transferred to the acceptor material, leaving a hole at the donor material. The photogenerated charged carriers are then transported to and collected at opposite electrodes.

### Light absorption

For an efficient collection of photons, the absorption spectrum of the photoactive organic layer should match the solar emission spectrum and the layer should be sufficiently thick to absorb most of the incident light. Though increasing the layer thickness is often advantageous for light absorption, charge transport might be hampered. The illumination of the layer results in the formation of an exciton.

### Exciton transport

For realisation of an efficient organic solar cell all excitons formed due to light absorption should lead to the formation of free charge carriers. However exciton transport is in competition with other decay processes such as luminescence or radiative recombination to the ground state.

For an efficient solar cell all excitons have to reach the photo-active interface within the lifetime of an exciton. Transport of the excitons occurs by diffusion and the distance an exciton is able to cross is given by:

$$L_{exc} = \sqrt{D_{exc} t_{exc}}$$

in which  $D_{exc}$  is the diffusion coefficient of the excitons. Since for molecular materials  $t_{exc}$  is often only several nanoseconds at most,  $L_{exc}$  is generally limited to 10nm. In practice this implies that only those excitons formed within a distance of  $L_{exc}$  from the interface will contribute to charge separation. To avoid this problem, research has been devoted to increase the diffusion coefficient of excitons or to make the interfacial area much larger, so that each generated exciton is always close to an interface.

### Charge separation

Creation of charges is one of the key steps in the conversion of solar light into electrical energy. In most organic solar cells, charges are created by photoinduced electron transfer. In this process an electron is transferred from an electron donor (D) material to an electron acceptor (A) material with the aid of the additional input energy of an absorbed photon with energy  $h\nu$ .

An electron donor is characterized by a molecular material with a small electron affinity. Vice versa an electron acceptor is a material with a high electron affinity. The difference

between both electron affinity levels is the driving force required for the exciton dissociation. In the photoinduced electron transfer process an exciton at the donor-acceptor interface decays by creation of the charge-separated state consisting of the radical cation of the donor and the radical anion of the acceptor.

For an efficient charge generation, it is essential that the charge-separated state is the thermodynamically and kinetically most favourable pathway for the exciton. In addition, the charge-separated state should be stabilized, so that the photogenerated charges can migrate to one of the electrodes.

In a homojunction between a p-type and a n-type silicon semiconductor under illumination electrons flow from the p-type to the n-type semiconductor. In a heterojunction based on an electron donor layer D and an electron accepting layer A, under illumination electrons flow from the donor layer to the acceptor one. Therefore the donor layer is also denoted as p-type layer and the acceptor layer as the n-type layer in analogy with a silicon pn junction.

### Charge transport

The charge transport mechanisms operating in inorganic photovoltaic cells (IPV) and organic solar cells to drive charge carriers towards the electrodes are very different.

Light absorption in IPV cells leads directly to the production of electrons and holes in the same material -due to the existence of a conductor band and a valence band. Since the two carrier types have the same spatial distribution, the concentration gradient, which is the driving force for the transport by diffusion is identical. Therefore both charge carriers are driven in the same direction. Since this is a small driving force in IPV cells, the electric potential gradient present at the interface of a p-n junction (the band bending) is able to separate the photo-induced electrons and holes effectively.

In contrast to IPV cells in organic solar cells after the charge transfer the electrons and holes are in close proximity. Therefore is a large chemical potential gradient that drives the charge carries away from the exciton dissociating interface.

Though for IPV cells the electric field is the main driving force for the charge transport, it is not yet clear to what extent the internal electrical field contributes to the charge transport in organic solar cells.

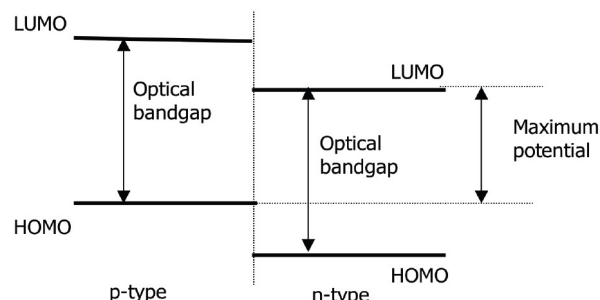
The mobility in molecular materials is relatively small (<0.1cm<sup>2</sup>/Vmm) as compared to inorganic semiconductors (100-10000Vmm). It is not yet clear if and how an electrostatic potential in an organic bilayer is formed. So the recombination processes are important parameters in particular for organic solar cells. These processes should be sufficiently slow to allow the charge carriers to reach the electrodes.

### Charged collection

The collection of charge carriers at the electrodes is regularly accomplished by a transparent conductive oxide (TCO) such as ITO or SnO<sub>2</sub>:F on one side and a metal contact on the other side.

For inorganic solar cells the open circuit voltage (V<sub>oc</sub>) is limited by the electrostatic potential at the junction. For organic solar cells reasonable open circuit voltages have been measured for cells build up by using a single photoactive molecular material and identical electrodes. From this observation it is evident that the V<sub>oc</sub> is determined by other factors than for an IPV cell.

For an organic solar cell based on two molecular materials optical excitation leads to the formation of an exciton in one of the layers. For the charge separation process part of the original energy of the photon is lost, yielding an electron in the n-type material and a positive charge carrier in the p-type material. In case there is no potential loss at the electrodes the maximum observed potential can be obtained by as shown in the figure:

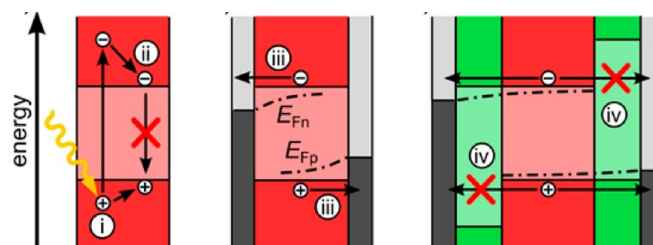


The names HOMO and LUMO correspond to "Highest Occupied Molecular Orbital" and "Lowest Occupied Molecular Orbital", respectively. The offset in the energy levels corresponding to LUMO forms the driving force for the dissociation of the exciton.

### Another point of view: Peter Würfel model

To describe PV cells in terms that are applicable to all possible device structures including p-n homo- and heterojunction cells (i.e., Si, CIGS, CdTe), bulk heterojunction devices (i.e., plastic solar cells), etc., we present a generalized approach.

Upon photon absorption, an electron is excited into an electronic state at higher energy, leaving a positive charge behind at low energy (process i). These charges are transferred into a metastable high- and low-energy state (process ii). A driving force is required to transport the electron to an external contact while the positive charge to reach the other contact (process iii). The contacts have to be selective to one type of charge carrier, preventing positive and negative charges from reaching the oppositely charged contact. So, as if they were filters.



This rather abstract definition describes all types of PV cells, which can be easily applied to cells with an intrinsic absorber (n-i-p or p-i-n).

### III. OUR ORGANIC SOLAR CELL

The project mainly consists in fabricate an organic solar cell. In order to get some good results we will use materials commonly used in the research group of UPC about organic solar cells. Therefore, the structure of the solar cell will consist in a support of glass, a transparent conductive layer of ITO (indium tin oxide) above it, a hole transport layer of MoO<sub>3</sub> after this, an absorbing blend layer of DBP (tetraphenyldibenzoperiflanthen) and C70 (fullerene) over it, continuing with an electron transport layer BCP (bathocuproine) and finishing with a font electrode of aluminum on top. We can see the structure of the solar cell in figure 1.

The reason we make this configuration can be founded in the different interpretation of the theory of organic solar cells made by Peter Würfel, in which the absorbing layer absorbs the photons generating some exciton that provides some electrons excited in the conducting band and some holes that are driven to each transport layer that acts like a filter, leaving the pass depending the type of carriers they are. Finally we extract the carriers by the font electrode and the transparent conductive layer that acts like the other electrode. The glass only is used to support and protect the structure and to leave the photons go through it.

Having explained that, we have to specify the thickness of the layers used, that are showed in the figure 2, chosen experimentally to enhance the efficiency, the Voc and the Jsc of the cell. Also, we can see the different energies (eV) of the conduction and valence bands of the different material that compound our cell.

We've talk about the composition of our organic solar cell and now we can observe the external structure of this, with the characteristic shape showed on the third figure. The black part corresponds to the electrodes of the cell while the grey part corresponds to the amount of films collocated one upon the other. All this is putted over the crystal, in which each side measures about 15mm.

In order to make our organic solar cell we followed some technologic steps mainly made at the CRNE (Centre for Research in Nanoengineering, UPC of Barcelona). First of all, we have to clean the samples with an ultrasonic bathroom during approximately 30 min into acetone, 30 min more into isopropanol and 30 more into water deionized. After that, we apply a technique called UVO (ozone) that eliminate the rest of contaminant molecules of the samples, during 30 min too. Only these introductory passes were made at the Clean Room of the electronic department of the UPC.

After this, we have to put our materials in the metal and organic chamber (depending on the material) and make the vacuum to arrive to pressures about. The metal and organic chambers are the deposits in which we put our samples in order to do the deposition layer by evaporation (localized at CRNE).

These two chambers are protected by a glove box that block the entrance of humidity. The process of making the vacuum can last about 5 hours more or less, so, we can leave it running during the night. After we wait, we can begin the layer deposition by evaporation. In order to do that, we heat the samples to evaporate them and allow the deposition at the top of the chamber.

As we want to regulate the deposit rate of the thin films, we use the shatters that close or open the recipient of the samples leaving one overture or other. In fact, it is done electronically. You only have to put the desired rate and observe the thick of layer deposited. Our deposit rate was about 2-5 Angstroms/segon. The order of deposition begins with the evaporation of MoO<sub>3</sub> at the metal chamber. It continues with the deposit of the DBP, C70, and BCP films at the organic chamber and it finishes evaporating the aluminum to form the top contact.

After all, we obtain our organic solar cell and we deposit it into a special recipient (figure 7) very useful to transport it without oxygen degradation and also it can be used as a testing system. Now it's time to take it and evaluate the response of our organic solar cell.

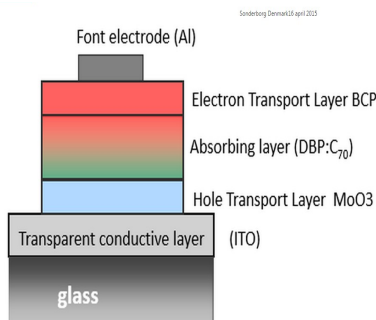


Figure1. Components of the cell

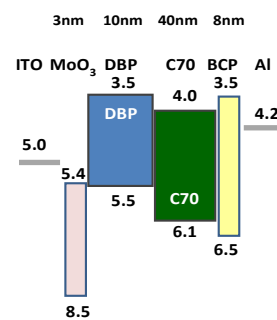


Figure2. Thickness of the layers

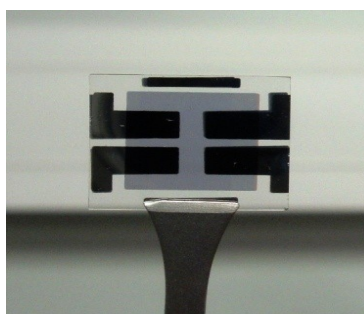


Figure3. Shape and external structure of the cell

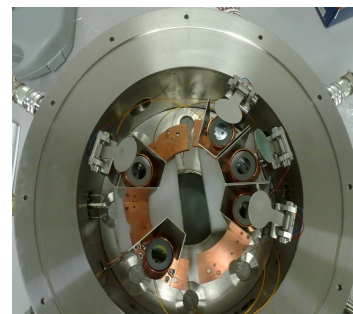


Figure4. Organic chamber with their sample recipients with shatters



Figure5. Glove box at CRNE



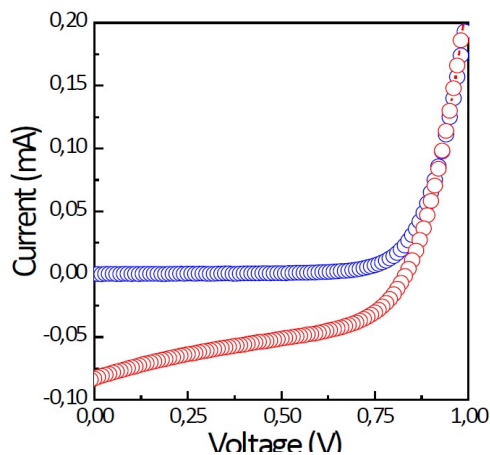
Figure 6. Transport recipient and tester

## IV. RESULTS AND DISCUSSION

Firstly, the current density–voltage (J–V) characteristics of the solar cells were measured using a Hewlett Packard source-measurement unit. The J–V curves under simulated one-sun illumination were obtained using a Newport Oriel Instruments solar simulator for AM1.5G irradiance (100 mW/cm<sup>2</sup>).

Some of the cells were defective, and their J-V characteristic bore no resemblance to a typical solar cell. The typical solar cell characteristic is described by a series of parameters, such as the open circuit voltage, the short circuit current and the fill factor. The fill factor is the ratio of the actual maximum obtainable power to the product of the open circuit voltage and short circuit current. This is a key parameter in evaluating performance. Cells with a high fill factor have a low equivalent series resistance and a high equivalent shunt resistance, so less of the current produced by the cell is dissipated in internal losses.

These are the data corresponding to our best solar cell. In dark we can see an almost perfect diode characteristic. Under simulated one-sun illumination, we obtain  $V_{oc}=0.8326V$  and  $I_{sc}=-0.02mA$ .



Probably the most important parameter though is the efficiency. Solar cell efficiency is the ratio of the electrical output of a solar cell to the incident energy in the form of sunlight. This is calculated by dividing a cell's power output (in watts) at its maximum power point ( $P_m$ ) by the input light ( $E$ , in W/m<sup>2</sup>) and the surface area of the solar cell ( $A_c$  in m<sup>2</sup>).

By convention, solar cell efficiencies are measured under standard test conditions (STC) unless stated otherwise. STC specifies a temperature of 25 °C and an irradiance of 1000 W/m<sup>2</sup> with an air mass 1.5 (AM1.5) spectrum. These conditions correspond to a clear day with sunlight incident upon a sun-facing 37°-tilted surface with the sun at an angle of 41.81° above the horizon. For our best solar cell, we got 3.53%.

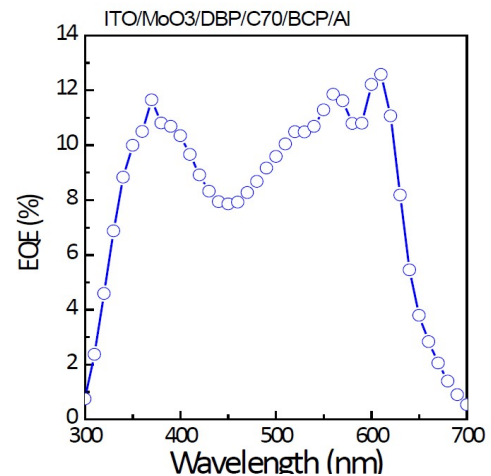
How does this compare? On January 16, 2013, Heliatek GmbH, the leader in organic solar films, announced a record breaking 12.0% cell efficiency for its organic solar cells. The 12.0% record cell on a standard size of 1.1 cm<sup>2</sup> combined two patented absorber materials, which converted light of

different wavelengths. Using two different absorber materials creates a stronger absorption of photons and improves energetic utilization through a higher photovoltage.

We are far from 12%, but our efficiency value is quite good. A heterojunction solar cell with the same materials fabricated at the same lab achieved a similar value (3.93%).

Finally, the external quantum efficiency (EQE) curves were measured using a PV Measurements, Inc. set-up with a lock-in amplifier and modulating the monochromatic light at a frequency of 80 Hz by means of a mechanical chopper. A solar cell's quantum efficiency value indicates the amount of current that the cell will produce when irradiated by photons of a particular wavelength.

Two types of quantum efficiency of a solar cell are often considered. The External Quantum Efficiency (EQE), which is the one we measure, is the ratio of the number of charge carriers collected by the solar cell to the number of photons of a given energy shining on the solar cell from outside (incident photons). To measure the IQE (internal quantum efficiency), one would first have to measure the EQE of the solar device, then measure its transmission and reflection, and combine these data to infer the IQE.



The ideal quantum efficiency graph has a square shape, where the QE value is fairly constant across the entire spectrum of wavelengths measured. However, as in our case, the QE for most solar cells is reduced because of the effects of recombination, where charge carriers are not able to move into an external circuit.

## V. LITERATURE USED

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