Organic solar cells - history, principles and efficiency

Solar Cells

Solar cells are cells or devices use for converting sunlight into electric current (electricity) or voltage. They are also called photovoltaic cells (PV) or devices and the process of generating electricity from sunlight is called photoelectric effect. Solar Energy conversion through photovoltaic effect can be achieved with many materials at different lifetimes. Over the years many research and development have been conducted in the area of solar energy (thin film applications)[1]-[3]. But most of these developments have been in inorganic solar cells with conventional silicon base solar cells dominating in the production of solar energy in the commercial market [4]-[5]. Silicon base cells for thin film application have enormous advantages like good absorption rate of sunlight, suitable band gap for photovoltaic applications, longer lifetimes and improving efficiency. But the process of silicon base cells generation of voltage is tedious and above all very expensive for the commercial market. Research for alternatives to silicon has been ongoing for some time now with some other inorganic materials like Copper Indium Gallium Selenium (Cu-In-Ga-Se)[6], Cadmium Sulfide (CdS)[7], Lead Cadmium Sulfide (PbCdS)[8], etc. But some have similar production problems like the silicon and as well expensive. Others also are of dangerous elements which are not environmentally friendly (CdS, PbCdS, etc). Another alternative to silicon base cells in terms of thin film (solar cells) research for photovoltaic application could be organic solar cells (also known as plastic solar cells)[9]. With this, photocurrents are generated from organic materials. In this review, brief history of organic solar cells is discussed, the basic principle of operation is outlined and some performance in terms of the materials absorption rate, efficiency, stability and degradation and comparison between organic solar cells and inorganic solar cells (silicon) are also discussed.

Chapter 2

Organic Solar cells (Plastic Solar cells)

The infancy of organic solar cells began in the late 1950s [10]. At this time, photoconductivity in some organic semiconductor cells (anthracene, chlorophyll) were measured with voltage of 1 V by some research groups[11][12]. They proposed that if a single layer PV cell is illuminated consisting of an organic layer, sandwich cell with low work function metal (aluminum, Al) and a conducting glass of high work function (indium tin oxide, ITO), photoconductivity will be observed. With this interesting result and less cost effective of these organic semiconductor cells and also a possibility of doping these materials to achieve more encouraging results caught up with many researchers in this field. The work done since has been unprecedented as shown in figure 2. 1 on the next page.

In the 1960s, semiconducting properties were observed in dyes particularly in methylene blue [13]. Efficiency of 10^{-5} % in sunlight conversion was reported in the early 1970s to an improvement of 1 % in the early 1980s [14]. This was achieved through an interesting phenomenon known as heterojunction[15]. This phenomenon is a surface between semiconducting materials of dissimilar layers. Photovoltaic devices were applied with heterojunction where donor-acceptor organic cells were tailored together. In recent years, photoconductivity has been measured in dyes and the dye solar cells have progressively been improved for laboratory cells[16]. Currently power conversion efficiency of organic photovoltaics in single-junction devices is over 9 %[17] and that of multi-junction cell is over 12 %[18].

Some materials of organic solar cells are dyes and some polymers like origomers[19], dendrimers[20], liquid crystal materials[21] and self-assembled monolayers [22]. All these need to be prepared carefully to obtain optimum efficiency and stability[23]

Figure 2. 1: Number of publications is plotted against the year of publications. This shows the inception of organic solar cells and how much interest the field has generated among scientists and the commercial entities over the years. Years below 1990 saw less publication (1960 to 1970 -10 and 1980 to 1990 29) compared to the years in the figure.

Principle of Operations.

In recent time, organic solar cells are of different operations due to their usage. Similar to inorganic solar cells, organic solar cells can be used to convert sunlight into electricity with the aid of a semiconductor. The basic principle behind this operation is outline below:

Most organic solar cells have very thin material layer either single or multi-layer where there is a strong absorption of light sandwich between two electrodes, an anode (A) and a cathode (C). The anode (usually indium tin oxide ITO) is transparent and has a high work function. The cathode (aluminum) is opaque and has a low work function. The material layer is usually a photosensitive organic semiconductor. When light of appropriate energy (sunlight) is incident on it, an electron is excited from the highest occupied molecular orbital (HOMO) to a lower uncopied state called lowest uncopied molecular orbital (LUMO) leaving a hole in the HOMO. This leads to exciton formation. That is, there is a creation of an electron-hole pair which is strongly bounded together. As the electron stays at the LUMO, there is a loss in energy by the electron through thermal relaxation as the electron penetrates the energy band gap. The electron-hole pair diffuses independent of the electric field and are separated (exciton dissociation) at the interface between the donor state (HOMO) and the accepter state (LUMO). The electron is collected at one end of the electrode (cathode) and the hole at the other end of the electrode (anode) thereby generation photocurrent in the process. If the electron and the hole after separation do not reach the interface, their absorbed energies are dissipated out and no photocurrent is generated. Step by step principle is illustrated in pictorial form below:

Figure 3. 2: a) Light is incident on an electron (red). (b) Electron is excited from the HOMO to the LUMO creating a hole (black) at the HOMO. (c) Exciton formation of electronhole pair. (d) Diffusion of exciton independent of electric field. (e) Exciton dissociation. (f) Collection of charges.

Chapter 4

Performance

4. 1 Absorption of light.

In organic solar cells, the thin organic semiconducting layer is responsible for light absorption. This layer has a valence band which is densed with electrons and a conduction band. These bands are separated by an energy gap. When the layer absorbs light, an excited state is created. This state is characterized by an energy gap. The energy gap is the energy difference between the higher energy state (LUMO) and the lower energy state (HOMO). It is usually of the range of (1. 0 -4. 0) eV[24] and it is determined as:

$E_g = E_{LUMO} - E_{HOMO}$. (4. 1)

Where Eg is the energy gap in electron volts (eV), ELUMO is the energy at LUMO (higher energy state) and EHOMO is the energy at HOMO (lower energy state).

The energy gap usually serves as an activation energy barrier. This activation energy barrier needs to be overcome before an electron is excited from the lower energy state to the higher energy state. The excited electron has energy greater than or equal to this activation energy barrier. This energy is determined as:

h. c

Ephoton = ≥ Eg . (4. 2)λphoton

Where Ephoton is the energy of the incident photon (light), h is Plancks constant (6. 626 $\times 10^{-34}$ Js), c is speed of light (2. 997 $\times 10^{8}$ ms^{-1}) and λphoton is wavelength of the photon (≈ (400 -700) nm).

As the excited electron remains at the LUMO, a hole is created in the HOMO. The electron undergoes thermal relaxation as it remains at the LUMO and this result in loss of energy by the electron. This energy loss is compensated for as:

El = Eelectron − Eg . (4. 3)

Where El is thermal energy loss of the electron, Eelectron is the energy of the electron at the LUMO and Eg is the energy gap.

Figure 4. 1: (a) Thin organic semiconductor layer (with both LUMO and HOMO) with energy gap (Eg). (b) Incident light of greater energy than the energy gap excites electron (red) from HOMO to LUMO. This creates a hole (black) at the HOMO (c) Energy lost by the electron through thermal relaxation.

4. 2 Stability and Degradation

In solar cell application, long operational lifetime performance is required. To achieve this, stability and degradation are few of the key important issues to look at in real-time application. Over the years, stability of organic solar cells has improved very much in terms of their power conversions[25]. This is clearly shown in the figure below:

Ideally the advantages of organic solar cells with their low cost materials, recyclable, easy production and production in large quantities, ï¬, exibility and durability (low weight), stability should be optimum. These advantages somehow also affect the stability of the organic cells. The active layer (thin organic semiconducting layer) component which is a core component of the cells is sometimes prone to degradations. These degradations occur during their production (printing in bulk quantities and rolling them together thereby introducing some mechanical properties which then affect the morphology of the active layer) and also reactions from weathering (UV light, oxygen, water). Extensive work on photo stability of some organic solar cells (large number of polymers) has been investigated by Manceau et al[27].

Figure 4. 2: Organic Photovoltaic (OPV) production with progression in years shown. The years below 2010 had lower production of OPVs (> 0. 5 MW) [26]. Chapter 5

Comparism between organic solar cells and inorganic solar cells (Silicon base solar cells).

Organic and inorganic solar cells serve similar applications but they interesting differences in terms of how they are made. Organic solar cells are cheap in terms of materials, production and are recyclable, they have very thin solar cells with little energy in making them, they are ï¬, exible, durable and have low weight, they are colourful and they have easy production and can be produced in large areas. But they have low efficiency and lifetime compared to silicon base solar cells. Inorganic solar cells are cost effective in terms of materials, production and are not recyclable, much energy is need to have thin layer cells, they are rigid and not durable, they are of dark grey materials with dark blue to black coating, they have complicated production and are difficult to produce in large areas. But they have good light absorption rate, better efficiency and longer lifetime.

Chapter 6

Conclusion

Organic solar cells can be alternative to silicon base solar cells with its interesting applications. They can be fabricated into our day to day usage materials and equipment with low cost technology in serving their purpose. Efficiency and stability still remains areas that should be addressed in the future to optimally have good power conversions.