Solar Photovoltaic Technology and Its Sustainability

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Abstract The renewable energy sources include the clean green technology, which motivates a healthy environment but also encourages using them in rural areas where grid supply is not available. The fundamentals of solar photovoltaic technologies and their sustainability on the earth are discussed in this chapter. The various internal phenomena that occur in the sun and the solar spectrum are discussed. The various applications of photovoltaics and modeling of the solar cell are also discussed.

Keywords Renewable energy · Solar energy · Photovoltaic

1 Introduction

Fossil fuels are the main sources worldwide for producing efficient electricity for users. However, the continuous use of these sources causes their depletion. Their use for production of electricity and in other applications pollutes the environment, increases emission of carbon dioxide in nature, causes global warming, and many more direct or indirect problems for nature and for living organisms (Shan et al. 2014). An alternative is the use of renewable energy sources, which result in very less emission of carbon dioxide. The main nonconventional sources of energy are solar, wind, and hydro. Solar energy is the best and most attractive energy source due to its less harmful impacts on the environment (Kumari and Babu 2012). Among the renewable energy sources, photovoltaic (PV) energy is widely used in low-power applications. Photovoltaic generators convert solar radiation directly into electricity.

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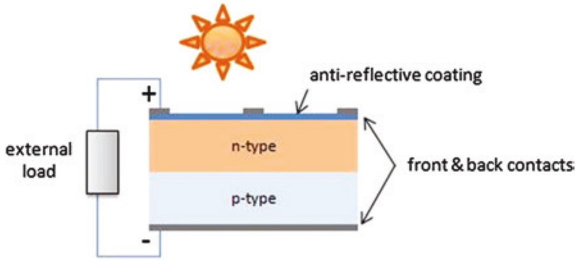

Fig. 1 Photovoltaic cell

Being inexhaustible, pollution-free, silent, and having no rotating parts makes it the best attractive alternative. The photovoltaic effect was first observed in 1839, by a French physicist. This effect was studied in solids such as selenium. The efficiency using selenium was very less, i.e., only 1–2 % (AIA Research Corporation 1976). The French physicist observed that under illumination, a voltage appeared across the two identical electrodes in a weak conducting solution.

In the 1950s, a new development in photovoltaics that occurred was silicon-based photovoltaic cells (AIA Research Corporation 1976). Silicon has been the main choice of material for photovoltaics and will continue to be so in the near future. A P–N junction-based photovoltaic cell circuit is shown in Fig. 1. The share of silicon solar cells and modules is about 90 % of the total PV market.

1.1 The Sun

The survival of animals and plants depends on the energy coming from the sun; the survival of microbes also depends on sunlight. In photovoltaics, sunlight is used for the production of electricity, which has become a basic human need.

The diameter of the sun is around 1,400,000 km. At the core of the sun, millions of tons of hydrogen is converted into helium through nuclear fusion to create the sun's energy; thus, its surface temperature is about 6,000 °C. The mean distance between the earth and the sun is 149,597,890 km. The solar mass is about 332,946 times the mass of the earth (Pavlovic et al. 2006), while the luminosity of the sun is about 3.86 × 1026 W.[1]

1.2 Solar Radiation

The electromagnetic radiation from the sun (i.e., visible light, infrared light, and ultraviolet radiation) spreads out in space in all directions. On earth, only a small fraction of the total radiation is reached. Solar radiation is composed of direct and diffuse radiations. Direct solar radiation, also called beam radiation, directly

[1] http://www.ips.gov.au/Educational/2/1/12.

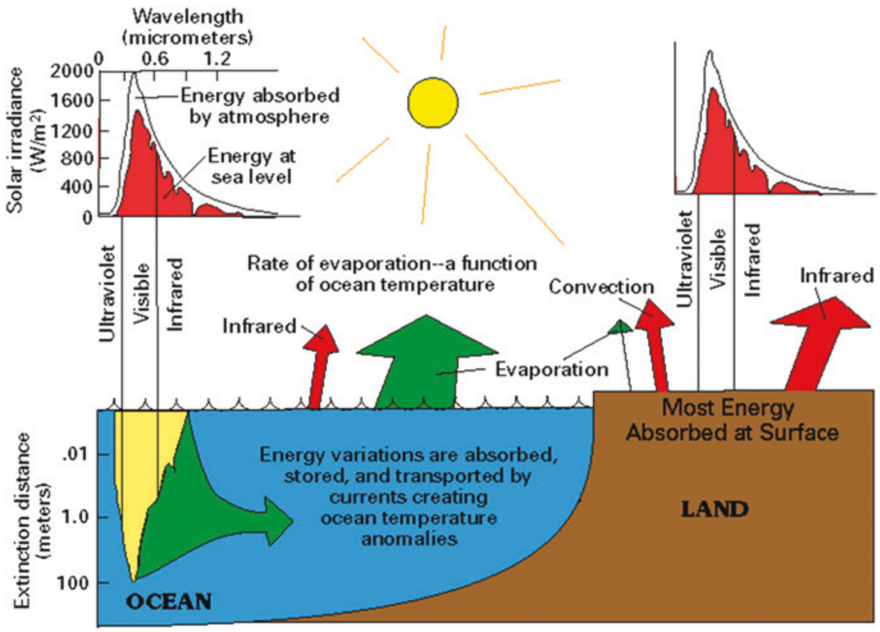

Fig. 2 Penetration of the solar radiation spectrum in water

reaches the surface of the earth. It has a definite direction. By contrast, diffuse solar radiation is scattered by molecules and particles available in the atmosphere before reaching the surface of the earth.

Solar radiations reach the surface of the earth at different proportions due to the varying atmospheric conditions. Some solar radiations coming from the sun are absorbed and reflected back to the environment, while some are scattered by the components of the atmosphere (Fig. 2).

The wavelength of ultraviolet, visible, and infrared solar radiation is 0.20–0.39, 0.39–0.76, and 0.76–100.00 μm, respectively (see Footnote 1). The ultraviolet radiations are absorbed by oxygen and nitrogen available in the atmosphere and converted into heat energy.

The visible light consists of orange, blue, red, yellow, and green as shown in Fig. 3. Visible and infrared solar radiations are emitted in 44 and 49 %, respectively, by the sun. Infrared solar radiation is absorbed by carbon dioxide, water present, and ozone in the atmosphere.

1.3 Advantages of Solar Energy

No Pollution/Clean System: A solar power system is a clean and nonpolluting power plant. During the operation of a solar power plant, no fuel such as carbon is

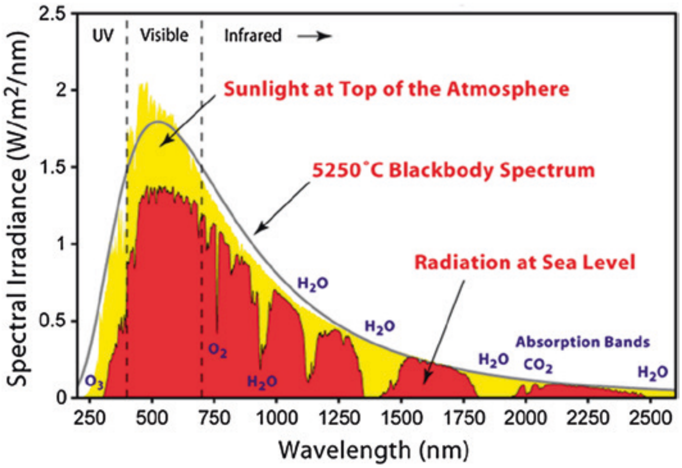

Fig. 3 Spectrum of solar radiation

required, thus there are no emissions of carbon dioxide, sulfur oxide, and nitrogen oxide, which pollute the environment.[2]

Less Maintenance/Noiseless Operation: The solar power system does not have any rotating part; it is a solid-state device, and thus, less maintenance is required.

Renewable Source of Energy: As long as the sun exists, solar energy will also exist. The input of the solar power system comes through the sun, which is a constant source of power and thus cannot be exploited in the future.

Stand-alone System: Solar power systems can be installed on the roofs of buildings or homes for electric supply. It does not require a large land area compared to conventional power plants.

1.4 Disadvantages of Solar Energy

Discontinuous source of energy: The solar energy coming from the sun is not constant, therefore, it cannot be utilized during nighttime. Solar energy also depends on the weather condition; it can be fully utilized in sunny weather, but less on cloudy days.

Costly: The solar energy is harnessed from solar panels, which is very costly.

Large land area: A solar power plant requires a large land area to meet the requirements.

[2] http://www.conserveenergyfuture.com/advantages_SolarEnergyphp#sthash.56FdYsIm.dpuf.

Replacement of batteries: The electricity produced from the solar cell/panel is direct current, which is used to charge the batteries; thus it requires replacement of batteries from time to time.

2 Classification of Solar Energy

Solar energy can be classified depending on its application: first, as a thermal system where thermal energy is utilized to heat the system and second, as a photovoltaic system where solar energy is utilized in the form of electrical energy.

1. **Solar thermal**—conversion of sunlight into heat
2. **Photovoltaic**—sunlight converted into electricity

In this chapter, our focus is on basic photovoltaic technologies and their applications. In a photovoltaic system, solar energy from the sun is utilized to produce electrical energy through solar panels. The solar cells are connected together to form a solar module, and solar modules are joined together to build a solar panel. The solar panels produce direct current. To connect the solar system to grid, DC power is required to be converted into AC power. The inverter is used to convert direct current into alternating current and batteries are required to store DC power for supplying power at night.

3 Semiconductors: Building Blocks of Photovoltaic

Solar photovoltaics is made of a semiconductor material. A semiconductor is not a good conductor of electricity and is a material whose resistivity lies between the conductor and the insulator (i.e., 10^{-4}–0.5 ohmmeter), for e.g., silicon, germanium, selenium. However, the resistance of the semiconductor decreases with increase in temperature, which shows that a semiconductor has a negative temperature coefficient. The valence band of the semiconductor is almost filled by electrons; whereas the conduction band is nearly empty. The forbidden energy gap is very less, about 1 eV, therefore, a small amount of energy is required for valence electrons to move toward conduction band.

3.1 Classification of Semiconductors

Semiconductors can be classified as: (1) intrinsic (pure semiconductor) and (2) extrinsic (impure semiconductor)

(a) **Intrinsic semiconductor**:

Intrinsic semiconductor can also be known as a pure semiconductor. At room temperature, electron–hole pairs are created. When a potential is applied across it,

Table 1 Difference between intrinsic and extrinsic semiconductor

Factors	Intrinsic semiconductor	Extrinsic semiconductor
Purity of semiconductor	Pure semiconductor	Impure semiconductor
Density of electrons	Density of electrons is equal to the density of holes	Density of electrons is not equal to the density of holes
Electrical conductivity	Electrical conductivity is low	Electrical conductivity is high
Temperature effect	Dependence on temperature only	Dependence on temperature as well as on the amount of impurity only
Impurities	No impurities	Trivalent impurity, pentavalent impurity

conduction commences through free electrons and holes caused due to the breaking of covalent bonds through thermal energy. Therefore, the current flow in the intrinsic semiconductor is a combination of electron and hole.

(b) **Extrinsic semiconductor**:

At room temperature, the intrinsic semiconductor has very less conduction. Therefore, for improving the conductivity of the intrinsic semiconductor, a small amount of impurity is added. This semiconductor is now called an extrinsic semiconductor. The process of the addition of impurities to the intrinsic semiconductor is called doping. In this process, either the number of electrons increases or the number of holes increases depending on the type of impurity added. Two types of impurities are added: (1) pentavalent and (2) trivalent. Addition of pentavalent impurity produces free electrons, while in case of trivalent impurity, additional holes are generated. Further differences between intrinsic and extrinsic semiconductor are given in Table 1.

3.2 Types of Extrinsic Semiconductors

- **P-type semiconductor**:

P-type semiconductor is formed by the addition of a small quantity of trivalent-type impurity to an intrinsic semiconductor. The trivalent impurities result in additional holes, which accept the electrons in the semiconductor; therefore, these impurities are also called acceptor impurities (Fig. 4).

- **N-type semiconductor**:

N-type semiconductor is formed by the addition of a small quantity of pentavalent type impurity to an intrinsic semiconductor. The addition of pentavalent impurities in pure semiconductor causes additional electrons in the semiconductor. The pentavalent impurities are also known as donor impurities as they donate free electrons to the semiconductor (Fig. 5).

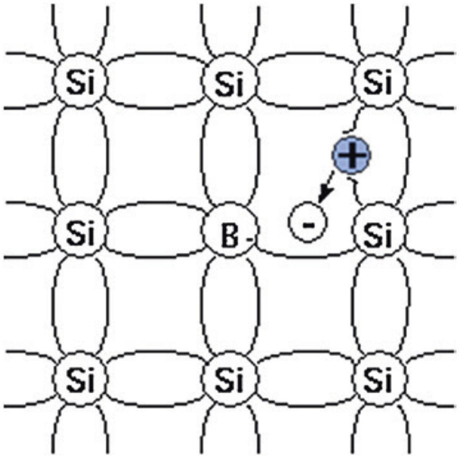

Fig. 4 Structure of p-type semiconductor

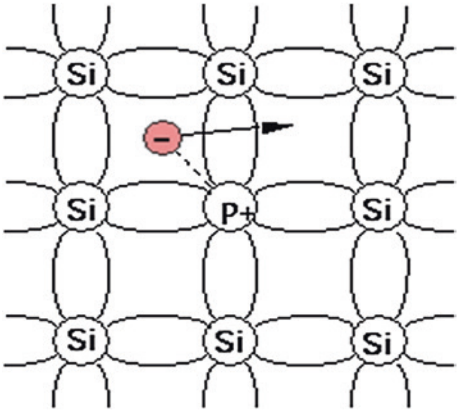

Fig. 5 Structure of n-type semiconductor

3.3 Formation of Photovoltaics

To develop a photovoltaic cell, two kinds of semiconductors are sandwiched together. When p-type and n-type semiconductors are joined together, they form a p–n junction or a solar cell. The p–n junction is the control element for a solar cell; thus, electrons will only flow in one direction but not in the other. In forward biased direction, current flows from p to n semiconductor or behaves like a short circuit, while in reverse direction, current does not flow and thus behaves like an open circuit. Structure of p–n photovoltaic cell is shown in Fig. 6. When the photovoltaic cell is exposed to sunlight, it reduces the width of the deletion layer and the current flows into the connected electrical load.

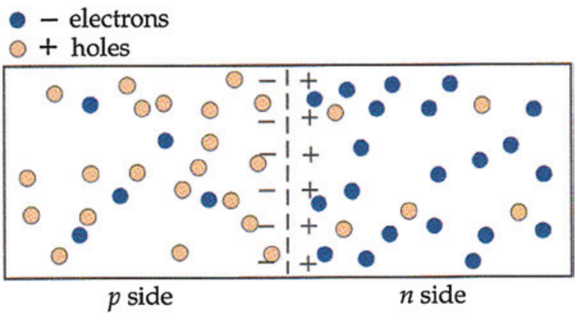

Fig. 6 Structure of photovoltaic

3.4 Working Principle of Photovoltaic Cell

When sunlight strikes on the solar panels, it absorbs photons that produce electrons and holes in the semiconductor material, and thus, electric current flows (Messenger and Ventre 2000). The constructional view of a photovoltaic system is shown in Fig. 7. The efficiency of the panel depends on the amount of solar energy absorbed by the semiconductor material. When light falls on the cell, photons are absorbed by the panel and the semiconductor generates electron–hole pairs. Then the electron–hole pairs are separated in the semiconductor. The electrons move toward negative terminal, while the holes move toward positive terminals. Thus, electrical energy is generated.

A photovoltaic cell behaves like an ordinary p–n junction under no illumination. When it is forward biased the excess electrons are moved from p to n semiconductor.

3.5 Modeling of Photovoltaic Cell

A single diode model of solar cell consists of a current source which represents a light-generated current in parallel with a diode. The photon current is directly

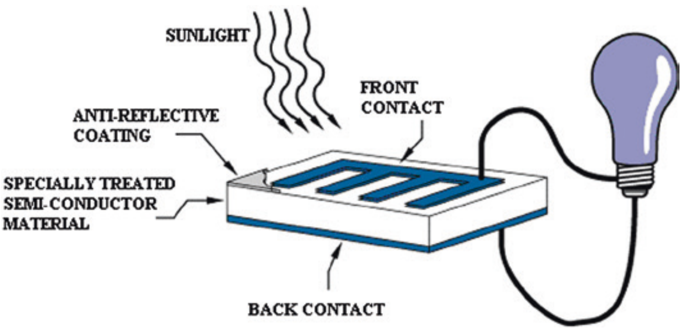

Fig. 7 Constructional view of photovoltaic system

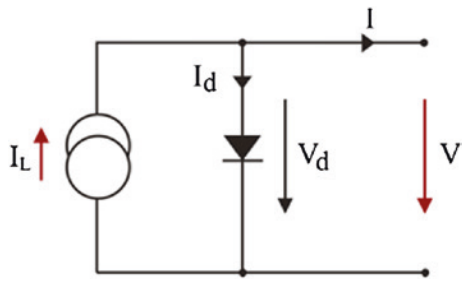

Fig. 8 Single diode model of photovoltaic

proportional to the solar radiations. When the light is not illuminated, a dark current is flown into the circuit similar to the diode (Fig. 8).

The typical equation for single diode model of solar photovoltaic is as follows (Bonkoungou et al. 2013):

$$I = I_L - I_R \left[e^{\{qV/mkT\}} - 1 \right] \tag{1}$$

where

I is the cell output current,
I_L is the light-generated current or photocurrent,
I_R is the reverse bias saturation current of diode,
Q is the electron charge,
V is the terminal voltage,
M is the diode ideality factor, and
T is the cell temperature.

A photovoltaic cell can also be characterized in terms of the short-circuit current, I_{SC}, and the open-circuit voltage, V_{OC}. At the constant junction temperature, when the terminal of solar cell is short-circuited, the short-circuit current Isc is given as follows:

For $V = 0$,

$$I_{SC} = I = I_L \tag{2}$$

At the constant junction temperature, when the terminal of solar cell is open-circuited, the open-circuit voltage Voc is given as follows:

For $I = 0$,

$$V = V_{oc} \tag{3}$$

Thus, the cell output voltage is given as

$$P = V\,[I_{sc} - I_R e^{\{qV/mkT\}} - 1] \tag{4}$$

Following are the basic terms related to modeling of the solar cell.

(a) **Short-circuit current (I_{SC})**:

Short-circuit current is calculated at short-circuiting terminals of the solar cell. It increases slightly with increasing temperature and is directly proportional to the incident optical power. Under the short-circuit condition of the solar cell, the voltage across the terminal is zero and the impedance offered is very low. The short-circuit current can be expressed by the following equation (Zhou et al. 2007):

$$I_{SC} = I + I_O\{\exp(V/V_T) - 1 \tag{5}$$

(b) **Open-circuit voltage (V_{OC})**:

The open-circuit voltage is expressed at the open terminals of the solar cell. It decreases with increases in temperature. The open-circuit voltage is logarithmically dependent on the solar irradiance. The open-circuit voltage can be expressed by the following equation (Zhou et al. 2007):

$$V_{OC} = V_T In\ \{(I_{sc}/I_O)\ + 1\} \tag{6}$$

(c) **Fill factor (FF)**:

The fill factor is defined as the ratio of the product of maximum value of voltage and current (i.e., actual power) to the product of open-circuit voltage and the short-circuit current (i.e., dummy power). It is a figure of merit for the solar cell performance (Zhou et al. 2007; Bowden and Rohatgi 2001).

$$\mathrm{FF} = V_m I_m / V_{oc} I_{sc} \tag{7}$$

(d) **Maximum output power (P_{max})**:

The maximum power may be defined as the power that can be delivered by the modules/array to the load. It can be utilized to evaluate the performance of a PV system. It is a function of the fill factor, open-circuit voltage, and short-circuit current.

(e) **Efficiency (η)**:

It is the ratio of electrical power that the solar cell delivers to the load to the optical power incident on it. Incident optical power is normally specified as the solar power on the surface of the earth, which is 1 mW/mm^2. The efficiency can be expressed by the following equation (Zhou et al. 2007; Bowden and Rohatgi 2001):

$$\eta = \mathrm{FF} V_{oc} I_{sc} / \text{solar power} \tag{8}$$

where

I_{sc} is the short-circuit current,
V_{oc} is the open-circuit voltage,
V_m is the maximum value of voltage,
I_m is the maximum value of current, and
V_T is the terminal voltage

4 Generations of Photovoltaic

4.1 First Generation

First generation solar cells refer to single-junction devices with large surface area, good quality, highly efficient, and high cost. These cells are usually fabricated using a silicon wafer. Structural view of crystalline solar cell is shown in Fig. 9. This generation of solar cell consists of monocrystalline and polycrystalline silicon solar cells. The monocrystalline silicon solar cell is the oldest solar cell technology. It is drawn from the Czochralski (CZ) method. A silicon ingot is made from a molten vat. Then, it is sliced into a number of ingots forming the substrate of the solar cell. The monocrystalline panels have shown the highest laboratory efficiency at about 24 % (Pavlovic et al. 2011). The main drawback of the monocrystalline solar cell is its high cost due to the expensive fabrication process. Another drawback is its decrease in efficiency as temperature decreases to about 25 °C. Proper maintenance is required for installing the panel such that air circulation is provided over the panel. Polycrystalline silicon solar cells are cheaper than monocrystalline solar cells, but suffer from less efficiency due to nonuniform lattices. Instead of a single large ingot, it has a number of ingots drawn from molten vat. The polycrystalline silicon solar cell has shown efficiency of only 12–14 %

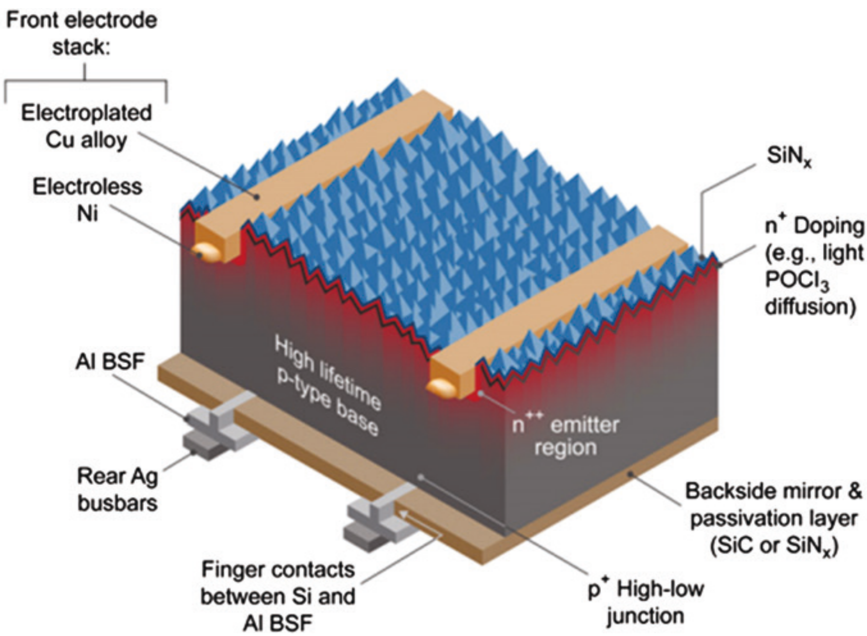

Fig. 9 Structural view of crystalline solar cell

(Pavlovic et al. 2011). The first generation solar cell is more attractive due to its high efficiency. However, they are very uneconomical.

4.2 Second Generation

The second generation includes thin-film solar cell. A structural view of thin-film solar cell is shown in Fig. 10. They are more economical than silicon crystalline solar cell, but lack efficiency. The development of dye-sensitized solar cells (DSSCs) belongs to the third generation in the era of solar cells, reflecting low-cost and high-efficiency features. However, the efficiency of DSSC is not greater than crystalline solar cell, but much greater than thin-film solar cell. These have more attractive features due to their environmental friendliness.

In a thin-film PV cell, a thin layer of semiconductor PV materials is deposited on glass, metal, or plastic foil. Due to their non-single-crystal structure, thin films suffer from poor efficiency and also require larger array areas, and thus, area-related costs such as mountings also increase. Cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and amorphous silicon (a-Si) are examples of thin-film technologies used as outdoor applications for photovoltaic solar power production.

A CdTe solar cell is fabricated by using a thin film of CdTe. This semiconductor layer absorbs photons and converts it into electricity. The main advantages of CdTe thin-film solar cells include low fabrication cost and increasing efficiency (Pavlovic et al. 2011). The CdTe material has a high optical absorption coefficient for visible portion of the thin film of CuInSe2 (CIS)-based photovoltaic (PV) modules and comprises low-cost substrates. CIS solar cell technology has high absorption coefficient of the solar cell absorber layer. Gallium arsenide-based thin-film solar cells have been manufactured and investigated to determine their suitability for future solar power systems. The vapor of gallium arsenide is deposited onto substrates of aluminum foil. Gallium arsenide (GaAs) is a compound of the

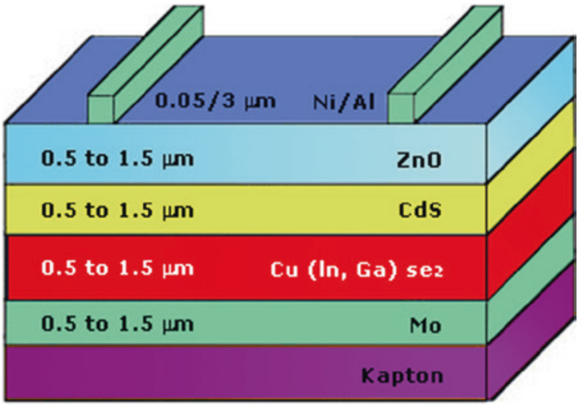

Fig. 10 Structural view of thin-film solar cell

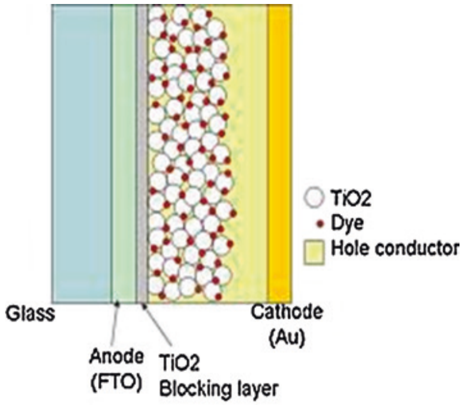

Fig. 11 Structural view of dye solar cell

elements gallium and arsenic. It can be used for manufacturing infrared light-emitting diodes, solar cells, etc. Recently, the efficiency of GaAs has been registered as 28.8 % (Pavlovic et al. 2011). A demerit of CdTe is that cadmium is a deadly poison, and hence not very eco-friendly.

4.3 *Third Generation*

The third generation refers to organic/dye-sensitized solar cell; structural view of a dye solar cell can be seen in Fig. 11. A DSSC consists of a titanium dioxide photo-anode electrode, a counter electrode as a cathode, an absorbed dye, and an electrolyte. Dye-sensitized solar cell (DSSC) is a semiconductor photovoltaic device that converts solar radiation from the sun into electric current. The natural dye sensitizer is excited when the DSSC is exposed to sunlight, and thus causes the formation of electrons from the titanium dioxide photoanode. Then, the electrons move to the counter cathode through the electrolyte and complete the circuit. Conducting glass is used as a substrate for improving the electrical conductivity of the DSSC. Mainly, indium-doped tin oxide and fluorine-doped tin oxide are used as substrates. The most attractive features of DSSC include low cost, simple fabrication, and low density. These can be employed for rooftop solar applications being lightweight.

5 Types of PV Cell Materials

PV cells are made of semiconductor materials. The major types of materials are crystalline and thin film, which vary from each other in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology, and cost of production.

5.1 Single-Crystal Silicon Solar Cell

Single-crystal silicon cells are the oldest in the field of solar cells. The crystalline solar cell is fabricated from the CZ method (Li et al. 1992). In this method, high-purity silicon is melted in a crucible. Some doping is added to improve the conductivity of the semiconductor. Generally, boron or phosphorous is used as a dopant. A seed crystal is dipped into the molten silicon and pulled upward and rotates continuously. After some time, single silicon ingot is formed from the melting silicon. Single-crystal silicon has a uniform molecular structure.

The silicon crystal panels are more suitable for outdoor applications. The higher penetration of sunlight into the solar cell results in high efficiency. The conversion efficiency of single-crystalline solar module is about 15–20 % (Li et al. 1992). However, the fabrication of single solar cell is a time-consuming process, complex, and expensive. The performance of monocrystalline solar cells is most affected as the temperature increases. However, the life span of these solar cells is large compared to other solar cells.

5.2 Gallium Arsenide Solar Cell

GaAs is formed by a mixture of gallium and arsenic that possess characteristics similar to silicon (Fig. 12). The conversion efficiency of GaAs is greater than that of crystalline silicon solar cells; also, GaAs solar cells are thinner but more expensive than crystalline solar cell. The GaAs solar cell accounts about 30 % efficiency (Aleksic et al. 2002; Yablonovitch et al. 2012). An advantage of GaAs is that it has high light absorption of sunlight. GaAs solar cells are more suitable for solar collector systems because they offer high resistance to temperature (AbuShama et al. 2004; Kim et al. 2007).

However, they are uneconomical because GaAs is grown onto a single-crystal substrate and thus is more applicable for concentrator-type systems. As the efficiency of these solar cells is high, they can be beneficial for space applications.

5.3 Thin-Film Solar Cell

Multiple thin-film layers of semiconductor materials are deposited on a substrate, i.e., glass, plastic foil, or metal to form thin-film solar cells. The thickness of the film is very less or less than a micrometer compared to traditional solar cells. This results in more lightweight and flexible solar cells. However, the efficiency of thin-film solar cells is very less compared to crystalline solar cell.

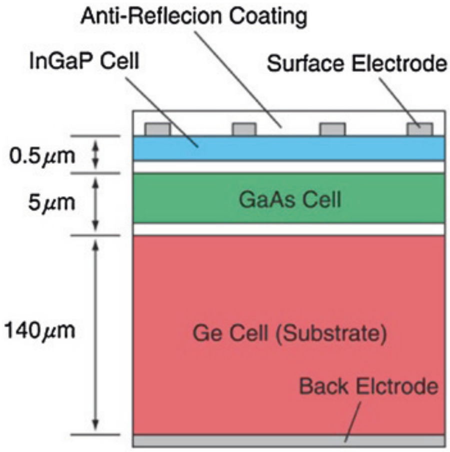

Fig. 12 Gallium arsenide solar cell

Advantages:

- High radiation tolerance;
- Flexible appearance makes it attractive for applications;
- Mass production of solar cells makes them cheaper than other solar cells.

Disadvantages:

- Poor efficiency;
- Large space area is required, which increases additional cost of mountings;
- Degrade faster than crystalline solar cells;
- Special handling is required.

Applications:

- Electronic powering circuits;
- Domestic lighting applications;
- In solar fields.

5.4 Amorphous Silicon Solar Cell

An a-Si solar cell is fabricated by using a noncrystalline form of silicon, i.e., a-Si solar cell. These can be used in small-scale applications as the thickness is about 1 μm, which is very less as compared to monocrystalline solar cell. A noncrystalline form of silicon has higher light absorptive capacity than single silicon crystalline structure, since the thin-film structure makes it more flexible and of less weight.

Disadvantages:

- Less efficiency, i.e., 5–9 % only
- Degrades fast

5.5 Cadmium Telluride Solar Cell (CdTe)

A CdTe solar cell is a compound made of cadmium and tellurium. CdTe solar cells are grown in substrate. Polyimide, metal foils, and glass are commonly used as the substrates. Their high efficiency, low cost, stability, and potential for low-cost production make them suitable for large-area applications. The CdTe solar cell has high absorption coefficience and has shown laboratory efficiency as high as 16.5 % (Lynn 2010; Fthenakis 2004). The commercial module efficiency is the same as an a-Si solar cell, i.e., 7–9 % (Tiwari and Agrawal 2011).

Advantages:

- High absorptive capacity.
- Economical manufacturing process.

Disadvantages:

- Toxicity: Cadmium is a toxic heavy element. It is the waste product of zinc refining.
- Less efficiency: Currently achieved efficiency of CdTe solar panels is 10.6 %, which is lower than the typical efficiencies of crystalline silicon solar cells.
- Abundance: The telluride has its limited natural reserves.

5.6 Organic Solar Cells

The main obstacles in front of inorganic solar cells are high material and manufacturing cost. Organic solar cells are light-weight, low-cost, and can be employed for energy generators for large areas. The organic materials have high optical absorption coefficients. The organic solar cells are made in thin film structure which offers a light weighted and flexible solar cell. These are made from organic semiconductors i.e polyphenylene vinylene, copper phthalocyanine and carbon fullerenes. However, the conversion efficiency of organic solar cells is less as compared to crystalline solar. The highest reported efficiency is about 11% (Su et al. 2012).

6 Photovoltaic Applications

6.1 Hybrid Solar Power System

Solar energy cannot be harnessed during night hours due to unavailability of sun radiations. Therefore, there is a need for a hybrid solar system, which consists of two or more power generation systems. A solar power system can be connected to a turbine to fulfill the electricity requirement during night hours. More than

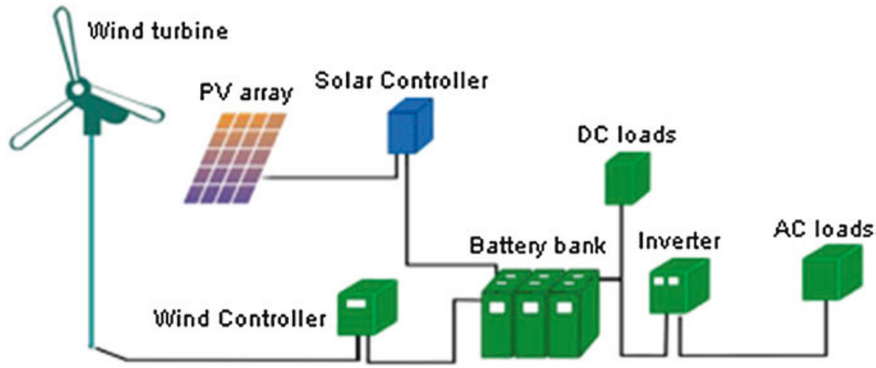

Fig. 13 Hybrid solar power system

one renewable energy source can be used, such as a wind power plant, which can be connected to the solar power plant and a turbine with a battery for backup. A hybrid solar power system is shown in Fig. 13. Direct current generated through a solar power plant is converted into alternating current using an inverter. The inverter feeds electrical energy to the house. Wind generators generate alternating current and so do not require any conversion terminal. A battery is used to meet secondary requirements.

6.2 Solar Lighting System

Suresh et al. developed a solar lighting system. They found variations in the theoretical and practical values used in the construction of the circuit in the laboratory. due to tolerances of the components and the intensity of sunlight (Suresh et al. 2011). Electrical circuit of solar lighting system is given in Fig. 14.

The conventional applications of lighting, heating, and pumping cause global warming and deplete these sources from the earth. On the other hand, the implementation of solar lighting systems reduces air pollution and as they are renewable sources, they cannot deplete.

6.3 Solar Lantern

In remote and rural areas, people use oil lamps which are expensive, unhealthy, not sufficient source, and dangerous, cause environmental problems, and produce greenhouse gases. Another alternative for oil lamps is the solar lantern. A solar lantern consists of a solar panel situated on the rooftop and a battery and a lamp as

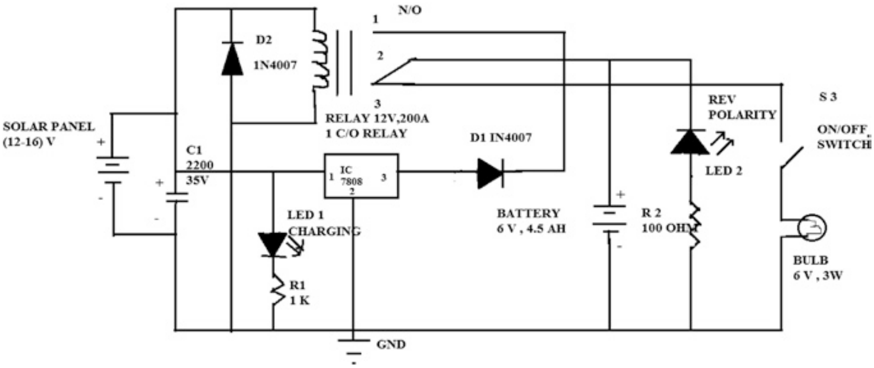

Fig. 14 Solar lighting system

load (Fig. 15). The solar lantern is the most beneficial device for the poor . During the day, it can be charged and thus provide light at night. It is a portable device and hence is easy to carry anywhere.

6.4 Organic Light-emitting Diode (OLED)

Zmija et al. performed various experiments to observe the performance of organic light devices. They also observed the basic difference between organic and inorganic devices. An organic LED is a monolithic, thin-film solid-state device that emits light after energizing (Fig. 16). Low power consumption, lightweight, high brightness, and high emission efficiency are the merits of organic LEDs. Being lightweight makes it a portable device (Mija and Maachowski 2009).

Fig. 15 Solar lantern

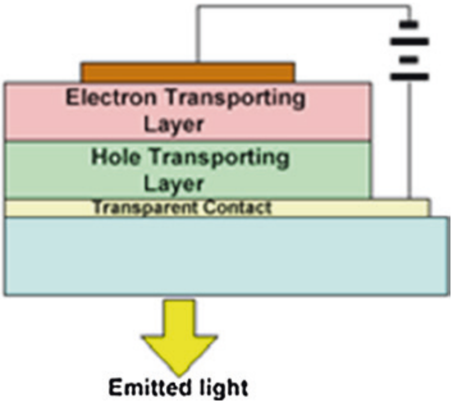

Fig. 16 Organic light-emitting diode

The cell structure of the OLED consists of a thin film of organic material sandwiched between two anode and cathode electrodes. One of the electrodes is required to be transparent to allow light into the thin layer of organic material and application in displays (Mija and Maachowski 2009).

Applications of OLED:

a. Digital versatile disk players;
b. Cellular phones;
c. Televisions;
d. Notebooks, etc.

Obstacles:

a. Limited lifetime: The lifetime of OLED is limited due to degradation of organic materials. Some displays are sensitive to moisture, resulting in limited life span.
b. Degradation of blue light: Organic materials degrade more rapidly than inorganic materials, resulting in poor performance of OLED, especially, the blue light output decreases more than the others.
c. Water impacts on OLED: Organic materials used for making OLED may be damaged in the presence of the water, especially in the rainy season.

7 Solar Power Projects

The burning of fossil fuel through conventional power plants pollutes the environment, causing global warming. Electricity produced by nonconventional sources such as solar, wind, and biomass causes no carbon emission and thus no global warming, resulting in less environmental problems. In India, nonconventional power plants accounted for about 31.15 GW of capacity as on January 31, 2014

(Power Generation from Various Renewable Energy Sources 2014; Ministry of New and Renewable Energy 2014).

The major contribution in the enhancement of solar energy is from Gujarat and Rajasthan. Gujarat accounts 858 MW capacity of solar energy, while Rajasthan contributes about 553 MW. Maharashtra and Madhya Pradesh account for 100 and 37 MW, respectively, of the total installed capacity of solar energy. A small contribution of 23 MW is by Andhra Pradesh. The capacity of solar power projects in various states of India is given in Fig. 17.

8 Comparison of Power Plants in India

The comparison of thermal, hydro, nuclear, and nonconventional power plants with regard to carbon emission, total installed capacity, and requirement of fuel is shown below. Carbon emission while using nonconventional sources is zero, while there is heavy carbon emission through thermal power plants. The primary source for nonconventional power plants is sun, water, wind, and biomass which cannot degrade in the future. Thus, renewable power plants are more beneficial for the safe environment and human healths. A comparison of the power plants in India is given in Table 2.

9 Sustainability of Photovoltaics

Vokas et al. designed a hybrid photovoltaic–thermal collector that can be used for heating and cooling applications for domestic purposes. It has thermal efficiency of about 9 %. However, the efficiency of photovoltaic–thermal collector is lower than the conventional solar collector.

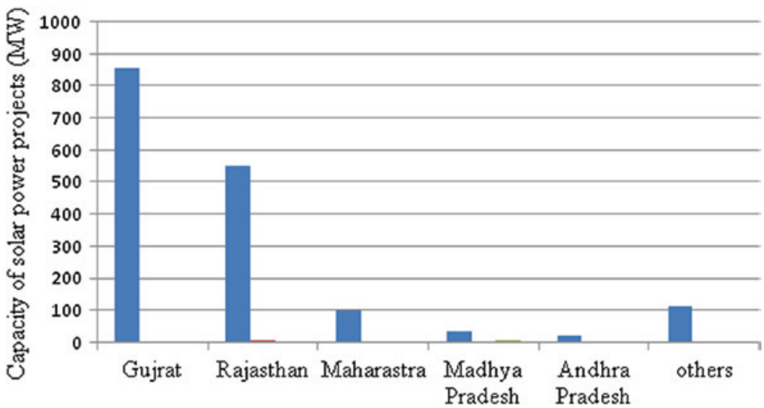

Fig. 17 Solar power projects in India

Table 2 Comparison of power plants in India (Ministry of New and Renewable Energy 2014)

Sources	CO_2 emission	Required fuel/primary source	Total installed capacity in India (in MW)
Thermal	164.39 kt CO_2	Coal/lignite	148,478
Hydro	0.0	Water	40,730
Nuclear	0.0	Uranium, thorium	4780
Non-conventional sources	0.0	Sun radiations, wind, biomass	31,692

The authors compared solar thermal energy produced through the photovoltaic–thermal system and conventional solar system for domestic heating and cooling loads and concluded that there is a difference 6.65 % between the two systems, and thus, the photovoltaic thermal system is more efficient and is a convenient choice (Vokas et al. 2006). Results of a survey of photovoltaic–thermal system in domestic heating and cooling loads in the region of Athens is given in Table 3.

Assoa and Menezo developed a solar photovoltaic/thermal (PV/T) hybrid air collector designed for natural ventilation. Electrical efficiency can be improved by heat extraction for cooling of PV modules. They designed a dynamic two-dimensional mathematical model of solar PV/T hybrid air collector to determine the impact of air gap ventilation on the preheated air thermal production and electrical production. They concluded that for cooling of integrated PV modules, natural ventilation is adequate (Assoa and Menezo 2014).

An-Seop Choi et al. proposed an integrated PV blind system with a daylight responsive dimming system. This integrated system produces and stores electrical lighting energy simultaneously. In buildings' photovoltaic system, very little research has been done in the field of integration with other energy saving systems. Electrical lighting through LED also increases the dimming efficiency. In the reference room, the power generation was about 68 % compared to those in the test room, while in the test room, the electrical lighting energy savings was about 65 % compared to those in the reference room. LED lighting resulted in greater dimming efficiency compared to conventional fluorescent lighting (Kim et al. 2014).

Mahapatra et al. compared CO_2 emissions via kerosene-based lamps with modern bioenergy systems and solar photovoltaics (Table 4). To determine CO_2 emissions, fuel consumption rates are required. In rural areas, compared to kerosene-based

Table 3 The average study of photovoltaic–thermal system in domestic heating and cooling loads in the region of Athens (Vokas et al. 2006)

Domestic load	Photovoltaic–thermal system (%)	Conventional solar system (%)
Domestic heating (for surface area, 30 m^2)	47.79	54.26
Domestic cooling (for surface area, 30 m^2)	25.03	31.87

Table 4 CO_2 emissions from different lighting systems (Mahapatra et al. 2009)

Type of system	Fuel consumption	Luminous flux (lumen)	Gross CO_2 emission	Net CO_2 emission
Kerosene wick lamp	21.6 (ml/h)	76	0.055a (kg/h)	0.055 (kg/h)
Noorie	50 (ml/h)	1250	0.128 (kg/h)	0.128 (kg/h)
Petromax	80 (ml/h)	1300	0.205 (kg/h)	0.205 (kg/h)
Biogas mantle lighting systems	0.125 m^3/h	600	0.246 (kg/h)	Nil
Biogas-based electricity	1 m^3 biogas and 80 ml diesel/kWh	81,900	2.185 (kg/kWh)	0.00537 (kg/kWh)
Biomass gasifier	1.4 kg wood/kWh	81,900	2.684 (kg/kWh)	0.00537 (kg/kWh)

lighting, solar photovoltaic and modern bioenergy systems are of great significance, providing reliable lighting with reduced CO_2 emissions. (Mahapatra et al. 2009).

Kumar and Rosen studied integrated photovoltaic–thermal solar collectors. The efficiency of an integrated system is greater compared to individual solar systems. Moreover, it encourages the utilization of solar energy and increases the useful energy per unit collector area. The overall efficiency of a solar photovoltaic thermal collector is higher than the addition of the efficiencies of individual solar photovoltaic and solar thermal systems. This combined system is more applicable for space heating and drying applications (Kumar and Rosen 2011).

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