زانكۆى سەلاحەدین - هەولێر
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Solar Cells Charecerization

Research Project Submitted to the Department of (physical) in partial fulfillment of the requirements for the degree of **B.Sc**. in **physical**

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Chapter One

Abstract

The light from the Sun is a non-vanishing renewable source of energy which is free from environ- mental 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 improvementsteps from one generation to another. Silicon based solar cells were the first generationsolar 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 under- stand fundamental mechanisms and functions of several solar technologies that are widely stu- died. In this article, 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 article also triesto emphasize the various practices and methods to promote the benefits of solar energy.

Contents:

1. Introduction.

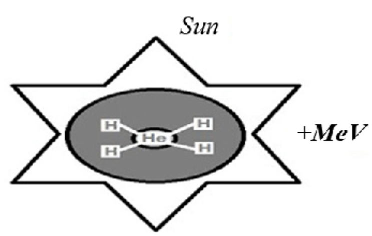
Everyday sun sends out tremendous amount of energy in the form of heat and radiations called solar energy. Solar energy is a limitless source of energy which is available at no costThe major benefit of solar energy over other conventional power generators is that the sunlight can be directly harvested into solar energy with the use of small and tiny photovoltaic (PV) solar cells [Choubey,2012]The Sun is assumed as a big spherical gas cloud made up of hydrogen and helium atoms. This big spherical gaseous cloud is mainly composed of several hydrogen nu lei combining to form helium energy with the emission of energy from the fusion of the hydrogen nucleiin inner core of the Sun via nuclear fusion(figure 1) [Grisham, 2015].

During this process of fusion, four hydrogen atoms combine to form one helium atom witha loss of mass which is radiated as thermal energy [Fahrenbruch,. and Bube,.1983]. This radiant energy produced byfusion reactions is free from any pollutant, gases, or other reaction by-product. This is whyit is the major driving force of all the clean energy technology, in view of the climatic disturbance caused by the emission of carbon from the fossil fuels deposits. One of the biggest advantages of solar energy is that it is free reachable to common people and available in abundant supply compared to that of the price of various fossil fuels and oils in the past decade [Choubey, 2012:] Moreover, solar energy requires considerably lower manpower expenses over conventional energy production technology.

Though the solar energy is freely available everywhere, there is still an initial expenditureon the equipment's for harvesting this radiant energy by developing solar cells, panels and modules [-These small and tiny solar cells produce no noise during their operation. On the other hand, the big power pumping devices produce unbearable sound pollution, and therefore they are very disturbing to the society [Peplow, M.2013:49]-Nowadays, due to thedecreasing amount of renewable energy resources, the per watt cost of solar energy device has become more important in the last decade, and is definitely set to become economical inthe coming years and grow as better technology in terms of both cost and applications Jetes

In spite of numerous advantages, this energy has few limitations too. Firstly, solar energy doesn't radiate at night. Secondly, the solar energy is almost not constant all the time. There must be plenty of sunlight available to generate electrical energy from a solar PV device [Srinivas,, Balaji, ,2015:] Moreover, apart from daily fluctuations in the intensity of radiant energy, the solar energy is hindered to reach the earth during bad climatic conditions. For example, the amount of sunlight reaching the earth's surface depends on location, time as well as weather as it falls during winter season as compared to the summer, and the Sun's radiation is less intense. To overcome these demerits of this technology, solar energy must be stored elsewhere at night and the highly efficient solar cells and modules needs to be developed.

There have been an enormous amount of research activities to harvest the Sun's energy effectively by developing solar cells/panels with high conversion efficiencies. The photovoltaic conversion efficiency is referred to the efficiency of solar PV modules, and is defined as the fraction of Sun's energy that can be converted into electricity. Solar panelsare a huge collection of tiny solar cells arranged in a definite geometrical shape to produce agiven amount of power supply. The storage of solar power is still has not been achieved successfully. Currently the radiation efficiency of solar panel is up to 22%. There are many solar photovoltaic batteries available which are usually more expensive and bulky. These are more suitable for small scale or household solar needs compared to large solar plants[Yadav, and Kumar, 2012]



$$ {}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + {}^{1}_{0}n + 3.27\text{MeV} $$

$$ {}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + 17.59\text{MeV} $$

Figure 1-1. Nuclear fusion reaction: source of solar energy [Yadav, and Kumar, 2012]

The working mechanism of solar cells is based on the three factors: (1) Adsorption of light in order to the charge careers, holes (p-type) and electrons (n-type) (2) Separationof charge careers, and (2) the of charge careers at the respective electrodes establishing the potential difference across the p-n junction. The generation of voltage difference noticed at the p-n junction of the cell in response to visible radiation is to do the work.

In the past, various kinds of semiconductor materials and technologies are devised to designsolar cells with low cost as well as high conversion efficiency. Traditional solar panelsmade from silicon crystalline wafer modules are heavier which makes the transportation difficult. These are generally the large sized solar panels covered with glass sheets. A heavier and bulky solar panel requires a lot of space and sometime big roofs to fit these bulky and large solar panels in case of high power applications [Bertolli, 2008:] Therefore, in this article keeping in mind the efficient use of solar energy by solar cells research and development, we will study the different types of solar cells.

2. **Generation of Solar Cell**

2.1. First Generation Solar Cell-Wafer Based

As it is already mentioned, the first-generation solar cells are produced on silicon wafers. Itis the oldest and the most popular technology due to high power efficiencies. The silicon

wafer based technology is further categorized into two subgroups named as [Whitburn,G.,2013:].

- Single/ Mono-crystalline silicon solar cell.
- Poly/multi-crystalline silicon solar cell.

2.2 Second Generation Solar Cells-Thin Film Solar Cells

Most of the thin film solar cells and a-Si are second generation solar cells, and are more economical as com- pared to the first generation silicon wafer solar cells. Silicon-wafer cells have light absorbing layers up to 350 μm thick, while thin-film solar cells have a verythin light absorbing layers, generally of the order of 1 μm thickness [Imamzai, Aghaei,2012:]. Thin film solar cells are classified as;

- a-Si.

- CdTe.
- CIGS (copper indium gallium di-selenide).

2.3 Third Generation Solar Cells

Third generation cells are the new promising technologies but are not commercially investigated in detail. Most of the developed 3rd generation solar cell types are [Wall,A.,2014:]:

1) Nano crystal based solar cells.
2) Polymer based solar cells.
3) Dye sensitized solar cells.
4) Concentrated solar cells.

3. Solar Spectrum of The Sun

The solar spectrum is the range of electromagnetic radiation emitted by the sun, extending from the ultraviolet to the infrared region. It is composed of photons with various wavelengths, which define the spectrum's shape and intensity. It can be defined in terms of solar radiation or solar irradiance.

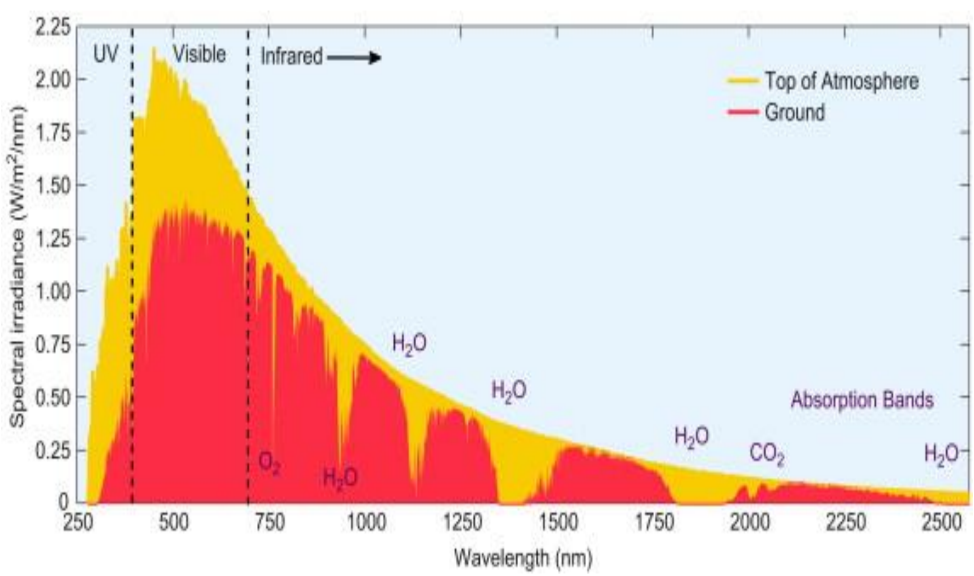


Figure 1-2 the solar spectrum of the sun

4. Solar Cell Structure

A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a *p-n* junction.

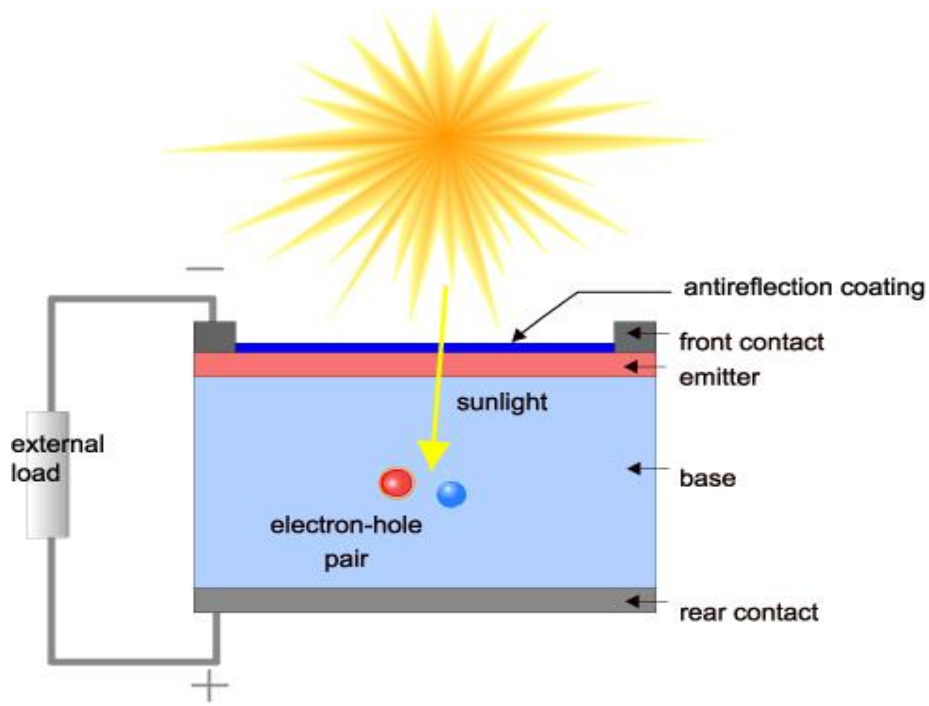


Figure 1-3 structure of sola cell

Cross section of a solar cell. Note: Emitter and Base are historical terms that don't have meaning in a modern solar cells. We still use them because there aren't any concise alternatives. Emitter and Base are very embedded in the literature and they are useful terms to show the function of the layers in a p-n junction. The light enters the emitter first. The emitter is usually thin to keep the depletion region near where the light is strongly absorbed and the base is usually made thick enough to absorb most of the light.

The basic steps in the operation of a solar cell are:

- the generation of light-generated carriers;
- the collection of the light-generated carries to generate a current;
- the generation of a large voltage across the solar cell; and
- the dissipation of power in the load and in parasitic resistances.

5. **Characterization of solar cell**

5-1. I-V Curve

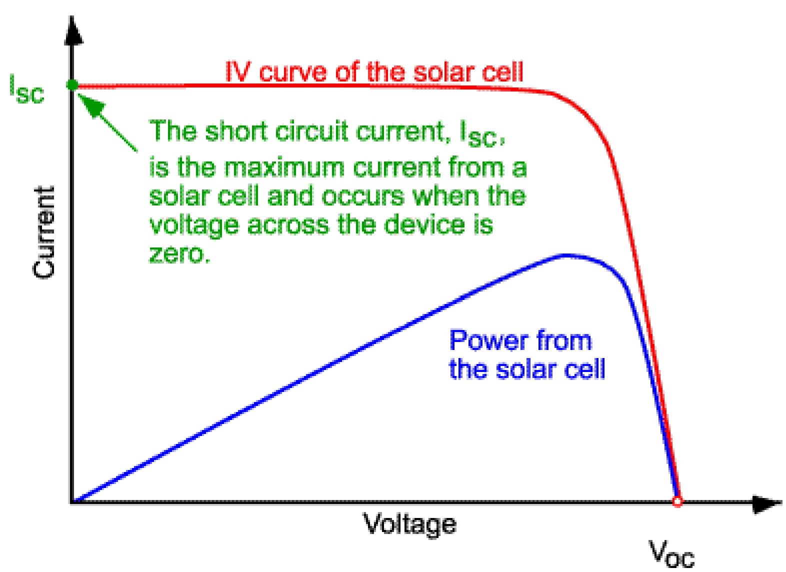
The I-V curve of a solar cell is the superposition of the IV curve of the solar cell diode in the dark with the light-generated current.1 The light has the effect of shifting the IV curve down into the fourth quadrant where power can be extracted from the diode. Illuminating a cell adds to the normal "dark" currents in the diode so that the diode law becomes:

$$I = I_0 \left[\exp\left(\frac{qV}{nkT} \right) - 1 \right] - I_L$$

where I_L = light generated current.

5-2. Short-Circuit Current

The short-circuit current is the current through the solar cell when the voltage across the solar cell is zero (i.e., when the solar cell is short circuited). Usually written as I_{SC}, the short-circuit current is shown on the IV curve below.



Figur 1-3 : I-V curve of a solar cell showing the short-circuit current.

The short-circuit current is due to the generation and collection of light-generated carriers. For an ideal solar cell at most moderate resistive loss mechanisms, the short-circuit current and the light-generated current are identical. Therefore, the short-circuit current is the largest current which may be drawn from the solar cell.

The short-circuit current depends on a number of factors which are described below:

- **the area of the solar cell.** To remove the dependence of the solar cell area, it is more common to list the short-circuit current **density** (J_{sc} in mA/cm^2) rather than the short-circuit current;
- **the number of photons** (i.e., the power of the incident light source). Isc from a solar cell is directly dependant on the light intensity as discussed in Effect of Light Intensity;
- **the spectrum of the incident light.** For most solar cell measurement, the spectrum is standardised to the AM1.5 spectrum;
- **the optical properties** (absorption and reflection) of the solar cell (discussed in Optical Losses); and
- **the minority-carrier collection probability** of the solar cell, which depends chiefly on the surface passivation and the minority carrier lifetime in the base.

5-3. Open-Circuit Voltage

The open-circuit voltage, V_{OC}, is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current. The open-circuit voltage is shown on the IV curve below.

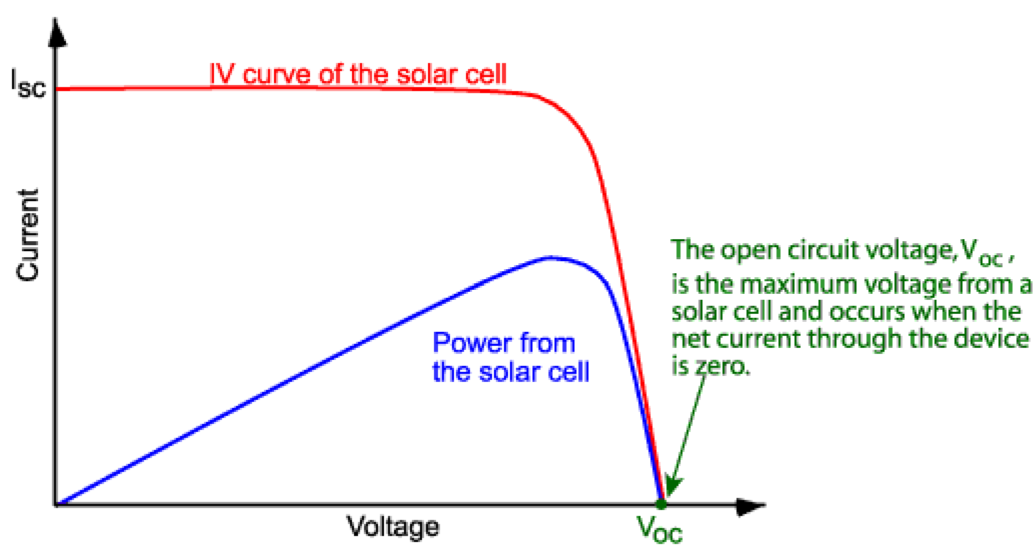


Figure 1-4. I-V curve of a solar cell showing the open-circuit voltage.

An equation for V_{oc} is found by setting the net current equal to zero in the solar cell equation to give:

$$V_{OC} = \frac{nkT}{q} \ln\left(\frac{I_L}{I_0} + 1\right)$$

A casual inspection of the above equation might indicate that V_{OC} goes up linearly with temperature. However, this is not the case as I_0 increases rapidly with temperature primarily due to changes in the intrinsic carrier concentration n_i. The effect of temperature is complicated and varies with cell technology. See the page "Effect of Temperature" for more details V_{OC} **decreases** with temperature. If temperature changes, I_0 also changes.

5-4. Fill Factor

The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero. The "fill factor", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc} so that:

$$FF = \frac{P_{MP}}{V_{OC} \times I_{SC}}$$

$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}}$$

Graphically, the FF is a measure of the "squareness" of the solar cell and is also the area of the largest rectangle which will fit in the IV curve. The FF is illustrated below.

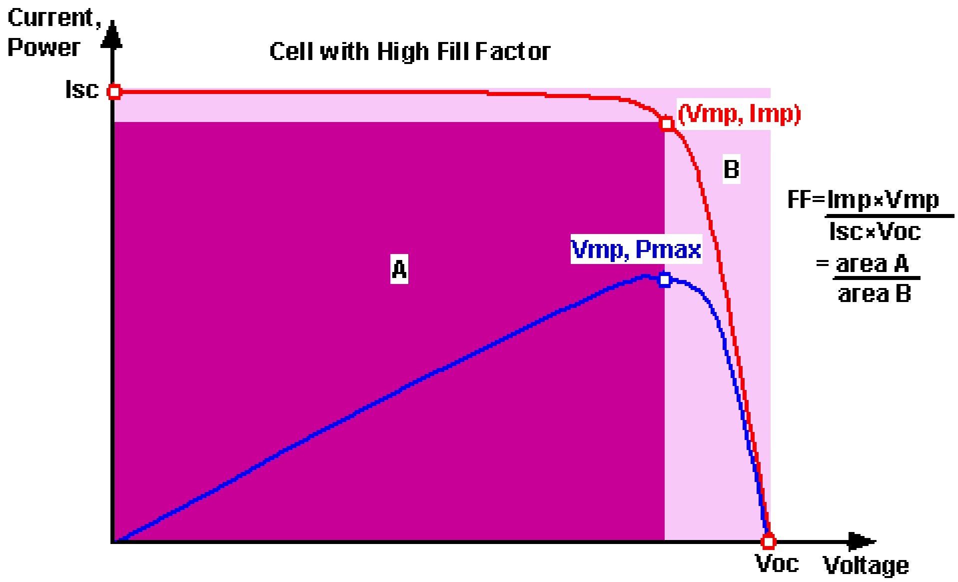


Figure1-5 :Graph of cell output current (red line) and power (blue line) as a function of voltage. Also shown are the cell short-circuit current (I_{sc}) and open-circuit voltage (V_{OC}) points, as well as the maximum power point (V_{mp}, I_{mp}).

5-5. Solar Cell Efficiency

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another. Terrestrial solar cells are measured under AM1.5 conditions and at a temperature of 25°C. Solar cells intended for space use are measured under AM0 conditions.

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{max} = V_{OC} I_{SC} FF$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

Where:
V_{oc} is the open-circuit voltage;
I_{sc} is the short-circuit current;
FF is the fill factor and
η is the efficiency.

Chapter Tow

Results and Discussion

2-1. Instrument& procedures

crystalline silicon solar cell laboratory with circular area 45.34 cm^2, halogen- Tungsten sours light, colour filters voltmeter, ammeter, and bridge resistance. Figure (1) shows the setup procedure for measurement parameters of solar cells.

Figure 2-1: the setup procedure for measurement parameters of solar cells.

2-2. I-V Characterization

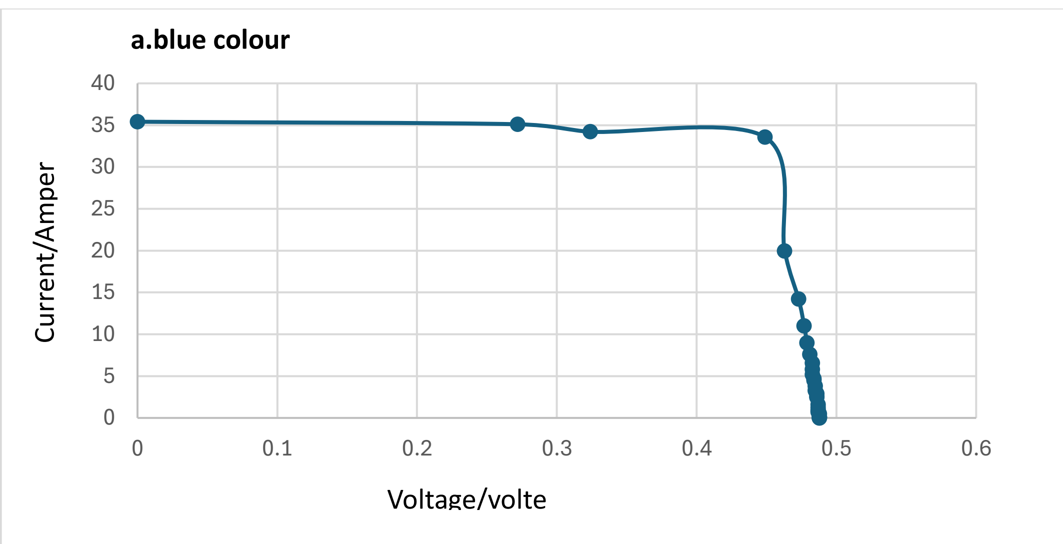
the main parameters that are used to characterise the performance of solar cells are the peak power Pmax, the short-circuit current density Isc, the open circuit voltage Voc, and the fill factor FF. These parameters are determined from the illuminated I-V characteristic as demonstrated in table 1. The conversion efficiency η can be determined from these parameters.

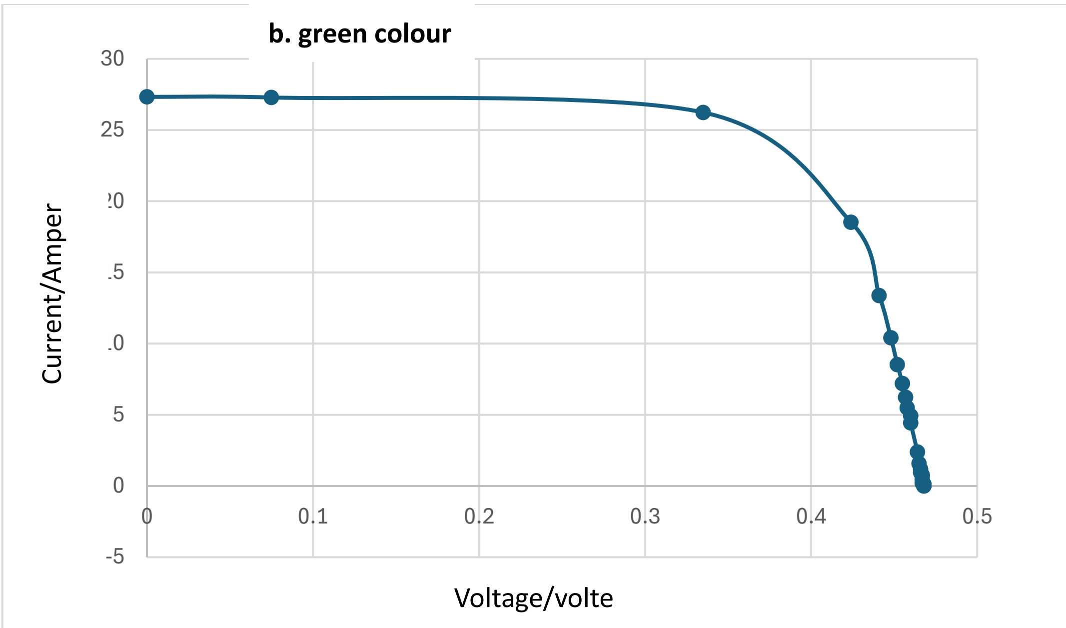
Figure (2-2) shows the I-V characteristics of solar cells under red, yellow, green and blue coolers. It indicates that the solar cells have a maximum power for (red) colour as showen in figure (2-3), and a high efficiency of solar cells.

Ther are another tow important parameters in solar cells are the series (R_S) and shunt (R_{shu}) resistance. A straight-forward method of estimating the series resistance from a solar cell is to find the slope of the I-V curve at the open-circuit voltage point as showen in figure (2-4 a). Series resistance in a solar cell has three causes: firstly, the movement of current through the emitter and base of the solar cell; secondly, the contact resistance between the metal contact and the silicon; and finally, the resistance of the top and rear metal contacts. The main impact of series resistance is to reduce the fill factor, although excessively high values may also reduce the short-circuit current. The effects of series resistance consist at high light levels in a flattening of the photovoltaic output characteristic and a related drop in the maximum power point voltage.

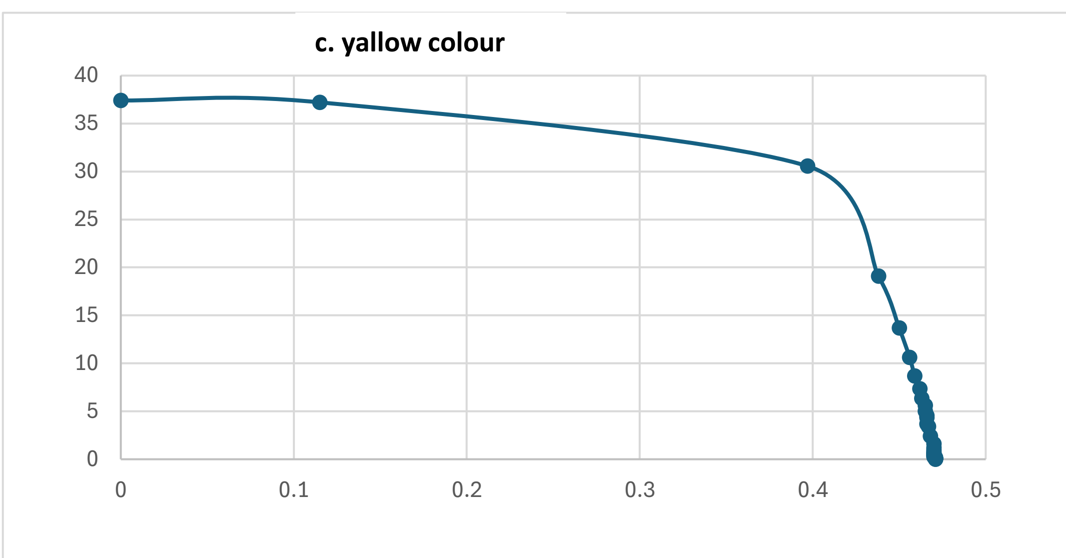
Additionally, an estimate for the value of the shunt resistance of a solar cell can be determined from the slope of the I-V curve near the short-circuit current point as showen in figure (2- 4 b). Low shunt resistance causes power losses in solar cells by providing an alternate current path for the light-generated current. Such a diversion reduces the amount of current flowing through the solar cell junction and reduces the voltage from the solar cell.

Figure (2-2 a,b,c,and d) shows the curves for calculating Rs and Rshu . the values the Rs and Rshu are recorded in (table 2-1). It indicated that the high of Rs for green colour reduces the low efficiency, minimum Imax, and Isc of solar cells, while the minimum of Rshu has high FF,V_{oc}, and Vmax of solar celles.





b. green colour
30
25
20
.5
.0
5
0
-5
0
0.1
0.2
0.3
0.4
0.5
Current/Amper
Voltage/volte



c. yallow colour
40
35
30
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5

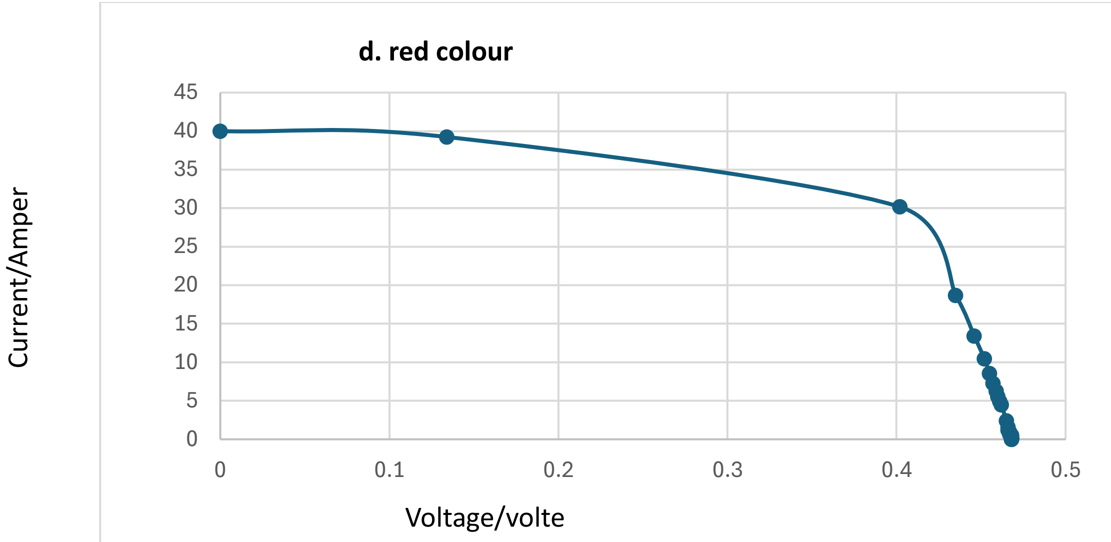


Figure 2-2: (a, b, c, and d) I-V characterization of solar cells at different colours.

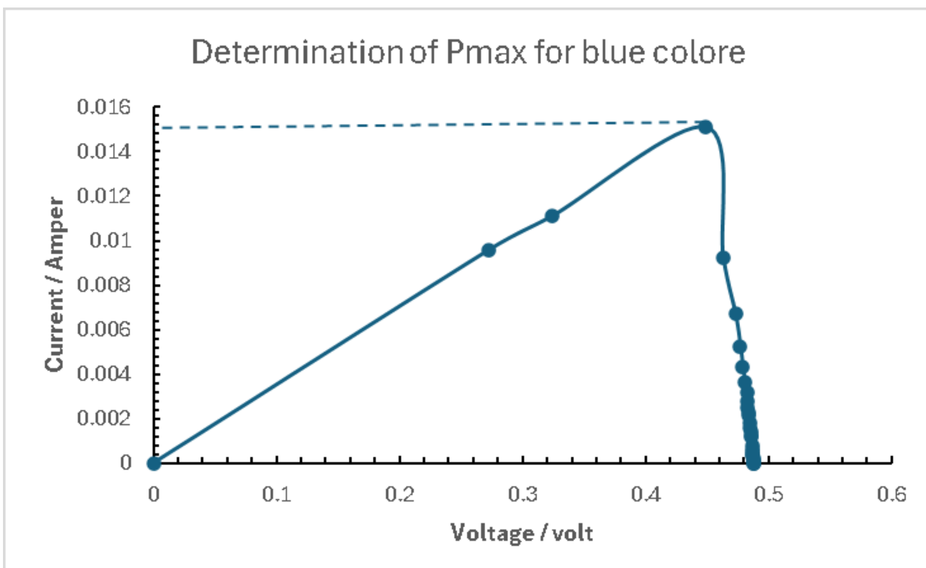
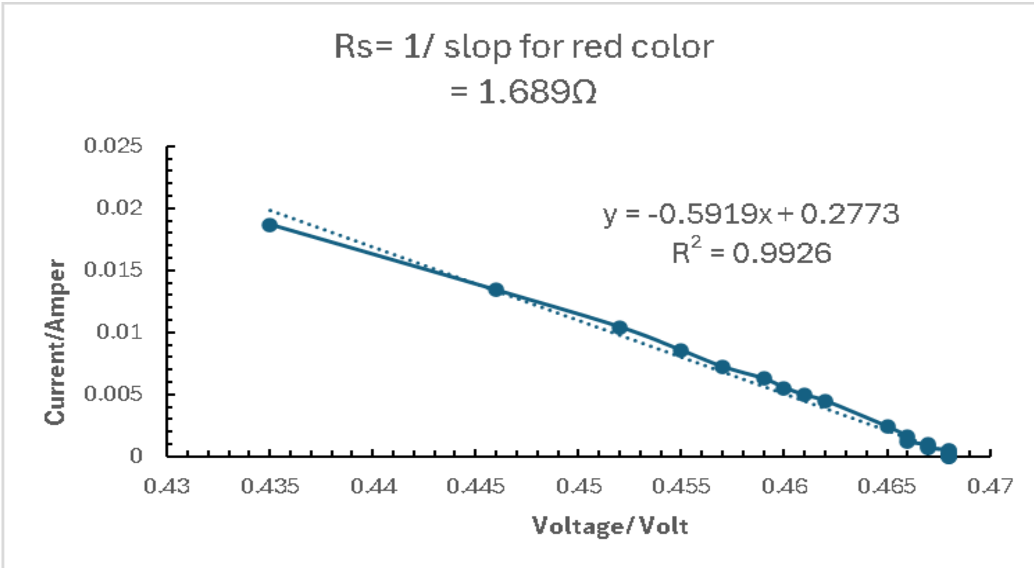


Figure 2-3: maximum power $P_{max}$of solar cells for blue colour.

a



b

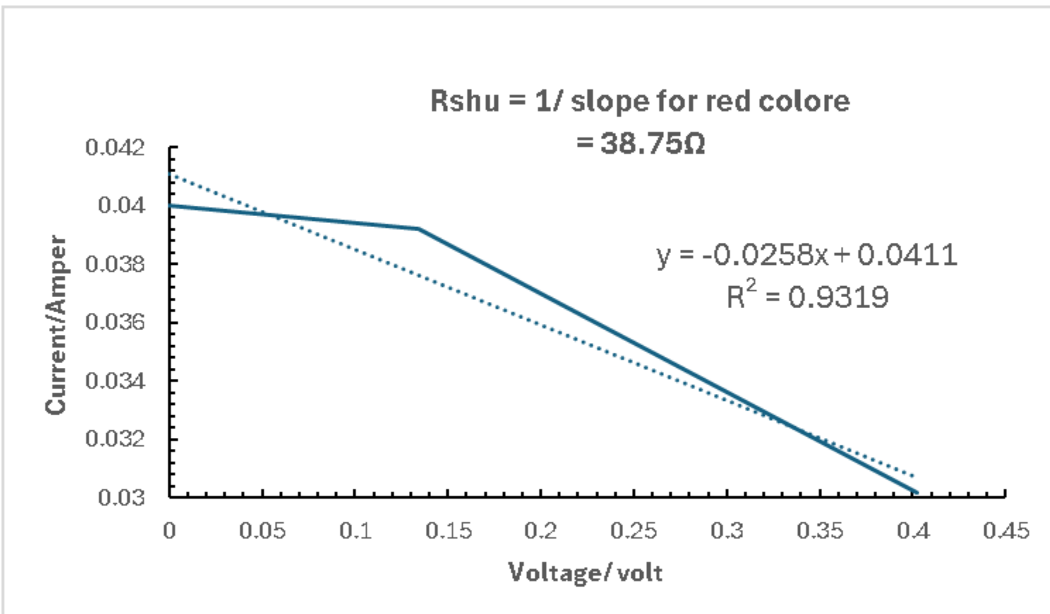


Figure 2-4 evalutiing (a)Rs,and(b) Rshu.of solar cells for red coloure.

Table 2-1: the parameters of solar cell for different colours.

colours	V_{oc} Volt	I_{sc} mA	V_{max} Volt	I_{max} mA	P_{inp} mW	P_{max} mW	FF	R_s Ω	R_{shu} Ω	η %
Blue	0.488	35.41	0.449	33.57	0.74	17.2	0.87	1.175	25.36	23.35
Red	0.468	40	0.402	30.17	0.66	18.7	0.64	1.689	38.75	28.15
Green	0.468	27.33	0.424	25.00	0.55	12.7	0.82	2.183	34.57	23.09
Yellow	0.471	37.41	0.39	30.56	0.67	17.5	0.67	1.602	54.21	25.96

2.3. Conclusion

1. Photovoltaics is the process of converting sunlight directly into electricity using solar cells.
2. Research and development of photovoltaics received its first major boost from the space industry in the 1960s which required a power supply separate from "grid" power for satellite applications.
3. Solar cells had entered the arena as a power generating technology. Their application and advantage to the "remote" power supply area was quickly recognized and prompted the development of terrestrial photovoltaics industry. Small scale transportable applications (such as calculators and watches) were utilised and remote power applications began to benefit from photovoltaics.
4. In the 1980s research into silicon solar cells paid off and solar cells began to increase their efficiency. In 1985 silicon solar cells achieved the milestone of 20% efficiency. Over the next decade, the photovoltaic industry experienced steady growth rates of between 15% and 20%, largely promoted by the remote power supply market.
5. The results indicated that the sollar cell has ahigh effiency for red colour28.15% and low eficency for green colour 23.09%.

References

Adam ,A.N.(2015-2016) Energy from the Sun, Student Guide. National EnergyEducation Development Project (NEED).

Bertolli, M. (2008) Solar Cell Materials. Course: Solid State II. Department of Physics,University of Tennessee, Knoxville.

Fahrenbruch, A.L. and Bube, R.H. (1983) Fundamentals of Solar Cells. Academic PressInc., New York.

Grisham, L.R. (2008) Nuclear Fusion in: Future Energy, Improved, Sustainable and Clean Options for our Planet, Edited by Trevor M. Letcher, 2nd Edition, Elsevier Ltd., Amsterdam, 291-301.

McEvoy, A., Castaner, L. and Markvart, T. (2012) Solar Cells: Materials, Manufactureand Operation. 2nd Edition, Elsevier Ltd., Oxford, 3-25.

Peplow, M. (2014) Organic Synthesis: The Robo-Chemist. Nature, 512, 20-22. http://dx.doi.org/10.1038/512020a

Rana, S. (2013) A Study on Automatic Dual Axis Solar Tracker System using 555 Timer. International Journal of Scientific & Technology Research, 1, 77-85.

Wall, A. (2014) Advantages and Disadvantages of Solar Energy. Process IndustryForum, 7 August 2013. Web. 2 Feb- ruary 2014.

Whitburn, G. (2012) Exploring Green Technology, Fundamental Advantages and Disadvantages of Solar Energy.

[1] Tsoutsos, T., Frantzeskaki, N. and Gekas, V. (2005) Environmental Impacts from theSolar Energy Technologies. Energy Policy, 33, 289-296. http://dx.doi.org/10.1016/S0301-4215(03)00241-6

[2] Yadav, A. and Kumar, P. (2015) Enhancement in Efficiency of PV Cell through P&OAlgorithm. International Jour- nal for Technological Research in Engineering, 2, 2642- 2644.

[3] Castellano, R. (2010) Solar Panel Processing. Old City Publishing Inc., Philadelphia.

[4] Srinivas, B., Balaji, S., Nagendra Babu, M. and Reddy, Y.S. (2015) Review on Presentand Advance Materials for So- lar Cells. International Journal of Engineering Research- Online, 3, 178-182.

[5] Chopra, K.L., Paulson, P.D. and Dutt, V. (2004) Thin-Film Solar Cells: An Overview.

Progress in Photovoltaics, 12, 69-92. http://dx.doi.org/10.1002/pip.541

[6] Imamzai, M., Aghaei, M., Hanum Md Thayoob, Y. and Forouzanfar, M. (2012) AReview on Comparison between.