



**Sudan University of Science and Technology**  
**College of Post Graduate Studies**



**A study of solar cell stability by use  
Coumarin 500 dye polymer**

**دراسة ثبات الخلية الشمسية البوليمرية باستخدام صبغة**

**الكومارين 500**

***A thesis submitted for partial fulfillments of the requirement  
of the degree of science master in physics***

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## **DEDICATION**

All praise to Allah, today we fold the days' tiredness and the errand summing up between the cover of this humble work.

To the utmost knowledge lighthouse, to our greatest and most honored prophet Mohamed - May peace and grace from Allah be upon him...

To the spring that never stops giving, to my mother who weaves my happiness with strings from her merciful heart....

To whom he strives to bless comfort and welfare and never stints what he owns to push me in the success way who taught me to promote life stairs wisely and patiently, to my dearest father...

To whose love flows in my veins and my heart always remembers them, to my brothers and sisters....

To those who taught us letters of gold and words of jewel of the utmost and sweetest sentences in the whole knowledge. Who reworded to us their knowledge simply and from their thoughts made a lighthouse guides us through the knowledge and success path, To our honored teachers and professors....

## **ACKNOWLEDGEMENT**

Firstly the praise is to Allah, for his generous bounties... My thanks to D. RawiaAbdelganiElobaid my supervisor who introduced me to this research and help me throughout this project ... my thank also extended to prof MubarkDirarAbd-alla , and to all people who made it possible for me accomplish this achievement .

# الآية

بسم الله الرحمن الرحيم

قال تعالى:

هُوَ الَّذِي جَعَلَ الشَّمْسَ ضِيَاءً وَالْقَمَرَ نُورًا وَقَدَرَهُ مَنَازِلَ لِتَعْلَمُوا عَدَدَ السِّنِينَ  
وَالْحِسَابَ ۗ مَا خَلَقَ اللَّهُ ذَكَكَ إِلَّا بِالْحَقِّ ۗ يُفَصِّلُ الْآيَاتِ لِقَوْمٍ يَعْلَمُونَ ﴿٥﴾

صدق الله العظيم

سورة يونس

الايه (5)

## ABSTRACT

in this work two dye polymer solar cells V-I characteristics were studied their stability .the Voltage-Current characteristics were studied for about one month ,the experimental results after (1,10,20,30) days was found that the open voltage current does not change while open circuit voltage changes slightly .

this means that the cells does not affected by environment and some water may evaporate .evaporation is responsible for current decrease.

## المستخلص

في هذا العمل تم دراسة استقرارية خصائص الجهد والتيار لاثنين من الخلايا الشمسية الصبغية البوليمرية. تم دراسة خصائص التيار والجهد لمدة شهر (1 و10 و20 و30) يوم, ومن التجارب المعملية وجد أن التيار الكهربائي المفتوح تغير قليلا بينما جهد الدائرة المفتوح لم يتغير. وهذا يعني أن الخلايا لم تتأثر بالبيئة وان بعض المياه قد تبخرت. التبخر هو المسؤول عن انخفاض التيار.

## Contents

### Table of content

No	Subject	Page No
1	DEDICATION	I
2	Acknowledgement	II
3	الأية	III
4	Abstract	IV
5	المستخلص	V
6	Table of content	VI
7	List of tables	VIII
8	List of Figure	IX
<b>Chapter one Introduction</b>		
1.1	Introduction	1
1.2	The goal of research	1
1.3	Problem Formulation	1
1.4	Literature review	2
1.5	Thesis Layout	3
<b>Chapter two Theoretical part</b>		
2.1	Introduction	4
2.2	Solar Energy	4
2.3	Advantages of Solar Energy	4
2.4	Disadvantages of Solar Energy	5
2.5	Solar Energy applications	6
2.6	Solar Cells	9
2.6.1	Photons	9
2.6.2	Absorption of photons	9
2.6.3	Doping	10
2.6.4	Generation of electrons and holes	10
2.6.5	Pn-Junctions	11
2.6.6	Electrons and Holes	13
2.6.7	<i>P-Type</i> and <i>n-Type</i> Semiconductors	14
2.7	Solar Cell Equation	15

2.7.1	Maximum Power and Fill Factor	17
2.8	Theories	19
2.9	Structure	20
2.10	Types of solar cells	21
<b>Chapter Three – Methodology</b>		
3.1	Introduction	25
3.2	Organic Solar Cells	26
3.3	Types of organic solar cells	29
3.3.1	Dye-Sensitized Solar Cells	28
3.3.2	Polymer solar cells	31
3.3.2.1	Basic processes of polymer solar cell	33
3.4	Methodology	34
<b>Chapter Four - Results and Discussion</b>		
4.1	Introduction	35
4.2	Results	35
4.3	Discussion	40
4.4	Concolution	40
4.5	Recommendations	40
	References	



# List of Tables

<b>No</b>	<b>Subject</b>	<b>Page No</b>
4.1	The value of current and voltage for sample one	35
4.2	The value of different current for sample one	36
4.3	The value of current and voltage for sample two	37
4.4	The value of different current for sample two	38

# List of Figures

No	Subject	Page No
2.1	Conductor, Semiconductor, and Insulator	12
2.2	Band Srtucture for Intrinsic Semiconductors	13
2.3	Band tructure for <i>n</i> -type Semiconductor	14
2.4	Band Structure for <i>p</i> -type Semiconductor	15
2.5	Equivalent circuit of solar cell	17
2.6	Band Diagram of Solar Cell	19
2.7	Mechanism of Solar Cell	20
2.8	Structure of Photovoltic Cell	20
3.1	Organic Solar Cell	27
3.2	Structure of dye-sensitized solar cell	30
3.3	Connection of the Circuit	33
4.1	Current and voltage for the Sample one	35
4.2	Current for the Sample onethe different	36
4.3	Current and voltage for the Sample two	37
4.4	Current for the Sample twothe different	38

# Chapter One

## 1.1 Introduction

The light from the Sun is a non-vanishing renewable source of energy which is free from environmental pollution and noise. It can easily compensate the energy drawn from the non-renewable Sources of energy such as fossil fuels and petroleum deposits inside the earth. The fabrication of solar cells has passed through a large number of improvement steps from one generation to another.

Silicon based solar cells were the first generation solar cells grown on Si wafers, mainly single crystals. Further development to thin films, dye sensitized solar cells and organic solar cells enhanced the cell efficiency.

The development is basically hindered by the cost and efficiency.

In order to choose the right solar cell for a specific geographic location, we are required to understand fundamental mechanisms and functions of several solar technologies that are widely studied.

In this Thesis, we have reviewed a progressive development in the solar cell research from one generation to other, and discussed about their future trends and aspects. The Thesis also tries to emphasize the various practices and methods to promote the benefits of solar energy.

## 1.2 The Goal of Research

The goal of this project is to establish an encapsulation procedure that provides increased performance stability for organic solar cells. the characterizing of the produced cells by I-V measurements to determine their efficiency. Furthermore the

cells are encapsulated and variations in the performances over time for different encapsulation materials are investigated.

### **1.3 Problem Formulation**

The core problem of this project is the degradation of the polymer solar cells which results in a short lifetime. The ultimate objective of this project is to investigate encapsulation of polymer solar cells in order to find materials that consider following requirements: a high barrier to water and oxygen, optical transparency, mechanical flexibility and low cost with the aim to establish an encapsulation procedure that prolongs the lifetime of the organic solar cell.

This project will include both theoretical and experimental aspects of polymer solar cells and their lifetime.

### **1.4 Literature review**

While most early reports of stability and degradation in polymer organic photovoltaics date back to the beginning of the 1990s, the topic has from the beginning not been independent but has been included as footnotes in other studies or briefly mentioned in passing. The earliest example is perhaps by Yu et al. from the group of A.J. Heeger that state the importance of degradation and stability and report preliminary data on the dark stability for devices kept in a glovebox over a period of 3 months. The illumination intensity used for the sporadic measurements of the efficiency was as low as  $20\text{mWcm}^{-2}$ . The authors in this paper also promised that a detailed study was under way but it has yet to be seen. From this point of view, it is problematic to find many of the reports, as they are fragmented and not readily searchable since the words rarely enter the title, abstract or keywords. An exhaustive list of these early pieces of information is thus impossible to provide while an overview is given in the following. There has also been a clear trend from

these early reports to single observations without ties to the existing literature on stability and degradation where the issue has been addressed properly over a well-defined period of time and most often the experiment was described to the extent that the results are useful. An absolute prerequisite is the knowledge of the incident light intensity, the spectrum of the incident light, the manner of illumination (continuous, intermittent, short, only during IV-curves), the temperature of the device during the experiment, the atmosphere (i.e. humidity, oxygen content, glove box, vacuum etc). Furthermore, a lot of the work pertaining to the stability of OLEDs and PLEDs that was reported in the 1990s is highly relevant for polymer/organic photovoltaics. There are however, some important differences in the operation of these two types of devices that might change some of the contributing factors significantly.

The final and most recent trend is the detailed and deliberate study of the stability of the devices and of the chemical and physical degradation mechanisms. Testing of the lifetime can be standardized to allow direct comparison from different research groups. Efficiency measurements and solar simulation has been standardized for some time according to IEC and ASTM standards, though some ambiguity still exists in the literature. Similarly, lifetime measurements could be standardized so that it might be possible to compare studies from different research groups and industry.

Stability/degradation of polymer solar cells has not been reviewed previously as a separate issue, but has received attention in other reviews. In contrast to the measure of power conversion efficiency, there is no single indicator for stability and for this reason most reports on stability employ different measures and different experimental conditions.

## **1.5 Thesis Layout**

This thesis is consist of four chapters, chapter one Introduction, chapter tow consist Basic Concepts of solar cells, chapter three consist Experimental Part (The materials and device and method), chapter four consist Results and Discussion.

## **Chapter Two**

### **Solar Cells**

#### **2.1 Introduction**

The direct conversion of light into electricity is done by solar cells. The usage of solar energy for heat has a long history but the origin of devices which produce electricity is much more recent. It is closely linked to modern solid-state electronics. Indeed, the firs usable solar cell was invented at Bell laboratories, the birthplace of the transistor in the early 1950. The first solar cells found a ready application in supplying electrical power to satellites.

#### **2.2 Solar Energy**

Except fossil fuels, there are still a lot of energy resources we could utilize in the world, such as nuclear power, wind power and hydro energy. The reason why we

choose solar energy instead of other energy source we could use is because solar energy possesses some advantages over the others.

### **2.3 Advantages of Solar Energy:**

Solar energy remains popular because it is both a renewable and clean source of energy. These advantages along with the hope that eventually nations can use solar power to decrease global warming ensure its popularity [1].

#### **❖ Renewable**

Solar energy is a true renewable resource. All areas of the world have the ability to collect some amount of solar power and solar power is available for collection each day.

#### **❖ Clean**

Solar energy is non-polluting. It does not create greenhouse gases, such as oil based energy does, nor does it create waste that must be stored, such as nuclear energy. It is also far quieter to create and harness, drastically reducing the noise pollution required converting energy to a useful form. Residential size solar energy systems also have very little impact on the surrounding environment, in contrast with other renewable energy sources such as wind and hydroelectric power.

Solar energy is easily available all around the world. Unlike wind power and hydro energy, solar energy spread out more evenly in the world.

#### **❖ Low Maintenance**

Solar panels have no moving parts and require very little maintenance beyond regular cleaning. Without moving parts to break and replace, after the initial costs of installing the panels, maintenance and repair costs are very reasonable.

Solar energy is easily available all around the world. Unlike wind power and hydro energy, solar energy spread out more evenly in the world. There are also more advantages of solar energy, such as minimum byproduct compared to other energies, no disposal method necessary, less space required and relative low cost and high efficiency

## **2.4 Disadvantages of Solar Energy:**

### **❖ Cost**

The largest problem of using primarily solar energy is the cost involved. Despite advances in technology, solar panels remain almost prohibitively expensive. Even when the cost of the panels is ignored, the system required to store the energy for use can also be quite costly

### **❖ Weather Dependent**

Although some solar energy can be collected during even the cloudiest of days, efficient solar energy collection is dependent on sunshine. Even a few cloudy days can have a large effect on an energy system, particularly once that fact that solar energy cannot be collected at night is taken into account.



## ❖ **Geographic Limitations**

While some areas would benefit from adapting solar power, other parts of the world would receive little benefit from current solar systems. Solar panels still require direct sunlight to collect large amounts of power, and in many areas of the world there are few days that would efficiently power a system.

## **2.5 Solar Energy applications:**

### ▪ **Concentrating Solar Power (CSP):**

Concentrating solar power (CSP) plants are utility-scale generators that produce electricity using mirrors or lenses to efficiently concentrate the sun's energy. The four principal CSP technologies are parabolic troughs, dish-Sterling engine systems, central receivers, and concentrating photovoltaic systems (CPV).

### ▪ **Solar Thermal Electric Power Plants:**

Solar thermal energy involves harnessing solar power for practical applications from solar heating to electrical power generation. Solar thermal collectors, such as solar hot water panels, are commonly used to generate solar hot water for domestic and light industrial applications. This energy system is also used in architecture and building design to control heating and ventilation in both active solar and passive solar designs.

### ▪ **Photovoltaic:**

Photovoltaic or PV technology employs solar cells or solar photovoltaic arrays to convert energy from the sun into electricity. Solar cells produce direct current electricity from the sun's rays, which can be used to power equipment or to recharge batteries. Many pocket calculators incorporate a single solar cell, but for larger applications, cells are generally grouped together to form PV modules that are in turn arranged in solar arrays. Solar arrays can be used to power orbiting satellites and other spacecraft, and in remote areas as a source of power for roadside emergency telephones, remote sensing, and cathode protection of pipelines.

- **Solar Heating Systems:**

Solar hot water systems use sunlight to heat water. The systems are composed of solar thermal collectors and a storage tank, and they may be active, passive or batch systems.

- **Passive Solar Energy:**

It concerns building design to maintain its environment at a comfortable temperature through the sun's daily and annual cycles. It can be done by (1) Direct gain or the positioning of windows, skylights, and shutters to control the amount of direct solar radiation reaching the interior and warming the air and surfaces within a building; (2) Indirect gain in which solar radiation is captured by a part of the building envelope and then transmitted indirectly to the building through conduction and convection; and (3) Isolated gain which involves passively capturing solar heat and then moving it passively into or out of the building via a liquid or air directly or using a thermal store. Sunspaces, greenhouses, and solar

closets are alternative ways of capturing isolated heat gain from which warmed air can be taken.

- **Solar Lighting:**

Also known as daylighting, this is the use of natural light to provide illumination to offset energy use in electric lighting systems and reduce the cooling load on HVAC systems. Daylighting features include building orientation, window orientation, exterior shading, saw tooth roofs, clerestory windows, light shelves, skylights, and light tubes. Architectural trends increasingly recognize daylighting as a cornerstone of sustainable design.

- **Solar Cars:**

A solar car is an electric vehicle powered by energy obtained from solar panels on the surface of the car which convert the sun's energy directly into electrical energy. Solar cars are not currently a practical form of transportation. Although they can operate for limited distances without sun, the solar cells are generally very fragile. Development teams have focused their efforts on optimizing the efficiency of the vehicle, but many have only enough room for one or two people.

- **Solar Power Satellite:**

A solar power satellite (SPS) is a proposed satellite built in high Earth orbit that uses microwave power transmission to beam solar power to a very large antenna on Earth where it can be used in place of conventional power sources. The advantage of placing the solar collectors in space is the unobstructed view of the

sun, unaffected by the day/night cycle, weather, or seasons. However, the costs of construction are very high, and SPSs will not be able to compete with conventional sources unless low launch costs can be achieved or unless a space-based manufacturing industry develops and they can be built in orbit from off-earth materials.

## 2.6 Solar Cells:

Solar cells are one type of photovoltaic cells which generate electrical power by converting energy of light into direct current electricity by using semiconductors that exhibit the photovoltaic effect. In the photovoltaic effect, electrons are transferred between different bands (usually from the valence bands to conduction bands) within the material, resulting in the buildup of voltage between two electrodes. In solar cell, the primary energy source is sunlight.

### 2.6.1 Photons:

Photons are particles of light. Photons to which the human eye reacts, that is which we see, have energies *heo* between 1.5 eV and 3eV. They always move with the velocity of light, in a vacuum with a velocity of  $c_0 = 3 \times 10^8$  m/s and in a medium with refractive index  $n$  with a velocity of  $c = c_0/n$ . The fact that we can also describe light as an electromagnetic wave is in no way contradictory. The square of the field strength of the electromagnetic wave describes the location of the photons. In contrast to the behavior familiar from shot pellets, photons obey the laws of quantum mechanics and not those of the more common Newtonian mechanics. The differences from Newtonian mechanics become apparent only for particles of very low energy (including the mass). Since it is difficult to visualize particles which do not move along a straight line, in a dualistic approach the wave

property is generally invoked to describe diffraction and interference phenomena and the particle property is used to describe the quantum-like transport of energy [2].

### **2.6.2 Absorption of photons:**

For solar cells, the generation of electrons and holes by the absorption of photons is the most important process. The probability for the absorption of a photon of energy is defined by the absorption coefficient, which is a material property, independent of the geometry of a body. Since absorption requires that an electron-hole pair is generated, is proportional to the density of occupied states in the valence band in which a hole can be generated, and unoccupied states in the conduction band in which an electron can be generated. The changes in occupation by the absorption of a photon must, of course, conserve momentum and energy.

### **2.6.3 Doping:**

Doping of semiconductors means the introduction of impurity atoms. In the simplest case, these atoms replace the atoms of the semiconductor at their lattice positions. Figure 3.11 depicts this schematically for a lattice of atoms with a valence of four.

Donors (D) are impurity atoms which, as a rule, have one valence electron more than is necessary for chemical bonding with the neighboring atoms. The electron not required for bonding is electrically bound to its atom by Coulomb forces as a negative charge in the field of a positive charge.

### **2.6.4 Generation of electrons and holes:**

Electrons and holes are produced by processes which can supply at least the minimum generation energy of an electron-hole pair. This includes impact ionization, in which an electron (or hole) with enough kinetic energy knocks a

bound electron out of its bound state (in the valence band) and promotes it to a state in the conduction band, thereby creating an electron and a hole. The same process of exciting an electron from the valence band to the conduction band may take place with a giant lattice vibration supplying the energy or by the absorption of a photon. In the presence of impurities providing states with energies in the energy gap, the excitation can take place in several steps and the generation energy can be supplied in smaller portions by phonons or even photons [2].

### **2.6.5PN-Junctions:**

To date, most solar cells are made of semiconductors. A semiconductor is characterized by a relatively narrow energy gap, typically a fraction of an electron volt to a few electron volts. Electrons can be excited by a photon from the valence band to the conduction band and form an electron–hole pair. The electron–hole pair stores a substantial portion of the photon energy. After formation of the electron–hole pairs, the pn-junction separates the electrons and holes to generate external electric current. In this chapter, we will learn the basic physics of semiconductors and pn-junctions.

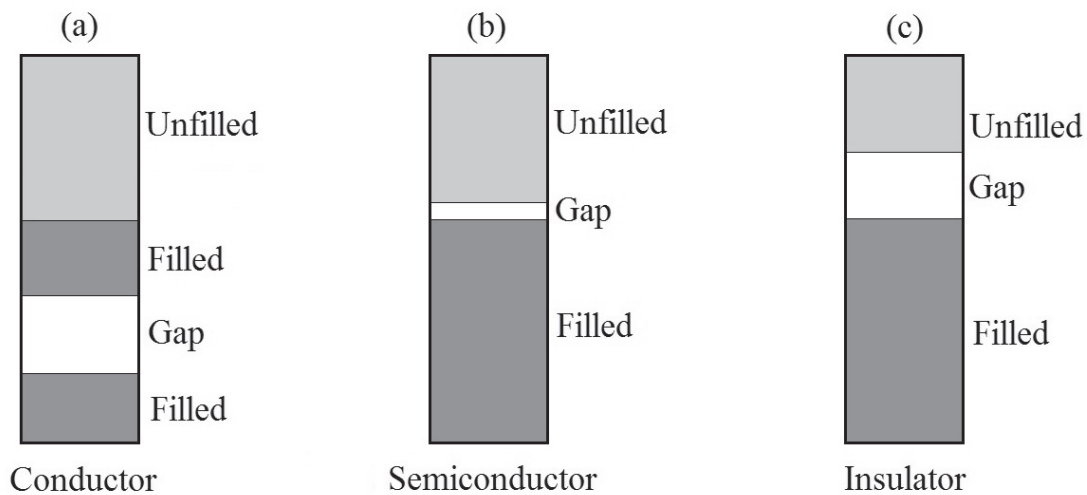
#### 2.1 Semiconductors

##### 2.1.1 Conductor, Semiconductor, and Insulator

When a large number of atoms come together to form a solid, the wavefunctions of atoms interact to form extended states which are similar to the one-dimensional crystal. A number of energy bands are formed. In general, the number of states is infinite. According to the Pauli Exclusion Principle, each state can only be occupied by one electron. Imagine electrons are added to a system one by one, starting from the state with lowest energy. At one point, the number of electrons equals the number of protons in the system and the system becomes neutral.

According to the relative position of the energy bands and the highest occupied energy level, there are three different cases, as shown in Fig. 2.1. In Fig. 2.1(a), the highest occupied energy level is in the middle of an energy band. The electrons can move to the unoccupied parts of the energy band. This type of material is called a conductor or a metal. If the highest occupied energy level matches the top of an energy band, which is called the valence band, marked as  $E_v$ , and the distance to the next energy band is large, the electrons are not easily excited to the higher band. This type of materials is called an insulator; see Fig. 2.1 (c).

An important case between those two is the semiconductor, where the gap between the top of the valence band  $E_v$  and the bottom of the next energy band  $E_c$  is small such that when the temperature is not too low electrons can be excited to the next energy band, the conduction band. Typically the energy gap is less than a few electron volts. Once the electrons are excited to the conduction band, some conduction can take place. See Fig. 2.1(b). Figure 2.2 shows the band gaps of a number of important semiconductors related to solar cells. [1]



### **Figure 2.1 Conductor, Semiconductor, and Insulator.**

(a) For conductors, the highest occupied energy level is in the middle of an energy band.

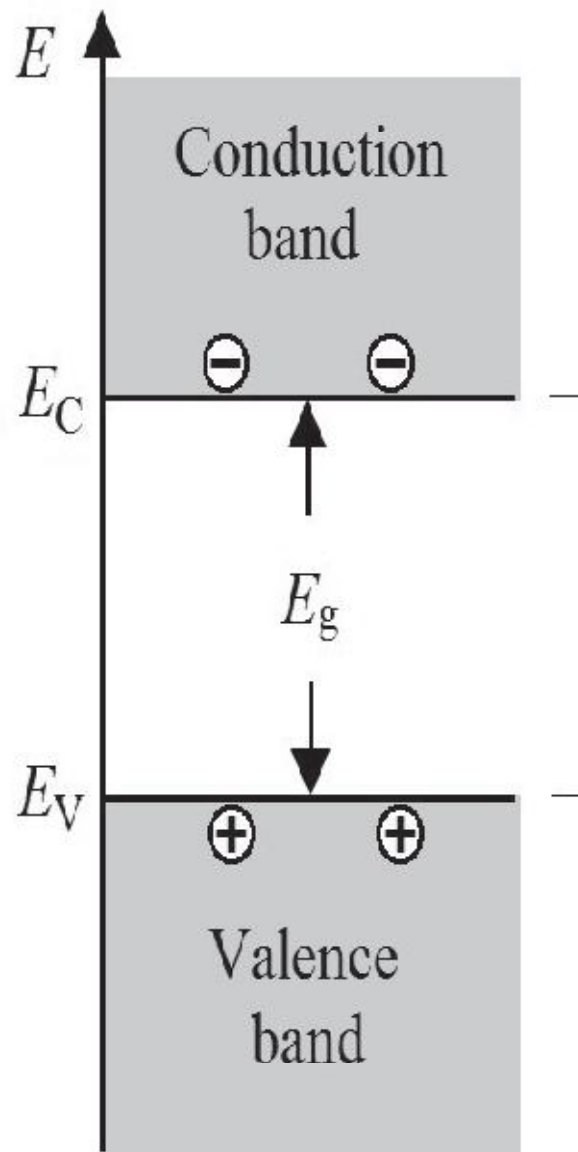
(b) For semiconductors, the highest occupied energy level matches the top of the valence band but the energy gap to the conduction band is small.

(c) If the energy gap is big, the solid is an insulator.

### **2.6.6 Electrons and Holes:**

At low temperature, pure semiconductors have almost no mobile electrons, and by raising the temperature, electrons in the valence band can be excited to the conduction band; see Fig. 2.2. Therefore, a semiconductor has an important property: Conductivity depends critically on temperature — the higher the temperature, the higher the conductivity.





**Figure 2.2 BAND STRUCTURE**

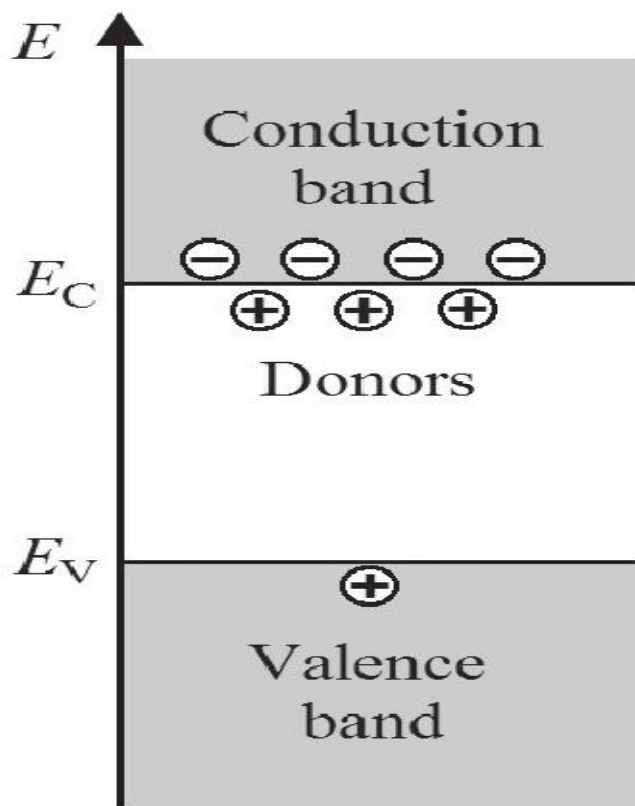
**Intrinsic semiconductors: Free electrons and holes**

Thermal excitation could raise electrons from the valence band to the conduction band, to make electron-hole pairs.

**2.6.7 P-Type and n-Type Semiconductors:**

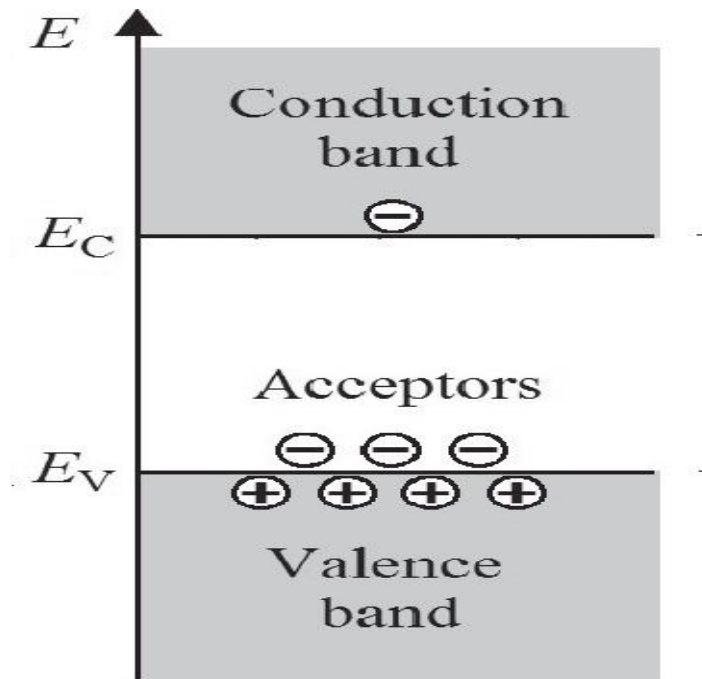
Semiconductors have an even more important property: their conductivity critically depends on the type and concentration of *impurities*. According to the position of the energy level of the atoms in the band gap of a semiconductor, there are two major types of impurities. The energy level of *donor* atoms is just below the bottom of the conduction band.

The impurity atom can easily be ionized to contribute an electron to the conduction



**Figure 2.3 Band Structure  
N-type semiconductor**

The donor atoms release electrons into the conduction band. The Fermi level shifts toward the conduction band. The concentration of free electrons approximately equals the concentration of donor atoms.



**Figure 2.4 BAND STRUCTURE  
The p-type Semiconductor.**

The acceptor atoms grab electrons from the valence band to create holes. The Fermi level shifts toward the valence band. The concentration of holes approximately equals the concentration of acceptor atoms. Where  $p$  is the hole concentration in an  $n$ -type semiconductor and  $n$  is the free-electron concentration in a  $p$ -type semiconductor.

## 2.7 Solar Cell Equation:

A solar cell can be represented by a current source connected in parallel with a *pn* junction diode. The current source is the photocurrent generated by incoming sunlight: [1]

$$I = I_0(e^{qV/kBT} - 1) - I_{sc} \quad (2.1)$$

Which is the fundamental equation of solar cells, while the voltage is always positive, the current is always negative. By considering the solar cell as a battery, the direction of current should be reversed. Therefore, a better form of the solar cell equation is

$$I = I_{sc} - I_0(e^{qV/kBT} - 1) - I_{sc} \quad (2.2)$$

where both voltage and current are always positive The open-circuit voltage is the voltage when the current is zero, defined by the condition

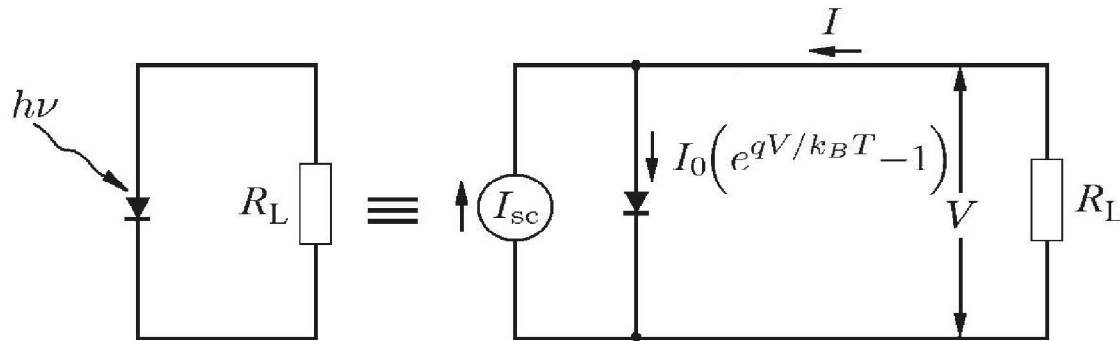
$$I_0(e^{qV_{oc}/kBT} - 1) = I_{sc} \quad (2.3)$$

Consequently,

$$V_{oc} = \frac{k_B T}{q} \ln\left(\frac{I_{sc}}{I_0} + 1\right) \quad (2.4)$$

Because  $I_{sc}$  is always much bigger than  $I_0$

$$V_{OC} = \frac{k_B T}{q} \ln \frac{I_{sc}}{I_0}$$



**Fig2.5 Equivalent circuit of solar cell.** A solar cell can be represented by a current source.

connected in parallel with a pn-junction diode. The current source is the photocurrent generated by

incoming sunlight.

### 2.7.1 Maximum Power and Fill Factor:

The output power of a solar cell is determined by the product of voltage and current.

$P = IV$  ., it is always smaller than the product of the short-circuit current  $I_{sc}$  and the open-circuit voltage  $V_{oc}$  The rated power of a solar cell is the maximum power output with an influx of photons of one sun, or 1

KW/m<sup>2</sup>, under favorable impedance-matching conditions. In general, the condition of maximum power is:

$$P = IV = (I_{sc} - I_0(e^{qV/kBT} - 1))^{-1} \quad (2.5)$$

From Fig. we observe that the voltage of maximum power is only slightly smaller than the open-circuit voltage. Introduce a voltage offset  $v$ , we write

$$V = V_{oc} - v \quad (2.6)$$

can be simplified to

$$P \approx I_{sc}(V_{oc} - v)(1 - e^{-qV/kBT}) \quad (2.7)$$

Taking the derivative of  $P$  with respect to  $v$ , the condition of maximum power is

$$e^{qv/kBT} = 1 + \frac{qV_{oc}}{kBT} \quad (2.8)$$

Eq. 2.8 becomes:

$$e^{qv/kBT} = 1 + \ln \frac{I_{sc}}{I_0}$$

Because  $I_{sc} \gg I_0$ , we find

$$(2.9) \quad v = \frac{k_B T}{q} \ln \ln \frac{I_{sc}}{I_0}$$

Therefore, the voltage at maximum power is

$$V_{mp} = V_{oc} - v = V_{oc} \left( 1 - \frac{\ln \ln(I_{sc}/I_0)}{\ln(I_{sc}/I_0)} \right) \quad (2.10)$$

and the current at maximum power is

$$I_{mp} = I_{sc}(1 - e^{-qV/kBT}) = I_{sc}(1 - \frac{1}{\ln(I_{sc}/I_0)}) \quad (2.11)$$

**After some simplification, maximum power is:**

$$P_{mp} = I_{mp}V_{mp} = V_{oc}I_{sc}(1 - \frac{1 + \ln \ln(I_{sc}/I_0)}{\ln(I_{sc}/I_0)}) \quad (2.12)$$

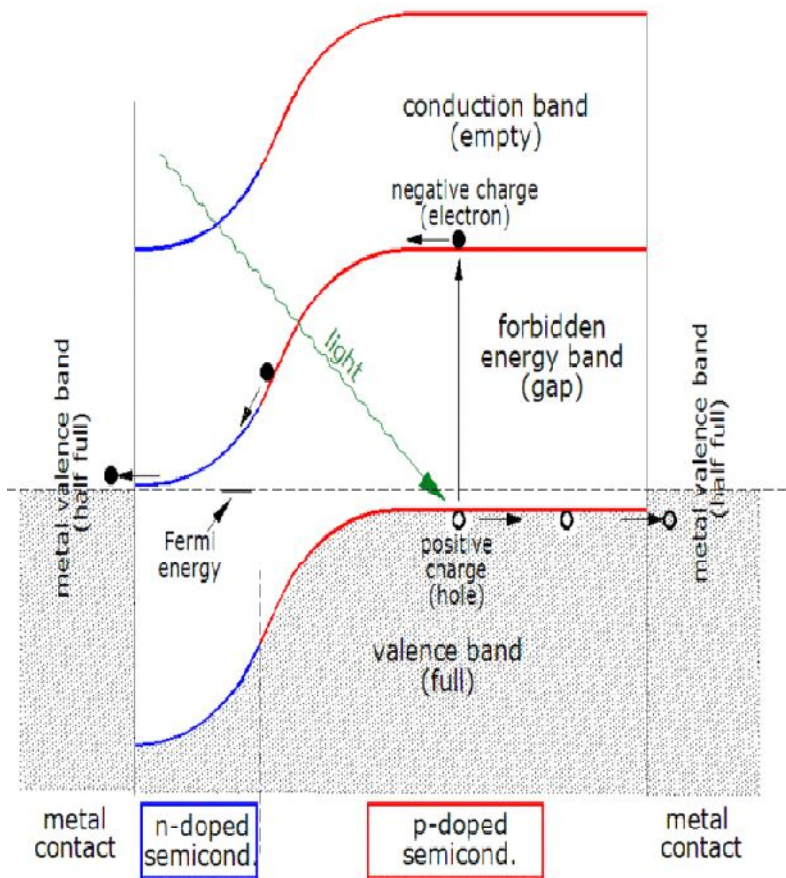
The fill factor  $\eta_f$ , defined as

$$(2.13) \quad \eta_f \equiv \frac{I_{mp}V_{mp}}{V_{oc}I_{sc}}$$

## 2.8 Theories:

In order to understand the function of solar cells and to improve the performance of it, theories behind solar cells should be studied and well understood.

The first step in solar cell function always involves photon absorption by a semiconducting material. When the photon is absorbed, the energy of photon will be transferred to valence electrons in crystal, which excite an electron to another band, called the conduction band, in which, electrons can freely move. Figure 2.6 shows different band gap in conducting materials [3]

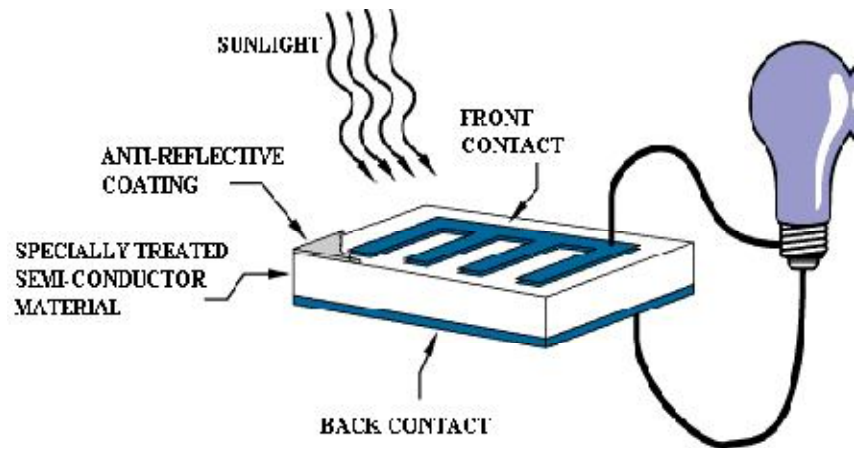


**Figure 2.6: Band Diagram of Solar Cell**

Then, the free electrons can move to one single direction because of the special composition of solar cells, which then generates current.

Finally, arrays of solar cell convert solar energy to electricity. Figure 2.7 illustrates the theories of solar cells





**Figure 2.7: Mechanism of Solar Cell**

## 2.9 Structure:

Figure 2.8 shows the complete structure of a common solar cell.



**Figure 2.8: Structure of Photovoltaic Cell**

The different parts in the solar cells are the parts listed below.

- A. Encapsulate – Encapsulate which is made of glass or other clear material such clear plastic seals the cell from the external environment.
- B. Contact Grid- The contact grid is made of a good conductor, such as a metal, and it serves as a collector of electrons.
- C. The Antireflective Coating (AR Coating) - Through a combination of a favorable refractive index, and thickness, this layer serves to guide light into the solar cell. Without this layer, much of the light would simply bounce off the surface.
- D. N-Type Silicon - N-type silicon is created by doping (contaminating) the Si with compounds that contain one more valence electrons than Si does, such as with either Phosphorus or Arsenic. Since only four electrons are required to bond with the four adjacent silicon atoms, the fifth valence electron is available for conduction.
- E. P-Type Silicon- P-type silicon is created by doping with compounds containing one less valence electrons than Si does, such as with Boron. When silicon (four valence electrons) is doped with atoms that have one less valence electrons (three valence electrons), only three electrons are available for bonding with four adjacent silicon atoms, therefore an incomplete bond (hole) exists which can attract an electron from a nearby atom. Filling one hole creates another hole in a different Si atom. This movement of holes is available for conduction.
- F. Back Contact - The back contact, made out of a metal, covers the entire back surface of the solar cell and acts as a conductor. [4]

## **2.10Types of solar cells:**

For clarity of the topic it will briefly introduce some of the important types of solar cell technologies.

- **Nanocrystalline solar cells**

These structures make use of some of the same thin-film light absorbing materials but are overlain as an extremely thin absorber on a supporting matrix of conductive polymer or mesoporous metal oxide having a very high surface area to increase internal reflections (and hence increase the probability of light absorption). Using Nano crystals allows one to design architectures on the length scale of nanometers, the typical electron diffusion length. In particular, single-nanocrystal ('channel') devices, an array of single p-n junctions between the electrodes and separated by a period of about a diffusion length, represent a new architecture for solar cells and potentially high efficiency.

- **Polymer solar cells**

The invention of conductive polymers may lead to the development of much cheaper cells that are based on inexpensive plastics. However, organic solar cells generally suffer from degradation upon exposure to UV light, and hence have lifetimes which are far too short to be viable. The bonds in the polymers, are always susceptible to breaking up when radiated with shorter wavelengths. Additionally, the conjugated double bond systems in the polymers which carry the charge, react more readily with light and oxygen. So most conductive polymers, being highly unsaturated and reactive, are highly sensitive to atmospheric moisture and oxidation, making commercial applications difficult.

- **Transparent conductors**

Many new solar cells use transparent thin films that are also conductors of electrical charge. The dominant conductive thin films used in research now are transparent conductive oxides ("TCO"), and include fluorine-doped tin oxide ( $\text{SnO}_2\text{:F}$ , or "FTO"), doped zinc oxide and indium tin oxide ("ITO"). These conductive films are also used in the LCD industry for flat panel displays. The dual function of a TCO allows light to pass through a substrate window to the active light-absorbing material beneath, and also serves as an ohmic contact to transport photogenerated charge carriers away from that light-absorbing material. The present TCO materials are effective for research, but perhaps are not yet optimized for large-scale photovoltaic production. They require very special deposition conditions at high vacuum, they can sometimes suffer from poor mechanical strength, and most have poor transmittance in the infrared portion of the spectrum (e.g.: ITO thin films can also be used as infrared filters in airplane windows). These factors make large-scale manufacturing more costly.

- **Infrared solar cells**

this devised has an inexpensive way to produce plastic sheets containing billions of nanoantennas that collect heat energy generated by the sun and other sources, which garnered two 2007 Nano50 awards. The company ceased operations in 2010. While methods to convert the energy into usable electricity still need to be developed, the sheets could one day be manufactured as lightweight "skins" that power everything from hybrid cars to computers and iPods with higher efficiency than traditional solar cells. The nanoantennas target mid-infrared rays, which the Earth continuously radiates as heat after absorbing energy from the sun during the day; also double-sided nanoantenna sheets can harvest energy from different parts

of the Sun's spectrum. In contrast, traditional solar cells can only use visible light, rendering them idle after dark.

- **UV solar cells**

transparent solar cell that uses ultraviolet (UV) light to generate electricity but allows visible light to pass through it. Most conventional solar cells use visible and infrared light to generate electricity. Used to replace conventional window glass, the installation surface area could be large, leading to potential uses that take advantage of the combined functions of power generation, lighting and temperature control.

This transparent, UV-absorbing system was achieved by using an organic-inorganic heterostructure made of the p-type semiconducting polymer PEDOT:PSS film deposited on a Nb-doped strontium titanate substrate. PEDOT:PSS is easily fabricated into thin films due to its stability in air and its solubility in water. These solar cells are only activated in the UV region and result in a relatively high quantum yield of 16% electron/photon. Future work in this technology involves replacing the strontium titanate substrate with a strontium titanate film deposited on a glass substrate in order to achieve a low-cost, large-area manufacture.<sup>[16]</sup>

Since then, other methods have been discovered to include the UV wavelengths in solar cell power generation. Some companies report using nano-phosphors as a

transparent coating to turn UV light into visible light. Others have reported extending the absorption range of single-junction photovoltaic cells by doping a wide band gap transparent semiconductor such as GaN with a transition metal such as manganese.

- **3D solar cells**

Three-dimensional solar cells that capture nearly all of the light that strikes them and could boost the efficiency of photovoltaic systems while reducing their size, weight and mechanical complexity. The new 3D solar cells, created at the Georgia Tech Research Institute, capture photons from sunlight using an array of miniature “tower” structures that resemble high-rise buildings in a city street grid. Solar3D, Inc. plans to commercialize such 3D cells, but its technology is currently patent-pending [8,9].

## **Chapter Three**

### **Polymer solar cells**

#### **3.1 Introduction**

Polymer solar cells (PSC) are generally flexible solar cells due to the polymer substrate. The first PSC were invented by the research group of Tang *et al.* at Kodak Research Lab. A PSC is composed of a serially connected thin functional layers coated on a polymer foil or ribbon. It works usually as a combination of donor (polymer) and a acceptor (fullerene). There are various types of materials for the absorption of sunlight, including organic material like a conjugate/conducting

polyme. In 2000, Heeger, MacDiarmid, and Shirakawa fetched the Nobel Prize in Chemistry for the discovering a new category of polymer materials known as conducting polymers. The PSC and other organic solar cells operate on same principle known as the photovoltaic effect, where the transformation of the energy occurs in the form of electromagnetic radiations into electrical current.

and its other derivatives to develop the first polymer solar cell and obtained a high power conversion efficiency . This process triggered the development of a new age in the polymer materials for capturing the solar power.

After significantly optimizing the parameters, researchers achieved efficiency over 3.0% for PPV type PSCs . These unique properties of PSCs opened a new gateway for new applications in the formation of stretchable solar devices including textiles and fabrics. A modern recycling concept known as polarizing organic photovoltaics (ZOPVs) was also developed for increasing the function of liquid crystal displays utilizing the same polarizer, a photovoltaic device and proper light conditions solar panel [1].

### **3.2Organic Solar Cells:**

Another approach to mitigate the high cost of crystalline silicon solar cells is to use organic semiconductors, or semiconducting polymers, to replace the expensive purified silicon. Because of its high absorption coefficient in the visible region, a very thin film of organic material is sufficient. These polymers can be deposited by screen printing, inkjet printing, and spraying, as these materials are often soluble in Furthermore, a solvent. these deposition techniques can take place at low

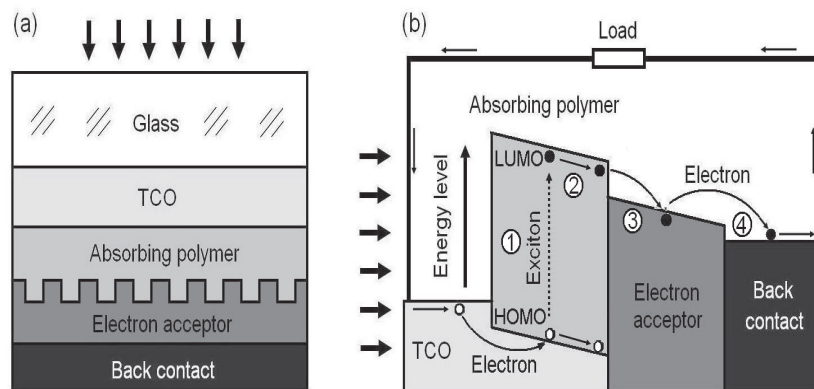


temperature, which allows devices to be fabricated on plastic substrates for flexible devices.

The basic structure of a bilayer organic solar cell is shown in Fig (3.1). There are two layers of polymer films: a film of an absorbing polymer, the *electron donor*, and a film of *electron acceptor*. The double layer is sandwiched between the anode, a TCO film, and a metal back contact, the cathode. The process of generating a photocurrent has four steps, see Fig. 10.10(b). In the first step, a photon is absorbed by the polymer, the electron donor. An exciton, an electron–hole pair, is generated. In the second step,

the exciton diffuses inside the absorbing polymer (the donor) toward the interface to the acceptor. In the third step, the electron transfers to the acceptor. Finally, the electron is collected by the cathode, or the back contact. Through the external electric circuit, the electron goes back to the anode (TCO) and eliminates the hole.

In the first successful bilayer organic solar cell, copper phthalocyanine (CuPc) is used for the absorbing polymer. The chemical structure and absorption spectrum are shown in Fig. It is a solid with dark blue color, as the red, yellow, green, and violet radiations are heavily absorbed. The absorption coefficient in some ranges is more than  $10^6 \text{ cm}^{-1}$ . Therefore, a very thin film of the absorbing polymer, typically around 100 nm, is used. A larger thickness is conversely a disadvantage because of the short diffusion length.



**Figure (3.1) Organic Solar Cell**

(a) A cross sectional view of the solar cell. Solar radiation comes from the top. Through a glass substrate and a transparent conducting oxide (TCO) film, light is absorbed by the absorbing polymer film, or the *electron donor*. The electron thus generated transfers to the *electron acceptor*, and then to a metal back contact or the cathode. (b) The working process.

- (1). A photon generates an excitation, typically electron in LUMO and leaves a hole in a HOMO.
- (2) The excitation diffuses towards the acceptor.
- (3) The exciton dissociates into a free electron and a hole.
- (4) The electron moves to the cathode, then drives the external circuit.

The second process, exciton diffusion, deserves much attention. In contrast to semiconductor solar cells, the *diffusion lengths* of excitons in organic polymers are very short, typically 5 – 10 nm. Therefore, the lifetime of the excitons are very short. If the polymer is too thick, the excitons generated by photoexcitation might not reach the donor–acceptor interface and then disappear. In order to increase the probability for excitons to reach the acceptor, a nonplanar interface is often used.

In the third process, the exciton dissociates into a free electron and a free hole. The material for the acceptor should facilitate the dissociation and the final transfer of the carrier to the back contact, the cathode. In the first successful demonstration of a bilayer organic solar cell, a perylenetetracarboxylic derivative is used . Similar to dye-sensitized solar cells, the bilayer organic solar cells have disadvantages. Its efficiency is less than one-half that of the crystalline silicon solar cells. The long-term stability of the organic materials still needs to be improved [2].

### **3.3Types of organic solar cells:**

There are some types such as:

1. Dye-sensitized solar cells: electrochemical cells.
2. Polymer solar cells: made by solution,low temperature processing.

#### **3.3.1Dye-Sensitized Solar Cells:**

The principles of photosynthesis have inspired the invention of a novel type of solar cell, the *dye-sensitized solar cell* [2, 3]. It has several advantages over the common crystalline silicon solar cell. The cost of materials and processing is greatly reduced because most of the process is by liquid-phase deposition instead of in a vacuum. In addition, it can be made on lightweight flexible substrates. To date, nearly 10% overall conversion efficiency from AM1.5 solar radiation to electrical power is achieved.

The sensitization of semiconductors to light of wavelength longer than that corresponding to the band gap has been used in photography and photo-electrochemistry.

The silver halides used in photography have band gaps on the order of 2.7 – 3.2 eV, and are not sensitive to most of the visible spectrum. Panchromatic films were made by adding dyes to sensitize silver halides, making them responsive to visible light.

The typical structure of a dye-sensitized solar cell is shown in Fig. 10.8. The most used semiconductor titanium dioxide ( $\text{TiO}_2$ ), has many advantages for sensitized photochemistry and photoelectrochemistry: It is a low-cost, widely available, nontoxic and biocompatible material. As such it is also used in health care products as well as domestic applications such as paint pigmentation. The band gap, 3.05 eV, corresponding to a wavelength of 400 nm, lies in the near-ultraviolet region, which is too high for the solar spectrum. A dye is needed to mitigate this problem.

The ideal sensitizer for a single junction photovoltaic cell converting standard global AM1.5 sunlight to electricity should absorb all light below a threshold wavelength of about 920 nm. In addition, it must also carry attachment groups such as carboxylate or phosphonate to firmly graft it to the semiconductor oxide surface. Upon excitation it should inject electrons into the solid with a quantum yield of nearly unity. The energy level of the excited state should be well matched to the lower bound of the conduction band of the oxide to minimize energetic losses during the electron transfer reaction.

Its redox potential should be sufficiently high that it can be regenerated via electron donation from the redox electrolyte or the hole conductor. Finally, it should be stable enough to sustain about 20 years of exposure to natural light. Much of the research in dye chemistry is devoted to the identification and synthesis of dyes matching these requirements while retaining stability in the photoelectrochemical environment.

The attachment group of the dye ensures that it spontaneously assembles as a molecular layer upon exposing the oxide film to a dye solution.

One of the most studied and used dyes is the N3 ruthenium complex shown in Fig3.2. The strong absorption in the visible region makes the dye a deep brown-black color, thus the name “black dye.” The dyes have an excellent chance of converting a photon into an electron, originally around 80% but improving to almost perfect conversion in more recent dyes. The overall efficiency is about 90%, with the “lost” 10% being largely accounted for by the optical losses in the top electrode. The spectral response for a dye-sensitized solar cell using an N3 ruthenium dye is shown in Fig 3.2(b).

The photocurrent response of a bare TiO<sub>2</sub> film is also shown for comparison.

The four-step process of generating electrical power is as follows :

1. A photon is absorbed by the dye to elevate an electron to the excited state, typically a LUMO.
2. The electron is transferred to the TiO<sub>2</sub> film.
3. The electron relaxes to be at the bottom of the conduction band of TiO<sub>2</sub>.
4. A photovoltage is generated by the cell, corresponding to the difference between the Fermi level in the semiconductor and the Nernst potential of the redox couple in the electrolyte.

Nevertheless, dye-sensitized solar cells have some disadvantages. First, the efficiency is about one-half of that of the crystalline silicon solar cells. Second, the necessity of a liquid-phase electrolyte made the solar cell mechanically weak. Third, the long-term stability of the organic materials needs to be improved



polymer solar cell and other forms of solar cells, however, is the same, namely the transformation of the energy in the form of electromagnetic radiation (light) into electrical energy (a current and a voltage), i.e. a physical phenomenon called the photovoltaic effect. This energy conversion is possible with the use of semiconductors. Semiconductors are a group of materials which are in-between an insulator and a conductor. Silicon is a classic example of a semiconductor and is also the material that is currently used in most solar cells, i.e. the first generation solar cells. The fact that polymers can behave as semiconductors is a discovery which Alan J. Heeger, Alan MacDiarmid and Hideki Shirakawa received the Nobel Prize in Chemistry for in the year 2000. This discovery of conjugated polymers being able to transfer electrons upon doping with iodine made it possible to prepare solar cells from polymers and thereby a new research area was born. Polymer solar cells have for a long time lagged behind traditional solar cells on both performance and stability. However, they have always had a potential advantage; that is their ability to be produced from solution. This means that they can be printed or coated, instead of using expensive vacuum deposition as for the first generation silicon solar cells. Today, performances of 10% have been demonstrated for polymer solar cells. The lifetime has also improved considerably and plastic solar cells with a shelf life of several years have been demonstrated. In addition, large scale production of polymer solar cells is today to some extent a reality.

The invention of conductive polymers may lead to the development of much cheaper cells that are based on inexpensive plastics. However, organic solar cells generally suffer from degradation upon exposure to UV light, and hence have lifetimes which are far too short to be viable. The bonds in the polymers are always susceptible to breaking up when radiated with shorter wavelengths. Additionally, the conjugated double bond systems in the polymers which carry the charge react

more readily with light and oxygen, so most conductive polymers, being highly unsaturated and reactive, are highly sensitive to atmospheric moisture and oxidation, making commercial applications difficult.

The molecules used in organic solar cells are solution-processable at high throughput and are cheap, resulting in low production costs to fabricate a large volume. Combined with the flexibility of organic molecules, organic solar cells are potentially cost-effective for photovoltaic applications. Molecular engineering (e.g. changing the length and functional group of polymers) can change the band gap, allowing for electronic tunability. The optical absorption coefficient of organic molecules is high, so a large amount of light can be absorbed with a small amount of materials, usually on the order of hundreds of nanometers. The main disadvantages associated with organic photovoltaic cells are low efficiency, low stability and low strength compared to inorganic photovoltaic cells such as silicon solar cells. Compared to silicon-based devices, polymer solar cells are lightweight (which is important for small autonomous sensors), potentially disposable and inexpensive to fabricate (sometimes using printed electronics), flexible, customizable on the molecular level and potentially have less adverse environmental impact. Polymer solar cells also have the potential to exhibit transparency, suggesting applications in windows, walls, flexible electronics, etc. An example device is shown in Fig. 1. The disadvantages of polymer solar cells are also serious: they offer about 1/3 of the efficiency of hard materials, and experience substantial photochemical degradation.

Polymer solar cells inefficiency and stability problems combined with their promise of low costs and increased efficiency made them a popular field in solar cell research. As of 2015, polymer solar cells were able to achieve over 10% efficiency via a tandem structure[5].



### **3.3.2.1 Basic processes of polymer solar cell:**

Varios architectures for organic solar cells have been investigated in recent years .in general , for successful organic photovoltaic cell four important processes have to be optimized to obtain a high conversion efficiency of solar energy into electrical energy .

1. Absorption of light
2. Charge transfer and separation of opposite charges
3. Charge transport
4. Charge collection

For an efficient collection of photons, the absorption spectrum of photoactive organic layer should match the solar emission spectrum and the layer should be sufficiently thick to absorb all incident light .a better overlap with the solar emission spectrum is obtained by lowering the band gap of the organic material, but this will ultimately have some bearing on the open-circuit voltage. Increasing the layer thickness is advantageous for light absorption, but burdens the charge transport.

Polymer solar cells are typically comprised of photon absorbing active layer sandwiched between electrodes and placed on a substrate of glass or clear plastic foil. One of electrodes is transparent in order to allow photons to penetrate into the absorbing layer. Indium tin oxide is commonly used as transparent electrode and metal like aluminum, Calcium and silver as the other electrodes.

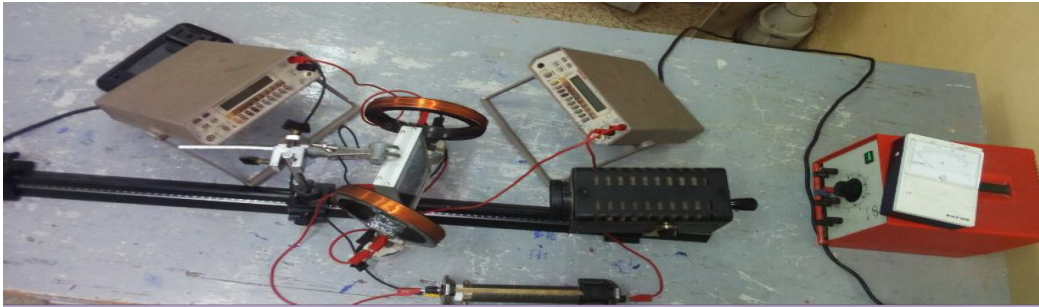
### **3.4.1 Aparouts:**

The devices which use in this experiment :

1. Polymer solar cells.
2. Voltmeter, that can read voltage.
3. A variable resistance box. This is an easy way to vary the resistance to known settings while it is still in the circuit. For truly accurate readings.
4. Short lengths of wires to connect all the components together.
5. Emitter , that can read current over a wide range.
6. A source of Light and Magnetic field.

### **3.4.2Method**

Theelectric circuit is connect astraight as shown below



**Figure 3.3**

**Connection of the Circuit**

## **Chapter Four**

### **Results and Discussion**

#### **4.1 Introduction:**

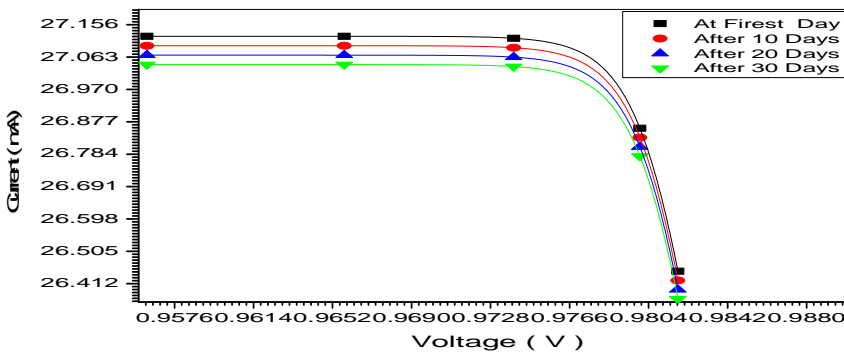
In This chapter summarize results from each experiment mentioned in the methodology chapter are presented and analyzed. Explanations are proposed for each result, all of the results were measured under 298K, 1 atm pressure with the

illumination of fluorescent light. Unless specified, all of the measurements in tables have units of Volts and mA .discussion and conclusion was also shown.

## 4.2 Results:

**Table (4.1) sample (1)**

Voltage ( V )	Current first day ( mA )	Current after 10 days ( mA )	Current after 20 days ( mA )	Current after 30 days ( mA )
0.95628	27.12287	27.09575	27.06866	27.04159
0.96576	27.12287	27.09575	27.06866	27.04159
0.97391	27.11714	27.09002	27.06293	27.03587
0.97998	26.85865	26.83179	26.80496	26.77816
0.98181	26.44761	26.42116	26.39474	26.36835

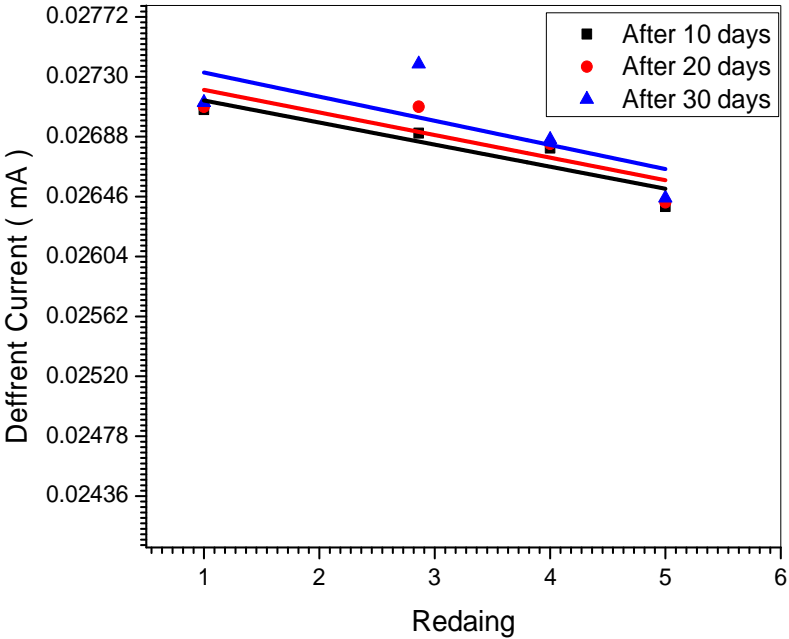


**Figure 4.1 Current and voltage for the Sample one**

From table (4.1) sample (1) show that the voltage is semi stable after (1,10,20,30) days and the current decreases by an amount less than 1mA.

**Table (4.2) sample (1)**

(1--10)day	(10--20)day	Day(20—30)
0.02712	0.02709	0.02707
0.02712	0.02709	0.02707
0.02739	0.02709	0.02436
0.02686	0.02683	0.02680
0.02645	0.02642	0.02639

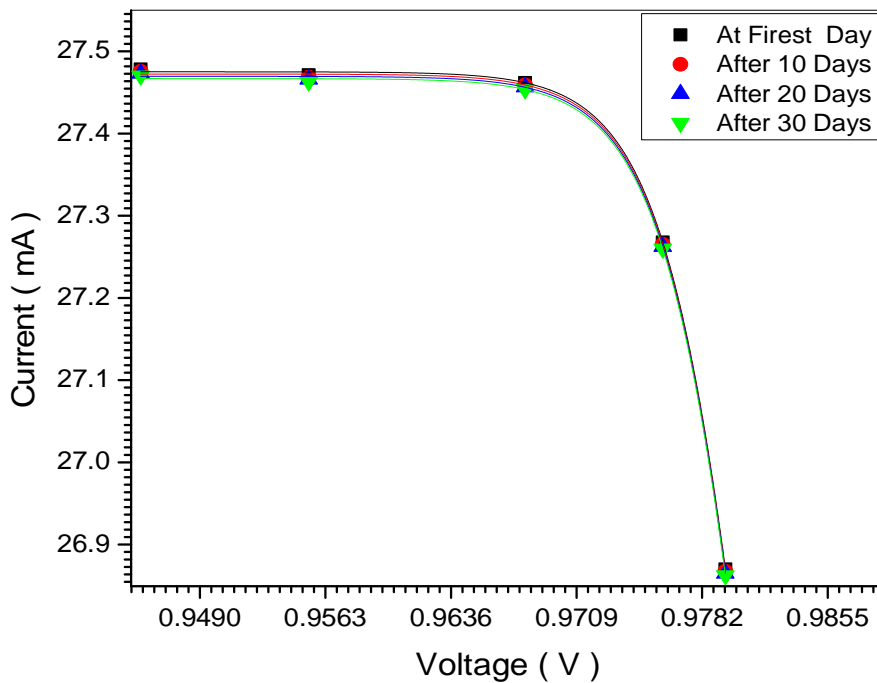


**Figure 4.2 different current sample (1)**

From table (4.2) sample (1) show that the ratio of the current is decreases slightly .

**Table (4.3) sample (2)**

<b>Voltage ( V )</b>	<b>Current first day ( mA )</b>	<b>Current after 10 days ( mA )</b>	<b>Current after 20 days ( mA )</b>	<b>Current after 30 days ( mA )</b>
0.94556	27.47856	27.47582	27.47307	27.47032
0.95533	27.47138	27.46863	27.46588	27.46314
0.96791	27.46194	27.45919	27.45644	27.4537
0.97591	27.26795	27.26522	27.26249	27.25977
0.97955	26.87032	26.86764	26.86495	26.86226

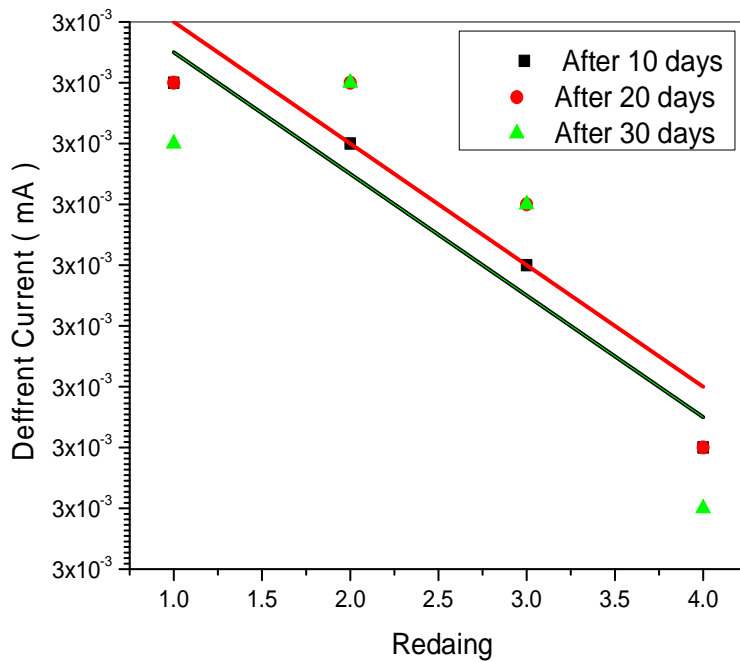


**Figure 4.3**  
**Current and voltage for the Sample two**  
 From table (4.3) sample

(2) show that the current is decreases by a little amount while the voltage is a stable.

**Table (4.4) sample (2)**

(1—10)day	Day(10—20)	Day(20--30 )
0.00274	0.00275	0.00275
0.00275	0.00275	0.00274
0.00275	0.00275	0.00274
0.00273	0.00273	0.00272
0.00268	0.00269	0.00269



### **Figure 4.4 different current sample (2)**

From table (4.4) sample (2) show that the ratio of current is not changing as in the sample (1) and it is more stable .

### **4.3Discussion:**

In view of figures and results it is very interesting to note that the voltage ( $V_{oc}$ ) is stable after day, 10, 20 and 30 days from starting measuring and studying Voltage-Current characteristic.

However the  $I_{sc}$  current decreases by an amount less than 1mA.

The non change of  $V_{oc}$  may imply that the cells chemical composition does not change and there is no interaction between cells and weather.

However  $I_{sc}$  change slightly this may be related to the evaporation of water from dyes which decreases current due to decrease of carriers mobility which decreases the velocity and current .

### **4.4Concolution:**

The stability study of two polymer solar cells shows that the open circuit voltages remain constant while the short circuit current decreases slightly, these may be due to water evaporation from dyes.

### **4.5Recommendations:**

In the future project, the current and voltage using same dye samples should be determined to discover any dependence between the last time or the magnitude of current and the identity or character of the dyes. The experiment should be reproduced to confirm the general trend of my results. And any further thoughts on this project should be considered and turned into control experiment to carry out.

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