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Review Article: The Effect of Double Spectrum Colors Factor on Solar Cells Performance in Inorganic Solar Cells

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ABSTRACT

Solar energy is abundant in available renewable energy sources on the earth. Solar cells; SC (photoelectric cells; PV) are used to convert solar energy into electric energy. A CS cell is an electronic constituent (a p-n junction diode) that produces the electricity when sunlight is radiated on them using the photovoltaic effect phenomenon. The inorganic solar cell efficiency depends on the total electric energy produced from solar energy were initially proved at Bell Laboratory in 1954; from this time inorganic PV cells have been used in various and more applications. The semiconductor material is usually used for making solar cells. It can absorb the sun's radiation in the form of light, and the transmitted energy is utilized by collecting the radiant light, and converting it directly into heat or electricity. The scientist Einstein's explanation of the photoelectric effect; is that the energy of electron ejected from a photoelectric plate is influenced by frequency the inverse of the wavelength, and not by light-intensity (the amplitude), as wave-theory prophesied. The incident light with the shorter wavelength has a greater frequency of light and more energy that can be held by expelled electrons. In the same way, the PV cell is sensitive to the wavelengths and it's rejoins well in some parts of the spectrum than others to sunlight. The efficiency of SC cells is impartially low related to high solar energy radiation on the Earth and this is because numerous factors influence photovoltaic system performance. The generation, parameters of the SC cells, factors influences on SC system performance efficiency, and the effect of double spectrum colours on the solar cells performance (reliant on different wavelengths (between long, medium, and short) with different effects on; (n-p) depilation regions) are reported in this review article.

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Content

1. Introduction

Solar energy is considered as the greatest renewable, a plentiful source of available energy in our planet. Electrical energy is a principal resource for progress in modern alive. As there are numerous techniques to produce electrical energy; green energy from the solar technique is permanent for a long time [1-5]. An abundant and clean primary source of energy is the sun, it offers 120,000 trillion Watts (TW) of radiation on the earth's surface every day, far higher than human needs even in the greatest countries request energy [6-13]. The Sunrays involve UV-Vis (Ultra-Violet, Visible) and IR (Infrared) radiation. The solar radiation quantity that arrives at any site is reliant on a number of factors like local weather, geographical location, land scope season, and daytime [14]. Solar cells; SC (Photovoltaic; PV) (**Figure 1**) are the electronic constituents (a p-n junction diode) that create electricity when sunlight is radiated on them using the photovoltaic effect phenomenon. Semiconductors are usually used for making SC cells. Semiconductors of SC can absorb the sun radiates in the appearance of light, and the transmitted-energy is utilized by a collecting of the radiant light, and converting it directly into heat or electricity as photovoltaic conversion energy (this is a physical-chemical phenomenon). Therefore, the resistance, voltage, and current vary when photoelectric cells are exposed to light. In most industries, the semiconductor is prepared as a principle material of the SC cell. The energy of conversion contains light absorption energy (photon) to generate (electron-hole pairs) in a semiconductor and a region of charge-carrier separation. A p–n junction (**Figure 1**) is used at charge carrier separation as the principle [15]. The junction effect of the SC in the P-N junction diodes is the principle of work in photovoltaic cells.

A generation of SC cells, basic working principle of a SC cell, inorganic SC cell technologies, parameters of the SC cell, factors influences on SC cell system performance efficiency, and the effect of double spectrum colours on the solar cells performance (reliant on different wavelengths (long, medium, and short) that have different effects on; (n-p) depilation regions) are reported in this review article.

2. The Solar Cells Generation

Solar cells (Photovoltaic cells) are made from different materials and compounds. Due to the SC development using materials, the generation of SC cell is classified as [16-18]:

2. 1. The 1st SC cells generation-(wafer based)

The first SC cells-generation is made from silicon wafers, or 3- 5 compounds. It is the most popular and the eldest technology owing to high efficiencies. Silicon-wafer SC cells have thickness light absorbing sheets up to (350) µm. The wafer of silicon -based technology is additionally branded into two important sub-groups titled as”;

1. Single/ Mono-crystalline silicon.
2. Poly/ Multi-crystalline silicon.

Mono-crystalline SC cell is prepared for pure silicon as mono-crystalline. The silicones material in these cells have lattice structure of

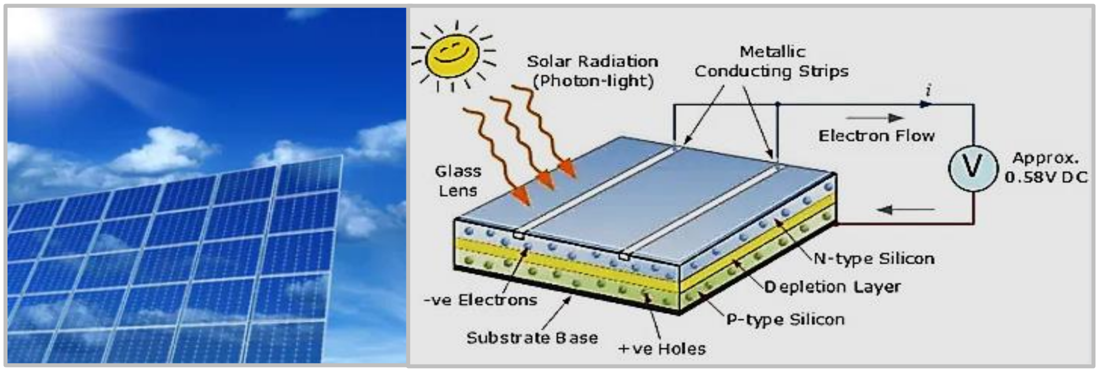

Figure 1. A- A solar panel, B-A “p-n junction” photovoltaic (PV) SC cell

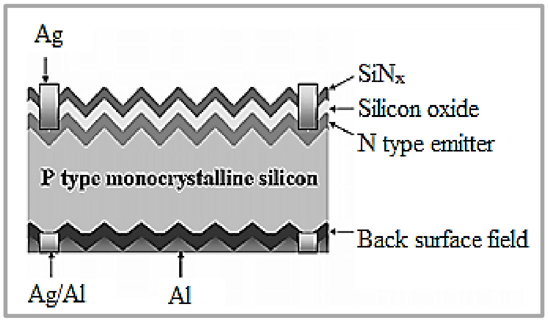

Figure 2. Schematic of mono-crystalline silicon SC cells (Single crystalline silicon SC cells)

continuous single crystal with virtually no defects or inclusions. The high efficiency is the central advantage of these SC cells, which is usually about 15%. The disadvantage of silicon cells as mono-crystalline is the complex practice for manufacturing these cells; this result in "slightly higher costs" compared to SC of various other technologies. One of the most common uses of these solar cells is in-home devices, the reason being that they are very efficient in converting sunlight into electrical energy. **Figure 2** displays the diagram contents of silicon SC cells as mono-crystalline.

2. 2. The 2nd SC generation (thin film SC)

The amorphous silicon and thin-film SC cells are classified in most as the 2nd generation SC cells and are further inexpensive as related to the silicon wafer the 1st generation SC cells. The SC thin-film has a very thin light-absorbing layer (generally in the limit of 1 μm thickness). Thin-film SC cells principle industries are classified as:

1. Amorphous (A)-Silicon (Si) solar cell (a-Si),
2. Cadmium (Cd)-Telluride (Te) solar cell (CdTe), and
3. Copper (C)-Indium (I)-Gallium (G) di-Selenide (S) (CIGS).

Amorphous silicon solar cell (a-Si) consists of silicon atoms in a homogeneous thin layer. Therefore, this silicon absorbs light more effectively than crystalline silicon, resulting in thinner SC cells, also well-known as thin-film photovoltaic technology. The biggest advantage of amorphous silicon cells has deposited the silicon on a variety of substrates, both flexible and rigid. While the low efficiency is it disadvantage, which reaches 6%. These solar photovoltaic cells are used in devices that necessitate very low power, like pocket calculators. The diagram of amorphous silicon SC cells contents is presented in **Figure 3**.

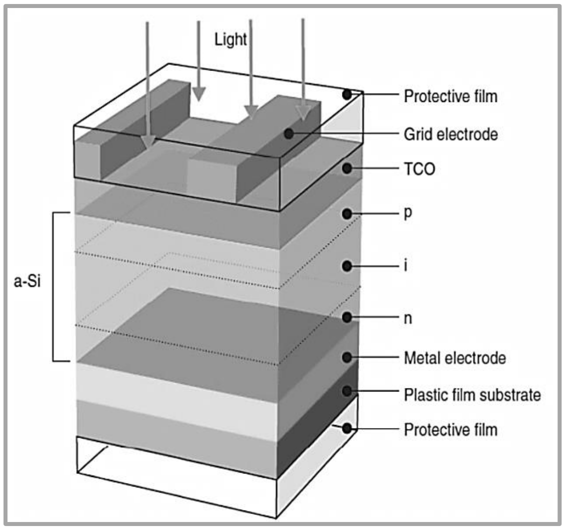

Figure 3. A schematic of amorphous silicon (a-Si) SC cells (thin-film SC cells)

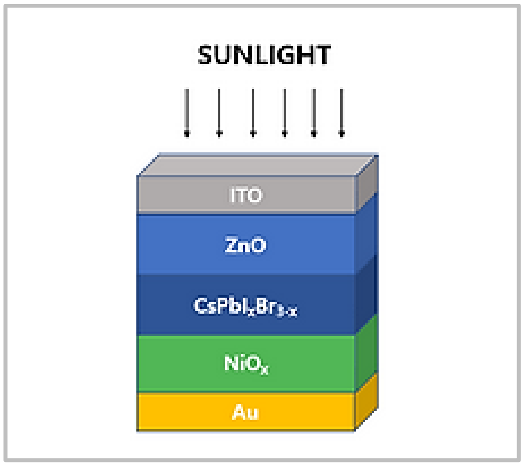

Figure 4. A schematic of nano-crystals SC cells (perovskite SC cells)

2. 3. The 3rd SC generation

The novel promising technology is the third-generation cells with weaknesses at commercially explored in more searches. Most of the advanced three-generation SC cells kinds listed as:

1. Nano-crystal-based SC cell,
2. Dye-sensitized-SC cell,
3. Concentrated-SC cell, and
4. Polymer-based-SC cell.

Photovoltaic nanotechnologies depend on mixing or coating flexible polymer materials with nano-substrates with electrical conductivity. The nano-crystals are classically relying on silicon, CIGS, or CdTe and the substrates are usually silicon or conductors of numerous organic materials. The advantages of Cesium (Cs) included a remarkable interest in the manufacture of high-performance perovskite SC cell. The contents of Perovskite-SC (nano-crystals cell) are illustrated in **Figure 4**.

Several applications, types, and efficiencies of generation solar cells [19], are illustrated in **Figure 5**. **Table 1** presents the advantages and disadvantages of inorganic SC cells.

3. Solar Cell Technologies

Photovoltaic cells have various uses in solar lighting, power pump, power plants, ventilation system, swimming pools, solar cars, and remote applications [20]. For example, the earth satellites, remote area power systems, consumer systems, like remote

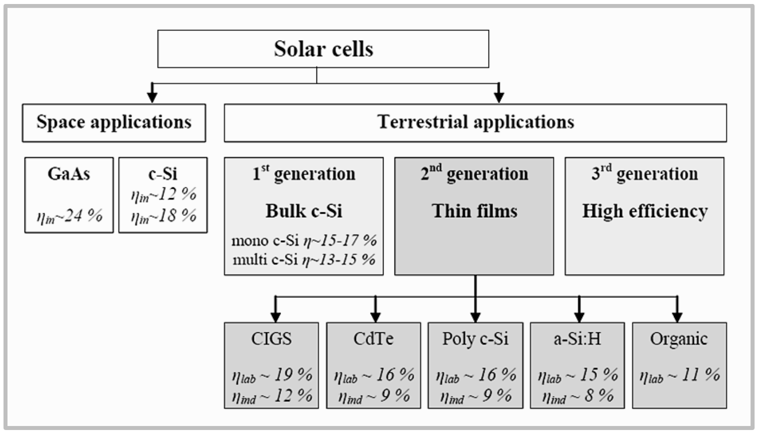

Figure 5. Schematic of several solar cells applications and types

Table 1. Advantages and disadvantages of inorganic SC cells

Material type	Material sub-type	Company and efficiency (%)	Advantages	Disadvantages
Crystalline	Mono-crystalline	US17 20.4	(1) "Consume less space" (2) "Perform better even in low light conditions and longest lifetime" (3) "Results in maximum efficiency because it made from the purest form of silicon" (4) "Perform better in summers because it is more heat tolerant"	(1) "Any kind of moisture shade, or dust on module would break the entire circuit unless it is supported by a micro inverter" (2) "Most expensive"
	Multi-crystalline	T10 16.9	(1) "More cost effective because it has waste less amount of silicon" (2) "Easy to maintain, and install"	(1) "Occupy a larger area" (2) "Made of impure silicon which makes them less efficient"
Thin Film	Amorphous Silicon	US13 13.8	(1) "Easy to create modules in a variety of voltages" (2) "Experience higher results as temperatures increase" (3) "Lower manufacturing costs" (4) "Much less susceptible to breakage during installation or transport" (5) "Produced in a variety of sizes and shapes"	(1) "Expected lifetime is shorter than the lifetime of crystalline cells" (2) "Manufacturing processes are more complex than crystalline silicon" (3) "Lower efficiency than mono-crystalline SC cells or even poly-crystalline SC cells"
	CdTe/CdS	First Solar 13.9	(1) "Cadmium is abundant" (2) "Good match with sunlight: captures energy at shorter wavelengths than is possible with silicon modules" (3) "Ease of manufacturing: simple mixture of molecules cadmium sulphide and cadmium telluride with different compositions"	(1) "Harmful to environment: Cadmium is toxic" (2) "Tellurium is an extremely rare element" (3) "Lower efficiency levels: lower than the typical efficiencies of silicon SC cells"
	CIS/CIGS	US7 15	(1) "Better resistance to heat than silicon based solar modules" (2) "Consumes less energy while manufacturing than crystalline silicon technology" (3) "Much lower level of cadmium is used. Hence, less harm to environment as compared to CdTe"	(1) "Cost of manufacturing is higher than crystalline silicon and CdTe" (2) "They are not as efficient as crystalline silicon SC cells. However, the most efficient of the thin film technologies"
	GaAs	N/A	(1) "High resistivity to radiation and heat"	(1) "Gallium material is expensive"

radiotelephones, handheld calculators, water pumping applications, and wristwatches. The technologies of solar cells play a significant role in energy production because of the large population and greater power consumption. The developing higher solar cells efficiency as converting light into electricity is a principle and important parameter [21], added to reductions the costs of solar cells [22].

Nowadays, two solar cell technologies are in competition, in this review, we concentration on inorganic solar cells which account in the market more than 90% with respect to that of organic-SC cells. The SC cell as inorganic technology is made from inorganic semiconductor materials like amorphous, crystalline, microcrystalline Si, multi-crystalline, alloys, and III-V compounds. Advancement in materials and manufacturing processes prepared an essential part in this progress. Yet, there are various challenges before solar cells could give abundant, clean, and inexpensive power [12]. The manufacture of "SC cells with high efficiency and low cost" is, at present, the biggest challenge for SC cell producers. Hence, several inorganic solar cell technologies have been made to make this source more competitive in the energy field.

3.1. Solar Cell Technologies

The French physicist E. Becquerel noted in 1839 that a string of elements as semiconductors provided an increase to spontaneous energy when enlightened. This chemical-physical phenomenon famous as the photovoltaic influence was clarified by Einstein in 1912. Photovoltaic cells' efficiency depends on the total electric energy produced from solar energy were initially proved at Bell Laboratory in 1954. The photovoltaic cell was used in space applications in 1958 to provide energy for the first satellite. In terrestrial applications in the 1970s, the oil crisis donated increase to a new boom. Before a "spectacular recovery" since the 2000s, the technology of the solar cell practiced is go-slow in the early 1990s. This reflection is clarified by "environmental challenges of global warming" and "announced shortage of fossil resources". This power that appears on the human scale limitless is completely deferential of the environment: its electric energy no greenhouse or waste gas emission.

Now, tendencies in solar cell manufacturing display accelerated progress associated with concentrated researches pointed to raising the conversion energy efficiency and decreasing the cost of solar cells industrial to make this source of power more inexpensive [7, 23, 24]. The realization of SC cell with low process cost and high efficiency, nowadays, are the greatest challenge for solar cell producers. The technology of solar PV cells has vast potential and benefits for society. Presently, numerous materials are developing in the solar cells market. The efficiency enhancement is the important factor for formation the PV technology [25]. Thus, numerous inorganic solar cells technologies have been reported to make this source of energy more competitive [23, 26, 27]. Lydia H. Wong *et al.* [27] detailed the solar parameters for the all-inorganic solar cells (**Table 2** lists the inorganic solar cells with energy functions) that are made of inorganic materials as semiconductors.

4. Basic Working Principle of Inorganic SC Cell

The basic part of "the solar energy generation system is the photovoltaic cell, where electrical energy is converted directly from visible light energy-deprived of any transitional process. The working of a solar cell exclusively is governed by its photovoltaic effect, so a solar cell is also famous for a photovoltaic cell (PV). Solar cells are fundamentally semiconductor p-n junction devices. It is designed by connexion p-type, (the deficiency of electron or high concentration of hole) and n-type, (the semiconductor material with a high concentration of electron). At the junction increasing with electrons from n-type try to diffuse top-side and vice- versa. The holes move to the (n-side) revelations negative ion cores in the (p-side), while the electrons move to the p-side revelations positive ion cores inside, these effects electric field at the junction and founding the depletion region. When the Sunlight covers the SC cell, photons with

Table 2. Photovoltaic functions for all-inorganic solar cells

Material	**Eff. (%)**	**V_{OC} (V)**	**J_{SC} (mA cm^{-2})**	**F. F. (%)**
Cu_2CdSnS_4Glass/Mo/CCdTS/CdS/ZnO/AZO/Ag	1.10٠	0.383	12.40	23.0
BiI_3Au/F_8/BiI_3/TiO_2/SnO_2:F	1.20٠	0.607	5.30٠	37.6
$ZnSnN_2$Au/$ZnSnN_2$/Al_2O_3/SnO	01.50	0.360	07.50	57.0
GeSe Glass/ITO/CdS/GeSe/Au	1.50٠	0.240	14.50	42.6
Cu_2BaSnS_4 (substrate) Glass/Mo/CBaTS/CdS/ZnO/ITO/Al	01.70	0.698	5.30٠	46.9
Cu_2BaSnS_4 (superstrate) CdS:O/CdS/ZnO/AZO	2.00٠	0.933	05.10	42.9
$CsSnBr_3$Au/Spiro-OMeTAD/$CsSnBr_3$/TiO_2/SnO_2:F	02.20	0.420	09.10	57.0
$Cu_2CdSn(S_{0.xx}Se_{0.yy})_4$Glass/Mo/CCdTSSe/CdS/ZnO/ITO/Al	2.80٠	0.356	18.80	41.6
Cu_2FeSnS_4ITO/Cu-NiO/CFeTS/Bi_2S_3/ZnO/Al	3.00٠	0.610	09.30	52.0
(In, Ga)NSiO2/Au/(Mg:GaN/GaN)/(In, Ga)N/Si:GaN	03.00	1.800	02.60	64.0
$CuSbS_2$Glass/Mo/$CuSbS_2$/CdS/ZnO/AZO	3.20٠	0.470	15.60	43.6
Bi_2S_3 Glass/ITO/P_3HT:Bi_2S_3/MoOx/Au	3.30٠	0.700	10.70	45.0
Cu_2OMgF_2/Al/Al:ZnO/Ga_2O_3/Cu_2O/Au	03.97	1.204	07.37	44.7
$Cu_2CdGeSe_4$ Graphite/Epoxy/CCdGeSe/CdS/ZnO/AZO/glue/Ag/glass	4.20٠	0.464	23.30	39.0
SnSGlass/Mo/SnS/SnO2/Zn(O, S):N/ZnO/ITO	04.36	0.372	20.20	58.0
$CuSbSe_2$Glass/Mo/$CuSbSe_2$/ZnO/AZO	4.70٠	4.700	26.30	53.0
$CsSnI_3$Au/PTAA/$CsSnI_3$/TiO_2/SnO_2:F	04.80	0.382	25.70	49.1
$Ag_2ZnSnSe_4$FTO/AgZTSe/MoO_3/ITO/Ni/Al	05.18	0.504	21.00	48.7
$Cu_2BaSn(S_{0.xx}Se_{0.yy})_4$Glass/Mo/CBaTSSe/CdS/ZnO/ITO/Ni/Al	5.20٠	0.611	17.40	48.9
Zn_3P_2ZnS/Mg/Ag:Zn_3P_2/Ag	6.00٠	0.492	14.90	71.0
$Cu_2ZnGe(S_{0.xx}Se_{0.yy})_4$Glass/Mo/CZGeSSe/CdS/ZnO/AZO/Ni/Al	6.00٠	0.617	NA	NA
$AgBiS_2$Glass/ITO/ZnO/$AgBiS_2$/PTB_7/MoO_3	6.31٠	0.450	22.10	63.0
Se Glass/FTO/TiO_2/ZnMgO/Se/MoO_3/Au	6.50٠	0.969	10.60	63.4
$Sb_2(S_xSe_{1-x})_3$ Glass/FTO/TiO_2/mp-TiO_2/Sb_2S_3/P_3HT/Au	6.60٠	0.475	24.90	55.6
CsSn0.5Ge0.5I_3Au/Spiro-OMeTAD/CsSn0.5Ge0.5I3/PCBM/SnO_2:F	7.10٠	0.630	18.60	60.6
InPAl/ZnO:Al/i-ZnO/InP:Zn/Au–Zn–Au	7.30٠	0.570	17.40	73.0
Sb_2S_3 Glass/FTO/TiO_2/mp-TiO_2/Sb_2S_3/PCPDTBT/PEDOT:PSS/Au	07.50	0.711	16.10	65.0
Sb_2Se_3 (superstrate) Glass/ITO/CdS/Sb_2Se_3/Au	07.60	0.420	29.90	60.4
$Cu_2ZnGeSe_4$Glass/Na-barrier/Mo/CZGeSe/CdS/ZnO/AZO/Ni/Al	07.60	0.558	22.80	59.0
Cu_2OMgF2/Al:ZnO/Zn0.38Ge0.62O/Cu_2O:Na/Au	08.10	1.200	10.40	65.0
Bi_2FeCrO_6Sn:In_2O_3/Bi_2FeCrO_6/$SrRuO_3$	8.10٠	0.840	20.60	46.0
$CsPbBr_3$C/CuPc+/$CsPbBr_3$/SnO_2/TiO_2/SnO_2:F	8.80٠	1.310	08.20	81.4
$Cu_2(Zn_{0.95}Mn_{0.05})Sn(S, Se)_4$Glass/Mo/CMZTSSe/CdS/ZnO/AZO/Ni/Al	8.90٠	0.418	33.70	63.3
Sb_2Se_3 (substrate) Glass/Mo/MoSe2/Sb2Se3/ZnO/AZO	09.20	0.400	32.60	70.3
$CsPbIBr_2$C/$CsPbIBr_2$/TiO_2/SnO_2:F	9.20٠	1.245	10.70	69.0
PbSGlass/ITO/ZnO/PbS(TBAI)/PbS(EDT)/Au	9.88٠	0.635	21.60	71.9
$Sb_2(S, Se)_3$Glass/FTO/CdS/Sb_2Se_3/Spiro-OMeTAD/Au	09.90	0.650	24.07	63.5
$(Ag_{0.05}Cu_{0.95})_2(Zn_{0.75}Cd_{0.25})Sn_4$Glass/Mo/ACCdZTS/CdS/ITO/Ag	10.10	0.650	23.40	66.2
Cu_2ZnSnS_4 (CZTS) Glass/Mo/CZTS/CdS/i-ZnO/ITO/Al/MgF_2	11.00	0.731	21.74	69.3
$Cu_2(Zn_{0.6}Cd_{0.4})SnS_4$Glass/Mo/CZCdTS/CdS/ZnO/ITO/Al/MgF_2	11.00	0.650	25.50	66.1

Table 2. (Continued)

Material	Eff. (%)	Voc (V)	Jsc (mA cm^{-2})	F. F. (%)
$(Ag_{0.05-0.3}Cu_{0.95-0.7})_2ZnSn(S, Se)_4$Glass/Mo/ACZTSSe/CdS/ZnO/ITO/Ag	11.20	0.464	36.20	66.5
$Cu_2ZnSnSe_4$ (CZTSe) Glass/Mo/CZTSe/CdS/ZnO/ITO/Ni/Al/MgF_2	11.60	0.423	40.60	67.3
$(Li_{0.06}Cu_{0.94})_2ZnSn(S, Se)_4$ Glass/SiOx/Mo/LiCZTSSe/CdS/ZnO/AZO/Ni/Al/MgF_2	11.60	0.531	33.70	64.8
$Cu_2ZnSnSe_4$Glass/Mo/CZTSe/CdS/ZnO/ITO/Ag/MgF_2	11.80	0.463	38.30	66.3
$Cu_2Zn(Sn_{0.78}Ge_{0.22})Se_4$Glass/Mo/CZTGTSe/CdS/ZnO/AZO/Ag/ARC	12.30	0.527	32.20	72.7
$Cu_2ZnSn(S_{0.25}Se_{0.75})_4$ (CZTSSe) Glass/Mo/CZTSSe/CdS/ZnO/ITO/Ni/Al/MgF_2	12.60	0.513	35.20	69.8
$Cu_2ZnSn(S_ySe_{1-y})_4$ (CZTSSe) Glass/Mo/CZTSSe/CdS/ZnO/AZO/Ni/Al/MgF_2	12.62	0.541	35.35	65.9
$CsPbI_3$Al/MoO_x/Spiro-OMeTAD/$CsPbI_3$/TiO_2/SnO_2:F/Glass/MgF_2	13.58	1.163	15.25	76.6
$CsPb_{0.95}Eu_{0.05}I_2Br$Au/Spiro-OMeTAD/CsPb0.95Eu0.05I2Br/TiO_2/SnO_2:F	13.70	1.220	14.60	76.6
$CsPbI_3$Au/Spiro-OMeTAD/$CsPbI_3$/SnO_2/In_2O_3:SnO_2	15.70	1.080	18.40	79.3
$CsPbI_2Br$Au/Spiro-OMeTAD/$CsPbI_2Br$/TiO_2/In_2O_3:SnO_2	16.10	1.230	16.80	77.8

energy larger than the semiconductor band-gap (g) are absorbed by the photovoltaic cell and produce an electron-hole (e-h) pair. These e-h pairs migrate correspondingly to n- and p- sides of the p-n junction owing to electrostatic interaction of the field through the junction. In this system, a potential difference has resulted between the cell sides. Typically a photovoltaic or solar cell has positive (+) back contact and negative (-) front contact. A p-n junction semiconductor is in the middle of (+) and (-) contacts. If an external circuit is joined to these sides, the current will flow generated from the positive to the negative side of the photovoltaic cell". **Figure 6** is illustrated the solar cell principle working [28].

5. Parameters of Solar Cell and Module for Measurement

Various equivalent circuits have been used in the references to exemplary the current-voltage (I-V) characteristic of a silicon PV cell; an ideal solar cell with one diode is used in this review as a simple module cell. Numerous functions are used with a solar cell to estimate a high efficiency and power depending on current-voltage curve (IV curve).

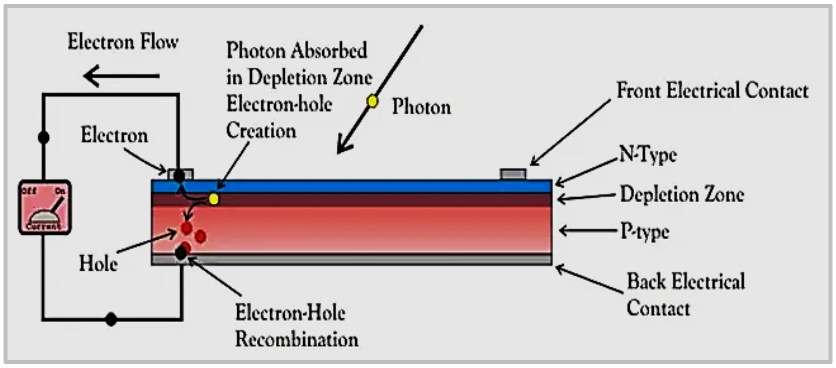

Figure 6. A schematic of the working solar cell principle

5.1 Solar cell IV curve

The IV-curve in a SC is the superposition of the light-generated current with the IV curve of diode in the dark. The visible light influences of shifting the IV curve down into the fourth quadrant where energy can be extracted from the diode so that the diode law becomes illuminating a cell adds to the normal "dark" currents in the diode" with Equation (**1**):

$$I = I_D - I_L \qquad (\mathbf{1})$$

The equations for the SC-IV curve in the 1st quadrant are as follow [29-31]:

$$I \cdot= I_L - I_D \qquad (\mathbf{2})$$

$$I_D = I_O\left[exp\left(\frac{qV}{nKT}\right) - 1\right] \qquad (\mathbf{3})$$

$$I_L = q \times n_{ph} \times \left[P_I \times \frac{\lambda}{hc} \times (1 - R)\right] \qquad (\mathbf{4})$$

$$I_O = qn_i^2\left(\frac{D_N}{L_N N_A} + \frac{D_P}{L_P N_D}\right) \qquad (\mathbf{5})$$

The -1 term can usually be neglected in Equation (**3**) (-1 term is not needed under illumination) with approximation to Equation (**6**).

$$I = I_L - I_O\left[exp\left(\frac{qV}{nKT}\right)\right] \qquad (\mathbf{6})$$

Drawing Equation (**6**), gives the IV curve **Figure 7** with the relevant points labelled on the curve. The power curve has the maximum signified as P_{MP} (where the SC cell operated to give the maximum power output P_{MP}). It is also denoted as "P_{MAX} or the maximum power point (MPP) and occurs at a current of I_{MP} and a voltage of V_{MP}. **Figure 7** illustrates the IV curve to obtain P_{MAX}".

5.2 Voltage of SC at maximum value of a power (V_{mp})

It is the highest SC voltage that "the solar cell can produce when connected to a system and working at peak efficiency. This voltage is usually around (70-80%) of the solar cell's open-circuit voltage (V_{OC}). Equation (**7**), presented V_{mp} related to V_{OC} (Open circuit voltage) [32].

$$V_{mp} \approx V_{OC} - \frac{nKT}{q} ln\left(\frac{qV_{OC}}{nKt} + 1\right) \qquad (\mathbf{7})$$

Figure 8 depicts the occurrences of V_{mp} in a solar cell.

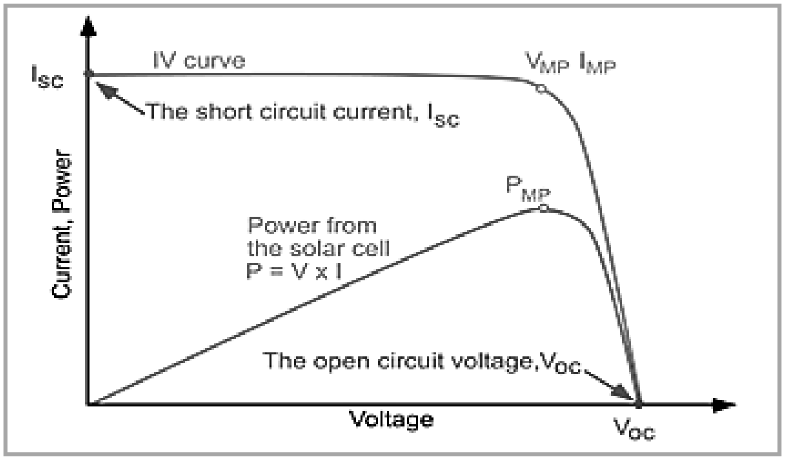

Figure 7. IV curve of a SC cell, the solar cell operated to give the maximum power output P_{MP}

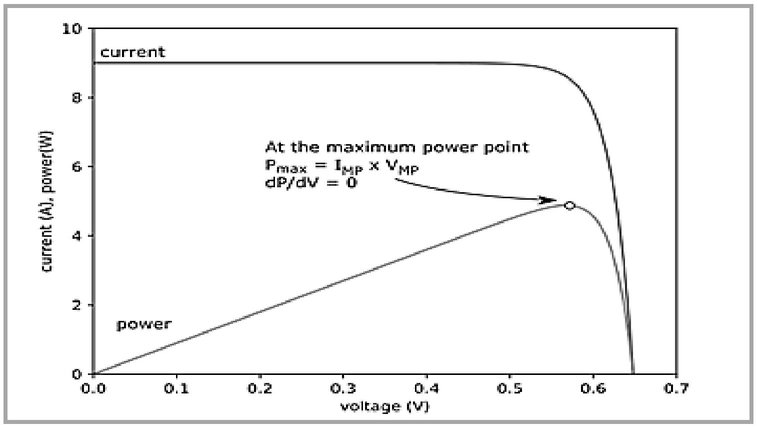

Figure 8. The V_{MP} occurs when the differential of power produced by the cell is zero

5.3 Open circuit voltage (V_{OC})

When a SC cell is not coupled to the electrical system or circuit, a maximum voltage can produce, this happened when the current via the solar cell is zero. V_{OC} can be tested with a meter directly contacting the solar cell ends or the terminals of its built-in cables. Equations (**8-10**) can be used to evaluate Voc value [29, 33, 34].

$$Voc = \frac{KT}{q} ln\left(\frac{I_L}{I_O} + 1\right) \qquad \textbf{(8)}$$

$$Voc = \frac{E_g}{q} - \frac{KT}{q} ln\left(\frac{A_g}{qn_L}\right) \qquad \textbf{(9)}$$

$$Voc = \frac{KT}{q} ln\left[\frac{(N_A+\Delta n)\Delta n}{n_i^2}\right] \qquad \textbf{(10)}$$

V_{OC} corresponds to the quantity of forwarding bias on “the solar cell owing to the light-generated current with the bias of the solar cell junction”. V_{OC} is presented on the IV curve in **Figure 9**.

5.4 Short circuit current (Isc)

The production and collection of visible light-produced carriers result in the short-circuit current (Isc), at most moderate resistive loss mechanisms for an ideal photovoltaic cell, the (Isc) and the current produced from light are identical. Therefore, the (Isc) is the biggest current that can be schemed from the photovoltaic cell.

Hence, when a photovoltaic cell is worked at a short circuit (V=0) and the current I via the ends is defined as I_{SC}, and it can be presented for a high-quality photovoltaic cell (high RSH, low RS, and I_O) with Equations (**11**, **12**) [35, 31].

$$I_{SC} = I_{ph} \qquad \textbf{(11)}$$

$$I_{SC} = qnG_r(L_n + L_p) \qquad \textbf{(12)}$$

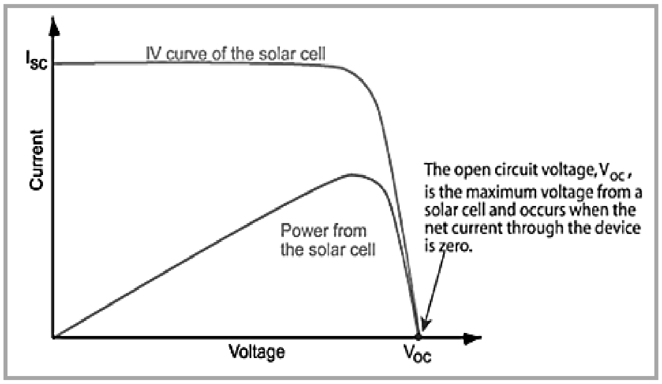

Figure 9. IV curve of a SC display the open-circuit voltage

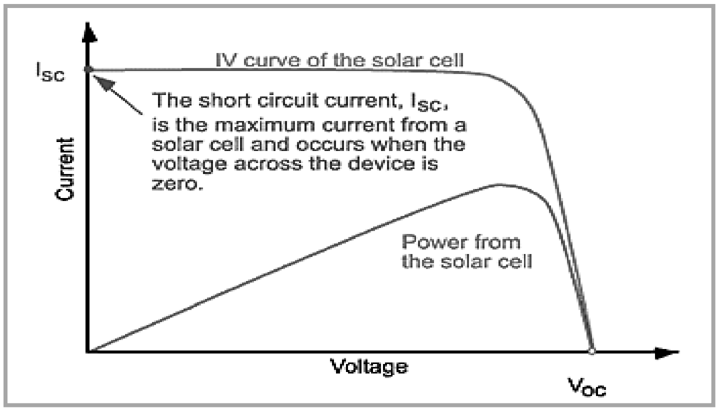

Figure 10. IV curve of a SC display the short-circuit current

The SC current as short-circuit can be publicized on the curve of the IV, as presented in **Figure 10**.

5.5 The maximum power of SC current (Imp)

It is defined as the greatest cell current obtainable when the SC is working at peak efficiency in a system, this means that "the I_{mp} is the current when the output power is the maximum" and can be found as follow [36]:

$$I_{MP} = \frac{P_{max}}{V_{MP}} \qquad \textbf{(13)}$$

5.6 The maximum power point (Pmax)

It is expressed as the power of the cell when the SC produces the greatest energy. Thus, the I and V, in this condition, are defined as I_{max} and V_{max} correspondingly, with Equation (**14**):

$$P_{max} = V_{mp} \times I_{mP} \qquad \textbf{(14)}$$

5.7 Fill factor (FF)

FF of a SC cell is a parameter that describes the SC presentation, and defined as the ratio of P_{max} divided by I_{SC} multiplied by V_{OC}, with Equation (**15**) [29]:

$$FF = \frac{P_{MP}}{V_{OC} \times I_{SC}} = \frac{V_{MP} \times I_{MP}}{V_{OC} \times I_{SC}} \qquad \textbf{(15)}$$

Supposing that the SC acts as "an ideal diode", the FF of photovoltaic cell is related to V_{OC} as follow [31]:

$$FF = \frac{v_{oc} - ln(v_{oc} + 0.72)}{v_{oc} + 1} \qquad \textbf{(16)}$$

$$v_{oc} = \frac{V_{OC} \times q}{KT} \qquad \textbf{(17)}$$

FF in Equation (**16**) is a good approximation of the ideal value for $v_{oc} > 10$.

5.8 Conversion efficiency (η)

Efficiency can be termed to the ratio of the solar cell energy-output P_{out} (converted absorbed visible light into electrical power) to the solar input energy P_{in} (product of irradiance from the sun (E), and the SC surface area (A_C)). Efficiency can be calculated by Equations (18-19) [23, 37]:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{MP} \times I_{MP}}{P_{in}} = \frac{V_{MP} \times I_{MP}}{E \times A} \qquad \textbf{(18)}$$

$$\eta = \frac{V_{OC} \times I_{SC} \times FF}{E \times A} \qquad \textbf{(19)}$$

The efficiency is a parameter most frequently used to compare one solar cell performance to another. In accumulation to reflect the performance of the solar cell itself, the effectiveness affected by the intensity and spectrum of the visible sunlight and the solar cell temperature. Therefore, occurrence conditions under which effectiveness is tested should be prudently organized in order to compare the efficiency of one solar cell to another.

5.9 Internal resistances of a solar cell

5.9.1. Series (RS) resistance

Series (RS) and shunt (RSH) resistances are internal parasitic resistances. During the operation of the solar cells, their efficiency is decreased by the dissipation of energy in these resistances. RS in a solar cell has three central causes: First, the current drive via the base and emitter of the SC cell, second, the connection resistance between the silicon and the metal contact, and finally the resistance of the back and top metal contacts. The chief influence of RS resistance is to decrease the fill factor.

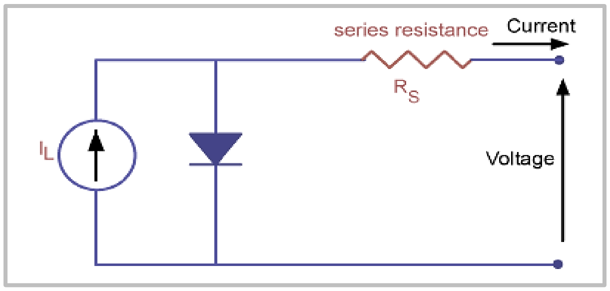

Figure 11. Schematic illustrated the solar cell circuit with series resistance

Although excessively great values can also decrease the short circuit current. Shunt resistance for an ideal solar cell will not provide an alternate path for current to flow and will be infinite, while series resistance will be zero, so before the load, the resulting is no further voltage drop. Reducing RSH and rising RS would be reducing the P_{MAX} and FF. **Figure 11** illustrates a solar cell circuit in the presence of series resistance.

The SC output current in the RS presence can be shown in Equation (**20**), and the influence of the RS on the SC (IV curve) is publicized in **Figure 12**.

$$I = I_L - I_O\, exp\left[\frac{q(V+IR_S)}{nKT}\right] \qquad (\mathbf{20})$$

5.9.2. The shunt resistance of SC, RSH

Significant energy decreases affected by "the existence of shunt resistance, RSH is classically owing to engineering defects, adding to lowly SC cell design. Small shunt resistance affects energy losses in a photovoltaic cell by providing an alternate current path for the visible light-produced current. Such a diversion decreases the voltage from the photovoltaic cell and decreases the quantity of current flowing via the photovoltaic cell junction. In particular, the influence of shunt resistance is severe at low visible light ranks, since there would be fewer lights-produced currents. The current loss to the shunt has a larger impact. Rather than, at lower voltages (the operational resistance of the photovoltaic cells is high), the effect of a resistance in parallel is great. **Figure 13** demonstrates a SC cell circuit in the presence of shunt resistance.

The equation of a SC including the shunt resistance can be shown as:

$$I = I_L - I_O\, exp\left[\frac{qV}{nKT}\right] - \frac{V}{R_{SH}} \qquad (\mathbf{21})$$

The influence of the SC low shunt resistance can be presented in **Figure 14**.

In the existence "of both series and shunt resistances, the IV curve of the solar cell" is illustrated by Equation (**22**) [29].

$$I = I_L - I_O\, exp\left[\frac{q(V+IR_S)}{nKT}\right] - \frac{V+IR_S}{R_{SH}} \qquad (\mathbf{22})$$

Therefore, the circuit diagram and the influence of the RSH on the IV curve of the SC can be publicized in **Figures** (**15** and **16**).

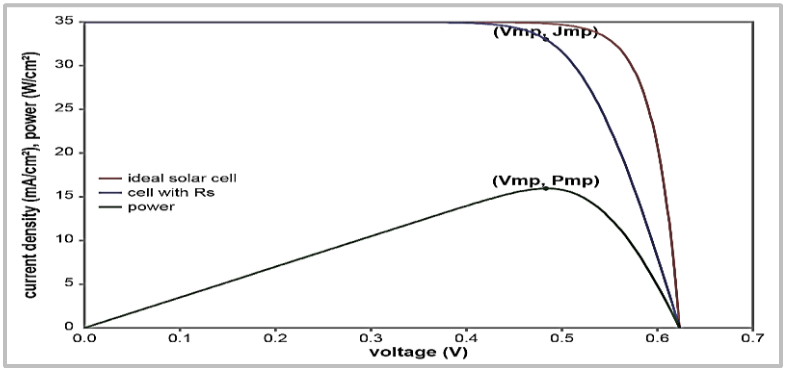

Figure 12. The influence of series (RS) resistance on FF

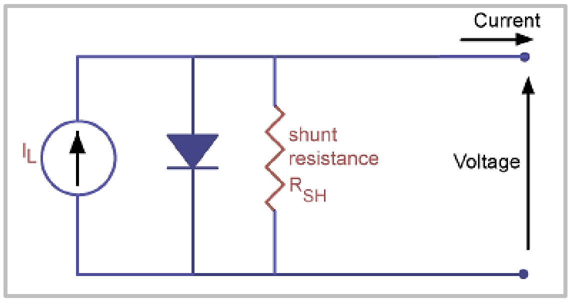

Figure 13. Circuit diagram of a SC cell with the shunt resistance

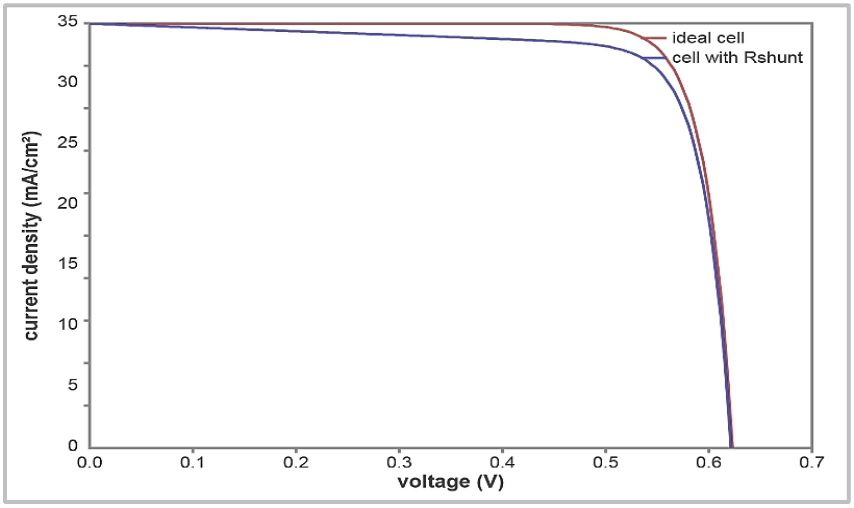

Figure 14. The RSH effect on FF

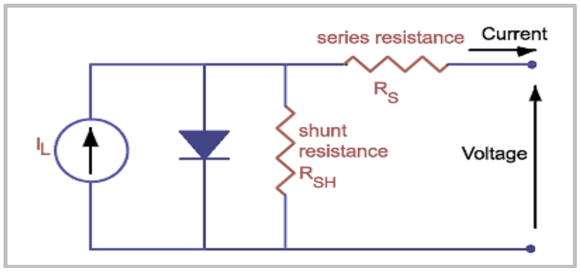

Figure 15. Parasitic series and shunt resistances in a SC cell

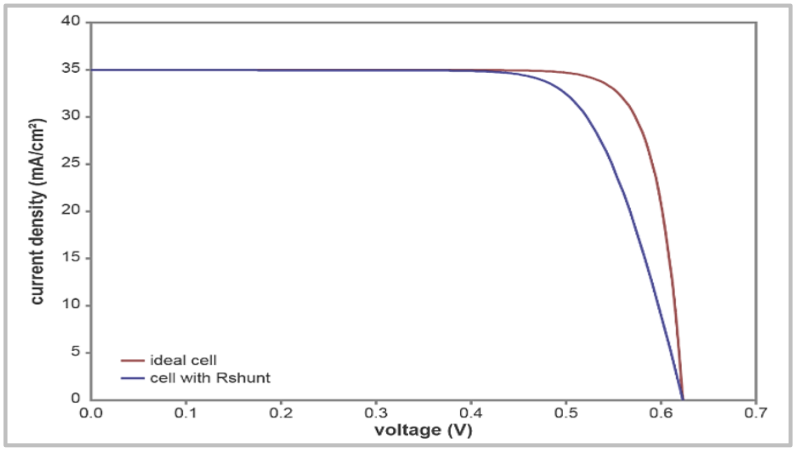

Figure 16. The influence of parasitic series and shunt resistances in a SC cell on FF

5.10. Solar cell performance with temperature effect

The influence of heat factor is varied and multifaceted through SC manufacture techniques [38]. Solar cell production decreases “with an increase in heat, fundamentally due to rising internal carrier recombination rates, affected by rising carrier concentrations. The working temperature plays an impact role in the SC cell conversion process” [37, 39-42]. Both the power output and the electrical efficiency of a solar cell module are influenced linearly by the operating temperature. The numerous relationships offered in the literature represent simplified operation relations which can be used to solar cell arrays or solar cell modules mounted on building-integrated solar cell arrays, solar cell-thermal collectors, and free-standing frames. Electrical production is principally influenced by the materials used in a solar cell. Various equations for cell temperature which have been applied in the literature include numerical variables and basic environmental parameters which are system or material-dependent [39]. The equations of I_{SC}, V_{OC}, P, and η related to temperature in a solar cell can be presented in Equations (**23-28**).

$$I_{SC} = I_{SC(T_{ref})}\left[1 + \alpha \times \left(T_C - T_{ref}\right)\right] \quad \textbf{(23)}$$

$$V_{OC} = V_{OC(T_{ref})}\left[1 - \beta \times \left(T_C - T_{ref}\right)\right] \quad \textbf{(24)}$$

$I_{SC(T_{ref})}$ and $V_{OC(T_{ref})}$ at reference temperature T, α, and β temperature coefficients mu/°C:

$$P = IV = I_{SC(T_{ref})}\left[1 + \alpha \times \left(T_C - T_{ref}\right)\right] \times V_{OC(T_{ref})}\left[1 - \beta \times \left(T_C - T_{ref}\right)\right] \quad \textbf{(25)}$$

$$P = P_{(T_{ref})}\left[1 + (\alpha - \beta) \times \left(T_C - T_{ref}\right)\right] [43] \textbf{(26)}$$

Both “the fill factor and open circuit voltage” reduce considerably with temperature while short-circuiting current rises, but only slightly (because the electrical properties of the semiconductor begin to dominate as the thermally excited electrons). Therefore, the net influence is leading to “a linear equation” in the structure:

$$\eta_C = \eta_{T_{ref}}\left[1 - \beta_{ref}\left(T_C - T_{ref}\right)\right] \quad \textbf{(27)}$$

Where,

$\eta_{T_{ref}}$: The PV cell electrical efficiency at the reference T, T_{ref}, and solar radiation of 1000 W/m^2.

β_{ref}: Temperature coefficient /K^{-1}

$$\beta_{ref} = \frac{1}{T_O - T_{ref}} \quad \textbf{(28)}$$

T_O: The high T at PV cell electrical efficiency drops to zero [39].

6. Factors Influences on Photovoltaic System Performance

A solar cell generates electricity directly from light. However, their efficiency is impartially low. Thus, the solar cell charges are costly as compared to the other resources of energy products. The produced output energy by a photovoltaic module and its time length depends on various factors, some of which include the received solar radiation intensity, PV material type, parasitic resistances, temperature of the cell, the orientation of module, geographical location, weather conditions, the cable thickness, inverter efficiency, and other effects. Numerous papers [23, 29, 44-48] studied the factors that affect solar cell efficiency.

Several factors play into the efficiency and effectiveness of solar panels, including environmental factors. The wind effect, for example, enhances solar energy efficiency by affecting the temperature and performance of solar cells, as wind-cooled panels allow more power to be generated than hot panels. When the wind is cools “the SC panels by 1 °C, the efficiency of the SC panels increases by 0.05 percent”.

The orienting in a direction and tilt perpendicular to the sun's rays is one important factor increasing the solar panels exposure to sunlight and increases their efficiency. “The angle of the solar panels varies throughout the year, so the optimal tilt angle for a PV panel in winter is different from the ideal tilt angle in summer”. In the spring months, the best angle for these panels is 45 degrees. The efficiency drops by 0.54% when the tilt angle is increased from 0° to 15°. Roshan, R. Rao *et al.* [44], reported a list of these factors that affect the solar cell energy output (**Table 3**) and the PV system yield (**Table 4**).

Table 3. The factors influencing the solar cell power output and source

No.	Factors being influenced	Factors influencing
1	Dust	
	Chemical composition	Chemical composition, aerosols, Atmospheric, Rain, and Wind
	Density, and Gravimetric dust	Size of the particles, Chemical composition, Cleaning interval, Density of the dust particles, Moisture, Wind speed and direction, Temperature of the glazing, and Tilt of the panel
	Interaction with glazing (electrostatic force/ adhesion)	Chemical composition of dust
	plasticity index of dust particles/ Moisture content	Humidity ratio, Chemical composition
	Morphology	Dust source, Chemical composition
	Size distribution	Wind direction, Wind speed, and Chemical composition
	Source	Location of the site of a PV system
	Specific gravity of dust particles	Chemical composition/species
	absorption/ Transmission /reflection of the dust layer	species of dust, Snow cover/ Gravimetric density, and Chemical composition
2	PV cell	
	Conversion efficiency	Solar cell material
	Isc, Voc, FF	Property of the SC cell
	Band gap and p/n junction	Property of the SC cell material
	Photovoltaic material and type of cell and its thermal/ optical properties	Solar PV market, and Total cost per area of the solar module
	PV cell temperature	Absorption coefficient, Refractive index, Temperature of the back panel sheet, Ambient temperature, Thermal conductivity of the material, Wind speed and direction, Solar insolation, Optical depth of the dust/snow layer, Tiltangle/angle of incidence
	Quantum efficiency	Solar cell material
	Spectral response	Band-gap of the SC cell
3	PV panel system	
	thermal properties, Back sheet	Strength requirements, availability and cost
	EVA (ethyl vinyl acetate) - absorption coefficient, thermal properties, and refractive index	Chemical inertness, lamination, availability and cost
	Glazing - thermal properties, absorption coefficient, surface texture, and refractive index	Chemical inertness, optical properties, external damage, availability and cost

Table 3. (Continued)

No.	Factors being influenced	Factors influencing
	Back panel temperature, and Glazing temperature	PV cell temperature, angle of incidence, reflectivity of the layers, thermal resistance, transmittance, dust layer/snow layer, and wind, ambient temperature, GHI/DNI
	Panel Frame - material, thermal and physical properties	Strength requirements, cost, and availability
	Contact probes, and Wiring	Reliability, longevity, availability and cost
4	Sun geometry, and Installation of panel	
	Orientation of the panel/ Fixed tilt angle	Location
	Installation- roof or ground-based	Land space/roof space
	Location on earth- latitude, longitude, altitude	
	Objects shadow on panel, partial shadowing	Trees, surrounding buildings
	Sun tracking - single and dual	Seasonal changes in solar earth geometry
	Time of the day and year	Objects shadow on panel, partial shadowing
5	Radiation and atmosphere	
	Ambient surface temperature	the intensity of the radiation, and Aerosols/cloud cover
	Aerosols, and atmospheric gases	
	Clouds	
	Dry duration (time between two rain events) and rain intensity (mm)	
	Relative humidity	
	Snow cover	
	Surface irradiance (GHI/DNI and diffuse)- (total and spectral)	The intensity of the radiation, and Aerosols/cloud cover
	Wind speed, and direction, and gust	
6	Cleaning maintenance	
	Cleaning interval/critical cleaning period	water/energy, Cost, labor,
	Cleaning technique (water-based, non-water based, manual, robotic)	Physical properties, availability of the water/energy, and Glazing hardness,
	Natural cleaning (rain, fog, etc.)	fog, Rain, and dew
7	Performance parameters	
	Daily, monthly and annual yield	Surface irradiance, conversion efficiency, and cell temperature
	DC conversion efficiency of the module	Cell temperature, and Quantum efficiency,
	Instantaneous power output	Surface irradiance, Conversion efficiency
8	Others	
	Availability of natural resources (like water, land area, sunshine, etc.)	Location, resources are also seasonal dependent
	Cost	
	Social-economic-political and market factors	

Table 4. Factors effecting PV system yield

No.	Factors	Types	No.	Factors	Types
1	Application	BAPV	6	Manufacturer/mfg. technique	Module durability change over years/ module warranty
		BIPV			Packaging/ Transportation
		Ground mount	7	Geography	Altitude
		Rooftop			Climate zone
2	Social factors	Buy back Policy			Latitude
		Govt subsidy			Longitude
		Land coast			Shadowing
		Market factors			Time of the year
		Other policies	8	Instillation maintenance	Cleaning panels
3	Climate change	Change in land use/ land pattern			Protection from wind
		Change in weather parameters			Solar reflectors
		Pollution			Sun- tracking devices
4	Environmental parameters	Ambient temperature			Tilt angle
		Dust levels (air borne)			Water sprinklers
		Pollution level	9	BOS module material	Back sheet
		Rain			Encapsulant
		RH			Frame
		Solar insolation			Glazing
		Surface pressure	10	Grid interaction	Battery storage
		Wind speed			Grid tie local grid (building level)
5	Failure mode	Back sheet Degradation			Micro grid
		Cracks in solar cell			National grid interaction
		Delamination (front and back)	11	System size	<100kW
		Discoloration on Metallization			GW
		EVA browning			kW - MW
		Glass/ frame Degradation			Module
		Hot spot	12	PV cell technology material	Amorphous
		Initial light induced degradation			Crystalline
		Interconnect breakage			Multi junction
		Junction box Degradation			Thin film
		Open circuit failure			
		Potential induced degradation			
		Snail trail			
		Solder bond failure			

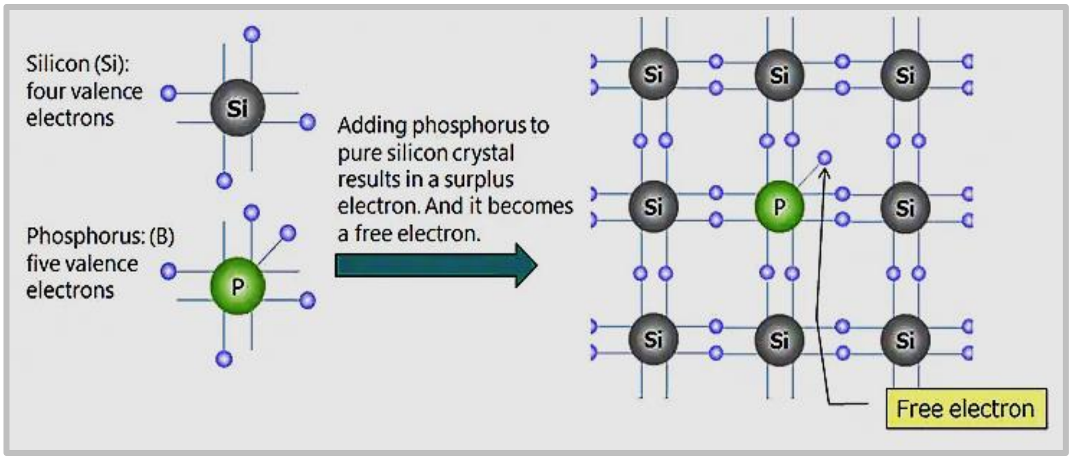

Figure 17. The formation of “free electrons and holes” in semiconductors of solar cells

7. The Effect of Double Spectrum Colors Factor on the Solar Cells Performance

Solar cells are the electronic constituents (a p-n junction diode) that create electricity when sunlight is radiated on them using the photovoltaic effect phenomenon. Semiconductors are usually used for making SC cells. Semiconductors can absorb the sun radiates in the appearance of light, and the transmitted-energy is utilized through collecting the radiant light, and converting it directly into heat or electricity. The “junction effect in the P-N junction diodes is the principle of work in photovoltaic cells. The n-type and p-type elements are the semiconductors (such as Cadmium Telluride, Gallium Arsenide, Indium Phosphide, Copper Indium Selenide, and Silicon), that contains some impurities, and the kind of semiconductor (either n- or p-type) is governed by the sort of impurity added to them. The SC cells are made by linking the layers of two kinds of semiconductors (n - and p-type), with each other, where one layer is able of accepting electrons (p-type; the holes are the mainstream charge carriers and the electron's unconventional charge carriers), and the other layer is able of donating electrons (n-type; the electrons are the mainstream charge carriers, and the holes are the unconventional charge carriers), as illustrated in **Figure 17**.

The n-layer is prepared as heavily doped “(with a large number of electrons and is usually kept thin to ensure that sunlight can easily pass through it to the other lower layers), while the p-layer is prepared as lightly doped to guarantee that most depletion region forms on the p-side. When the p and n layers are combined, the electrons from the heavily doped layer begin moving in the direction of the holes at the lightly doped layer close to the junction. This will be creating an area called the "depletion region" around the junction, where the electrons fill the holes to the induced potential difference across the junction. If the electrons are emitted from the depletion layer, the electric field (E) will force the electrons to transfer in the n-layer and the holes to the p-layer. When an external load is linked, the electrons from the n-layer region will travel to the p-layer region through the depletion region and then passes through the external wires linked at the back of the n-layer. Therefore, the flow of electricity begins, as depicted in **Figure 18** [16, 49-52].

The electric current quantity is formed directly “proportional to the quantity of light absorbed by the surface of the solar cell ("the further the quantity of sunlight radiated on the solar cells will be the further electricity generated"). Any photon with energy greater than 1.11 eV can be dislodge an electron from the atom of silicon and send it into the conduction band. In practice, however, the photons with very short wavelength (with an energy of more than 3 eV) send electrons clear out of the conduction band and render them unavailable to do work” [53].

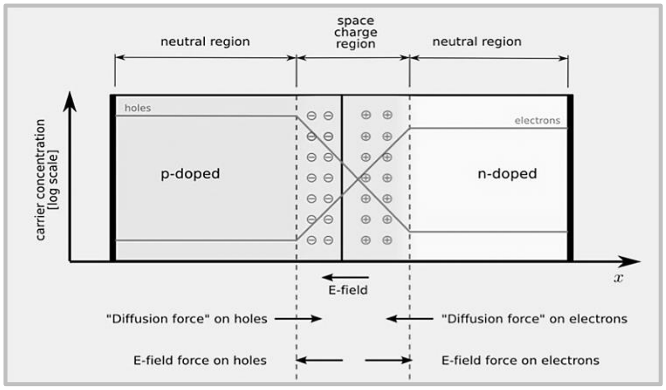

Figure 18. The transfers of electrons and holes through the depletion region under applied electric field

7.1. Photoelectric effect

Solar cell is the electronic constituents ("a p-n junction diode") that produce electricity when sunlight is radiated on them using the photovoltaic effect phenomenon. "Einstein's scientist explanation of the photoelectric effect is that the energy of the electrons ejected from a photoelectric plate depended not on light intensity (amplitude), as wave theory predicted, but on frequency, which is the inverse of wavelength. The shorter the wavelength of the incident light, is the higher the frequency of the light and the more energy possessed by ejected electrons. In the same way, photovoltaic cells are sensitive to wavelength and respond better to sunlight in some parts of the spectrum than others" (**Figure 19**).

When "photon is incident on a conducting material, it collides with the electrons in the individual atoms. If the photon has enough energy, it releases the electron in the outermost shells. These electrons are then free to circulate through the material depending on the energy of the incident photons" [53-63], as demonstrated in **Table 5** and **Figure 20** and **21.**

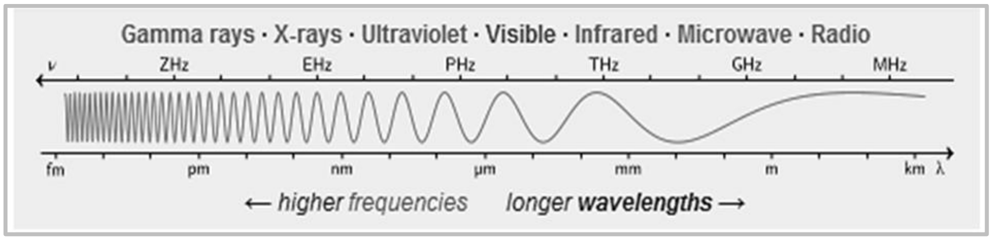

Figure 19. Electromagnetic spectrum

Table 5. The wavelength, photon energy, and frequency of different colors

Color	Wavelength (nm)	Photon energy (eV)	Frequency (10^{14} Hz)
Red	620-750	1.65-2.00	4.29-4.62
Orange	590-620	2.00-2.10	4.62-5.00
Yellow	570-590	2.10-2.17	5.00-5.16
Green	495-570	2.17-2.50	5.16-5.45
Blue	450-495	2.50-2.75	5.45-6.66
Violet	380-450	2.75-3.26	6.66-7.50

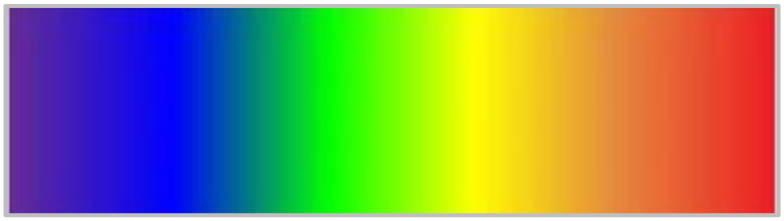

Figure 20. Visible spectrum

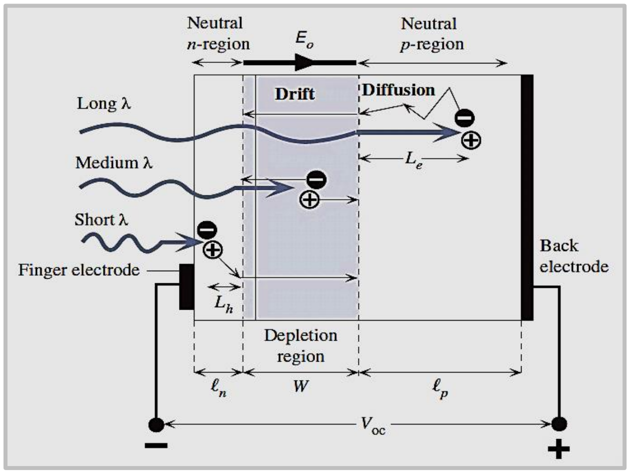

Figure 21. The effect of different wavelengths on solar cell regions

7.2 Tested of double spectrum colors effect on the solar cells performance

An experiment test after connecting two photovoltaic modules (Cell-1 and Cell-2) used the solar modules ("properties; open circuit voltage (21.6 V), short circuit current (0.61 A), the maximum power voltage (17.8 V), the maximum power current (0.56 A) and power (10 W))", as well as different colors of polyethylene filters. The intensity of solar radiation was record using a Solar Radiation Meter. The measurements of voltage and current were taken in June for four consecutive days on sunny days from ten o'clock to twelve o'clock in the morning, and the result was recorded after the stability of the reading of the avometer device and for three repeated readings.

The solar cells performance is calculated related to full factor and efficiency, the important factors with the suitable equations (**15**, **16**, **17**).

The SC data of the experiment investigation can be listed in **Tables** (**6-12**).

From the results, it is found that the best group of two colors that increased the efficiency factor values of the SC cells is violet with other colors as **Table 12** has introduced.

As indicated in **Table 12**, the double colours give more efficiency in the violet (short-wavelength; 380-450 nm) and the orange (long-wavelength; 590-620 nm) relative to other colours.

Table 6. The efficiency and FF factores of one color-cell

Cell 1	Cell 2	Voc	Isc	v_N	FF	Efficiency %
Violet	Violet	19.27	0.72	745.749	0.989802	24.04221
Orange	Orange	19.11	0.61	739.557	0.989728	20.19846
Red	Red	19.09	0.59	738.783	0.989719	19.51559
Blue	Blue	19.06	0.57	737.622	0.989705	18.82415
Green	Green	18.92	0.54	732.204	0.989639	17.70123

Table 7. The efficiency and FF factores of double colors-cells (red color stable)

Cell 1	Cell 2	Voc	Isc	v_N	FF	Efficiency %
Red	Violet	19.27	0.67	745.749	0.989802	22.37261
Red	Orange	19.14	0.59	740.718	0.989742	19.56716
Red	Blue	19.13	0.58	740.331	0.989737	19.22536
Red	Green	19.10	0.55	739.170	0.989723	18.20210

Table 8. The efficiency and FF factores of double colors-cells (orange color stable)

Cell 1	Cell 2	Voc	Isc	v_N	FF	Efficiency %
Orange	Violet	19.34	0.78	748.458	0.989834	26.14118
Orange	Red	19.21	0.69	743.427	0.989774	22.96806
Orange	Blue	19.20	0.68	743.040	0.98977	22.62331
Orange	Green	19.13	0.64	740.331	0.989737	21.21419

Table 9. The efficiency and FF factores of double colors-cells (blue color stable)

Cell 1	Cell 2	Voc	Isc	v_N	FF	Efficiency %
Blue	Violet	19.24	0.70	744.588	0.989788	23.33765
Blue	Orange	19.19	0.66	742.653	0.989765	21.94638
Blue	Red	19.17	0.64	741.879	0.989756	21.25896
Blue	Green	19.14	0.61	740.718	0.989742	20.23045

Table 10. The efficiency and FF factores of double colors-cells (green color stable)

Cell 1	Cell 2	Voc	Isc	v_N	FF	Efficiency %
Green	Violet	19.13	0.65	740.331	0.989737	21.54567
Green	Orange	19.04	0.58	736.848	0.989695	19.13410
Green	Red	19.02	0.57	736.074	0.989686	18.78428
Green	Blue	19.00	0.56	735.300	0.989676	18.43514

Table 11. The efficiency and FF factores of double colors-cells (violet color stable)

Cell 1	Cell 2	Voc	Isc	v_N	FF	Efficiency %
Violet	Orange	19.16	0.78	741.492	0.989751	25.89571
Violet	Red	19.14	0.77	740.718	0.989742	25.53680
Violet	Blue	19.12	0.76	739.944	0.989733	25.17859
Violet	Green	19.07	0.73	738.009	0.989709	24.12086

Table 12. The wavelength, photon energy, and frequency of different colors

Cell-1	Cell-2	Efficiency %
Violet	Orange	25.90
Violet	Red	25.54
Violet	Blue	25.12
Violet	Green	24.12

8. Conclusion

In this review, we can conclude the following principal points:

Inorganic solar cells efficient depend on the total electric energy produced from solar energy were initially proved at Bell Laboratory in 1954. From this time onward, inorganic SC cells have been used in various kinds of applications. The inorganic solar cell is made from inorganic semiconductor materials like amorphous, crystalline, microcrystalline Si, multi-crystalline, alloys, and III-V compounds. In three-generation solar cells, inorganic solar cells are taking an important role. The solar module is the photovoltaic (PV) system heart. The tendencies in solar cell manufacturing display accelerated progress associated with concentrated researches pointed to raise the conversion energy efficiency and decreasing the cost of solar cells industrial to make this source of power more inexpensive. Numerous factors that influence photovoltaic system performance depend on solar cell efficiency. Various functions are used with a solar cell to estimate a high efficiency and power depending on the current-voltage curve (IV curve). The influence of heat (temperature) is varied and multifaceted with solar cells generation technology. Solar cell production "decreases with an increase in temperature". The highest conversion efficiency (η) has 25% with various practical inorganic SC cells technologies prepared from inorganic "materials as semiconductors".

In this review article, the effect of different double wavelengths in the visible spectrum region on the efficiency performance of SC cells is investigated depending on various wavelengths, which have a different effect on the diode regions. The data is showed that the best grouping of two colors increased the efficiency factor of the SC cells, namely violet with other colors, specifically the two colors orange (long wavelength; 590-620 nm) and violet (short wavelength; 380-450 nm), and this may be attributed to the fact that different wavelengths of solar spectrum affect different regions ("the p-n junction diode") of solar cell in different ways, as the long wavelength has more influences on the p-region, while the short wavelength has more influences on the n-region.

Nomenclature

Symbol		**Unit**
V_{mp}	Voltage at maximum power	Volt
V_{oc}	Open circuit voltage	Volt
n	Ideality factor	(without unit)
K	Boltzmann constant	joule/Kelvin
T	Temperature	Kelvin
q	Elementary charge	Coulomb
I_L	Light generated current	Amber
I_O	Dark saturation current	Amber
E_g	Band gap	Electron Volt
A_g	E_g dependent parameter	(without units)
n_L	Sum of absorbed incident photon	$(\text{centimetre})^{-2}$ sec^{-1}
N_A	Doping concentration	$(\text{centimetre})^{-3}$
Δn	Excess carrier concentration	$(\text{centimetre})^{-3}$
n_i^2	Intrinsic carrier concentration	$((\text{centimetre})^{-3})^{2}$
D_N	(Electron) diffusion length in the n-type region	$(\text{centimetre})^{2}\text{sec}^{-1}$
D_P	Hole) diffusion length in the p-type region	$(\text{centimetre})^{2}\text{sec}^{-1}$
L_N	The minority-carrier (electron) diffusion length in the n-type region	metre
L_P	The minority-carrier hole) diffusion length in the p-type region	metre
N_D	Emitter layer uniform concentration	$(\text{metre})^{-3}$
I_{SC}	Short-circuit current	Amber
G_r	Generation rate	$(\text{centimetre})^{-3}\text{sec}^{-1}$
FF	Fill Factor %	(without units)
P_{MP}	Maximum power point	Watt
P	Solar cell power	Watt
η	Solar cell efficiency	(without units)

A_C	Surface area of the solar cell	(metre)^2
G	Irradiance (input light)	Watt
V_{oc}	Normalized voltage	(without units)
P_{out}	Maximum power output	Watt
P_{in}	Maximum power input	Watt
E	Incident radiation flux	Watt
A	Area of collector	(metre)^2
I	The cell output current	Amber
I_L	The light generated current	Amber
V	The voltage across the cell terminals	Volt
R_S	The cell series resistance	ohm
R_{SH}	The cell shunt resistance	ohm
R	Number of incident hotons are reflected from the surface	(without unit)
P_I	The incident irradiance	Watt
h	The Planck constant	Joule.sec
c	The speed of light	metre.sec^{-1}
λ	The wavelength of light	metre
n_{ph}	No. of photons	(without unit)
α	Temperature coefficients	mu/^{o}C
β	Temperature coefficients	mu/^{o}C
T_C	Cell temperature	^{o}C
T_{ref}	Reference cell temperature	^{o}C

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