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REVIEW PAPER

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# A review on PV cells and nanocomposite-coated PV systems

K. Rakesh Tej Kumar[1] | M. Ramakrishna[1] | G. Durga Sukumar[2]

[1] Department of Mechanical Engineering, Vignan's Foundation for Science, Technology and Research VADLAMUDI, Guntur District, Andhra Pradesh 522213, India

[2] Vignan Institute of Technology and Science, Deshmukhi, Yadadri Bhuvanagiri District, Telangana 508284, India

**Correspondence**
M. Ramakrishna, Department of Mechanical Engineering, Vignan's Foundation for Science, Technology and Research VADLAMUDI, Guntur District, Andhra Pradesh 522213, India.
Email: drmramakrishnaa@gmail.com

G. Durga Sukumar, Vignan Institute of Technology and Science, Deshmukhi, Yadadri Bhuvanagiri District, Telangana 508284, India.
Email: durgasukumar@gmail.com

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**Summary**

Solar radiation can be converted into electrical energy and generate electric power that can be utilized in multiple ways. The technological improvements have provided enormous solutions to the mankind for utilizing the solar energy although photovoltaic's (PV) by consuming sunlight. Photovoltaic is popularly known by the process of converting light to electricity. The current estimated growth by producing global power around 368 GW in 2017 and projecting 3000 to 10 000 GW by 2030. Looking at all the available solar cells, it has been observed that the dye-sensitized solar cell (DSSC) when compared to mono-Si or poly-Si has been effective in its performance and also reduces production cost to a great extent. The power conversion efficiency (PCE) of DSSC has reached to a better extent and been discussed in the paper. There are other mechanisms through which the efficiency can be improved like applying the antireflection coating. Reflection is a usual phenomenon that happens when light incident from one medium to another varies in refractive index. This reflection is one of the important reasons for the loss of power in the PV Cell. So to improve the PCE, the Mono-Si or DSSC PV Cells can be applied with a thin film antireflection coating by the nanocomposite film consisting of single- or multi-wall carbon nanotubes with $TiO_2$ and other efficient nanoparticles. This paper discusses on different kinds of nanocomposite materials, and their functionalities has been clearly given. Remarkable improvements have been recorded in the last 1 year by applying the antireflection coating; the PCE has further been increased enormously when compared to the uncoated solar cell for both DSSC and Mono-Si PV cells.

**KEYWORDS**

amorphous silicon, crystalline silicon, DSSC, hetero junction solar cells, hybrid solar cells, mono-Si, multijunction solar cell, MWCNT, polyaniline, poly-Si, $SiO_2$, CIGS, SWCNT, $TiO_2$

## 1 | INTRODUCTION

Literature review has been conducted for almost 6 decades to understand the evolution of the techniques in utilization of solar energy and its efficient ways of converting light energy to electrical energy through photovoltaic (PV) solar cells. The kind of investigation brought a great assessment on different kinds of PV Cells available and how they have been effectively used in terms of their strengths. In this journey of exploration of detailed analysis, it was known that there are lots of limitations for most of the PV cells and finally understood the most efficient PV cells by considering lot of parameters.[1-4]

Based on the observations and the real-time statistics, most of the popular energy services industries are looking at the PV technology for generating additional power to serve their customers.[5-7] The PV technology has created a revolution based on the material used for its manufacturing; as we all know, PV cells silicon is the second most abundant material available in the earth's crust.

Light energy gets converted to electrical energy when sunlight hits the surface of PV cell where the semiconductor material creates the electricity with the principle of creating the potential energy difference between the photon and electron. Solar cell is the smallest unit of the PV system and where these cells connect together to form a module and module together form a panel. These panels group together to form an array and several arrays together form an array field. Usually in India, the setups of panels are placed on the roof or installation area by getting exposed to direct sunlight with a facing angle towards south, and it differs from one country to other. Solar trackers can also be used to efficiently move along the perpendicular direction of the sunlight so as to gain more photo conversion efficiency. As solar PV systems can go from small-scale application to a large-scale application with panels connecting to one another and creating a system called solar array.[8]

A lot of research going in the area of solar energy systems; this paper reports the solar cell evolution and which type of solar cells are more effective and efficient in terms of power conversion efficiency, production cost, and easy availability in the market. In addition to the type of panel, the investigation is done on how to improvise the performance of photo conversion efficiency by applying an antireflection coating with nanocomposite materials on top of the PV panel. This paper also provides what are the current trends going in the nanocomposite materials and what would be the best combinations in improving the efficiency of panel.

The solar cells are usually flat plate and proved to be more efficient in terms of efficiency like monocrystalline and polycrystalline solar cells. Eventually, based on the research developments, the thin film solar cells are evolved as second generation solar cells, which are prepared by cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and amorphous silicon (A-Si) by doping onto a substrate. After the continuous development in improving the type of solar cells, the third generation solar cells are identified, which are prepared by the new materials other than silicon like printable solar panels with solar inks, solar dyes, and conductive plastics etc.[9-15] Solar collectors are one of the ways to improve the efficiency of the solar panels, but this is definitely a costly process and lot of maintenance is required in cleaning the reflecting surfaces like mirrors or lenses to keep them away from dust.

Based on the technological advancements, the research is continuously improving the PCE by applying the microlayer and nanolayer thin film coating on the PV panels. Rather than the micro, the nanocomposite materials are showing promising improvement in PCE, and the efficiency of PV cells can be greatly improved by applying the coating on mono-Si PV panel with CNT–$TiO_2$–$SiO_2$, which has shown a considerable improvement in conversion efficiency of solar cells by 31.25% when compared to uncoated cells. Keeping the above discussion in mind, let us see how the evolution happened.

Today, silicon wafer-based photovoltaic is the first generation PV cells, which is the prevailed technology for worldwide applications. Mono-Si-crystalline and poly-Si-crystalline wafers, used in commercial production, allow PCE up to 27% for mono-Si and 18% for poly-Si, although the fabrication technologies at present limit them to about 15%. The second generation of PV materials are based on the use of thin-film deposits of semiconductors, such as noncrystalline forms of silicon, ie, amorphous silicon (a-Si), CdTe, copper indium gallium di-selenide (CIGS), or copper indium sulfide (CIS). The thin film solar cells seem to be least efficient with a maximum efficiency of 12% when compared to conventional solar cells; manufacturing cost is also lower, so that a price in terms of $/watt of electrical output can be reduced. The panels are manufactured with light weight, which can decrease the mass. This allows to fit the panels on light materials or flexible materials or even on textiles. The third generation of photovoltaic cells uses organic materials such as small molecules or polymers. Thus, polymer solar cells are a subcategory of organic solar cells. The third generation also covers expensive high-performance experimental Hetero-junction solar cells, which hold the world record in solar cell performance. These cells are high in its production cost and cannot be used for commercial purpose. The approaches include dye-sensitized nanocrystalline or Gratzel solar cells, organic polymer-based photovoltaic, tandem solar cells, hot carrier solar cells, multiband and thermo-photovoltaic solar cells. Even though the third generation solar cells are evolved, the performance and stability of the third generation solar cells are still limited compared to the first and second generation solar cells; they have great potential and are already commercialized. There are new kind of solar cells called quantum dot solar cells (QDSCs) that are prepared of silicon semiconductor and coated with a thin film of quantum dots. These QDs are sized in few nanometers in its diameter. Quantum dots can be mixed with solutions and can be applied on the film using spin coating technique. Solar power's popularity continues to grow every year, and along with that popularity, the number of solar technologies has also grown.

In Figures 1 and 2, it shows how the world is rapidly growing in utilizing renewable energy resources like solar energy. In this process, the installed capacity of PV cells

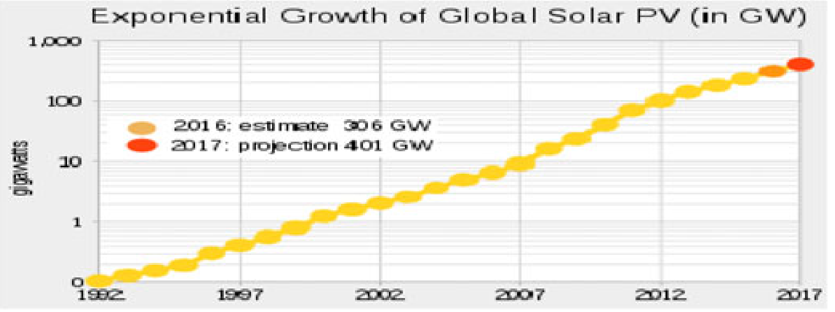


**FIGURE 1** Worldwide growth of photovoltaics on a semilog plot since 1992.[8] By the end of 2020, the PV Installed capacity has been enormously increased[16-20] [Colour figure can be viewed at wileyonlinelibrary.com]

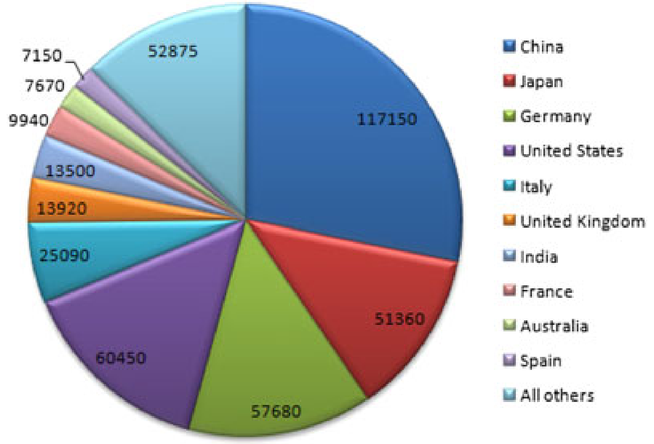


**FIGURE 2** Top 10 countries in PV installed capacity till the end of 2020, all Units in MW [Colour figure can be viewed at wileyonlinelibrary.com]

has enormously increased exponentially from 100 MW in 1992 to 368 GW in 2017. As shown in Table 1, it clearly explains the use percentage of top 10 countries with their PV installed capacity.

**TABLE 1** Use percentages of top 10 countries in PV installed capacity till the end of 2020

| Country | % of Projected PV Installed Capacity |
|---|---|
| China | 29.73 |
| Japan | 13.03 |
| Germany | 14.64 |
| United States | 15.34 |
| Italy | 6.37 |
| United Kingdom | 3.53 |
| India | 3.43 |
| France | 2.52 |
| Australia | 1.95 |
| Spain | 1.81 |
| All others | 13.42 |

## 2 | CATEGORIES OF PV CELLS

Currently, the most popular solar PV Cells used are as follows:

The photovoltaic industry, however, groups them into two distinct categories.

### 2.1 | First generation solar cells

#### 2.1.1 | Crystalline silicon solar cells

Mono c-Si or uni–c-Si is the source material for Si chips used in most of the semiconductor devices in the ongoing developments. Mono-Si provides PV and also as absorbed sunlight material in the fabrication of photo cells.

It has a continuous solid crystal lattice structure as shown in Figure 3, in its formation with unbroken in its edges, and no grain boundaries. The preparation of mono-Si is done with pure silicon or doped with other materials in very less quantity to change the semiconductor properties.[22-26] Czochralski process is used to grow most mono-crystaline Si up to a length of 2 mts and weigh around hundred kilograms. For further processing, these cylinders are then sliced into wafers with different thicknesses in few hundred microns. These are most efficient in its performance up to 21% and perform well at standard temperatures with cost/watt as 1.589 USD.[27-30] The advantage of monocrystalline solar cells is that it does not have the grain boundaries because of its continuous structure and the main disadvantages are cost of processing, loss of material, and problem with absorption.

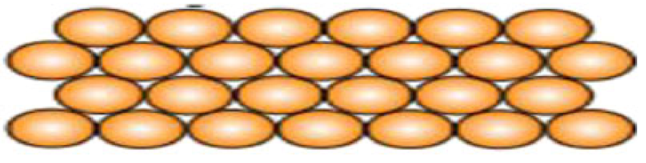

**FIGURE 3** Lattice structure of mono-Si solar cell[21] [Colour figure can be viewed at wileyonlinelibrary.com]

### 2.1.2 | Poly c-Si solar cells

Poly c-Si is a more pure structure of Si, used as a source material in PV and semiconductor industry. Poly-Si is manufactured by scientific grade Si by a chemical purification process, called the Siemens process that entails distillation of vaporizable Si compounds and their breakdown into Si at elevated temperatures. Poly-Si consists of minute crystals as shown in Figure 4, called as crystallites, which gives the material a distinctive metal flake outcome. The usual crystal size is greater than 1 mm. The most popular type of solar cells are multicrystalline solar cells as shown in Figure 5, which are highly consumed across the world. To generate 1 MW of conventional solar setups, around 5 tons of poly-Si is needed. Its efficiency is around 16%, which is considered to be less when compared to mono-Si.[32,33] Poly-Si performs well at high temperatures, and cost/watt is 1.418 USD. In this, there lies several grain boundaries in the polycrystalline cells that inhibit the continuous flow of the excited electrons in the semiconductor, leading to a radical drop in efficiency.

### 2.1.3 | Hybrid photo or solar PV cell

Hybrid photo or solar cells are composed of the properties of different kinds of semiconductors like organic and inorganic as shown in Figure 6. These PV cells have conjugated polymers as materials of organic category, which

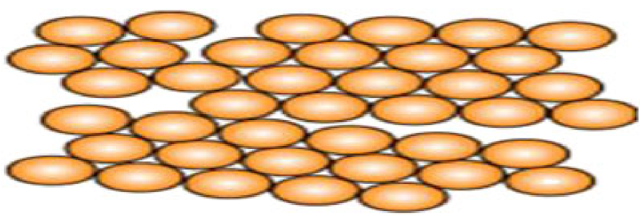

FIGURE 4 Lattice structure of poly-Si solar cell[31] [Colour figure can be viewed at wileyonlinelibrary.com]

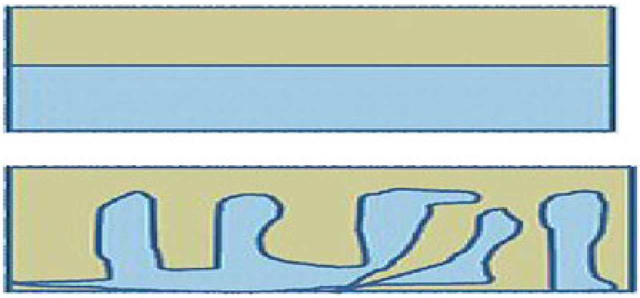

FIGURE 6 Two different structures of heterojunctions[34] [Colour figure can be viewed at wileyonlinelibrary.com]

absorbs sunlight as the donor and moves the holes; the other inorganic category materials are used as the receiver and create the movement of electrons in the structure of the cell. The hybrid photo or solar cells stands highly efficient in moderate cost-processing model, which also generates the power conversion using solar.[35]

### 2.1.4 | Advantages and disadvantages of first generation solar cells

As silicon has been heavily used in manufacturing the PV cells, the performance will be degraded at high temperatures, but the main advantage of this generation PV cells are, they are more efficient at low temperatures and require less area for a given unit power.

## 2.2 | Second generation solar cells

### 2.2.1 | Thin film solar PV cell

A thin film solar PV cell is manufactured by depositing multiple thin films (TF) of PV substances on a substrate, such as metal, or glass or plastic. Cadmium telluride, copper indium gallium diselenide, and amorphous thin-film silicon (a-Si) are used commercially in various technologies around the globe. The film thickness usually varies from nano (nm) to micro (μm) or even much more

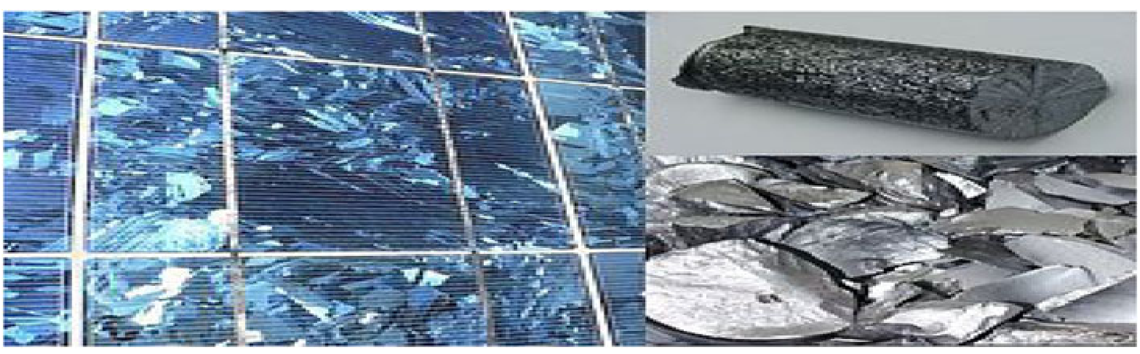

FIGURE 5 Solar cells made of multicrystalline silicon. Right side: polysilicon rod (top) and chunks (bottom)[31] [Colour figure can be viewed at wileyonlinelibrary.com]

thinner than thin-film's of the conventional solar cell (c-Si) that uses wafers of up to 200 to 250 μm.[36-45] Because of this reason, the thin films are usually very low in weight and are used in building integrated PV's that can be laminated onto windows. The efficiency seems to be 12% less when compared to the conventional methods of preparing the PV's and the performance will be good at high temperatures with a cost/watt as 0.67 USD. Thin-film technologies reduce the amount of active material in a cell. Most sandwich active material between 2 panes of glass. Since silicon solar panels only use one pane of glass, thin film panels are approximately twice as heavy as crystalline silicon panels, although they have a smaller ecological impact (determined from life cycle analysis). Most of the film panels have 2 to 3 percentage points lower conversion efficiencies than crystalline silicon. CdTe, CIGS, and a-Si are 3 thin-film technologies often used for outdoor applications.

### 2.2.2 | Amorphous silicon solar cell

Amorphous silicon is the noncrystalline appearance of Si with no definite arrangement of atoms as shown in Figure 7. These are also thin films that can be used on different substrates like metals or glass or plastics. The a-Si solar cells are of low efficiency but proved to be more environmentally friendly PV cells. This uses less silicon and also does not contain the aluminum frame, but on the flip side, the efficiency is between 6% to 12% and less popular as they are harder to replace.[47-56] Amorphous alloys of silicon and carbon (amorphous silicon carbide, also hydrogenated, a-Si1 − xCx:H) are an interesting variant. Introduction of carbon atoms adds extra degrees of freedom for control of the properties of the material. The film could also be made transparent to visible light.

Increasing the concentration of carbon in the alloy widens the electronic gap between conduction and valence bands (also called "optical gap" and bandgap). This can potentially increase the light efficiency of solar cells made with amorphous silicon carbide layers. On the other hand, the electronic properties as a semiconductor (mainly electron mobility) are adversely affected by the increasing content of carbon in the alloy, due to the increased disorder in the atomic network. The density of amorphous Si has been calculated as 4.90 × 1022 atom/cm$^3$ (2.285 g/cm$^3$) at 300 K. This was done using thin (5 micron) strips of amorphous silicon. This density is 1.8 ± 0.1% less dense than crystalline Si at 300 K. Silicon is one of the few elements that expands upon cooling and has a lower density as a solid than as a liquid.

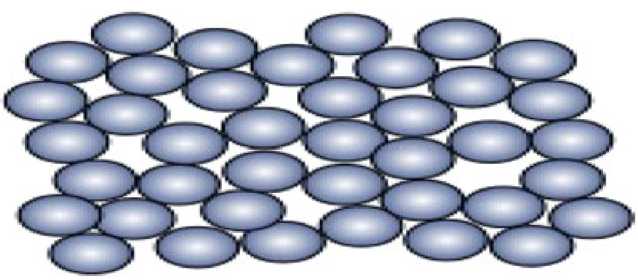

FIGURE 7 Lattice structure of a-Si Solar cell[46] [Colour figure can be viewed at wileyonlinelibrary.com]

### 2.2.3 | Cadmium telluride solar cell

Cadmium telluride photovoltaic's describes a technology with thin semiconductor using the CdTe. Cadmium (Cd), a toxic heavy metal considered as a hazardous substance and tellurium is a rare, mildly toxic metalloid that is primarily used as a machining additive to steel. The design as shown in Figure 8 is in such a way that the thin film converts sunlight into electricity and the cadmium is an environmental concern mitigated by the recycling of CdTe modules at the end of their life time.[57-60] As the CdTe is a rare material, the use becomes a limiting factor to the industrial scalability of CdTe technology.[61-65] Cadmium telluride PV is the only thin film technology with lower costs than conventional solar cells made of crystalline silicon in multikilowatt systems.

### 2.2.4 | Concentrated PV solar cell (CPV and HCPV)

A copper indium gallium selenide PV solar cell (or CIGS cell, sometimes CIS cell) belongs to a thin-film solar cell family group as shown in Figure 9, which converts solar energy to electric energy. It is fabricated by storing a thin layer of CIGS on plastic or glass substrate by placing the electrodes on both sides to draw current. Since the

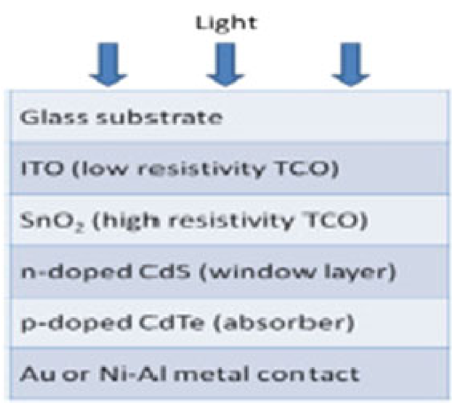


FIGURE 8 Process of conversion considering different layers [Colour figure can be viewed at wileyonlinelibrary.com]

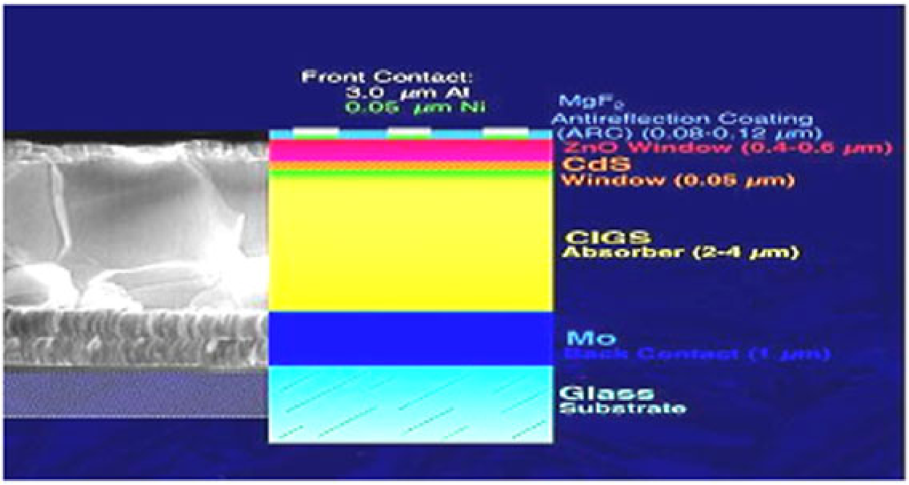


**FIGURE 9** Structure of a CIGS device. CdS is used optionally and some CIGS cells contain no cadmium at all[66] [Colour figure can be viewed at wileyonlinelibrary.com]

material has a huge absorption coefficient and unequivocally assimilates daylight, semiconductor properties allow solar cells to operate more efficiently in concentrated light, as long as the cell junction temperature is kept cool by suitable heat sinks. A significantly more lean film is needed than the supplementary semiconductor type materials.

Concentration photovoltaics is a PV expertise that generates current from sunlight through some conventional PV systems. In this approach, it utilizes the lenses of different kinds and various concave and convex mirrors to focus sunlight onto a point, which is called focal point from where the electricity can be generated. It is highly efficient, and it is an efficient multijunction (MJ) solar cells. Systems using high-concentration photovoltaics (HCPV) especially have lot of potentiality to create revolution in the future.[67] These are not used a rooftop segmented PV systems and the installation cost for a 10-MW CPV power plant could lie between €1.40 and €2.20 (~$1.50-$2.30) per watt-peak ($W_p$).

### 2.2.5 | Dye-sensitized solar cell

A dye-sensitized solar cell (DYSC, DSC, DSSC, or Gratzel solar cell) proves to be a very low-priced solar PV cell that belongs to the group solar thin film cells. As shown in Figure 10. This is manufactured by involving photosensitized anode, an electrolyte, a photo electro chemical system. The DYSC is also commonly known as Gratzel cell and has a number of striking features like easy to incorporate the conventional roll-printing technique, also its semi translucent that offers diverse range to make use of glass based systems.[69-85] Over a period of research in developing DSSC with modern methods, it has overcome the use of costly material in it and finally leading to reduced cost in the fabrication of the solar cell. The

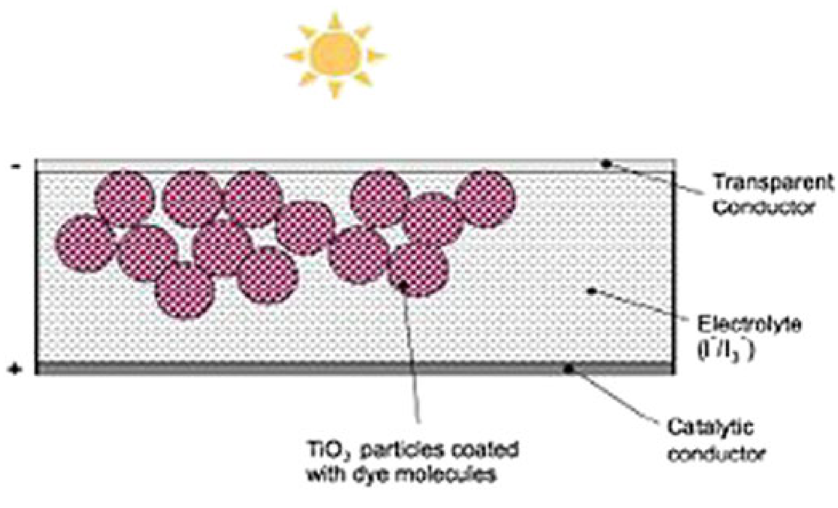


**FIGURE 10** Type of cell made at the EPFL by Gratzel and O'Regan3[68] [Colour figure can be viewed at wileyonlinelibrary.com]

conversion efficiency may be less practical when compared to other solar cells, but theoretical results give better efficiency ratios that will be sufficient to run the grid parity in achieving fossil fuel electricity generation. The DSSC solar cell splits the 2 functions provided by Si in a conventional cell structural design as shown in Figure 11. Typically, the silicon goes about as both the wellspring of photoelectrons and in addition, giving the electric field to isolate the charges and make a current. In the color-sharpened sun-based cell, most of the semiconductor is utilized exclusively for charge transport; the photoelectrons are given from a different photosensitive color. Charge partition happens at the surfaces between the color, semiconductor, and electrolyte.

The color particles are very little (nanometer measured), so to meet the end goal and to catch a sensible measure of the approaching light, the layer of color particles should be made genuinely thick, considerably thicker than the particles themselves. To address this issue, a nanomaterial is utilized as a framework to hold substantial quantities of the color particles in a 3-D grid, expanding the quantity of atoms for any given surface territory of cell. In existing outlines, this framework is given by the semiconductor material, which serves twofold obligations.

For comparison, a traditional silicon-based solar cell offers current of about 35 mA/cm$^2$, whereas current DSSCs[86-96] offer about 20 mA/cm$^2$.

### 2.2.6 | Multijunction solar cell

Multijunction solar cells are fabricated with various p-n junctions, which are prepared with diverse semiconductor type of materials.[97] The current will be produced out of each p-n junction with different wave lengths of light incident on the PV cell as shown in Figure 12. Because of the use of different semiconductor materials, there will be a broader range of wavelength by absorbing the sunlight

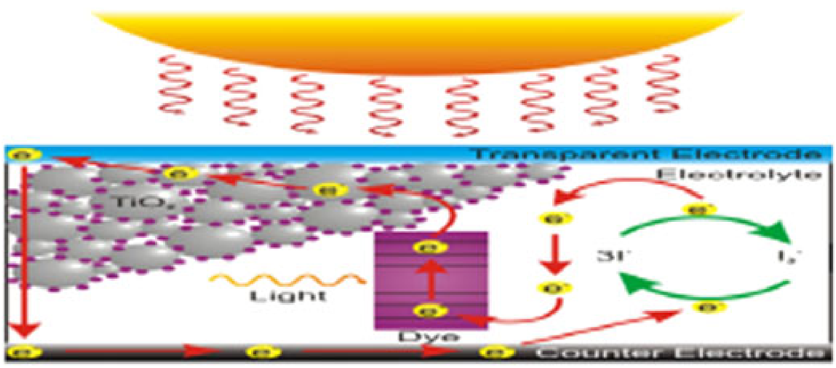


**FIGURE 11** Operation of a Gratzel cell[68] [Colour figure can be viewed at wileyonlinelibrary.com]

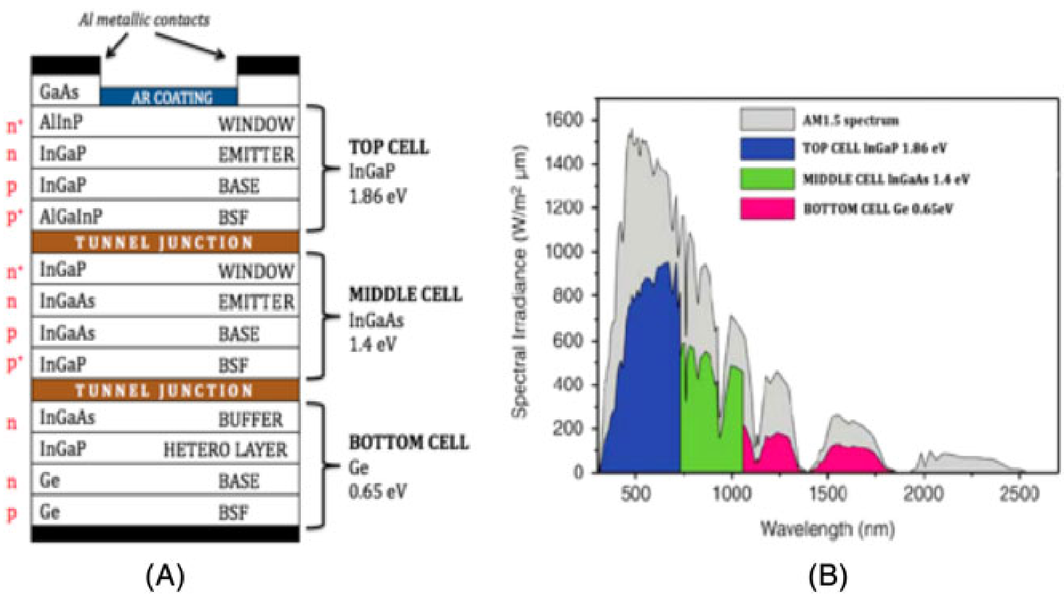


**FIGURE 12** The structure of an MJ solar cell and graph of spectral irradiance E vs wavelength λ[98] [Colour figure can be viewed at wileyonlinelibrary.com]

and improving the conversion efficiency to a greater extent.[99]

Usually the 1-junction cells have a maximum TCE of 33.16%, but the infinite number of junctions would have a restraining efficiency of 86.8% below considerable sunlight due to concentration effect.[98] Most of the multijunction cells that have been produced to date use 3 layers (although many tandem a-Si:H/mc-Si modules have been produced and are widely available). However, the triple junction cells require the use of semiconductors that can be tuned to specific frequencies, which has led to most of them being made of gallium arsenide (GaAs) compounds, often germanium for the bottom, GaAs for the middle, and GaInP2 for the top cell.

### 2.2.7 | Organic solar cell

Organic electronics deal with the organic polymers that generates the electricity through sunlight. This can be achieved through the organic solar cell or plastic solar cell that can convert the energy through the PV means.[100] It is observed that most of the organic photovoltaic cells are polymer-based solar cells. The molecules used in this process are solution-processable at high temperatures and are cheap in manufacturing with low production cost.[101,102] The color atoms are very little (nanometer measured), so keeping in mind the end goal to catch a sensible measure of the approaching light, the layer of color particles should be made genuinely thick, considerably thicker than the particles themselves. To address this issue, a nanomaterial is utilized as a framework to hold substantial quantities of the color particles in a 3-D grid, expanding the quantity of atoms for any given surface territory of cell. In existing outlines, this framework is given by the semiconductor material, which serves twofold obligation.

### 2.2.8 | Nanocrystal solar cell

Nano c-Si solar cells are the PV cells that are coated with a nanocrystals on a substrate. These crystals are typically made with silicon or CdTe or CIGS. Here, substrates generally play a key role, and that is the reason why the materials picked for the substrate are usually made of silicon or various organic conductors. As the nanotechnology is doing wonders in the world, the efficiency outputs with these PV cells would be enormously high and the production cost will be less. The research is going rigorously in this area.[103-105] Although research is still in its infancy, in the future, nanocrystal photovoltaics may offer advantages such as flexibility (quantum dot polymer composite photovoltaics) lower costs, clean power generation, and an efficiency of 65%, compared to around 20% to 25% for first-generation, crystalline silicon-based photovoltaics.

### 2.2.9 | Quantum dot solar cell

A QDSC utilizes the dots as an absorbing PV metals. This approach replaces the materials like Si, CIGS, or CdTe and will be more efficient in its approach.[106] These dots will have a bandgap and can change to wide range of energy levels by just adjust the size of the dots as shown in Figure 13. This property makes quantum specks alluring for multi-intersection sun-powered cells to enhance productivity by reaping different parts of the sunlight-based range.[108,109] The QDSCs are a special class of semiconductors, which are nanocrystals, composed of periodic groups of II-VI, III-V, or IV-VI materials and can confine electrons (quantum confinement). When the size of a QD approaches the size of the material's exciton Bohr radius, quantum confinement effect becomes prominent and electron energy levels can no longer be treated as continuous band; they must be treated as discrete energy levels. Hence, QD can be considered as an artificial molecule with energy gap and energy levels spacing dependent on its size (radius). The energy band gap increases with a decrease in size of the quantum dot.

## 3 | ANTIREFLECTION COATING ON PV CELLS

Photovoltaic cells are made up of silicon, which is the second largest material available in abundant on the earth's crest that has the nature of high surface reflection property. Because of this reason, around 30% of sunlight reflects once it falls on the PV panel, which is enormously decreasing the conversion efficiency. Lots of research on coatings on PV panel is going on to overcome the reflection property of silicon. Based on the latest advancements, either microcoating or nanocoating of antireflection materials on the PV panel are improving the conversion efficiency of the solar energy. When the further investigation happened, it is observed that nanocomposite materials are highly used as antireflection materials like single-walled carbon nanotube (SWCNT), multiwall carbon nanotube (MWCNT), silicon dioxide ($SiO_2$),

**FIGURE 13** Quantum dots organized on a substrate[107] [Colour figure can be viewed at wileyonlinelibrary.com]

titanium dioxide ($TiO_2$), aluminum iso-propoxide ($C_9H_{21}AlO_3$), zinc sulfide (ZnS), silicon nitride (SiN), silicon oxynitride (SiON), and polyaniline.

## 3.1 | Different types of nanocomposite coatings

### 3.1.1 | Carbon nanotubes

Carbon nanotubes are allotropes of carbon with a cylindrical nanostructure. These cylindrical carbon nanostructured molecules have unusual properties, which are valuable for electronics, nanotechnology, optics, and other fields of materials science developments. The CNT materials are of exceptional strength and stiffness with length-to-diameter ratio up to 132 000 000:1. This ratio is significantly larger than for any other material.

### 3.1.2 | Single-walled carbon nanotube

The SWCNTs have a diameter to length ration as close to 1 nm to many times long in its length. The SWNT structure can be described by packaging an atom-thick layer of graphite as shown in Figure 14, known as graphene into a flawless cylinder. The graphene sheet is wrapped and the way is spoken to by a couple of records ($n$,$m$). The whole numbers n and m speaks to the quantity of unit vectors along two bearings in the honeycomb precious stone cross section of graphene. In the event that $m = 0$, the nanotubes are known as crisscross nanotubes, and if $n = m$, the nanotubes are known as easy chair nanotubes.[111] Else, they are called as chiral. The ideal nanotube's diameter can be calculated from its ($n$,$m$) indices as below:

$$d = \frac{a}{\pi}\sqrt{(n^2 + nm + m^2)} = 78.3\sqrt{\left((n+m)^2 - nm\right)}\ \text{pm},$$

where $a = 0.246$ nm.

### 3.1.3 | Multiwall carbon nanotube

Multiwall carbon nanotube is made up of multiple rolled layers of grapheme concentric tubes as shown in Figure 15. The 2 major properties that can describe the structures of multiwall nanotubes are their morphology and resistant to chemicals. This is highly important when there is any need of chemical functions on to the surface of the nanotubes to add other properties to the CNT. Covalent fictionalization of SWNTs may break, but in DWNTs, only the outer wall is modified by which it will not impact the mechanical and electrical properties.[113,114]

Usually, the MWCNT agglomerates inside the TiO2 matrix acting as trapping sites that obstruct the fast charge collection at the electrodes. Therefore, its proved that low amount of MWCNT adding to $TiO_2$ will increase the PV performance.

### 3.1.4 | Silicon dioxide

Silicon dioxide is also known as silica, and the chemical formula is $SiO_2$, which is available as quartz $SiO_2$. This is found in various living creatures. Silica is found majorly in sand in most parts of the world and is more abundant available in the earth's crust. Few examples

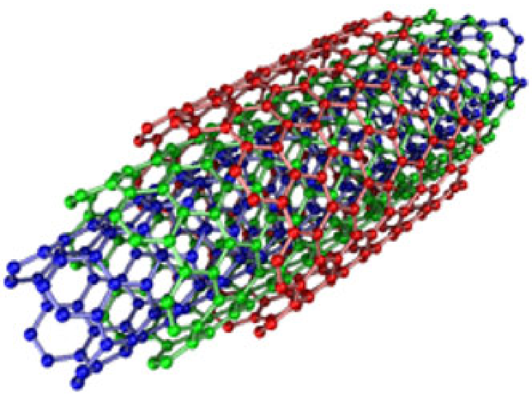

**FIGURE 15** Multiwall (triple) armchair carbon nanotube[112] [Colour figure can be viewed at wileyonlinelibrary.com]

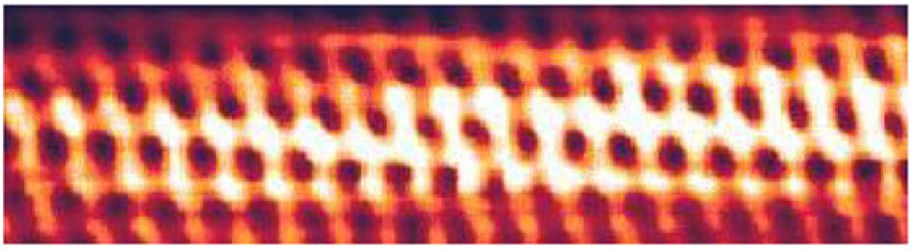

**FIGURE 14** A scanning tunneling microscopy image of single-walled carbon nanotube[110] [Colour figure can be viewed at wileyonlinelibrary.com]

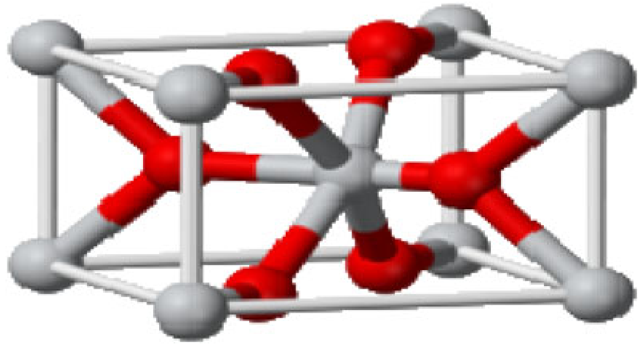

**FIGURE 16** The unit cell of rutile[116] [Colour figure can be viewed at wileyonlinelibrary.com]

of silica are fused quartz, aerogels, fumed silica, and silica gel.[115]

### 3.1.5 | Titanium dioxide

TiO2 is also known as titanium(IV) oxide or titania. It is a naturally occurring oxide of titanium.

Usually, it is prepared from ilmenite, rutile, and anatase. It has an ample range of purposes that can be used to prepare paint, sunscreen, and food coloring, as shown in Figure 16. The DSSC using composite films

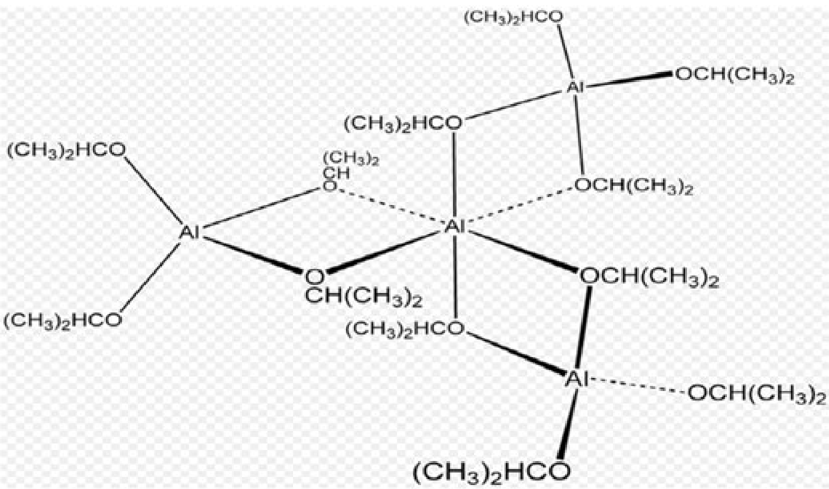


**FIGURE 17** One enantiomorph of Al4(OiPr)12[117]

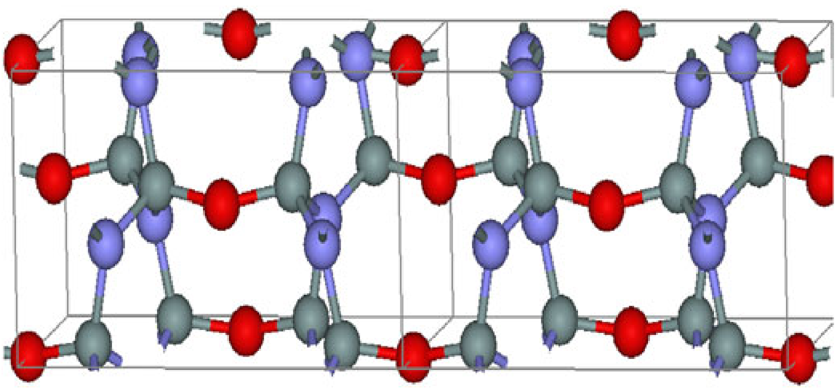

**FIGURE 18** Crystal structure of $Si_2N_2O$. Atoms: red = O; blue = N; gray = Si[118] [Colour figure can be viewed at wileyonlinelibrary.com]

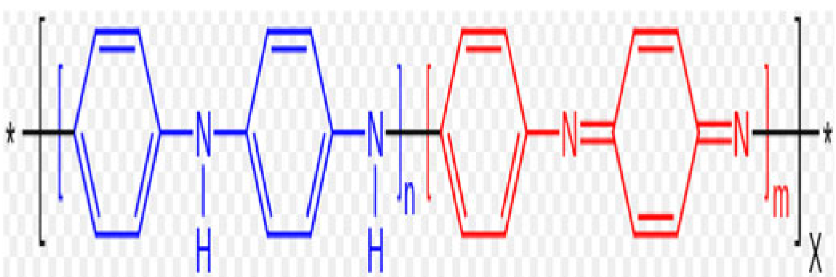


**FIGURE 19** Main polyaniline structures n + m = 1, x = half degree of polymerization [Colour figure can be viewed at wileyonlinelibrary.com]

consisting of titanium oxide (TiO2) nanoparticles with combination of other nanomaterials gives better PCE.

### 3.1.6 | Aluminum isopropoxide

The chemical compound described with the chemical formula as $Al(O\text{–}i\text{–}Pr)_3$, where i–Pr is the isopropyl group $(CH(CH_3)_2)$[117] as shown in Figure 17. As a colorless solid, this is used as a reagent in organic synthesis. Being a complex structure, this material is time-dependent and depends on solvent.

### 3.1.7 | Silicon oxynitride

Silicon oxynitride has a chemical formula $SiO_xN_y$. This is a ceramic material when in amorphous forms, its composition can continuously vary between $SiO_2$ (silica) and $Si_3N_4$ (silicon nitride). The known intermediate crystalline phase is $Si_2N_2O$ as shown in Figure 18. It is a rare mineral and can be produced in the laboratory.

### 3.1.8 | Polyanilin

Polyaniline (PANI) belongs to a semiflexible rod polymer family group and it is a conducting polymer as shown in Figure 19. This material gained attention because of high electrical conductivity property it holds.[119-121] The key properties of PANI are that it has rich chemistry properties and is most studied conducting polymers available in the market. The composition of PANI with SWCNT changes the nature of the hetero junction properties that simultaneously improves the PCE.[122]

## 4 | CONCLUSIONS

In the thorough review done taking all types of PV solar cells, it is understood that the c-Si solar cells are giving better performance in terms of PCE when compared to other types of solar cells. As silicon is the second most abundant material available in the earth's crust, the data available on the properties of silicon are huge, and this gave lot of scope for a better study on this material. As the lattice structure of c-Si is flat and uniform in nature the transfer of photons into the semiconductor, ie, PV panel will be at a higher ratio when compared to the nonuniform PV panels. The maintenance of panels is easy and not expensive as they are very durable and not environmentally hazardous. Production cost is also reasonable but might be slightly higher than the DSSC. But as the DSSC belongs to thin-film solar cells family, the efficiency of PCE might be slightly less when compared to c-Si. Usually, thin-film solar cells are highly efficient at high temperature; the manufacturers are doing lot of research in reducing the thickness of the c-Si panels. The latest observations say that the thickness of the c-Si panels are reduced from 400 to 200 μm and even further less, which will ideally improve the PCE. In addition to thickness of the panel, the area of the panel also should increase so that more area with less thickness will be more efficient. For this, the required measures are taken, and there have been increased from 100 to 240 $cm^2$. Other than the cost of the c-Si when compared to DSSC as it is at higher side in most of the properties but definitely production cost matters a lot. Manufacturing a silicon substrate of 200-μm thickness is definitely costly, but the overall saving should be compared between c-Si and DSSC to identify which approach is better. To further improve the PCE, the best way is to apply a nanocomposite coating on top of the PV panel that has increased the efficiency enormously. Major work is going in identifying different nanocomposite materials, and the efficiency seems to be improved with the nano composites like CNT, $TiO_2$, and $SiO_2$, which are giving the highest PCE based on the available literature survey. The solar cell assembled with photoanode containing 0.06% MWCNTs shows the highest efficiency of 5.25%, which is 46% greater than unmodified photoanode for DSSC when compared between coated and uncoated samples. But the c-Si PV panels have given the best performance by comparing the results of various coated cells, the CNT coated gave the best result of 31.25% improvement. Keeping the availability, production cost, and easy to maintenance in mind, the best option from the above panels and the type of nanocomposite materials should be picked for the better performance of PCE. The third generation PV cells are potentially able to overcome the Shockley–Queisser limit of 31% to 41% power efficiency for single-bandgap solar cells. This includes a range of alternatives to cells made of semiconducting p-n junctions ("first generation") and thin film cells ("second generation"). Common third-generation systems include multilayer ("tandem") cells made of amorphous silicon or gallium arsenide, while more theoretical developments include frequency conversion (ie, changing the frequencies of light that the cell cannot use to light frequencies that the cell can use—thus producing more power), hot-carrier effects, and other multiple-carrier ejection techniques.

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## ORCID

*K. Rakesh Tej Kumar* http://orcid.org/0000-0001-5775-504X

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