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Research Article

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Experimental Investigation of Silicon and Dye Sensitized Solar Cells Based on Wavelength Dependence

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Abstract

As fossil fuels, the major source of energy used today, create the greenhouse gas carbon dioxide which causes global warming, alternative energy sources are necessary in the future. There is a need for different types of renewable energy sources. Photovoltaics use the energy of the sun and convert it into electricity. Photovoltaics PV, called also solar cells are made from light-absorbing materials. When the cell is joined with a load, optically generated carriers create an electric current. The conventional material used for solar cells is the silicon.

Another type of solar cells is dye-sensitized solar cells, which is a field of applied research that has been growing rapidly in the last decade leading to power-conversion efficiency of 10 percent. One major reason for this field is a potentially low-cost production of solar modules on flexible (polymer) substrate.

The aim of this research is to compare the performance of dye-sensitized solar cells to silicon based solar cells in order to reduce the cost of solar cell and increase the efficiency by analysis of their characterization. This work is based on experimental work for solar cells comprising.

The current-voltage characteristics (I–V) of a solar cell reflect the electrical processes in the device. Therefore, the (I–V) curve is selected as means of comparison between experimental data. These (I–V) characteristics were measured for different light wavelengths. The parameters of each solar cell, the short circuit current, open-circuit voltage, fill factor and efficiency were determined in the wavelength range 460 nm to 589 nm.

The experimental results show that the cell efficiency for poly-crystalline silicon and dye-sensitized solar cells are nearly constant while it increases towards longer wavelengths for mono-crystalline and thin film silicon solar cells.

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1. Introduction:

Photovoltaics (PV), discovered by Edmond Becquerel in 1839, is the collective name for devices converting the energy of the sun, photons, into electricity. The photovoltaic effect refers to when photons are falling upon a semiconductor and generating an electron-hole pair. The electron and the hole can be directed to two different contacts, a circuit can connect the two and an electric potential difference will be established. The unique features of semiconductors are their electrical conductivity which could be controlled by doping, optical properties and photoconductivity. Photovoltaic occurs in its simplest form, when light Photons having energy greater or equal to the band gap energy of the semiconductor are absorbed. The photon energy strikes the electron in the valence band; transfers it to the conduction band. This leaves behind a positively charged hole particle in the valence band. Then, the built-in field (due to p-n junction) pulls the excited electrons away before they can relax, and feeds them into an external circuit-load. In crystalline silicon solar cells, the generation of the electron-hole pair occurs mainly in the p-type layer. In the second-generation solar cells, the electric field spreads through the whole device and the electron-hole pair is immediately separated after generation and if the photo-generate charge carriers have not recombined in the process, they arrive at the terminals of the device, generating an electric charge across them [1].

The solar cell conversion efficiency is used to compare the performance of solar cells. It's the ratio of output power from the solar cell to input solar radiation power. The performance of a solar cell depends on the spectrum, intensity of the incident sunlight and the temperature of the testing location. Fill factor, FF, is defined to be the ratio of the maximum power generated by the cell divided by open circuit voltage and short circuit current [7].

The common Types of the Solar Cells are:

A. Mono-Crystalline Solar Cell: It is the base material for silicon chips used approximately in all electronic equipment today which has been commercially developed since the 1960's. It also serves as photovoltaic, light-absorbing material in the manufacture of solar cells. It consists of silicon in which the crystal lattice of the entire solid is continuous and unbroken to its edges. For m-Si PV module, Voc =18.66V and Vm =14.78 V Φ = 200 W/m2 whereas they were 20.32 and 16.18 V for Φ= 500 W / m2 [5].

B. Polycrystalline Solar Cell (Multi-Si): Polycrystalline silicon, also called poly silicon or poly-Si, is a high purity, Poly-crystalline form of silicon. Poly-silicon is produced from metallurgical grade silicon by a chemical purification manufacturing process. These cells are slightly less efficient than mono-crystalline cells. They have better Heat Tolerance than Mono (Depending on Manufacturer), Better shade tolerance than Mono (15% of panel can be covered), Poly-silicon is distinct from mono-crystalline silicon and amorphous silicon [4], and usually offer a lower cost per watt of power produced. Jinhee and Heo (2013) found that the electrical properties of prepared solar cells were measured using a solar cell simulator system were: V_{oc} is 0.59 V, I_{sc} is 48.5mA, I_{max} is 41.3mA, V_{max} is 0.49 V, P_{max} is 20 mW, FF is 0.7 and ∏ is 13.6% [10]

C. Thin Film Solar Cell (TFSC): is a second generation solar cell that is made by depositing one or more thin layers of silicon atoms, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Solar cells with initial efficiencies up to 11.8% have been achieved with a high Voc value of 632 mV [13]. Thin-film solar cells are commercially used with several technologies. The major drawback of thin-film silicon technology is its lower conversion efficiency, which is in the range of (7–10%) for commercial modules versus (15–21%) for those based on crystalline Si. Thin film panel performs better under higher temperatures, when compared with the other types. Good thin film materials (raw materials) are low cost, non- toxic, solid, abundant and stable [13].

D. Dye-Sensitized Solar Cell (DSSC): Dye Sensitized solar cells also named a semiconductor-electrolyte-contact cells.This type classified third generation photovoltaic cells [2]. The first DSSC solar cell was introduced by Michel Gratzel in Swiss Federal Institute of Technology [3], so that these cells are often referred to as the Gräetzel cell, or G Cell.The measuring parameters of $DSSC_s$ like electrical conversion efficiency, open circuit voltage, short circuit current density, fill factor, interface charge resistance and an incident photon to current efficiency depend on morphological properties of semiconductors, spectroscopic properties of dyes and the electrical properties of electrolytes [6]. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte. The drawback with DSSCs is the high band gap of the core materials, e.g. TiO_2 particles (50–70nm) in size (3.2eV, wavelength 385nm in the ultraviolet range), compared to other semiconductors, which is illustrated by its absorption of UV light but not visible light. In the case of solar ultraviolet rays, only 2–3% of the sunlight (in the UV spectrum) can be utilized [6]. DSSC is a low-cost solar cell comparing to the group of thin film solar cells [2, 3 and 6], (The production cost of DSSC is 30% that of traditional silicon solar cells) [6].

The aim of this work is to compare different parameters of solar cells manufactured commercially with different technologies. They are dye-sensitized, thin film silicon polycrystalline silicon and mono-crystalline silicon solar cells. This comparison is achieved by measuring the current voltage characteristics for each cell for different Light wavelength. Then the solar cell parameters: short-circuit current, open-circuit voltage; fill-factor and efficiency are determined.

1. Solar Cell Model

The equivalent electrical circuit of a solar cell can be treated as a current source parallel with a diode, as shown in Fig.1. As can be seen, some losses exist in the real operation of the solar cell. To pick up these losses, a series resistance Rs and a shunt resistance Rsh are added to the PV system. The electrical characteristic of the solar cell used is almost same as that of the diode, which is represented by the equation of Shockley [4]:

$$I = I_{sc} - I_o\left(e^{\frac{q(V+IRS)}{nKT}} - 1\right) - \frac{V+IRs}{Rsh} \qquad (1)$$

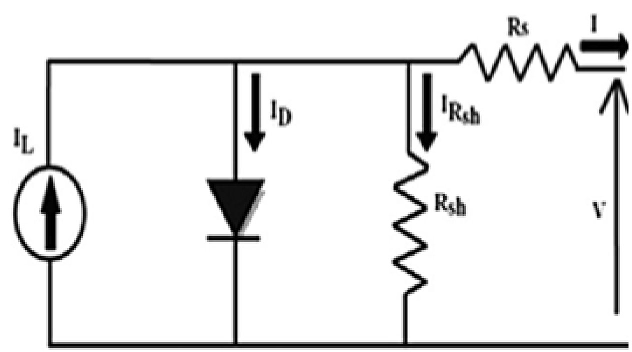


Fig (1): Equivalent circuit for solar cell system [4]

where I_{sc} is the short circuit photo current, I_o is the diode reverse saturation current, V is the cell voltage, q the electron's charge, n is the diode's ideality factor, K is Boltzmann's constant, T is temperature, R_S is the series resistance, Vt is the thermal voltage, and R_{Sh} is the shunt resistance.

The photocurrent Isc, generated by a solar cell at short circuit condition is dependent on the photon flux. The photocurrent is related to the photon flux of a solar cell through the cell quantum efficiency (QE) which is the probability that a photon of certain energy E, can deliver an electron to an external load from the solar cell. QE is determined by the solar cell material absorptivity [8, 9].

The open circuit voltage Voc is the voltage between the terminals when zero amount of current is drawn or load resistance is infinite. The short circuit current Isc, is the current when the terminals are connected to each other with no load resistance. They are the most important characteristic of a solar cell. Short circuit current increases with concentration of photons. Increase in photons concentration means more photons on a unit square area of the cell, which in turn means more electrons and holes generated. The short circuit current Isc is proportional to the area of the solar cell [11, 12].

The fill factor (F.F) of the solar cell was determined from the equation :

$$\text{F.F.} = \frac{\text{maximum power}}{\text{open circuit voltage} * \text{short circuit current}} \quad (2)$$

The conversion power efficiency (η) was determined from the equation :

$$\eta = \frac{\text{output electirical power}}{\text{input optical power}} \quad (3)$$

2. Experimental Setup

The spectral response (wavelength dependent measurements) has been performed by the solar cells based on laser lines, sodium lamp, and filter-based light sources. Fig. 2 shows the experimental measuring system employed in this work.

The light illuminating the solar cell are emitting from red laser diode at 650 nm, green laser diode at 532 nm, sodium lamp at 589 nm, and filter-based mercury lamp at 460 nm, 500 nm, 540 nm, and 570 nm wavelengths. The intensity of light has been measured by a photo detector calibrated in units of Lux. A calibration and correction factors including the area of detector different from cell area and detector sensitivity have been considered.

The output of a solar cell has been measured by an electrical circuit that consists of variable resistors suitable for the resistance of each cell in conjunction with a microammeter and voltmeter. The errors of the instruments were considered due to their drift and stability of the reading data. The reading data were analyzed by computer under MATLAB environment.

The temperature of the solar cell was monitored by temperature probe in conjunction with calibrated temperature meter.

The solar cells investigated in this work are commercial type consisted of mono-crystalline silicon, poly-crystalline silicon, thin film silicon, and dye-sensitized solar cell. Table 1 shows the investigated solar cells and the corresponding areas.

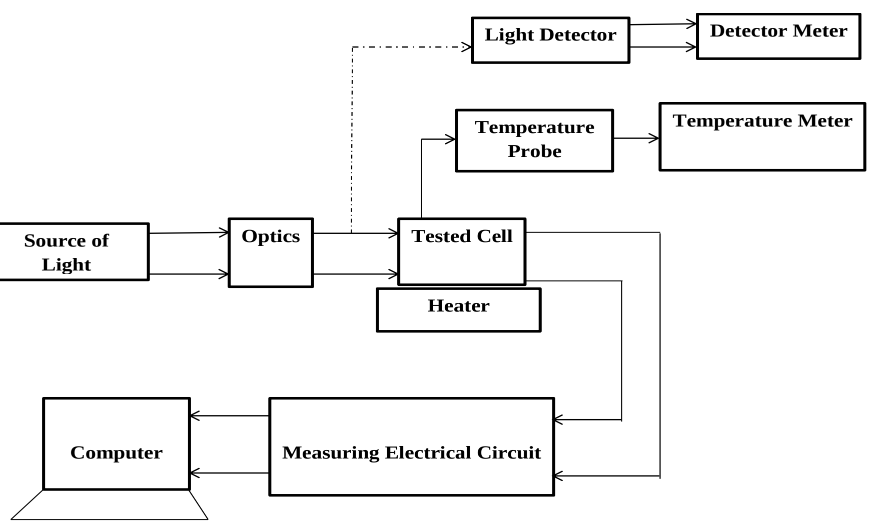


Fig (2): The Experimental Setup

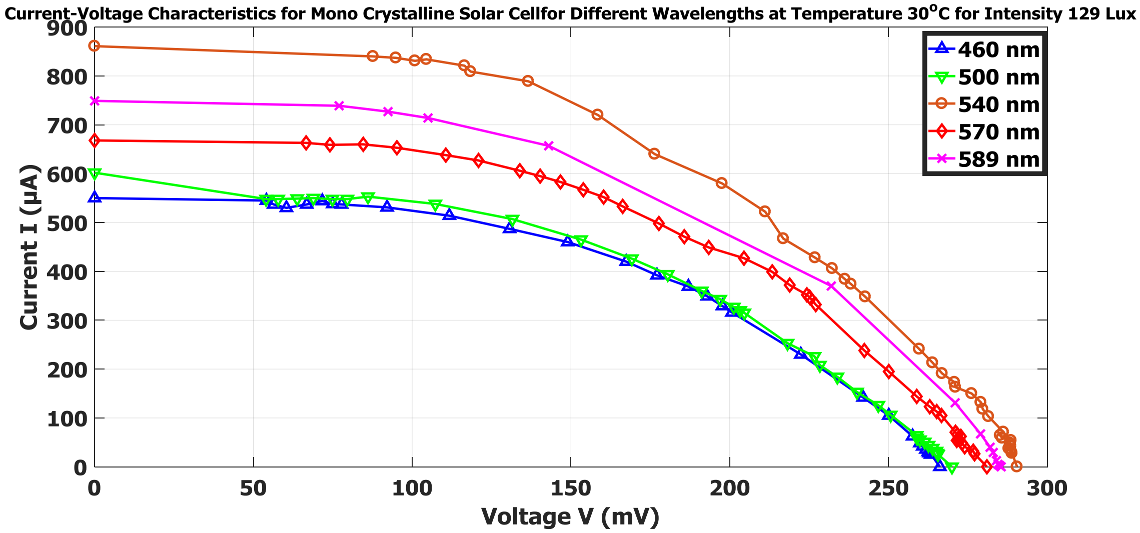
Table (1): The investigated solar cells

Solar cell	manufacture	material	area
Dye-sensitized solar cell	solaronix SA company	N719 and Titanium Dioxide	30.25 mm^2
Thin film silicon solar cell	Sanyo, Japan model "CASIO""fx-91ES"	Silicon	392 mm^2
Polycrystalline silicon solar cell	China	Silicon	4400 mm^2
Mono crystalline silicon solar cell	Lucas service overseas England module F1219	silicon	3.142 cm^2

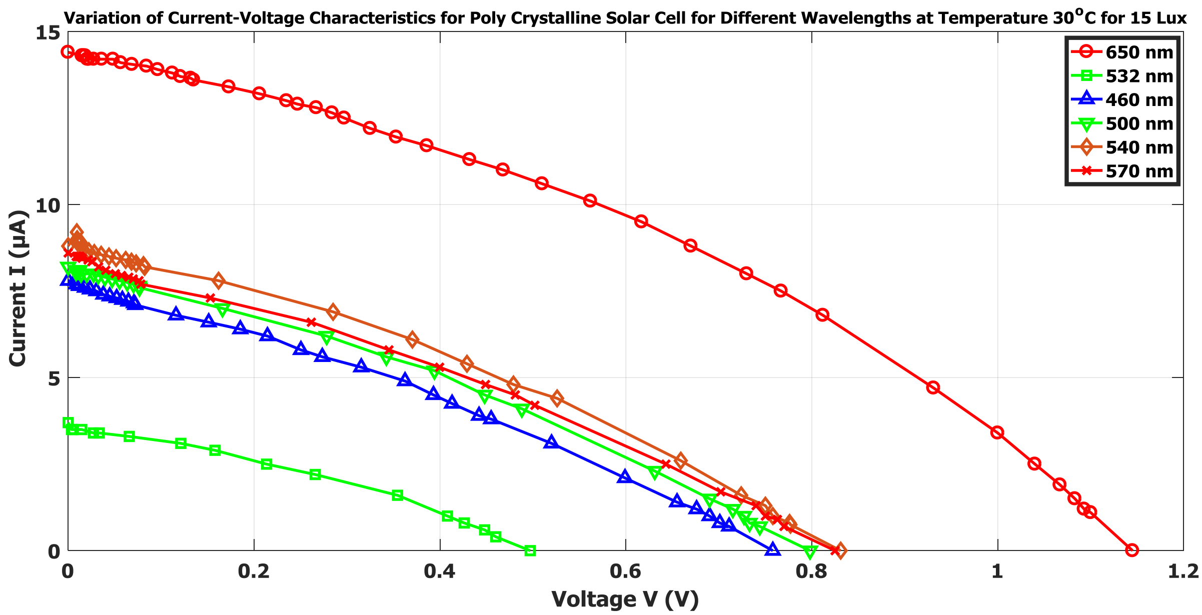
3. Results and Discussions

4.1 Dependence of Solar Cells Parameters on Wavelength

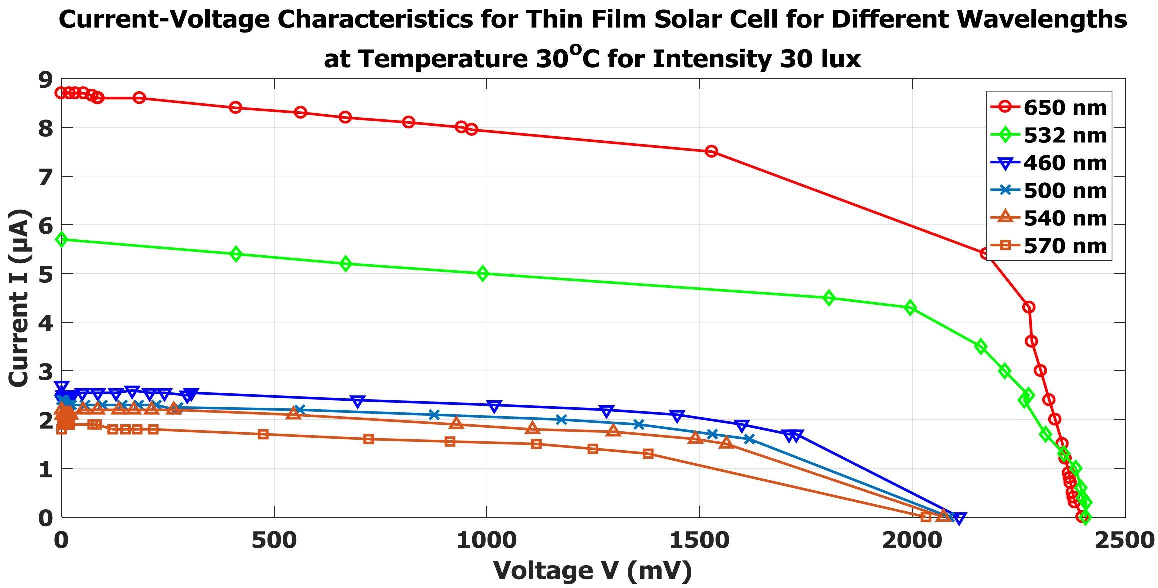
The (I-V) characteristics for the solar cells for different wavelength in the range from 460 nm to 650 nm are shown in Fig.3. The behavior of I-V characteristics of mono-crystalline silicon and thin film silicon varied better than poly crystalline silicon and dye-sensitized solar cell for keeping the constant current over wider voltage range.



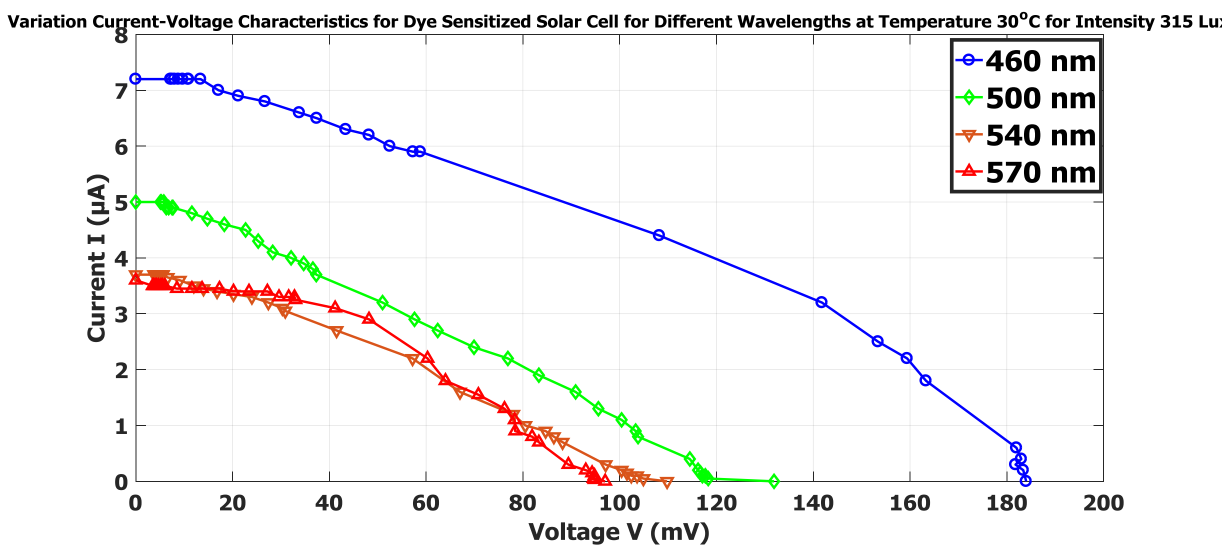
(a) Mono-crystalline silicon solar cell



(b) Poly-crystalline silicon solar cell



(c) Thin Film Silicon Solar Cell



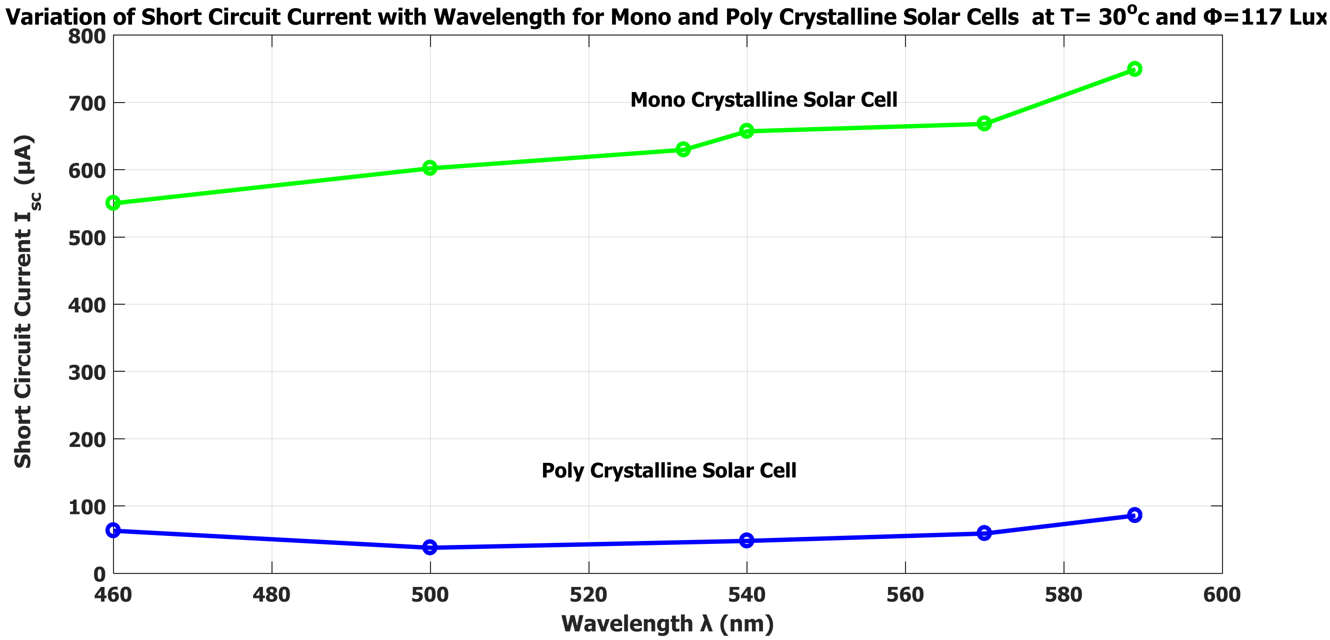
(d) Dye-Sensitized Solar Cell

Fig (3): I-V characteristics of solar cells for different wavelengths

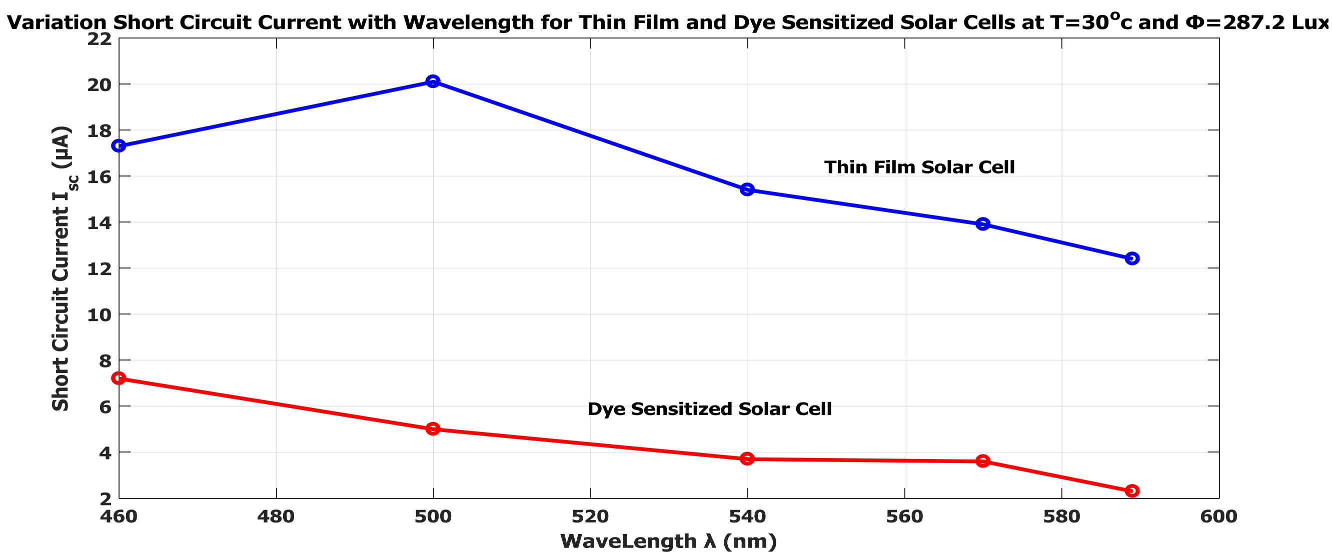
The variation of short-circuit current I_{sc} for the solar cells with wavelength in the range 460 nm to 589 nm is shown in Fig. 4. The short circuit current shows slight variation in the wavelength. There is a maximum in the short-circuit current for thin film solar cell at λ=500 nm. The short circuit current increases slightly towards longer wavelength for mono-crystalline and poly-crystalline silicon solar cell while there is a slight decrease in the short-circuit current for dye-sensitized solar cell.

This decrease in the short circuit current for dye sensitized solar cell is due its wide band gap which requires high photon energy or lower wavelength photons to generate the carriers as indicated by Suriat Suhaimi (2015) [3]

The maximum short circuit current at 500 nm for thin film solar cell is due to the maximum in external quantum efficiency as indicated by YAMAMOTO (2003) [14].



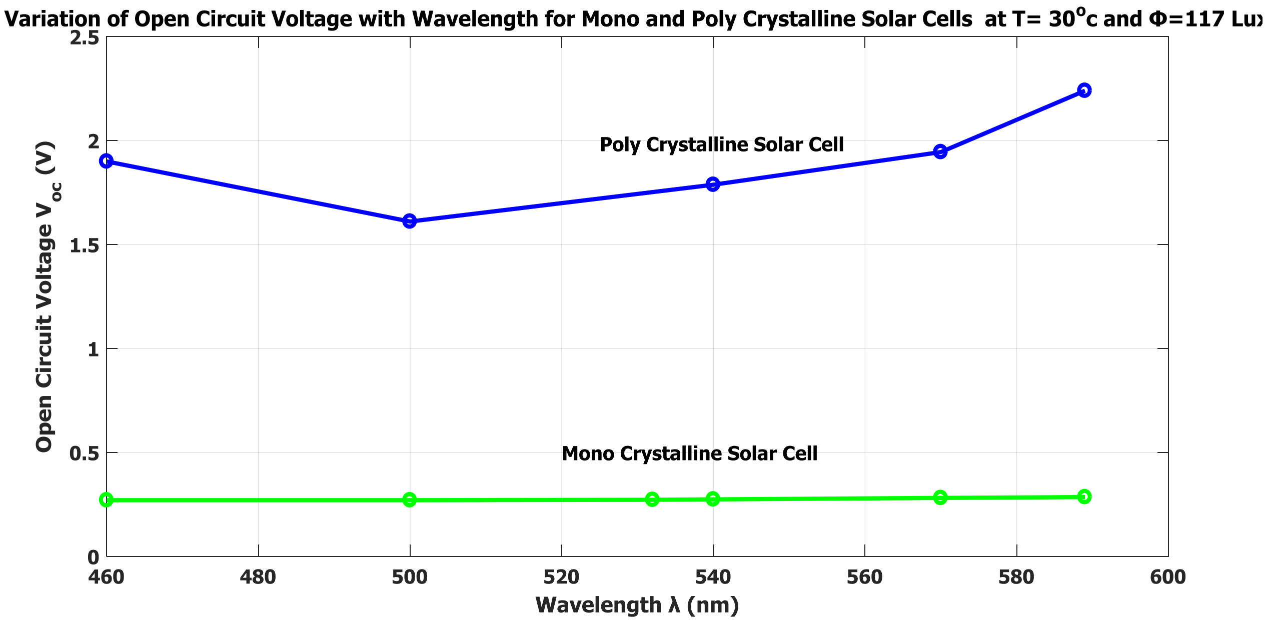
(a) Mono-crystalline and poly-crystalline silicon solar cells



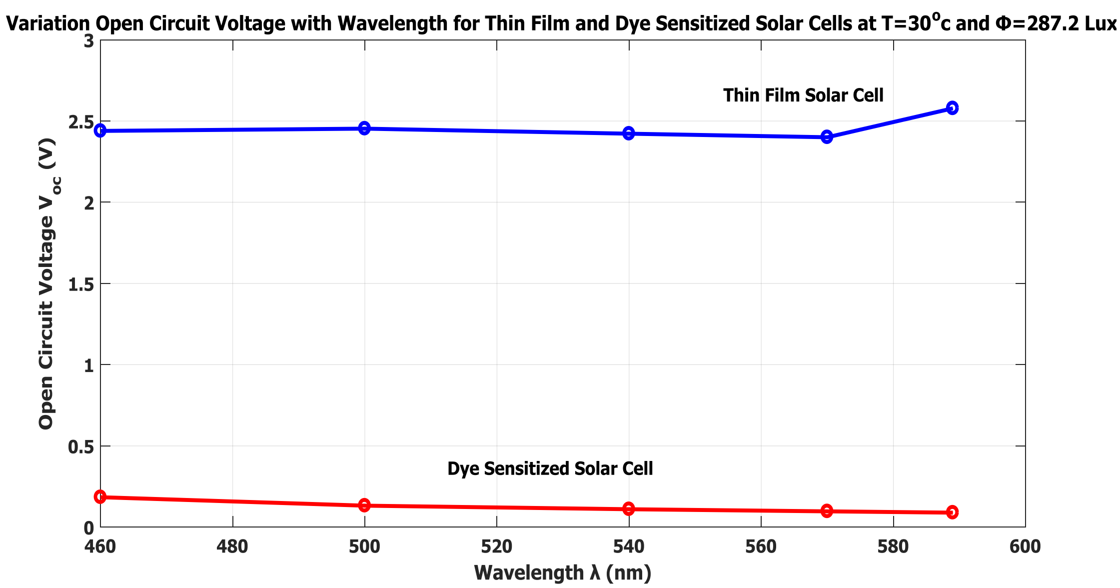
(b) Thin film crystalline silicon and dye-sensitized solar cells

Fig (4): Variation of short-circuit current of solar cells with wavelength

The variation of open-circuit voltage with wavelength in the range 460 nm to 589 nm is shown in Fig.5. There is a slight increase in the voltage with wavelength for poly-crystalline silicon and thin film silicon and nearly constant voltage for mono-crystalline and dye-sensitized solar cells.



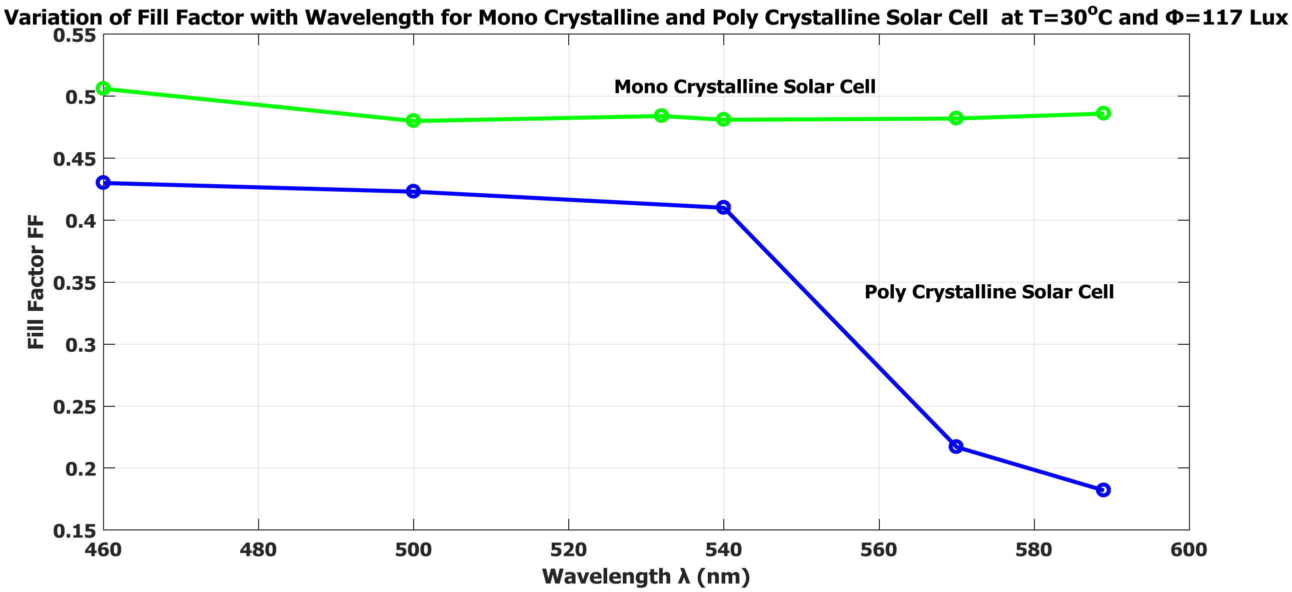
(a) Mono-crystalline and poly-crystalline silicon solar cells



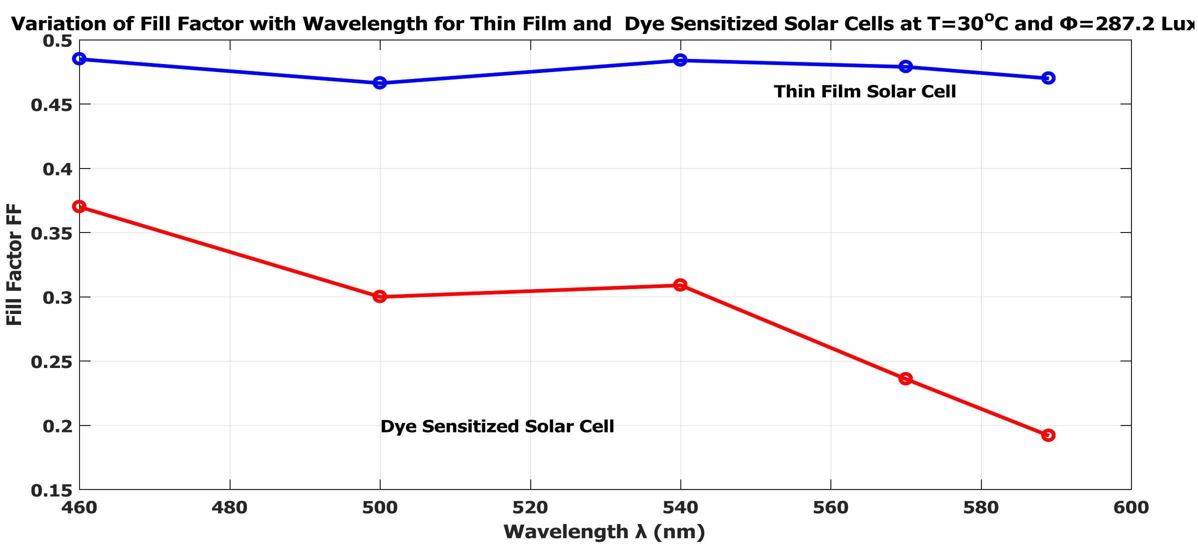
(b) Thin film crystalline silicon and dye-sensitized solar cells

Fig (5): variation of open circuit voltage with wavelength

The variation of fill factor with wavelength is shown in fig.6. For the solar cells in the range 460 nm to 589 nm. The fill factor for mono crystalline and thin film silicon solar cells are nearly constant while the fill factor of poly crystalline silicon and dye-sensitized solar cells decrease towards longer wavelengths.



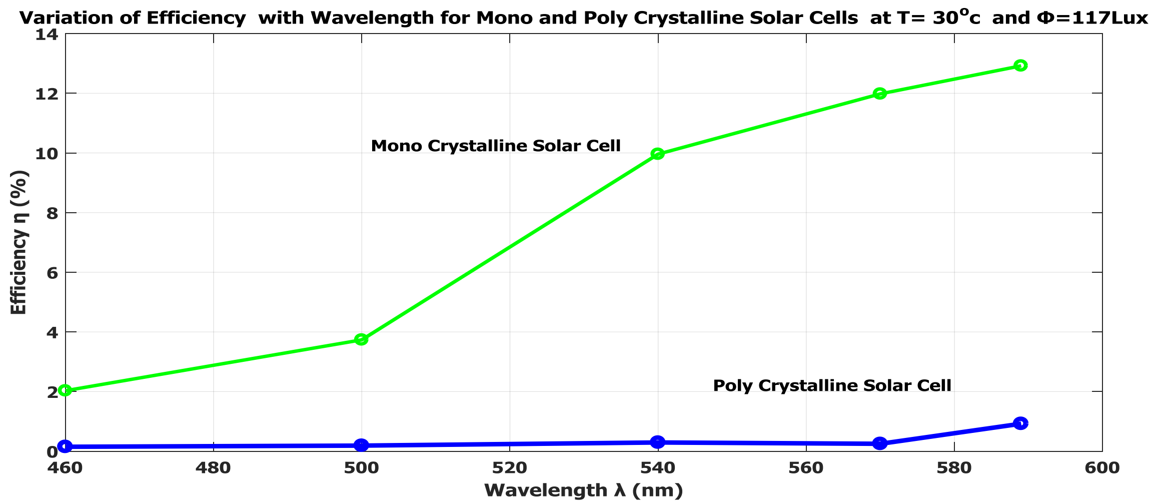
(a) Mono-crystalline and poly-crystalline silicon solar cells



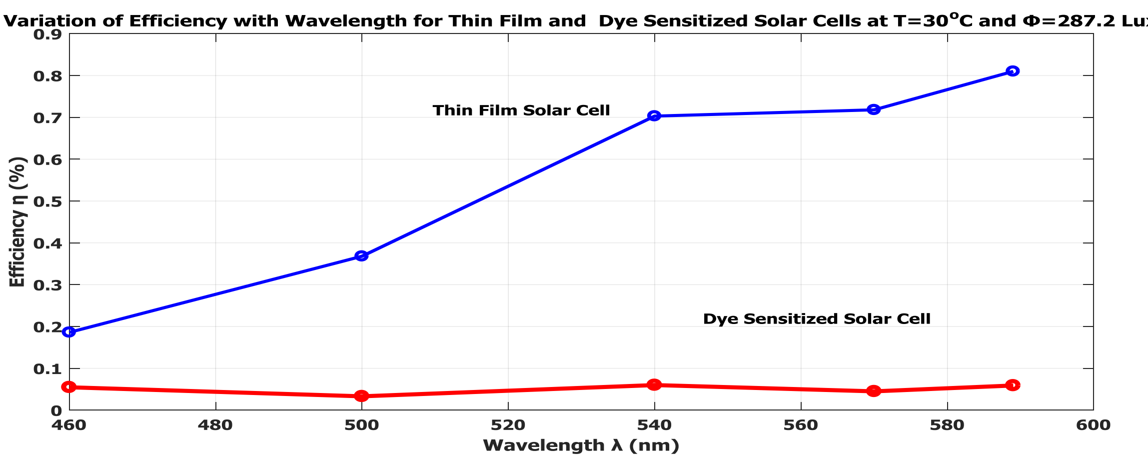
(b) Thin film crystalline silicon and dye-sensitized solar cells

Fig (6): Variation of fill factor with wavelength

The variation of efficiency with wavelength in the range 460 nm to 589 nm for the solar cells is shown in Fig. 7. The efficiency for poly-crystalline silicon and dye-sensitized solar cells are nearly constant while it increases towards longer wavelengths for mono-crystalline and thin film silicon solar cells. The results are in good agreement with the measurements carried out by Heo (2013) [10], and Mahmoud et.al (2014) [2].



(a) Mono-crystalline and poly-crystalline silicon solar cells



(b) Thin film crystalline silicon and dye-sensitized solar cells

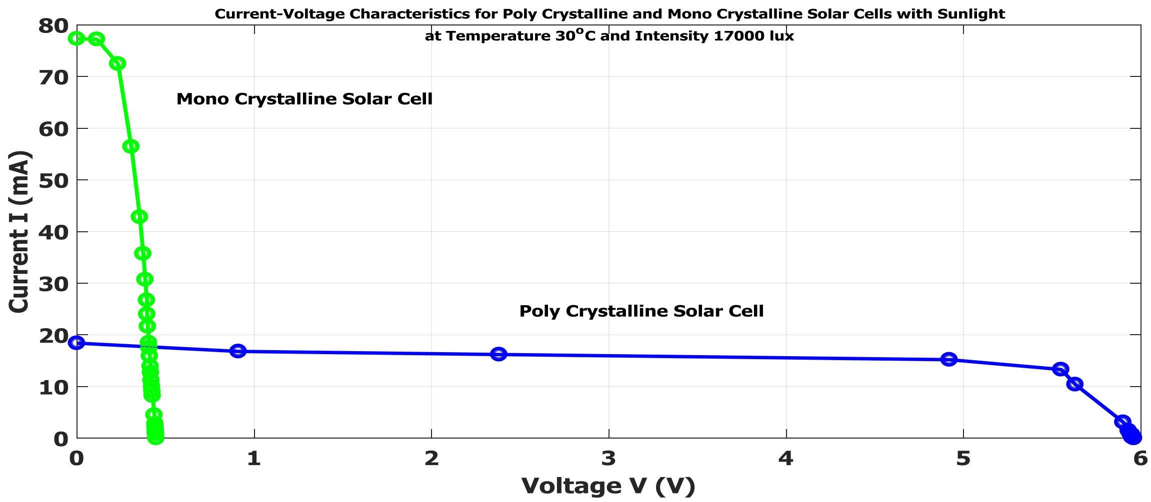
Fig (7): variation of efficiency with wavelength

3.2 Response of the Solar Cells to Sunlight

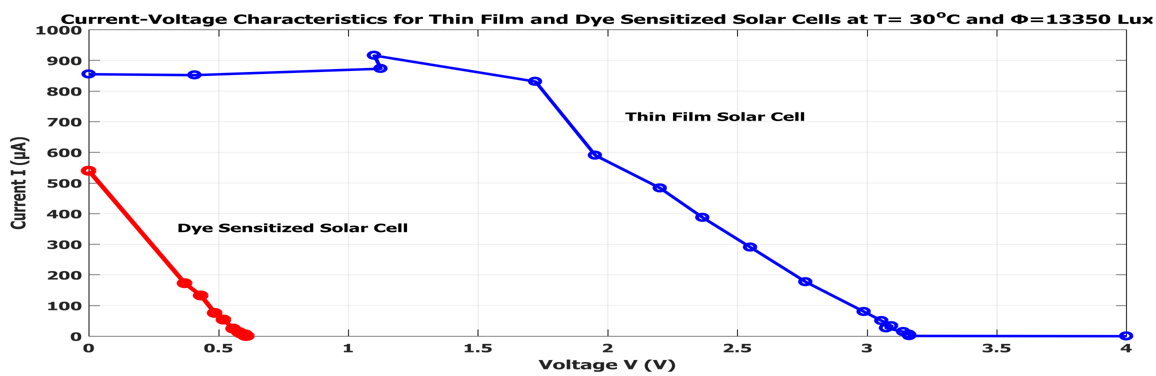
The I-V characteristics of the different solar cells under sunlight 1M is shown in Fig. 8. The parameters of the solar cells are given in Table 2.

Table (2): Solar cells parameters when illuminated with sunlight

Solar cell	I_{SC} [mA]	V_{OC} [V]	FF	η [%]
Dye-sensitized solar cell	0.539	0.61	0.194	0.42
Thin film silicon solar cell	0.855	4	0.418	0.73
Polycrystalline silicon solar cell	18.4	5.96	0.682	3.4
Mono crystalline silicon solar cell	73.3	0.447	0.515	11.33



(a) Mono-crystalline and polycrystalline solar cell



(b) Thin film and dye sensitized solar cells

Fig (8): I-V Characteristics for different solar cells illuminated with sunlight

4. Conclusions

Solar cells with the types of mono-crystalline, poly-crystalline and thin films based silicon are compared to dye-sensitized solar (DSC) cell under different characteristic and efficiency. In this study, it has been shown that the efficiency of each solar cell is influenced by the wavelength of the incident light. The difference in electrical behavior between these solar cells under varying operating conditions was experimentally investigated.

Great differences in electrical behavior of the investigated DSCs and silicon cells have been identified. The results obtained in the lab provide an understanding of cell performance under conditions which can be highly controlled and can be related to theory. Good correspondence experimental results and similar published results were achieved.

The experimental results show that the cell efficiency is strongly influenced by irradiance, as a reduction in overall cell performance for the DSC was seen for increasing irradiance levels. This is interpreted as losses in the DSC which increase for increasing irradiance due to charge transport limitation. The silicon on the other hand exhibits positive performance dependence with highest efficiency at high irradiance level.

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