

# Types of Solar Cells and its Applications

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**Abstract:** A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a p-n junction. With regard to the development of sustainable energy, such as solar energy, in this article we will Study types of solar cells and their applications.

**Keywords:** solar cells, semiconductor materials, sustainable energy, absorption, photovoltaic energy

## 1. Introduction

The Earth receives an incredible supply of solar energy. The sun, an average star, is a fusion reactor that has been burning over 4 billion years. It provides enough energy in one minute to supply the world's energy needs for one year. In one day, it provides more energy than our current population would consume in 27 years. In fact, "The amount of solar radiation striking the earth over a three-day period is equivalent to the energy stored in all fossil energy sources." Solar energy is a free, inexhaustible resource, yet harnessing it is a relatively new idea. Considering that "the first practical solar cells were made less than 30 years ago," we have come a long way. The prolongation of solar professional companies designing unique and specific solar power systems for individual homes means there is no longer an excuse not to consider solar power for your home. The biggest jumps in efficiency came "with the advent of the transistor and accompanying semiconductor technology. There are several advantages of photovoltaic solar power that make it "one of the most promising renewable energy sources in the world." It is non-polluting, has no moving parts that could break down, requires little maintenance and no supervision, and has a life of 20-30 years with low running costs. It is especially unique because no large-scale installation is required. Remote areas can easily produce their own supply of electricity by constructing as small or as large of a system as needed. Solar power generators are simply distributed to homes, schools, or businesses, where their assembly requires no extra development or land area and their function is safe and quiet. As communities grow, more solar energy capacity can be added. Solar energy is most sought today in developing countries, the fastest growing segment of the photovoltaic's market. People go without electricity as the sun beats down on the land, making solar power the obvious energy choice. "Governments are finding its modular, decentralized character ideal for filling the electric needs of the thousands of remote villages in their countries." It is much more practical than the extension of expensive power lines into remote areas, where people do not have the money to pay for conventional electricity. There are only two primary disadvantages to using solar power: amount of sunlight and cost of equipment. The amount of sunlight a location receives "varies greatly depending on geographical location, time of day, season and clouds. Considering the importance of the use of solar cells and efficient use of solar energy, in this article we will examine the different types of solar cells.

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.[1] It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels. Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

The operation of a photovoltaic (PV) cell requires 3 basic attributes:

1. The absorption of light, generating either electron-hole pairs or exactions.
2. The separation of charge carriers of opposite types.
3. The separate extraction of those carriers to an external circuit.

The first generation cells—also called conventional, traditional or wafer-based cells—are made of crystalline silicon, the commercially predominant PV technology, that includes materials such as polysilicon and monocrystalline silicon. Second generation cells are thin film solar cells that include amorphous silicon, CdTe and CIGS cells and are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics or in small stand-alone power system. The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaics—most of them

have not yet been commercially applied and are still in the research or development phase. Many use organic materials, often organometallic compounds as well as inorganic substances. Despite the fact that their efficiencies had been low and the stability of the absorber material was often too short for commercial applications, there is a lot of research invested into these technologies as they promise to achieve the goal of producing low-cost, high-efficient solar cells.

1

“First generation” panels include silicon solar cells. They are made from a single silicon crystal (mono-crystalline), or cut from a block of silicon that is made up of many crystals (multi-crystalline - shown at right).

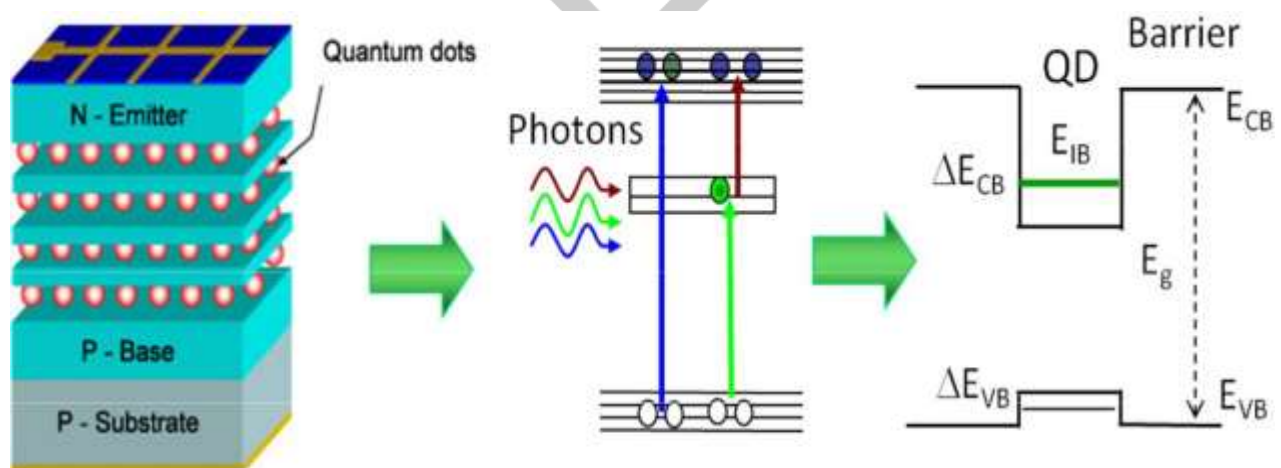
2

“Second generation” thin-film solar cells are less expensive to produce than traditional silicon solar cells as they require a decreased amount of materials for construction. The thin-film PV cells are, just as the name implies, a physically thin technology that has been applied to photovoltaics. They are only slightly less efficient than other types but do require more surface area to generate the same are formed by vapor-depositing a thin layer of silicon material – about 1 micrometer thick – on a substrate material such as glass or metal. Amorphous silicon can also be deposited at very low temperatures, as low as 75 degrees Celsius, which allows for deposition on plastic as well. In its simplest form, the cell structure has a single sequence of p-i-n layers. However, single layer cells suffer from significant degradation in their power output (in the range 15-35%) when exposed to the sun. The mechanism of degradation is called the Staebler-Wronski Effect, after its discoverers. Better stability requires the use of a thinner layers in order to increase the electric field strength across the material. However, this reduces light absorption, hence cell efficiency. This has led the industry to develop tandem and even triple layer devices that contain p-i-n cells stacked one on top of the other. One of the pioneers of developing solar cells using amorphous silicon is Uni-Solar. They use a triple layer system (see illustration below) that is optimized to capture light from the full solar spectrum. As you can see from the illustration, the thickness of the solar cell is just 1 micron, or about 1/300th the size of mono-crystalline silicon solar cell. While crystalline silicon achieves a yield of about 18 percent, amorphous solar cells’ yield remains at around 7 percent. The low efficiency rate is partly due to the Staebler-Wronski effect, which manifests itself in the first hours when the panels are exposed to sunlight, and results in a decrease in the energy yield of an amorphous silicon panel from 10 percent to around 7 percent. The principal advantage of amorphous silicon solar cells is their lower manufacturing costs, which makes these cells very cost competitive.

## 2.1 Quantum Dot Solar Cell

A quantum dot solar cell is a solar cell design that uses quantum dots as the absorbing photovoltaic material. It attempts to replace bulk materials such as silicon, copper indium gallium selenide (CIGS) or CdTe. Quantum dots have bandgaps that are tunable across a wide range of energy levels by changing the dots' size. In bulk materials the bandgap is fixed by the choice of material(s). This property makes quantum dots attractive for multi-junction solar cells, where a variety of materials are used to improve efficiency by harvesting multiple portions of the solar spectrum. Quantum dots are semiconducting particles that have been reduced below the size of the Exciton Bohr radius and due to quantum mechanics considerations, the electron energies that can exist within them become finite, much alike energies in an atom. Quantum dots have been referred to as "artificial atoms". These energy levels are tuneable by changing their size, which in turn defines the bandgap. The dots can be grown over a range of sizes, allowing them to express a variety of bandgaps without changing the underlying material or construction techniques.[67] In typical wet chemistry preparations, the tuning is accomplished by varying the synthesis duration or temperature.

The ability to tune the bandgap makes quantum dots desirable for solar cells. Single junction implementations using lead sulfide (PbS) CQDs have bandgaps that can be tuned into the far infrared, frequencies that are typically difficult to achieve with traditional. Half of the solar energy reaching the Earth is in the infrared, most in the near infrared region. A quantum dot solar cell makes infrared energy as accessible as any other.[68]



*Schematic of operating principle and energy band diagram of proposed III-(As, Sb)solar cell*

*Figure 2.1: Quantum dot solar cell.*

Moreover, CQDs offer easy synthesis and preparation. While suspended in a colloidal liquid form they can be easily handled throughout production, with a fumehood as the most complex equipment needed. CQDs are typically synthesized in small batches, but can be mass-produced. The dots can be distributed on a substrate by spin coating, either by hand or in an automated process. Large-scale production could use spray-on or roll-printing systems, dramatically reducing module construction costs. Early examples used costly molecular beam epitaxy processes, but less expensive fabrication methods were later developed. These use wet chemistry (colloidal quantum dots – CQDs) and subsequent solution processing. Concentrated nanoparticle solutions are stabilized by long hydrocarbon ligands that keep the nanocrystals suspended in solution. To create a solid, these solutions are cast down[clarification needed] and the long stabilizing ligands are replaced with short-chain crosslinkers. Chemically engineering the nanocrystal surface can better passivate the nanocrystals and reduce detrimental trap states that would curtail device performance by means of carrier recombination. This approach produces an efficiency of 7.0%.[69] In 2014 the use of iodide as a ligand that does not bond to oxygen was introduced. This maintains stable n- and p-type layers, boosting the absorption efficiency, which produced power conversion efficiency up to 8%.[70] Solid-state solar cell

## 2.2 Thin Film Solar Cell (TFSC)

A thin-film solar cell (TFSC), also called a thin-film photovoltaic cell (TFPV), is a second generation solar cell that is made by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous and other thin-film silicon (a-Si, TF-Si).

Film thickness varies from a few nanometers (nm) to tens of micrometers ( $\mu\text{m}$ ), much thinner than thin-film's rival technology, the conventional, first-generation crystalline in most solar PV systems.[71]:23,24 Despite these enhancements, market-share of thin-film never reached more than 20 percent in the last two decades and has been declining in recent years to about 9 percent of worldwide photovoltaic production in 2013.[71] Other thin-film technologies, that are still in an early stage of ongoing research or with limited commercial availability, are often classified as emerging or third generation photovoltaic cells and include, organic, dye-sensitized, and polymer solar cells, as well as quantum dot, copper zinc tin sulfide, nanocrystal, micromorph and perovskite solar cells.

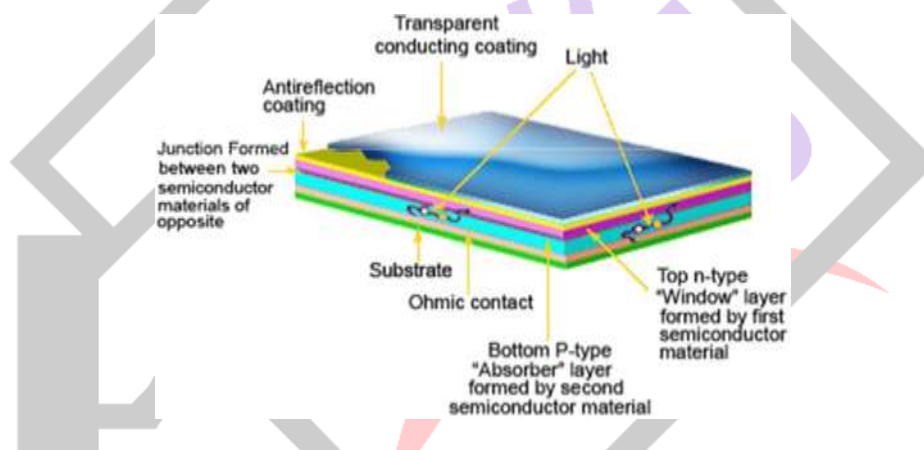


Figure 2.2: Structure of thin film solar cells.

## 2.3 Black Silicon Solar Cells

Black silicon solar cells are similar to crystalline silicon solar cells. Really similar. The difference is that black silicon solar cells are treated so that they appear to be black on the surface. Why is that a big deal? Think of wearing a black T-shirt on a hot summer day. The black color tends to absorb more sunlight, which translates to an uncomfortable summer afternoon for you, but more energy gathered for a solar cell. It's an attractive option for areas that don't get as much sunlight but still want to make good use of the light they do receive. Until now, turning silicon cells black tended to undercut their efficiency at turning sunlight into power, however. Black silicon can be manufactured simply by adding a dense network of nanoscale needles on top of a standard piece of silicon. Modifying the material in this way makes it a lot less reflective, allowing solar cells that use it to trap light even when it's coming from very low angles. This could be a good way to increase the yield of solar cells throughout the day, particularly in countries at higher latitudes. On top of this, black silicon cells could also be cheaper, as they don't need the antireflection coatings used by many other types of solar cells. The main issue that has stifled the progress of black silicon cells is something known as carrier recombination. When a photon hits a silicon atom inside a solar cell, the excess energy frees up an electron that is later used to generate electricity. Using Black Silicon as substrate allows fabricating Black Silicon solar cells. For the Black Silicon laser process, the laser pulse shape was altered by optical laser pulse shaping equipment. With these shaped laser pulses, less crystal damage is achieved in the silicon This facilitates minimizing surface recombination losses. The laser structuring itself simultaneously forms the front side texture and the emitter in one single process step, while it also modifies the raw silicon material enabling it to absorb the IR portion of the sun spectra. Using Black Silicon as substrate allows to fabricate Black Silicon solar cells. For the Black Silicon laser process, the laser pulse shape was altered by optical laser pulse shaping equipment. With these shaped



laser pulses, less crystal damage is achieved in the silicon during the laser silicon interaction. This facilitates minimizing surface recombination losses. The laser structuring itself simultaneously forms the front side texture and the emitter in one single process step, while it also modifies the raw silicon material enabling it to absorb the IR portion of the sun spectra. After laser structuring, evaporated front contacts and a screen printed rear contact are deposited. An edge isolation is not necessary, as the emitter is only formed on the front side. The process flow of the femtosecond laser processed Black Silicon solar cell is displayed. As the front side texturing and the emitter formation take place during the laser process, the total number of process steps is significantly reduced and can potentially cut production costs. The finished solar cells display high short circuit current densities in the range of  $38\text{mA/cm}^2 < J_{sc} < 42\text{mA/cm}^2$  due to their increased absorption of IR light. We achieve an efficiency of 4.5% with no passivation layers applied. The previously reported record efficiency realized by Harvard University was 2.2% for a laser processed Black Silicon solar cell.

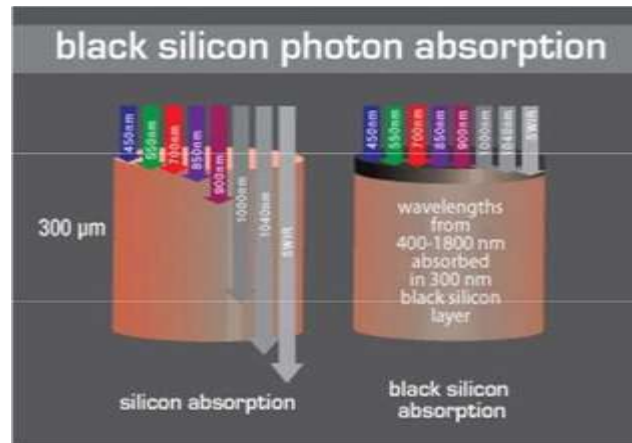


Figure 2.3: The Future of Black Silicon.

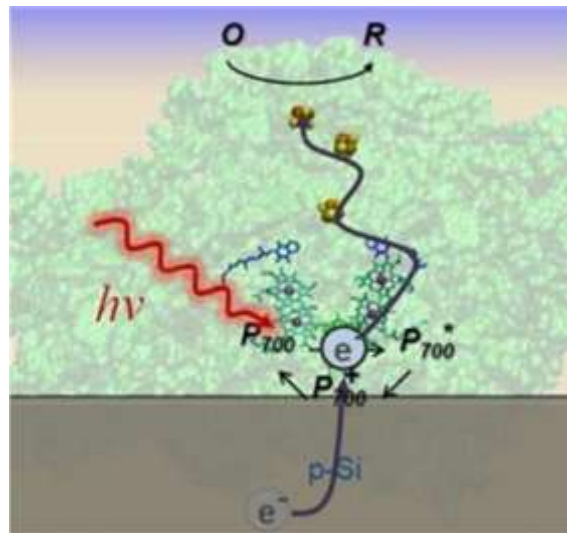
Occasionally, though, the electron simply recombines with a silicon atom, effectively wasting the energy provided by the photon. Recombination is proportional to the surface area of the silicon, and the needles on the surface of dark silicon raise surface area so much that about half of the freed electrons are "lost" in this way. Now, a team of researchers led by assistant professor Hele Savin has managed to get around the issue, and in so doing, it has increased the record efficiency of black silicon cells by almost four percentage points, up to 22.1 percent. Their real-life performance of silicon solar cell (c-Si), that uses silicon wafers of up to 200  $\mu\text{m}$ . This allows thin film cells to be flexible, lower in weight, and have less drag. It is used in building integrated photovoltaics and as semi-transparent, photovoltaic glazing material that can be laminated onto windows. Other commercial applications use rigid thin film solar panels (sandwiched between two panes of glass) in some of the world's largest photovoltaic power stations.

same nominal efficiency over the course of the entire day. Savin and colleagues put recombination in check by applying a thin aluminum film, acting like a chemical and electronic shield, on top of the nanostructures. They also integrated all the metal contacts on the back side of the cell, for added absorption. Two changes meant that only four percent of the freed up electrons recombined, as opposed to the previous 50 percent. The new cell design is however likely not pushing this technology to its limit just yet, since it made use of p-type silicon rather than the more durable n-type silicon. According to the scientists, a better choice of materials or a better cell structure would push efficiencies even further. The near-term goal for the researchers is to apply their technology to other cell structures, thin and multi-crystalline cells in particular – but also, Savin tells us, other devices like screens and photodetectors.

## 2.4 Biohybrid Solar Cell

A biohybrid solar cell is a solar cell made using a combination of organic matter (photosystem I) and inorganic matter. Biohybrid solar cells have been made by a team of researchers at Vanderbilt University. The team used the photosystem I (a photoactive protein complex located in the thylakoid membrane) to recreate the natural process of photosynthesis to obtain a greater efficiency in solar energy conversion. These biohybrid solar cells are a new type of renewable energy.[3][4]

Multiple layers of photosystem I gather photonic energy, convert it into chemical energy and create a current that goes through the cell. The cell itself consists of many of the same non-organic materials that are found in other solar cells with the exception of the injected photosystem I complexes which are introduced and gathered for several days in the gold layer. After days the photosystem I are made visible and appear as a thin green film. It is this thin film that helps and improves the energy conversion. The biohybrid cell however, is still in the research phase. The team from Vanderbilt University began conducting research on the photosynthesis when they began to see and focus on the photosystem I protein. After seeing how widely available and efficient the protein was at solar conversion they began to look to incorporate and improve different technologies. The team used spinach as their source for the photosystem I. Thylakoid membranes were isolated and then went into a purification process to separate the photosystem I from the thylakoid membrane. Their research resulted in a greatly improved electrical current (1000 times greater) compared to those previously made by other solar cells. The team has been gathering a group of undergraduate engineers to help build the first prototype of the biohybrid solar cell. The team has also come up with a second design of the protein complex the photosystem II.



*Figure 2.4: Making Multilayered Bio-Hybrid Solar cells.*

### 2.5 Cadmium Telluride Solar Cell (CdTe)

Cadmium telluride (CdTe) photovoltaics describes a photovoltaic (PV) technology that is based on the use of cadmium telluride, a thin semiconductor layer designed to absorb and convert sunlight into electricity.[10] Cadmium telluride PV is the only thin film technology with lower costs than conventional solar cells made of crystalline silicon in multi-kilowatt systems.[6][7][8]

On a lifecycle basis, CdTe PV has the smallest carbon footprint, lowest water use and shortest energy payback time of all solar technologies.[9][10][11] CdTe's energy payback time of less than a year enables for faster carbon reductions without short-term energy deficits. The toxicity of cadmium is an environmental concern rare abundance of tellurium—of which telluride is the anionic form—is comparable to that of platinum in the earth's crust and contributes significantly to the module's cost.[17]CdTe photovoltaics is used in some of the world's largest photovoltaic power stations, such as the Topaz Solar Farm. With a share of 5.1% of worldwide PV production, CdTe technology accounted for more than half of the thin film market in 2013.[18] A prominent manufacturer of CdTe thin film technology is the company First Solar, based in Tempe, Arizona.

## 2.6 Concentrated PV Cell (CVP and HCVP)

Following the sun. A Concentrating Photovoltaic (CPV) system converts light energy into electrical energy in the same way that conventional photovoltaic technology does, but uses an advanced optical system to focus a large area of sunlight onto each cell for maximum efficiency. Different CPV designs exist, sometimes differentiated by the concentration factor, such as low-concentration (LCPV) and high concentration (HCPV). Concentrator photovoltaic's (CPV) is a photovoltaic technology that generates electricity from sunlight. Contrary to conventional photovoltaic systems, it uses lenses and curved mirrors to focus sunlight onto small, but highly efficient, multi-junction (MJ) solar cells. In addition, CPV systems often use solar trackers and sometimes a cooling system to further increase their efficiency.[20]:30 Ongoing research and development is rapidly improving their competitiveness in the utility-scale segment and in areas of high solar insulation.

CPV technology has been around since the 70s. Recent technological advancements have enabled CPV to reach viability and compete with traditional fossil fuel plants, such as coal, natural gas, and oil, when installed in regions of the world with sunny and dry climates. Concentrating photovoltaic systems work by converting solar light into electricity. Traditional rooftop solar modules rely on the same basic concept to generate electricity. CPV systems have an optical component, which “concentrates” significant amounts of sunlight onto “multi-junction” solar cells. Especially High concentrating photovoltaic (HCPV) systems have the potential to become competitive in the near future. They possess the highest efficiency of all existing PV technologies, and a smaller photovoltaic array also reduces the balance of system costs. Currently, CPV is not used in the PV roof top segment and far less common than conventional PV systems. [21]

Concentrating photovoltaic (CPV) modules work in much the same way as traditional PV modules, except that they use optics to concentrate the sun onto solar cells that do not cover the entire module area. This concentration factor – in Semprius’ case over 1,100 times – dramatically reduces the amount of semiconductor needed (<0.1 percent) and opens up the potential to cost-effectively use very high-performance multi-junction cells with efficiency levels greater than 41 percent. In order to work properly, however, CPV modules must accurately face the sun. Therefore, CPV modules are used in conjunction with high-performance highest efficiency of all existing PV technologies, and a smaller photovoltaic array also reduces the balance of system costs. Currently, CPV is not used in the PV roof top segment and far less common than conventional PV systems. [21]

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Figure 2.6: Efficiency of CPV.

### 2.7 Micromorph Cells (Tandem-Cell Using $\alpha$ -Si/ $\mu$ c-Si)

Micromorph cells are thin film solar cells based on a multijunction-architecture consisting of two solar cells that are stacked on top of each other. While the thin amorphous silicon top cell absorbs the blue light, the thicker microcrystalline silicon bottom cell absorbs the red and near-infrared light, allowing this so-called tandem cell to cover a wider range of the solar spectrum. “Micromorph” tandem solar cells consisting of a microcrystalline silicon bottom cell and an amorphous silicon top cell are considered as one of the most promising new thin-film silicon solar-cell concepts. Their promise lies in the hope of simultaneously achieving high conversion efficiencies at relatively low manufacturing costs. Since the bandgaps of amorphous Silicon (1.7eV) and microcrystalline Silicon (1.1eV) are well suited for tandem solar cells, the Shockley-Queisser limit of this cell allows conversion efficiencies of over 30%. In reality this limit can not be reached and typical stable efficiencies are about 9% (world record 11.7%). That is well over the stable efficiencies of single junction thin film silicon solar cells which are around 6%. One reason of the low costs of silicon thin film solar cells is its very low thickness (2  $\mu$ m) compared to silicon wafer (200  $\mu$ m). In the red and infrared wavelength range 2  $\mu$ m of silicon are not enough to absorb all light and therefore Light trapping is needed.

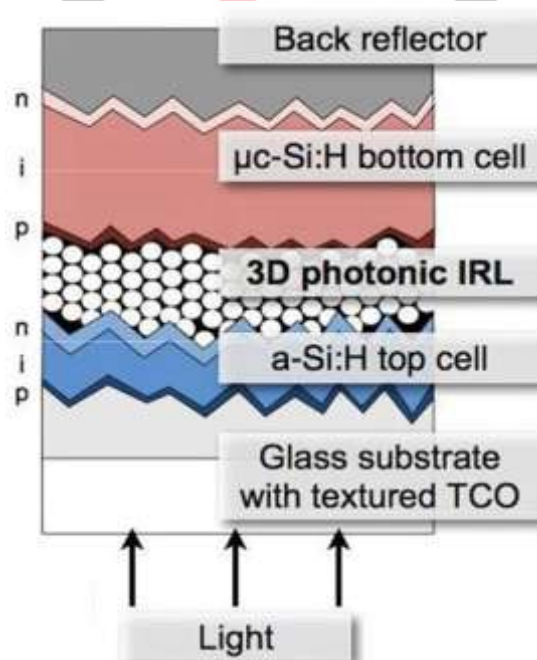


Figure 2.7: Schematic structure of a micro morph silicon tandem cell.



### 3. Result and Discussion

Solar energy which is a combination of light and heat is produced by sun. This energy moves from sun and reaches the earth where human collects it through solar collectors and convert it into any desirable form of energy. According to an assumption this renewable source of energy is powerful enough to replace the need of electricity that we get from 650 barrels of oil per year.

Some of Applications of solar energy

Power plants: In conventional power plants non-renewable energy sources are used to boil water and form steam so that turbines can rotate and water to produce electricity. But with application of solar energy heat of sun can boil that water to create steam and rotate turbines. To convert sunlight into electricity solar panels, photoelectric technologies and thermoelectric technologies etc are used.

1. Homes: Use of solar energy is increasing in homes as well. Residential appliances can easily use electricity generated through solar power. Besides this solar energy is running solar heater to supply hot water in homes. Through photovoltaic cell installed on the roof of the house energy is captured and stored on batteries to use throughout the day at homes for different purposes. In this way expenditure on energy is cutting down by home users.

2. Commercial use: on roofs of different buildings we can find glass PV modules or any other kind of solar panel. These panels are used there to supply electricity to different offices or other parts of building in a reliable manner. These panels collect solar energy from sun, convert it into electricity and allow offices to use their own electrical power for different purposes.

3. Ventilation system: at many places solar energy is used for ventilation purposes. It helps in running bath fans, floor fans, and ceiling fans in buildings. Fans run almost every time in a building to control moisture, and smell and in homes to take heat out of the kitchen. It can add heavy amount on the utility bills, to cut down these bills solar energy is used for ventilation purposes.

5. Power pump: solar power not just help in improving ventilation system at your homes but with that it can also help in circulating water in any building. You can connect 6- power pump with solar power supply unit but you must run it on DC current so that water circulate throughout your home.

6. Swimming pools: swimming pools are great joy for kids and adults in all seasons. But during winters it is tough to keep water hot in these pools with minimum power usage. Solar energy can help many in this matter as well. You can add a solar blanket in the pool that will keep the water hot with energy generated from sunlight. Besides this you can install a solar hot water heating system with solar hot water heating panels.

7. Solar Lighting: these lights are also known as day lighting, and work with help of solar power. These lights store natural energy of sun in day time and then convert this energy into electricity to light up in night time. Use of this system is reducing load from local power plants.

8. Solar Cars: it is an electrical vehicle which is recharged from solar energy or sunlight. Solar panels are used on this car that absorb light and then convert it into electrical energy. This electrical energy is stored in batteries used with the car, so that in night time as well we can drive these vehicles.

9. Remote applications: Remote buildings are taking benefit of solar energy at vast scale. Remote schools, community halls, and clinics can take solar panel and batteries with them anywhere to produce and use electric power.

Next-generation solar cells could be infinitely more useful thanks to a newly discovered nanotube structure capable of transporting electrical charges 100 million times higher than previously measured. Most solar cells currently use silicon to absorb light, however inefficiencies in the material have led scientists to develop carbon nanotubes that can be implemented to enhance the light absorption capabilities of current cells. However, until now the nanotubes have been randomly placed within the solar cells in suboptimal structures as they are difficult to arrange. A new generation of solar panels made from a mineral called perovskite has the potential to convert solar energy into household electricity more cheaply than ever before, according to a study from Britain's Exeter University.

Super-thin, custom-colored panels attached to a building's windows may become a "holy grail" for India and African countries, Senthilarasu Sundaram, one of the authors of the study, told the Thomson Reuters Foundation. In those countries these types of material will be like a holy grail: they can both shade windows and at the same time produce electricity. With a thickness measured in billionths of a meter, solar panels made of perovskite will be more than 40 percent cheaper and 50 percent more efficient than those commercially produced today. Unlike other solar panels, those made of perovskite can absorb most of the solar spectrum and work in various atmospheric conditions, rather than only in direct sunlight. "This type of material for solar cells works in diffused conditions much, much better than the other types of solar cells," said Sundaram. "It won't be 100 percent, but it will be much more than what we have now." Researchers have already tested the material in the Americas, Asia, Europe and the Middle East. Current commercial products used to generate solar power, such as silicon or thin-film based technologies, are expensive because they are processed using vacuum-based techniques renewable energy production and CO2 emission.

## References

- [1] <http://www.chemistryexplained.com/Ru-Sp/Solar-Cells.html>
- [2] <http://www.solarstik.com/stikopedia/stiktm-u>
- [3] Ciesielskia, Peter N; Frederick M. Hijazib, Amanda M. Scott, Christopher J. Faulkner, Lisa Beard, Kevin Emmett, Sandra J. Rosenthal, David Cliffler, G. Kane Jennings (May 2010). "photosystem I- Based biohybrid photoelectrochemical cells". *Biosource Technology* 101 (9): 3047–3053. doi:10.1016/j.biortech.2009.12.045. Retrieved 24 October 2013.
- [4] Yehezkeli, Omer; Ran Tel-Vered, Julian Wasserman, Alexander Trifonov, Dorit Michaeli, Rachel Nechushtai, Itamar Willner (13 March 2012). "Integrated photosystem II-Based photoelectrochemical cells". *Nature communication*. doi:10.1038/ncomms1741.
- [5] Wohlgemuth JH, Narayanan S. Buried contact concentrator solar cells. Twenty Second IEEE Photovoltaic Specialists Conference. 1991 ;1:273-277.
- [6] "Publications, Presentations, and News Database: Cadmium Telluride". National Renewable Energy Laboratory.
- [7] K. Zweibel, J. Mason, V Fthenakis, "A Solar Grand Plan", *Scientific American*, Jan 2008. CdTe PV is the cheapest example of PV technologies and prices are about 16¢/kWh with US Southwest sunlight.
- [8] Further mention of cost competitiveness: "Solar Power Lightens Up with Thin-Film Technology", *Scientific American*, April 2008.
- [9] Peng et al. (2013). "Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems". *Renewable and Sustainable Energy Reviews* 19: 255–274. doi:10.1016/j.rser.2012.11.035.
- [10] de Wild-Scholten, Mariska (2013). "Energy payback time and carbon footprint of commercial photovoltaic systems". *Solar Energy Materials & Solar Cells* 119:296–305.
- [11] Fthenakis, Vasilis M. (2004). "Life cycle impact analysis of cadmium in CdTe PV production" (PDF). *Renewable and Sustainable Energy Reviews* 8 (4): 303–334. doi:10.1016/j.rser.2003.12.001. Archived from the original on 23 September 2014.
- [12] Werner, Jürgen H. (2 November 2011). "Toxic Substances In Photovoltaic Modules". [postfreemarket.net](http://postfreemarket.net). Institute of Photovoltaics, University of Stuttgart, Germany - The 21st International Photovoltaic Science and Engineering Conference 2011 Fukuoka, Japan. p. 2. Archived from the original (PDF) on 23 September 2014. Retrieved 23 September 2014.
- [13] "Water Solubility of Cadmium Telluride in a Glass-to-Glass Sealed PV Module" (PDF). Vitreous State Laboratory, and AMELIO Solar, Inc. 2011.
- [14] Herman Trabish, The Lowdown on the Safety of First Solar's CdTe Thin Film, [greentechmedia.com](http://greentechmedia.com) March 19, 2012
- [15] Robert Mullins, Cadmium: The Dark Side of Thin-Film?, September 25, 2008
- [16] Supply Constraints Analysis, National Renewable Energy Laboratory
- [17] Fraunhofer ISE Photovoltaics Report, July 28, 2014, pages 18,19
- [18] <http://www.solar-facts-and-advice.com/amorphous-silicon.html>
- [19] <http://www.iea.org> (2014). "Technology Roadmap: Solar Photovoltaic Energy" (PDF). IEA. Archived from the original on 7 October 2014. Retrieved 7 October 2014.
- [20] Fraunhofer ISE and NREL (January 2015). "Current Status of Concentrator Photovoltaic (CPV) Technology" (PDF). Archived from the original on 25 April 2015. Retrieved 25 April 2015.
- [21] "DOE Solar Energy Technologies Program Peer Review" (PDF). U.S. department of energy 2009. Retrieved 10 February 2011.
- [22] Wan, Haiying "Dye Sensitized Solar Cells", University of Alabama Department of Chemistry, p. 3
- [23] "Dye-Sensitized vs. Thin Film Solar Cells", European Institute for Energy Research, 30 June 2006