بسم الله الرحمن الرحيم

Sudan University of Science and Technology

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Study of the Efficiency of polymer Solar Cells Fabricated from some Dyes

دراسة كفاءة الخلايا الشمسية البوليمرية المصنوعة من بعض الصبغات

A thesis Submitted in partial fulfillment for the requirements of master degree in physics

By

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August 2015

بسم الله الرحمن الرحيم

قال تعالى (هُوَ الَّذِي جَعَلَ الشَّمْسَ ضِيَاءً وَالْقَمَرَ نُورًا وَقَدَّرَهُ مَنَازِلَ لِتَعْلَمُوا عَدَدَ السِّنِينَ وَالْحِسَابَ مَا خَلَقَ اللَّهُ ذَلِكَ إِلَّا بِالْحَقِّ يُفَصِّلُ الْآيَاتِ لِقَوْمٍ يَعْلَمُونَ) يونس (5)

صدق الله العظيم

Chapter one

1.1 Introduction

Silicon solar cells (SSC) are based on the physical principles described by Planck's Law. This law states that the energy of a single photon is equal to $h\upsilon$, where (h) is Planck's constant and υ is the frequency of the light. The energy is thus proportional to the frequency and inversely proportional to the wavelength. The silicon solar cell is the traditional solar cell and has found applications in various areas such as calculators, garden lamps, and roof mounted large area cells etc. The SSC has so far been the best candidate for conversion of sunlight and therefore the development and research of solar cells has been dominated by this. The SSCs trace their history back to the 1950s where the first SSC was reported by Chapin, Fuller and Pearson. It had a power conversion efficiency of 6%. The price per watt was very high, being as much as 200 $ per watt. This meant that SSCs were not seriously considered as an everyday power source for many decades, only in very remote places and if the costs were made unimportant by the benefits of SSCs, e.g. satellites. The SSCs has benefited from the fast development in the integrated circuit industry. This means that it is now possible to produce SSCs with efficiencies as high as 25%. In addition, this will lead to inexpensive, efficient and reliable SSCs than what was previously estimated. The prices for a solar cell generated power today lies between $ 10and $12W^{-1}$, based on today's prices on the internet.

1.2 Research problem:

The high cost of these silicon solar cells and their complex production process has generated interest in developing alternative photovoltaic technologies. Also there is other type of solar cell fabricated from polymer most photovoltaic cells that have been fabricated have low efficiency and high coast. We was need to see how low cost and fabricated polymer solar cells.

1.3 The aim of this research:

To study efficiency of polymer solar cells by using different types of dyes(Law Sonia - Ink - Comorian (500) - Roselle - D.DTc and Erio chrome Black T) concentration 3 mg in 1 mm of ethanol.

1.4 Research methodology:-

To have about 6 samples from nano and polymer cells (Law Sonia - Ink - Comorian (500) - Roselle - D.DTc and Erio chrome Black T) concentration 3 mg in 1 mm of ethanol. For the purpose of the present study polymeric devices were made following the generally accepted methods. The fabrication process started by preparing the polymer and the dye of interest then spin coated on indium tin oxide glass. Gold electrode was used to complete the formation of organic polymer solar cell. To find the efficiency (η) of the dye-sensitized solar cell.

1.5 Research Layout:

This research has come into five chapters. Chapter one is the introduction. Chapter two is theoretical backgrounds of the polymer solar cell. Chapter three is concerned Thin Film Physics. Chapter four is the Materials and Method and in chapter five Results , discussion and Recommendation.

Chapter Tow

The backgrounds of the solar cell

2.1 Introduction

The sun, an inexhaustible source of energy on the ground, is one of many renewable energy sources. Obviously the direct exploitation of solar energy is the best choice because it is renewable energy, and pollution free can be sufficient for humans possibly forever if possible exploited efficiently.

Si-based solar cells have been utilized in many occasions as a renewable energy source; however, it has been impossible to replace other conventional nonrenewable energy sources with the solar cells because its manufacturing cost is much higher than that of other nonrenewable energy sources. However the organic based solar cells, can possibly offer special opportunities as renewable energy source because they can be fabricated over large area using low cost printing technologies. The progress in the field of the polymer based solar cells has been promising with the recently reported power-conversion efficiency of ~6%. Although it is still ineffective to be the technology utilized in commercial products, there could be plenty of room for the improvement in the power conversion efficiency of the polymer based solar cells. In this research, we will present the synthesis methodology to produce high mobility polymers that can possibly be utilized in polymer-based solar cells with improved power-conversion efficiency.

It is important to understand how organic or polymer based solar cells work to improve its power conversion efficiency. A simple organic solar cell has the planer structures, and the structure is very similar to that of the Si based solar cells with the p-n junction sandwiched with the transparent conductor such as ITO and metal electrodes. The working principle is also similar to each other. The photo excited species are generated in the P or n-type semiconductor materials, and they are separated as holes and electrons at the p-n junction. To take out energy from a solar cell, the separated holes and electrons have to be collected at the electrodes. Thus, the materials need to satisfy the following criteria to be a good solar cell material:

1) High absorption of light.

2) Efficient charge separation.

3) Sufficient charge transport [2].Solar energy can be exploited in many important purposes in our lives.

2.2 Application of solar cell

Solar cells had been in the operation of many devices 30 years ago or more. The most important use was in space satellites. It Has now become possible use to run various mechanisms such as fans, pumps, refrigerators ,calculators and other electronic appliances[3]Power generated is used in

- Water pumping
- Lighting
- Refrigeration and air conditioning

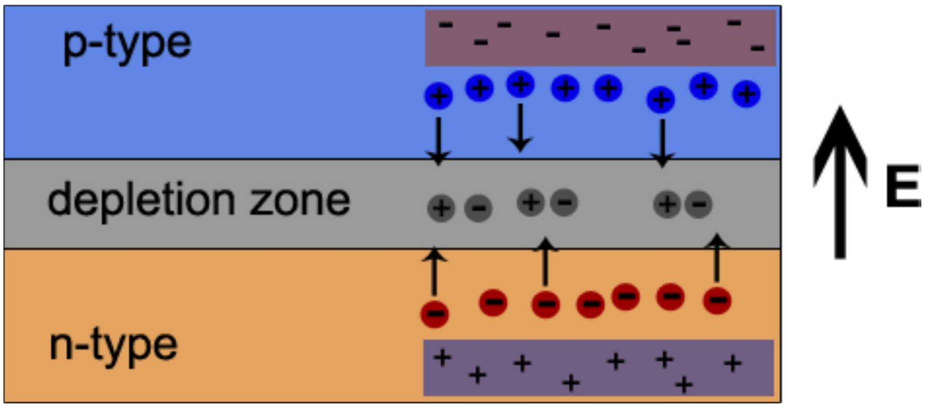
2.3 Principle of solar cell

Silicon solar cells are based on the physical principles described by Planck's Law. This law states that the energy of a single photon is equal to hυ, where (h) is Planck’s constant and υ is the frequency of the light. The energy is thus proportional to the frequency and inversely proportional to the wavelength.

When light, with a frequency corresponding to an energy larger than the

Band gap, hits a semiconductor like silicon some of the electrons are excited into higher energy levels. Only if the energy of the photons are larger than the band gap, the electron can be excited. If the energy is much larger than the band gap the electron can be ejected from the material. This is known as the photoelectric effect. In these excited states the electrons are freer to move, and can thus lead a current if a potential difference is imposed across the cell. This potential difference arises from a built in asymmetry in the cell.

SSCs are built from several different layers, two of them being n-type silicon (negative - excess of electrons) and p-type silicon (positive – excess of holes). Naturally found silicon has 14 electrons, 4 of them being valence electrons. In the solid state silicon forms covalent bonds with four neighboring silicon atoms, and this forms the crystal lattice. To create n-type and P -type silicon, impurities are introduced into the crystal lattice. This controlled and on purpose contamination of silicon is known as doping. n-type silicon can be created by doping with phosphorus. Phosphorus is incorporated into the crystal lattice where it occupies a lattice point which would otherwise be occupied by a silicon atom. Because phosphorus contains five valence electrons, and only four of them are used for bonding, there is one excess electron per unit cell. Similarly, to create P -type silicon, atoms with three valence electrons, for example boron, are incorporated into the lattice producing an excess amount of holes. When P-type and n-type silicon are brought together a p-n junctions formed at the interface. Because of the excess of electrons on one side, and the excess of holes on the other side electrons and holes recombine at the junction creating an insulating junction which is termed the depletion zone. When electrons flow from the n-type side towards the junction, excess positive charge is left behind. Similarly, excess negative charge is left behind when holes flow to the junction. This excess charge is not free to move because it is part of the chemical bonds between atoms. As a result an electric field directed from the n-type side to the p-type side is established. This is illustrated in Figure (2.1).



Fig(2.1)Illustration of the depletion layer. When the p-type and n-type layer are brought together, electrons from the n-type side recombine with holes from the-type side at the depletion layer. The depletion layer is therefore an insulating layer because there are no free charge carriers.

A basic SSC unit produces a photo-voltage of between 0.5 and 1.0 volt and a photocurrent of some tens of milliamps per cm^2 when illuminated by the sun. This voltage is too small for most applications and therefore multiple cells are connected in series into modules [3].Although the manufacturing costs of SSCs have dropped dramatically since the first cells was produced in the 1950's, the costs are still too high for large scale energy production. Furthermore, the production is not an easy task, the SSCs are not very flexible and silicon is in great demand due to the ever growing computer industry. This is not subject to change; therefore different paths must be examined.

2.4 Type of solar cells

Three generations

2.4.1 First Generation

First-generation cells are based on expensive silicon and make up 85% of the current commercial market due efficiency to 26%.

2.4.2 Second Generation

Second-generation cells are based on thin films of materials such as Amorphous Silicon , Nano crystalline silicon, cadmium telluride, or Copper indium selenite. The materials are less expensive, but research is needed to raise the cells' efficiency to the levels shown if the cost of delivered power is to be reduced.

2.4.3 Third Generation

Third-generation cells are the research goal: a dramatic increase in efficiency that maintains the cost advantage of second-generation materials. Their design may make use of carrier multiplication, hot electron extraction, multiple junctions, sunlight concentration, or new materials. The horizontal axis represents the cost of the solar module only; it must be approximately doubled to include the costs of packaging and mounting.

- High-efficiency Multi-junction Concentrator Solar Cells based on III-V’s and III-V ternary analogs
- Dye-sensitized cells
- Organic (excitonic) cells
- Polymeric Cells
- Nanostructure cells including Multi-carrier per photon cells.

2.5 polymer solar cell

Polymer solar cells (PSC) is one of the possible replacements. These solar cells add some very interesting properties to the solar cell as well as reducing the price considerably. Have demonstrated that the production of large area PSC ($1m^2$) can be done at a cost 100 times lower than that of Nano crystalline silicon solar cells in terms of material cost. Another area where the PSC has advantages over silicon cells is in flexibility. Whereas silicon crystal is rigid a polymer layer is very flexible yielding the possibility of a very flexible thin film solar cell. This is a property that can enable a variety of new applications. However there are still challenges to overcome. Firstly the service life of a PSC is very short, only a few hours for a simple metal/polymer/metal solar cell. Secondly the efficiency of the PSC is not high compared to theses. PSCs has power conversion efficiencies around 3% using different optimization methods. In This research we used thin film method to fabrication polymer solar cell.

Chapter Three

Thin Film Physics

3.1 Introduction

Thin film is a small system less than 1 µm layered on a substrate that acts as a carrier. Thin Film Deposition technology can well be regarded as the major key to the creation of devices such as computers, since microelectronic solid-state devices are all based on material structures created by the deposition techniques. Electronic engineers have continuously demanded films of improved quality and sop. Equipment manufacturers have made successful efforts to meet the requirements for improved and more economical deposition systems process monitors and controls for measuring film parameters. The improved understanding of the physics and chemistry of films, surfaces, interfaces, and microstructures made possible by the remarkable advances in analytical instrumentation during the past twenty years. A better fundamental understanding of materials leads to expanded applications and new designs of devices that incorporate these materials. A good example of the crucial importance of deposition technology is the fabrication of semiconductor devices, an industry that is totally dependent on the formation of thin solid films of a variety of materials by deposition from the gas, vapor, liquid, or solid phase.

3.2 Application of thin film

The selection of a specific technology for the deposition of thin films can be based on a variety of considerations. A multitude of thin films of different materials can be deposited for a large variety of applications; hence, no general guidelines can be given of what the most suitable deposition technology should be. In selecting an appropriate deposition technology for a specific application, several criteria have to be considered. In considering the different applications of deposited thin films, the following generic categories can be identified:

3.2.1 Electronic Components

The fabrication of electronic components, especially solid-state devices and microelectronic integrated circuits, have undoubtedly found the widest and most demanding applications for thin film depositions. These films typically consist of semiconductor materials, dielectric and insulating materials, and metal or refractory metal silicide conductors.

3.2.2 Electronic Displays

Electronic displays are used for interfacing electronic equipment with human operators. Different components and device structures are required, such as: solar cell fabrication, Liquid-crystal displays, Light emitting diodes (LEDs) Electroluminescent displays, Plasma and fluorescent displays & Electro-chromic displays. The fabrication of these displays requires conductive films, transparent and conductive films, luminescent or fluorescent films as well as dielectric and insulating layers.

3.2.3 Optical Coatings

Optical coatings are applied for antireflection purposes, as interference filters on solar panels, as plate glass infrared solar reflectors, and for laser optics. In the fabrication of filter optics, thin films with refractive index gradients are deposited on performs from which the optical fibers are drawn. These coatings require dielectric materials with precisely defined indices of refraction and absorption coefficients. Laser optics require metal reflective coatings which can withstand high radiation intensities without degradation. Infrared reflecting coatings are applied to filament lamps to increase the luminous flux intensity.

3.2.4 Magnetic Films for Data Storage

Thin films are finding increasing commercial use for optical data storage devices in compact disks and computer memory applications. Processes for the deposition of organic polymer materials as storage media and as protective overcoats are required for this technology.

3.2.5 Antistatic Coatings

Thin films of conductive or semi conductive materials are deposited to provide protection from electrostatic discharges.

3.2.6 Hard Surface Coatings

Thin film coatings of carbides, silicate's, nitrides, and borides are finding increased uses to improve the wear characteristics of metal surfaces for tools, bearings, and machine parts. Of particularly great current interest are films of diamond-like carbon because of this material's heat dissipation properties electrical insulation, hardness, and resistance to high-temperature and high-energy radiation.

3.3 Classification of Thin-Film Deposition Technologies

- ❖ Evaporative Methods
- ❖ Glow-Discharge Processes
- ❖ Gas-Phase Chemical Processes
- ❖ Liquid-Phase Chemical Techniques

3.4 Liquid-Phase Chemical Formation

The growth of inorganic thin films from liquid phases by chemical reactions is accomplished primarily by electrochemical processes (which include iodization and electroplating), and by chemical deposition processes (which include reduction plating, electro less plating, conversion coating, and displacement deposition). A number of extensive reviews of these film formation processes discuss theory and practice. Another class of film forming methods from the liquid phase is based on chemically reacting films that have been deposited by mechanical techniques. Finally, liquid phase epitaxial is still being used for growing a number of single-crystal semiconductors. Polymer deposition in this research method is used spin coating It's an easy and quick way and inexpensive.

Chapter Four

Materials and Method

4.1 Introduction

A solar cell was made by depositing the polymer solution on ITO a glass manner Spin Coating, and another layer was deposited from dyes a layer of polymer . Gold was fabricated on the layers to represent the anode and ITO Cathode. A clean glass plate with a thin layer of ITO (Indium Tin Oxide) is needed. The ITO acts as the first part of the solar cell, the first electrode. However a bit of the ITO has to be removed, to avoid short-circuiting.

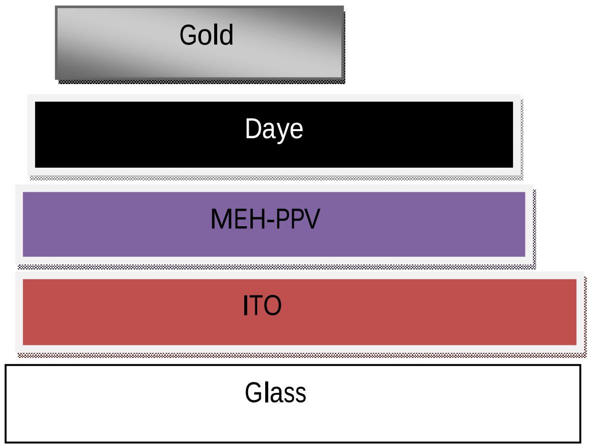


Fig (4.1) schematic structure of polymer solar cell formed with a single organic layer of MEH-PPV

4.2 The Materials of an Organic Solar Cell

4.2.1 Polymer

Polymer is a Greek phrase which means many parts. Large molecules made of repeating units of smaller molecules. Small molecules are called “monomers" monomers link together like a chain resulting in new and exciting properties.

Conjugated polymers are organic macromolecules with alternating single and double bonds. Conjugated polymers are organic semiconductors, the semiconducting behavior being associated with the pi-molecular orbital's delocalized along the polymer chain. Due to the sp2 hybridization of the electron system, conjugated polymers are mostly planar, extended macromolecules. They combine the optical and electrical properties with the mechanical advantages for preparation of optoelectronic devices .There is one unpaired electron per C- atom, which forms pi-pi* conduction and valence bands in the macromolecule due to the fact, that they describe a one-dimensional crystal.The Noble Prize in Chemistry 2000 was awarded jointly to Alan J.Heeger , Alan G. MacDiarmid and Hideki Shirakawa "for the discovery and development of conductive polymers", This discovery led, subsequently, to the discovery of electroluminescence in a poly(p-phenylenevinylene) (PPV) [10].In1990 The first light-emitting products based on electroluminescence in conjugated polymers have already been launched at the consumer market by Philips (The Netherlands) in 2002, whereas light-emitting products based on conjugated molecules have been introduced by the joint venture of Kodak and Sanyo (Japan). Going from discovery to product within a little bit more than one decade truly holds a huge promise for the future of plastic electronics. Other emerging applications are coatings for electrostatic dissipation and electromagnetic-interference shielding Conjugated polymers and molecules have the immense advantage of facile, chemical tailoring to alter their properties, such as the band gap. Conjugated polymers combine the electronic properties known from the traditional semiconductors and conductors with the ease of processing and mechanical flexibility of plastics. In this research we used poly(2-methoxy-5-(2'-ethyl-hexyloxy)-1.4 phenylene) (MEH-PPV) due to the corresponding internal quantum efficiency .The absorbed photons to electrons, is estimated to be nearly 100% in the short circuit case. The main limiting factor towards higher efficiencies is the spectral mismatch of the active layer absorption, with a maximum around 500 nm, to the terrestrial solar spectrum with a maximal photon flux between 600 and 800 nm. Therefore, the use of low band gap {E_g~ 2.0 eV}. Polymers is a viable route to increase the amount of absorbed photons and consequently the power efficiency of solar cells**.**

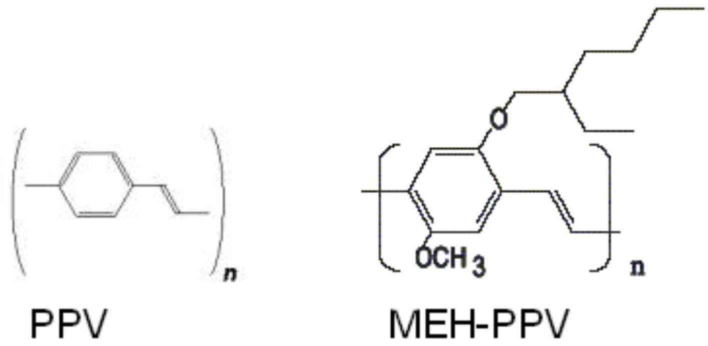


Fig (4.2) the two figures is the monomer of MEH-PPV (right) and the monomer of PPV (left)

Characterized polymers that can be turned into solids or semi-conductive for electricity as we mentioned earlier, and to make solar cells must first add a certain percentage of oxidizing substances or shorthand to become article polymeric. Similar properties semiconductors inorganic and lead impurities to situations within the scope of the gap between the bands valance band conduction. Has found that the energy gap of the semiconductor in some polymers ranging from (1.5-3 eV) and thus wider than the gap in the energy inorganic materials that range where the energy gap between 0.1-2.2 eV in and fit so with photon energy in the visible range of the solar radiation.

4.2.2 ITO

ITO (Indium Tin Oxide)is a transparent conductive material. It is a mixture of indium oxide(In_2O_3) and tin oxide (SnO_2). ITO is used as one of the electrodes in the solar cell.ITO can absorb light at the same wavelength as MEH-PPV. This is important because only the light absorbed by MEHPPV may result excitations.

4.2.3 Dyes

- **Eriochrome Black T**

Eriochrome Black T is a complex metric indicator that is part of the complex metric titrations, e.g. in the water hardness determination process. It is an azo dye. Eriochromeis a trademark of Ciba-Geigy. In its protonated form, Eriochrome Black T is blue. It turns red when it forms a complex with calcium, magnesium, or other metal ions.

- **Dry Ink**

Ink fluid containing pigment and chemical components and variety of molecules used in writing and printing on different sheets of paper or other scripts to show the different colorful graphics and designs. Inks compounds mixtures of chemical contents is not as simple as it contains the different types of solvents and oil and pigment particles chemical compounds intermingle and unite to give different properties in terms of density and flow of liquid and harmony and contrast colors in in different uses required

- **Comorian 500**

Constitution $C_{12}H_{10}NO_2F_3$ • MW: 257.21CharacteristicsLambda chrome® number: 5010 CAS registry number: - Appearance: yellow, crystalline solid Absorption maximum (in ethanol): 395 nm Molar absorptive: 1.85 x 10^4 L mol^{-1} cm^{-1} Fluorescence maximum: - For research and development purposes only

4.3 The Methodology

For the purpose of the present study polymeric devices were made following the generally accepted methods. The fabrication process started by preparing the polymer and the dye of interest then spin coated on indium tin oxide glass. Gold electrode was used to complete the formation of organic polymer solar cell.

4.3.1 Sample preparation

The polymer solar cell was made on ITO glass. The ITO glasses were firstly cleaned by ethanol and distilled water. 10mg of poly(2-methoxy-5-(2'-ethyl-hexyloxy)-1.4-phenylenevanillin) (MEH-PPV) was dissolved into 0.5ml of chloroform and 3mg of dyes (Law Sonia - Ink - Comorian (500) - Roselle - D.DT and Eriochrome Black T) dissolved into 0.5 of high pure chloroform was deposited on polymer .Been insert electrical circuit containing the (voltmeter and Ammeter and a light source) Lamp with the intensity radiological" and a solar cell). Six cells was offered to light and fulfilled taking the results of the current and voltages.

4.3.2 Spin coating

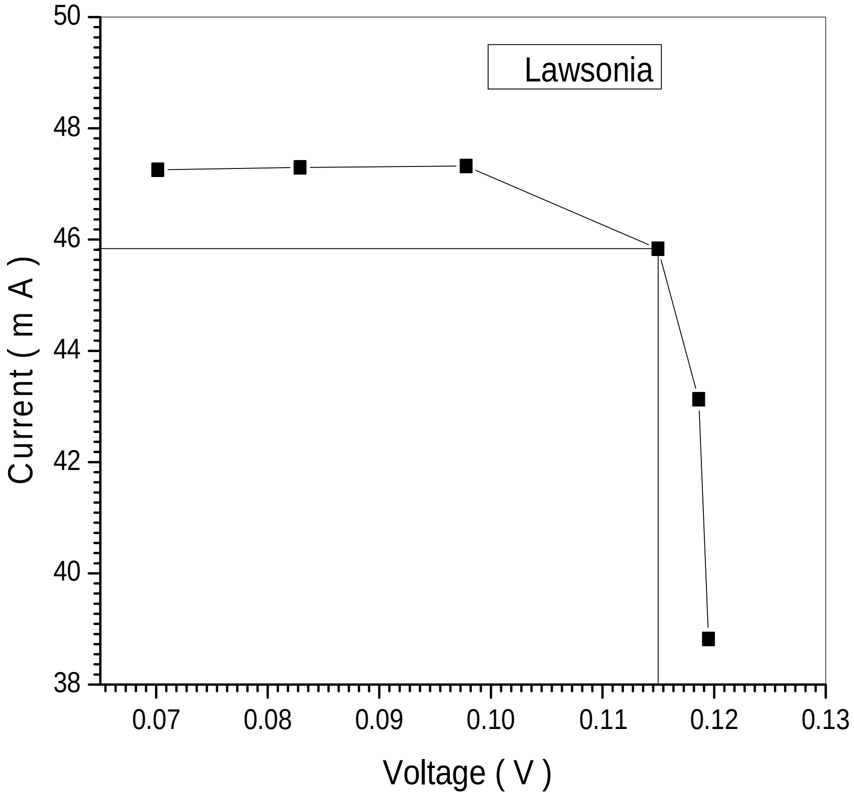
Usually a polymer thin film is made by the spin coating method. It is versatile and simple .The number of round depended of the voltage, the number of round proportional increases with the voltage, then the thickness decreases with an increase in the number of round.

Chapter five

Results and discussion

5.1 Results

In this chapter we present the results and curves obtained by the IV characteristic



curve.

Fig (5.1) several factors for characterization of polymer solar cell of Law Sonia

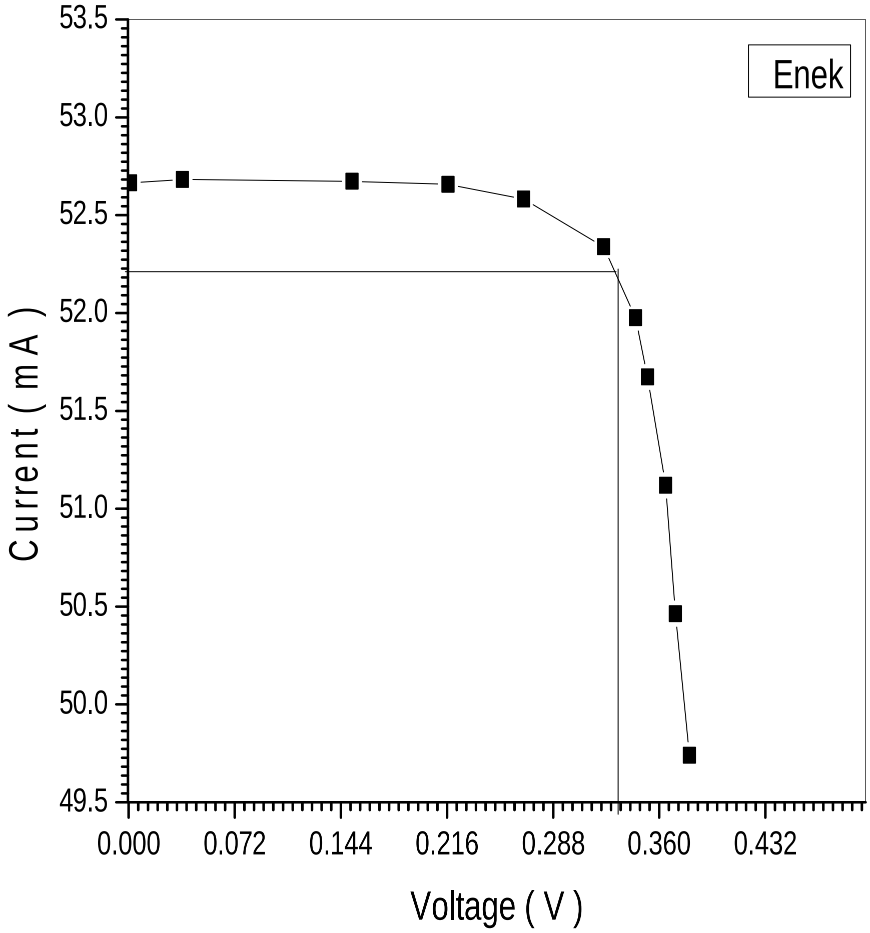
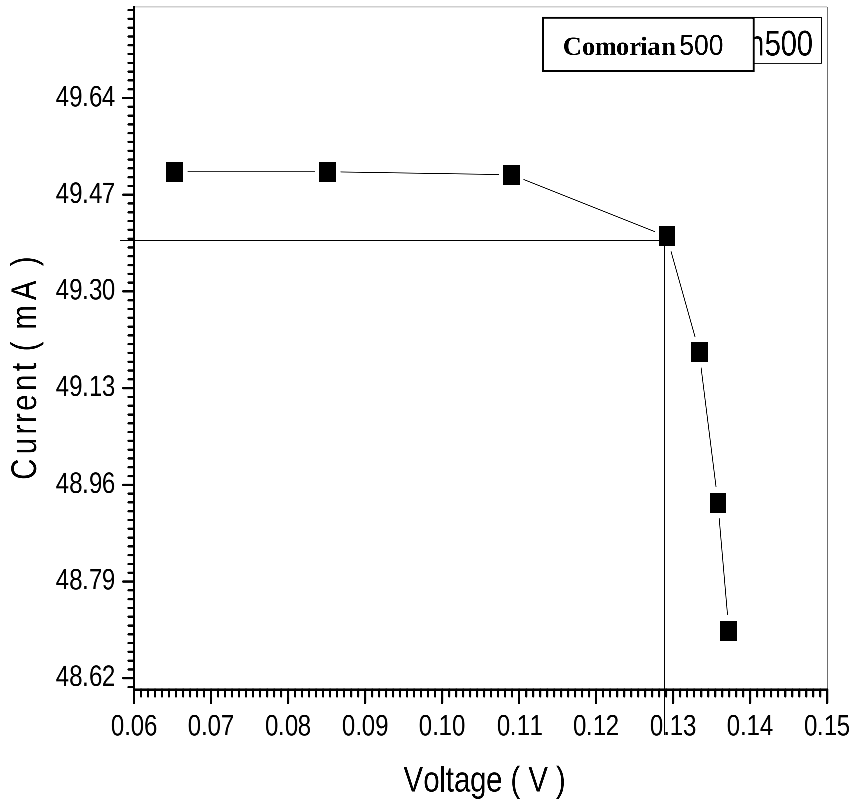


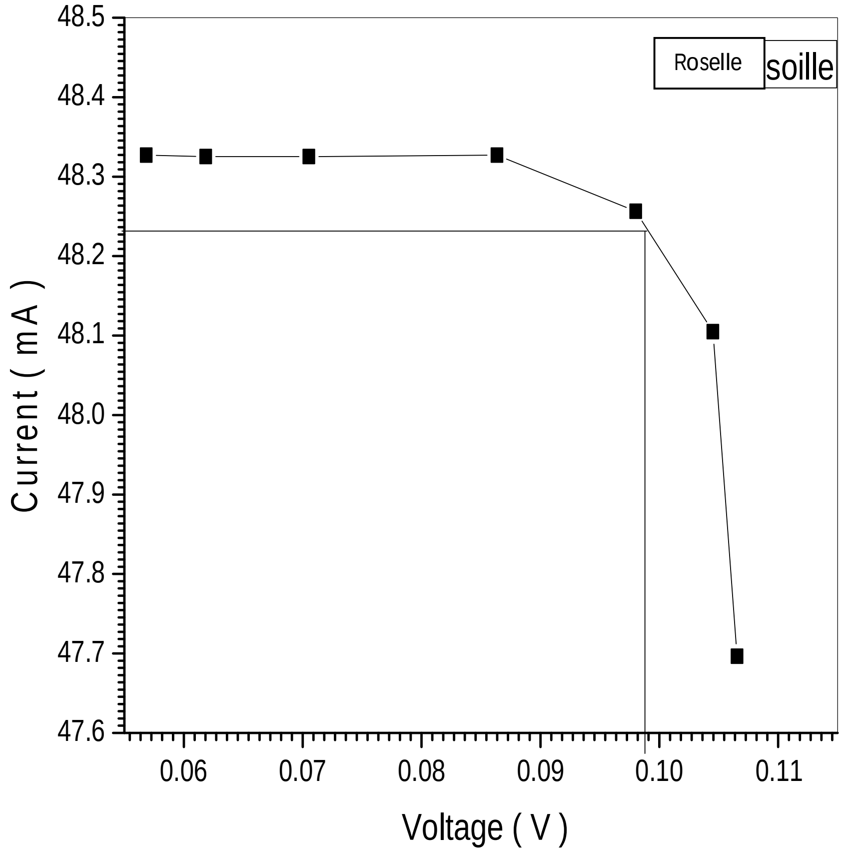
Fig (5.2) several factors for characterization of polymer solar cell of Ink

Fig **(5.3)**



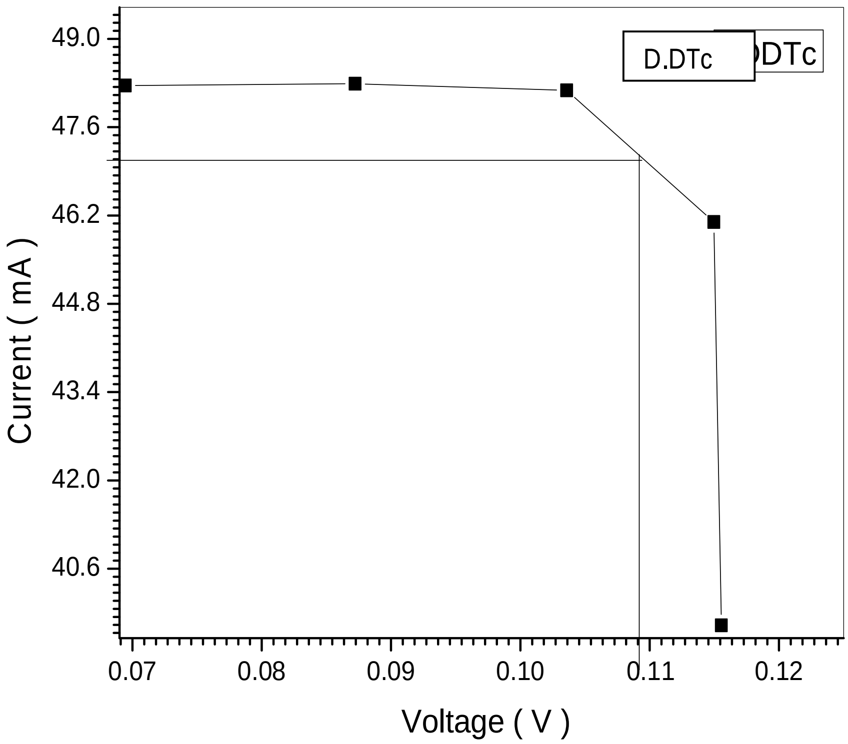
several factors for characterization of polymer solar cell of Comorian (500)

Fig



(5.4) several factors for characterization of polymer solar cell of Roselle

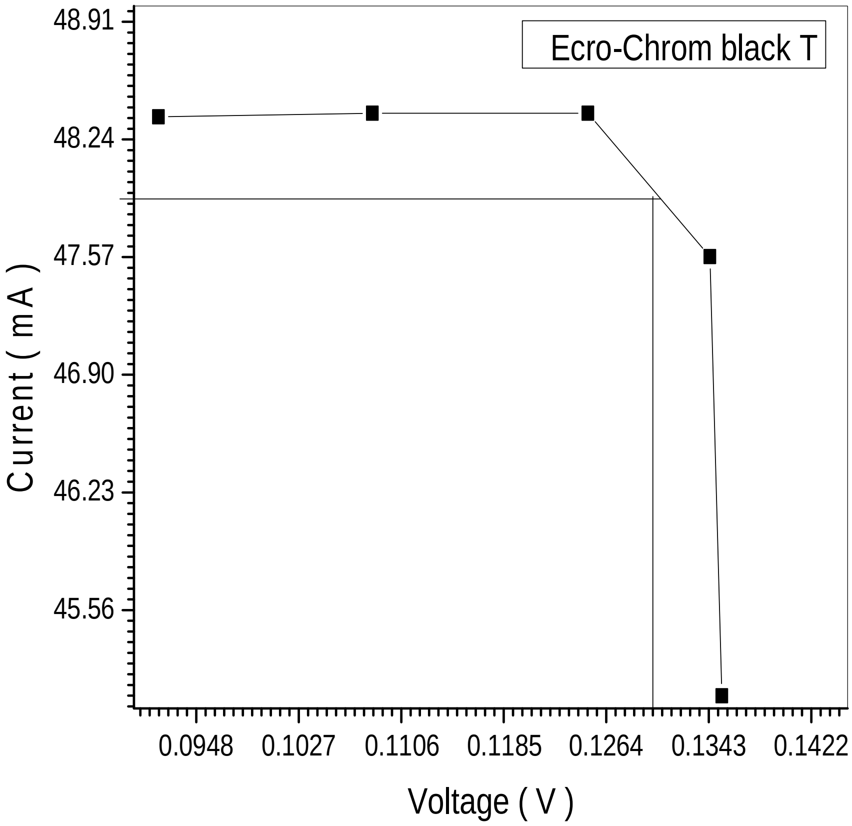
Fig



(5.5) several factors for characterization of polymer solar cell of D.DTc

Ecr-chrome

Fig



(5.6) several factors for characterization of polymer solar cell of Ecr-chrome black T

5.2 Discussion

Short-circuit current (I_{sc}) and Short-circuit current density (J_{sc})If the external circuit is simply a wire and has no appreciable resistance, the current that flows is the short-circuit current (I_{sc}) and is directly related to the number of photons of light being absorbed by the cell. Short-circuit current density (J_{sc}) is short-circuit current per active area.

$I_{SC} =$ A ……………...……………………………………………. (5.1)

$J_{sc} = I_{sc} \div active\ aera =$Acm^{-2}…………………………………. (5.2)

Open – circuit voltage (V_{oc})

V_{oc}= V…………………………………………………………… (5.2)

Fill factor (FF)

The fill factor (FF) is obtained by diving the product of current and voltage measured at the power point (maximum output power P_{max}) by the product of short-circuit current and the open-circuit voltage. The power point is the maximum product of the cell voltage and the photocurrent obtained on the I-V curve.

$P_{max} = I_{max} \times V_{max}$ =W…………………………………………. (5.3)

$FF = P_{max} \div I_{sc} \times V_{oc}$………………………………………………. (5.4)

Power conversion efficiency

The power conversion efficiency (η) of the dye-sensitized solar cell is determined by the photocurrent density measured at short-circuit, V_{oc}, the FF of the cell, and the open-circuit and J_{sc}as shown in follow equation.

$\eta = V_{oc} \times I_{sc} \times FF \div P_{in=}$%……………………………………… (5.5)

To apply all equation for the six samples Results as show in the fig (5.1- 5.2 -5.3 - 5.4 – 5.5 and 5.6) and keep the Results in table (5.1) and (5.2).

Table (5.1) the IV characteristic of Organic solar cells

1	Law Sonia	47.22	45.85	0.119	0.115
2	ENK	52.67	52.21	0.381	0.332
3	Comorian	49.5	49.38	0. 137	0.1286
4	Roselle	48.33	48.22	0. 107	0.098
5	D.DT	48.3	47.07	0.116	0.109
6	Ecr-chrome black T	48.36	47.90	0.135	0.129

Table (5.2) the IV characteristic 0f Organic solar cells

No	Sample	Area (A)cm^2	FF	J_{sc} (mA/cm^2)	η%
1	Law Sonia	6.25	0.90	7.56	0.81×10^{-3}
2	Ink	6.25	0.86	8.35	2.74×20^{-3}
3	Comorian (500)	6.25	0.94	7.92	1.02×10^{-3}
4	Roselle	6.25	0.91	7.733	$0. 75\times10^{-3}$
5	D.DT	6.25	0.92	7.73	0.83×10^{-3}
6	Ecr-chrome block T	6.25	0.95	7.74	0.96×10^{-3}

No	Sample	I_{sc} (mA)	I_{max}(mA)	$V_{oc(Volt)}$	V_{max}

5.3 Conclusion

- The application of conducting polymers to optoelectronic devices such as solar cell, light emitting diodes, and electrochemical sensors are of practical significance, because the polymer mixture can be easily prepared and modified by rich chemical procedures to meet optical and electronic requirements.
- Organic solar cell based on a Thin Film single organic active layer of (2-methoxy-5-(2-ethylhxylaxy)-p-phenylenylene)(MEH-PPV) sandwiched between Au and Indium Tin Oxide (ITO) electrodes are fabricated.
- The conversion of light energy into electrical energy, the efficiency and fill factor of polymer solar cells where are fabricated from different types of dyes (Law Sonia –Ink- Comorian (500)-Roselle - D.DT and Ecr-chrome block T) were calculated the efficiency was (Law Sonia = 0.81×10^{-3} Ink = 2.74×10^{-3} Comorian (500) = 1.02×10^{-3} Roselle = 0.75×10^{-3}DDT =0.83×10^{-3} and Ecr-chrome black T =0.96×10^{-3}). We found that the efficiency was changed when we used different types of dyes.

5.4 Recommendation

Work to increase the efficiency of solar cells integration of another type of polymer with a polymer(hetro junction) used in this research. Can also study the effect of change both the concentration of the polymer or dyes and thickness of the deposited layer. Finally these results will be different if the experiment was conducted in a wide field of solar cell where it was subjected to direct solar radiation.

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