OPV cells as a Promising Future Prospect: a review

Vikas S Pathak, Aruna.Dani

Deptt of Applied Physics, Priyadarshini College Of Engineering, India

ABSTRACT: *The predicted exhaustion of fossil energy resources and the pressure of environmental constraints are stimulating an intensification of research on renewable energy sources in general, and on the photovoltaic conversion of solar energy, in particular. In this context, organic solar cells are attracting increasing interest which is motivated by the possibility of fabricating large-area, lightweight, and flexible devices using simple techniques having low environmental impact. Unfortunately Organic Photovoltaic, OPV cells have significantly low efficiency as compared to inorganic-based devices, highlighting its weakness at present. Hence to compete with inorganic solar cells the efficiency of organic solar cells has to be improved by a factor of 2-3 In this paper an attempt has been made to review the possibility of photo voltaic (PV) electricity as one of the best options for future energy requirements of the world.OPV cells have promising prospects as renewable energy due to their low cost, light weight, and mechanical flexibility. This paper describes some of the different approaches towards understanding and improving organic photovoltaic devices.*
KEYWORDS: *Constraints, OPV, Photovoltaic, Photovoltaic conversion.*

1. 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. 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. These cells have been studied since late 1950s albeit at a fairly low level until recently. One of the great promises of organic electronics is that synthetic chemists can produce compounds matching the opto-electronic properties desired. 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. [1] 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 and 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.

2. Molecular materials

Organic molecules and polymers have the immense advantage of facile, chemical tailoring to alter their properties, such as the optical band gap. For example conjugated polymers (see Figure 1) combine the electronic properties known from the traditional semiconductors with the ease of processing and mechanical flexibility of plastics. The research on these kinds of organic materials was initiated by Heeger, MacDiarmid and Shirakawa, who discovered that the conductivity of polyacetylene (PA) could be increased by seven orders of magnitude. Since then, this new class of materials has attracted considerable attention owing to its potential of providing environmentally safe, flexible, lightweight, and inexpensive electronics.
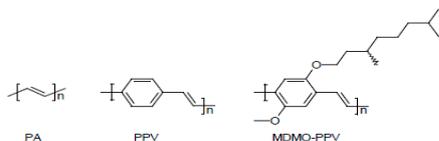

fig1. Molecular structures of the conjugated polymers trans-polyacetylene (PA), poly(pphenylene vinylene) (PPV), and a substituted PPV (MDMO-PPV).

The cost reduction mainly results from the ease of processing from solution. However, solution processing requires soluble polymers. Poly [p-phenylene vinylene] (PPV, Figure 1) is hardly soluble. Attachment of side-

groups to the conjugated backbone, as in poly[2-methoxy-5-(3′,7′-dimethyloctyloxy)-1,4-phenylene vinylene] (MDMO-PPV, Figure 1), enhances the solubility of the polymer enormously. Recent developments in ink-jet printing, micro-contact printing, and other soft lithography techniques have further improved the potential of conjugated polymers for lowcost fabrication of large-area integrated devices on both rigid and flexible substrates. Examples of use of such kind of polymers in commercial products are the light emitting diodes. Architectures to overcome possible electronic scale-up problems related to thin film organics are being developed. In contrast to conjugated polymers, conjugated molecules are mainly thermally evaporated under high vacuum. However this method is more expensive than solution processing and, therefore, less attractive. The energy levels in molecular materials can be related to the energy levels of inorganic semiconductors (see Figure2). In molecular materials also electrons can be liberated from the so-called highest occupied molecular orbital (HOMO) to the vacuum. The energy involved can roughly be estimated on basis of the electrochemical oxidation potential (*vs.* NHE) of the molecules using the relation: EHOMO ≈ ENHE - Vox, with ENHE = -4.5 V *vs.* vac. In a similar way the electron affinity can be estimated from the reduction potential of the molecules using: ELUMO ≈ ENHE – Vred. The difference between both energy levels corresponds to the optical bandgap of the molecules. 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.
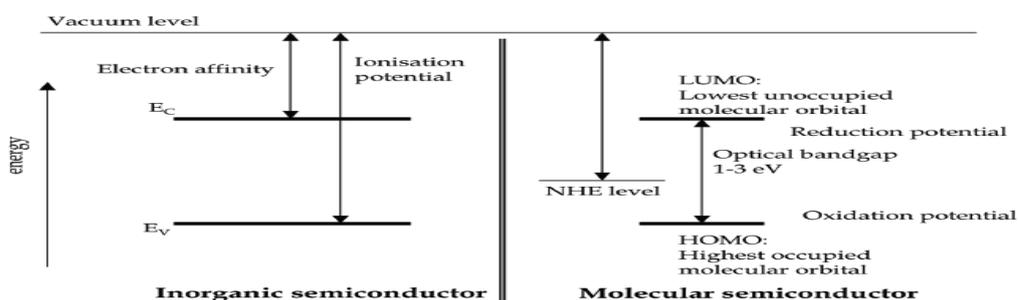

fig2. Overview of energy levels in inorganic semiconductors (left) and molecular semiconductors (right).

Molecular materials that have a low ionisation 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.

3. WORKING PRINCIPLE OF OPV CELL

In OPV cells, the photovoltaic process of converting light to electricity is composed of five consecutive steps.
3.1. Absorption of light and generation of excitons **3.2**. Diffusion of excitons to an active interface
3.3. Charge separation **3.4**. Charge transport **3.5**. Charge collection

3.1 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. [2]
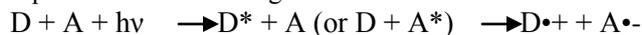
3.2 Excitons transport
In an efficient OPV cell when excitons formed due to light absorption should lead to the formation of free charge carriers. Then exciton transport is in competition with other decay processes such as luminescence or radiative recombination to the ground state. The exponential lifetime of an exciton (гe) 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 гe. Transport of the excitons occurs by diffusion and the distance an exciton is able to cross, Le, is given by: $Le = [\ De\ гe\ ]^{1/2}$ In which De is the diffusion coefficient of the excitons.

3.3 Charge separation
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 hν. 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•+) and the radical anion of the acceptor (A•-).

$$D + A + h\nu \longrightarrow D^* + A \text{ (or } D + A^*) \longrightarrow D\bullet+ + A\bullet-$$

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

3.4 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.

3.5 Charge collection

The collection of charge carriers at the electrodes is regularly accomplished by a transparent conductive oxide (TCO) such as ITO or SnO_2: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. [3]

4. Advantages of Flexible Organic Compared to Rigid Conventional Solar Cells

a) Manufacturing process: Organic solar cells can be easily manufactured compared to Si based cells, and this is due to their molecular nature of the materials used. Molecules are easy to work with and can be used with thin films substrates that are 1,000 times thinner than Si cells (in the order of few hundred nanometers). This fact by itself can reduce the cost production significantly compared to conventional semiconductive cells and can reduce cost by a factor of 10 or 20.

b) Tailoring molecular properties: An important advantage of organic materials used in solar cell manufacturing is the ability to tailor it molecular properties in order to fit the application. Molecular engineering can change the molecular mass, bandgap, and the ability to generate charges by modifying the length and functional group of the polymers. Moreover, new unique formulations can be developed with the combination of organic and inorganic molecules, making possible to print the organic solar cells in any desired pattern or color.

c) Desirable properties: The tailoring of molecular properties and the versatility of production methods described earlier enable organic polymer solar cells to present series of desirable properties. These solar modules are amazingly lighter and more flexible compared to their heavy and rigid counter parts, and thus less prone to damage and failure. They can exist in various portable forms like rolled forms etc and their flexibility makes storage, installation, transport much easier.

d) Environmental impact: The energy consumed to manufacture organic solar cells is less compared to that of manufacturing conventional inorganic solar cells. Consequently, the energy efficiency doesn't have to be as high as that of conventional solar cell's efficiency. An extensive use of organic solar cells could contribute to increased use of solar power globally and make renewable energy sources friendlier to the average customer.

e) Multiple uses and applications: The present situation indicates that organic solar cells cannot substitute conventional solar cells in energy conversion field. However, their use seems to be more targeted towards specific applications such as recharging surfaces for laptops, phones, clothes, and packages, or to supply power for small portable devices, such as cell phones and MP3 players. Research in US (Konarka) has shown that organic cells could be used in soldier tents to generate electricity and supply power to other military equipment such as night vision scopes, and GPS (Global Positioning System) receivers. Beside all the already mentioned advantages, such as lower impact on nature, less weight, and more flexible, a huge merit of OPVCs is that they produce also a significant amount of electricity in diffused light so that they can extrapolate a much larger scope than conventional solar cells.

5. Disadvantages

Until now the efficiency of OPVCs is lower than those of conventional solar cells (Table 1) but once this factor increases above that of the conventional OPVCs they may replace inorganic solar cells due to the price and efficiency.

Table 1: Efficiency and cost of solar cells (11) (12) (7) the costs per kWp are averaged over the found data.

Type	Subtype	Efficiency (in production/laboratory)	Costs per kWp
silicon	monocrystalline (6)	15-20% (p)	3.000 €
	polycrystalline (7)	13-18% (p)	2.000 €
	amorphous	Ca. 8% (p)	
thin (8)	Copper Indium Gallium Selenide	11% (p)	1.000 €
	Cadmium telluride (9)	10% (p)	3.250 €
	Gallium arsenide (10)	30%(p)	50.000 €
Organic (11) (12) (13) (14)	Small molecule	4-8% (l)	
	Polymer solar cells	4-10% (p)	
	dye-sensitized	11% (l)	

6. Research Situation

In solar cells based on inorganic semiconductors such as silicon, the absorbed photons lead to the direct creation of free charge carriers. In contrast, in organic semiconductors based on π-conjugated systems because of the low dielectric constant of these materials, light absorption leads to the creation of excitons, strongly Coulombically bound electron-hole pairs. These excitons must then be dissociated by an electric field of sufficient intensity. In organic heterojunctions formed by contacting a donor and an acceptor material, the driving force for exciton dissociation is provided by the energy offset between the molecular orbitals of the donor and acceptor. Exciton dissociation into free charge carriers thus represents a key process that imposes one of the major limitations to the power conversion efficiency of organic solar cells. An efficient way to bypass this obstacle consists of the realization of interpenetrated networks of the donor and acceptor materials. In such a bulk heterojunction (BHJ), the huge extension of the donor/acceptor contacting area between the donor and acceptor materials leads to a considerable increase of the number of excitons dissociated and hence of the conversion efficiency of the cell.[4]. However, a key issue concerns the realization of appropriate phase segregation in order to create domains of donor and acceptor material of optimal dimensions consistent with the exciton diffusion length while ensuring the continuity of the transport of holes and electrons in their respective phase. In 1992, Sariciftci et al. Demonstrated that photoexcitation of a mixture of a poly-(p-phenylene vinylene) derivative and C60 fullerene resulted in an ultrafast highly efficient photoinduced electron transfer.[5] Furthermore, the long lifetime of the metastable charge-separated state associated with the delocalization of the positive and negative charges over the π-conjugated system and the fullerene group respectively allow both efficient charge transport and charge collection at the electrodes. Fullerenes and in particular soluble C60 derivatives such as [6,6]-phenyl-C61-butyric acid methyl ester (PCBM) have been a key component for the development of BHJ solar cells.[6] Besides a LUMO level allowing efficient photoinduced charge transfer from the donor, the spherical geometry of C60 leads to isotropic electron transport through a 3D percolation system, which seems particularly appropriate for charge transport in disordered media. Since the first reports on solution-processed BHJ solar cells, soluble π-conjugated polymers have represented the exclusive class of donor materials owing to their interesting combination of optical, electrical, and mechanical properties and to their availability in sufficient quantities. The first prototypes of BHJ cells were based on polymers of the PPV series initially developed for light emitting devices. In recent years, these polymers have been supplanted by regioregular poly(3-hexylthiophene) P3HT, which presents the advantages of a lower band gap and higher hole mobility.[7-9] Within a relatively short period P3HT has become the archetype donor for BHJ cells and power conversion efficiencies of ≈5% have been recently reported by several groups.[7-9] Despite these remarkable results, P3HT poses a number of problems related to its synthesis, purification, and intrinsic electronic properties. The initial synthesis of regioregular P3HT involved rather complex procedures under cryogenic conditions.[10] While the Grignard metathesis method has greatly simplified the process, both methods lead to polymers with remnant terminal bromine atoms, which must be eliminated by appropriate chemical treatment.[11] The regioregularity, molecular weight, and polydispersity of P3HT have been shown to significantly affect the performances of BHJ solar cells.[12] Owing to a band gap of around 1.90 eV and a rather narrow absorption band (fwhm ≈ 150 nm), P3HT can absorb only a limited fraction of the solar photons (≈30%). Furthermore, a relatively high-lying HOMO level sets the maximum cell voltage to 0.60-0.65 V and represents a potential cause of instability in atmospheric conditions. Finally, the achievement of conversion efficiencies of 4-5% requires application of a post process thermal treatment to the PCBM-P3HT composite material in order to improve the morphology of the bicontinuous phase and the crystallinity of P3HT.[13] Because of their one-dimensionality, linearly π-conjugated systems such as poly(3-alkylthiophenes) present an anisotropic charge transport that is maximal in the stacking direction of the conjugated chains in the microcrystalline domains . Although this anisotropy is randomized by a large number of micro domains, it is not certain that one-dimensional π-conjugated systems represent the best molecular architecture to ensure 3D hole transport in BHJ cells. A possible solution to these problems could consist in the replacement of π-conjugated polymers by soluble small conjugated molecules as donor material. Such an approach would present several potential advantages:

• A perfectly defined chemical structure erases the problems posed by the structural variability of polymers, namely, the control of the regioregularity, molecular weight, and polydispersity, as well as the elimination of remnant bromide groups.

• Materials derived from molecular elemental units show in general higher charge-carrier mobilities than polymers.

• The analysis of the relationships between chemical structure, electronic properties, and device performances is more straightforward than that for polymers for which structural modifications can indirectly affect the electronic properties through changes in molecular weight, polydispersity, and effective conjugation length.

• The high molecular extinction coefficients of many molecular dyes permits limiting the thickness of the active layer, thus minimizing problems associated with charge transport and series resistance.

Conceptually similar to the bulk heterojunction, there is a wide research field of dye sensitized, electrochemical solar cells. The early steps in the development [14–19] were largely improved by the Graetzel group. However, in recent years, by the introduction of organic hole conductors as replacement for the liquid electrolytes in electrochemical solar cells and by the exchange of the electron conducting acceptor materials in organic heterojunction devices with inorganic nanocrystals, electrochemical and organic photovoltaic research directions are gradually merging together. For practical application, not only the power conversion efficiency but also the lifetime of the photovoltaic device is of importance. The stability of organic solar cells is mainly affected by photodegradation of the active materials. However, encapsulation techniques as applied in organic light-emitting diodes (LEDs) can provide an efficient sealing against oxidizing agents, but still a high intrinsic photostability of the organic materials is required.

7. Conclusion

As the demand for electrical power increases, producers and consumers will continue to look for alternative sources. One such source of renewable energy is, of course, the sun and researchers have been working for decades to develop devices that efficiently capture solar energy. Solar cells made from inorganic semiconductors have successfully reached the marketplace, but those made from organic materials still need to make the leap out of the lab. As materials scientists develop a better understanding of the structure-property relationships of organic photovoltaic devices, the efficiencies of organic solar cells will improve and new device architectures will emerge. As a concluding remark of this brief review concerning organic solar cell, we like to stress the fact that this field of research is just at the beginning. Efforts need to be done in order to get bulk-ordered separated structures of p and n organic semiconductors in order to improve contemporaneously both the charge separation processes and the transport of the free charge to the electrodes.

References

[1] Pulfry L.D., Photovoltaic Power Generation,(New York : VanNostrand Reinhold Co., 1978).

[2] Lungenschmied, C.; Dennler, G.; Neugebauer, H.; Sariciftci, S.N.; Glatthaar, M.; Meyer, T.; Meyer, A. Flexible, long-lived, large-area, organic solar cells. Sol. Energy Mater. *Sol. Cells 2007, 91, 379-384.*

[3] Tom J. Savinije, DelftChemTech, Organic solar cells, Faculty of Applied Sciences Delft University of Technology

[4] Brabec, C. J.; Sariciftci, N. S.; Hummelen, J. C. Plastic solar cells. *Adv. Funct. Mater. 2001, 11, 15–26.*

[5] Sariciftci, N. S.; Smilowitz, L.; Heeger, A. J. Photoinduced electron-transfer from a conducting polymer to buckminsterfullerene. *Science 1992, 258, 1474–1476.*

[6] Hummelen, J. C.; Knight, B. W.; Lepec, F.; Wudl, F.; Yao, J.; Wilkins, C. L. Preparation and characterization of fulleroid and methanofullerene derivatives. J. *Org. Chem. 1995, 60, 532–538.*

[7] Li, G.; Shrotriya, V.; Huang, J.; Yao, Y.; Moriarty, T.; Emery, K.; Yang, Y. Highefficiency solution processable polymer photovoltaic cells by self-organization of polymer blends. *Nat. Mater. 2005, 4, 864–868.*

[8] Ma, W.; Yang, C.; Gong, X.; Lee, K.; Heeger, A. J. Thermally Stable efficient polymer solar cells with nanoscale control of the interpenetrating network morphology. *Adv. Funct. Mater. 2005, 15, 1617–1622.*

[9] Reyes-Reyes, M.; Kim, K.; Carroll, D. L. High-efficiency photovoltaic devices based on annealed poly(3-hexylthiophene) and 1-(3-methoxycarbonyl)-propyl-1-pheny- (6,6)C61 blends. *Appl. Phys. Lett. 2005, 87, 083506.*

[10] McCullough, R. D.; Lowe, R. D.; Jamarayan, M.; Andersson, D. L. Design, synthesis and control of conducting polymer architectures: structurally homogeneous poly(3- alkylthiophenes). J. *Org. Chem. 1993, 58, 904–912.*

[11] Jeffries, M. ; R.McCullough, R. D. In Handbook of Conducting Polymers, 3rd ed.; Skotheim, T. A., Reynolds, J. R., Eds.; CRC Press: Boca Raton, FL, 2007.

[12] Thompson, B. C.; Fré´ chet, J. M. Polymer-fullerene composite solar cells. Angew. *Chem., Int. Ed. 2008, 47, 58–77.*

[13] Padinger, F.; Ritterberger, R. S.; Sariciftci, N. S. Effects of post-production treatment on plastic solar cells. *Adv. Funct. Mater. 2003, 13, 85–88.*

[14] H. Tributsch and M. Calvin: Electrochemistry of excited molecules. Photoelectrochemical reactions of chlorophylls.*Photo-chem. Photobiol.14,95 (1971).*

[15] H. Tributsch: Reaction of excited chlorophyll molecules at electrodes and in photosynthesis. *Photochem. Photobiol.16,261(1972).*

[16] T. Osa and M. Fujihira: Photocell using covalently-bound dyes on semiconductor surfaces. *Nature 264,349 (1976).*

[17] M. Fujihira, N. Ohishi, and T. Osa: Photocell using covalently- bound dyes on semiconductor surfaces. *Nature 268, 226 (1977).*

[18] H. Tsubomura, M. Matsumura, K. Nakatani, K. Yamamoto, and K. Maeda:'Wet-type'solar cells with semiconductor electrodes. *Sol. Energy 21, 93 (1978).*

[19] M. Matsumura, S. Matsudaira, H. Tsubomura, M. Takata, and H. Yanagida: Sintered ZnO electrode for dye-sensitized photo- cell. Yogyo Kyokai Shi *87, 167 (1979).*