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The Effect of Optical Filters on the Output Power and Efficiency of the Silicon Solar Cell

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Abstract: In this work solar cell was subjected to light source (Lamp) Power was (100 w) and different optical filters with different colors, different wavelength with the same surface area, the solar cell was fabricated monocrystalline with surface area of 0.0224m^2, Open-circuit volte 13.5V Short circuit current 0.5A, maximum power 3 w voltage at p_{max} 9V different optical filters such as Red orange yellow green blue and violet was put in front of light source. The optical filters passed one color to transmission to obtain of solar cell I-V characteristics, The results of output power and efficiency of the solar cell was compared with and without filter, the voltages, current and power variation of the module with different filters are presented , due to filters the solar cell power was significantly reduced in comparison with the solar cell without filters, greater amount of current was generated when light of a longer wavelength fell upon the solar cell, However the wavelengths of violet and orange light did not follow the trend, this signifies that a relationship between wavelength and current may not be completely linear, outside factors may have also influenced the result, we assumed that blue light shining on a solar cell would give off the higher volt reading because it has the shortest wavelength and the highest energy, but it was actually the lowest.

Keywords: Solar cell, Temperature, Power density, Light intensity, Efficiency, Optical filters.

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1. Introduction:

Optical filters are devices that selectively transmit light of different wavelengths, usually implemented as plane glass or plastic devices in the optical path which are either dyed in the bulk or have interference coatings. The optical properties of filters are completely described by their frequency response, which specifies how the magnitude and phase of each frequency component of an incoming signal is modified by the filter mostly belong to one of two categories, there are interference filters optical filters selectively transmit light in a particular range of wavelengths, that is colors while blocking the remainder, they can usually pass long wavelengths only (long pass), short wavelengths only (short pass), or a band of wavelengths, blocking both longer and shorter wavelengths (band pass), the pass band may be narrower or wider, the transition or cutoff between maximal and minimal transmission can be sharp or gradual, there are filters with more complex transmission characteristic, for example with two peaks rather than a single band these are more usually older designs traditionally used for photography filters with more regular characteristics are used for scientific and technical work (Bunea et al., 2020).

Optical filters are commonly used in photography (where some special effect filters are occasionally used as well as absorptive filters), in many optical instruments, and to color stage lighting. In astronomy optical filters are used to restrict light passed to the spectral band of interest, e.g., to study infrared radiation without visible light which would affect film or sensors and the desired infrared, optical filters are also essential in fluorescence applications such as fluorescence microscopy and fluorescence spectroscopy (Capar , 2017).

Photographic filters are a particular case of optical filters, and much of the material here applies, photographic filters do not properties and precisely defined transmission curves of filters designed for scientific work, and sell in larger quantities at correspondingly lower prices than many laboratory filters. Some photographic effect filters, such as star effect filters, are not relevant to scientific work (Evans and Florschetz, 2019).

2. Concept of the solar cell

2.1. Solar Cell External Parameters

The main parameters that are used to characterize the performance of solar cells are the maximum power, Pmax, the short-circuit current density, Isc, the open-circuit voltage, Voc, and the fill factor, FF. The conversion efficiency, η, is determined from these parameters (Jafari *et al.*, 2019).

2.2. Short-Circuit Current

The short-circuit current, Isc, is the current that flows through the external circuit when the electrodes of the solar cell are short circuited. The short-circuit current of a solar cell depends on the photon flux density incident on the solar cell, that is determined by the spectrum of the incident light, the Isc depends on the area of the solar cell, the short-circuit current density is often used to describe the maximum current delivered by a solar cell, the maximum current that the solar cell can deliver strongly depends on the optical properties (absorption in the absorber layer and total reflection) of the solar cell.

2.3 Open-Circuit Voltage

The open-circuit voltage is the voltage at which no current flows through the external circuit. It is the maximum voltage that a solar cell can deliver, the Voc corresponds to the forward bias voltage, at which the dark current compensates the photo-current, the Voc depends on the photo-generated current density.

2.4 Maximum Power

A solar cell may operate over a wide range of voltages (V) and currents (I). By increasing the resistive load from zero (a short circuit) to a very high value (an open circuit) can determine the maximum-power point.

2.5 Fill Factor

The fill factor is the ratio between the maximum power (Pmax = Vm × Im) and the product of the open-circuit voltage (Voc) and The short-circuit current (Isc) (Erdem *et al*., 2018).

2.6 Conversion Efficiency

The conversion efficiency is calculated as the ratio between the generated maximum power and the incident power (Garg *et al*., 2020)

$$\textbf{Efficiency} = \frac{P_{Input}}{P_{Output}} = \frac{V_m I_m}{P_{Output}} = \frac{V_{oc} I_{sc}}{E} \frac{FF}{A} \qquad (1)$$

3. Experimental work, Results and Discussion

3.1 Experimental work

In this work solar cell subjected to light source (Lamp) Power was (100 w) and different optical filters with different color and same surface area, the experiment repeated for the solar cell without filters.

3.2 Materials and Methods

The solar cell was fabricated mono crystalline with surface area of 0.0224m^2, open-circuit voltge13.5V Short circuit current 0.5A , maximum power 3 w voltage at p_{max} 9V and different optical filters (Red –orange-yellow-green-blue and violet) put in front of light source (lamp)power was100 w, Used DC ammeter and DC voltmeter, the optical filters passed one color to transmission to obtain of solar cell

I-V characteristics experiment was collected about 12 pm, the results were tabulated and illustrated in the form of graphs

3.3 Results and Discussion

Table (1) the I-V solar cell reading for the Red optical filter

Optical Filter Color	**Red**		
Time : 12 Pm	**Open Circuit Voltage(V_{oc}= 7.4V)**		
Temperature= 29 c	**Short Circuit Current (I_{sc}=3.5mA)**		
Resistance (R) Ω	V (v)	I (m A)	P (m w)
0.000	0	3.5	0
1000	3	3	9
2000	5.2	2.6	13.52
3000	6.4	2.2	14.08
4000	6.8	1.7	11.56
5000	7	1.4	9.8
6000	7.1	1.2	8.52
7000	7.2	1.1	7.92
8000	7.2	0. 9	6.48
9000	7.3	0. 8	5.84
∞	7.4	0	0

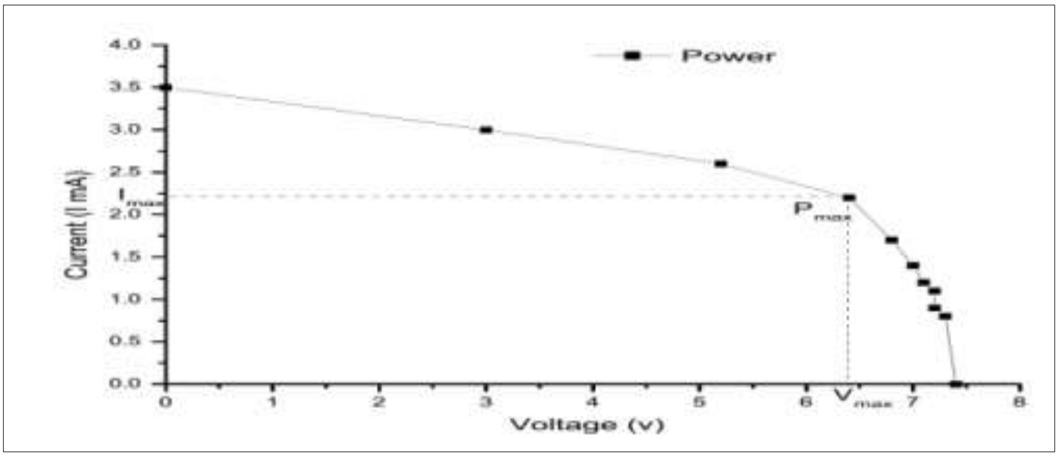

Figure (1) the I-v curve of solar cell for red optical filter

$$FF_{\text{red optical filter}} = \frac{Pmax}{Voc\ .\ Isc} = \frac{V_m\ .\ I_m}{V_{oc}\ .\ I_{sc}} = \frac{6.4}{7.4} X \frac{2.2}{3.5} = \frac{14.08}{25.9} = 0.54$$

$$\eta = \frac{Voc\ .\ Isc\ .\ FF}{E\ .\ A} = \frac{7.4x3.5x10^{-3}x0.54}{350x224x10^{-4}} = \frac{0.013986}{7.84} = 0.00178 = 0.18\ \%$$

Table (2) the I-V reading solar cell for orange optical filter

Optical Filter Color	Orange		
Time : 12 Pm	Open Circuit Voltage(V_{oc}= 6.5v)		
Temperature= 29 c	Short Circuit Current (I_{sc}= 1.9mA)		
Resistance (R) Ω	V (v)	I(m A)	P (m w)
0.000	0	1.9	0
1000	1.6	1.7	2.72
2000	3	1.5	4.5
3000	4	1.3	5.2
4000	4.6	1.2	5.52
5000	5.2	1	5.2
6000	5.5	0.9	4.90
7000	5.7	0.8	4.56
8000	5.9	0.7	13 .4
9000	6	0.6	3.6
∞	6.5	0	0

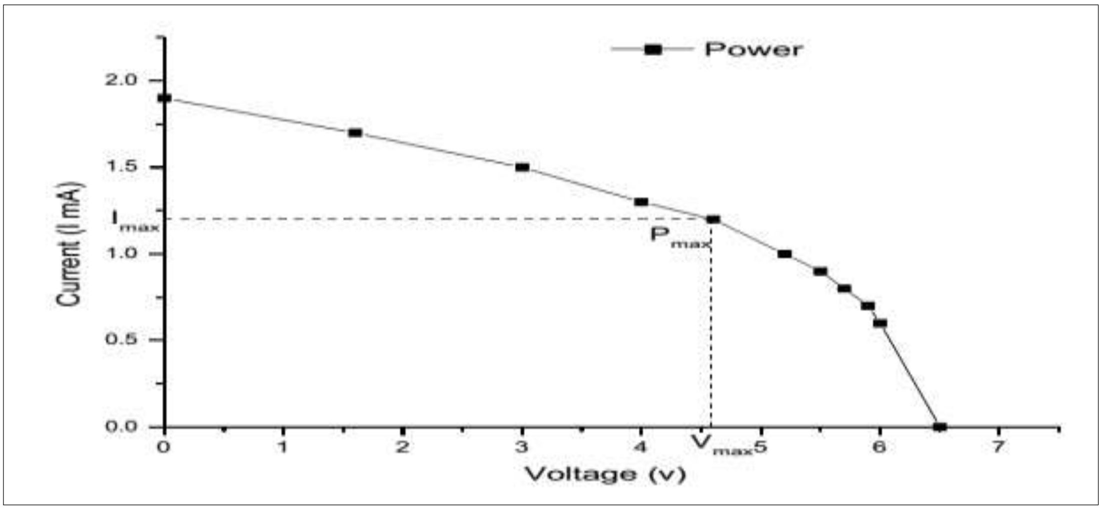

Figure (2) the I-v curve of solar cell for Orange optical filter

FF orange optical filter $= \frac{Pmax}{Voc\,.\,Isc} = \frac{Vm\,.\,Im}{Voc\,.\,Isc} = \frac{4.6x1.2}{6.5x1.9} = \frac{5.52}{12.35} = 0.45$

$\eta = \frac{Voc\,.\,Isc\,.\,FF}{E\,.\,A} = \frac{6.5x1.9x10^{-3}x0.45}{350x224x10^{-4}} = \frac{0.0055575}{7.84} = 0.00070 = 0.07\ \%$

Table (3) the I- V solar cell reading for yellow optical filter

Optical Filter Color	**Yellow**		
Time : 12 Pm	**Open Circuit Voltage(V_{oc}= 6.3V)**		
Temperature= 29 c	**Short Circuit Current (I_{sc}=1.5mA)**		
Resistance (R) Ω	V (v)	I (m A)	P (m w)
0.000	0	1.5	0
1000	1.4	1.4	1.96
2000	2.5	1.2	3
3000	3.4	1.1	3.74
4000	4	1	4
5000	4.5	0.9	4.05
6000	5	0.8	4
7000	5.3	0.7	3.71
8000	5.4	0.7	3.78
9000	5.5	0.6	3.3
∞	6.3	0	0

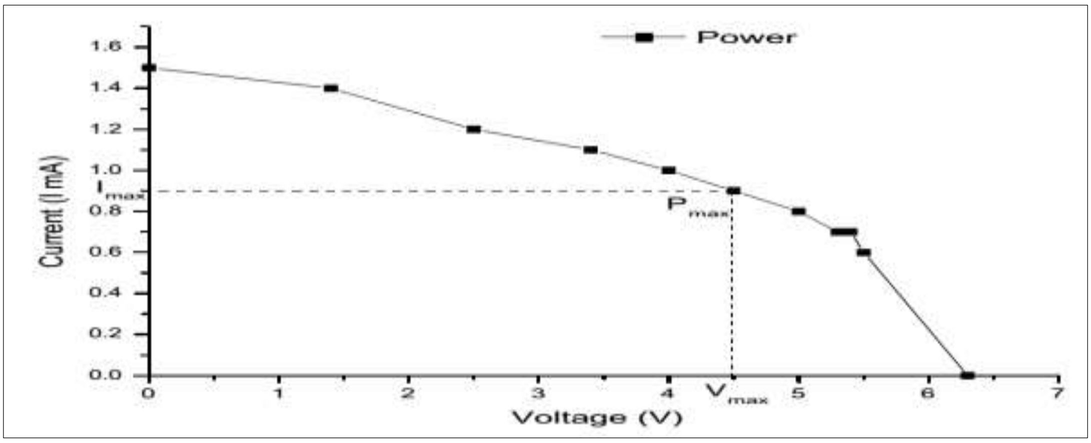

Figure (3) the I-v curve of solar cell for yellow optical filte

FF yellow optical filter $= \frac{Pmax}{Voc\ .\ Isc} = \frac{Vm\ .\ Im}{Voc\ .\ Isc} = \frac{4.5x0.9}{6.3x1.5} = \frac{4.05}{9.45} = 0.43$

$\eta = \frac{Voc\ .\ Isc\ .\ FF}{E\ .\ A} = \frac{6.3x1.5x10^{3-x0.43}}{350x224x10^{-4}} = \frac{0.0040635}{7.84} = 0.00052 = 0.05\%$

Table (4) the I-V solar cell reading for green optical filter

Optical Filter Color	**Green**		
Time : 12 Pm	**Open Circuit Voltage(V_{oc}= 6.6V)**		
Temperature= 29 c	**Short Circuit Current (I_{sc}=2mA)**		
Resistance (R) Ω	V (v)	I (m A)	P (m w)
0.000	0	2	0
1000	1.8	1.8	3.24
2000	3.1	1.5	4.65
3000	4.1	1.3	5.33
4000	4.8	1.2	5.76
5000	5.4	1.1	5.94
6000	5.6	0.9	5.04
7000	5.9	0.8	4.72
8000	6	0.7	4.2
9000	6.1	0.7	4.27
∞	6.6	0	0

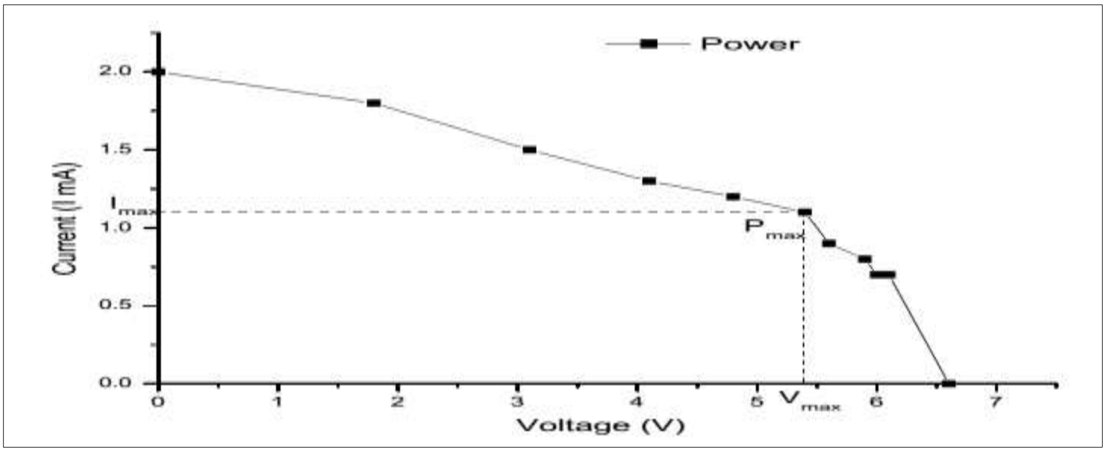

Figure (4) the I-v curve of solar cell for Green optical filter

FF $_{\text{green optical filter}}$ $= \frac{Pmax}{Voc\,.\,Isc} = \frac{Vm\;.\;Im}{Voc\,.\;Isc} = \frac{5.4x1.1}{6.6x2} = \frac{5.94}{13.2} = 0\,.45$

$\eta = \frac{Voc\,.\,Isc\,.\,FF}{E\,.\,A} = \frac{6.6x2x10^{-3}x0.45}{350x224x10^{-4}} = \frac{0.007128}{7.84} = 0.000909 = 0.09\ \%$

Table (5) the I-V solar cell reading for blue optical filter

Optical Filter Color	**Blue**		
Time : 12 Pm	**Open Circuit Voltage(V_{oc}=6.7V)**		
Temperature= 29 c	**Short Circuit Current (I_{sc}=2.3mA)**		
Resistance (R) Ω	V (v)	I (m A)	P (m w)
0.000	0	2.3	0
1000	2	2	4
2000	3.5	1.7	5.95
3000	4.6	1.5	6.9
4000	5.4	1.3	7.02
5000	5.8	1.1	6.38
6000	6	1	6
7000	6.1	0.9	5.49
8000	6.3	0.8	5.04
9000	6.4	0.7	4.48
∞	6.7	0	0

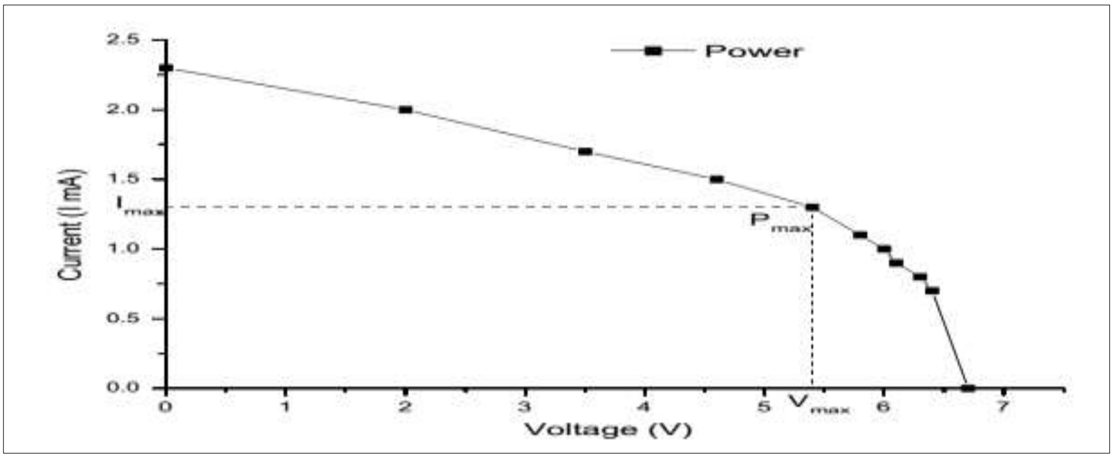

Fig (5) the I-v characteristic of solar cell for blue optical filter

$$FF_{\text{blue optical filter}} = \frac{Pmax}{Voc\ .\ Isc} = \frac{Vm\ .\ Im}{Voc\ .\ Isc} = \frac{5.4x1.3}{6.7x2.2} = \frac{7.02}{14.74} = 0.48$$

$$\eta = \frac{Voc\ .\ Isc\ .\ FF}{E\ .\ A} = \frac{6.7x2.3x10^{-3}x0.48}{350x224x10^{-4}} = \frac{0.0073968}{7.84} = 0.00094 = 0.09\ \%$$

Table (6) the I-V solar cell reading for violet optical filter

Optical Filter Color	Violet		
Time : 12 Pm	Open Circuit Voltage(V_{oc}= 6.8v)		
Temperature= 29 c	Short Circuit Current (I_{sc}=2.2mA)		
Resistance (R) Ω	V (v)	I (m A)	P (m w)
0.000	0	2.2	0
1000	2	1.9	3.8
2000	3.4	1.7	5.78
3000	4.5	1.5	6.75
4000	5.4	1.3	7.02
5000	5.9	1.2	7.08
6000	6	1	6
7000	6.2	0.9	5.58
8000	6.3	0.8	5.04
9000	6.4	0.7	4.48
∞	6.8	0	0

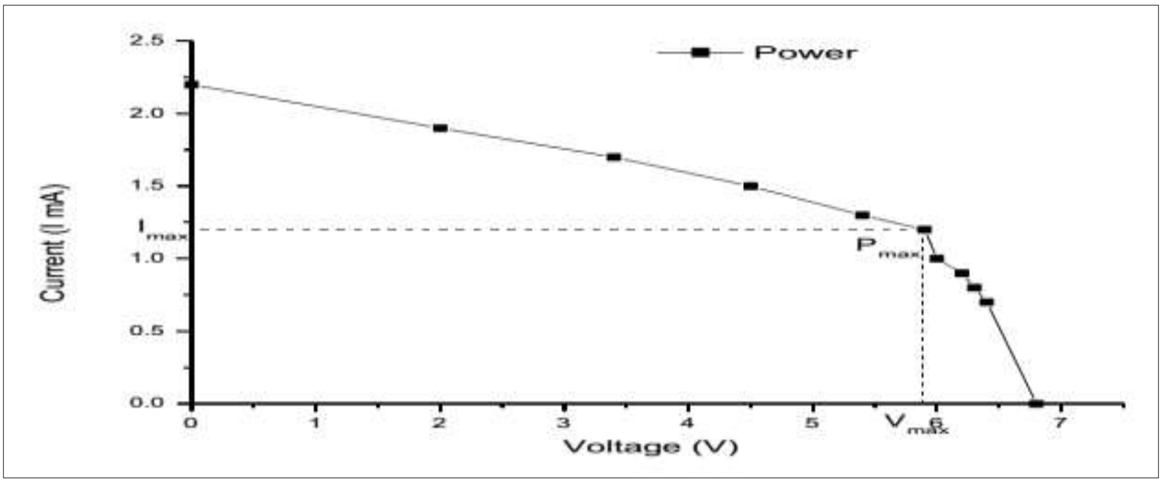

Figure (6) the I-v characteristic of solar cell for Violet optical filte

$FF_{\text{violet optical filter}} = \frac{Pmax}{Voc\,.\,Isc} = \frac{Vm\ .\ Im}{Voc\,.\ Isc} = \frac{5.9x1.2}{6.8x2.2} = \frac{7.08}{14.96} = 0.47$

$\eta = \frac{Voc\,.\,Isc\,.\,FF}{E\,.\,A} = \frac{6.8x2.2x10^{-3}x0.47}{350x224x10^{-4}} = \frac{0.0070312}{7.84} = 0.000896 = 0.09\ \%$

Table (7) the I-V solar cell reading for visible light

Optical Filter Color	**Visible light(without filter)**		
Time : 12 Pm	**Open Circuit Voltage(V_{oc}=8 V)**		
Temperature= 29 c	**Short Circuit Current (I_{sc}=5mA)**		
Resistance (R) Ω	V (v)	I (m A)	P (m w)
0.000	0	5	0
1000	4.5	4.3	19.35
2000	7	3.4	23.8
3000	7.5	2.5	18.75
4000	7.5	1.9	14.25
5000	7.6	1.5	11.4
6000	7.7	1.3	10.01
7000	7.8	1.1	8.58
8000	7.8	1	7.8
9000	7.8	0.9	7.02
∞	8	0	0

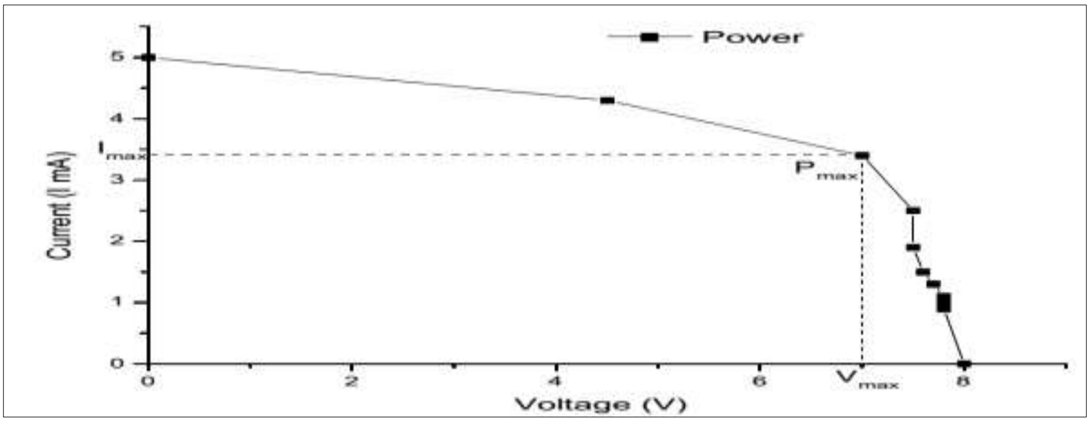

Figure (7) the I-v curve of solar cell for Visible light

$$FF_{\text{visible light}} = \frac{Pmax}{Voc\,.\,Isc} = \frac{Vm\,.\,Im}{Voc\,.\,Isc} = \frac{7x3.4}{8x5} = \frac{23.8}{40} = 0.59$$

$$\eta = \frac{Voc\,.\,Isc\,.\,FF}{E\,.\,A} = \frac{8x5x10^{-3}x0.59}{350x224x10^{-4}} = \frac{0.0236}{7.84} = 0.003010 = 30\ \%$$

Table (8) the output power and efficiency of the solar cell

Color	Wave length nm	$Voc(V)$	Isc**)**	**Pm(mw)**	FF	η**%**
Visible light	550	8	5	23.8	0.59	0.30
Red	660	7.4	3.5	14.08	0.54	0.18
Orange	605	6.5	1.9	5.52	0.45	0.07
Yellow	575	6.3	1.5	4.05	0.43	0.05
Green	520	6.6	2	5.94	0.45	0.07
Blue	455	6.7	2.3	7.02	0.48	0.09
Violet	415	6.8	2.2	7.08	0.47	0.09

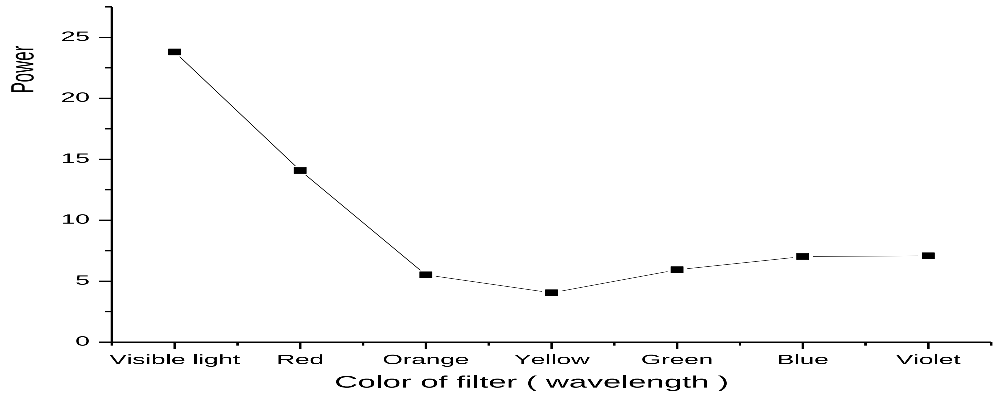

Figure (8) the relationship between color of filter and power

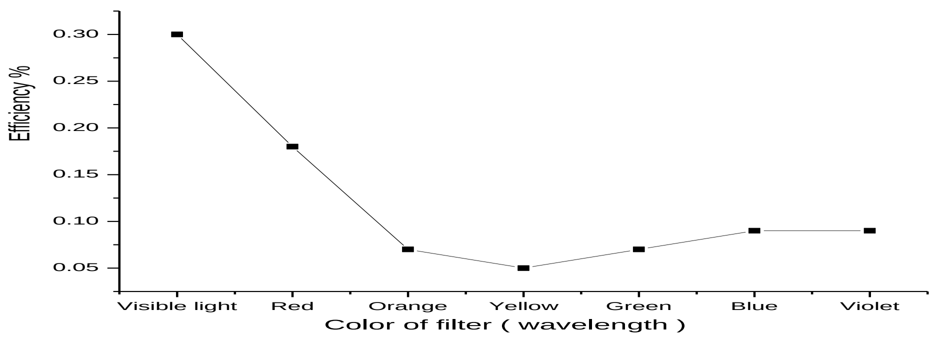

Figure (9) the relationship between color of filter and efficiency

The voltages, current and power variation of the solar cell with different filters are presented in table (8), figure (8), figure (9) due to filters the solar cell power was significantly reduced in comparison with the solar cell without filters (Stanley and

Frank, 2019). a greater amount of current was generated when light of a longer wavelength fell upon the solar cell, However the wavelengths of violet and orange light did not follow the trend, this signifies that a relationship between wavelength and current may not be completely linear, outside factors may have also influenced the result, we assumed that blue light shining on a solar panel would give off the higher volt reading because it has the shortest wavelength and the highest energy, but it was actually the lowest.

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