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Organic Solar Technique using P3HT and PCBM as Promising Materials

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ABSTRACT

The Solar cells have the ability to meet some of these power demands by directly converting sunlight into electricity and can potentially generate power anywhere there is light. Organic solar cells represent of organic semiconductors have attracted considerable attention in the areas of electronics and photonics during the last decade. The conversion of sunlight to electricity by organic solar cells is very interesting and promising since organic solar cells offer the possibility of fabricating large area, flexible, light-weight, cost-effective devices using simple and environmental friendly techniques. Compared with inorganic solar cell, organic photovoltaic cell are less in cost, considering that organic solar cells can be fabricated onto the substrate by high-throughput, low cost fabrication methods. As a clean renewable energy source organic solar cells are rapidly developing. Power conversion efficiency over 7–8% was reported recently. On the other hand, there is a considerable progress in the evolution of organic solar cells from pure scientific research to a possible industrial application. Recent efforts are devoted to the investigation of operating mechanisms, new synthesis routes, new device architectures, stability of the organic materials, lifetime, encapsulation, etc.

Keywords - **P3HT, PCBM, organic photovoltaic, organic material**

1. INTRODUCTION

Many solar technologies exist with varying degrees of development, and organic solar cells are one of the newer classes of these technologies. Current production is highly dominated by crystalline silicon (Si) modules, which represent 94% of the market. Maximum theoretical power conversion efficiency (PCE) of almost 31% under direct air mass (AM) 1.5 sunlight is expected for silicon-based devices. An organic solar cell consists of an organic layer which realizes the basic steps in photovoltaic (PV) conversion such as light absorption, charge carrier generation, charge carrier transport and extraction or injection of charge carriers through the contacts. Two main approaches have been considered in the research of organic solar cell (OPV): bulk hetero-junction, which is represented in an ideal case as a bi-continuous composite of acceptor and donor phases and donor– acceptor bi-layers achieved by vacuum deposition of organic molecules. In polymer-based BHJ solar cells, which are achieved by blending a polymer donor and acceptor, the most common donor polymers are poly[2-methoxy-5-(3,7-dimethyloctyloxy)-1,4-phenylene vinylene] (MDMO-PPV), regioregular poly(3-hexylthiophene) (RR-P3HT, and poly [2-methoxy-5-(2'-ethylhexyoxy)-1,4-phenylene vinylene] (MEH-PPV). The most widely used acceptor material of choice has been [6, 6]-phenyl C61-butyric acid methyl ester (PCBM). . Several small organic materials, such as zinc pthalocyanine (ZnPc) and copper pthalocyanine, have also been used as donors in bilayer heterojunction solar cells. Optimized organic devices have PCE of 5–8%.Although there has been important improvement in organic solar cell PCEs, they still have not reached that of conventional solar cell. In order to compete with the conventional inorganic cells, a PCE of more than 10% is desirable. Various approaches to organic solar cell designs have been employed such as combination of inorganic and organic (hybrids) as active layer materials, tandem cells and also, various techniques have been applied to improve the performance of organic solar cells such as low band gap polymers, polymer–polymer blends new device structures etc. The efficiencies can be advance improved by tailoring the materials and also engineering of the device structures. However, one should note that stability and life times are also important issues.

In this paper, an overview of basic operation principles, organic solar cell materials, and possible routes for performance improvement of organic solar cells will be overviewed.

2. FUNDAMENTAL OF OPV

2.1 OPV MATERIALS

Research on organic solar cells concentrates on two types of materials, one is solution processed such as semiconducting polymers/molecules, and the other is vacuum processed, such as small organic molecules. New generation of polymers: materials that exhibit the optical and electrical properties of

metals or semiconductors and hold the attractive mechanical properties and processing advantages of polymers. Saturated polymers in which all of the four valence electrons are used in covalent bonds

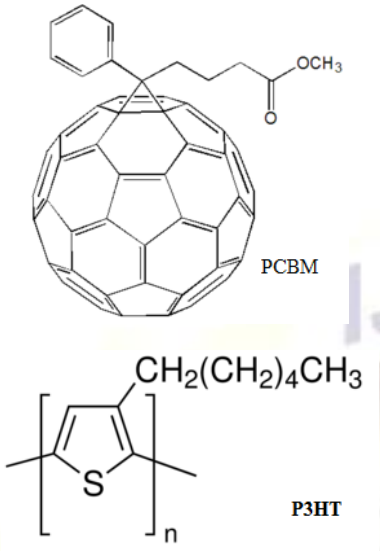

Fig. 1 PCBM as an accepter and P3HT as a donor used in organic solar cell

are not very interesting as electronic materials since they are insulators. And chemical bonding in conjugated polymers leads to one unpaired electron (π electron) per carbon atom and π bonding leads to electron delocalization along the back bone of the polymer which provides the high way for charge mobility along the backbone of the polymer chain. As a result, such polymers can exhibit semiconducting or even metallic properties. Materials that have an extended delocalized π electron system can absorb sunlight and create photo-generated charge carriers and also transport these charge carriers, which makes them interesting as optoelectronic materials. Conjugated polymers have become the materials of choice not only for solar cells but also for various optoelectronic applications, such as organic light emitting diodes (OLEDs) and organic field effect transistors (OFETs). Organic materials for use in PV devices require a good chemical stability and high optical absorption in the visible range with respect to the AM1.5G spectrum. Efficiencies of the first hole conducting polymers based on conjugated polymers were less than satisfactory High performance organic solar cells use polymer-fullerene blends in which the polymer acts as a donor whereas the fullerene acts as an acceptor. The Buckminsterfullerene, C60, is a strong acceptor. A soluble derivative of C60, namely PCBM (1-(3-methoxycar-bonyl) propyl-1-phenyl [6,6] C61), which has been widely used in polymer/fullerene solar cells. Most semiconducting polymers are hole conductors (electron donors). Important representatives of hole conducting donor-type semiconducting polymers are derivatives of phenylene vinylene backbones such as poly[2-methoxy-5-(3,7- dimethyloctyloxy)]-1,4-phenylenevinylene) (MDMO-PPV), thiophene chains such as poly(3-hexylthiophene) (P3HT) and fluorene backbones such as (poly(9,90-dioctylfluorene-co-bis-N,N0-(4-butylphenyl-1,4 phenylenediamine) (PFB) and PCDTBT. Light harvesting by PCDTBT is better than that of P3HT due to its smaller band gap. Phthalocyanine and perylene have commonly found applications in thin-film organic solar cells. Phthalocyanine is a reprensentative of the p-type, hole conducting materials that work as electron donors, whereas perylene and its derivatives show n-type, electron conducting behavior, and serve as the electron acceptor materials.

2.2 Operation Principles

There are four important steps for the conversion of solar illumination into photocurrent in organic solar cells: (i) absorption of a photon to create an exciton, (ii) diffusion of the exciton to a donor–acceptor interface, (iii) charge transfer of an exciton into an electron in the acceptor and a hole in the donor, and (iv) collection of the charges at the electrodes. The efficiency of exciton diffusion in organic solar cells is determined by the exciton diffusion length and the morphology of the donor–acceptor interface. Once excitons are created they can diffuse over a length of approximately 5–15 nm. Then they decay either radiatively or non-radiatively. Excitons must be separated into free charge carriers within their lifetime for PV purposes. In Figure 2, a single layer cell with ITO and Al electrodes is shown. Figure 2a shows the short-circuit conditions. The current delivered by a solar cell under zero bias is called the short-circuit current (Isc). In the MIM picture, the built-in potential is equal to the difference in the work functions of the metal electrodes. Exciton dissociation and charge transport are driven by the built-in potential. Figure 2b shows the open-circuit case. The voltage where the current equals to zero is called open-circuit voltage (Voc). Voc is equal to the difference between the metals work functions and balances the built-in potential. Thus, the current is zero since there is no net driving force acting on the charge carriers. Figure 2c shows the negative bias case. The diode works as a photo-detector. Under illumination, the charge carriers drift to the appropriate electrodes. Figure 2d shows the forward bias case. In the case of an applied forward bias larger than Voc the contacts start injecting charges into the semiconductor. If these charges recombine radiatively, the diode works as a LED.

2.3 Device Architecture

As substrates, transparent and conducting electrodes (for example, glass or plastic covered with indium-tin-oxide (ITO)) are used. As a transparent conductive electrode ITO allows light to pass through the cell. However, ITO is not the ideal conductive material due to the following problems: release of oxygen and tin into the organic layer, poor transparency in the blue region and complete crystallization of ITO films, which requires high-temperature processing.

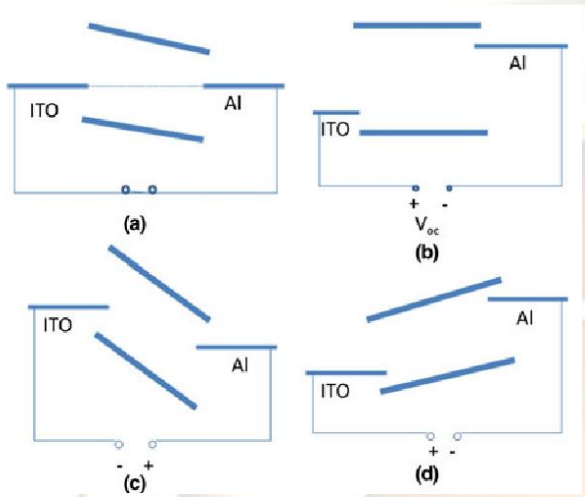

Fig. 2 metal insulator metal (MIM) models of an organic diode: (a) short circuit, (b) open circuit, (c) reversed bias, and (d) forward bias

Also, the increasing cost of indium prevents large-scale use of ITO in low-cost PV devices. Therefore, an alternative for ITO electrode such as carbon nanotube network electrodes is being investigated. Alternatives for ITO electrode such as carbon nanotube network electrodes are being investigated. The substrate electrode can be structured by etching. On the transparent conducting substrate, PEDOT: PSS, poly (ethylene-dioxythiophene) doped with poly- styrene-sulphonic acid is commonly coated from an aqueous solution. This PEDOT:PSS layer improves the surface quality of the ITO electrode i.e. reducing the probability of shorts and facilitates hole injection/extraction. Furthermore, the work function of this electrode can be changed by chemical/electrochemical manipulation of the PEDOT layer. PEDOT: PSS is the most promising organic-based electrode material and currently, various modification of PEDOT:PSS with even greater conductivities are being investigated as electrodes for organic devices. As already mentioned, there are two major classes of organic semiconductors: low molecular weight materials and polymers. They have in common a conjugated π electron system formed by the p_z orbital of sp^2 hybridized C atoms in the molecules. Spin coating, doctor blading, screen printing, and ink jet printing are the most common wet processing techniques. Most widely used device forms in organic solar cells are summarized below.

2.3.1 Single Layer Organic Solar Cells

The first organic solar cells were based on single layers sandwiched between two metal electrodes of different work functions. One of the electrodes must be (semi-) transparent, generally ITO, but a thin metal layer can also be used. The other electrode is generally aluminium (calcium, magnesium, gold and others are also used). Photo excitations in an organic semiconductor lead to formation of bound electron–hole pairs (excitons). Excitons created in an organic semiconductor must dissociate into free charge carriers according to the PV requirements. The only way to break apart the excitons in the devices consisting of pristine polymers is to use an electric field. In a single-layer device, since only a small region contributes to the photocurrent generation, the efficiency of such devices is rather low

2.3.2 Bilayer Heterojunction Organic Solar Cells

The major problem in single-layer organic solar cells is inefficient charge generation in conjugated polymers. To overcome this limitation, the donor/acceptor approach has been suggested. A bilayer device is prepared by stacking a donor and an acceptor material.

2.3.3 Bulk Heterojunction Organic Solar Cells

In a bulk heterojunction organic solar cell, donor and acceptor components are mixed to form an interpenetrating network at the nanometer scale Figure.5. The bulk heterojunction concept maximizes the donor–acceptor contact area. The bulk heterojunction is presently the most widely used photoactive layer. One of the most promising combinations of materials is a blend of a semiconducting polymer and a fullerene derivative as the acceptor. P3HT has been another choice of material as a donor in bulk heterojunction cells. The high charge carrier mobility and lower band gap compared to MDMO- PPV make this material advantageous over MDMO-PPV. P3HT/PCBM blends provided an increased PV performance as compared to MDMO-PPV/PCBM solar cells. Recently, 5% efficiency has been achieved using P3HT as the donor and PCBM as the acceptor. By introducing a TiOx layer as the optical spacer they were able to achieve polymer solar cells with PCE approximately 50% higher than similar devices fabricated without an optical spacer.

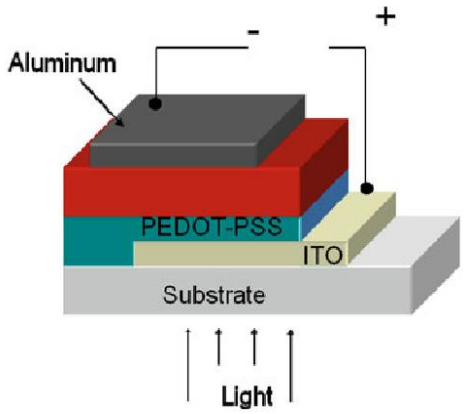

Fig. 5 Bulk heterojunction configuration of organic solar cells

2.4 Current–Voltage Characteristics of an Organic Solar Cell

The characteristic parameters of an organic solar cell can be deduced from current–voltage (I–V) curves. I–V characteristics of a solar cell in the dark and under illumination are shown in Fig. 6. In the dark there is almost no current flow until the start to inject at forward bias. When a cell is illuminated, the I–V curve is shifted down by the short-circuit current (Isc). The maximum current that can run through the cell is determined by the Isc. Voc is related to the energetic relation between the donor and the acceptor. The energy difference between the highest occupied molecular orbital (HOMO) of the donor and the lowest unoccupied molecular orbital (LUMO) of the acceptor is closely correlated with the Voc value. The solar cell operates in the fourth quadrant. At the maximum power point (MPP), the product of current and voltage is the largest. The largest power output (Pmax) is determined by the point where the product of voltage and current is maximized. Division of Pmax by the product of Isc and Voc yields the fill factor (FF). The photovoltaic PCE of a solar cell is determined by the following formula:

$$\eta_e = \frac{V_{oc} * I_{sc} * FF}{P_{in}}$$

$$FF = \frac{I_{mpp} * V_{mpp}}{I_{sc} * V_{oc}}$$

Where Voc is the open-circuit voltage, Isc is the short-circuit current, FF is the fill factor and Pin is the incident light intensity. The light intensity at 1,000 W/m2 with a spectral intensity distribution matching that of the sun on the earth‘s surface at an incident angle of 48.2°, which is called the AM1.5G spectrum is accepted as standard for solar cell testing. An experimentally accessible value is the external quantum efficiency or incident photon to current efficiency (IPCE). IPCE is defined as the number of photogenerated charge carriers contributing to the photocurrent per incident photon. IPCE is calculated using the following formula:

$$IPCE = \frac{1240 * I_{sc}}{\lambda * P_{in}}$$

Where k (nm) is the incident photon wavelength, Isc (lA/cm2) is the photocurrent of the device and Pin (W/m2) is the incident power.

The performance of PV cells is commonly described in terms of their efficiencies with respect to the standard reporting conditions (SRC) define by the temperature, spectral irradiance, and total irradiance. The SCR for the performance of the PV cells are as follows: 1,000W/m^2 irradiance AM 1.5 global reference spectrums, and 25°C cell temperature. Since Isc also directly affects the efficiency, it is an essential parameter of the solar cells. It was calculated that 240 nm thick P3HT is only capable

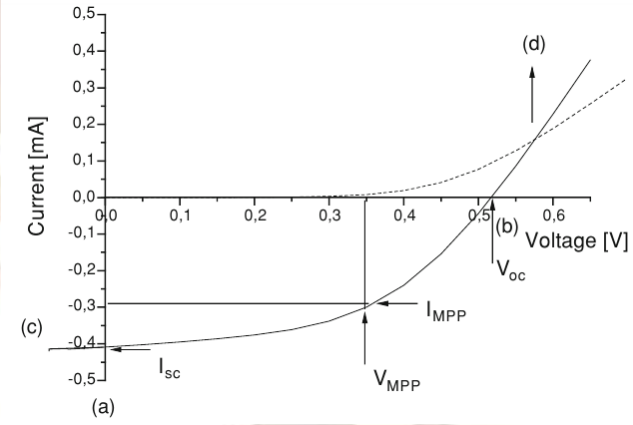

Fig. 6 Current–voltage (I–V) curves of an organic solar cell (dark, dashed; illuminated, full line)

of absorbing 21% of the sun’s photons. The band gap is defined as the difference between the HOMO and LUMO energy levels in polymers, neglecting Coulombic interactions. Low band gap polymers are defined as those having band gaps below approximately 2 eV. An ideal band gap of 1.3–1.6eV for a bulk heterojunction device. The origin of the open-circuit voltage is studied using cells with different electrodes and different donor materials. While changing the electrodes does not affect open-circuit voltage, it is greatly modified by changes in the donor.

3. Conclusion

The electrical properties of P3HT:PCBM bulk heterojunction solar cells are discussed. Recent milestones and improved efficiencies achieved by organic solar cells opened up a possibility for OPV devices to take their place in the market. The biggest advantages of organic-plastic solar cells are their

low cost, flexibility and ability to be wrapped around structures or even applied like paint. Three key parameters will determine the success of organic solar cells: price, efficiency and lifetime. In conclusion, our investigation shows that P3HT:PCBM polymer solar cells could enhance the performance of the devices and more research want to improve performance of solar cell.

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