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Research paper

Organic Solar Photovoltaic Cells: Synthesis of Indium Tin Oxide using Sol-Gel Method

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Abstract

Solar cells are a solution for the demand for clean and non-pollutant energy. The first two generations of solar cells were costly and bulky, or with rare metals. The third generation are thin films with a polymer or natural dye as active layer. The active layer materials are common in use and non-polluting. A side for the active layer, other layer must be implanted to make the circuit complete and let electrons flow trough. This work focusses on the production of Indium Tin Oxide (ITO) which act as a transparent conductive electrode. The ITO will be placed in a dye-sensitized solar cell consisting of DNA-chlorophyll active layer. The focus is on the production process of the ITO using the sol-gel method. The precursors that are used are $InCl_3$, $SnCl_4$ and NH_3 solutions. To obtain the sols for thin film preparation, the Sn-doped indium hydroxide needs to be dialyzed, aged, and dispersed in ethanol. Then calcination has to be done for preparing proper ITO. When spin coated in to a thin film characterisation can be done like X-ray diffraction, scanning electron microscopy and UV-Vis and near IR spectroscopy. The thin film can be placed in a DNA-chlorophyll as an active layer. After reviewing the simple structure of electrodes and active layer, some hole transmitting layers or electron transmitting layers to reduce the losses. The overall solar cell can be tested and the efficiency will be determined.

Keywords: *Organic Solar Photovoltaic cells, Indium Tin oxide, Dye-sensitized solar cell, DNA cholorphyll layer.*

1. Introduction

The third generation of solar cells was implemented when the solar cell had an active layer of organic or dye-sensitised material. This is the most recent studies and the aim was to decrease the cost from $1/watt to $0.5/watt or even lower [1]. With using the advantages of the thin film but also reducing the disposal of toxic materials. The third generation of solar cells include multi junction, perovskite, dye, organic and quantum dot solar cells. The theory is very different in each type of solar cell. The focus in this paper will be on dye-sensitized and organic solar cells.
Dye-sensitized solar cells have as an active layer an natural organic polymer or substance. This dye works similar as the photosynthesis in plants. Dye sensitized solar cell consists of a natural molecular dye like Chlorophyll in combination with a catalyst and electrodes. This paper will overview every layer of a solar cell and his function. There will be given some materials for these layers as well.

1.1 Working of Organic PV

The solar cell standard form is shown in figure 1. The use of every layer will be discussed in this paragraph with the help of figure 1. Figure 1a shows an organic heterojunction solar cell in its simplest form; In this case transparent ITO anode will have this function. There are two major loss mechanisms in Figure 1a because of no additional layers. For example when there is an ITO anode (Φ = - 4.7 eV) and a silver cathode (Φ = - 4.26 eV) [3] the VOC produced by the cell would thus be limited to ~0.44 V. The other major loss is caused by back-diffusion. In a normal cell the excited electron goes from donor to acceptor and the holes the other way around. Because the electron moves downwards along the energy band, while the holes move upwards. When there is no other barrier to prevent the electron to randomly move to the wrong electrode, the electrons will recombine to the ground state and represent loss in energy as shown in Figure 1a.

For this problem the electron transmitting layer (ETL) and the hole transmitting layer (HTL) are created. As illustrated in Figure 1b a semiconducting layer (ETL) with a deep HOMO band provides a barrier for the holes to cross to the cathode. Likewise with the HTL that has a high LUMO level to block the electrons from diffusing to the anode. Figure 1c shows the energy band diagram which shows the function of hole transport layer.

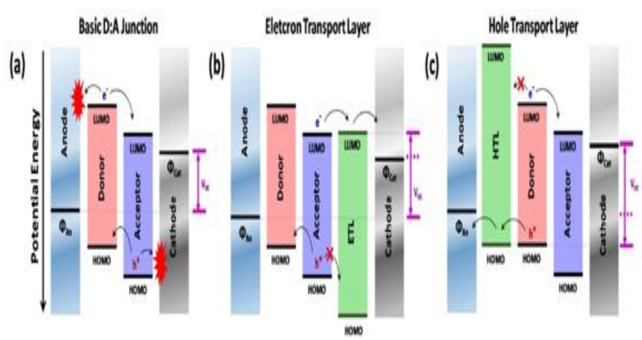

Fig. 1: Schematic diagrams. (a) Energy band diagram of a basic donor-acceptor junction. (b) Energy bad diagram illustrating the function of an electron transport layer. (c) Energy band diagram illustrating the function of hole transport layer.

2. Materials and Methods

2.1 Materials for photoanode

In the simple solar cell the core is the active layer and the electrodes. There is an anode and a cathode needed. The electrodes have to conduct the electron but one electrode has to be transparent. This is because the light has to reach the active layer to excite an electron. Widely the most used transparent electrode is indium tin oxide (ITO) [2,4,5]. This material is indium oxide which is doped with tin, it is highly transparent and well conducting. It is easily produced by a couple of methods. The various methods of producing ITO thin films are radiofrequency sputtering [6], spray pyrolysis [7], chemical vapor deposition [8], electron beam evaporation [9], pulsed-laser deposition [10] and sol–gel processes [11]. The transparency differs a little when the preparation method varies or the coating method. The most appropriate chemical synthesis of ITO is the sol-gel method. This is because of the advantages like controllability of composition, relative low cost (no vacuum or expensive devices needed)[5].

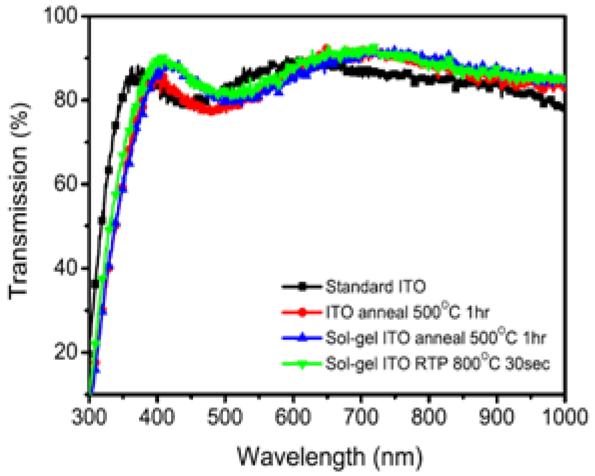

Fig. 2: The optical transmission spectra of standard ITO substrate and post-processed ITO substrates with and without the sol-gel ITO [12]

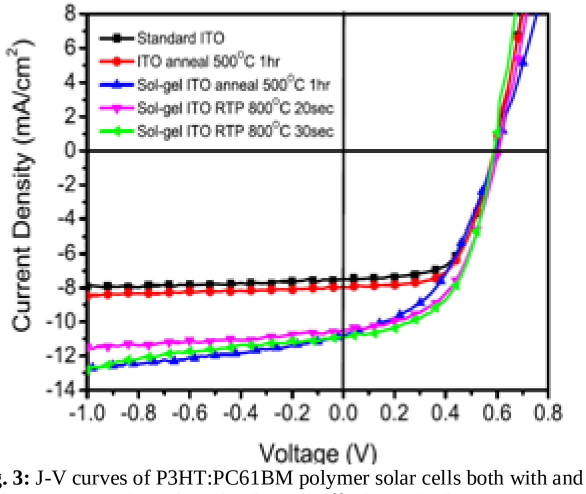

Fig. 3: J-V curves of P3HT:PC61BM polymer solar cells both with and without the sol-gel ITO buffer layers[12].

The transparency of ITO is around 80% above the 400nm which is very high[12]. ITO would suite as a perfect anode material. In the figures reported in Fig 2 and Fig 3 are some analysis of an ITO film that is produced for solar cell purpose.

Other relevant materials for the conductive transparent thin film are ZnO and TiO_2. But the problem with ZnO thin film is that they have less transparency[13]. The conductivity is similar. To solve this problem it is possible to dope the zinc with some other atoms. One of these is Al. The advantages of metal oxides are the excellent stability, low cost and desirable electronic properties like high charge carrier mobilities. The downside of metal oxide film, they are, compared to others, rather thick. They also suffer some disadvantages like high temperature processing steps, some problems with organic-inorganic oxide layers and other compatibility issues[2]. Recent study shows that graphene could maybe fill in this roll of transparent conductive electrode. Graphene has a very high conductivity. But this is still in the research phase.

2.2 Materials for sensitizers

The active layer consist of an electron donor and acceptor material. In this paper it will be a DNA-chlorophyll. The use of chlorophyll in solar cells would solve some of the challenges. Chlorophyll is sustainable, clean, cheap and is an effective method for energy. The chlorophyll must be extracted first, but the process is around for many years so it is considered to be perfected in these modern times [14]. The chlorophyll layer absorbs some wavelengths which are used to make the electrons flow. The absorbance spectra of chlorophyll is very important because the light cannot be absorbed in an earlier layer. In the figure 4 below an absorbance spectra of some chlorophyll molecules is shown.

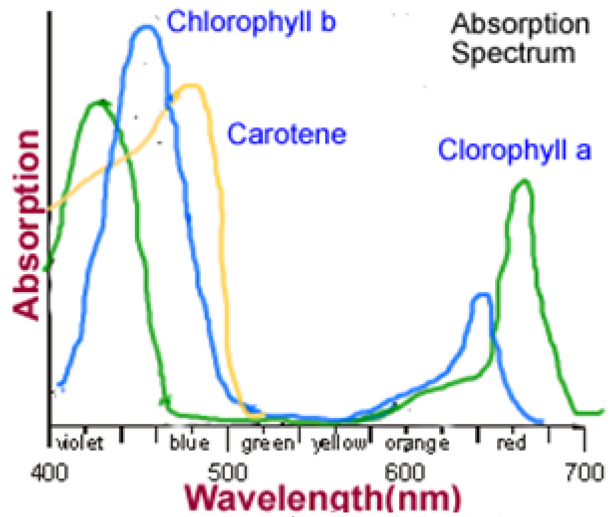

Fig. 4: Absorbance of the chlorophyll molecule

The use of DNA in a solar cell is not yet been found in literature. But it is found that DNA can transfer electrons [15]. And like chlorophyll it is clean and cheap. A solution of DNA-chlorophyll should be made for the solar cell coating to work. This is been done by the method described in other papers [16]. The HOMO and LUMO levels are yet unknown for DNA and Chlorophyll, that is why there is not much to work with yet. After the first test this will be more clear so the other layers could be optimized.

2.3 Materials for Transmitting Layers

The transmitting layers have been researched for quite some time [2, 5]. Because the use a new active layer the best option will be to go for layers that are the most common and only the essentials so that the active layer can be tested. The most essential transmitting layer is the hole transmitting layer. One of the most common HTL [5] is PEDOT:PSS, which is used earlier, stands for poly(3, 4-ethylenedioxythiophene)/poly(styrenesulfonate).

The molecule is shown in the following Figure 5 (a) and 5(b) PEDOT:PSS is transparent and helps for smoothening the rough electrode surface to increase the work function and contact of the electrode. Additionally it strengthens the internal electric-field in the device and increases the hole-extracting rate and the mobility of the holes. All this will lead to improvement of the overall solar cell. Because PEDOT:PSS has to be transparent a transmission spectra would give more information about this. In the next figure is a spectra [17] shown along with an ITO spectra, and as you can see they have similar transmission wavelengths which is perfect for a solar cell. Another important matter was the band gap. For PEDOT:PSS it generally goes from -2.2 eV to -5.2 eV [19] which is very large and suitable for a solar cell.

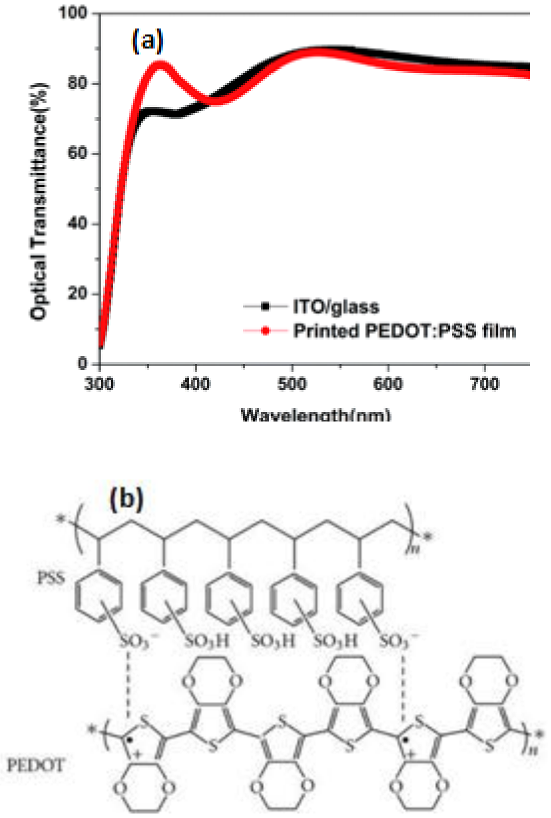

Fig. 5: (a) Optical transmittance measurement of inkjet printed PEDOT:PSS film on ITO/glass substrate. For comparison, spectra of ITO/Glass substrate is also shown. (b) PEDOT:PSS molecule [18].

The ETL will not yet be decided because there for the information of the active layer has to be evaluated. The most common ETL are metal oxides like ZnO or TiO2 [2]. But these could make the cell less stable because like previously mentioned the organic-inorganic bonding is not that stable. Therefore the use of conjugated polyelectrolytes (CPEs) could be used. These materials are previously used in organic semiconducting materials as well as OLEDS and transistor devices. These are large polymeric materials like PDPPNBr which is shown underneath. The molecules have a great conductivity and are compatible with the organic active layer. The work function of the ITO/PDPPNBr is also shown underneath.

2.4 Materials for counter electrode (cathode)

The counter electrode does not have to be transparent. The most used are silver and aluminium. The reason for this is their great conductivity and common use.

3. Methodology

3.1 Preparation of ITO

The ITO will be produced using following steps [4,5]:
Preparation of the solution was carried out using following steps
1) $InCl_3$ and $SnCl_4.5H_2O$ is dissolved in 100 ml of distilled water
2) During intensive stirring at room temperature 2.0 ml of aqueous ammonia solution (25%) is added.
3) The solution undergoes ultrasonic treatment for 5 minutes
4) After that the solution is put in a centrifuge at a speed of 5000 rpm
5) The sediment is dispersed again in 50 ml of distilled water, after that the dispersion is dialyzed for 3 days
6) The dispersion will be centrifuged at a speed of 12000 rpm
7) The sediment is washed with 50 ml of absolute ethanol
8) The centrifuge (6) and washing process (7) will be repeated 3 times
9) The sediment is then dispersed in 50 ml of ethanol and ultrasound is applied
10) The obtained matter is called a xero-gel

Preparation of the ITO:
1) Previous obtained xero-gels are calcinated in an air furnace for 30 minutes at 550℃
2) Thin film preparation with the spin coating technique.

3.2 Preparation of DNA-chlorophyll solution

The preparation of the active layer will be done by another student so this will be covered in his paper. The method is described in referred paper [6].For the synthesis of the solar cell the method used is spin coating.

4. Results and Discussion

The ITO production process results are shown below. ITH is indium tin hydroxide. This is the form of the product before doing the calcination.
When producing the ITO it should look similar to the XRD patterns that is shown in Fig 6 . Then it is certain that the process is stable and that it could be reproduced.

After doing the XRD patterns the coating has to be done. After that the SEM analysis can be used for checking of the surface. SEM image will show if the surface of the ITO thin film is rather rough or smooth. This could be an important factor for coating the layers of the solar cell.

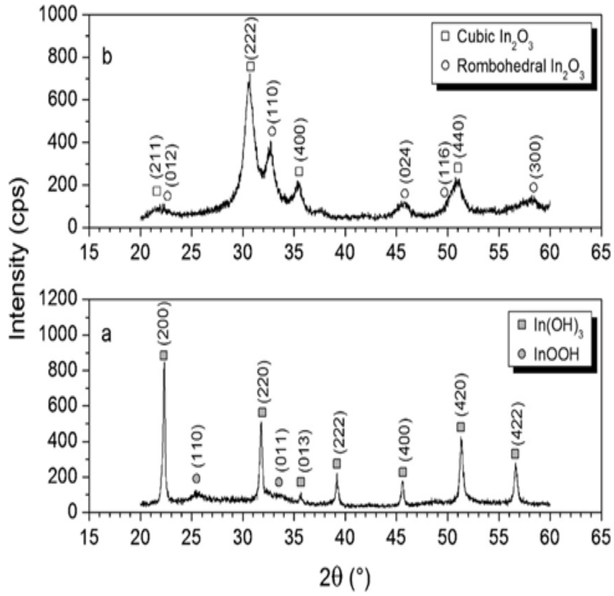

Fig. 6: XRD patterns of (a) ITH and (b) ITO powders

5. Conclusion

The solar cell has promising expectations and uses common and cheap methods to prepare. This will have an impact on further research of solar cells. The production of ITO in sol-gel method is under mild conditions and with simple apparatus. The spin coating of the solar cell is quite common and is the easiest way for good contact between the layers.
Further research is of course bringing the theoretical assumptions in to a practical test. If the solar cell is completed and tests have been done the efficiency can be calculated. When this is known layers like ETL or HTL can be replace for better efficiency, or

layers can be added for multi junction or other higher efficiency methods.

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