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A review on Fabrication of Dye-sensitized solar cells.

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ABSTRACT

Our energy consumption relies heavily on the three components of fossil fuels (oil, natural gas and coal) and nearly 83% of our current energy is consumed from those sources. The use of fossil fuels, however, has been viewed as a major environmental threat because of their substantial contribution to greenhouse gases which are responsible for increasing the global average temperature. Last four decades, scientists have been searching for alternative sources of energy which need to be environmentally clean, efficient, cost-effective, renewable, and sustainable. One of the promising sustainable sources of energy can be achieved by harnessing sun energy through silicon wafer, organic polymer, inorganic dye, and quantum dots based solar cells. Among them, Dyesensitized solar cell (DSSC) is the only solar cell that can offer both the flexibility and transparency. Its efficiency is comparable to amorphous silicon solar cells but with a much lower cost. DSSCs differ from conventional semiconductor devices in that they separate the function of light absorption from charge carrier transport. Dye sensitizer absorbs the incident sunlight and exploits the light energy to induce vectorial electron transfer reaction. This review briefly overviews the present performance of different materials-based solar cells including silicon wafer, quantum dots based solar cells, organic solar cells, and dye-sensitized.

Introduction:

The use of fossil fuels has been viewed as a major environmental threat because of their substantial contribution to greenhouse gases. The world energy consumption outlook 2011 which was published by the US Environmental Information Administration (EIA) disclosed that our energy consumption which relies heavily on the three components of fossil fuels (oil, natural gas and coal) is increasing despite some attempts incorporating other sources [1]. The report revealed that 83% of our present primary energy source was exploited from fossil fuels as depicted in Figure 2. Only 6% of our energy consumption of that year came from nuclear power. However, the recent massive earthquake and subsequent Tsunami in Japan resulted in an unprecedented nuclear disaster which raised many questions on public health and safety in the use of nuclear energy [2]. Although contributions from the renewable sources slightly increased since the previous years, these sources still contributed only 11% of our energy uses. The major challenge, therefore, in our energy sector is to increase the contribution from renewable energy sources. These alternative sources of energy need to be very abundant, environmentally clean, efficient, sustainable, renewable, safe, and cost effective. These conditions encourage many researchers to harness the sun's energy which could not just solve the present energy problem but also fulfill our future demand. As one hour solar energy can be used for one year, therefore, we only need to harvest less than 0.02 of solar energy [3].

Silicon Based Solar Cells:

There are many initiatives solving our energy problems and most efficient and popular one is the silicon based solar cells [4]. The lab based performance of silicon based solar cell has recently reached about 25%; however, market based efficiency is lower in the range of 15%–22.4%. In this year, the market based silicon solar panel produced by Suntech [5] has an efficiency of 15.7%; however, solar panel installed by the Sun Power [6] has a record efficiency of 22.4%. Although silicon solar cells made by mono, multi crystalline, and amorphous thin films share about 85% of today's market, the major cost factors related with silicon based solar cell include requirements of high purity silicon, high preparation temperature, and large amount of materials in order to prepare a tiny cell [7]. A report on cost profile of PV technologies disclosed that monocrystalline, multicrystalline, and amorphous silicon based solar panels cost \$3.83, \$3.43, and \$3.00, respectively which are comparatively higher than other solar panels [8]. It is expected that silicon based photovoltaic technology will be dominated in the future market.

Organic Solar Cells:

The seminal work of Heeger, Shirakawa and MacDiarmid (winners of 2000 Nobel Prize in Chemistry) opened a new window to use organic conducting polymer for wide range of semiconductor devices such as light emitting diodes, solar cells, and thin film transistors [9–11]. The motivation of developing organic materials for solar cell is to reduce the cost related to raw materials and manufacturing. Solarmer and Konarka Power Plastic, two US based companies, produce flexible polymer solar cells for many applications including portable electronics, smart fabrics, and integrated solar cells. The lab based power conversion efficiency of the polymer based single solar cells is reached to 8.6% reported by several groups [12–15]. Two well-known challenges associated with the donor-acceptor based polymer solar cell are that these polymers cannot cover the sun’s broad spectrum due to their comparatively high bandgap (1.6–2.0 eV) and they have lower carrier mobility. In order to exploit light from sun’s full spectrum, recently Dou et al. [15] developed a pyrrole (DPP) and dithiopene (BDT) based conjugated polymer (PBDTT-DPP) having a bandgap of 1.44 eV depicted in Figure: 1.a. This conjugated polymer has relatively higher carrier mobility. The tandem cell was constructed using Poly (3-hexylthiophene) (P3HT) and indene-C60 bis-adduct (IC60BA) as front-cell materials, and PBDTT-DPP together with the acceptor phenyl-c71-butyric acid methyl ester (PC71BM) as back-cell materials as shown in Figure: 1.b. Very recently, the solution phase tandem polymer based solar cell is achieved a record highest efficiency of 10.6% which is certified by NREL [16]. The life time of the polymer based solar cell (PSC) is comparatively low to 3–7 years which is one of the major challenges of PSC facing in market [17].

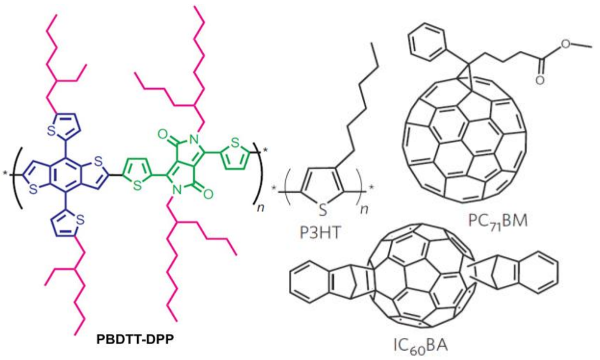

Fig.1.a: Molecular structures of PBDTT-DPP, P3HT, PC71BM and IC60BA

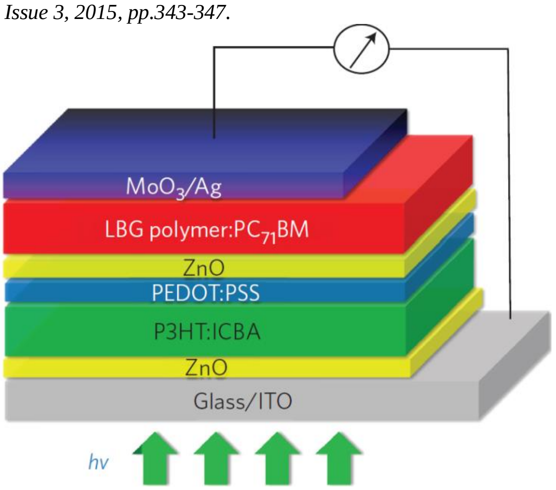

Fig.1.b: PBDTT-DPP together with the acceptor phenyl-c71-butyric acid methyl ester (PC71BM)

Carbon Dot Based Solar Cells:

It is obvious that metal based quantum dots are expensive and very vulnerable for health and environment. As a long term research goal, it would more appropriate if we can use other non-hazardous materials. In a previous study, Peng and Travas-Sejdic [18] synthesized luminescent carbogenic dots using carbohydrate as precursor materials presented in Figure 10A. This carbon dot first passivated by amine-terminated compounds, and due to less photoluminescence further passivation was performed with 4,7,10-trioxa-1,13-tridecanediamine (TTDDA). However, this carbogenic dot was not used for solar cell application. Highly soluble black graphene quantum dot have been prepared using a solubilization technique where polyphenylene dendrimer acts as a precursor [19]. This dot is used for sensitizing the TiO2 and comparable results are observed for short circuit current (Isc = 20 mA/cm2), open circuit voltage (Voc = 480 mV) and fill factor (FF = 0.58). Multiple exciton generation (MEG) is observed and collected in single-walled carbon nanotube based semiconductor; however, substantial future studies are required to integrate this material for solar cell application [20]. Recently, the Ozin group in Toronto was able to synthesize the carbon dots by dehydration of the γ-butyrolactone precursor depicted in Figure 10B [21]. Carbon dot can be emerged as a potential candidate in quantum dots based solar cells as sources of carbon are very versatile compare to metal based QDs. They were able to sensitize TiO2 with their carbon dots. However, the efficiency of the carbon dots based solar cell is only 0.13%. In this case, they used an I−/I3− redox couple which is certainly not a good choice. Improving the efficiency of carbon dots based single solar cell requires finding out an optimal condition in case of size of quantum dots, ligands, electrolytes, and electrodes through comprehensive studies. In addition, carbon dots based tandem solar cell will be an ultimate choice in order to promote efficiency so that it can compete with other competitors.

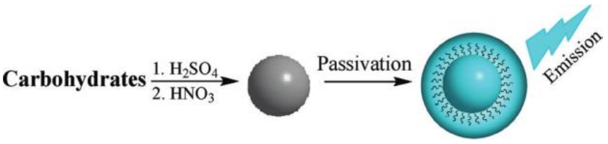

Fig. 2.a: Synthesis protocol of carbogenic dot.

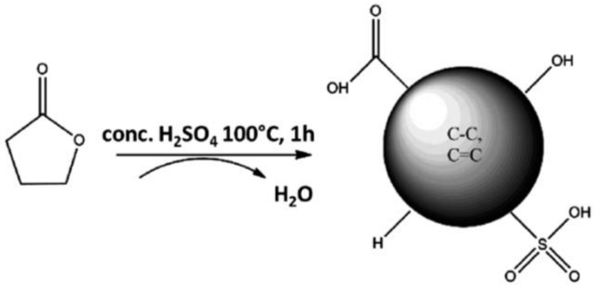

Fig. 2.b: Carbon dots prepared by Ozin group at Toronto

Dye Sensitized Solar Cells:

Dye-sensitized solar cells (DSCs) invented by Michael Grätzel became a very popular alternative to silicon based solar cells because of their great potential to convert solar energy into electric energy at low cost [22–26]. This cell can be made from cheap materials such as inorganic and organic dyes which do not need to be highly pure as is required for silicon wafer [27]. The working principle of the solar cell is presented in Figure 3A. Here we can see inorganic dye is anchored to a wide bandgap mesoscopic semiconductor. The popular dyes used for DSC are ruthenium bipyridine and zinc porphyrin complexes. For a mesoscopic semiconductor, TiO2 (anatase) is widely used in the solar cells; however, other alternative metal oxides such as ZnO, SnO2 and Nb2O5 can be used. After excitation of dye by light, the dye releases its electron from the HOMO (highest occupied molecular orbital) to the LUMO (lowest unoccupied molecular orbital). This photoelectron then swiftly transfers from the LUMO of the dye to the conduction band of the semiconductor TiO2. The semiconductor carries the electron to the photoanode which passes the electron to the platinized counter electrode. Regeneration of the oxidized dye takes place by a redox couple such as iodide/triodide which reduces the dye by providing a continuous supply of electrons [28]. Over many years, the overall conversion efficiency of most solar cells was unchanged from 11.18% [29] as shown in Figure 3B. Only recently, Grätzel group was able to exceed the power conversion efficiency 12.3% [30]. In this research, they used donor-p-bridge-acceptor zinc porphyrin dyes of YD2-o-C8 and YD2 (see in Figure 4A) incorporating Co(II/III)tris(bipyridyl)–based redox couple instead of iodide/triiodide redox shuttle. The incident photon-to-electric current conversion efficiency of the YD2-o-C8 dye is relatively higher than the YD2 dye as depicted in Figure 4B. This study concluded that the incorporation of non-volatile electrolyte and new anchoring groups to the porphyrin dye increase the power conversion efficiency to 13%.

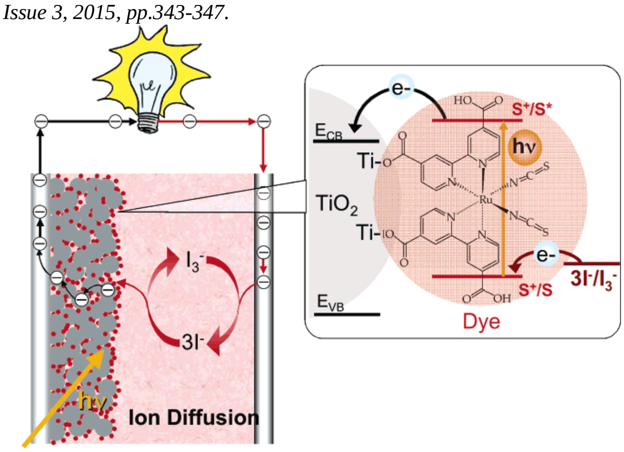

Fig. 3: The dye sensitized solar cell

Preparation of Dye Sensitized Solar Cells:

Based on the scientific references found in earlier literature chapter, the prototype of “hybrid dye sensitized solar cell b on TiO2/graphite” was constructed. In this chapter, details of procedures to conduct the experiments will be presented. The preparation of dyes will also be provided in this section. The different techniques will be demonstrated and discussed in this section as well.

Assembling the Dye-Sensitized Solar Cell:

1. Determine the conductive side of glass in the model kit by touching both of protruding leads of the multi-meter with one side of the glass. The conductive side could be identified with average resistance from 20-38 ohms.
2. Fix three sides of the plate using tape with the conductive sides facing up shown by Fig.4.

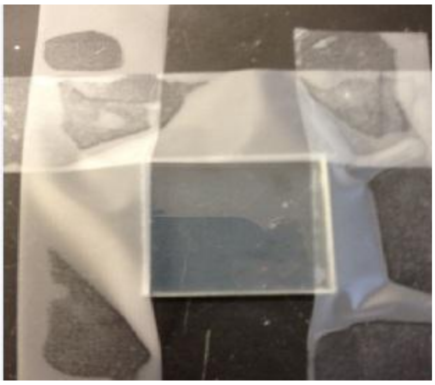

Fig. 4: Fix the conductive side by tape**.**

3. Prepare the titanium dioxide paste by adding a few drops of very dilute acetic acid (0.035M) to 1 gram (about 2 table spoons) TiO2. The resulting mixture was grinded in a mortar and pestle until a colloidal suspension with a smooth consistency (like cake icing) was observed. (Grazel, 2005).
4. Add 2-3 drops of the TiO2 suspension onto the conductive side and spread out the TiO2 evenly on the surface of the plate with glass rod. Carefully remove the tape without perturbing the TiO2 layer.

5. Dry the glass with TiO2 under room temperature over 4 hours and then heat to 420 oC for another 20 min, until the dried TiO2 turns brown and then white again.
6. While heating, light the candle and coat the conductive side of the other piece of glass with graphite over 45 sec.
7. Cool both plates to room temperature.
8. Submerge the plate with TiO2 face-down in the dye solution and take out quickly but carefully without cracking the TiO2.
9. Wash the dye layer with ethanol carefully.
10. Clamp both the plates together and apply 2 drops of KI/I2 electrolyte solution onto the interface between the two plates.
11. Allow the electrolyte to cover the surface of TiO2 by capillary action.
12. Measure the photo-voltage under the UV and fluorescent light after forming a circuit using a multimeter.

Preparing the Dye Solution:

Synthesis of Copper Phthalocyanines:

Copper Phthalocyanines was the first dye molecule we chose to synthesize because the easy accessibility of starting material and the simple experiment procedure. There are two commonly used protocols for synthesizing copper phthalocyanines, microwave irradiation and direct heating. Although the most commonly used one is the microwave irradiation with high yield and easier isolation and workup method (Shaabani, 1998), our group decided to use the direct heating method because of the difficulty of instrumental handling.

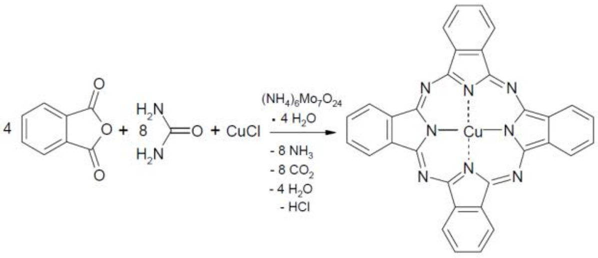

Fig. 5: synthesis scheme of copper phthalocyanines (Moser and Thomas, 1963)

Reaction apparatus was a test tube (18*125mm) set up in the 320 degree of centigrade oil bath. The temperature was carefully controlled.

In the test tube, 1.84 g (30.7 mmol) of urea, 0.89 g (6.0 mmol) of phthalic anhydride and 167 mg (1.67 mmol) of copper (I) chloride was charged. The mixture was well swirled with a glass rod over 5 min to obtain a thoroughly mixture. Next, 25 mg (0.02 mmol) of ammonium heptamolybdate was charged to the test tube followed by another mixing over 3 min. Then, the test tube was heated by the oil bath over 5 min. The melting of the entire solid was first observed. When the color turned to greenish blue, the heating apparatus was removed and the mixture was allowed to cool to room temperature.

The work up procedure was composed of two steps. At the first stage, 2.5 mL of conc. HCl was added to the crude product with 20 mL of water. The mixture was swirled over 10 min to get rid of the un-reacted starting material. After filtration, the filtrate was discarded. Then, the solid on the filter was washed with 20 mL of ethanol. Solid was then removed from the filter paper and allowed to dry under air. (Yield: 0.381 g, 44.1%)

Preparation of the Raspberry Dye Solution

Raspberry juice, rich in anthocyanine, is a great source of dye in our dye-sensitized solar cell. (Wu, 2004) Smestad developed the nano-TiO2/raspberry DSSC in 1998. (Smestad, 1998) This kind of DSSC provides very stable photo-voltage. Due to the easy accessibility and stable outcome, the raspberry was among the best choices of the dyes.

Preparation of the raspberry solution requires some skill of filtration. 4-5 pieces of frozen raspberry were grinded in a mortar until a crude mixture was observed, usually about 4-5 min. The crude mixture was then transferred slowly to a pre-assembled filtration apparatus. If the resulting mixture is very thick, i.e., no filtrate, several drops of water or acetone was used to wash the mixture and add the total liquid amount. A spatula or a glass rod can be used to swirl the mixture to give off more solution.

The resulting solution, although might not be chemically pure, is rich of anthocyanine; thus, it could be used in DSSC.

Conclusion:

Provided in protocol and other literatures (Grazel, 2005, etc), coating graphite onto the conductive side is one of crucial steps for making the DSSC and The type of the dye materials play the major role in making the DSSC. We are studying the dependence of the thickness of graphite layer with the performance of the cell. Recognize the semiconductor layer thickness dependency. Temperature dependence of the performance of DSSC, Dark Current Measurement

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