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# A survey on the evolution of solar cell materials

*Romit N. Shirguppi*
*romit232091@gmail.com*
*Gogte Institute of Technology, Belgaum, Karnataka*

*S. G. Kulkarni*
*sgkulkarni@gmail.com*
*Gogte Institute of Technology, Belgaum, Karnataka*

*A. N. Joshi*
*anj_eegit@git.edu*
*Gogte Institute of Technology, Belgaum, Karnataka*

## ABSTRACT

***It is curious to know the evolution of the solar cell materials and hence a literature survey on the enhancement of photoconductivity is done. A survey is conducted to know the properties, advantages, and disadvantages of different solar cell materials used to date.***

***Keywords***: *Evolution, Photovoltaic cell, Survey on solar cell materials, Selenium, Photovoltaic effect*

## 1. INTRODUCTION

A comprehensive treatment on the evolution of solar cells is done to date. The evolution of the solar cell materials has been surveyed to know how there is an enhancement in the efficiency of photovoltaic cells. The evolution started in the photoconductivity of the selenium rods. The first selenium module was produced whose conversion efficiency was less than 1% due to some properties of selenium. The reason for conversion of sunlight into electric current was explained by Einstein with respect to Plank's Theory.

The method of single crystal growth of silicon was invented where the crystallized metal was a single crystal with 1mm in diameter and up to 150cm long. The theory of high purity semiconductor devices/materials was developed which explained how the energy bands of electrons can make a material a conductor a semiconductor or an insulator. The major breakthrough during this period was the discovery of the efficiency of thallium sulphide photocell to be greater than 1% which indicated that solar PV can be used for producing electricity in bulk.

The p-n junction and photovoltaic effects were discovered in silicon that led to the development of silicon solar cells. The first doped silicon solar cell whose efficiency was 1% was produced concluding that semiconductors such as silicon can be doped with a small number of foreign particles to create interesting new properties. After overcoming few disadvantages the first silicon solar cell was produced by The Bell Labs whose conversion efficiency was 6%. This was the beginning for the usage of different types of semiconducting materials for the solar cell operation. However, the use of eco-friendly materials for the manufacture of the solar panels is encouraged.

A Survey is conducted to know the different properties, advantages, and disadvantages of the solar cell materials used till date.

## 2. EVOLUTION PROCESS

### 2.1 First Semi-Conducting Material - Selenium

The photoconductivity of selenium was discovered by Willoughby Smith in 1873 where the conductivity of selenium rods increased significantly when exposed to sunlight. This discovery later led to the invention of photoelectric cells. While selenium seemed the solution in the lab it had a disadvantage that it gave inconsistent results, its conversion efficiency was less and the conductivity of the selenium rods decreased significantly when exposed to strong light. During 1876 William Adams and Richard Day subjected selenium to several experiments, and they used the same selenium bars which were used by Smith. Selenium produces an electrical current when it was exposed to sunlight without any moving part. They concluded that "it was clear that a current could be started in the selenium by the action of the light alone." They felt confident that they had discovered something completely new - that light caused "a flow of electricity" through a solid material. They called the current produced by light to be photoelectric [3] [5].

### 2.2 First Selenium Module

The first "real" working solar module was built in 1883 by Charles Fritts who constructed modules by coating a wide plate of copper with selenium and then topped it with an extremely thin semi-transparent layer of gold leaf. He reported that the module produced a current "that was continuous, constant, and of considerable force". The current was responsive to not only sunlight but to dim daylight and even candlelight. The world's first rooftop solar array, using Fritts module was installed in 1884 on a New York City rooftop. The resulting modules had disadvantages like the electrical conversion efficiency was only 1% due to the properties of selenium, in addition to the cost of selenium, the high cost of gold made these early solar modules not commercially feasible [3] [5].

**2.3 Hallwachs Effect**

Hallwachs in 1888 formulated a hypothesis that a conductive plate on which to focus the ultraviolet light carries a positive charge because the electrons were gouged out. Interestingly this happened with more intensity in selenium. The phenomenon was called the Hallwachs-Effect, now called the photoelectric effect. The investigation of the photoelectric effect laid the foundation for the development of the photoelectric cell, photoelectricity and Albert Einstein's quantum light hypothesis.

**2.4 Photoelectric Cell**

The first to develop the photoelectric cell was Julius Elster and Hans Geitel in 1893. This cell was sensitive to both visible & UV light. These cells could be used to measure the intensity of light.

**2.5 Photoelectric Effect**

The electron concept was not discovered till 1897 and no one knew the reason for the generation of electricity of some materials over the exposure to UV/visible light. Even the wave theory assumed that the emission of an electron from the surface depends on the intensity of the light incident on it. If the intensity of the incident light is high then the electron emission will be more. The electron concept was discovered by J.J. Thomson in 1897. The photoelectric effect was first observed in 1887 by Heinrich Hertz during experiments with a spark-gap generator. Later studies by J.J. Thomson showed that this increased sensitivity was the result of light pushing on electrons (which he discovered in 1897.

The earliest, definitive studies of the photoelectric effect were conducted by P. Linerd. Results of a typical photoelectric experiment were-Red light do not eject photoelectrons (even if it is very bright). Greenlight does eject photoelectrons (even if it is very dim). Blue light ejects photoelectrons with more energy than green light (even if it is very dim). The above results were not typical as most of the elements have threshold frequencies that are in the ultraviolet region of the spectrum and only a few dips down low enough to be green or yellow like the example is shown above. The materials with the lowest threshold frequencies are all semiconductors. Some have threshold frequencies in the infrared region of the spectrum.

Einstein explained the concept in 1905 with respect to Plank's Theory and provided all the answer which made the revolution in semiconductor electronics. He said that light contains packets of energy which he called light quanta or photons. He suggested that the amount of power that quanta carry varies according to the wavelength of light - the shorter the wavelength, the more power. The shortest wavelength contains photons that are about four times as powerful as those of the longest. In semiconductor materials, photons can knock electrons from their atomic orbits and if connected properly by a circuit, could generate enough electricity to do "work" [3] [5].

**2.6 Mono-Crystalline Silicon**

Czochralski invented the single crystal growth of silicon in 1918 when he accidentally dipped his pen into a crucible of molten Tin rather than his inkwell. He immediately pulled his pen out to discover that a thin thread of solidified metal was hanging from the nib. The nib was replaced by a capillary, and he verified that the crystallized metal was a single crystal with 1mm in diameter and up to 150cm long. This method was used for measuring the crystallization rate of metals such as tin, zinc, and lead.

**2.7 High Purity Semiconductors**

The theory of high purity semiconductor devices/materials was developed by A.H. Wilson in 1931, which explained how the energy bands of electrons can make a material a conductor a semiconductor or an insulator.

**2.8 Thallium Sulphide**

The major breakthrough during this period was provided by A.F. Loffe in 1931 where he worked on thallium Sulphide photocell and discovered the efficiency to be greater than 1%. He formulated that solar PV can be used for producing electricity in bulk.

**2.9 Cadmium Sulphide**

The photovoltaic effect in Cadmium Sulphide (CdS) was discovered in 1932 by Audobert and Stora which is still in use. Today the use of CdS in the manufacture of thin-film solar panels is one of the new technologies being hailed to replace the use of costly crystalline silicon solar panels.

**2.10 PN Junction and Photovoltaic Effect in Silicon**

Russel Ohl discovered the p-n junction and photovoltaic effects in silicon in 1940 that led to the development of solar cells. Much of his research was devoted to producing ultra-pure silicon crystals. His purified crystals were now 99.8% pure. He said that the imperfection in silicon crystals allow the crystals to continuously emit electricity when the light is fed on them. It is the impurities that make such sections more resistant to electric flow than others. And thus it is the barrier between these areas of different purity that make the crystal work. He exposed silicon slab to bright light, the current flowing through the slab jumped appreciably. He also noticed that different parts of the crystal yielded opposite electrical effects. He and his colleague Jack Scaff found a separation of the silicon into regions containing distinct kinds of impurities. One impurity, the element phosphorus yielded a slight excess of electrons in the sample while the other, boron, led to a slight deficiency (later recognized as "holes"). They called the regions n-type (for negative) and p-type (positive); the surface or "barrier" where these regions met became known as a "p-n junction." Light striking this junction stimulated electrons to flow from then-side to the p-side, resulting in an electric current. In 1941 Ohl created the first doped silicon solar cell whose efficiency was 1%. He discovered that semiconductors such as silicon can be doped with a small number of foreign particles to create interesting new properties [3] [5].

**2.11 Germanium**
The first single crystal growth of germanium was proposed by G.K. Teal and J.B. Little in 1948. They improved the Czochralski Process of crystal growth. These solar cells are more efficient & expensive and are used mainly in space applications. They produced the first monocrystalline silicon and it is the building block of a solar cell. The first theoretical calculation of the efficiencies of various semiconductor materials of different band gaps based on the spectrum of the sun was proposed by Dan Trivich in 1953.

**2.12 Bell Labs –First Practical Solar Cell**
Pearson was an experimentalist while Fuller, a chemist, learned how to control the addition of impurities that would transform silicon into good semiconductor devices. During one of their experiments with gallium doped silicon which was then treated with a lithium bath, they had inadvertently developed a pretty good solar cell. In sunlight with wires connected to the p-n junction, Pearson recorded a significant current.

Chapin worked on commercial selenium cell and found that it only had an energy efficiency of about 0.5 percent which was very less and Pearson suggested him to leave selenium and gave him a silicon solar cell developed earlier. Chapin measured the efficiency and concluded the efficiency to be 2.3%. As it was much better than selenium, he dropped selenium and concentrated on improving the silicon cell with a goal to reach an efficiency of 5.7 percent. After months of work, he had not been able to improve the first silicon cell that Pearson had given him. One problem was making good electrical contact with the silicon and another was that lithium could migrate further into the cell at room temperature and therefore move the p-n junction further away from the surface. Chapin then guessed that the p-n junction should be near the surface and he coated phosphorous vaporized onto positive silicon. However, after a month of work with poor results he had found that the shiny surface was reflecting the sunlight rather than absorbing it. Therefore he coated the cell with dull plastic coating and got an energy conversion efficiency of about 4%. Now he used arsenic to give the silicon a negative charge and used boron to create a thin positive top layer. Three samples were treated with the dull plastic coating and tested and one achieved an energy efficiency of nearly six percent in early 1954 [3] [5].

## 3. SOLAR CELL MATERIALS WITH ENHANCED EFFICIENCY
Hoffman Electronics developed solar cells which had an efficiency of 8% in 1957, 9% in 1958 and 10% in 1960. They enhanced the performance by reducing the contact resistance of the materials. Amorphous silicon was first used in solar powered wristwatches in 1968. The highly effective GaAs heterostructure solar cell was created by Zores Alferov in 1970. The amorphous solar cell with an efficiency of 2.6% was developed in 1976 by RCA Labs. The first solar-powered calculator was developed in 1978 using amorphous silicon. The thin film solar cell efficiency exceeding 10% was developed by the Institute of Delaware by using $Cu_2$/CdS technology in 1980. The Kyocera Corp is the first manufacturer to mass produce polysilicon using costing method, today’s industry standard, 20% efficient cells were obtained under 1 sun conditions. Reflectors were first used in silicon solar cells in 1989. An efficiency of 35% was obtained for concentrator solar cells in 1990. By using Cadmium Telluride an efficiency of 16% was achieved for thin film cells in 1992. The NREL developed a new solar cell from Gallium Indium Phosphide and Gallium Arsenide that exceeded 30% conversion efficiency in 1994.

Two new thin-film solar modules were developed in 2000 which broke the previous records. The $0.5m^2$ modules achieve 10.8% efficiency, the highest in the world of its kind and its $0.9m^2$ module achieves 10.6% efficiency and a power output of 91.5watts, the highest power output for any module at that time. Since then many solar cell technologies were developed [3] [5].

## 4. DEVELOPMENTS IN SOLAR CELL MATERIALS
Around 1960s Dr. Fred Shurland, substituted CDs, a substance which also produces the photovoltaic effect, for Silicon. In 1967 his firm developed a new photovoltaic cell that could be mass produced economically by deposition of CDs onto plastic. However, a low-cost CdS cell could never materialize. Majority of such cells failed when exposed to other elements. While many researchers continued to work on CdS during the 1960s and 1970s, a few others toyed with the idea of making low-cost solar cells from dyes which can convert sunlight into electricity. Later on, this idea resurfaced in a modified form.

In that era, c-Si remained the dominant solar cell material, essentially the same substance that was discovered at Bell Telephone Labs in the early 1950s. The crystals for single crystal Silicon cells continue to be grown as they were in Chapin’s time by melting Silicon at 1410 degree Celsius. Over the next two decades, the researchers could enhance the efficiency of polycrystalline Si cells by a few percentage points only but never beyond six percent. This led to the understanding that higher efficiency could not be reached with this material. This was disproved by Lindenmayer, .who found another way to lower the price of solar cells was to direct more light on them than they would ordinarily receive, built of inexpensive plastic concentrators work like a magnifying glass. It was possible to produce the same amount of electricity with 95 percent less solar cell materials than previously required by focussing 20 times the sun’s energy onto solar cell panels. A method of manufacturing low-cost solar cell involves depositing a small amount of solar cell material onto an inexpensive supporting material, like glass or plastic. Solar cells made in this way are known as thin films.

In 1976, Radio Corporation of America (RCA) could achieve the 5.5 percent efficiency in the a-Si solar cell from a mere 0.2 percent. The achievement of relatively high efficiency surprised many researchers as the prevailing theoretical models predicted against the development of solar cell devices out of amorphous materials. By inadvertently contaminating a-Si with hydrogen the scientists at RCA improved the photovoltaic capabilities greatly. It was called hydrogenated amorphous Silicon (a-SiH). However, it turned out that a-Si solar cell had a self-destructive characteristic. Subsequently, it was discovered that if the cells were made very thin this self-destructive characteristic could be checked. Further research on this understanding led to the achievement of 10 percent efficiency in a-SiH by 1982. Dr. Subehndu Guha, a scientist of Indian origin, at United Solar Systems Corporation, a manufacturer of a-SiH modules, stacked three subcells to form the most efficient amorphous solar device ever built. Each layer responds to a different spectrum. The bottom layer, made of Germanium (Ge), absorbs green light. The spectral-splitting method allows more absorption of the solar spectrum. Moreover, unlike c-Si, amorphous solar cells gain power as temperatures increases, which is ideal for rooftop installation as well as very hot climates in the developing world. An advantage in manufacturing any thin film solar device is that it requires lesser energy than the production of the traditional solar cell.

## 5. PHOTOVOLTAIC COMPOUNDS AND ALLOYS

### 5.1 First Generation Materials

Research on a large number of different types of solar cells is being pursued, which include c-Si, a-Si, CdTe and Copper Indium Diselenide. The candidature of Cadmium is fraught with environmental issues on account of its toxicity. However, most of the solar cells being produced have been based on first generation materials based on crystalline or multi-crystalline silicon wafers. Over the last, more than five decades c-Si solar cells have the longest production history and account for about 90% of entire solar cell production in 2008. C-Si solar cells are also capable of providing highest energy conversion efficiencies of all commercial cells are abundantly available in nature and environmentally safe. Passivated Emitter Rear Localized (PERL) monocrystalline Si solar cell remains the most efficient type of cell during the past decade. Fraunhofer Institute of Solar Energy has developed a polycrystalline silicon solar cell with 20.3% energy conversion efficiency. C-Si cells have proven long track record of field operation and provide high efficiency at the same time offering fewer resource issues than many competing technologies.

#### 5.1.1 Mono-crystalline Silicon

| | | |
|---|---|---|
| Band gap – 1.1eV | Area of the cell – 79cm$^2$ | Open circuit voltage – 0.738V |
| Current density – 42.65mA/cm$^2$ | Fill factor – 84.9% | Efficiency - 26.7% -- [4] [8] |

**Advantages**: These solar panels have the highest efficiency among all silicon panels since they are made out of the highest-grade silicon. These are space-efficient and yield the highest power outputs. They require the least amount of space compared to any other types. They produce power up to four times when compared to thin-film solar panels. These panels live the longest and tend to perform better than similarly rated polycrystalline solar panels at low-light conditions [1] [2] [6].

**Disadvantages**: These panels are the most expensive when compared to polycrystalline silicon and thin-film. When the solar panel is partially covered with shade, dirt or snow, the entire circuit can break down. The Czochralski process results in large cylindrical ingots were four sides are cut out of the ingots to make silicon wafers where a significant amount of the original silicon ends up as waste. They tend to be more efficient in warm weather and performance suffers as temperature goes up, but less so than polycrystalline solar panels [1] [2] [6].

#### 5.1.2 Polycrystalline Silicon

| | | |
|---|---|---|
| Band gap – 1.1eV | Area of the cell – 3.923cm$^2$ | Open circuit voltage – 0.6742V |
| Current density – 41.08mA/cm$^2$ | Fill factor – 80.5% | Efficiency – 22.3% -- [4] [8] |

**Advantages**: The process used to make polycrystalline silicon is simpler and cost-effective. The amount of waste silicon is less compared to mono-crystalline. Unlike mono-crystalline based solar panels, these panels do not require the Czochralski process. They tend to have slightly lower heat tolerance than mono-crystalline solar panels which means that they perform slightly worse than mono-crystalline solar panels in high temperatures. Heat can affect the performance of solar panels and shorten their lifespan [1] [2] [6].

**Disadvantages**: The efficiency of polycrystalline-based solar panels is typically 13-16% because of lower silicon purity, these solar panels are not quite as efficient as mono-crystalline solar panels. It has a Lower space-efficiency which means that you need to cover a larger surface to output the same electrical power as you would with a solar panel made of monocrystalline silicon. Mono-crystalline and thin-film solar panels tend to be more aesthetically pleasing since they have a more uniform look compared to the speckled blue color of polycrystalline silicon [1] [2] [6].

### 5.2 Second Generation Materials

The Second generation thin film solar cells based on amorphous silicon/ hydrogen alloys or polycrystalline compounds have started appearing in increasing volume. The cells based on dye-sensitized, organic and nano solar cells have also registered their presence in the market. Lots of developments have taken place in exploring new materials for developing solar cells and at the same time increasing their conversion efficiency during the last two decades or so. These include solar cells based on materials like GaAs, $GaInP_2$, aSi: H, CIGS, and CdTe, dye-sensitized nano-structured TiO2 solar cells etc. Second generation solar cells are cost-effective but they have lower efficiency.

#### 5.2.1 Amorphous Silicon

| | | |
|---|---|---|
| Band gap - 1.7eV | Area of the cell – 1cm$^2$ | Open circuit voltage - 0.896V |
| Current density – 16.36mA/cm$^2$ | Fill factor – 69.8% | Efficiency – 10.5% -- [4] [8] |

**Advantages:** The advantage of these cells is their lower manufacturing cost. Since amorphous silicon is full of defects naturally, any other defects such as impurities, do not affect the overall characteristics of the material. They can be produced in a variety of shapes and sizes like round, square, hexagonal, or any other complex shape which makes it an ideal technology to use in a variety of applications such as powering electronic calculators, solar wristwatches, garden lights, and to power car accessories. Unlike crystalline solar cells in which cells are cut apart and then recombined, these cells can be connected in series at the same time when the cells are formed making it is easy to create panels in a variety of voltages. Some panels also come with shade-resistant technology or multiple circuits within the cells, so that if an entire row of cells is subject to complete shading, the circuit won't be completely broken and some output can still be gained. This is especially useful when installing solar panels on a boat. The development process of a-Si solar panels also renders them much less susceptible to breakage during transport or installation. This can help reduce the risk of damaging your significant investment in a photovoltaic system. It has greater resistance to heat which means that these modules experience higher results as temperatures increases [1] [2] [6].

**Disadvantages:** These panels have a lower efficiency than mono-crystalline cells or polycrystalline cells. The expected lifetime of amorphous cells is shorter than the lifetime of crystalline cells [1] [2] [6].

**5.2.2 Cadmium Telluride**

| | | |
|---|---|---|
| Band gap – 1.49eV | Area of the cell – 1.06cm$^2$ | Open circuit voltage - 0.8759V |
| Current density – 30.25mA/cm$^2$ | Fill factor – 79.4% | Efficiency – 21.3% -- [4] [8] |

**Advantages ---**Due to its high efficiency of about 21% when compared to amorphous silicon as well as production costs that are far below those of silicon-based solar modules, CdTe solar cells are currently one of the most employed thin films and rank only second to crystalline panels. Due to a sunlight absorption rate that is close to the ideal wavelength, these modules are much more efficient than silicon cells. Cadmium is a waste and by-product in the mining industry which is an abundant resource and thus less prone to price fluctuations [1] [2] [6].

**Disadvantages** --- It is difficult to procure Tellurium, which is as scarce as gold which makes it costly. Apart from that, CdTe is toxic and modules using CdTe solar cells are thus bound to have a restriction. The main concern with CdTe panels is pollution. Cadmium is one of the most toxic materials and CdTe also has some toxic properties. The general opinion on using CdTe is that it is not harmful to humans or the environment in residential or industrial rooftop applications, but disposal of old CdTe panels continues to be a concern [1] [2] [6].

**5.2.3 Copper Indium Gallium Selenide**

| | | |
|---|---|---|
| Band gap – 1.7eV | Area of the cell – 1cm$^2$ | Open circuit voltage – 0.718V |
| Current density – 40.07mA/cm$^2$ | Fill factor – 74.3% | Efficiency – 21.7% -- [4] [8] |

**Advantages** --- Unlike most thin-film solar technologies, CIGS solar panels offer a potentially competitive efficiency to traditional silicon panels. The efficiency of these panels exceeds 20%. CIGS cells also use the toxic chemical cadmium but CdTe panels have a higher percentage of cadmium, and CIGS cells are a relatively responsible thin-film option for the environment. Even in some models, the cadmium is completely removed in favor of zinc. This material can be deposited on substrates such as glass, plastic, steel, and aluminum, and when deposited on a flexible backing, the layers are thin enough to be allowing full-panel flexibility [1] [2] [6].

**Disadvantage** ---The manufacturing process of these panels is costly where they can't compete with traditional silicon or cadmium telluride panels. Production costs continue to be an issue for the CIGS solar panel market [1] [2] [6].

**5.2.4 Organic Cell**

| | | |
|---|---|---|
| Area of the cell – 0.99cm$^2$ | Open circuit voltage – 0.780V | Current density – 19.30mA/cm$^2$ |
| Fill factor – 74.2% | Efficiency – 11.2% -- [4] [8] | |

**Advantages**: Due to the ability to use various absorbers in an organic cell, these cells can be colored in several ways, or even made transparent, which has many applications in unique solar solutions. The materials needed to build organic solar cells are abundant, leading to low manufacturing costs and subsequently low market prices [1] [2] [6].

**Disadvantages**: They operate at relatively low efficiencies of about 11%. Much of the research currently surrounding OPVs is on how to boost their efficiency. It has a shorter lifespan than both thin-film options and traditional mono-or poly-crystalline panels. Cell degradation occurs in organically-based photovoltaic products but it does not occur in inorganic cells [1] [2] [6].

**5.3 Third Generation Materials**

The third generation of solar cells include technologies like a quantum dot, tandem/ multi-junction cells, upconversion and down conversion technologies. The approach is to use high-efficiency devices but still use thin film, second-generation deposition methods. To overcome efficiency barriers of c-Si solar cell the University of South Wales has initiated research on Quantum Dot technology however, these technologies incur higher costs compared to standard silicon cells. The high-efficiency tandem cells are based on single crystal Group III-V materials, like, GaAs, GaInP, GaInAs with a substrate of Germanium (Ge). This also includes organic/polymer and dye-sensitized solar cells but they have stability issue as compared to Si solar cells.

**5.3.1 Dye Sensitised Cell**

| | | |
|---|---|---|
| Area of the cell – 1.005cm$^2$ | Open circuit voltage – 0.744V | Current density – 22.47mA/cm$^2$ |
| Fill factor – 71.2% | Efficiency – 11.9% -- [4] [8] | |

**Advantages**: Low production cost and lower investment costs compared with conventional PV technologies and are nontoxic. There is feedstock availability to reach terawatt scale. These cells have enhanced performance under real outdoor conditions mainly at the diffuse light and higher temperature. Bifacial cells capture light from all angles. Cell voltage does not decrease much under low light intensity. Performance is stable over a long lifetime. They have design opportunities such as transparency and multi- color options. They are flexible and have lightweight [1] [2] [6].

 

**Disadvantages**: There were difficulties with sealing the cell causing leakage and evaporation of the electrolyte. They had lower efficiencies compared with conventional solar cells due to the corrosive nature of the iodide/tri-iodide redox mediator. There were difficulties in scaling up the production to large modules [1] [2] [6].

**5.3.2 Quantum Dot Cell**

**Advantages**: They have favorable power to weight ratio. They have High efficiency. Mass and area savings, as well as flexibility, leads to miniaturization. They have lower power consumption. Versatility. Increased electrical performance at low production costs. They can be used in complete buildings including windows and not just rooftops [1] [2] [6].

**Disadvantages**: CdSe based quantum dot solar cells are highly toxic in nature and require very stable polymer shell. In aqueous and UV conditions its degradation increases. This is being studied. The shells can alter optical properties and it is hard to control the size of the particles [1] [2] [6].

**5.3.3 Perovskite solar cell**

| | | |
|---|---|---|
| Bandgap – 1.5 to 2.3eV | Area of the cell – 0.991$cm^2$ | Open circuit voltage – 1.125V |
| Current density – 24.92$mA/cm^2$ | Fill factor – 74.5% | Efficiency – 27.9% -- [4] [8] |

**Advantages**: Perovskite material offers direct optical band gap of around 1.5eV. These materials offer long diffusion length and long minority carrier lifetimes. It has broad absorption range from visible to near infrared spectrum (800 nm) and high absorption coefficient ($10^5$ $cm^{-1}$ ). These cells deliver efficiencies of more than 22%. Perovskite materials such as methylammonium lead halides are far inexpensive and simple to manufacture. It has high dielectric constant, fast charge separation process, long transport distance of electrons and holes and long carrier separation lifetime. This low-cost material helps in converting windows of buildings, top of cars and walls to achieve solar power generation. Perovskite uses less material in order to absorb the same amount of light compared to silicon. Hence it is cheaper than silicon [1] [2] [6].

**Disadvantages** --- Degradation issue of methylammonium lead iodide perovskite need to be studied. Main issues in perovskite solar cells are film quality and thickness. The perovskite material will break down quickly due to exposure to heat, moisture, snow etc. The material is toxic in nature [1] [2] [6].

**5.4 Fourth Generation Materials**

New knowledge and understanding are still being conceived and evolved in developing high efficiency, environmentally friendly and practical solar cells. However, multi-junction group III-V concentrator of different types have a conversion efficiency of over 40% and is the only third generation technology to enter commercial power generation market so far. The fourth generation solar cell which is the current technological pursuits characterize inorganics in organics. Inorganic nano-components like graphene and its derivates, metal oxides, metal nanoparticles, carbon nanotube have played a central role in improving device performance and longevity of third generation polymer solar cells. The search for new material is exemplified by Copper Zinc Tin Sulphide (CZTS) which is emerging alternative to the toxic CdTe and expensive CIGS materials. Solar cell research is being pursued vigorously in most parts of the world, including India.

## 6. CONCLUSION

A comprehensive treatment on the evolution of solar cells is done to date. The evolution of the solar cell materials has been surveyed to know how there is an enhancement in the efficiency of photovoltaic cells. A Survey is conducted to know the different properties, advantages, and disadvantages of the solar cell materials.

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