Solar Photovoltaic Materials Development and Analysis

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Abstract

A potential solution to the world’s energy crisis has been demonstrated in the use of sunlight to generate electricity. Solar cells, which convert solar energy into electrical energy, must be reliable and cost effective in order to compete with traditional sources. The purpose of this paper is to describe the different generations of photovoltaic cells and the current and upcoming technologies that will be utilised in the photovoltaic systems. The introduction describes the fundamentals of photovoltaic (PV) cells, including their working principle and their main properties. After that the paper discusses all generations of PV cells, mainly in terms of the efficiency at which they can convert sunlight to electricity as well as the materials used. A comparison of the latest efficiencies of the PV cells is provided. With the advancement of photovoltaic technology, the possibilities of increasing efficiencies, production and innovations are also discussed. The limitations as well as possible solutions and future hopes are outlined in the conclusion.

Keywords — Photovoltaic cells, photoelectric effect, generations, types, performance, efficiency, production, utilisation, innovations, limitations

Introduction

When a substance absorbs electromagnetic radiation, electrically charged particles are discharged. This is known as the photoelectric effect. It’s also known as the emission of electrons from a metal plate in the presence of light [1]. It is also possible to describe the energy in terms of infrared, visible, ultraviolet, X-rays,
or gamma rays in a broader sense [1]. Electrons may be emitted in addition to ions (electrically charged atoms or molecules) depending on whether the substance is solid, liquid, or gas [1]. The intriguing problems about light-particle vs wavelike behavior of light that this phenomenon posed and that Albert Einstein was able to settle in 1905 were an essential component of modern physics [1]. This phenomenon has proven critical in a variety of fields, including materials science and astrophysics, as well as serving as the foundation for a variety of useful gadgets [1]. Figure 1 depicts the phenomenon of photo-electric effect.

Figure 1. Photoelectric effect [2]

Photovoltaic Cell

In 1887, Germany’s physicist Heinrich Rudolf Hertz discovered the photoelectric effect [3]. The study of radio waves led Hertz to observe that ultraviolet light affects the voltage at which sparks occur when it is aimed at two electrodes with a voltage applied between them [3]. In 1902, another German physicist, Philipp Lenard, advanced the development of photoelectricity by clarifying how light and electricity are related [3]. He demonstrated that when a metal surface was exposed by light, it ejected electrically charged particles that were identical to the electrons found by Joseph John Thomson in 1897 [3].

According to wave theory, the ideal kinetic energy of the released electrons should have been proportional to the light intensity, but in one observation, it was instead related to its frequency [4]. In other words, the number of electrons emitted from the metal was determined by the light intensity (measured by electric current) [4]. Another surprising discovery was that there was no obvious lag time between photon arrival and electron emission. Based on this unexpected behaviour, Albert Einstein presented a new corpuscular theory of light in 1905 [5]. According to the idea, every photon, or particle of light, has a defined quantum of energy that varies based on its frequency [6]. To be precise, the energy of a photon is equal to hf. In which f denotes the frequency of light and h denotes the universal constant. It was discovered in 1900 that Planck’s universal constant, which characterises the wavelength distribution of blackbody radiation emitted by a heated body [7]. The relationship can also be expressed in the following way:

\[ E = \frac{hf}{\lambda} \quad \text{(1)} \]

Where \( c \) represents the speed of light, and \( \lambda \) denotes the wavelength. Thus, it can be concluded that an inverse relationship exists between wavelength and photon energy [8].

In his theory, Einstein assumed that an electron gains energy from a photon passing through the material [9]. Electrons then move through metals at extremely high speeds and emerge from the material at high speed. Its kinetic energy will decrease by an amount called the work function. Essentially, it represents the energy needed to let an electron escape a metal, like the electronic work function [1]. Einstein arrived at the photoelectric equation,

\[ E_k = hf - \quad \text{(2)} \]
The kinetic energy of an emitted electron is determined by conservation of energy, where $E_k$ represents that energy [1].

Silicon is the most common semiconductor material used in solar cells [10]. The silicon atom’s valence shell has four electrons. In solid crystals, the sharing of their four valence electrons generates covalent bonds between silicon atoms [11]. The tetrahedral structure of silicon crystal is created using this method [12]. Some light rays are reflected, some are passed through them, and the rest are absorbed when they touch any substance [13].

A silicon crystal experiences the same thing. The crystal will absorb enough photons if the input light intensity is high enough [14]. Several of these photons then cause electrons in covalent bonds to be excited [15]. Once they have enough energy, these electrons migrate from the valence to conduction bands, as seen in Figure 2.

Figure 2. Energy Band Diagram in an Intrinsic Semiconductor [16]

In 1839, a French physicist named Edmond Becquerel discovered the photoelectric effect [17]. Charles Fritts succeeded in developing the first working solar cells in 1883 [18]. He used a thin gold-coated selenium sheet. Solar panels are a relatively new power and heat generation technology [19]. Since the early 1900s, solar energy has been harnessed to generate electricity. In 1954, Bell Labs produced the first large-scale crystalline silicon solar cells. PV cells developed by Bell Laboratory converted 4% of solar energy into electricity, which was considered cutting-edge in energy technology at the time [20]. Silicon-based solar cells with a 6% efficiency were developed by Daryl M. Chapin [21]. Scientists have continued to enhance and develop the original solar cell design, which can recover 20% of the energy it produces [22]. As knowledge of the effects of global warming and demand for renewable energy sources rose in the late 1900s, scientists worked to improve silicon PV. Solar cells with a 24 percent electricity recovery rate were available in the early 2000s [23]. Using space age materials, scientists were able to improve the electricity recovery rate of silicon solar cells in just seven years. By 2007, the energy recovery rate of contemporary silicon PV solar cells had reached 28 percent [24]. PV cell technologies and applications abound in today’s market [25].

Different Types of PV Cells

First-Generation: Crystalline Silicon

The energy bandgap of silicon, a semiconductor material suitable for PV applications, is 1.1 eV [26]. PV cells and modules made of crystallized silicon are the most popular in the industry right now, with modules made of C-Si wafers dominating the market. There are three types of crystalline silicon cells:

a. Mono-crystalline (Mono c-Si).
b. multi-crystalline or poly-crystalline (Poly c-Si) or (mc-Si).

c. Silicon ribbon.

Sharp Corporation of Japan put 242W PV modules on a lighthouse and began producing PV modules in 1963, which was the first time C-Si modules were commercially produced [26]. At the time, it was the world’s largest commercial PV facility [27]. In 2010, crystalline silicon accounted for about 87 percent of global PV sales [28]. The efficiency of crystalline silicon modules ranges from 14 percent to 19 percent [29]. A mature technology continues to be improved by advances in materials and manufacturing methods, in addition to ongoing cost reductions. If the market continues to grow, it has the potential to produce many high-volume manufacturers.

**Mono-Crystalline Silicon**

In comparison to the three most common technologies, silicon mono-crystalline cells are the most efficient at 20% [30].

It is a kind of photovoltaic material made of single crystal silicon structure. PV cells are made from processing the thin pieces (wafers) of high-purity silicon made by cutting rods (ingots) that are extracted from the cast. The life expectancy of these cells is typically 25-30 years [31]. A mono-crystalline silicon cell is shown in Figure 3.
Figure 3. Mono-Crystalline solar panel [32]

Merits:
1. It has high performance.
2. Stable efficiency.
3. It has long service life [22].

Demerits:
1. Manufacturing cost is high.
2. Temperature sensitivity is higher.
3. Absorption problem.
4. Material loss is greater [22].
5. Poly-Crystalline Silicon
The molecular structure of silicon is made up of several tiny groups or crystal grains that are separated by barriers. They are more cost-effective and efficient to manufacture than monocrystalline cells. Solar cells have a lower efficiency than mono-crystalline silicon. It is cast into blocks, unlike mono-crystalline silicon. When crystals are cemented, they form varying-sized crystal formations with edge flaws. These flaws impair efficiency; laboratory efficiency ranges from 8% to 23%, whereas manufacturing efficiency ranges from 14% to 17% [31]. Figure 4 depicts a poly-crystalline silicon cell.

![Poly-Crystalline Silicon Cell](image)

**Figure 4. Poly-Crystalline Silicon Cell [33]**

**Merits:**

1. Well-established and tested technology.
2. Stable efficiency.
3. Cheaper than single crystal silicon.
4. Packing density is optimized with square cells [26].

**Demerits:**

1. Utilization of costly materials.
2. Wafer slices.
3. Slightly less efficient than single crystals [26].
4. **Ribbon Silicon**

String Ribbon Si wafers are grown via vertical sheet growth. Evergreen Solar is now producing it in multi-megawatt capacity [34]. Because of the high utilisation of Si feedstock, this technique can generate Si at
a lower cost. String Ribbon wafers of good quality have previously been shown to have long lifetimes for minority carriers after cell processing. The focus of recent research on string ribbon cell processing has been on industrial applications. Screen printing is utilised in this case to metalize the inks and fire them at somewhat deep joints. It once established a world record by obtaining a 16.2 percent efficient cell ratio [26]. Cells generated with modern screen printing, on the other hand, are currently reaching the 16 percent level [26].

Second-Generation: Thin-Film

There have been numerous deployments of thin-film solar cells. In terms of power, thin-film solar cells have the potential to be less expensive than c-Si wafer-based solar cells [35]. Thin-film solar cells are made up of a 1 to 4 m thick sheet of solar cells. Cadmium is utilised as a catalyst, and it is deposited on large, low-cost substrates such as glass, polymer, or metal (is a by-product of zinc). The problem is that tellurium is generated in far smaller quantities than cadmium, therefore its supply may change over time. The ability of the copper sector to improve extraction, refining, and recycling yields is crucial. Cadmium’s use is restricted due to toxicity concerns. As a result, less semiconductor material is required to absorb the same amount of sunlight (up to 99 percent less than crystalline solar cells) [26]. Thin films can also be packed into a lightweight, flexible framework that can readily be integrated into Building Integrated Photovoltaic (BIPV) building components.

The three principal types of commercially developed thin film solar cells are

- Amorphous silicon (A-Si and A-Si/c-Si),
- Cadmium-Telluride (CdTe),
- Copper-Indium-Selenide (CIS), and Copper-Indium-Gallium Diselenide (CIGS) [4].

Thin-film solar cells are depicted in Figure 5.

Figure 5. Thin-film solar cells, a second generation of photovoltaic (PV) solar cells [36]

Amorphous Silicon Solar Cells

Along with CdTe PV cells, these are the most developed and well-known thin film solar cells. The continuous deposition process can layer amorphous silicon on low-cost, big substrates (glass up to 5.7m²), drastically cutting manufacturing costs. Companies are also developing lightweight and flexible A-Si modules that may
be used on both flat and curved surfaces. The efficiency of amorphous silicon modules ranges from 4% to 8%. Very small cells can attain a 12.2 percent efficiency in the laboratory [37, 38]. Amorphous silicon solar cells are depicted in Figure 6.

Figure 6. Amorphous Silicon Solar Cells [39]

The biggest disadvantage of amorphous silicon solar cells is that with time their energy and power production diminish (15 percent to 35 percent) [26]. Even thinner layers can strengthen the electric field across the material, offer stability, and reduce power output, but they also diminish light absorption, lowering cell efficiency. A multi-junction thin film silicon (a-Si or c-Si) solar cell made of a-Si cells with an extra layer of A-Si and microcrystalline silicon (c-Si) layers is a significant version of an amorphous silicon sun cell.

The c-Si layer has the advantage of absorbing lighter in the red and near-infrared regions of the spectrum, boosting efficiency by up to 10% [26]. The c-Si layer has a thickness of roughly 3 m, making the cell thicker and more stable. Current deposition techniques allow for the creation of multi-junction thin films with a surface area of up to 1.4 m$^2$ [90].

Merits:

1. It is less expensive.
2. Available in vast quantities.
3. It is non-toxic.
4. Absorption coefficient is very high [22].

Demerits:

1. It has lower efficiency.
2. It is difficult to select the right dopant materials.
3. Lifetime of minority carrier is lower [22].
4. **Cadmium - Telluride (CdTe)**

CdTe stands for cadmium telluride (CdTe), a compound composed of tellurium and cadmium [22]. Although less expensive than silicon, this material is less efficient. To assure module recovery after reinstallation, heavy metal cadmium is utilised. Currently, a maximum efficiency of 16 percent has been achieved [26]. Solar cells made of cadmium-telluride are shown in Figure 7.
Figure 7. Cadmium Telluride Solar Cells [40]

Merits:

1. Absorption coefficient is very high.
2. Production requires less material.
3. Cd is easily available [22, 23].

Demerits:

1. Manufacturing cost is high.
2. Cd is very toxic.
3. Te is available in limited quantities.
4. High temperature sensitivity [22].

5. Copper-Indium-Selenide (CIS) and Copper-Indium-Gallium Selenide (CIGS)

Among all thin-film PV technologies, (CIGS) PV cells have the best efficiency. Many businesses have successfully commercialised CIS solar cell manufacture. Module efficiencies currently vary from 7% to 16%, however C-Si cells have attained efficiencies of up to 20.3 percent in the lab [41]. The competition currently is to make commercial modules more efficient. Solar Frontier, a CIGS manufacturer, has reached a production capacity of 1 GW per year [42]. The CIGS modules have the advantage of having low static loading light cells that can absorb both direct and indirect sunlight, making them appropriate for usage on flat roofs or throughout the winter. A PV cell constructed with CIGS technology is shown in Figure 8.
Figure 8. CIGS cell on a flexible plastic backing [43]

Merits:

1. Production requires less material.
2. It has high efficiency.
3. It is less expensive.
4. It is easy to fabricate [22, 23].

Demerits:

1. In and Ga are scarce.
2. Very expensive.
3. It is not very stable.
4. Temperature sensitivity is higher.
5. Very unreliable [22, 23].
6. **Third Generation:**

Third-generation photovoltaic (PV) aims to develop high-efficiency devices while still using second-generation thin-film deposition methods. The goal is to reduce cost per watt while allowing only the field costs to increase [44]. Furthermore, these would utilise non-toxic and abundant materials, like Si-based second-generation thin-film technology. To put it another way, these third-generation technologies can be used to build large-scale PV systems. Although it involves more energy and time, the process differs from first-generation manufacture of high-quality, low-defect mono crystalline PV devices with high efficiency at the limiting potential for single-band gap devices [45].

**Organic Solar Cells**

Organic solar cells are made from polymer or organic materials. They are not particularly efficient, despite their low cost. Commercial organic PV modules have a conversion efficiency of 4% to 5%, while laboratory organic PV modules have a conversion rate of 6% to 8% [46]. Organic cell manufacturers are also pushing up their efforts to get their goods to market, with aspirations to produce over 1 gigawatt of solar cells per year [47]. Roll-to-roll manufacturing at high speeds and low temperatures, as well as normal printing techniques, are employed in the creation of organic cells. Organic solar cells have been able to compete with
other photovoltaic technologies in some applications due to lower manufacturing costs [48]. Like the printing and coating industries, organic cells can be applied to plastic sheets. Organic solar cells, in other words, are light and flexible, making them ideal for mobile applications and uneven surfaces. This is particularly beneficial for portable devices, such as cell phones, computers, radios, flashlights, toys, and nearly any other battery-powered gadget. It can also be folded or rolled up when not in use. Organic PV modules will be appealing for building integration applications since they have these unique qualities, which will increase the shapes and forms of PV systems. Furthermore, this technique takes advantage of readily available non-toxic ingredients and is based on a scalable and highly productive manufacturing process. Aside from the above-mentioned third-generation technologies based on quantum dots and wires, quantum wells, or superlattices, a few unique and modern solar cell concepts are also gaining traction [49]. These technologies can focus on reaching very high efficiencies in PV technologies by overcoming the thermodynamic limits of traditional (crystalline) cells. Nanotechnology is frequently utilised into innovative concepts to improve the active layer’s solar spectrum compatibility [50]. Figure 9 depicts an organic photovoltaic cell.

![Figure 9. Organic solar cell](image)

**Merits:**

1. The processing costs are low.
2. Lighter in weight.
3. The flexibility is high.
4. Good thermal stability [22].

**Demerits:**

Very low efficiency [22].

**Dye-sensitized Solar Cells (DSSCs)**

In DSSC, a wide bandgap oxide semiconductor is used, as well as a sensitizer that absorbs visible light electromagnetic (EM) waves. In 1972, the chlorophyll-sensitive zinc oxide (ZnO) electrode solar cell (DSSC) was invented [52]. In 1976, Carlson and Wronski published the first 2.4 percent efficient amorphous silicon
photovoltaic cell [53]. Since then, DSSC has grabbed the curiosity of solar energy experts. The main issue is that only 1% of incident solar light can get through a single layer of dye molecules on the surface, limiting further advancement [54]. DSSC research produced a breakthrough in 1991 [53]. The rate of efficiency was 7.1 percent. Approximately 80% of the absorbed photons were converted into electric current [55]. Because of its low production cost and simple structure, many researchers throughout the world have been motivated to enhance its efficiency to a level suitable for commercialization.

The DSSC functions similarly to the photosynthetic process [55], which employs dyes to imitate chlorophyll. Charge (electron) transfer from the DSSC to the external circuit begins when electrons depart the semiconductor network layer, and it ends when the redox mediator in the charge transport medium returns it to the photosensitizer. The purity of the semiconductor material in this generation of solar cells is less significant than in previous generations. A DSSC is depicted in Figure 10.

![Dye-sensitized Solar Cells](image)

**Figure 10. Dye-sensitized Solar Cells [56]**

**Merits:**
1. Cost is lower.
2. Low light and wide-angle operation.
3. It is robust.
4. It has long service life [22].

**Demerits:**
1. It has problem with temperature stability.
2. Raw materials are poisonous and volatile [22].
3. Quantum dot-sensitized solar cells (QDSSCs)

As DSSC research progressed, the notion of using quantum dot-sensitized solar cells to replace dyes surfaced. QDs are nano-scale devices with tiny band gaps that absorb light in the visible spectrum. As a result, the excited electrons of the QDs could be transported to the mesoporous TiO$_2$ layer after depositing on it. In the 1960s, researchers began investigating the use of narrow bandgap materials like dyes to sensitise broadband bandgap semiconductors. Gerisher et al. [57] employed QDs for the first time in 1986 to sensitise broad band gap semiconductors. The DSSC was founded because of advances in sensitization research. QDs were introduced to change colours based on the porous TiO$_2$ DSSCs introduced by O’ Regan and Grätzel [58]. Numerous studies have been undertaken to improve QDSSC’s performance. Currently, the maximum efficiency documented is nearly 9% [59, 60].
Inorganic QDs have various benefits over organic dyes. This is because inorganic QDs are simple to make and last a long time [61]. The optical bandgap of the QDs can also be adjusted [62]. QDs also have the unique ability of generating at least two electron-hole pairs per photon with a hot electron. The effect of ionisation in QD nanoscale semiconductor materials is responsible for this [63].

QDs can also help solar power systems run more efficiently by lowering dark currents. This is due to the high extinction coefficient of QDs [64]. When the carrier diffusion due to the action of ionisation was considered, the theoretical efficiency of QDSSC was 44.4 percent [65]. Figure 11 illustrates a QDSSC.

Figure 11. Quantum dot-sensitized solar cells [66]

There are several parallels and distinctions between QDSSC and DSSC. The sensitizer is where they differ the most. QDSSC makes use of nanoscale semiconductor QDs, while DSSC makes use of light-absorbing dyes. Material compatibility is another distinction. Some materials that operate well in DSSC are incompatible with QDSSC and may have a negative impact on the cell’s performance.

Merits:

- Production cost is low.
- Energy consumption is low [22].

Demerits:

1. It exhibits high toxicity
2. High degradability [22].

3. Perovskite-sensitized Solar Cell

DSSC’s main restrictions are the manufacturing and chemical stability of organic dyes. As a result, a new class of materials called as perovskites and quantum dots (QDs) has been proposed as a molecular dye replacement, with record efficiency of over 20% in ultra-small regions [46]. Recent research has revealed that cost-effective and promising organic-inorganic halide perovskite solar cells are achievable. Because of its high-power conversion efficiency, it’s particularly appealing as a next-generation solar device. In 2009, Miyasaka et al. developed the first perovskite solar cells with a 3.81 percent power conversion efficiency [67]. Perovskite solar cells are now reported to produce more power than organic thin-film solar cells, with a maximum energy conversion efficiency of more than 21% [68]. The highest efficiencies have been achieved using methylammonium lead halide in perovskite solar cells. In the perovskite structure of the general formula ABX$_3$ (X=halogen), the cation ‘A’ occupies the cubic octahedral site, while the cation ‘B’ occupies the cubic unit cell’s octahedral site. A and B are commonly divalent or tetravalent when O$^2-$ anion is used. There are, however, several extra options. At the A and B sites, halogen anions in perovskites ensure...
charge neutrality for monovalent and divalent cations. In this inorganic halide lead perovskite material, A represents the organic methyl-ammonium cation, B represents Pb or Sn, and X represents the halide anion. Cation A must be both large enough to produce a dense perovskite structure and small enough to fit between four adjacent MX$_6$ octahedra with shared corners. Geometrical tolerance coefficients are used to calculate perovskite formability. Optical absorption spectra of different lead halide perovskites, including methyl ammonium iodide, which has a band gap of 1.5 to 1.6 eV [68], were measured up to wavelength 800 nm [68]. It produces a significant amount of light, which is used in solar cells. There are two types of perovskite solar cells: thick layers of TiO$_2$ and mesoporous layers of TiO$_2$. The second is a perovskite-based low molecular weight organic solar cell with just a dense TiO$_2$ layer. Perovskite solar cells have a nearly 40nm [68], thin TiO$_2$ layer on top of a transparent conducting oxide. When light is absorbed by the porous layer of perovskite (CH$_3$CH$_2$NH$_3$PbX$_3$), electron hole pairs with electrons in the conduction band (-3.93 eV) and holes in the valence band are generated (-5.43 eV) [68]. To produce a photocurrent in the device, electrons are injected into TiO$_2$ (-4.0 eV) and holes are transported to a platinum counter electrode (-5.0 eV) [68]. Furthermore, employing roll-to-roll manufacturing techniques, third-generation devices may be easily manufactured from polymer solar cells. The stability and performance of this generation’s solar cell technologies are limited. Although they are still under research, they have a lot of potential. Figure 12 displays perovskite solar cell geometries, which could be easily marketed soon.

Figure 12. Perovskite solar cell configurations [69]

Merits:
1. Production cost is low.
2. It has a simplified structure.
3. Lighter in weight.
4. The flexibility is high.
5. It has high efficiency [22].

Demerits:
It is highly unstable [22].

Black Silicon Solar Cell

Figure 13 depicts a new nanostructured silicon solar cell with a protective film. Nanostructures on silicon surfaces could be a potential way to remove front reflection in solar systems that don’t have anti-reflective coatings. It could also result in lower production costs and higher efficiency for solar cells. Due to enhanced charge carrier recombination at the nanostructured surface, all previous attempts to incorporate black silicon into solar cells resulted in cells that were less than 20% efficient [70]. According to these findings, conformal
alumina films can provide excellent chemical and electrical passivation to black silicon solar cells to solve surface recombination problems. The study shows that in thick interdigitated back contact cells, the efficiency can be over 22%, even though front passivation has a large effect on carrier transport [70]. It thus means that black silicon solar cells have real industrial potential since the recombination problems with the surface have been solved. Furthermore, it shows that energy output with black silicon can be increased by 3% over a reference cell with the same efficiency, because of the improved angular acceptance [70].

Figure 13. Black Silicon Solar Cell [71]

Fourth Generation:

The fourth generation of solar cells are composites that belong to the conjectural generation. The composites are built up of polymers and nanoparticles that have the qualities of a single absorber layer. This generation of solar cells is less expensive and more efficient than previous generations because they can be stacked into thin multispectral layers [68]. The efficiency of a solar cell can be improved by dividing the sunlight spectrum into numerous portions for greater absorption across the whole wavelength range. A buffer layer connects the upper and lower solar cells in tandem solar cell devices. GaAs absorbs solar energy in the upper solar cells, while Si absorbs it further in the bottom solar cells. The produced charge carriers are recovered from the electrodes and transmitted through a photocurrent in the thin buffer layer between the solar cells [68].

4G solar cells are the fourth generation of solar cells. This technology uses a combination of inorganic and organic materials to improve the efficiency and cost-effectiveness of solar panels. The fourth-generation solar cell [72] is built at the solar scale and combines the flexibility of a conductive polymer film (organic material) with the stability of a stable nanostructure (inorganic material).

The most popular solar cell substrate is transparent tin-doped indium oxide, but new alternatives such as graphene, metal nanowires, and metal grid architectures are being developed. Because of the nature of the nanoparticles used in these solar cells, vast amounts of nanomaterials can be filled around the nanomaterial’s utilising conductors such as polymers [72].
In compared to other technologies, 4G solar cells offer the benefit of integrating organic and inorganic substrates to absorb solar energy, resulting in improved efficiency and cost reductions [72].

Fifth Generation:

Maxeon Solar Technologies has introduced a new generation of SunPower Performance 5 double-sided panels. The fifth-generation high-performance solar panel was created with large-scale power plant uses in mind [73]. There are presently over 144 patents and patent applications protecting it. Performance 5 panels are projected to be commercially available in the fourth quarter of 2020, with deliveries starting in the fourth quarter [73]. SunPower Performance 5 panels take advantage of the company’s extensive experience in solar power plant design, development, and construction, allowing them to satisfy the needs of large-scale, multi-megawatt solar power plants [73]. The corporation manages more than 5 gigawatts (GW) of solar power around the world. The new Performance 5 panels are among the first to use double-sided mono PERC (Passivated Emitter and Rear Cell) solar cells made from large 8-inch G12 wafers, delivering industry-leading efficiencies of over 21%, improved shade resistance, and unmatched durability to lower system lifetime energy costs [73].

G12 wafer is a 210 mm full square wafer [74]. It is the largest commercially available wafer. Presently, only four companies are producing it – Canadian Solar Inc. (CSI), Risen, Trina Solar and Maxeon, a spinoff from US-based SunPower [74].

These high-power panels may output up to 625 watts, allowing you to get the most energy out of your space. They are ideally adapted to the needs of power plant developers [73].

Comparison of The Efficiencies of PV Cells

![Figure 14. Development of Laboratory Solar Cell Efficiencies [75]](image)

From Figure 14, it could be concluded that there is a huge increase in the efficiency of III-V Multi-Junction Concentrator Solar Cells over the last decade and had reached an efficiency almost close to 50%. III-V on Silicon cells has shown an exponential rise in efficiency within the time of a few years and looks very promising to photovoltaic development. Mono Crystalline Silicon cells, even though quite popular in utilisation, shows minimal increase in efficiency. On the other hand, the most widely used solar cell, Multi Crystalline Silicon cell has shown more increase in efficiency than Mono Crystalline Silicon. Other types of solar cells like CIGs, CdTe and Perovskite has shown significant increase in their efficiencies, it will still require more research and development before it could be used commercially. Lastly, the Organic solar cells although in its developmental stage has shown an increase in efficiency curve almost the same as III-V Multi-Junction Concentrator Solar Cells. It looks very promising for the future.
Table 2. Comparison of Generations of PV Cells [22, 23]

<table>
<thead>
<tr>
<th>Generation</th>
<th>First Generation</th>
<th>First Generation</th>
<th>Second Generation</th>
<th>Second Generation</th>
<th>Second Generation</th>
<th>Third Generation</th>
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<tbody>
<tr>
<td>Solar Cells</td>
<td>Mono-Crystalline</td>
<td>Poly-Crystalline</td>
<td>Amorphous Silicon</td>
<td>CdTe</td>
<td>CIS/ CIGS</td>
<td>Organic</td>
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<tr>
<td>Efficiency</td>
<td>20%</td>
<td>16%</td>
<td>11.3%</td>
<td>18.3%</td>
<td>22.8%</td>
<td>9 – 11%</td>
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<td>Band gap</td>
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<td>1.7 eV</td>
<td>1.45 eV</td>
<td>1.75 eV</td>
<td>-</td>
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<tr>
<td>Life Span</td>
<td>25 years</td>
<td>14 years</td>
<td>15 years</td>
<td>20 years</td>
<td>12 years</td>
<td>-</td>
</tr>
</tbody>
</table>

SPECIFICATIONS OF SOME SOLAR PANELS IN INDIA

Table 2. Specifications of Some Solar Panels in India [76]

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Solar Panel</th>
<th>Voltage at maximum power (V)</th>
<th>Current at maximum power (A)</th>
<th>Open circuit voltage (V)</th>
<th>Short circuit current (A)</th>
<th>Dimensions (In mm)</th>
<th>Performance Warranty (Years)</th>
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<td>Microtek 150W/12V Polycrystalline Panel</td>
<td>17.72</td>
<td>8.47</td>
<td>22.47</td>
<td>8.90</td>
<td>1495x665x35</td>
<td>25</td>
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<tr>
<td>2</td>
<td>Luminous 100W/12V Polycrystalline Panel</td>
<td>18</td>
<td>5.56</td>
<td>22</td>
<td>6.06</td>
<td>1035x670x34</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Loom solar 125W/12V Monocrystalline Panel</td>
<td>20.4</td>
<td>6.13</td>
<td>23.8</td>
<td>6.45</td>
<td>1020x665x35</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>Su-Kam 100W/12V Polycrystalline Panel</td>
<td>20.4</td>
<td>6.13</td>
<td>23.8</td>
<td>6.45</td>
<td>666x35x1006</td>
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</tr>
<tr>
<td>5</td>
<td>Solodine 100W/12V Polycrystalline Panel</td>
<td>20.4</td>
<td>6.13</td>
<td>23.8</td>
<td>5.1</td>
<td>666x35x1006</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Patanjali 100W/12V Polycrystalline Panel</td>
<td>20.4</td>
<td>6.13</td>
<td>23.8</td>
<td>5.1</td>
<td>666x35x1006</td>
<td>25</td>
</tr>
<tr>
<td>Sl. No.</td>
<td>Solar Panel</td>
<td>Voltage at maximum power (V)</td>
<td>Current at maximum power (A)</td>
<td>Open circuit voltage (V)</td>
<td>Short circuit current (A)</td>
<td>Dimensions (In mm)</td>
<td>Performance Warranty (Years)</td>
</tr>
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<tr>
<td>7</td>
<td>Usha 100W/12V Polycrystalline Panel</td>
<td>18.8</td>
<td>5.72</td>
<td>22.5</td>
<td>5.81</td>
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<td>5.61</td>
<td>21.60</td>
<td>5.98</td>
<td>1055×665</td>
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Conclusion

Evolution of different types of photovoltaic technologies are precisely discussed in this paper. Starting from the first generation of PV cells to the fifth generation, types and performance of the PV cells as well as their application is summarized. This paper starts with the principle of photoelectric effect and photovoltaic conversion of energy and continues with the discussion on its effect on related materials, photovoltaic cell, types, generations, efficiency, production and utilization. Finally, it ended with a quick discussion about present concerns and potential future applications of photovoltaics.

Based on the discussion above, we can conclude that photovoltaic technology is a very promising alternative energy source with a lot of potential. At the present scenario many PV cells are showing their potential in energy generation. Hence, PV cells could overcome their current limitations soon and be used widely in both the industrial and domestic sectors. Additionally, we hope that this review will be useful for understanding of the current trends in the development of the technology of photovoltaic cells.

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