

Analysis of Organic Photovoltaic Cell

S.V.D. Prasad, V.Krishnanaik, K. R Babu

Abstract: In this paper analysis of photo voltaic (PV) electricity is one of the best options for most impartment and ecological future energy requirements of the world. Organic photovoltaic (OPV) cells are hopeful views for common renewable energy unpaid to light weight, low cost, and flexibility. But, presently the best total power conversion efficiency of OPV cell is round 8.3% that is very low. The research paper focuses, the basic design, the recent progresses in organic materials, processing technique and operation of organic photovoltaic cells as well as crucial feature of their performance are reviewed. To achieve significantly higher efficiency future development that need to be addressed are discussed to this article

Index Terms: Efficiency, Cost effective, Molecular Materials, OPV-Organic Photovoltaic cell, Temperature Effect, Processing Technique.

I. INTRODUCTION

An organic solar cell or organic photovoltaic (OPV) cell is a photovoltaic cell that uses organic electronics—a branch of electronics that deals with conductive organic polymers or small organic molecules for light absorption and charge transport. The plastic used in OPV cells has low production costs in high volumes. Combined with the flexibility of organic molecules, OPV cells are potentially cost-effective for photovoltaic applications. The optical absorption coefficient of organic molecules is high so a large amount of light can be absorbed with a small amount of materials. [2] The main disadvantages associated with organic photovoltaic cells are low efficiency, low stability and low strength compared to inorganic photovoltaic (IPV) cells. A fundamental difference between solar cells based on organic materials and conventional IPV cells are that light absorption results in the formation of excitons in molecular materials, rather than in free electrons and holes.

An exciton in an organic semiconductor can be considered as a tightly coulombically bound electron hole pair. Due to its electrical neutrality and the strong binding energy between the hole and the electron it can be regarded as a mobile excited state. Due this fundamental difference the processes involved in the conversion of photons into electrical energy are not the same as those occurring in IPV cells. In this article, solar cells in which excitons are generated due to light absorption, here after denoted as OPV cell will be discussed. First some more relevant properties of organic materials often referred to as molecular materials are given in section 2. Section 3 describes the working principle of OPV cell. In section 4 more details about the processing technique of OPV cells. The temperature effects and cost &

life time of OPV cell are discussed in section 5&6 respectively.

Future developments regarding efficiencies for organic OPV cells are discussed in section 8 of this article.

II. OPV CELL MATERIALS

Organic molecules and polymers have the vast advantage of too easy, chemical tailoring to alter their properties, such as the optical band gap. For example conjugated polymers combine the electronic properties known from the old-style semiconductors with the ease of processing and mechanical flexibility of plastics. Conjugate organic polymer including *p* phenylenevinylens (PPVs), polythiophens (PTs), C₆₀, C₆₁, polyacetylene (PA), poly 3-hexylthiophene (P3HT), 6-6 phenyl-C61-butyric acid methyl ester (PCBM), 3-4 ethylenedioxythiophene (PEDOT), and poly styrenesulfonate (PSS). This organic material has fascinated considerable attention owing to its potential of providing flexible, lightweight, environmentally safe, and inexpensive electronics circuitry.

A system is formed where carbon atoms covalently bond with alternating single and double bonds, in other words these are chemical reactions of hydrocarbons. These hydrocarbons electrons *pz* orbitals delocalize and form a delocalized bonding π orbital with a π^* antibonding orbital. The delocalized π orbital is highest occupied molecular orbital (HOMO), and the π^* orbital is the lowest unoccupied molecular orbital (LUMO). [3] The energy involved can roughly be estimated on basis of the electrochemical oxidation potential (vs. NHE) of the molecules using the relation: In a similar way the electron affinity can be estimated from the reduction potential of the molecules using:

$$E_{\text{LOMO}} - E_{\text{NHE}} - V_{\text{red}}$$

The difference between both energy levels corresponds to the optical band gap of the molecules. The band gap of OPV molecules are typically in the range of 1-4 eV. Alternative methods to determine the energy levels in molecular layers include ultraviolet photoelectron spectroscopy (UPS) and Kelvin probe measurements. The concentration of mobile Charge carriers within intrinsic molecular layers in the dark at room temperature is usually small. The resulting conductivity of these layers is therefore relatively small. Intentional doping to form n- or p-type layers is not straightforward, since this causes often degradation of the organic material. Molecular materials that have a low ionization potential and thus can easily donate an electron are denoted as electron donors. Materials that have a high electron affinity and thus can easily take up an electron are denoted as electron acceptors. If a molecule is an electron donor or an electron acceptor is an intrinsic property of the compound. [4]

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S.V.D. Prasad, Department of Mechanical Engineering, D.V. R College of Engineering & Tech, Kashipur, Medak, India.

V.Krishnanaik, Department of Electrical and Computer Engineering, Aksum University, Aksum, Ethiopia.

R.K.BABU, Department of Mechanical Engineering, Turbomachinery Institute of Science & Technology, India.

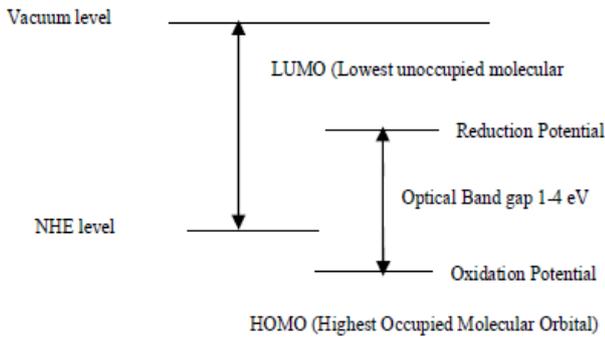


Figure.1: Energy levels in molecular semiconductor.

A. States in molecular materials :

Light absorption in organic materials almost always results in the production of a mobile excited state. This is due to two reasons: first the dielectric constant of the organic material, secondly in molecular materials the non-covalent electronic interaction between the molecules. For these two reasons the wave function of the electron is spatially restricted to the potential well induced by its positive counterpart. Therefore the usual product of light absorption in molecular materials is a tightly bound, neutral electron/hole pair or exciton. To see the effect of a potential well in more detail the binding energy E_b , between two opposite charges in a molecular material is calculated using:

$$E_b = \frac{q^2}{4\pi\epsilon_0\epsilon_r r_c}$$

Where r_c the critical distance between both is charged carriers ϵ_r is the relative dielectric constant and is the permittivity of free space. A charge carrier becomes free from the coulomb attraction of an opposite charge when $E_b \leq k_B T$ which amounts to 25 meV at room temperature. This yields together with:

$$r_c \geq \frac{q^2}{4\pi\epsilon_0\epsilon_r k_B T}$$

However, to obtain a PV effect in an organic solar must be dissociated. Dissociation of the exciton is accomplished by electron transfer between the two compounds. The energy gained by this process should then exceed the exciton binding energy. In this way the photo-generation of free charge carriers is much more efficient as compared to the individual, pure materials, in which the formation of bound electron-hole pairs or excitons is generally favored. [4]

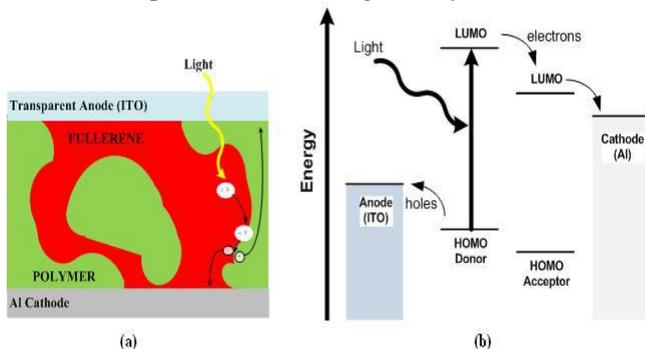


Figure 2: a) Interfacial exciton dissociation in an OPV cell and b) Band Diagram.

III. PRINCIPLE OF OPV CELL

In OPV cells, the photovoltaic process of converting light to electricity is composed of five consecutive steps.

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

A. Absorption of light and generates of exciton :

The first step is light absorption leading to exciton formation. When sunlight is directed onto photosensitive semiconducting organics, electrons in HOMO are excited to LUMO. After light absorption, inorganic semiconductors immediately produce free carriers, while organic semiconductors require additional processes to produce free carriers. First, organic semiconductors form exciton, which are strongly bound electron-hole pairs, which then diffuse inside of the organic semiconductor, which is independent on an applied electric field. [7]

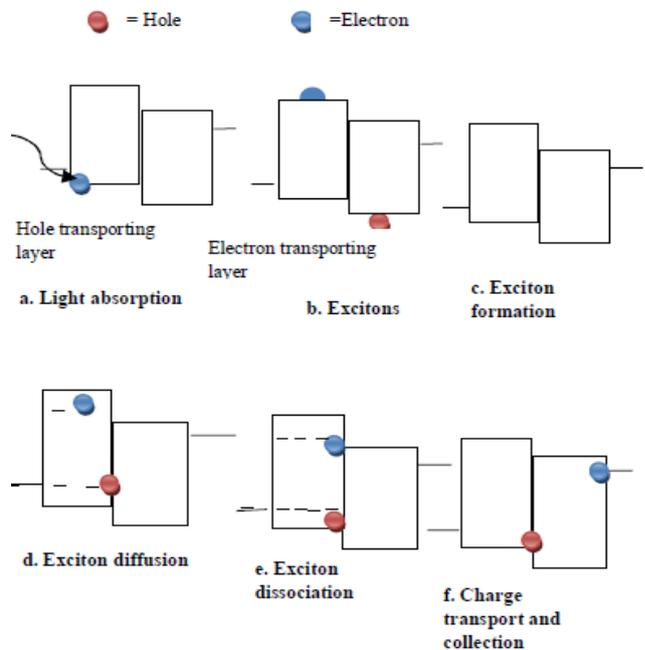


Figure 3: Device working principle from light absorption to charge collection

B. Excitons transport:

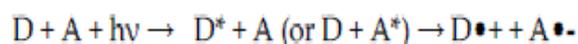
In an efficient OPV cell when excitons formed due to light absorption should lead to the formation of free charge carriers. Then exciton transport is in competition with other decay processes such as luminescence or radiative recombination to the ground state. The exponential lifetime of an exciton (τ_e) is determined by the reciprocal value of all radiative and non radiative decay rates together. For an efficient solar cell all excitons have to reach the photo-active interface within τ_e . Transport of the excitons occurs by diffusion and the distance an exciton is able to cross, L_e , is given by:

$$L_e = \sqrt{D_e \tau_e}$$

In which D_e is the diffusion coefficient of the excitons.

C. Separation of Charge:

Creation of charges is one of the key steps in the conversion of sunlight into electrical energy. In most OPV cells, charges are created by photo induced 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 D/A interface decays by creation of the charge-separated state consisting of the radical cation of the donor ($D^{\bullet+}$) and the radical anion of the acceptor ($A^{\bullet-}$).



For an efficient charge generation, it is essential that the charge-separated state is the thermodynamically and kinetically most favorite pathway for the exciton.

D. Charge transport :

The charge transport mechanisms operating in OPV cells to drive charge carriers towards the electrodes. In OPV cells after the charge transfer the electrons and holes are in close proximity. Therefore there is a large chemical potential gradient that drives the charge carriers away from the exciton dissociating interface.

E. Collection of charge :

The collection of charge carriers at the electrodes is regularly accomplished by a transparent conductive oxide (TCO) such as ITO or $\text{SnO}_2:\text{F}$ on one side and a metal contact on the other side. Charge has to be taken that an Ohmic contact between the electrodes and the molecular layers is formed. In practice special contact layers have been developed to obtain better performance of the solar cell. [4]

IV. PROCESSING TECHNIQUE OF OPV CELL

Mostly organic films for photovoltaic applications are deposited by spin coating, vapor-phase deposition, nanoimprint lithography and vacuum thermal evaporation. However each method has certain draw backs. Spin coating is a simple and precise method that uses centrifugal force to produce a uniform thin film ranging from 20 to 300nm in thickness. Nanoimprint lithography is a novel method to fabricate nanometer scale patterns. It is a simple process with low cost, high throughput, and high resolution. It creates patterns by mechanical deformation of imprint resist and subsequent processes.

Another deposition technique is "Vacuum thermal evaporation" (VTE) which involves the heating of an organic material in vacuum. Thermal evaporation is a method to deposit thin film of metal or small molecule organic semiconductors. [8] Organic thin film grown from "Vapor phase deposition" (VPD) is proven to give better control on the structure and morphology of the film than vacuum thermal evaporation. The process involves evaporation of the organic material over a substrate in the presence of an inert

carrier gas. Resulting film morphology can be changed by changing the gas flow rate and the source temperature. [9]

V. TEMPERATURE EFFECTS ON OPV CELL

For OPV cells as temperature increases the mobility of charge increases. In organic materials, the delocalization process can be assisted by phonons. At low temperature, the probability to find a phonon of sufficient energy to facilitate a hop to the nearest site will be low. As the temperature increases, charge carrier mobility and, therefore, conductivity should also increase. For OPV cells at low temperatures, few charge carriers are thermally generated and are not easily transported, therefore, the current without illumination is low. The open-circuit voltage of OPV cells decreases almost linearly increasing the temperature from 80 to 300 K. Power conversion efficiency increase as the increase of temperature but after 350 K it tends to decreasing. [11]

VI. LIFE TIME & COST OF OPV CELL

Cost has been the main factor inhibiting large scale use of solar energy, an abundant and clean form of energy. A large portion of this cost goes for solar panels that contain photovoltaic cells necessary for converting the sun's energy into a usable form (electricity). OPV cells are made out of light absorbing polymers and do not contain silicon. Because of that, they are cheaper to make. They do not consume as much energy for manufacturing as silicon based solar cells do. Because they do not consume so much energy, manufacturing of OPV cells is also relatively more environment-friendly. [12] Recently, conversion efficiencies of 8.3% have been achieved in research efforts. With the use of nanotechnology, the efficiency is expected to improve further, to a level where it can compete with that of silicon based cells. OPV cells have certain disadvantages including their low efficiency and short lifetime. This breakthrough paves the way to commercial OPV cells with an operational lifetime of 5 years. [13]

VII. FUTURE DEVELOPMENT OF OPV CELL

OPV cells are cheaper to produce, light weight and flexible but they offer much lower efficiencies than IPV cells. This makes them suitable for a wider range of applications than rigid solar cells, including clothing and bags. Recently Konarka has been producing its OPV cells under the name of Power Plastic for a number of years now and the National Energy Renewable Laboratory (NREL) has just announced that Konarka's latest OPV solar cells have demonstrated a record breaking 8.3 % efficiency. [10] Of course any practical application of OPV cells requires that the cells are stable during the operation. Similar to the polymer light-emitting diodes, the present-day OPV cells must be protected from ambient air to prevent degradation of the active layer and electrode materials by the effects of water and oxygen. Even with proper protection there are several degradation processes that need to be eliminated to ensure stability. Apart from device integrity, the materials must be photo chemically stable and the nano

scale uniformity of donor-acceptor blend in the active layer should be preserved.

New combinations of materials that are being developed in various laboratories focus on improving the three parameters that determine the energy conversion efficiency of a solar cell, i.e. the open-circuit voltage (Voc), the short-circuit current (Jsc), and the fill factor (FF) that represents the curvature of the current density-voltage characteristic. For ohmic contacts the open-circuit voltage of OPV cells is governed by the energy levels of the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) of donor and acceptor, respectively. In most polymer/fullerene solar cells, the positioning of these band levels of donor and acceptor is such that up to 0.4 to 0.8 eV is lost in the electron transfer reaction. By more careful positioning of these levels, it is possible to raise the open-circuit voltage well above 1V. The trade-off of increasing the donor-HOMO to acceptor- LUMO energy is that eventually a situation will be reached in which the photo induced electron transfer is held back by a loss of energy gain. [14]

One of the important parameters for increasing the photocurrent is the absorption of more photons. This may be achieved by increasing the layer thickness and by shifting the absorption spectrum of the active layer to longer wavelengths. Although the first improvement may seem trivial at first sight, an increase of the layer thickness is presently limited by the charge carrier mobility and lifetime. When the mobility is too low or the layer too thick, the transit time of photo generated charges in the device becomes longer than the lifetime, resulting in charge recombination. The use of polymers such as P3HT that are known to have high charge carrier mobilities allows an increase in film thickness from the usual ~100nm to well above 500 nm, without a loss of current. The absorption of the active layer in state-of-the-art devices currently spans the wavelength range from the UV up to about ~ 650 nm. In this wavelength range the monochromatic external quantum efficiency can be as high as 70% under short-circuit conditions, implying that the vast majority of absorbed photons contribute to the current. The intensity of the solar spectrum, however, maximizes at 700 nm and extends into the near infrared. Hence, a gain in efficiency can be expected when using low-band gap polymers.

VIII. CONCLUSIONS

The analysis in this paper leads to a surprising conclusion regarding the life time and efficiency of OPV cells. In this review work we see that the photo- generation of a free electron and hole in OPV cells are simultaneous, with and identical process. OPV cells may perform potentially better at higher temperature because of the mobility of charge increases as cells temperature increases. A simple derivation of the limit of efficiency for OPV shows that while the band gap discontinuity between donor/acceptor materials is essential for exciton dissociation. The organic semiconductor has narrow electronic bandwidth because a single organic material can be potentially photoactive only in a narrow optical- wavelength range of the solar spectrum. Despite the limits of structure and transport discussed in this article, the low-cost of solution processed polymers and the impressive

increase in efficiency over the last decade suggests bright prospects of OPV in applications like building integrated PV where its low-cost, unique fill-factor, reduced weight, semi-transparency, 'excellent appeal' may not be matched by more traditional PV technologies.

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AUTHOR PROFILE



Sri. S.V.D PRASAD, pursuing Ph.D., currently working as Assoc. Professor, in the Department of Mechanical Engineering, D.V.R College of Engineering & Tech, Kashipur, Medhak, India. He studied B.Tech from Bangalore University, and M.Tech from J.N.T.U, Hyderabad, A.P, India. He is having 28+ years of work experience in Academics, Teaching, and Industry & Research. He participated and presented research papers in both national and international conferences, seminars and workshops.



Sri.V. KRISHNANAIAK, pursuing Ph.D., currently working as Asst. Professor, in the Department of Electrical & Computer Engineering, College of Engineering & Tech, Aksum University, Axum, Ethiopia and North East Africa. He studied B.E (ECE) from C.B.I.T, Osmania University, Hyderabad and M.Tech (Systems & Signal Processing) from J.N.U.C, J.N.T.U, Hyderabad, A.P, India. He is having 12+ years of work experience in Academics, Teaching, and Industry & Research. He participated and presented research papers in both national and international conferences, seminars and workshops; also published 7 research papers in national and international peer reviewed journals.