

REVIEW ARTICLE

Inorganic Photovoltaic Solar Cells; A Review

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ABSTRACT

A solar cell is a device that converts the energy of light into electrical energy as a photovoltaic conversion concept. 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 solar cells have been used in various applications. Inorganic solar cells are made from semiconductor inorganic materials like amorphous, crystalline, microcrystalline Si, multi-crystalline, alloys, and III-V group compounds. The tendency in solar cell manufacturing displays accelerated progress associated with concentrated research pointed to raising the conversion energy efficiency and decreasing the cost of the solar cells industry to make this source of power more inexpensive. The efficiency of solar cells is impartially low related to high solar energy radiation on the Earth's surface and this is because numerous factors influence photovoltaic system performance. The generation of solar cells, solar cell system, basic working principle of a solar cell, factors influences on solar cell system performance, parameters of the solar cell, the module for measurement, and inorganic solar cell technologies are reported in this review article.

Keywords: Electrical energy, Solar cell, Photovoltaic cell, Semiconductor

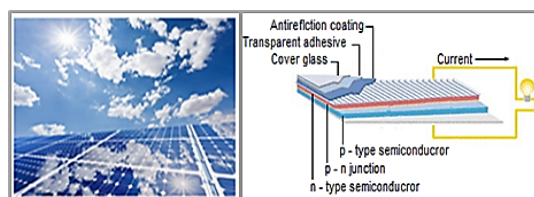
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INTRODUCTION

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]. 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 [2- 9]. 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 [10]. Solar cell (Fig. 1) is a key device that depends on

the concept that converts the energy of light into electrical energy as photovoltaic conversion energy (This is a physical-chemical phenomenon). So, the resistance, voltage, and current vary when photoelectric cells are exposed to light. In most cases, the semiconductor is used as a material of

Fig. 1. A- A solar panel, B- A *p-n* junction photovoltaic (PV) solar cell



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the solar cell. The energy conversion contains light absorption energy (photon) to generate (electron-hole pairs) in a semiconductor and charge-carrier separation. A p-n junction (Fig. 1) is used at charge carrier separation as the principle [11].

Photovoltaic cells have various uses in solar lighting, power pump, power plants, ventilation system, swimming pools, solar cars, remote applications [12], e.g. Earth satellites, remote area power systems, consumer systems, like remote 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 to electricity is a principle and important parameter [13], added to reductions the costs of solar cells [14]. 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 solar cells. The inorganic solar cell 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 [8].

The manufacture of solar cells with high efficiency and low cost is, at present, the biggest challenge for solar cell producers. Hence, several inorganic solar cell technologies have been made to make this source more competitive in the energy field. So the generation of solar cells,

solar cell system, basic working principle of a solar cell, factors influences on solar cell system performance, parameters of solar cell and module for measurement, inorganic solar cells technologies are reported in this article.

GENERATION OF SOLAR CELLS

Solar cells are made from different materials and compounds. Due to the development of the solar cell with using materials, the generation of solar cells are classified to [15, 16, and 17]:

First Generation Solar Cell—Wafer Based

The first-generation solar cells are made from silicon wafers or 3 - 5 compounds. It is the most popular and the eldest technology owing to high efficiencies. Silicon-wafer cells have thickness light absorbing layers up to 350 μm . The wafer of silicon-based technology is additionally branded into two subgroups titled as;

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

Mono-crystalline silicon cells are made of pure mono-crystalline silicon. The silicon in these cells has a lattice structure of continuous single crystal with virtually no defects or inclusions. The high efficiency is the main advantage of these cells, which is usually about 15%. The disadvantage of mono-crystalline silicon cells is the complex process for manufacturing these cells; this result in slightly higher costs compared to those of 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.

Fig. 2, illustrated the diagram contents of Mono-crystalline silicon solar cells.

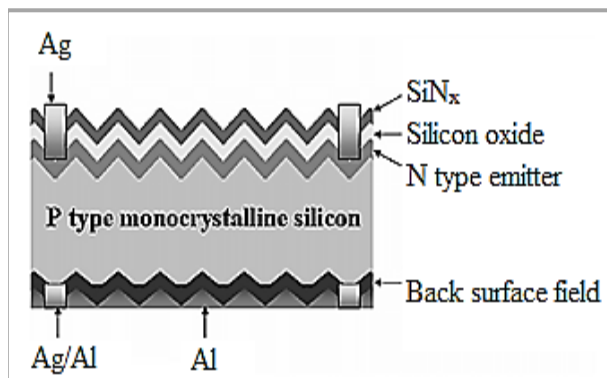


Fig. 2. Schematic diagram of Mono-crystalline silicon solar cells (Single crystalline silicon solar cells).

Second Generation Solar Cells (Thin Film Solar Cells)

Most of the amorphous silicon and thin-film solar cells are classified as second-generation solar cells and are further inexpensive as related to the silicon wafer first-generation solar cells. The thin-film solar cell has a very thin light-absorbing layer (generally in the limit of 1 μm thickness). Thin-film solar cells are classified as;

1. Amorphous Silicon solar cell (a-Si)
2. Cadmium Telluride solar cell (CdTe)
3. Copper Indium Gallium di-Selenide (CIGS)

Amorphous silicon solar cell (a-Si) consist of silicon atoms in a homogeneous thin layer, so this silicon absorbs light more effectively than crystalline silicon, resulting in thinner cells, also 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 its 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 solar cells contents can be shown in Fig. 3.

Third Generation Solar Cells

The new promising technologies are third-generation cells with weaknesses at commercially investigated in detail. Most of the advanced three-generation solar cell kinds are:

1. Nano crystal-based solar cells.

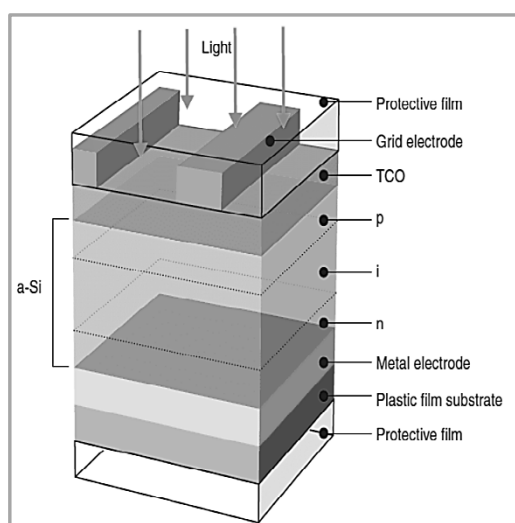


Fig. 3. Schematic diagram of amorphous silicon (a-Si) solar cells (thin-film solar cells).

2. Dye-sensitized solar cells.
3. Concentrated solar cells.
4. Polymer-based solar cells.

Photovoltaic nanotechnologies depend on mixing or coating flexible polymer materials with nano-substrates that have 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 solar cells. The contents of Perovskite (nano-crystals) solar cells can be illustrated in Fig. 4.

Several applications, types, and efficiencies of generation solar cells [18], are illustrated in Fig. (5).

SOLAR CELL SYSTEM

Pre-engineered solar cell system can be obtained with all the components from manufacturers. The solar module is the photovoltaic (PV) system heart. Numerous photovoltaic cells are wired together to produce a solar module. Fig. (6) is illustrated a principle solar cell system.

The photovoltaic modules are generally rated under standard test conditions (STC) with solar radiation of (1000 W/m^2), cell temperature of (25°C), and solar spectrum of (1.5) by the producers [19]. Fig. (7) is illustrated a standard solar cell system.

BASIC WORKING PRINCIPLE OF A SOLAR CELL

The basic unit of the solar energy generation system is the photovoltaic cell, where electrical energy is converted directly from visible light

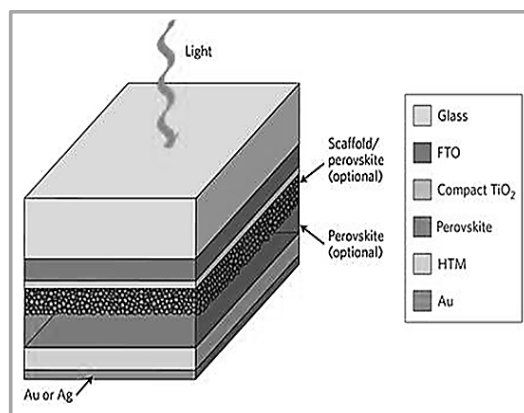


Fig. 4. Schematic diagram of nano-crystals solar cells (Perovskite solar cells).

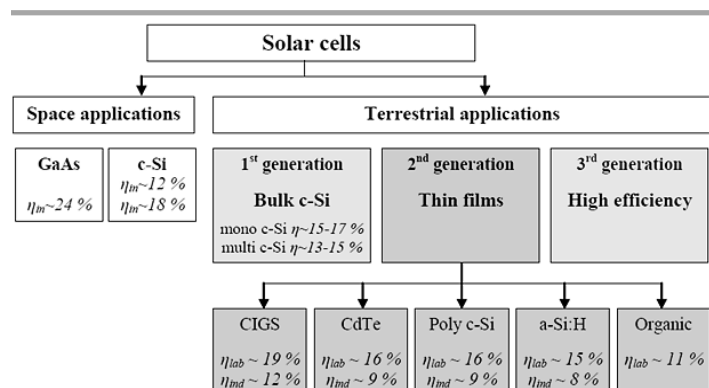


Fig. 5. Schematic illustration of several solar cells applications and types.

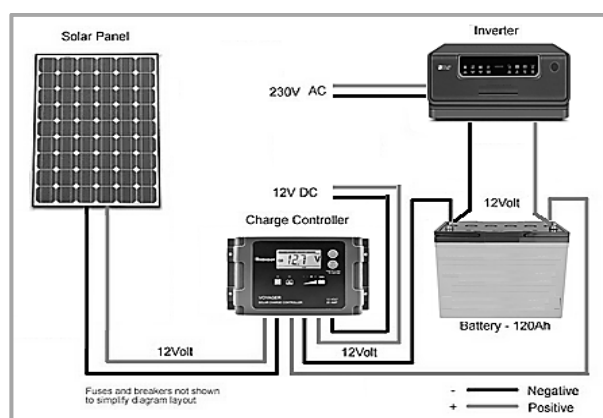


Fig. 6. Solar cell system equipment.

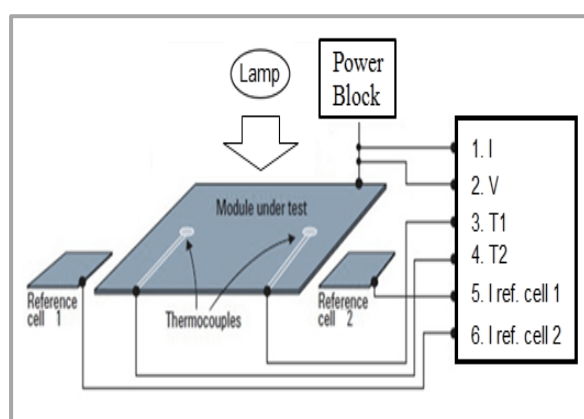


Fig. 7. Typical integrated solar cell test system

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.

Movement of the holes to the (n-side) reveals negative ion cores in the (p-side), while the movement of the electrons to the p-side reveals positive ion cores inside, these effects electric field at the junction and founding the depletion region. When the Sunlight covers the solar cell, photons that have energy larger than the semiconductor band-gap 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.

Fig. (8) is illustrated the solar cell principle working [20].

FACTORS INFLUENCES ON PHOTOVOLTAIC SYSTEM PERFORMANCE

A solar cell generates electricity directly from light. However, their efficiency is impartially low. So, the solar cell charges are costly as compared to other resources of energy products. The produced output energy by a photovoltaic module and its time length depends on various factors. Some of these include the received solar radiation intensity, PV material type, parasitic resistances, temperature of the cell, the orientation of module, geographical location, weather conditions, the thickness of cable, inverter efficiency, and other effects. Numerous papers [21 - 27] studied the factors that affect solar cell efficiency.

Several factors play into the efficiency and

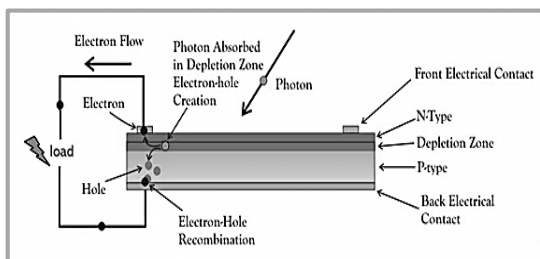


Fig. 8. A schematic is illustration of the solar cell principle working.

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 solar panels by 1°C, the efficiency of the solar 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 [21], reported a list of these factors that affect the solar cell energy output (Table 1) and the PV system yield (Table 2).

PARAMETERS OF SOLAR CELL AND MODULE FOR MEASUREMENT

Different equivalent circuits have been used in the references to model 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).

Solar cell IV curve

The IV curve in a solar cell is the superposition of the light-generated current with the IV curve of the 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 the formula:

$$I = I_D - I_L \quad (1)$$

The equations for the IV curve in the first quadrant are:

$$I = I_L - I_D \quad (2)$$

$$I_D = I_o \left[\exp \left(\frac{qV}{nKT} \right) - 1 \right] \quad [22] \quad (3)$$

Table 1. The factors influencing the solar cell power output and the influence source.

No.	Factors being influenced	Factors influencing
1	Dust	
	Size distribution	Chemical composition, Wind speed, and wind direction
	Chemical composition	Chemical composition, Atmospheric aerosols, Rain, Wind
	Morphology	Dust source, Chemical composition
	Source	Location of the site of a PV system
	Moisture content/plasticity index of dust particles	Humidity ratio, Chemical composition
	Specific gravity of dust particles	Chemical composition/species
	Gravimetric dust density	Size of the particles, Chemical composition, Moisture, Density of the dust particles, Tilt of the panel, Wind speed and direction, Temperature of the glazing, Cleaning interval
	Interaction with glazing (adhesion/electrostatic force)	Chemical composition of dust;
	Transmission/absorption/reflection of the dust layer	Gravimetric density, Chemical composition/species of dust, Snow cover
2	PV cell	
	Photovoltaic material and type of cell and its thermal/optical properties	Total cost per area of the solar module, Solar PV market
	Spectral response	Band-gap of the solar cell
	Isc, Voc, FF	Property of the solar cell
	Quantum efficiency	Solar cell material
	Conversion efficiency	Solar cell material
	p/n junction and band gap	Property of the solar cell material
	PV cell temperature	Absorption coefficient, Refractive index, Thermal conductivity of the material, Temperature of the backpanel sheet, Ambient temperature, Wind speed and direction, Solar insolation, Optical depth of the dust/snow layer, Tiltangle/angle of incidence
3	PV panel system	
	Panel Frame - material, thermal and physical properties	Strength requirements, cost, and availability
	EVA (ethyl vinyl acetate) - refractive index, absorption coefficient, thermal properties	Lamination, chemical inertness, cost and availability
	Glazing - refractive index, absorption coefficient, surface texture, thermal properties	Chemical inertness, external damage, optical properties, cost, and availability
	Back sheet, thermal properties	Strength requirements, cost, and availability
	Wiring, contact probes	Reliability, longevity, cost, and availability
	Glazing temperature, back panel temperature	PV cell temperature, thermal resistance, transmittance, reflectivity of the layers, angle of incidence, dust layer/snow layer, wind, ambient temperature, GHI/DNI
4	Installation of panel and sun geometry	
	Fixed tilt angle/orientation of the panel	Location
	Sun tracking - single and dual	Seasonal changes in solar earth geometry
	Time of the day and year	Objects shadow on panel, partial shadowing
	Objects shadow on panel, partial shadowing	Trees, surrounding buildings
	Location on earth- latitude, longitude, altitude	
	Installation- roof or ground-based	Land space/roof space
5	Radiation and atmosphere	
	Clouds	
	Atmospheric gases and aerosols	
	Dry duration (time between two rain events) and rain intensity (mm)	
	Wind speed and direction and gust	
	Ambient surface temperature	Aerosols/cloud cover, the intensity of the radiation
	Surface irradiance (GHI/DNI and diffuse)- (total and spectral)	Aerosols/cloud cover, the intensity of the radiation
	Relative humidity	
	Snow cover	
6	Cleaning maintenance	
	Cleaning interval/critical cleaning period	Cost, labor, water/energy
	Cleaning technique (water-based, non-water based, manual, robotic)	Glazing hardness, physical properties, availability of the water/energy
	Natural cleaning (rain, fog, etc.)	Rain, fog, dew
7	Performance parameters	
	Instantaneous power output	Conversion efficiency, surface irradiance
	Daily, monthly and annual yield	Conversion efficiency, surface irradiance, cell temperature
	DC conversion efficiency of the module	Quantum efficiency, cell temperature
8	Others	
	Cost	
	Social-economic-political and market factors	
	Availability of natural resources (like water, land area, sunshine, etc.)	Location, resources are also seasonal dependent

Table 2. Factors effecting PV system yield.

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

$$I_L = q \times n_{ph} \times \left[P_i \times \frac{\lambda}{hc} \times (1 - R) \right] \quad [28] \quad (4)$$

$$I_O = qn_i^2 \left(\frac{D_N}{L_N N_A} + \frac{D_P}{L_P N_D} \right) \quad [28, 29] \quad (5)$$

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

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

Drawing equation 6, gives the IV curve Fig. (9) with the relevant points labelled on the curve. The power curve has a maximum signified as P_{MP} (where

the solar cell operated to give the maximum power output P_{MP}). It is also denoted as P_{MAX} or maximum power point (MPP) and occurs at a current of I_{MP} and a voltage of V_{MP} . Fig. 9 illustrated the IV curve to obtain P_{MAX} .

Voltage at maximum power (V_{mp})

It is the highest 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).

$$V_{mp} \approx V_{OC} - \frac{nKT}{q} \ln \left(\frac{qV_{OC}}{nKt} + 1 \right) \quad [30] \quad (7)$$

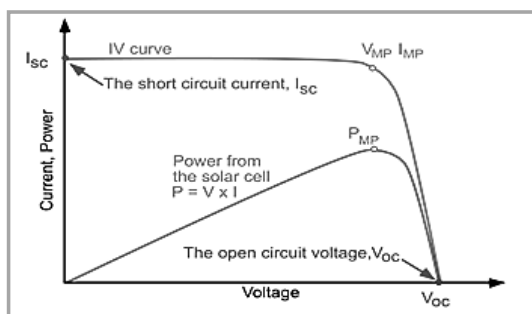


Fig. 9. IV curve of a solar cell. To get the MPP of a solar cell it needs to operate at P_{MP}

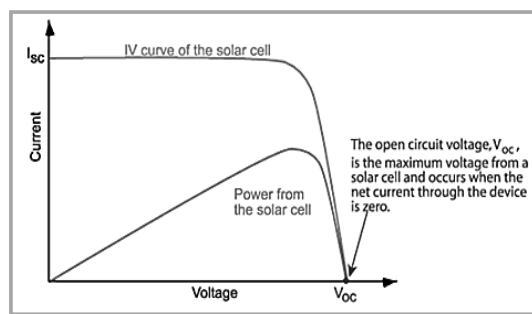


Fig. 11. IV curve of a solar cell showing the open-circuit voltage

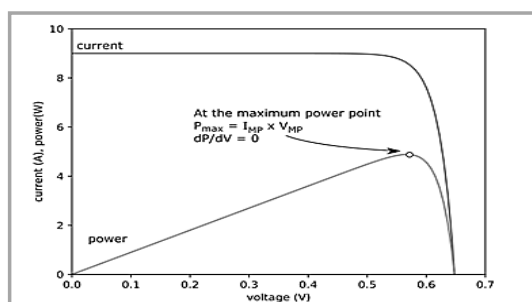


Fig. 10. The V_{MP} occurs when the differential of the power produced by the cell is zero

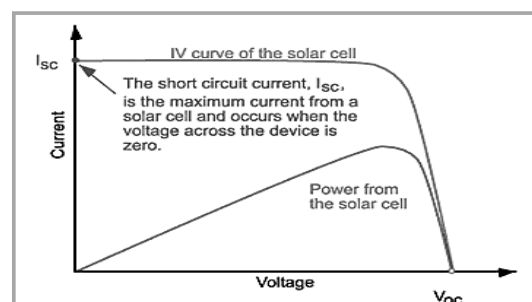


Fig. 12. IV curve of a solar cell showing the short-circuit current

Fig. 10. is Illustrated the occurrences of V_{mp} in a solar cell.

Open circuit voltage (V_{oc})

When a solar cell is not connected to an 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 V_{oc} value.

$$V_{oc} = \frac{KT}{q} \ln \left(\frac{I_L}{I_o} + 1 \right) \quad [22] \quad (8)$$

$$V_{oc} = \frac{E_g}{q} - \frac{KT}{q} \ln \left(\frac{A_g}{qn_L} \right) \quad [31] \quad (9)$$

$$V_{oc} = \frac{KT}{q} \ln \left[\frac{(N_A + \Delta n) \Delta n}{n_i^2} \right] \quad [32] \quad (10)$$

The 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. The V_{oc} is shown on the IV curve below in Fig. 11.

Short circuit current (I_{sc}).

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

So, 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 relations 11-12:

$$I_{sc} = I_{ph} \quad [34] \quad (11)$$

$$I_{sc} = qnG_r(L_n + L_p) \quad [29] \quad (12)$$

The short-circuit current can be publicized on the IV curve as in Fig. 12.

Maximum power current (I_{mp}).

It is the greatest current obtainable when the solar cell 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:

$$I_{MP} = \frac{P_{max}}{V_{MP}} \quad [19] \quad (13)$$

Maximum power point (P_{max}).

It is the power when the solar cell produces the greatest energy, So the I and V in this condition are defined as I_{max} and V_{max} correspondingly, with equation:

$$P_{max} = V_{mp} \times I_{mp} \quad (14)$$

Fill factor (FF).

FF is a parameter used to describe the presentation of the solar cell, and defined as the ratio of P_{max} divided by I_{SC} multiplied by V_{OC} , with relation:

$$FF = \frac{P_{MP}}{V_{OC} \times I_{SC}} = \frac{V_{MP} \times I_{MP}}{V_{OC} \times I_{SC}} \quad [22] \quad (15)$$

Assuming that the photovoltaic cell acts as an ideal diode the FF can be expressed as related to V_{OC} as:

$$FF = \frac{v_{oc} - \ln(v_{oc} + 0.72)}{v_{oc} + 1} \quad [29] \quad (16)$$

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

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

Conversion efficiency (η).

Efficiency is defined as the ratio of the solar cell energy output P_{out} (converted from absorbed visible light to electrical power) to Sun input energy P_{in} (product of irradiance from the Sun (E) and the solar cell surface area (A_c)). Efficiency can be calculated by equations 18-19.

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{MP} \times I_{MP}}{P_{in}} = \frac{V_{MP} \times I_{MP}}{E \times A} \quad [27] \quad (18)$$

$$\eta = \frac{V_{OC} \times I_{SC} \times FF}{E \times A} \quad [35] \quad (19)$$

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

Internal resistances of a solar cell:

Series (R_S) resistance

Series (R_S) and shunt (R_{SH}) resistances are internal parasitic resistances. During the operation of the solar cells, their efficiency is decreased by the dissipation of energy in these resistances. R_S in a solar cell has three causes: first, the current drive via the base and emitter of the solar cell; second,

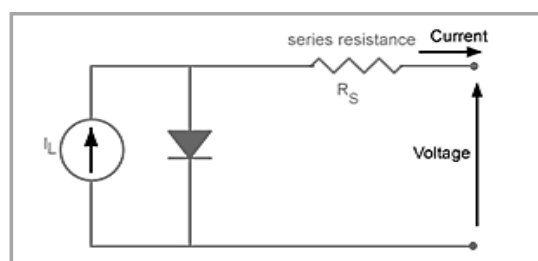


Fig. 13. Schematic illustrated the solar cell circuit with series resistance.

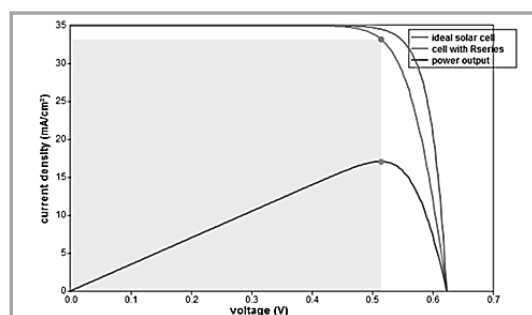


Fig. 14. The effect of R_S on FF.

the connection resistance between the silicon and the metal contact; and lastly the resistance of the back and top metal contacts. The chief influence of RS resistance is to decrease the fill factor. 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. Fig. 13 illustrated a solar cell circuit in the presence of series resistance.

The cell output current in the presence of RS can be shown in relation (20), and the effect of the RS on the IV curve is shown in Fig. (14).

$$I = I_L - I_o \exp \left[\frac{q(V + IR_s)}{nKT} \right] \quad (20)$$

Shunt resistance, RSH

Significant energy losses affected by the presence of shunt resistance, RSH, are classically owing to engineering defects, adding to lowly solar 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 levels, since there would be fewer lights - produced currents. The current loss to the shunt has a larger impact. Rather than, at lower voltages (the effective resistance of the photovoltaic cell is high), the effect of a resistance in parallel is great. Fig. 15 is illustrated a solar cell circuit in the presence of shunt resistance.

The equation for a solar cell including the shunt resistance can be shown as:

$$I = I_L - I_o \exp \left[\frac{qV}{nKT} \right] - \frac{V}{R_{SH}} \quad (21)$$

The influence of low shunt resistance is shown in Fig. (16).

In the existence of both series and shunt resistances, the IV curve of the solar cell is illustrated by equation 22.

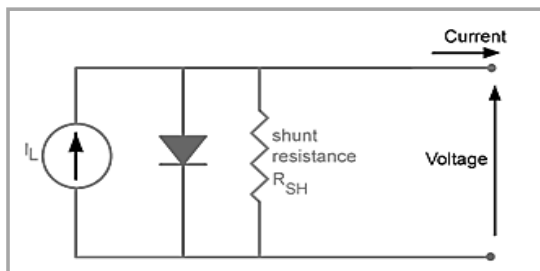


Fig. 15. Circuit diagram of a solar cell including the shunt resistance.

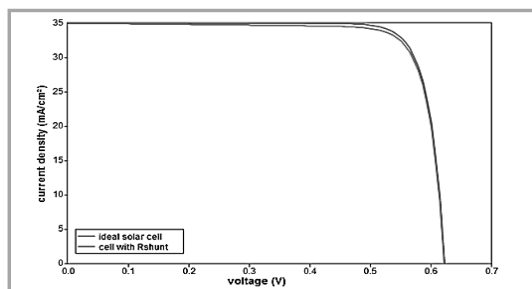


Fig. 16. The effect of RSH on FF.

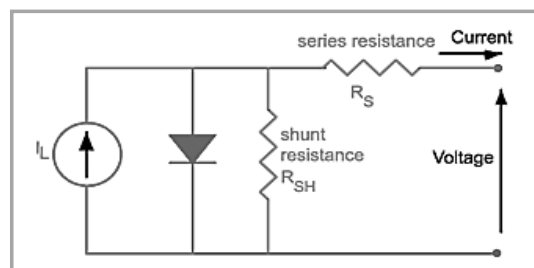


Fig. 17. Parasitic series and shunt resistances in a solar cell

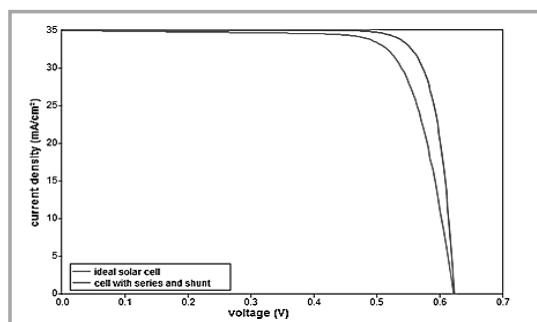


Fig. 18. The effect of Parasitic series and shunt resistances in a solar cell on FF.

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

So the circuit diagram and the effect of the RSH on the IV curve of the solar cell can be shown in Figs. (17 and 18).

Solar cell performance with temperature

The influence of temperature is varied and multifaceted with solar cell technology [33]. Solar cell production decreases with an increase in temperature, fundamentally due to rising internal carrier recombination rates, affected by rising carrier concentrations. The working temperature plays an important role in the solar cell conversion process [35, 36, 37, 38, and 39]. 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 [36]. The equations of I_{SC} , V_{OC} , P , and η related to temperature in a solar cell can be presented in equations 23 – 28.

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

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

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

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

$$P = P_{(T_{ref})} \left[1 + (\alpha - \beta) \times (T_C - T_{ref}) \right] \quad [40] \quad (26)$$

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 leads to a linear equation in the form;

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

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

β_{ref} Temperature coefficient $/\text{K}^{-1}$

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

T_O The high T at PV cell electrical efficiency drops to zero [36].

INORGANIC SOLAR CELLS 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

Table 3. Photovoltaic functions for the all-inorganic solar cells.

Material	Eff. (%)	V _{oc} (V)	J _{sc} (mA cm ⁻²)	F. F. (%)
Sb ₂ Se ₃ (substrate)	09.20	0.400	32.60	70.3
Glass/Mo/MoSe ₂ /Sb ₂ Se ₃ /ZnO/AZO				
Cu ₂ ZnSnS ₄ (CZTS)	11.00	0.731	21.74	69.3
Glass/Mo/CZTS/CdS/i-ZnO/ITO/Al/MgF ₂				
Cu ₂ ZnSn(S _{0.25} Se _{0.75}) ₄ (CZTSSe)	12.60	0.513	35.20	69.8
Glass/Mo/CZTSSe/CdS/ZnO/ITO/Ni/Al/MgF ₂				
Cu ₂ ZnSn(S _{0.25} Se _{0.75}) ₄ (CZTSSe)	12.62	0.541	35.35	65.9
Glass/Mo/CZTSSe/CdS/ZnO/AZO/Ni/Al/MgF ₂				
Cu ₂ ZnSnSe ₄ (CZTSe)	11.60	0.423	40.60	67.3
Glass/Mo/CZTSe/CdS/ZnO/ITO/Ni/Al/MgF ₂				
Cu ₂ O	03.97	1.204	07.37	44.7
MgF ₂ /Al/Al:ZnO/Ga ₂ O ₃ /Cu ₂ O/Au				
CsPbI ₃	13.58	1.163	15.25	76.6
Al/MoO _x /Spiro-OMeTAD/CsPbI ₃ /TiO ₂ /SnO ₂ :F/Glass/MgF ₂				
SnS	04.36	0.372	20.20	58.0
Glass/Mo/SnS/SnO ₂ /Zn(O, S) ₂ N/ZnO/ITO				
Sb ₂ Se ₃ (superstrate)	07.60	0.420	29.90	60.4
Glass/ITO/CdS/Sb ₂ Se ₃ /Au				
Sb ₂ (S, Se) ₃	09.90	0.650	24.07	63.5
Glass/FTO/CdS/Sb ₂ Se ₃ /Spiro-OMeTAD/Au				
PbS	9.880	0.635	21.60	71.9
Glass/ITO/ZnO/PbS(TBAI)/PbS(EDT)/Au				
AgBiS ₂	6.310	0.450	22.10	63.0
Glass/ITO/ZnO/AgBiS ₂ /PTB ₇ /MoO ₃				
Zn ₃ P ₂	6.000	0.492	14.90	71.0
ZnS/Mg/Ag:Zn ₃ P ₂ /Ag				
CuSbSe ₂	4.700	4.700	26.30	53.0
Glass/Mo/CuSbSe ₂ /ZnO/AZO				
CuSbS ₂	3.200	0.470	15.60	43.6
Glass/Mo/CuSbS ₂ /CdS/ZnO/AZO				
Cu ₂ CdSnS ₄	1.100	0.383	12.40	23.0
Glass/Mo/CCdTS/CdS/ZnO/AZO/Ag				
Cu ₂ ZnSnSe ₄	11.80	0.463	38.30	66.3
Glass/Mo/CZTSe/CdS/ZnO/ITO/Ag/MgF ₂				
Cu ₂ BaSnS ₄ (substrate)	01.70	0.698	5.300	46.9
Glass/Mo/CBaTS/CdS/ZnO/ITO/Al				
Cu ₂ BaSnS ₄ (superstrate)	2.000	0.933	05.10	42.9
CdS:O/CdS/ZnO/AZO				
Cu ₂ FeSnS ₄	3.000	0.610	09.30	52.0
ITO/Cu-NiO/CFeTS/Bi ₂ S ₃ /ZnO/Al				
Cu ₂ CdSn(S _{0.25} Se _{0.75}) ₄	2.800	0.356	18.80	41.6
Glass/Mo/CCdTS/CdS/ZnO/ITO/Al				
Cu ₂ BaSn(S _{0.25} Se _{0.75}) ₄	5.200	0.611	17.40	48.9
Glass/Mo/CBaTS/CdS/ZnO/ITO/Ni/Al				
Cu ₂ ZnGe(S _{0.25} Se _{0.75}) ₄	6.000	0.617	NA	NA
Glass/Mo/CZGeSe/CdS/ZnO/AZO/Ni/Al				
Cu ₂ ZnGeSe ₄	07.60	0.558	22.80	59.0
Glass/Na-barrier/Mo/CZGeSe/CdS/ZnO/AZO/Ni/Al				
Ag ₂ ZnSnSe ₄	05.18	0.504	21.00	48.7
FTO/AgZTSe/MoO ₃ /ITO/Ni/Al				
Cu ₂ (Zn _{0.6} Cd _{0.4})SnS ₄	11.00	0.650	25.50	66.1
Glass/Mo/CZCdTS/CdS/ZnO/ITO/Al/MgF ₂				
(Ag _{0.05-0.3} Cu _{0.95-0.7}) ₂ ZnSn(S, Se) ₄	11.20	0.464	36.20	66.5
Glass/Mo/ACZTSSe/CdS/ZnO/ITO/Ag				
(Ag _{0.05} Cu _{0.95}) ₂ (Zn _{0.75} Cd _{0.25})Sn ₄	10.10	0.650	23.40	66.2
Glass/Mo/ACCdZTS/CdS/ITO/Ag				
Cu ₂ Zn(Sn _{0.78} Ge _{0.22})Se ₄	12.30	0.527	32.20	72.7
Glass/Mo/CZTGTS/CdS/ZnO/AZO/Ag/ARC				
(Li _{0.06} Cu _{0.94}) ₂ ZnSn(S, Se) ₄	11.60	0.531	33.70	64.8
Glass/SiOx/Mo/LiCZTSSe/CdS/ZnO/AZO/Ni/Al/MgF ₂				

Table 3. Photovoltaic functions for the all-inorganic solar cells.

Material	Eff. (%)	V _{oc} (V)	J _{sc} (mA cm ⁻²)	F. F. (%)
Cu ₂ (Zn _{0.95} Mn _{0.05})Sn(S, Se) ₄	8.900	0.418	33.70	63.3
Glass/Mo/CMZTSSe/CdS/ZnO/AZO/Ni/Al				
Cu ₂ O	08.10	1.200	10.40	65.0
MgF ₂ /Al:ZnO/Zn _{0.38} Ge _{0.62} O/Cu ₂ O:Na/Au				
Bi ₂ FeCrO ₆	8.100	0.840	20.60	46.0
Sn:In ₂ O ₃ /Bi ₂ FeCrO ₆ /SrRuO ₃				
InP				
Al/ZnO:Al/i-ZnO/InP:Zn/Au-Zn-Au	7.300	0.570	17.40	73.0
(In, Ga)N				
SiO ₂ /Au/(Mg:Ga ₂ N/GaN)/(In, Ga)N/Si:Ga ₂ N	03.00	1.800	02.60	64.0
ZnSnN ₂				
Au/ZnSnN ₂ /Al ₂ O ₃ /SnO	01.50	0.360	07.50	57.0
BiI ₃				
Au/F ₈ /BiI ₃ /TiO ₂ /SnO ₂ :F	1.200	0.607	5.300	37.6
CsPbBr ₃				
C/CuPc+/CsPbBr ₃ /SnO ₂ /TiO ₂ /SnO ₂ :F	8.800	1.310	08.20	81.4
CsPbI ₃				
Au/Spiro-OMeTAD/CsPbI ₃ /SnO ₂ /In ₂ O ₃ :SnO ₂	15.70	1.080	18.40	79.3
CsPbI ₂ Br				
Au/Spiro-OMeTAD/CsPbI ₂ Br/TiO ₂ /In ₂ O ₃ :SnO ₂	16.10	1.230	16.80	77.8
CsPbI ₂ Br ₂				
C/CsPbI ₂ Br ₂ /TiO ₂ /SnO ₂ :F	9.200	1.245	10.70	69.0
CsPb _{0.95} Eu _{0.05} I ₂ Br				
Au/Spiro-OMeTAD/CsPb _{0.95} Eu _{0.05} I ₂ Br/TiO ₂ /SnO ₂ :F	13.70	1.220	14.60	76.6
CsSnBr ₃				
Au/Spiro-OMeTAD/CsSnBr ₃ /TiO ₂ /SnO ₂ :F	02.20	0.420	09.10	57.0
CsSnI ₃				
Au/PTAA/CsSnI ₃ /TiO ₂ /SnO ₂ :F	04.80	0.382	25.70	49.1
CsSn _{0.5} Ge _{0.5} I ₃				
Au/Spiro-OMeTAD/CsSn _{0.5} Ge _{0.5} I ₃ /PCBM/SnO ₂ :F	7.100	0.630	18.60	60.6
Se				
Glass/FTO/TiO ₂ /ZnMgO/Se/MoO ₃ /Au	6.500	0.969	10.60	63.4
GeSe				
Glass/ITO/CdS/GeSe/Au	1.500	0.240	14.50	42.6
Sb ₂ S ₃				
Glass/FTO/TiO ₂ /mp-TiO ₂ /Sb ₂ S ₃ /PCPDTBT/PEDOT:PSS/Au	07.50	0.711	16.10	65.0
Sb ₂ (S _x Se _{1-x}) ₃				
Glass/FTO/TiO ₂ /mp-TiO ₂ /Sb ₂ S ₃ /P ₃ HT/Au	6.600	0.475	24.90	55.6
Bi ₂ S ₃				
Glass/ITO/P ₃ HT:Bi ₂ S ₃ /MoO _x /Au	3.300	0.700	10.70	45.0
Cu ₂ CdGeSe ₄				
Graphite/Epoxy/CCdGeSe/CdS/ZnO/AZO/glue/Ag/glass	4.200	0.464	23.30	39.0

conversion energy efficiency and decreasing the cost of solar cells industrial to make this source of power more inexpensive [3], [27], [41]. The realization of solar cells with low process cost and high - efficiency, nowadays, are the greatest challenge for solar cell producers. Thus, numerous inorganic solar cells technologies have been reported to make this source of energy more competitive [27], [42], [43]. Lydia H. Wong et.al [43] detailed the solar parameters for the all-inorganic solar cells (Table

3 are listed the inorganic solar cells with energy functions) that made from inorganic materials as semiconductors.

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. Mehreen Gul, et.al. [44] offers a brief comparison and notes between all kind of materials with their

Table 4. The advantages and disadvantages of inorganic solar cells.

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

advantages and disadvantages. From Table 4, it can be shown that a crystalline solar cell module has the highest efficiency with a percentage (20.4%) related to all other solar materials.

CONCLUSION

In this review we can conclude principal points:

1. 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 inorganic solar cells have been used in various applications.
2. The inorganic solar cell is made from inorganic semiconductor materials like amorphous, crystalline, microcrystalline Si, multi-

crystalline, alloys, and III-V compounds.

3. In three-generation solar cells, inorganic solar cells are taking an important role.
4. The solar module is the photovoltaic (PV) system heart.
5. The 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.
6. Numerous factors that influence photovoltaic system performance depend on solar cell efficiency.
7. 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 temperature is varied and multifaceted with solar cell technology. Solar cell production decreases with an increase in temperature.
 - The highest conversion efficiency (η) has 25% with various inorganic solar cells technologies made from inorganic materials as semiconductors.

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	(centimetre) ⁻² sec ⁻¹
N_A	Doping concentration	(centimetre) ⁻³
Δn	Excess carrier concentration	(centimetre) ⁻³
n_i^2	Intrinsic carrier concentration	((centimetre) ⁻³) ²
D_N	(Electron) diffusion length in the n-type region	(centimetre) ² sec ⁻¹
D_P	(Hole) diffusion length in the p-type region	(centimetre) ² 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	(metre) ⁻³
I_{sc}	Short-circuit current	Amber
G_r	Generation rate	(centimetre) ⁻³ 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 photons 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)

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REFERENCES

- Praveen, J., & VijayaRamaraju, V. (2017). Materials for Optimizing Efficiencies of Solar Photovoltaic Panels. *Materials Today: Proceedings*, 4, 4D, 5233 – 5238.
- Lewis, N. S., Nozik, A. J., Wasielewski, M. R., Alivisatos, P., & Kung, H. (2005). basic research needs for solar energy utilization, office of science.
- Tao, M. (2008). Inorganic Photovoltaic Solar Cells: Silicon and Beyond, *The Electrochemical Society Interface*, 30-35.
- International Energy Agency (2014) Trends 2014 in photovoltaic applications. Available at: http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA_PVPS_Trends_2014_in_PV_Applications_-_lr.pdf (accessed 19 December 2015).
- International Energy Agency (2015a) 2014 snapshot of global PV markets. Available at: http://helapco.gr/pdf/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2014.pdf (accessed 19 December 2015).
- Ryan C (2014) Solar Power Portal. UK overtaken by Japan in renewable energy country attractiveness index. Available at: http://www.solarpowerportal.co.uk/news/uk_overtaken_by_japan_in_renewable_energy_country_attractiveness_index_erns (accessed 19 December 2015).
- Caldés N, Varela M, Santamaria M, et al. (2009). Economic impact of solar thermal electricity deployment in Spain, *Energy Policy*, 37: 1628–1636.
- Samy Almosni, Amaury Delamarre, Zacharie Jehl, Daniel Suchet, Ludmila Cojocaru, Maxime Giteau, Material challenges for solar cells in the twenty-first century: directions in emerging technologies, *Science and Technology of Advanced Materials*, 19, 1, 336-369. <https://doi.org/10.1080/14686996.2018.1433439>.
- Mehdi Jahangiria, Omid Nematollahib, Elham Heidari Soorshjania, Azadeh Heidari Soorshjani, (2020). Journal of Solar Energy Research, Investigating the Current State

- of Solar Energy Use in Countries with Strong Radiation Potential in Asia Using GIS Software, A Review, Journal of Solar Energy Research, 5, 3, 477-497.
- [10] Rajput, S. K. (2017). Solar Energy Fundamentals, Economic and Energy Analysis, First Edition, Northern India Textile Research Association
 - [11] Soga, T. (2006). Nanostructured Materials for Solar Energy Conversion, 1st Edition, Elsevier Science.
 - [12] Bagher, A. M., Abadi Vahid, M. M., & Mohsen, M. (2015). Types of Solar Cells and Application, American Journal of Optics and Photonics, 3(5), 94-113.
 - [13] Yaragalla, S., Mishra, R. K., Thomas, S., Kalarikkal, N., & Maria, H. (2019). Carbon-Based Nanofillers and Their Rubber Nanocomposites, Elsevier Inc., pp.259-283. DOI: 10.1016/B978-0-12-813248-7.00009-2
 - [14] Blakers, A., Zina, N., McIntosh, K. r., & Fong, K. (2013). High Efficiency Silicon Solar Cells, Energy Procedia, 33, 1 - 10.
 - [15] Hussain, C. M. (2018). Handbook of Nanomaterials for Industrial Applications, Elsevier Science.
 - [16] Sharma, S., Jain, K. K., & Sharma, A., (2015). Solar Cells: In Research and Applications—A Review, Materials Sciences and Applications, 6, 1145-1155,
 - [17] Le Donne, A., Scaccabarozzi, A., Tombolato, S., Marchionna, S., Garattini, P., Vodopivec, B., Acciarri, M., & Binetti, S. (2013). State of the Art and Perspectives of Inorganic Photovoltaics, *ISRN Renewable Energy*, 2013, ID 830731, 1-8.
 - [18] Minnaert, B., & Veelaert, P. (2014). A Proposal for Typical Artificial Light Sources for the Characterization of Indoor Photovoltaic Applications, *Energies*, 2014, 7, 1500-1516. doi:10.3390/en7031500
 - [19] Jakhrani, A. Q., Samo, S. R., Kamboh, S. A., Labadin, J., & Rigit, A. R. H., (2014). An Improved Mathematical Model for Computing Power Output of Solar Photovoltaic Modules, *International Journal of Photoenergy*, 2014, ID 346704, 1 - 9. <http://dx.doi.org/10.1155/2014/346704>
 - [20] Images Scientific Instruction, Photovoltaic Cells – Generating electricity, <https://www.imagesco.com/articles/photovoltaic/photovoltaic-pg4.html>
 - [21] Rao, R. R., Mani, M., & Ramamurthy, P. C. (2018). An updated review on factors and their inter-linked influences on photovoltaic system performance, *Heliyon*, 4 (e00815), 1-34. doi: 10.1016/j.heliyon.2018. e00815.
 - [22] Dinçer, F., & Meral, M. E. (2010). Critical Factors that Affecting Efficiency of Solar Cells, *Smart Grid and Renewable Energy*, 1, 47-50. doi:10.4236/sgre.2010.11007
 - [23] Chikate, B. V., & Sadawarte, Y.A. (2015). The Factors Affecting the Performance of Solar Cell, *International Journal of Computer Applications (0975 - 8887) International Conference on Quality Up-gradation in Engineering, Science and Technology (ICQUEST2015)*, p: 1- 5. IJCATM : www.ijcaonline.org
 - [24] Vidyanandan, K.V. (2017). An Overview of Factors Affecting the Performance of Solar PV Systems, *Energy Scan*, 27, 2-8
 - [25] Das, M. R. (2019). Effect of Different Environmental Factors on Performance of Solar Panel, *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 8, 11, 15-18. DOI: 10.35940/ijitee.J9889.0981119
 - [26] Hussin, N. S. M., Amin, N. A. M., Safar, M. J. A., Zulkafli, R. S., Abdul Majid, M. S., Rojan, M. A., & Zaman, I. (2018). Performance Factors of the Photovoltaic System: A Review, *MATEC Web of Conferences*, 225, 03020, 1-8.
 - [27] Karzazi, Y., & Arbouch, I. (2014). Inorganic photovoltaic cells: Operating principles, technologies and efficiencies – Review, *J. Mater. Environ. Sci.*, 5, 5, 1505-1515.
 - [28] Zeman, M. Solar Cells, Chapter 1., Introduction To Photovoltaic Solar Energy, p:40, 58.
 - [29] Jäger, K., Isabella, O., Smets, A. H. M., van Swaaij, R. A. C. M. M., & Zeman, M. (2014). Solar Energy, Delft University of Technology, p58, 95, 98.
 - [30] PV Education.Org, voltage at the maximum power point-Vmp, <https://www.pveducation.org/pvcdrom/voltage-at-the-maximum-power-point-vmp>
 - [31] Henry, C.H. (1980). Limiting efficiencies of ideal single and multiple energy gap terrestrial solar cells, *J. Appl. Phys.*, 51, 4494,
 - [32] Sinton, R. A., & Cuevas, A. (1996). “Contact-less determination of current-voltage characteristics and minority-carrier lifetimes in semiconductors from quasi-steady-state photoconductance data,” *Applied Physics Letters*, 69, 2510-2512.
 - [33] PV Education.Org, Open Circuit Voltage, <https://www.pveducation.org/pvcdrom/solar-cell-operation/open-circuit-voltage>
 - [34] Ilo Frederick, U. (2017). Determination of the effect of temperature changes on power output of solar panel, *International Journal of Research in Engineering and Applied Sciences (IJREAS)*, 7, 9, 70-79.
 - [35] Fesharaki, V. J., Dehghani, M., Fesharaki, J. J., & Tavasoli, H. (2011). The Effect of Temperature on Photovoltaic Cell Efficiency, *Proceedings of the 1st International Conference on Emerging Trends in Energy Conservation – ETEC*, Tehran, Iran, 1-6.
 - [36] Dubey, S., Sarvaiya, J. N., & Seshadri, B. (2013). Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World A Review, *Energy Procedia*, 33, 311 - 321.
 - [37] El-Adaw, M K., Shalaby, S A., Abd El-Ghany, S.E. S., & Attallah, M.A. (2015). Effect of Solar Cell Temperature on its Photovoltaic Conversion Efficiency, *International Journal of Scientific & Engineering Research*, 6, 3, 1356- 1384.
 - [38] Javed, A. (2014). The Effect of Temperatures on the Silicon Solar Cell, *International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS)*, 9, 3, 305-308
 - [39] Al-Naser, Q. A. H., Al-barghooth, N. M., and Al-Ali, N. A. (2012). The Effect of Temperature Variations on Solar Cell Efficiency, *International Journal of Engineering, Business and Enterprise Applications (IJEBAE)*, International Association of Scientific Innovation and Research (IASIR), 1, 4, 555-563
 - [40] Patel, M. R. (2006). Wind and Solar Power Systems, Design, Analysis, and Operation, Second Edition, CRC Press is an imprint of Taylor & Francis Group, p:174.
 - [41] Miles, R. W., Zoppi, G., & Forbes, I. (2007). Inorganic photovoltaic cells, 2007, materialstudy, 10 ,11 , 20-27.
 - [42] Zhang, L., Hu, T., Li, J., Zhang, L., Li, H., Lu, Z. & Wang, G. (2020). All-Inorganic Perovskite Solar Cells With Both High Open-Circuit Voltage and Stability, *Frontiers in Material*, 6, 330, 1-8. doi: 10.3389/fmats.2019.00330
 - [43] Wong , L. H., Zakutayev, Z., DMajor, J., Hao, X., Walsh, A., Todorov, T. K., & Saucedo, E. (2019). Emerging inorganic solar cell efficiency Tables (Version 1), *J. Phys.: Energy*, 1, 032001, 1-15. <https://doi.org/10.1088/2515-7655/ab2338>.
 - [44] Gul, M., Kotak, Y. & Muneer, T. (2016). Review on recent trend of solar photovoltaic technology, *Energy Exploration & Exploitation*, 34, 4, 485–526.