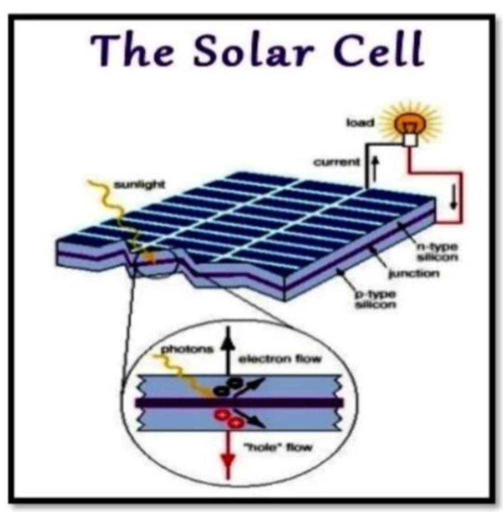
CONTENTS

INTRODUCTION TO SOLAR CELL

- **Solar cells are a promising and potentially important technology and are the future of sustainable en-Ergy for the human civilization.**
- **This article describes the latest information achievement in the field Of solar cells [Solar cell efficiency tables (version 48) containing the latest efficiency of different types Of solar cells published on July 2016. The article also contains data related to the worlds' energy and Particularly that part which related to the conversion of solar energy into electrical energy.**
- **On the ba-Sis of these data prospects of solar energy for human and the possible ways of implementing the lat-Est advanced Photovoltaic technology are defined. Also, methods of conversion of solar energy into Electricity, working principles and materials used for various types of photovoltaic technology, as well As the global solar market, present cost of solar energy and roadmap of solar energy is presented in This paper. Imagine solar cells installed in cars to absorb solar energy to replace the traditional use Of diesel and gas. Using the same principle, cell phones can also be charged by solar energy.**
- **There Are such a wide variety of applications.This is the time of nanotechnology. But today There is nothing more important than energy, Since the lack of energy means a significant ob-Stacle to the present civilization, i.e not enoughFood, warm shelter and connection to the Inter-Net, including the consumption of nanotechnolo-Gy products. The development of modern trends Of energy demands promising new technologies And even new physical and chemical processes For the**

establishment and operation of efficient Systems to generate, accumulate, transform and Transport of energy into its various forms [01].

- **Although global fossil fuel resources have not Yet been exhausted, the negative social, health, And environmental impacts of our current un-Sustainable patterns of energy use are apparent [02,03,04,05,06]. In the future, large-scale alter-Native methods of producing the vast quantities Of energy needed to sustain and enhance our Standard of living are necessary [07,08,09,10].**
- **If current trends continue, future society will Require increased electrical energy. It seems Highly probable that greenhouse gas emissions Will lead to significant global warming over the Next 50 years. Climate change is real and it is Happening right now, it is the most urgent threat Facing our entire species and we need to work Collectively together and stop it.**



Fortunately, adVances in science and technology have provided Us with several alternative means of producing Energy on a sustainable level, such as wind, Geothermal, biomass, and solar [11]. Solar is a Cleaner, safer investment for our family and busi-Ness. We can immediately reduce your electricity Bill, enjoy energy independence from rising en-Ergy costs and increasing carbon dioxide (CO_2) Emissions, and increase your home or building's Value.

- **Solar energy is ready today.Ever since the Becquerel discovered the first Photovoltaic effect in 1839, using solar energy Has been a goal in the scientific world. EveryHour the energy absorbed by Earth's atmoSphere from the sun is more than enough to sat-Isfy global energy needs for an entire year.**
- **For This reason, research in the last few decades has Exploded to find the most efficient and cost ef-Fective solar cells so the world does not remain Fossil fuels dependant. PV technology offers a Number of significant benefits. Solar power is a Renewable resource that is available everywhere In the world. Solar PV technologies are small and Highly modular and can be used virtually any-Where, unlike many other electricity generation Technologies. Unlike conventional power plants Using coal, nuclear, oil and gas, solar PV has no Fuel costs and relatively low operation and main-Tenance (O&M) costs. Thus, PV will continue to Produce power indefinitely (as long as the sun Shines). Photovoltaic are truly a sustainable and Environmentally friendly method of producing Energy. Not only this but it's for free, so why shall .**

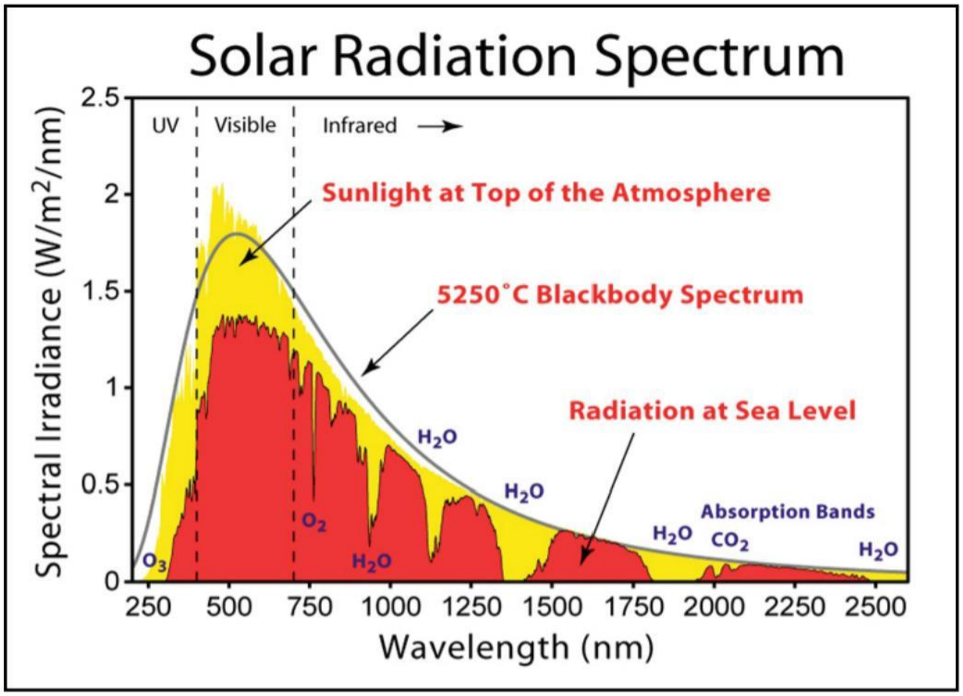


Figure 1: Solar irradiance spectrum above atmosphere and at surface

- **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 electricalcharacteristics, 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:

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

HISTORY OF SOLAR CELL:-

- **Solar technology isn't new. Its history spans from the 7th Century B.C. to today. We started out concentrating the sun's heat with glass and mirrors to light fires. Today, we have everything from solar-powered buildings to solar-powered vehicles.**
- **Here you can learn more about the milestones in the historical development of solar technology, century by century, and year by year. You can also glimpse the future.**

This timeline lists the milestones in the historical developmentof solar technology from the 7th Century B.C. to the 1200s A.D.

7th Century B.C.

- **Magnifying glass used to concentrate sun's rays to make fire and to burn ants.**

3rd Century B.C.

- Greeks and Romans use burning mirrors to light torches for religious purposes.

2nd Century B.C.

- As early as 212 BC, the Greek scientist, Archimedes, used the reflective properties of bronze shields to focus sunlight and to set fire to wooden ships from the Roman Empire which were besieging Syracuse. (Although no proof of such a feat exists, the Greek navy recreated the experiment in 1973and successfully set fire to a wooden boat at a distance of 50 meters.)

20 A.D.

- Chinese document use of burning mirrors to light torches for religious purposes.

1st to 4th Century A.D.

- The famous Roman bathhouses in the first to fourth centuries A.D. had large south facing windows to let in the sun's warmth.

6th Century A.D.

- Sunrooms on houses and public buildings were so common that the Justinian Code initiated "sun rights" to ensure individual access to the sun.

1200s A.D.

- Ancestors of Pueblo people called Anasazi in North America live in south-facing cliff dwellings that capture the winter sun.

1767

Swiss scientist Horace de Saussure was credited with building the world's first solar collector, later used by Sir John Herschel to cook food during his South Africa expedition in the 1830s.

1816

On September 27, 1816, Robert Stirling applied for a patent for his economiser at the Chancery in Edinburgh, Scotland. By trade, Robert Stirling was actually a minister in the Church of Scotland and he continued to give services until he was eighty-six years old! But, in his spare time, he built heat engines in his home workshop. Lord Kelvin used one of the working models during some of his university classes. This engine was later used in the dish/Stirling system, a solar thermal electric technology that concentrates the sun's thermal energy in order to produce power.

1839

French scientist Edmond Becquerel discovers the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution—electricity-generation increased when exposed to light.

1860s

French mathematician August Mouchet proposed an idea for solar-powered steam engines. In the following two decades, he and his assistant, Abel Pifre, constructed the first solar powered engines and used them for a variety of applications. These engines became the predecessors of modern parabolic dish collectors.

1873

Willoughby Smith discovered the photoconductivity of selenium.

1876

1876 William Grylls Adams and Richard Evans Day discover that selenium produces electricity when exposed to light. Although selenium solar cells failed to convert enough sunlight to power electrical equipment, they proved that a solid material could change light into electricity without heat or moving parts.

1880

Samuel P. Langley, invents the bolometer, which is used to measure light from the faintest stars and the sun's heat rays. It consists of a fine wire connected to an electric circuit. When radiation falls on the wire, it becomes very slightly warmer. This increases the electrical resistance of the wire.

1883

Charles Fritts, an American inventor, described the first solar cells made from selenium wafers.

1887

Heinrich Hertz discovered that ultraviolet light altered the lowest voltage ca-pable of causing a spark to jump between two metal electrodes.

1891

Baltimore inventor Clarence Kemp patented the first commercial solar water heater

This timeline lists the milestones in the historicaldevelopment of solar technology in the 1900s:-

1904

Wilhelm Hallwachs discovered that a combination of copper and cuprous oxide is photosensitive.

1905

Albert Einstein published his paper on the photoelectric effect (along with a paper on his theory of relativity).

1908

1908 William J. Bailley of the Carnegie Steel Company invents a solar collector with copper coils and an insulated box—roughly, it's present design.

1914

The existence of a barrier layer in photovoltaic devices was noted.

1916

Robert Millikan provided experimental proof of the photoelectric effect.

1918

Polish scientist Jan Czochralski developed a way to grow single-crystal silicon. For more information on Czochralski, see the article and His Contribution to the Art and Science of Crystal Growth.

1921

Albert Einstein wins the Nobel Prize for his theories (1904 research and techni-cal paper) explaining the photoelectric effect.

1932

Audobert and Stora discover the photovoltaic effect in cadmium sulfide (CdS).

1947

1947 Passive solar buildings in the United States were in such demand, as a result of scarce energy during the prolonged W.W.II, that Libbey-Owens-Ford Glass Company published a book entitled Your Solar House, which profiled forty-nine of the nation's greatest solar architects.

1953

Dr. Dan Trivich, Wayne State University, makes the first theoretical calculations of the efficiencies of various materials of different band gap widths based on the spectrum of the sun.

1954

1954 Photovoltaic technology is born in the United States when Daryl Chapin, Calvin Fuller, and Gerald Pearson develop the silicon photovoltaic (PV) cell at Bell Labs—the first solar cell capable of

converting enough of the sun's energy into power to run everyday electrical equipment.

1955

Western Electric began to sell commercial licenses for silicon photovoltaic (PV) technologies. Early successful products included PV-powered dollar bill changers and devices that decoded computer punch cards and tape.

Mid-1950s

Architect Frank Bridgers designed the world's first commercial office building using solar water heating and passive design. This solar system has been continuously operating since that time and the Bridgers-Paxton Building, is now in the National Historic Register as the world's first solar heated office building.

1956

William Cherry, U.S. Signal Corps Laboratories, approaches RCA Labs' Paul Rappaport and Joseph Loferski about developing photovoltaic cells for proposed orbiting Earth satellites.

1957

Hoffman Electronics achieved 8% efficient photovoltaic cells.

1958T. Mandelkorn, U.S. Signal Corps Laboratories, fabricates n-on-p silicon photovoltaic cells (critically important for space cells; more resistant to radiation).

1958

The Vanguard I space satellite used a small (less than one watt) array to power its radios. Later that year, Explorer III, Vanguard II, and Sputnik-3 were launched with PV-powered systems on board. Despite faltering attempts to commercialize the silicon solar cell in the 1950s and 60s, it was used successfully in powering satellites.

1959

Hoffman Electronics achieves 10% efficient, commercially available photovoltaic cells. Hoffman also learns to use a grid contact, reducing the series resistance significantly.

1959

On August 7, the Explorer VI satellite is launched with a photovoltaic array of 9600 cells (1 cm x 2 cm each). Then, on October 13, the Explorer VII satellite is launched.

1960

Hoffman Electronics achieves 14% efficient photovoltaic cells.

1960

Silicon Sensors, Inc., of Dodgeville, Wisconsin, is founded. It starts producing selenium and silicon photovoltaic cells.

1962

Bell Telephone Laboratories launches the first telecommunications satellite, the Telstar (initial power 14 watts).

1963

Sharp Corporation succeeds in producing practical silicon photovoltaic modules.

1963

Japan installs a 242-watt, photovoltaic array on a lighthouse, the world's larg-est array at that time.

1964

NASA launches the first Nimbus spacecraft—a satellite powered by a 470-watt photovoltaic array

1965

Peter Glaser conceives the idea of the satellite solar power station.

1966

NASA launches the first Orbiting Astronomical Observatory, powered by a 1-kilowatt photovoltaic array, to provide astronomical data in the ultraviolet and X-ray wavelengths filtered out by the earth's atmosphere.

1969

The Odeillo solar furnace, located in Odeillo, France was constructed. This featured an 8-story parabolic mirror.970sDr. Elliot Berman, with help from Exxon Corporation, designs a significantly less costly solar cell, bringing price down from $100 a watt to $20 a watt. Solar cells begin to power navigation warning lights and horns on many offshore gas and oil rigs, lighthouses, railroad crossings and domestic solar applications began to be viewed as sensible applications in remote locations where grid-connected utilities could not exist affordably.

1972

The French install a cadmium sulfide (CdS) photovoltaic system to operate an educational television at a village school in Niger.

1972

The Institute of Energy Conversion is established at the University of Delaware to perform research and development on thin-film photovoltaic (PV) and solar thermal systems, becoming the world's first laboratory dedicated to PV research and development.

1973

The University of Delaware builds "Solar One," one of the world's first pho-tovoltaic (PV) powered residences. The system is a PV/thermal hybrid. The roof-integrated arrays fed surplus power through a special meter to the utility during the day and purchased power from the utility at night. In addition to electricity, the arrays acted as flat-plate thermal collectors, with fans blowing the warm air from over the array to phase-change heat-storage bins.

1976

The NASA Lewis Research Center starts installing 83 photovoltaic power sys-tems on every continent except Australia. These systems provide such diverse applications as vaccine refrigeration, room lighting, medical clinic lighting, tele-communications, water pumping, grain milling, and classroom television. The Center completed the project in 1995, working on it from 1976-1985 and then again from 1992-1995.

1976

David Carlson and Christopher Wronski, RCA Laboratories, fabricate first amorphous silicon photovoltaic cells.

1977

Total photovoltaic manufacturing production exceeds 500 kilowatts.

1978

1978 NASA's Lewis Research Center dedicates a 3.5-kilowatt photovoltaic (PV) system it installed on the Papago Indian Reservation located in southern Arizona—the world's first village PV system. The system is used to provide for water pumping and residential electricity in 15 homes until 1983, when grid power reached the village. The PV system was then dedicated to pumping water from a community well.

1980

At the University of Delaware, the first thin-film solar cell exceeds 10% efficiency using copper sulfide/cadmium sulfide.

1981

Paul MacCready builds the first solar-powered aircraft—the Solar Challenger—and flies it from France to England across the English Channel. The aircraft had over 16,000 solar cells mounted on its wings, which produced 3,000 watts of power.

1982

The first, photovoltaic megawatt-scale power station goes on-line in Hisperia, California. It has a 1-megawatt capacity system, developed by ARCO Solar, with modules on 108 dual-axis trackers.

1982

Australian Hans Tholstrup drives the first solar-powered car—the Quiet Achiever—almost 2,800 miles between Sydney and Perth in 20 days—10 days faster than the first gasoline-powered car to do so.

1982

The U.S. Department of Energy, along with an industry consortium, begins operating Solar One, a 10-megawatt central-receiver demonstration project. The project established the feasibility of power-tower systems, a solar-thermal electric or concentrating solar power technology. In 1988, the final year of operation, the system could be dispatched 96% of the time.

1982

Worldwide photovoltaic production exceeds 9.3 megawatts.

1983

ARCO Solar dedicates a 6-megawatt photovoltaic substation in central California. The 120-acre, unmanned facility supplies the Pacific Gas & Electric Company's utility grid with enough power for 2,000-2,500 homes.

1983

Worldwide photovoltaic production exceeds 21.3 megawatts, with

1991

President George Bush redesignates the U.S. Department of Energy's Solar Energy Research Institute as the National Renewable Energy Laboratory.

1992

A 7.5-kilowatt prototype dish system using an advanced stretched-membrane concentrator becomes operational.

1993

1993 Pacific Gas & Electric completes installation of the first grid-supported photovoltaic system in Kerman, California. The 500-kilowatt system was the first "distributed power" effort.

1994

The National Renewable Energy Laboratory develops a solar cell—made from gallium indium phosphide and gallium arsenide—that becomes the first one to exceed 30% conversion efficiency.

1998

Subhendu Guha, a noted scientist for his pioneering work in amorphous silicon, led the invention of flexible solar shingles, a roofing material and state-of-the-art technology for converting sunlight to electricity.

1999

1999 Construction was completed on 4 Times Square, the tallest skyscraper built in the 1990s in New York City. It incorporates more energy-efficient building techniques than any other commercial skyscraper and also includes building-inte-grated photovoltaic (BIPV) panels on the 37th through 43rd floors on the south-and west-facing facades that produce a portion of the buildings power.

2000

First Solar begins production in Perrysburg, Ohio, at the world's largest photovoltaic manufacturing plant with an estimated capacity of producing enough solar panels each year to generate 100 megawatts of power.

2000

At the International Space Station, astronauts begin installing solar panels on what will be the largest solar power array deployed in space. Each "wing" of the array consists of 32,800 solar cells.

2000

Two new thin-film solar modules, developed by BP Solarex, break previous performance records. The company's 0.5-square-meter module achieves 10.8 % conversion efficiency—the highest in the world for thin-film modules of its kind. And its 0.9-square-meter module achieved 10.6% conversion efficiency and a power output of 91.5 watts — the highest power output for any thin-film module in the world.

2001

PowerLight Corporation places online in Hawaii the world's largest hybrid system that combines the power from both wind and solar energy. The grid-connected system is unusual in that its solar energy capacity—175 kilowatts— is actually larger than its wind energy capacity of 50 kilowatts. Such hybrid power systems combine the strengths of both energy systems to maximize the available power.

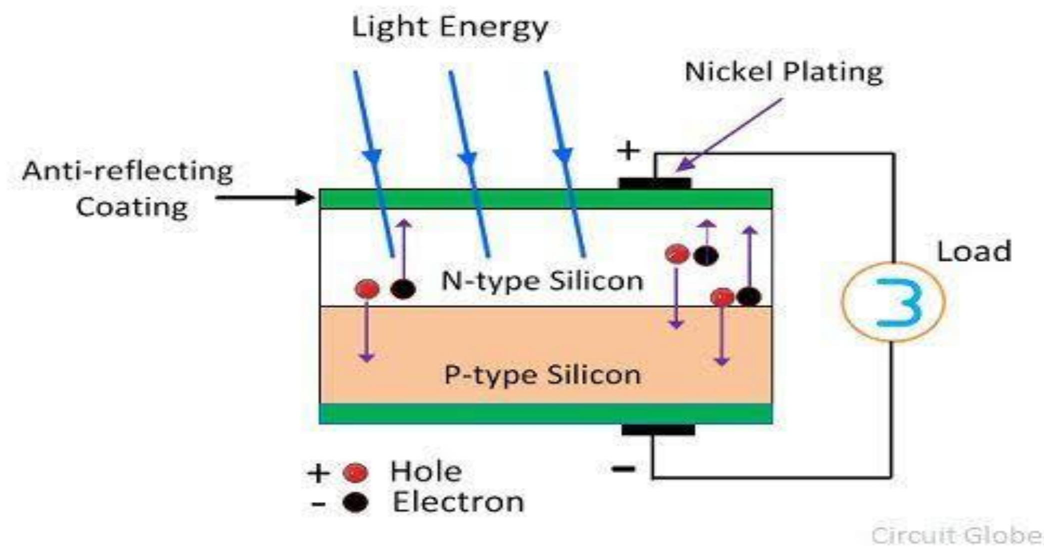
2001

Powerlight Corporation installs the largest rooftop solar power system in the United States—a 1.18 megawatt system—at the Santa Rita Jail in Dublin, California.Here's a look at the expected future direction of solar technology.All buildings will be built to combine energy-efficient design and construction practices and renewable energy technologies for a net-zero energy building. In effect, thebuilding will conserve enough and produce its own energy supply to create a new generation of cost-effective buildings that have zero net annual need for non-renewable energy.Photovoltaics research and development will continue intense interest in new ma-terials, cell designs, and novel approaches to solar material and product develop-ment. It is a future where the clothes you wear and your mode of transportation can produce power that is clean and safe.Technology roadmaps for the future outline the research and development path to full competitiveness of concentrating solar power (CSP) with conventional power in the Southwest United States is comparable in scale to the hydropower resource of the Northwest. A desert area 10 miles by 15 miles could provide 20,000 megawatts of power, while the electricity needs of the entire United States could theoretically be met by a photovoltaic array within an area 100 miles onaside.Concentrating

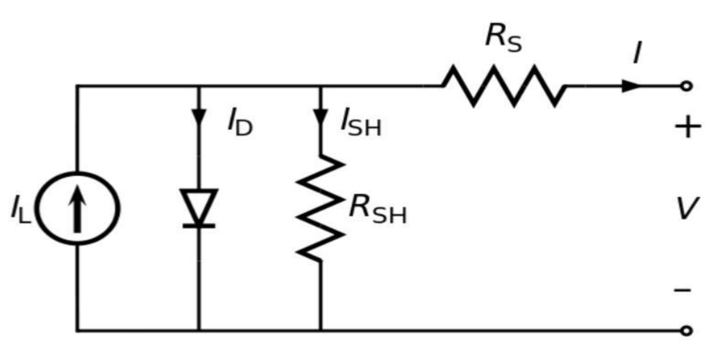
solar power, or solar thermal electricity, could harness the sun's heat energy to provide large-scale, domestically secure, and environmentally friendly electricity.

THEORY OF SOLAR CELL

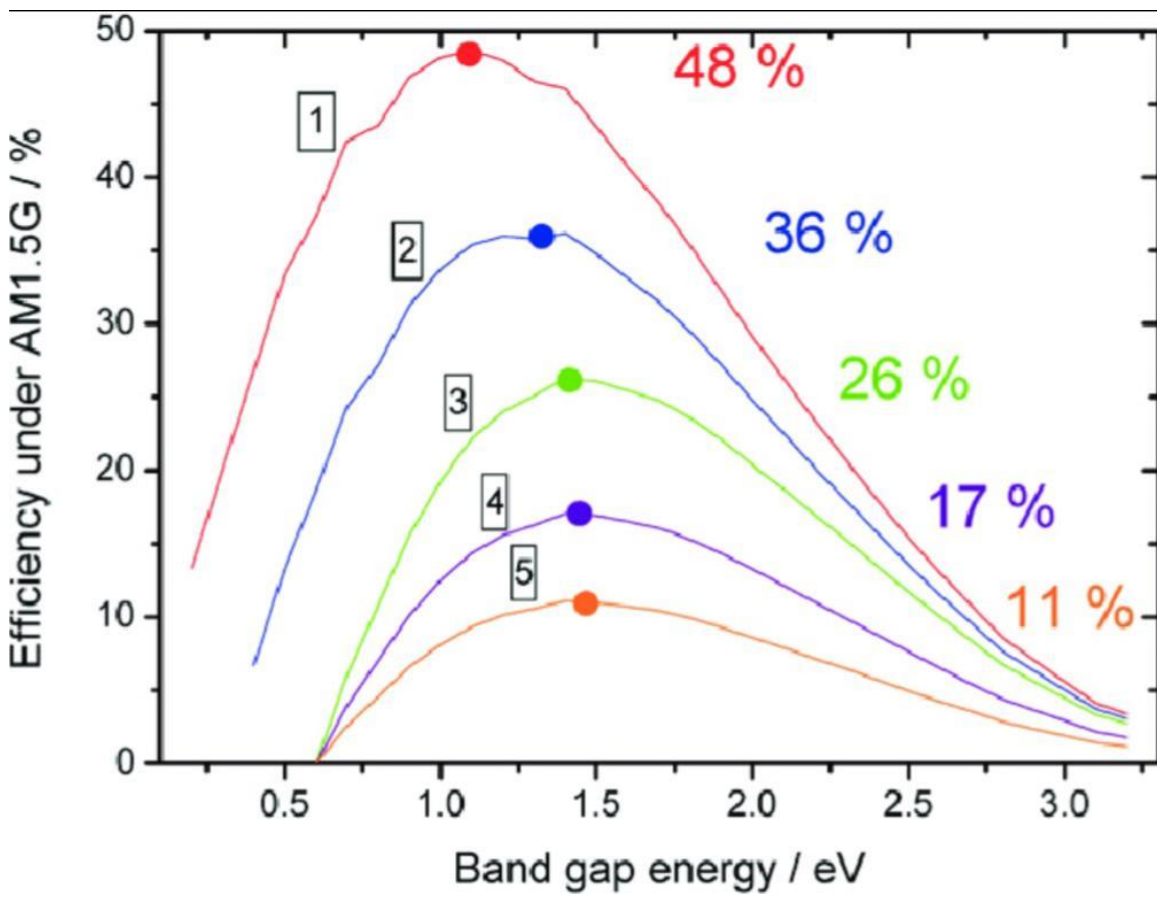
- **we present a very simple model of a solar cell. Many notions presented inSthis chapter will be new but nonetheless the general idea of how a solar cell works shouldbe clear.**
- **All the aspects presented in this chapter will be discussed in greater detail in thefollowing chapters.The working principle of solar cells is based on the photovoltaic effect, i.e. the generationof a potential difference at the junction of two different materials in response to electromag-netic radiation.**
- **The photovoltaic effect is closely related to the photoelectric effect, whereelectrons are emitted from a material that has absorbed light with a frequency above amaterial-dependent threshold frequency. In 1905, Albert Einstein understood that this ef-fect can be explained by assuming that the light consists of well defined energy quanta,called photons.**
- **The energy of such a photon is given by**
  - **$E = h\nu$,**
- **where h is Planck's constant and ν is the frequency of the light. For his explanation of thephotoelectric effect Einstein received the Nobel Prize in Physics in 1921 .**
- **The photovoltaic effect can be divided into three basic processes:**



- **The electronic behavior of a solar cell is understood by modeling it with anequivalent electronic circuit, which is useful to extract the basic relations forvoltage and current generated from a solar cell under illumination. The powerlosses that exist in real solar cells are modeled as resistances in series and parallelto the solar cell.**



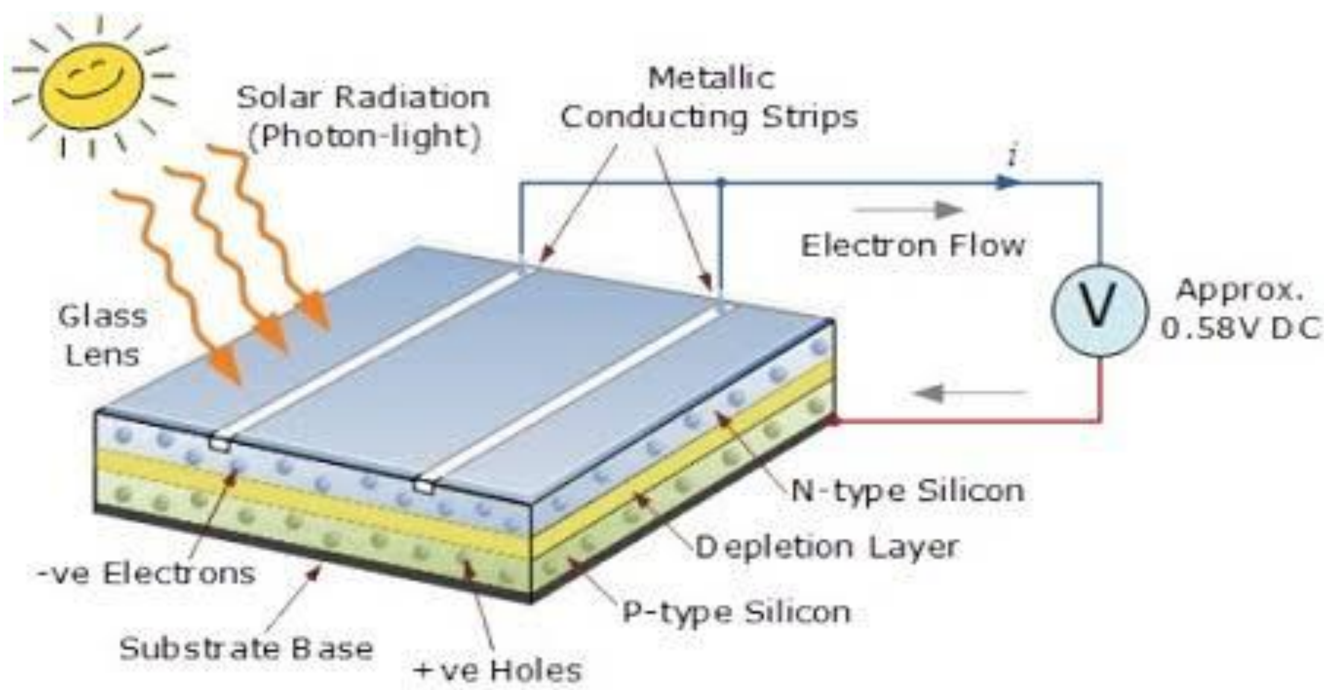
Furthermore, I will talk about the electron-hole recombination in solar cells,which limits the efficiency of the cell, and the theoretical thermodynamic limit ofa single junction solar cell as set by Shockley and Queisser . The efficiencylimit is set by the so called detailed balance principle which simply has to do withthe fact that the solar cell exchanges thermal radiation with its surroundings,reducing the efficiency. Along with that and other considerations having to dowith the band gap of the material, the solar spectrum etc. they obtain that for asingle junction solar cell the following graph (figure 3).



- Light of greater energy can alter the electrical prop-erties of the crystal. If such light strikes a bound elec-tron, the electron is torn from its place in the crystal.
- This leaves behind a silicon bond missing an electronand frees an electron to move about in the crystal.
- Abond missing an electron, rather picturesquely, iscalled a hole. An electron free to move throughout thecrystal is said to be in the crystal's conduction bandbecause free electrons are the means bywhich electricity flows.
- Both the conduction-bandelectrons and the holes play important parts in theelectrical behavior of PV cells. Electrons and holesfreed from their positions in the crystal in this mannerare said to be light-generated electron-hole pairs.
- A hole in a silicon crystal can, like a free electron,move about the crystal.
- The means by which the holemoves is as follows: An electron from a bond near ahole can easily jump into the hole, leaving behind anincomplete bond, i.e., a new hole.
- This happens fastand frequently-electrons from nearby bonds tradepositions with holes, sending holes randomly and er-ratically throughout the solid.
- The higher thetemperature of the material, the more agitated theelectrons and holes and the more they move.
- A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes.
- A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer.

- These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the solar cell from any mechanical shock.

CONSTRUCTION :



Solar Cell Working :

- **Once the solar energy falls on a solar panel, then it absorbs. Each panel in the solar panel includes semiconductor material to combine the properties of insulators and metals. So it makes to convert the light energy into electrical.**
- **Once the energy from the sun falls on the panel then a semiconductor absorbs, the energy of photons transfers to electrons and allows the flow of electrons through the material like an electrical current.**
- **There are different kinds of semiconductor materials used in solar cells like Silicon, Photovoltaics like Thin-film, Organic, and Concentration photovoltaics.**

Series Combination of PV Cells

- **When two or more solar cells are connected in series then it is called a series combination of solar cells.**
- **The connection of solar cells in series can be done by connecting the +Ve terminal of the panel to the –Ve terminal of the second panel.**
- **In this connection, the output current of the solar cells is the same but their i/p voltage becomes twice.**

- **For example: If we connect four solar panels in a series combination then each solar panel rated at 10 V & 5 amps, then the total array of panels would be 40 volts at 5 amps.**

Parallel Combination of PV Cells

- **When two or more solar cells are connected in parallel then it is called a parallel combination of solar cells.**
- **The connection of solar cells in parallel can be done by connecting all the +Ve terminals of the panels jointly whereas all the –Ve terminals of the panels jointly.**
- **In this parallel connection, the output current of the solar cells is twice but their i/p voltage is the same.**

Series-Parallel Combination of PV Cells

In series to the parallel combination of solar cells, both the magnitudes of the current as well as voltage increases. Thus, these panels are designed with the series and parallel connection of the cells.

Advantages

The advantages of the solar cells include the following.

- **It is a renewable energy source**
- **By using this, electricity bills can be reduced.**
- **Maintenance cost is less**
- **Simple to operate**
- **It does not generate noise and emissions**
- **It does not use water or fuel to generate electricity.**
- **The lifespan of these cells is around 30 years**
- **It needs less maintenance**

Disadvantages of Solar Energy

- **The disadvantages of the solar cells include the following.**
- **It depends on the weather**
- **Storage of solar energy is expensive**
- **Occupies more space**

Applications

The applications of the solar cells include the following.

- **Electric fences**
- **Remote lighting systems**
- **Water treatment**
- **Water pumping**
- **Emergency power**
- **Satellites**
- **Power supplies which are portable**

MANUFACTURE OF SOLAR CELL

Abstract :

Crystalline silicon solar cell (c-Si) based technology has been recognized as the only environment-friendly viable solution to replace traditional energy sources for power generation. It is a cost-effective, renewable and long-term sustainable energy source. The Si-based technology has a market growth of almost 20-30% and is projected to attain an energy share of ~100 giga watt (GW) per year in the current fiscal year, 2020. There have been constant efforts in reducing manufacturing cost of solar

panel technology, which is about three-four times higher in comparison to traditional carbon-based fuels. In the manufacturing domain, fabrication of three basic c-Si solar cell configurations can be utilized, which are differentiated in the manner of generation of electron-hole (E-H) pairs on exposure to sunlight. The generation of electricity by impinging light on a semiconductor material requires production of electrons and holes such that electrons in the valence band become free and jump to the conduction band by absorbing energy. Thus, jumping of highly energetic electrons to different material generates an electromotive force (EMF) converting light energy into electrical signals. This is known as the photovoltaic (PV) effect.Si is widely used in PV cell technology since it is cheaper, abundant and Si-fabrication technology is highly developed. First of all, polished Si wafers cut from highly pure industrial grade Si boules are prepared which can be singlcrystalline,polycrystalline or even amorphous. After wafer procurement/fabrication, Si is doped selectively to make p-njunctions and is processed to furnish a solar cell.The manufacturing requirements of PV modules are cheaper cost of production and further promotion of cost reduction by improved technology, greenemanufacturing methodology and no constraints in materials supply. For Si-based manufacturing technology, supply chain is an important factor.

INTRODUCTION :

- There has always been a surge to discover newer sources of energy which can be effective alternatives for the orthodox sources of energy, such as, petrol, kerosene, wind energy, thermal power generators .
- In this quest, the sun is a natural huge source of renewable green energy. It is noteworthy that the terrestrial soil is exposed to enormous amount of solar energy as large as about ten thousand times of all the energy used around the globe.
- The terrestrial hemisphere facing the sun receives power in excess of 50,000 terawatt (TW) in each instance, which makes reception of enormous amount of energy possible .Photovoltaics (PV) technology is a technology that relies on this infinite source of sunlight and possesses inherent qualities of highly reduced service costs since sun provides free energy, reliability, noiseless, minimum maintenance costs and readily installation features .
- As a matter of fact, thermonuclear fusion reactions happen non-stop at a temperature of millions of degrees to generate huge energy in form of electromagnetic radiation of sunlight.
- The outer layer of the earth's atmosphere receives partial energy of the total energy from the sun with a solar constant or an average irradiance of approximately 1367 Wm-2 with a variation of ±3% .
- This value of solar constant is dependent on the earth-to-sun distance and on the solar activity.
- The solar constant is defined as the intensity of solar electromagnetic radiation impinging on a unit surface area and is expressed in units of kWm-2and is equal to the integral of the

power of the individual frequencies in the spectrum of solar radiation. The geometry of the sun-to-earth distance is displayed in Fig. 1 given below.

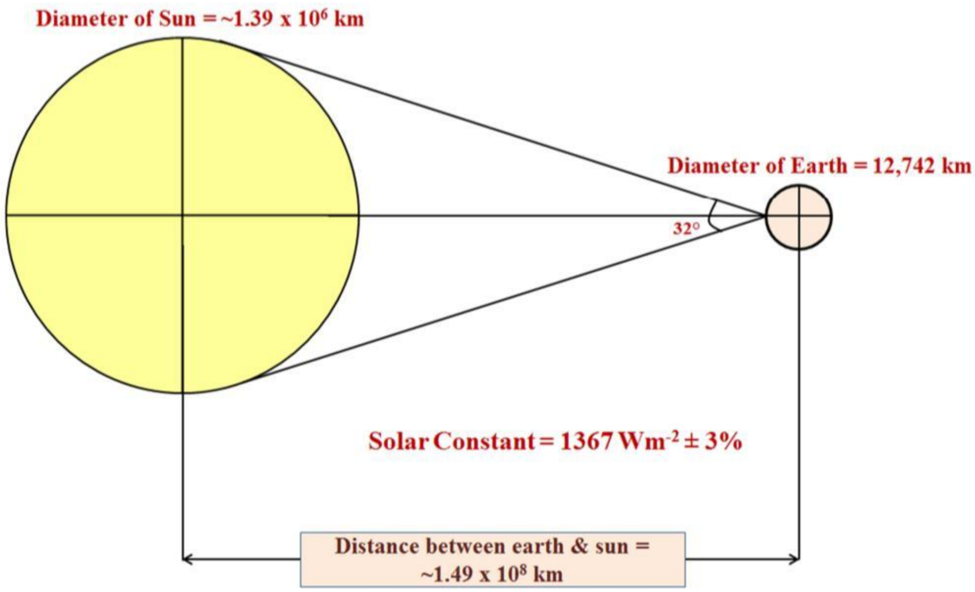


Figure 1. The above schematic shows the sun-earth geometry portraying distance between the two celestial objects, diameters and the value of solar constant.

- Solar irradiation is the integral of solar irradiance over a particular period of time depicted by kWhm-2and the radiation falling on the surface of the earth is actually diffuse radiation.
- Diffuse radiation is that part of light radiation striking the surface from whole ofthe sky, while other radiations are the part reflected from the ground, and by surrounding atmosphere.

❖ **Different types of radiation received by a solar panel [9] are displayed in Fig. 2 as shown below.**

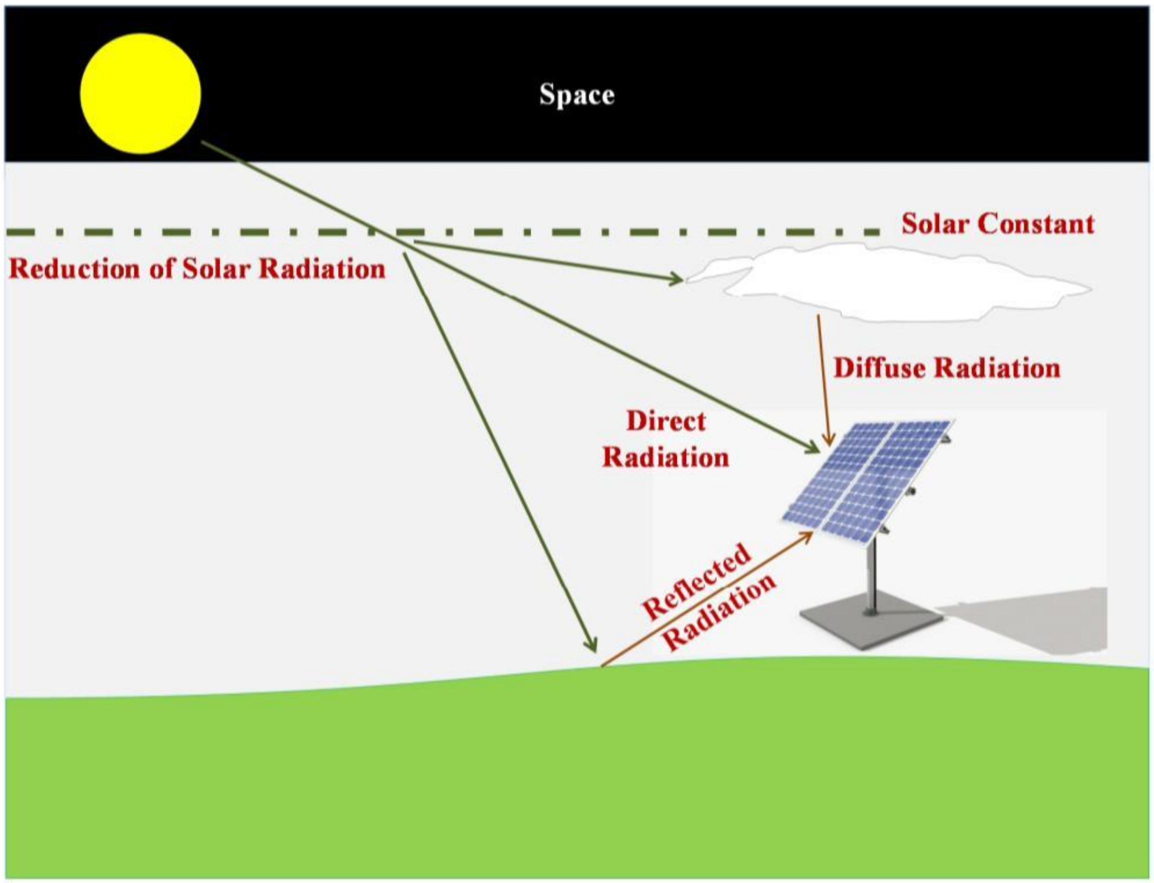


Figure 2. The above figure portrays different radiations occurring from the sun which consists of direct, diffuse and reflected radiations.

Introduction To Si Wafer :

- **Silicon is a member of group 14 in the periodic table and is tetravalent metalloid, semiconductor and brittle crystalline solid .**
- **In 1906, silicon radio crystal detector was developed as the first silicon based semiconductor device by Greenleaf Whittier Pickard . Russell Ohl discovered the nonlinear semiconductor devices, p-n junction,and photovoltaic effect in the metalloid Si in 1940 .**
- **During Second World War in 1941, radar microwave detectors were invented by developing techniques for production of high quality germanium (Ge) and Si crystals .**
- **William Shockley proposed a field-effect amplifier based on Ge and Si in 1947, but, however, could not demonstrate the prototype practically .**
- **John Bardeen and Walter Brattain built the first workingdevice, point-contact transistor, in 1947 itself under the direction of William Shockley only .**
- **The first Si-based junction transistor was fabricated by the physical chemist Morris Tanenbaum in 1954 at Bell Labs . At Bell Labs in 1954, Carl Frosch and Lincoln Derick found out by accident that it is possible to grow silicon-di-oxide (SiO_2) on Si wafers . Later on, in 1958, they discovered that this as-grown SiO_2 could be used to mask Si surfaces during diffusion processes .Si atom has fourteen electrons with electronic configuration 2,8,4 [$1s^2$, $2s^2$, $2p^6$, $3s^2$, $3p^2$] specifying that the number of valence electrons is 4 [10,11]. These valence electrons occupy the 3s orbital and two 3p orbitals.**

- In order to complete its octet and attain the stable noble gas configuration of Argon (Ar), itcan combine with other elements to form SiX4 derivatives by forming sp3hybrid orbitals.
- In this case, the central Si atom taking part in the bonding with other element shares an electron pair with each of the four atoms of the bonding element.Si and Ge crystallize in a diamond type cubic lattice structure which has the space-lattice of face-centered cubic (fcc) [20, 21]. The atomic positions in the diamond-type cubic lattice projected on a cubic platform are shown In a space-lattice of fcc-

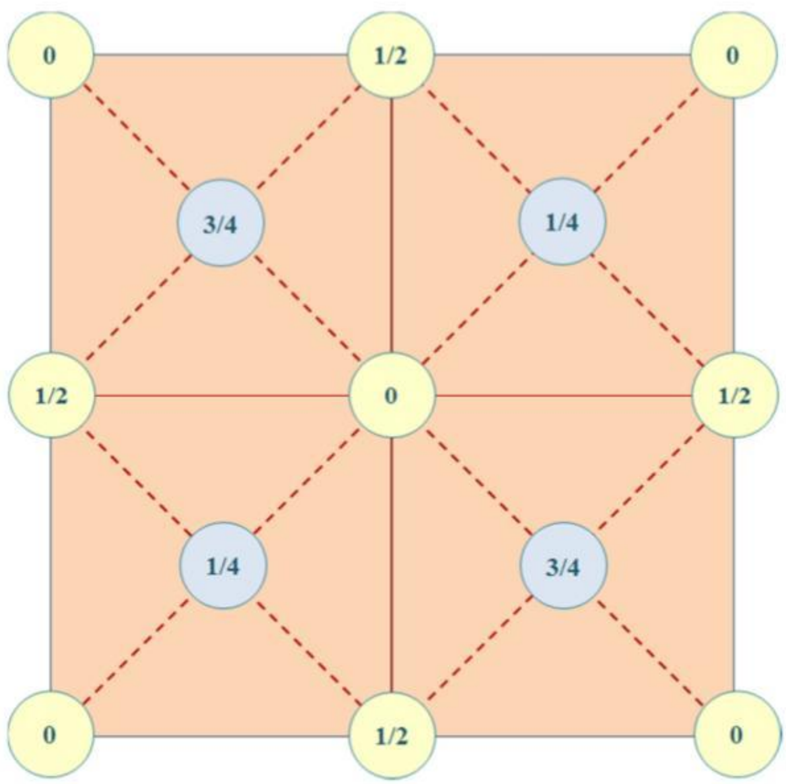


Figure 3. Schematic to show atomic positions in diamond-type cubic lattice.

- **Si is tetravalent and can be made p-type by adding dopants of boron (B), aluminium (Al) & gallium (Ga), and addition of antimony (Sb), phosphorous (P) & arsenic (As) generates n-type semiconductor material [10,11,20,21].**
- **B and Ga possess only three valence electrons and when they are mixed into the Si lattice, deficiency of an electron is created which is termed as positively charged "vacancy" or "hole". Holes take part in conduction accepting an electron from the neighbour and transitioning over the atoms.**
- **For making Si an n-type semiconductor, Sb, P and As are added into the Si lattice in small quantities each having five valence electrons, which creates an extra electron into the lattice.**
- **The availability of these free electrons as a whole in the material creates a net flow of negatively charged carriers to constitute current. Thus, addition of small amounts of either of two types of foreign atoms changes Si crystal into a medium-type of conductor, which is semiconductor.**
- **Joining of two types of semiconducting materials constitutes a device entailed as nonlinear semiconductor diode [10,11,20-22]. Figure 4 shows a similar picture to portray the doping of two types of foreign atoms in Si lattice.**

EFFICIENCY OF SOLAR CELL

INTRODUCTION :

Renewable Energy: Energy which is produced by processes that are continuously replenished. There are the main following renewable technologies.

- **Wind Energy**
- **Hydro Power**
- **Solar Energy**
- **Biomass**
- **Bio fuel**
- **Geothermal Energy**

A. Solar Energy :

Solar Energy is the biggest source of energy. There are two basic techniques to get energy from Sun. One is passive solar technique and other one is active solar technique. In passive solar techniques, the orientation of building to circulate air and dispersing sunlight is included shown in figure 1.

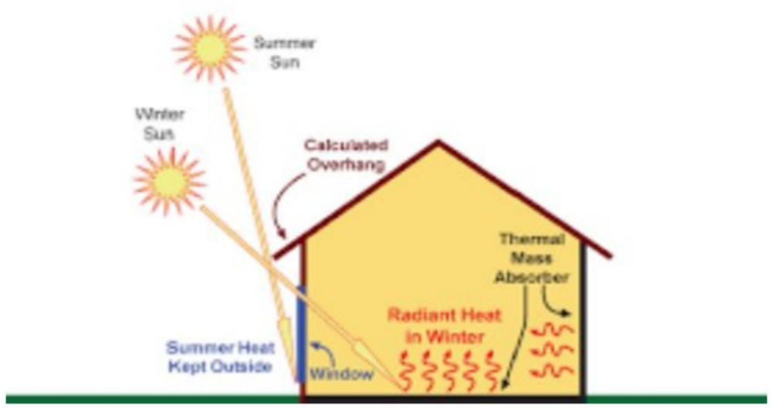


Figure 1: Passive Solar Technique

- **In active solar techniques the heating of fluid materials by thermal collector as shown figure 2.**

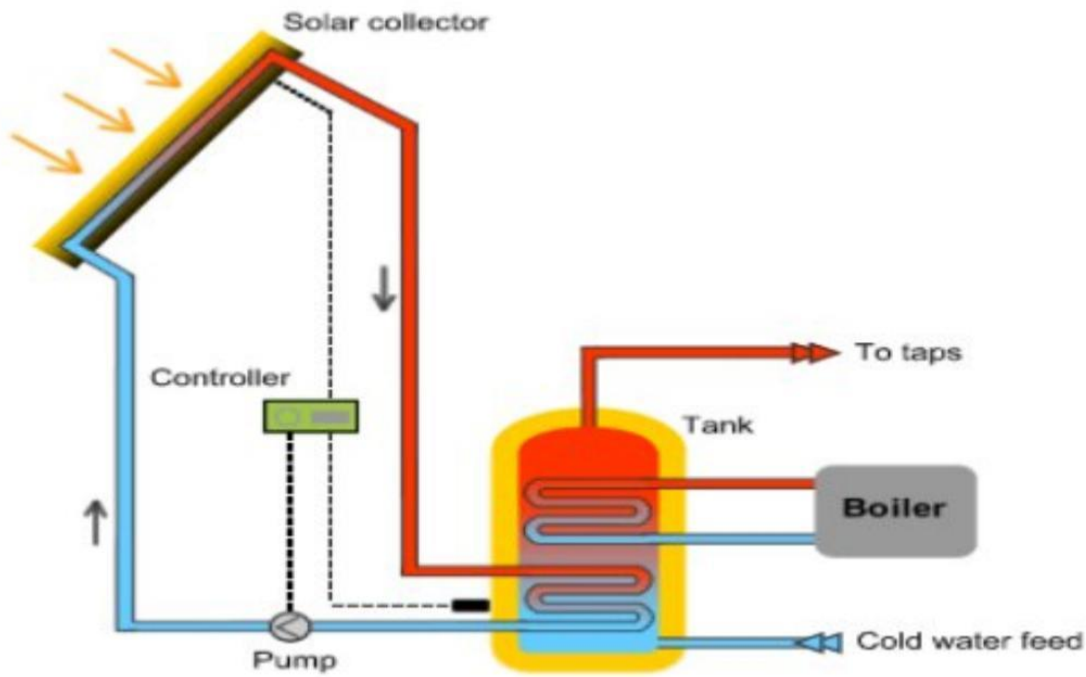


Figure 2: Active Solar Technique

- **Electrical energy is producing through photoelectric effect is shown in the figure 3.**

Figure 3: Active Solar Technique

B. PV module specification:

- **In the world, 90% PV module is of crystalline silicon. Solar cell made by czharlski process by some chemical reaction and after obtaining silicon crystal in the form of ingots, a solar cell is made by some extra processes like cutting, slicing, wayfaring etc.**
- **A solar cell is of 0.5 to 0.6 volts .To make a PV module solar cells are connected in series. The size of solar cell decides the capacity of current in solar cell.**

- The size of solar cell is 3 inches to 6 inches and current is 3 amps to 9 amps accordingly. When PV modules are connected together, a PV array is made.
- Table 1 shows the comparison of specification of different PV module.

PV Module type	Mono-crystalline	Poly-crystalline	Thin Film
Theoretical efficiency	25.0%	20.4%	18.7%
Practical efficiency	15-20%	13-16%	9-11%
Area/kW	6-9 ? ?	8-9 ? ?	10 ? ?
Warranty	25 years	25 years	10-25 years
Lowest price	0.75$/w	0.62 $/w	0.7$/w
Temperature resistance	Performance Drops but good	Slightly better	Not good
Fill factor	70-75%	70-75%	50-60%

Table 1: Specification Comparison

C. Battery requirement:

- By focusing on the present energy crisis in Pakistan, we can see how much important it has been to store charge for which batteries are being used from several years & gaining more importance with time in our solar system and for other purposes. Just like any appliance or any house hold thing being use frequently, batteries also require proper maintenance.
- If they are not carefully handled they may result in short life of battery or may damage permanently even batteries can explode in case of inappropriate charging voltages. But battery can get damage from over discharging also which is actually a bigger issue as compared to overcharging.
- So it is really important to connect such protections & control system with our battery which may protect battery from over or inappropriate charging & over discharging as well.If the battery is not allowed to discharge below 50% it would improve battery's life more than 3x as compared to a battery which is sometimes drained to 0% charging level (as it damages batter's cells permanently).

D. Battery protection

It is really important to connect such protections & control system with our battery which may protect battery from over or inappropriate charging & over discharging as well. The basic goal of this smart system is to provide battery will all necessary protections controls in a cheap price with control over battery's charging if there is any malfunctioning in the charging circuit or if the battery has drained to 50% charging

PROCEDURE :

In Solar PV system, there are proper procedure to maintain the efficiency and reliability of this system. There are following steps to design an efficient system.

- **Selecting location**
- **Find azimuth angle**
- **Calculate tilt angle**
- **Irradiation measurement**
- **Load calculation**
- **Module calculation**
- **Find required area**
- **Battery sizing**
- **Charge controller sizing**
- **Inverter sizing**

Now in first five steps, there are the factors discussed above. By practical approach we conclude some results accordingly for the purpose of solar Photovoltaic system efficiency.

Types and components of PV system :

- **On-grid PV system**
- **Off-grid PV system**
- **Hybrid PV system**

And the basic components of solar system are

- **PV module**
- **Charge controller**
- **Battery**
- **Solar inverter**
- **Load**

Efficiency of PV system :

Now this system requires deeply study of all the factors which affects its efficiency in which solar cell efficiency is the main factor. In this factor, solar cell efficiency is maximum 25%. But if we see about the capability of solar cell to produce power is about 1000W/? ?.In simple words, area of a mono crystalline PV module of 250Watts has a capability to produce 1000watts which is the most important factor affecting the efficiency of solar PV system. Solar cells are manufactured in China, Japan and Germany. According to current research on solar cell, the efficiency record is 43.6%. And due to this progress, solar will become the most important source of energy in future. Now the discussion is to point out the other factors affecting the efficiency of solar PV system. The Nomenclature of these given factors is pointed out by proper methods.

- **Effect of direction on PV module**
- **Effect of angle on PV module**
- **Effect of irradiance on PV module**
- **Effect of temperature on PV module**
- **Effect of shade on PV module**
- **Effect of load on PV module**

Effect of Direction :

By changing the direction of module, short circuit current changes. If the direction of the PV module is not according to Azimuth angle thenthe overall power is reduced. Practically, the location of installation has a specific azimuth angle, if we do not place the module according to azaimuth angle of that location . Then current will reduce

which reduce the power produced. According to location of Uet Lahore, the results of 250W module panel model JC250 M-241Bb are shown in table 2

When the azimuth angle is not calculated then the variation in current reduces the power generated. For the problem of this solution, there

Direction	E-S ???	E-S ???	S ??	S-W ???	S-W ???	S-W ???
???????	27.2	27	25.4	25.9	25.9	25.8
?????? ??	4.8	5.2	4.43	3.9	3.78	3.6
???(volts)	33	33.5	33.2	32.8	32.8	32.8
???(amp)	6.84	6.32	4.95	4.45	4.33	3.98

Table 2: Effect of Direction

are two methods of finding Azimuth angle. First method is manually to use compass and by finding the E-S direction and 15 degree angle, we have to place PV module. And the Best solution is to connect a Solar Tracker which moves our module in the direction of maximum Sunlight automatically. Solar tracker is good but expensive and consumes power to operate. So, before installation we have to makesure about the direction.

Effect of Tilt Angle :

After placing the module in true south direction, the angle is a factor which changes the current and finally results in reducing the power of the System.

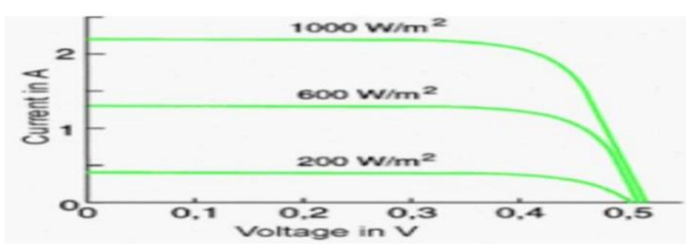
Effect of Irradiance :

when the irradiance changes then the power generated is changed. Solar irradiance record at 10am in Uet, Lahore is 558. And current is changed by changing the irradiance. So the result is shown in table 4. that solar irradiance affects the power.

Irradiance	558(10:20am)	569(10:25am)	580(10:45am)
?? ???????	25.1	25.13	25.9
?? ??? ??	1.89	2.6	2.64
???(volts)	33.2	33.1	33.19
???(amp)	5.69	5.76	5.9

Table 4: Effect of irradiance

So, the study is always under consideration for overall efficiency of the system [6]. The effect of irradiance is shown in general graph 1.



Graph 1: Behavior due to irradiance

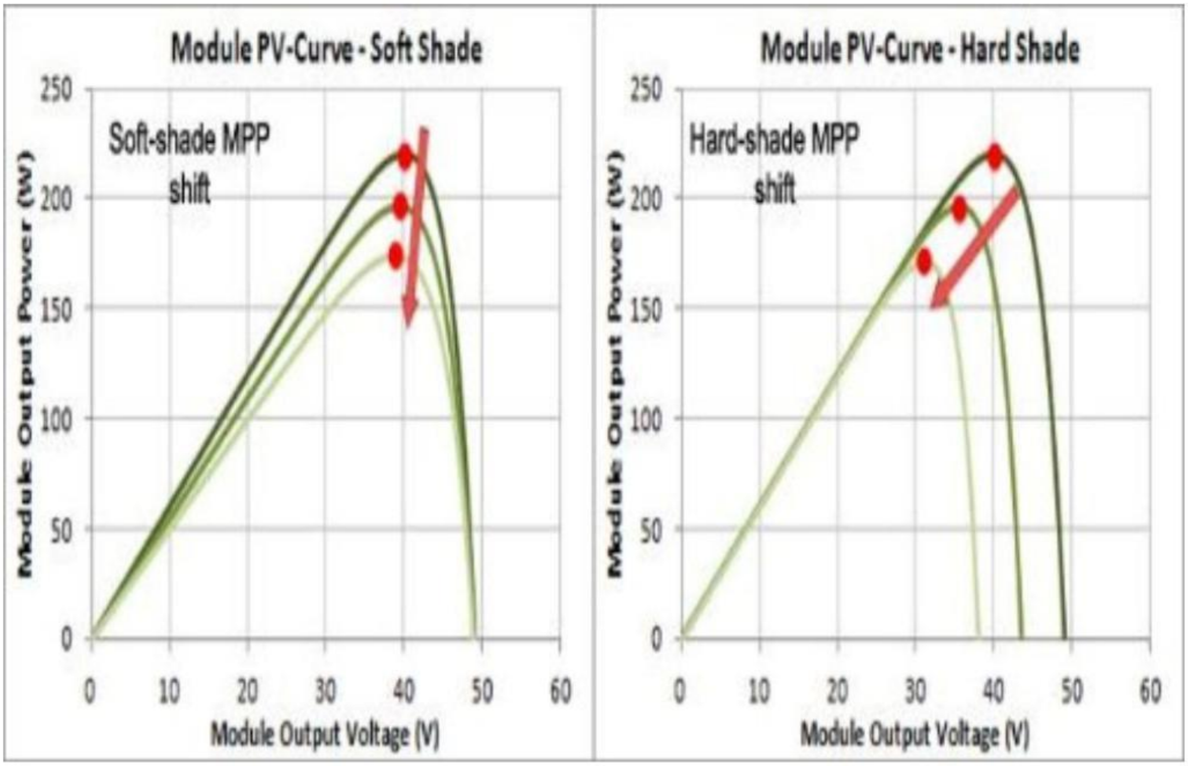
By the practical result after varying the temperature of PV module as shown in table conclude that temperature of cell is an important factor to enhance the efficiency of solar PV system. Mono-Crystalline PV module is best for low Temperature areas. Poly-Crystalline is affected by high temperatures more than mono-crystalline.So, the selection of PV module is always according to the temperature and other weather conditions of the location.

Effect of Shade :

Solar module is fabricated with solar cells connected in series. There is a Bypass diode between two columns of solar cells which is actually placed because when the breakage or fault of solar cell occurs then these diodes bypass the remaining circuit but overall power of module decreases badly. Same phenomenon happens when shade is fall on solar module. Due to this shade the current or voltage of solarmodule decreases according to the type of shade. There are two kinds of shades

- **Soft shade**
- **Hard shade**

When solar module is covered by soft shade, current decreases due to which power of the module decreases. And in case of hard shade , voltages drop badly and Power decrease.



Due to disturbance in power generation, there is a need of Bypass circuits which can improve the efficiency of solar system. Effect of soft shade observed practically is shown in table 6.

Shade	One cell	Two cells of different columns	Three cells of different columns
$?_{??}$???????	25.1	25.09	25.05
$?_{??}$??? ??	2.49	2.11	1.61
$?_{??}$(volts)	33.2	33.1	33.03
$?_{??}$(amp)	5.8	5.69	2.06

Table 6.Effect of shade

The output of a system is directly related with the stability of that system. The problem of shade effect is solved by using trackers or by performing proper arrangement of module so that there will be no effect of shade.

Effect of load :

When solar system is being installed then load calculation is compulsory part for the reliability of the solar system because Off-grid PV system which is also called stand-alone system dependent on battery capacity corresponding to load and back up hours at which sun is not available. Load is the factor which makes our system reliable. If our load consumes more power than system capacity when sun is not available then the output of the system becomes zero soon due to which efficiency becomes zero. So, as we increase the load beyond the capacity requirements then battery life as well as module efficiency reduces.

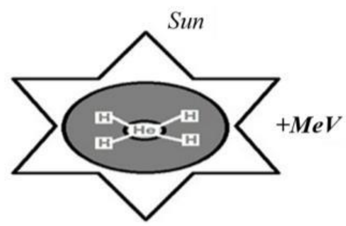
Battery life protection:

Using such an embedded system for controlling the battery’s charging & discharging is quite efficient if considered the health of battery on long term basis. Since a very major reason for battery’s short life & eventually decreasing efficiency is usually the abrupt charging/discharging behavior with no proper control & the discharging of battery.J. Working of Smart System:Its main working is based on the voltages of battery while charger is connected or disconnected. It will consistently fetch data using ADC to keep track of battery voltages. Once it has calculated battery voltages using formulas used .

RESEARCH IN SOLAR CELL

Introduction :

- **Everyday sun sends out tremendous amount of energy in the form of heat and radiations called solar energy.**
- **Solar energy is a limitless source of energy which is available at no cost . The major benefit of solar energy over other conventional power generators is that the sunlight can be directly harvested into solar energy with the use of small and tiny photovoltaic (PV) solar cells .**
- **This big spherical gaseous cloud is mainly composed of several hydrogen nu lei combining to form helium energy with the emission of energy from the fusion of the hydrogen nuclei in inner core of the Sun via nuclear fusion .**



$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + 3.27\text{MeV}$$

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n + 17.59\text{MeV}$$

Figure 1. Nuclear fusion reaction: source of solar energy [5].

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- **In spite of numerous advantages, this energy has few limitations too.Firstly, solar energy doesn't radiate at night. Secondly, the solarenergy is almost not constant all the time.**
- **There must be plenty of sunlight available to generate electrical energy from a solar PV device . Moreover, apart from daily fluctuations in the intensity of radiant energy, the solar energy is hindered to reach the earth during bad climatic conditions.**
- **For example, the amount of sunlight reaching the earth's surface depends on location, time as well as weather as it falls during winter season as compared to the summer, and the Sun's radiation is less intense .**
- **To overcome these demerits of this technology, solar energy must be stored elsewhere at night and the highly effi-cient solar cells and modules needs to be developed. There have been an enormous amount of research activities to harvest the Sun's**

energy effectively by devel-oping solar cells/panels with high conversion efficiencies. The photovoltaic conversion efficiency is referred to the efficiency of solar PV modules, and is defined as the fraction of Sun's energy that can be converted into electricity.

- **Solar panels are a huge collection of tiny solar cells arranged in a definite geometrical shape to pro-duce a given amount of power supply. The storage of solar power is still has not been achieved successfully. Currently the radiation efficiency of solar panel is up to 22% [11]. There are many solar photovoltaic batteries available which are usually more expensive and bulky.**
- **These are more suitable for small scale or household so-lar needs compared to large solar plantsThe working mechanism of solar cells is based on the three factors: Adsorption of light in order to gener-ate the charge careers, holes (p-type) and electrons (n-type) Separation of charge careers, and the collec-tion of charge careers at the respective electrodes establishing the potential difference across the p-n junction.**
- **The generation of voltage difference noticed at the p-n junction of the cell in response to visible radiation is uti-lized to do the work.**

First Generation Solar Cell : (Wafer Based)

As it is already mentioned, the first generation solar cells are produced on silicon wafers. It is the oldest and the most popular technology due to high power efficiencies. The silicon wafer based technology is further catego-rized into two subgroups named as .

- **Single/ Mono-crystalline silicon solar cell.**
- **Poly/Multi-crystalline silicon solar cell.**

Single/Mono-Crystalline Silicon Solar Cell

- **Mono crystalline solar cell, as the name indicates, is manufactured from single crystals of silicon by a process called Czochralski process.During the manufacturing process, Si crystals are sliced from the big sizedingots.**
- **These large single crystal productions require precise processing as the process of "recrystallizing" the cell is more expensive and multi process. The efficiency of mono-crystalline single-crystalline silicon solar cells lies between 17% - 18%.**

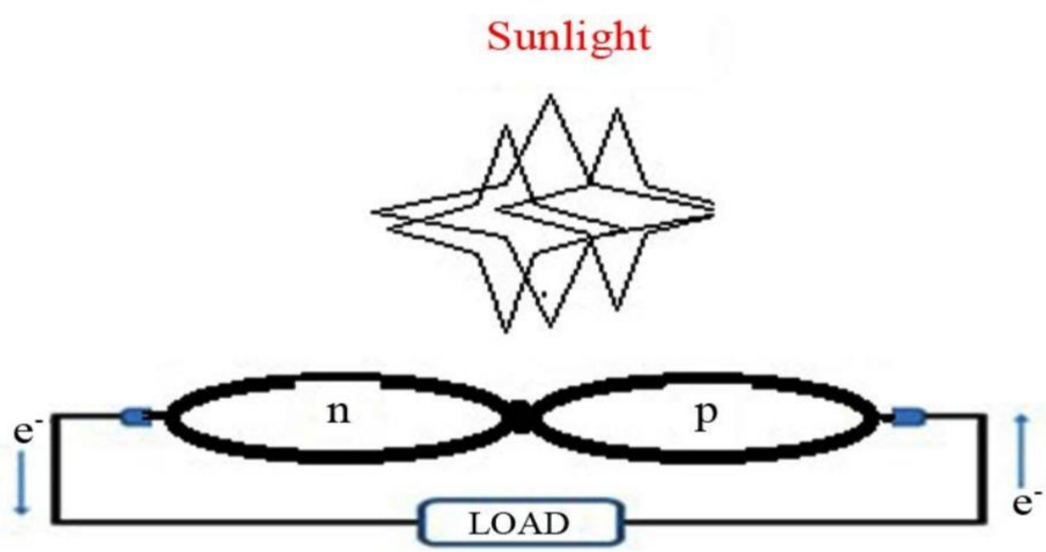


Figure 2. The semiconductor p-n junction solar cell under load.

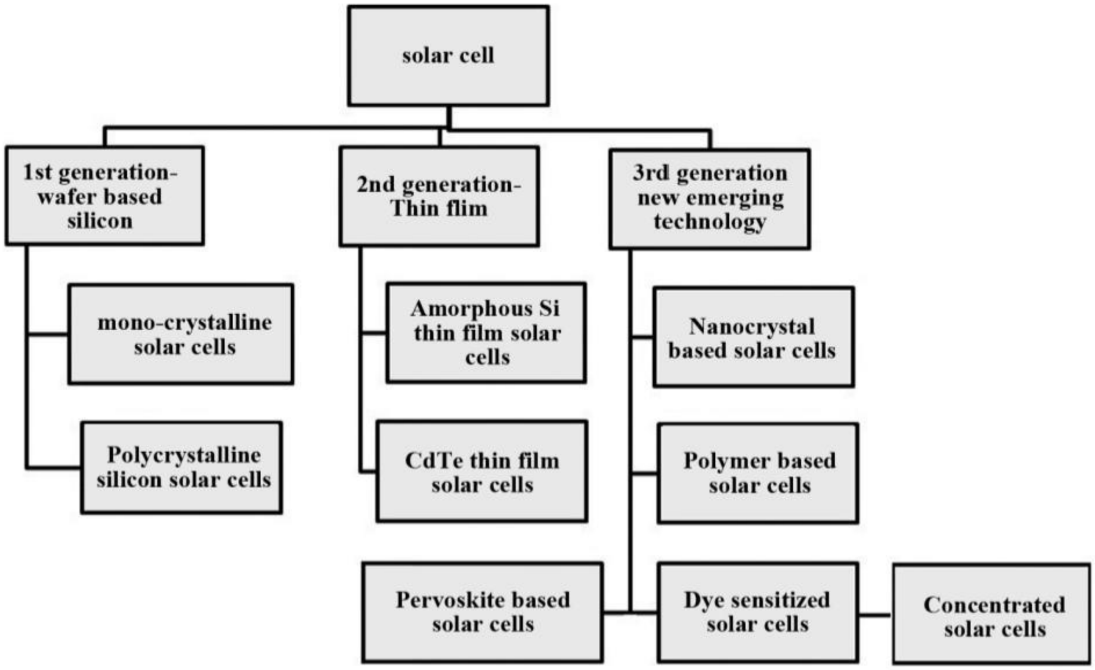


Figure 3. Various types of solar cell technologies and current trends of development [2] [16].

MATERIAL OF SOLAR CELL

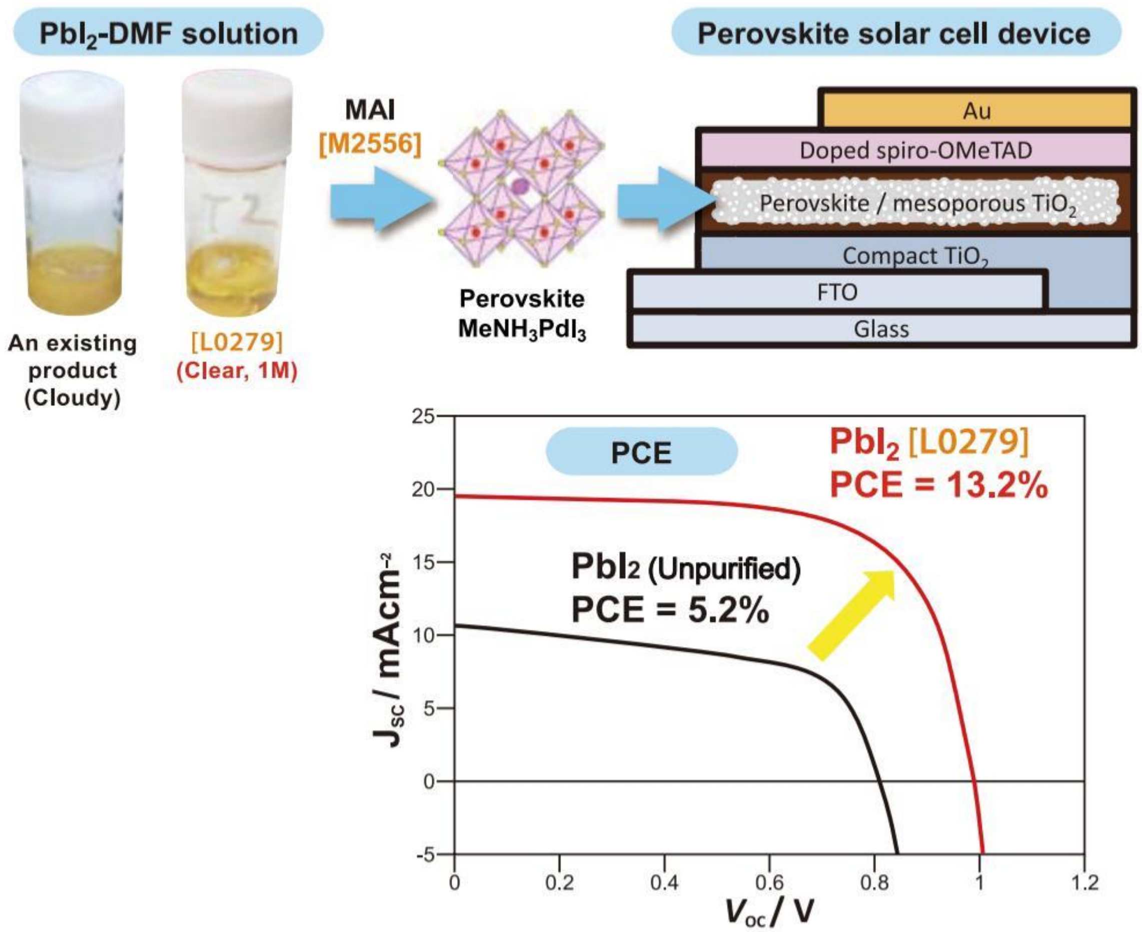
Sunlight is one of the renewable energy sources that can globally contribute to environmental and energy solutions in the 21st century. In order to use sunlight as efficiently as possible, low cost and efficient solar cells have been vigorously developed for practical use. As is generally known, practical silicon-based solar cells involve high manufacturing cost, as well as any other inorganic-based solar cells. On the basis of the cost problem, we have developed new solar cells based on organic and organic-inorganic hybrid materials.

1.Perovskite Solar Cell (PSC) Materials :

- **A perovskite solar cell, that was first reported by Miyasaka et al. in 2009, has recently received much attention.1) The organic-**

inorganic perovskite, RNH3PbX3 (X = Cl, Br, I; R = Me, NH=CH, etc.), can function as a light absorption layer.

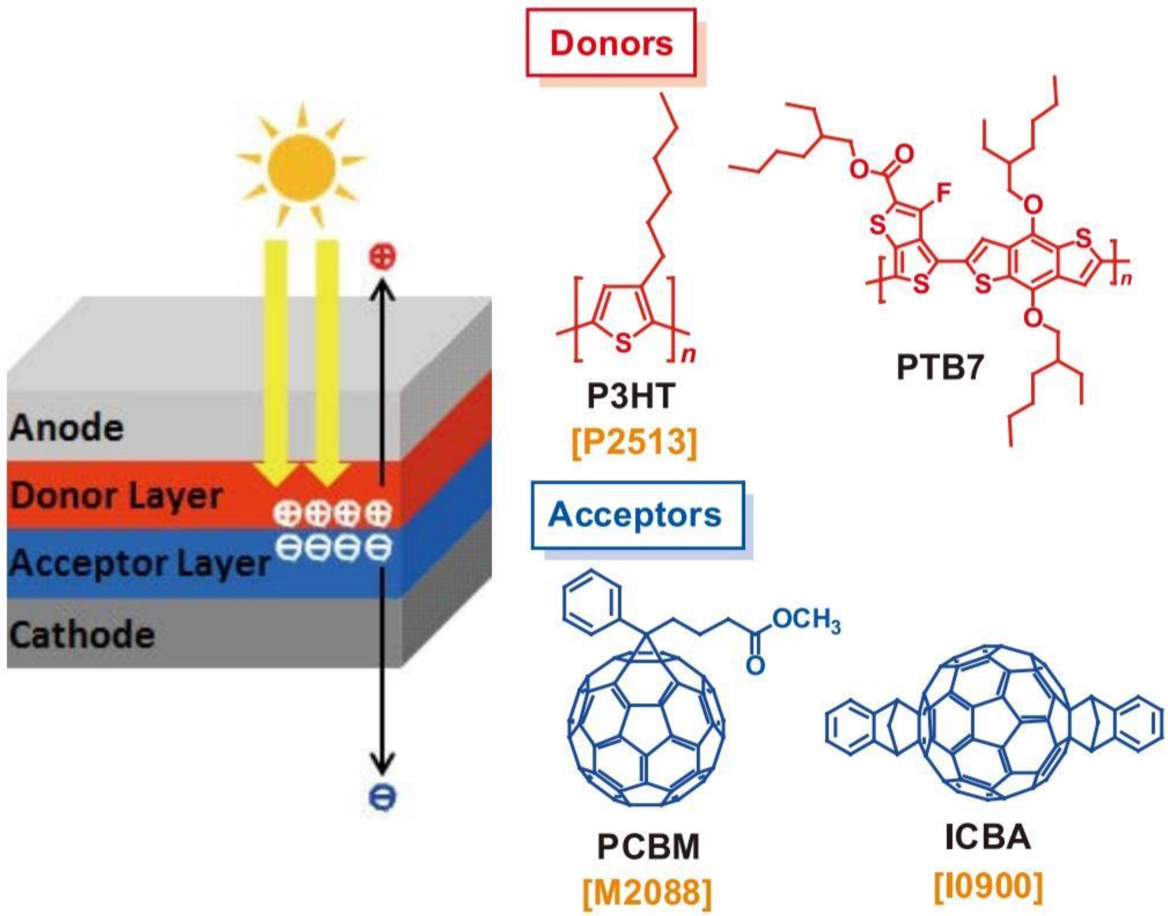
- Since 2012, power conversion efficiency (PCE) of the perovskite solar cell has been drastically improved and it has reached >15% better than those of OPV and DSSC.2-5) A device of the perovskite solar cell is solution-processible for fabrication at low cost. The organic-inorganic perovskites RNH3PbX3 are easily prepared from HX salts of organic amines and lead halides.
- A modification of the halide X in the (MeNH3)PbX3 can control the range of absorption wavelength.6) The perovskite compound with X = Br is useful for light absorption in shorter wavelengths and the compound with X = I is relatively useful for that in longer wavelengths. Wakamiya et al. reported that use of highly dried lead(II) iodide is a key to fabricate efficient perovskite solar cell devices (PCE > 10%) with high reproducibility.7,8) Carrier behavior in the perovskite layer is different from that in OPV, thus there are free carriers in which electrons and holes can be movable freely.9) According to the reason, the perovskite layer can transport both electron and hole carriers without recombination.



2. Organic Photovoltaics (OPV) Materials

- **A prototype of organic photovoltaics (OPV) was reported by Tang et al. in 1986.10) In order to fabricate an OPV device.**
- **we can use highly productive methods such as printing and roll-to-roll methods.**

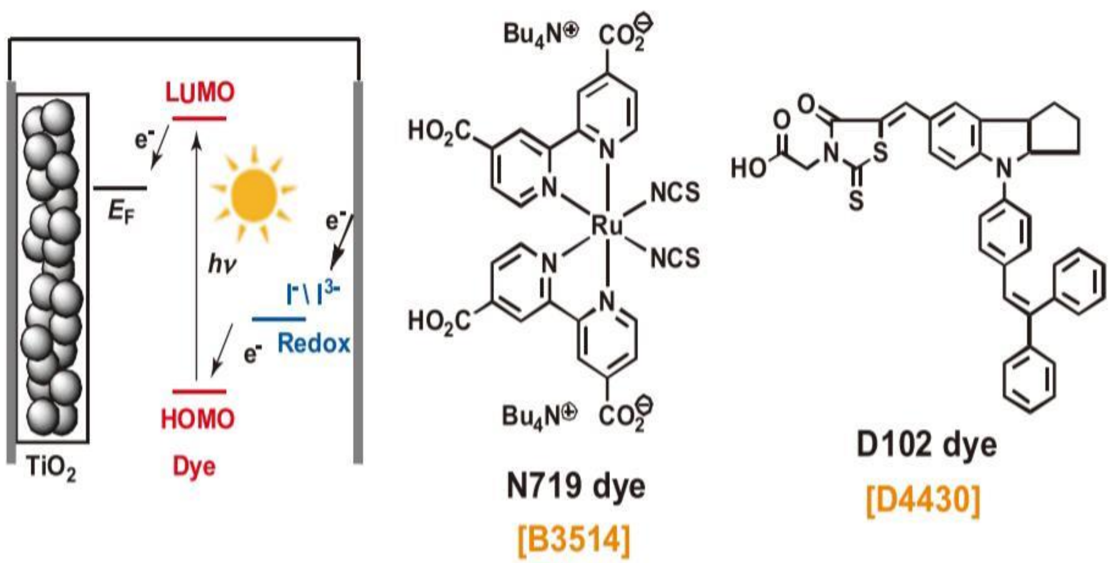
- **The OPV device usually requires bulk heterojunctions (BHJ) which can be fabricated by mixing an electron-donor (p-type semiconductor) and electron-acceptor (n-type semiconductor).**
- **The former material involves a p-conjugated polymer and a small molecule semiconductor, and the latter material is normally a fullerene derivative.**
- **PCBM, that is a solubility-enhanced fullerene, efficiently provides a bulk heterojunction.**
- **ICBM gives a high open-circuit voltage because it has a higher energy LUMO than that of PCBM.**
- **A C70 derivative usually gives higher cell efficiency compared with that of the corresponding C60 one, because the C70 derivative absorbs light better than the C60.**
- **We can introduce an acceptor component into the structure of a p-type semiconducting polymer to form a donor-acceptor (DA-type) polymer, that shows light absorption in the long wavelength area based on a charge transfer.**



3. Dye-Sensitized Solar Cell (DSSC) Materials

- **Grätzel et al. first developed a dye-sensitized solar cell (DSSC) in 1991. The DSSC is a liquid-type device that involves nanoporous titanium oxide (TiO2) as a semiconducting electrode, organic dye-sensitizer and an electrolyte solution containing a redox component.**

- This is expected to be a low cost solar cell, because there is a simple device structure compared with other solar cells. The DSSC is usable under conditions with weak light.
- Thus, it is expected that theDSSC may be installed in a room. A ruthenium complex with a bipyridine ligand is one popular organic dye for solar cells.In the polypyridine ligand ofthe ruthenium complex, we can introduce some carboxyl or phosphonic acid groups forming a linkage with TiO2. In addition, metal-free organic dyes were also developed, because they do not contain any expensive ruthenium atoms,
- Recently, efficient green-colored zinc-porphyrin dyes were developed for DSSC showing more than 10% of PCE. Furthermore, efficient blue-colored metal-free organic dyes having a diketopyrrolopyrrole structure were developed for DSSC (PCE > 10%).



APPLICATION OF SOLAR CELL

Amorphous Silicon Solar Cell (A-Si) :

- **Amorphous silicon (a-Si) is the non-crystalline form of silicon. It is the most well developed of the thin film technologies having been on the market for more than 15 years.**
- **It is widely used in pocket calculators, but it also powers some private homes, buildings, and remote facilities. United Solar Systems Corp. (UniSolar) pioneered amorphous-silicon solar cells and remains a major maker today, as does Sharp and Sanyo.**
- **Amorphous silicon panels are formed by vapor-depositing a thin layer of silicon material – about 1 micrometer thick – on a substrate material such as glass or metal.**

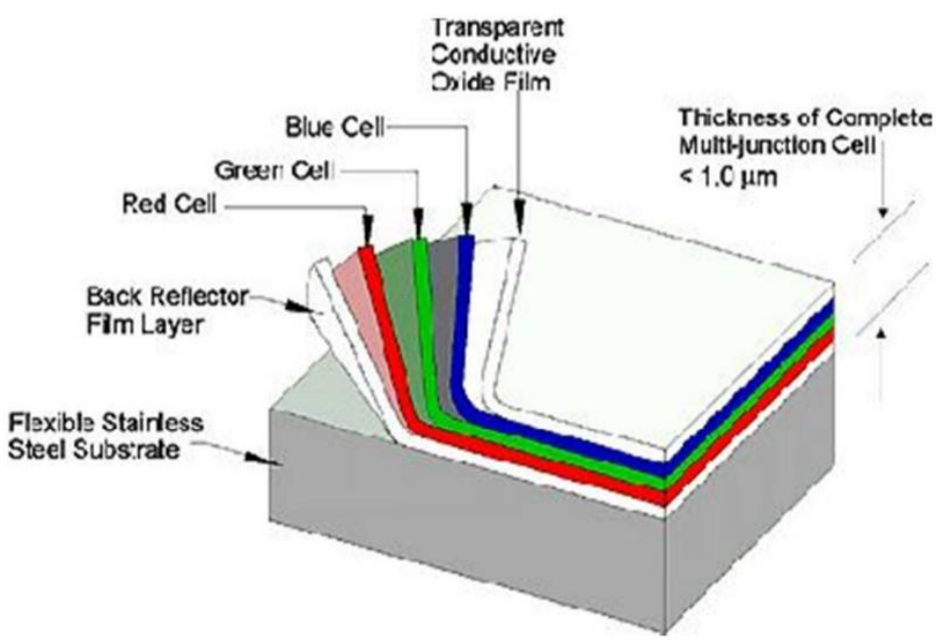


Fig. 1. Amorphous silicon is Uni-Solar. They use a triple layer system.

Biohybrid Solar Cell :

- **A biohybrid solar cell is a solar cell made using acombination 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**

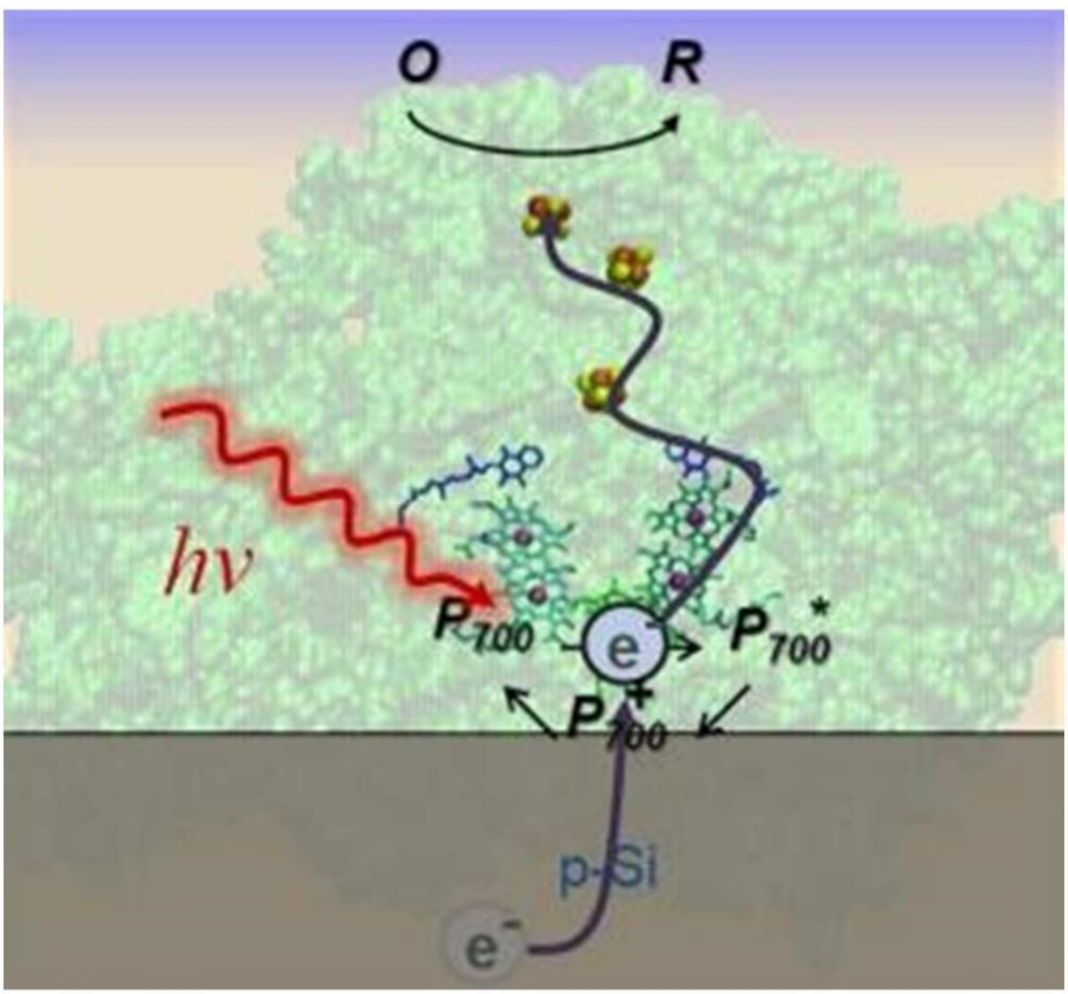


Fig. 2. Making Multilayered Bio-Hybrid Solar cells.

energy conversion. These biohybrid solar cells are a new type of renewable energy.

Buried Contact Solar Cell :

The buried contact solar cell is a high efficiency commercial solar cell technology based on a plated metal contact inside a laser-formed groove. The buried contact technology overcomes many of the disadvantages associated with screen-printed contacts and this allows buried contact solar cell to have performance up to 25% better than commercial screen-printed solar cells. A schematic of a buried contact solar cell is shown in the figure below.

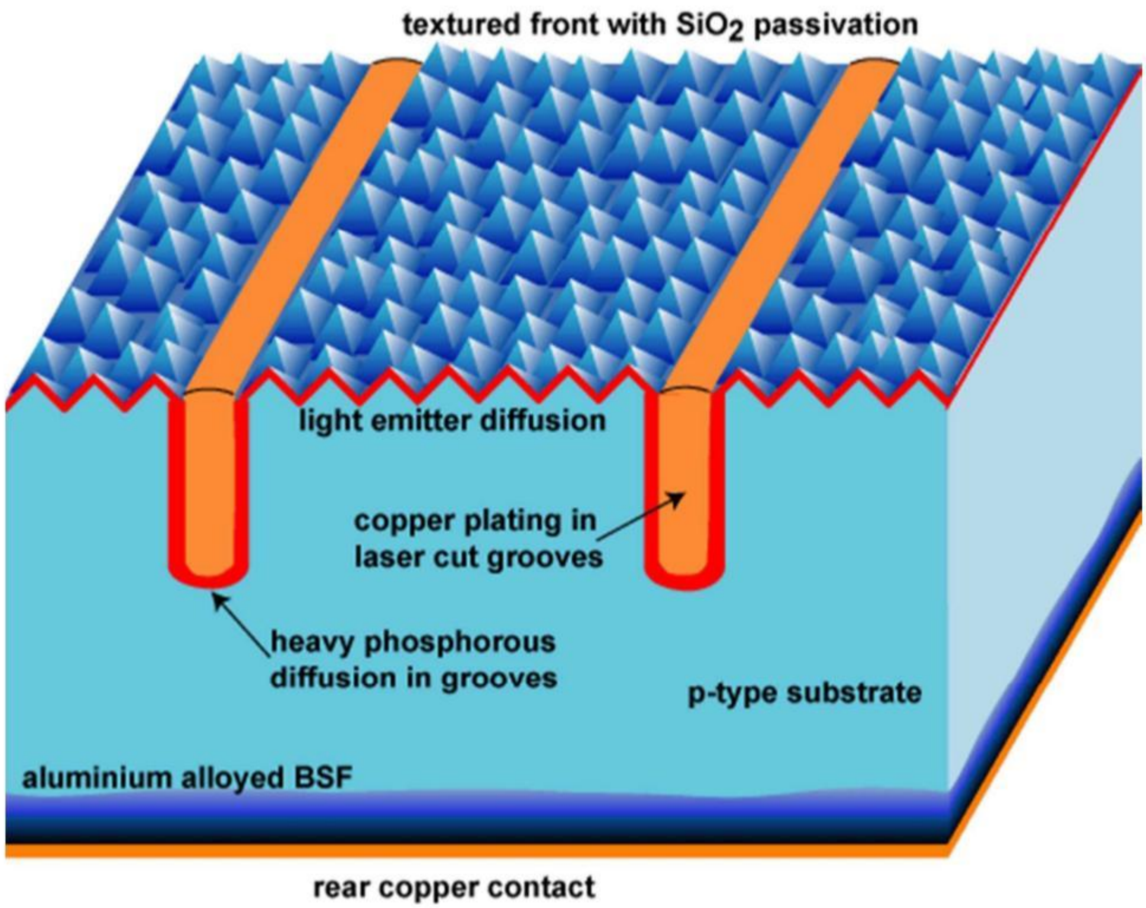
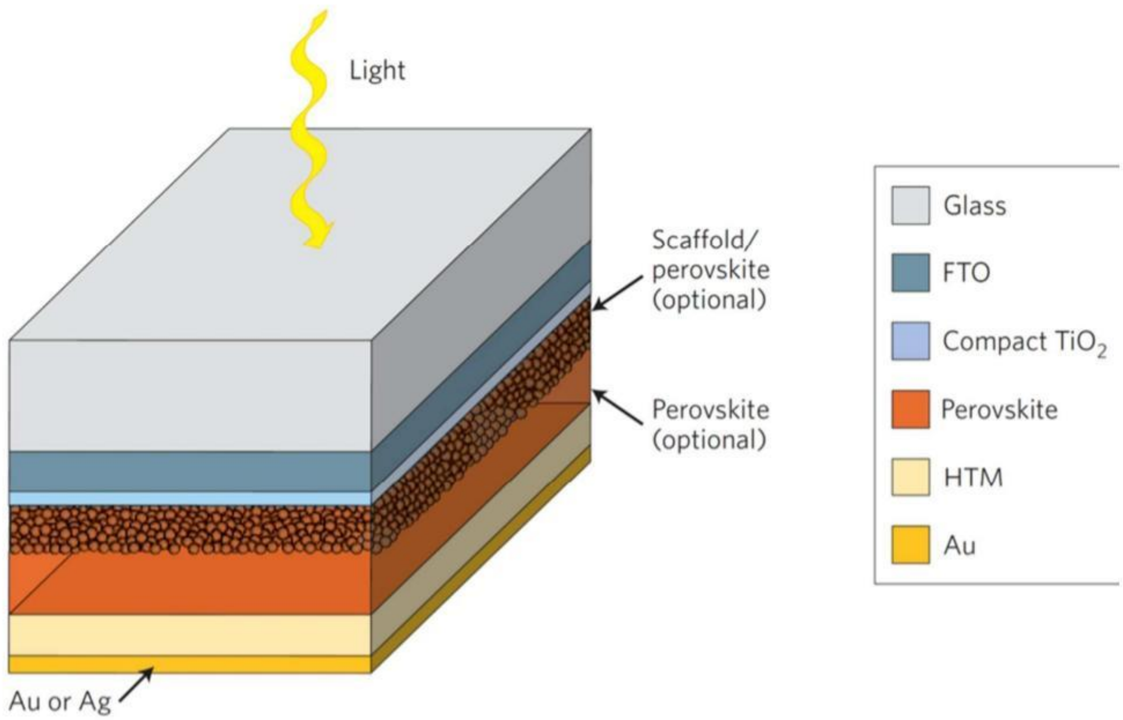


Fig. 3. *Cross-section of Laser Grooved, Buried Contact Solar Cell.*

Perovskite Solar Cell :

- **The name 'perovskite solar cell' is derived from the ABX3 crystal structure of the absorber materials, which is referred to as perovskite structure.**
- **The most commonly studied perovskite absorber is methylammonium lead trihalide (CH3NH3PbX3, where X is a halogen ion such as I−, Br−, Cl−), with an optical bandgap between 2.3 eV and 1.6 eV depending on halide content.**

Formamidinum lead trihalide (H2NCHNH2PbX3) has also shown promise, with bandgaps between 2.2 eV and 1.5 eV.



CONCLUSION :

- **After looking at the data collected we can conclude multiple things. Firstly. water does not affect the voltage output of a solar panel since its transparent allowing sunlight to beam through it. Secondly, there is an obvious jump in voltage output from a clean solar panel to a dusty solar panel. We lost approximately 0.03V as a result of the dust/dirt accumulated.**

- **While this number is small when this it is put in perspective with bigger scale solar panels that output 12 V the voltage lost could easily be around 3-4 V.**
- **A more thorough conclusion can be made with additional testing such as measuring the current output from the solar panel which can be used to calculate the power (wattage) the panel is outputting.**

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