

Solar Photovoltaic (SPV) Conversion: A Brief Study

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Abstract

The sun is a sphere of intensely hot gaseous matter, continuously generating heat by thermo-nuclear fusion reactions, which convert hydrogen atoms to helium atoms. This energy is radiated from the sun in all directions and a very small fraction of it reaches the earth. It is in the utilization of this small fraction of the total solar energy which reaches to the earth that we are interested in. Fusion energy is a form of nuclear energy released by the fusion (or combination) of two light nuclei (i.e. nuclei of low mass number) to produce a heavier nucleus. For two nuclei to fuse, they must come close enough to interact. However, similar electric charges repel one another, and since all nuclei carry a positive charge, an increasing force of repulsion develops as the two nuclei are brought closer together. Consequently, for the nuclei to fuse, they must have enough kinetic (or motion) energy to overcome the force of electrical repulsion that keeps them apart. For the force of repulsion to be small, and thus make fusion easier to achieve, the interacting nuclei should have small positive charges (i.e., low atomic numbers). The element hydrogen has the lowest atomic number, since the nuclei of its three isotopes all carry a single positive charge. Hence, hydrogen isotopes, which also have the light nuclei, should be particularly suitable for the production of energy by the fusion of two light nuclei to form a heavier nucleus. Using this solar radiation PV cell is used for generation of electricity. A brief study has been discussed about SPV conversion. This paper has discussed about the unit solar cell, solar module, solar panel, solar array, conversion efficiency of a solar cell, ideal I-V characteristics of a solar cell, Fill Factor (FF) of a solar cell, Building integrated SPV system, Grid connected SPV system, thin film solar cell and die-sensitized solar cell.

Keywords: Solar Photovoltaic, Classifications, Thinfilm Solar cell, Efficiency, Building integrated solar cell, fusion reaction

Introduction:

Earth receives radiant energy from sun which is vast and hot mass of hydrogen, and helium gases in the proportion of 3:1. In the sun, energy is generated in its central core which may be considered as a giant nuclear reactor[1-3]. The energy is released in accordance with the given reaction: $4\ ^1\text{H} \longrightarrow\ ^4\text{He} + 26.7\ \text{MeV}$. The energy is the above reaction results from the fact that four protons have a total uncombined mass of 4.0304 and mass of helium nucleus is 4.0027. Thus 0.0277 mass units of matter are converted into energy in accordance with the energy (E), mass (m) relation ($E=mc^2$), given by Einstein; C is velocity of light. It is this energy which continuously flows out of the sun; the portion of the energy intercepted by earth passes through terrestrial energy processes and sustains life and activity. The principal characteristics of the sun are: Mass, $M = (1.99 \pm 0.002) \times 10^{30}$ kg, Radius, $R = (6.960 \pm 0.001) \times 10^8$ km, Average density, $\rho = 1.410 \pm 0.002$ g/cm³, Temperature (average on the surface), $T = 5762 \pm 50^\circ\text{K}$. The sun rotates about its axis, but not as a rigid body. The period of rotation varies from about 25 earth days at its equator to about 27 days at 40° latitude[4-10]. The structure of the sun is generally divided into three regions---solar interior, the photosphere and the solar atmosphere. The solar interior constitute the main mass of the sun and has gases at a pressure of a billion atmosphere and temperatures of 8×10^6 to 40×10^6 °K. The density is about 80 to 100 times that of water. It is almost a continuous fusion reactor with its constituent gases as the containing vessel retained by gravitational forces. Its most of the energy is generated because of continuous conversion of hydrogen (i.e. four protons) to helium (i.e. one helium nucleus); the mass of the helium nucleus is less than that of the four protons, mass having been lost in the reaction and converted to energy.

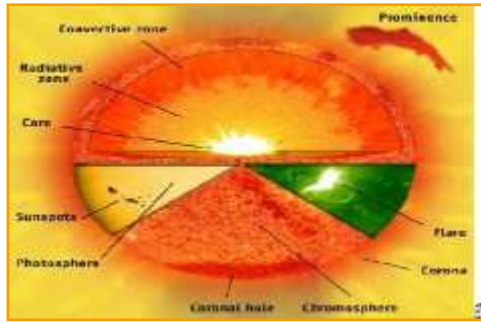


Figure: 2.1 The Source of all Energy.

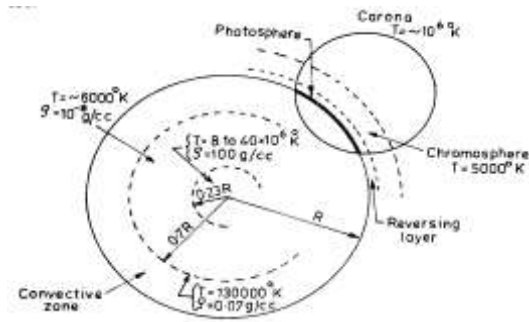


Figure 2.2 : Structure of the sun

These reactions take place in the presence of carbon and nitrogen[11-19]. The energy is produced in the interior of the solar sphere, is transferred to the surface and radiated into space. Structure of the sun is shown schematically in Fig: 2.2. It is estimated that 90% of the energy is generated in the region 0 to 0.23 R is the radius of the sun, which contains 40% of the mass of the sun. The energy created in this reactor region is transferred outward by radiation in the form of α and γ (gamma) rays upto a distance of about 0.07 R From the centre, where the temperature has dropped to about 130,000 °K and the density has dropped to 0.07 g/cm³. Outside this region there is a fluid in which the energy is mainly by convection and is, therefore, known as the convective zone. Within this zone the density drops to 10⁻⁸ g/cm³ and the temperature falls to about 6000 °K [20-27]. The upper layer of the convective zone is called the photosphere and it is our source of light and heat. It is essentially opaque, as the gases of which it is composed are strongly ionized and able to absorb and emit a continuous spectrum of radiation. Above the photosphere there is a transparent layer of rarefied gas 10,000 km thick. It is known as the chromosphere because of its red colour resulting from the strong H α line of hydrogen in the spectrum of the layer, a continuous band of low intensity mainly caused by the scattering of solar radiation. Its density gradually decreases from 10⁻⁸ g/cm³ at high altitude. Its luminosity fades at 6000-7000 km above the photosphere. The temperature of the chromosphere is about 4500 °K at the base and 10⁶ °K at an elevation of 12,000 km where it ends and the isothermal corona starts. The light emitted by the chromospheres is of short wavelength because of the high temperature and is very weak because of the rarefication of its gases. It contributes by a factor of 10⁻³ to the energy emitted by the sun. Finally there is the corona, a whitish glowing layer that may be observed in all in beauty only during total solar eclipses. It is made of highly ionized gases of very low density. Its temperature, supposed to be raised by shock waves, is about 10⁶ °K as confirmed by the recent X-ray coronal spectra taken on the Skylab[28-35].

I. Methods and Materials

II A. Applications of Solar Technology

Solar chemical processes use solar energy to drive chemical reactions. These processes offset energy that would otherwise come from an alternate source and can convert solar energy into storable and transportable fuels. Solar induced chemical reactions can be divided into thermo chemical or photochemical. Average insolation showing land area (small black dots) required to replace the total world energy supply with solar electricity. Insolation for most people is from 150 to 300 W/m² or 3.5 to 7.0 kWh/m²/day[36-40].

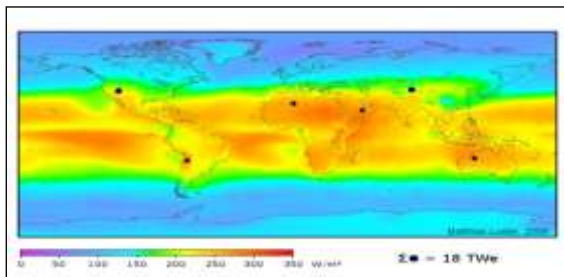


Figure 2.3 : Total world energy supply with solar electricity.



Figure 2.4: PV Cell.

Solar energy refers primarily to the use of solar radiation for practical ends. All other renewable energies other than geothermal derive their energy from energy received from the sun. Solar technologies are broadly

characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use photovoltaic panels, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies[41-50].

II B. Photovoltaic (PV): Photovoltaic (PV) is solid-state device that simply makes electricity out of sunlight, silently and with little to no maintenance, no pollution and no significant depletion of material resource. It is shown in Fig.2.4.

II C. Solar Photovoltaic (SPV) Conversion: The process in which solar radiation converts directly into electricity is called solar photovoltaic (SPV) conversion. In Photovoltaic conversion, solar radiation falls on devices which convert the sunlight directly into electricity[51-55].

How do Photovoltaic's Work?

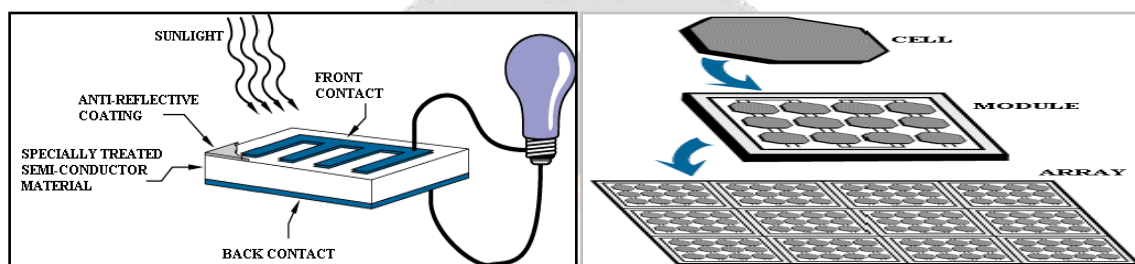


Figure 2.5: Operation of a Photovoltaic cell. Figure 2.6: Cell, Module and Array.

Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons[56-60]. When these free electrons are captured, electric current results that can be used as electricity. The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications[61-70]. The diagram above illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solar cells are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current - that is, electricity. This electricity can then be used to power a load, such as a light or a tool. A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module[71-72]. Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity that will be produced. Photovoltaic modules and arrays produce direct-current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination[73-76].

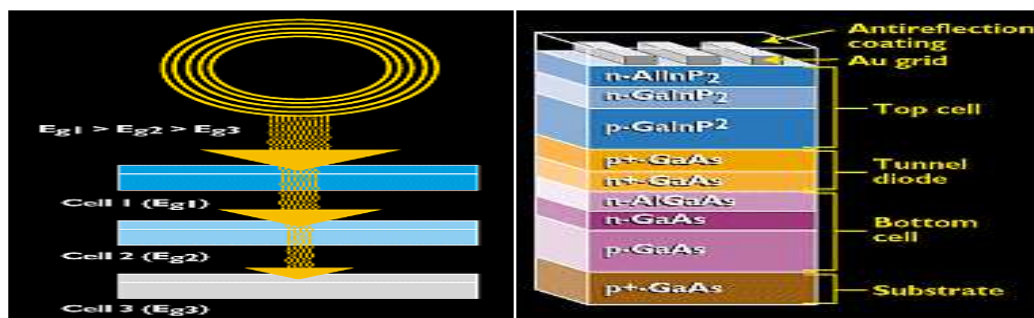


Figure 2.7: Sun ray and Cells.

Figure 2.8: Multi-junction cells.

Today's most common PV devices use a single junction, or interface, to create an electric field within a semiconductor such as a PV cell. In a single-junction PV cell, only photons whose energy is equal to or greater than the band gap of the cell material can free an electron for an electric circuit. In other words, the photovoltaic response of single-junction cells is limited to the portion of the sun's spectrum whose energy is above the band gap of the absorbing material, and lower-energy photons are not used. One way to get around this limitation is to use two (or more) different cells, with more than one band gap and more than one junction, to generate a voltage. These are referred to as "multijunction" cells (also called "cascade" or "tandem" cells). Multijunction devices can achieve a higher total conversion efficiency because they can convert more of the energy spectrum of light to electricity. As shown below, a multijunction device is a stack of individual single-junction cells in descending order of band gap (E_g). The top cell captures the high-energy photons and passes the rest of the photons on to be absorbed by lower-band-gap cells [77-85].

Much of today's research in multijunction cells focuses on gallium arsenide as one (or all) of the component cells. Such cells have reached efficiencies of around 35% under concentrated sunlight. Other materials studied for multijunction devices have been amorphous silicon and copper indium diselenide. As an example, the multijunction device below uses a top cell of gallium indium phosphide, "a tunnel junction," to aid the flow of electrons between the cells, and a bottom cell of gallium arsenide.

II D. Future PV

Here's a look at some things we can expect in the future from solar PV technologies. In photovoltaic research and development, there will be more breakthroughs in new materials, cell designs, and novel approaches to product development. In a solar future, your mode of transportation –and even the clothes you wear –could produce clean, safe electric power. With today's technology roadmaps to lead the way, concentrating solar power will be fully competitive with conventional power –generating technologies within a decade. Concentrating solar power, or solar thermal electricity, could harness enough of the sun's energy to provide large –scale, domestically secure, and environmentally friendly electricity. Within 10 years, photovoltaic power will be competitive in price with traditional sources of electricity. Solar electricity will be used in an electrolysis process that separates the hydrogen and oxygen in water so the hydrogen can be used in fuel cells for transportation and in buildings [86-90].

II E Solar PV Cell

Solar PV cell is the basic unit in a PV system. It consists of a junction between two thin layers of dissimilar semi conducting materials. One is the positive type semiconductor or P –type and the other is the negative type semiconductor or N- type. These semi conductors can be made from Silicon, Germanium, Gallium-Arsenide, Indium-Phosphate, Cadmium-Sulphide, Cadmium-Telluride etc. But semiconductors are usually made Silicon. Because Silicon is one of the most available elements on earth. It exists in nature predominantly in a combined form (Silicon-Oxide). For solar PV cell the pure Silicon is needed [91-99].

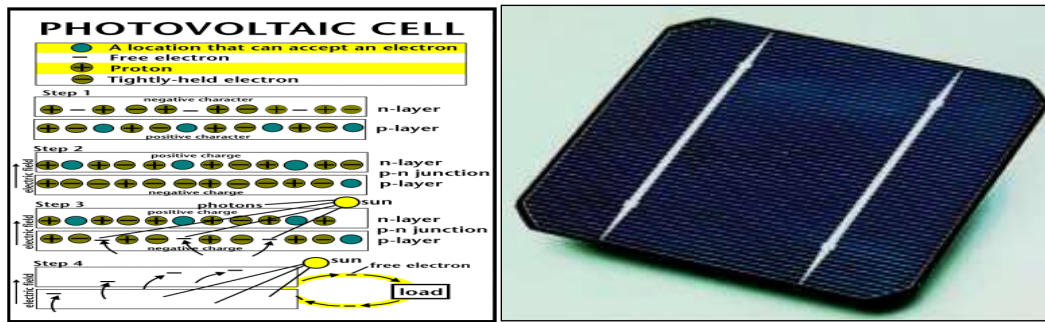


Figure 2.9: Solar PV cell.

N –type semi-conductors are made from crystalline silicon that is doped with tiny quantities of an impurity (usually phosphorus) in such a way that the doped materials possess a surplus of free electrons. P-type semiconductor are also made from crystalline silicon that is doped with very small amount of a different impurity (usually boron) which causes the material to have deficit of electrons. An individual solar cell can vary in size from about 1 cm (0.4 inch) to about 15 cm (6 inches) across and typically produces between 1 and 2 watts, hardly enough power for the great majority of applications. The power is increased by connecting cells together.

II F Classification of Solar Photovoltaic Cell

Solar cells can be separated into the following categories, according to their crystalline structure:



Fig.2.10: Classifications of SPV cell. Fig. 2.11: Mono-crystalline silicon cell. Fig. 2.12: Poly crystalline silicon cell.

(a) Mono-Crystalline Silicon Cells

These cells are made from pure mono crystalline silicon. The silicon has a single and continuous crystal lattice structure with almost no defects or impurities. The principal advantage of mono crystalline cells is their high efficiency, typically around 15 per cent, although the manufacturing process required to produce mono crystalline silicon is complicated, resulting in slightly higher costs than other technologies. Different manufacturing methods are used, depending largely upon the Czochralski method of growing, or pulling a perfect crystal that has a solid, cylindrical shape EFG (Edge defined

Film fed Growth) has become popular, where the cells are cut from an octagon to allow higher packing densities in modules. Another approach deposits grown films of crystalline silicon onto a low cost substrate. The cost of silicon ingot sawing is eliminated and the quantity of silicon per solar module can be reduced significantly[100]. A third approach is a string ribbon technique, where shallow silicon melts and the molten silicon expands and freezes between the strings.

(b) Poly-or Multi-Crystalline Silicon Cells

Poly crystalline (also called multi –crystalline) cells are produced using ingots of multi –crystalline silicon. In the manufacturing process, molten silicon is cast into ingots, which are square or rectangular in shape and allowed to cool so as to form large crystals. These ingots are then cut into very thin wafers and assembled into complete cells. New manufacturing methods also use the approach of grown films of poly crystalline silicon on a low cost substrate. Such substrates have included a metallurgical grade silicon sheet, stainless steel, ceramics and quartz glass, using a variety of growth techniques to deposit silicon films onto these substrates. Poly-crystalline cells are cheaper to produce than mono -crystalline cells, due to be slightly less efficient however, with average efficiencies of around 12 per cent.

(c) Amorphous Silicon Cells

Amorphous silicon cells are composed of silicon atoms in a thin homogenous layer, rather than a crystal structure. Amorphous silicon is produced by deposition onto a substrate, rather than wafer sawing, so the cells can be thinner. For these reason, amorphous silicon is also known as a ‘thin film’ PV technology. Amorphous silicon can be deposited on a wide range of substrate, both rigid and flexible which makes it ideal for curved surfaces and fold away modules. Amorphous cells are however, less efficient than crystalline based cells with typical efficiencies of around 6 per cent, but they require less material and are therefore cheaper to produce. Their low cost makes solar they ideally suited for many applications where high efficiency is not required and low cost is important. For instance, their early market has been in appliances such as calculators and watches. Other thin films PV technologies are Copper Indium diselenide (CIS), cadmium Telluride (Cd Te), CIGS and Gallium Arsenide (GaAs) which are now being used for PV modules.



Figure 2.13: Amorphous Silicon Cell.

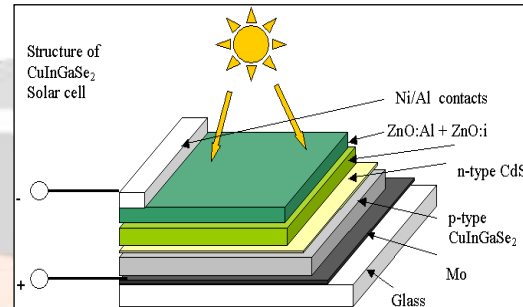


Figure 2.14: Typical layout of CIGS solar cell

Other thin films:

A number of other promising materials such as copper indium diselenide (CIS), a cadmium telluride (CdTe) and CIGS are now being used for PV modules. The attraction of these technologies is that they can be manufactured using relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, and typically offer higher module efficiencies than amorphous silicon. Some of the raw materials required, however, are less abundant than silicon and there are lingering concerns over the environmental toxicity of some of the elements used, although it appears possible to overcome these, with careful manufacturing, recycling and disposal processes. Copper indium diselenide (CuInSe₂ or "CIS") has an extremely high absorptivity, which means that 99% of the light shining on CIS will be absorbed in the first micrometer of the material. Cells made from CIS are usually heterojunction structures – structures in which the junction is formed between semiconductors having different bandgaps [101-110].

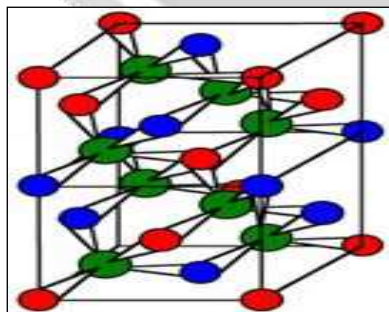


Figure 2.15 : CuInSe₂.



Figure 2.16 : Copper indium diselenide (CIS).

The most common material for the top or window layer in CIS devices is cadmium sulfide (CdS), although zinc is sometimes added to improve transparency. Adding small amounts of gallium to the lower absorbing CIS layer boosts its bandgap from its normal 1.0 electron-volts (eV), which improves the voltage and therefore the efficiency of the device. This particular variation is commonly called a copper indium gallium diselenide or "CIGS" PV cell[111-115].

Dye - Sensitised Solar Cell (DSC):

Dye –sensitised solar cell (DSC) technology is best considered as artificial photosynthesis. It performs well under indirect radiation, during cloudy conditions and when temporarily or permanently partially shaded. DSC technology has been dominated by the Gratzel titanium dioxide (TiO₂) cell. Particles of titanium dioxide are coated with a

photosensitive dye and suspended between two electrodes in a solution containing iodine ions. When this dye is exposed to light energy, some of its electrons jump on to the titanium dioxide particles, which are the attracted to one of the electrodes. At the same time, the iodine ions transport electrons back from the other electrons around the circuit. Efficiencies over time are still to be established but technically could achieve around 10 per cent or more, and are very effective over a wide range of sunlight conditions[116-120].



Figure 2.17: Gratzel titanium oxide crystals cheap.

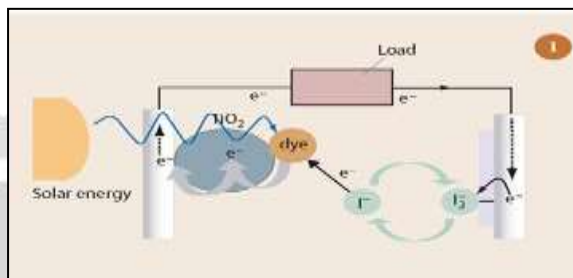


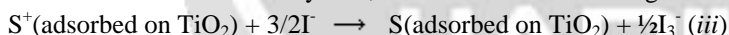
Figure 2.18 : Gratzel solar cell mechanism.

Mechanism of Grätzel cell:

The mechanism for converting solar energy into electrical energy in a dye-sensitised solar cell is a five-step process (see Fig: 2.18). Solar energy ($h\nu$, as photons of light) causes electrons in the molecular orbitals within the adsorbed dye sensitizer (S) molecules to become photoexcited (S*): **S(adsorbed on TiO₂) + $h\nu \rightarrow$ S*(adsorbed on TiO₂) (i)**

(The trapping of solar energy by a sensitizer molecule is analogous to the light-absorbing chlorophyll molecule found in Nature, which converts carbon dioxide and water to glucose and oxygen.).The excited electrons escape from the dye molecules: **S*(adsorbed on TiO₂) \rightarrow S+(adsorbed on TiO₂) + e⁻ (ii)**

The free electrons then move through the conduction band of TiO₂, gather at the anode (the dyed TiO₂ plate), and then start to flow as an electric current through the external load to the counter electrode. The oxidised dye (S⁺) is reduced to the original form (S) by regaining electrons from the organic electrolyte solution that contains the iodide/tri-iodide redox system, with the iodide ions being oxidised (loss of electrons) to tri-iodide ions:



To restore the iodide ions, free electrons at the counter (graphite) electrode (which have travelled around the circuit) reduce the tri-iodide molecules back to their iodide state. The dye molecules are then ready for the next excitation/oxidation/reduction cycle.

Putting it all together:

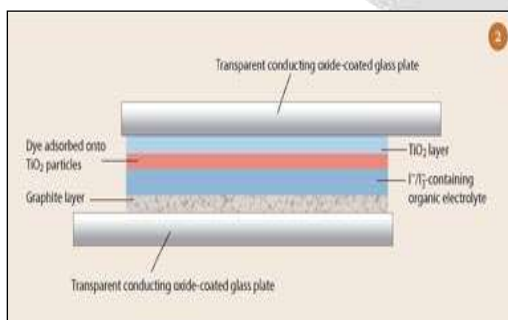


Figure 2.19: Gratzel solar cell structure

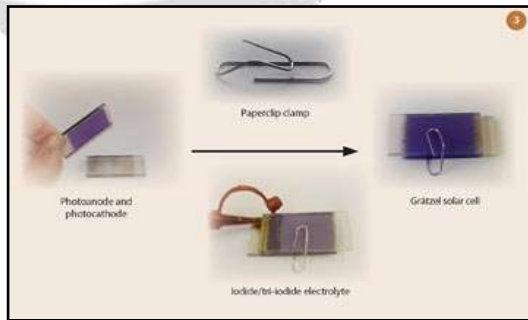


Figure 2.20 : Gratzel solar cell assembly

Grätzel cells comprise two transparent conducting oxide glass plates sandwiched together (Figs 2 and 3). Typically fluorine-doped indium oxide or tin-doped indium oxide are used. The thin oxide coating on one side of the glass makes the glass surface electrically conducting. The upper plate (the 'photoanode'), has the sensitising dye adsorbed onto a 10 μm layer of randomly-stacked nanoparticles (ca 20 nm in diameter) of

TiO₂. For research investigations, a thin film of platinum is chemically deposited onto the lower plate as a conductor and catalyst. However, for demonstrations, simply coating the lower plate with graphite from a soft pencil will suffice. The upper and lower plates are secured together with a paperclip 'clamp' (Fig 3). To finish the cell, a drop of organic electrolyte solution, which contains the iodide/tri-iodide redox couple, is applied between the plates[121-125].

Table- 2.1 : Comparison of solar cell efficiencies

Name of the Item	Typical efficiencies %	Maximum recorded outdoors	Maximum recorded Laboratory efficiency %
Mono-crystalline(m-Si)	12-15	22.7%±0.6	27.7
Poly-crystalline (p-Si)	11-14	15.3 %±0.4	19.8
Amorphous silicon (a-Si)	6-8	10.4%±0.5	12.7
Cadmium telluride (CdTe)	7-10	10.7%±0.5	16.0
Copperindiumdiselenide(CIS)	8-12	13.0 %±0.6	18.8
Gallium Arsenide (GaAs)		25.1%± 0.8	
Titanium Dioxide Gratzel cell (TiO ₂)	10	n/a	

II G Principle of Working of a Solar Cell

Two important steps are involved in the principle of working of a solar cell. These are:

- (a) Creation of pairs of positive and negative charges (called electron hole pairs) in the solar cell by absorbed solar radiation and (b) Separation of the positive and negative charges by a potential gradient within the cell.

For the first step to occur, the cell must be made of a material which can absorb the energy associated with the photons of sunlight. The energy (E) of a photon is related to the wavelength (λ) by the equation, $E=hc/\lambda$ -----
-----(1), Where h = Planck's constant = 6.62×10^{-27} erg-s And c = velocity of light = 3×10^8 m/s. Substituting these values, we get

$E = 1.24/\lambda$ ------(2), Where E is in electron-volts (eV) and λ is in μm .

The only materials suitable for absorbing the energy of the photons of sunlight are semiconductors like silicon, cadmium, sulphide, gallium arsenide, etc. In a semiconductor, the electrons occupy one of two energy bands – the valence band and the conduction band. The valence band has electrons at a lower energy level and is fully occupied, while the conduction band has electrons at a higher energy level and is not fully occupied. The difference between the energy levels of the electrons in the two bands is called the band gap energy E_g . Photons of sunlight having energy E greater than the band gap energy E_g are absorbed in the cell material and excite some of the electrons*. These electrons jump across the band gap from the valence band to the conduction band leaving behind holes in the valence band. Thus electron-hole pairs are created. The electrons in the conduction band and the holes in the valence band are mobile. They can be separated and made to flow through an external circuit (thereby executing the second step of the photovoltaic effect) if a potential gradient exists within the cell. In the case of silicon, the potential gradient is obtained by making the cell as a sandwich of two types of silicon, p-type and n-type. Silicon of p-type is silicon 'doped' with some atoms of boron, while silicon of n-type is silicon 'doped' with some atoms of phosphorus. The energy levels of the conduction and valence bands in p-type silicon are slightly higher than the corresponding levels in n-type silicon. Thus when a composite of the two types of silicon is formed, a jump in energy levels occurs at the junction interface (Fig:10.2). This potential gradient is adequate to separate the electrons and holes, and cause a direct electric current to flow in the external load. In a silicon cell, the junction is the thin region separating the n-type and p-type portions. Since the basic material is all silicon, such a junction is more specifically called a homojunction. Solar cells can also be made from dissimilar materials. For example, in one type a layer of copper sulphide is deposited on a layer of cadmium sulphide, the junction being formed along the contact between the two materials. Such a junction is called a heterojunction[126].

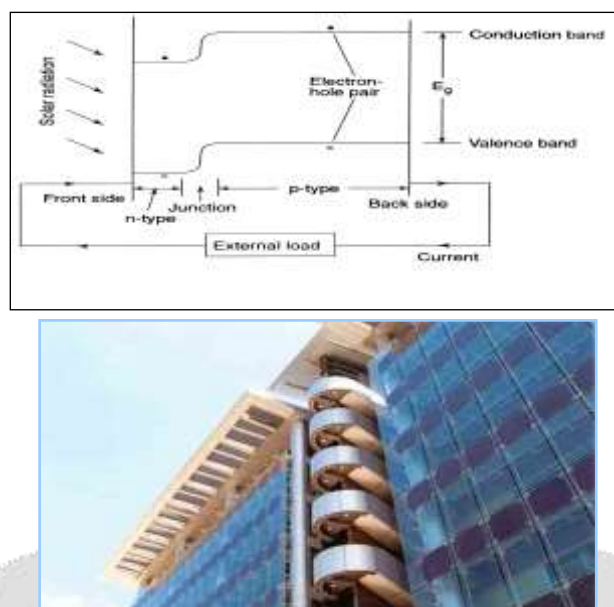


Fig. 2.21(a): Principle of working of a Solar cell **Fig. 2.22(a): Fixing detail of vertical structural glazing façade.**

II H Building Integrated PV (BiPV) System

Building- integrated photovoltaics (BiPV) involves combining solar photovoltaic electricity technologies with those of building construction. This subject is of great interest to those in the fields of energy conservation and building design. Its significance, however, cannot be underestimated in the context of the more familiar notion of sustainable development. The concept of sustainability is more relevant than ever, it is a dynamic process that enables all people to realise their potential, and improve their quality of life in ways which simultaneously protect and enhance the Earth's life-support systems. BiPV addresses these essential aspects. The current level of fossil fuel power generation is by far the greatest barrier to a state of sustainable society. The relevance of BiPV in a sustainable world becomes clear after close examination of the three words in the acronym: Building (S), Protect against the extremes of climate. They evoke mood, they can excite, delight, and create a sense of wellbeing and repose. In the developed world, buildings also account for approximately one half of all energy consumed. The current energy generation process and reliance on fossil fuel sources is one of the major threats to achieving sustainable goals for the building sector.

Integrated means interdependence and interaction. In a sustainable world, it is recognized that each action has consequences beyond the specific end at which it is aimed. The construction of a building may successfully accommodate and enhance the activities contained within it, but it will also have an effect on its immediate physical setting, the climate, the neighbors and local community, the region and, ultimately, the globe itself. Sustainable development endeavors to anticipate these effects and, through integration with one another, ensures that adverse effects are minimized and, if unavoidable, are in some way balanced by those that are benign or of equal value. Integration in sustainable development therefore seeks to reduce and harmonise detrimental environmental impacts. It also seeks economy of means and of materials in developing new industry opportunities [127]. This, in the right hands, promotes elegant design. The goals of integration in BiPV are just those of sustainable development. **Photovoltaics** is a technology whereby sunshine is converted into electricity as plants use chlorophyll to photosynthesise the sun's irradiation in order to provide energy for their growth, a building can use particular composite solar components to meet the energy needs of its occupants. Only 14.4 percent of sunshine survives filtering from the Earth's atmosphere and falls on land where it can be harvested. This is, however, 2,800 times more than our energy need.

BiPV design Process:

The PV system was not applied in the original design. However, the policy to use BiPV for the exterior was incorporated over six months into the construction phase. The south façade presented a large surface area and ample solar gain. The voltage of the system is assumed to be the same for each unit and is linked to a central 10 KW inverter. Electrical connection boards are installed every three to four floors reduce the overall length of

thick wiring run (120 meters) from the modules to the inverter. Shading was an obvious problem for the proposed façade installation. Typically, partial shading of the modules greatly affects potential generation capacity. This impact was reduced by devising an internal parallel circuit design. As a result, the adverse shading effect on power generation was decreased, and the PV was installed without an adverse effect on the design of the building. The result was about a 70 per cent improvement in the amount of power generation, compared with conventional wiring strategies. The PV powers a large electrical display on an advertising tower during peak day time electricity demand. It switches to supplying emergency power in the advent of a blackout or earthquake, keeping essential telephone communication systems running in the building.

BiPV Integration Techniques:

The building envelope provides a number of possibilities for the integration of PV. The four main options are:

- Sloped roof
- Flat roof
- Façade special applications
- Shading system

Sloped roof applications have the advantage of using the inclined roof as a platform whereas flat roof applications need a special mounting structure to provide the required orientation angle for the modules. Façade installations have a high profile, due to the high visibility of the installation. The technical requirements are mostly higher than for a flat or sloped roof installation, because of the wiring and the junction boxes, which have to be hidden, and the increased difficulty in fixing the array to the building. The fourth category relates to special applications, for example, shading elements, atriums, louvers, balconies and skylights[128]. This section focuses on the four categories and presents different typologies of integration.

II J Results and Discussion

Current-voltage Characteristic:

The behaviour of a solar cell is displayed by plotting its current –voltage characteristic. A typical characteristic curve is shown in Fig: 2.22 The intercepts of the curve on the x –axis and y –axis are called the short circuit current I_{sc} and the open circuit voltage V_{oc} The maximum useful power corresponds to the point on the curve which yields the rectangle with the largest area. We denote the values of current and voltage yielding the maximum power by the symbols I_m and V_m . The ratio $(I_m V_m / I_{sc} V_{oc})$ is called the fill factor (FF) of the cell. Its value obviously ranges between 0 and 1.

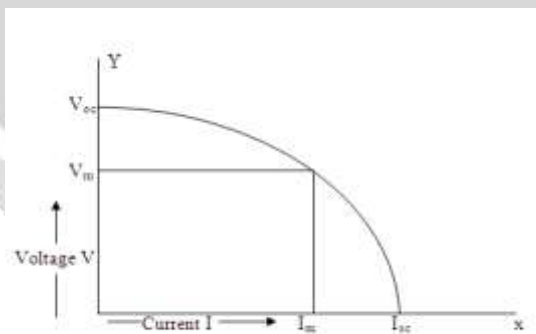


Figure 2.22: Current –voltage Characteristic of a Solar cell

Maximum Conversion Efficiency

The maximum conversion efficiency of a solar cell is given by the ratio of the maximum useful power to the incident solar radiation. Thus:

$$\eta_{max} = \frac{I_m V_m}{I_T A_c} = \frac{FF I_{sc} V_{oc}}{I_T A_c} \dots\dots\dots 10.3$$

Where, I_T = incident solar flux and A_c = area of the cell. For an efficient cell, it is desirable to have high values of fill factor, short circuit current and open circuit voltage. From solid state physics theory, expressions can be derived for each of these quantities. The expression show that high values of I_{sc} are obtained with low band gap materials, while high values of V_{oc} and FF are possible with high band gap materials. Thus if theoretical values

of η_{\max} are calculated for different values of E_g it is obvious that a maximum value would be obtained at some value of E_g . Fig. 10.4 shows the results of such calculations for homojunction cell. *These calculations are done on the basis of a few idealizations.

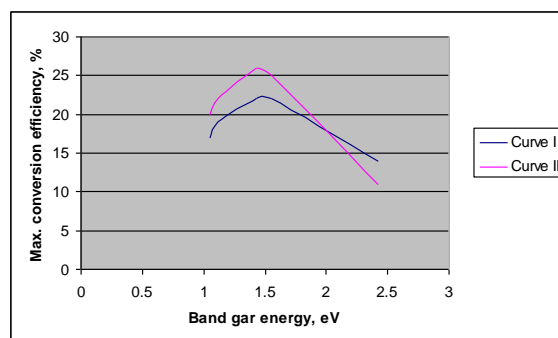


Figure 2.23 :Theoretical Variation of Maximum Conversion Efficiency with Band Gap Energy.

Curve I is obtained by assuming that extra –terrestrial radiation (AM0) is incident on the cell. Essentially similar curves differing only in detail would be obtained if the idealizations were changed or if spectral values corresponding to terrestrial conditions were assumed. Thus for example, curve II is obtained by assuming the incident radiation to be AM2 under a clear sky (750 W/m^2). It is seen from fig 10.4.that the theoretical maximum value of η_{\max} is 23 per cent at a band gap energy around 1.5 eV for curve I and 26 per cent at a band gap energy of 1.4 eV for curve II. Many semiconductors have band gap energies around this value. Because of this, it was stated earlier that semiconductors generally considered to be suitable are listed in Table 10.1 along with their band gap energies and theoretical values of Maximum conversion efficiency.

Table 2.2: Theoretical Maximum Conversion Efficient for Some Semiconductors.

Material	E_g (eV)	η_{\max} %	
		Curve I	Curve II
Copper Indium Diselenide	1.05	17	20
Silicon	1.12	19	22
Gallium arsenide	1.43	22	26
Cadmium telluride	1.55	22	25
Cadmium sulphide	2.42	14	11

N.B. The band gap energy values are for material in bulk crystalline form at 300 K

IV Conclusions

Photovoltaic power is the best and least expensive option today in the small power range in remote and rural areas. PV systems are now available every where for easy installation with all necessary accessories in a competitive market[129]. These are being used along with the conventional system in many developed and developing countries. In Bangladesh most of the electricity generators are run by indigenous has and generation is also very low. The actual demand of electricity is much higher than the electricity supplied at present PV electricity is receiving wider acceptance every year in Bangladesh especially in remote and rural areas due to their various advantages[130-135]. For utilizing PV energy efficiently and cost effectively optical design of the PV systems with proper knowledge of the devices ad system components is very important. Some examples of application of PV system in our rural area are as follows:

- (a) Education (b)Charging cellular phone (c)Lighting Rice mill (d) Lighting saw mill (e) Lighting Grocery shop
- (b) (f) Lighting Tailoring shop (g) Lighting clinic (h)Lighting restaurants (i) Bazaar (j) Water pump (k) Radio TV
- (l) Computer training center etc.

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