A Review On Light Trapping Capacities of Different Photovoltaic Cells

Nayanjyoti Deka[1], Papul Changmai[2]

[1,2] Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University,
Airport Road, Azara, Guwahati -781017, Assam, INDIA.
[1]njdtrade@gmail.com, [2]papuljec5@gmail.com*

Abstract: ***As human beings mostly depend on fossil fuels for all of their daily energy usages. But due to the exponential increase in the graph of the price of the fossil fuels, as well as the gradually decreasing graph of their availability on a large scale, makes the people to divert their attention towards a new source of sustainable energy which could fulfil their daily energy needs reliably, efficiently as well as cost-effectively. Among all renewable sources, the solar energy is an energy source whose availability is free and in an enormous amount; but the main thing is that steps should be undertaken in order to harness the solar energy properly. The following contents in the paper are based on the ways that how solar energy could be harnessed profitably.***

Keywords: Light Absorption, Solar Efficiency, Amorphous silicon, Light trapping.

1. Introduction

Solar energy is free from pollution and noise; thus a clean source of energy [2]. PV systems are easy to get installed and are long lasting while the cost of maintenance and operation are minimal [1]. Also, it has no parts that move when oriented in a particular angle, so no fear of breakage [11]. Thus the abundant or inexhaustible [11] nature of solar rays and its reliable operation as well its non-degrading nature without any public fear; leads to its prime worthiness. Efficiency, reliability, and cost are the basic parameters, which acts as a wheel for its success commercially [3]. The visible range of the solar rays contains the highest energy density, that is why, whatever the solar cell type is, it is designed in such a way that the cell performs better by absorbing the sunlight properly in the visible range. Sunlight is composed of (i) Direct or beam radiation- sunlight received by the surface of the earth, (ii) Diffuse radiation- also called scattered sunlight, and (iii) Albedo radiation- the reflected sunlight from the ground. The sum of these three components of light is called global radiation. When this global radiation enters the atmosphere of the earth, the molecules that are present in the atmosphere faces three situations, i.e. absorption of the light, scattering of the light and passing of the light unaffected. The ozone layer of the atmosphere absorbs the ultraviolet (UV) region of the sunlight; along with that CO_2 is absorbed by visible region and water vapour particles are absorbed by the infrared region. The best advantage of the photovoltaic (PV) panels is that they are able to absorb both the direct and diffuse irradiations, as a result of which PV panels functions even on cloudy days [7]. The standard condition for testing a solar cell during its designing is under the Standard Test Conditions: Air Mass 1.5 (AM1.5). It specifies a module temperature of 25°C, an irradiance of 1000 W/ m² with an air mass 1.5 (AM1.5) spectrum and zero wind speed. Going back to its history then we got that in 1839, Alexandre Edward Becquerel was the first person to discover the Photovoltaic cells, which are based on the photovoltaic effect. He found it while experimenting with an electrolytic cell that certain materials are there which generates a little amount of current when it is exposed to the light. But, he did not provide any details regarding the factors based on which the electron's generation from an irradiated metal varied by changing the wavelength of light. Then Albert Einstein in 1905, based on his research described the photovoltaic effect as nothing but the photoelectric effect, which means that light acts as a particulate matter. Later, Russel Ohl in 1946, invented the first modern solar cell made of silicon [2].

1. Solar Cell Basics (PN Junction)

To construct a solar cell, a p-n junction is required in semiconductors, which is created through dopants. A p-n junction cannot be made just by placing a p-type and an n-type semiconductor in close contact with each other because at the atomic level, at their junctions the continuous contact is not possible; that's why both the acceptor and donor impurity must be grown on the same crystal. The 'n-type' side of a semiconductor has dopants from either group a V or VI column materials of the periodic table with one electron, that it wants to remove from the valence band to the conduction band; and the 'p-type' side of a semiconductor has dopants from either group II or III column materials in the periodic table, that want to accumulate an electron. In n-type, electrons are the major charge carriers and holes are minor charge carriers; but in p-type it is totally opposite to that of the n-type. But, whatever be the level or type of doping, the doping does not disturb the overall charge neutrality of the semiconductor. Along with that, as long as the lattice structure remains the same, the rate of recombination, as well as the rate of generation, remains the same. Also, further we see the energy band or band gap energy (E.g., 1.17 for Silicon (Si) and 0.74 for Germanium (Ge)), which is comprised of enormously large number of energy levels which are closely spaced within a very small range of energy. Then, there is the Fermi energy, i.e., the energy level corresponding to the Fermi level, which is defined as the highest energy level in the conduction band filled up with electrons at absolute zero temperature. When we see the p-n junction, we get a small portion of the junction, which is devoid of any free charge carriers or what we call it as "immobile ions region"; this portion is called depletion layer [4].

The process of solar energy conversion is explained with the help of Figure 1 below.

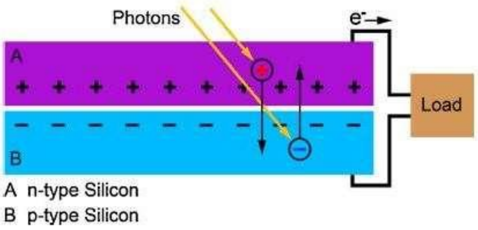

Figure 1: operation of a PN device [22]

When light or photon energy hits the semiconductor, and the incident light has the energy equal to the band gap energy then it extracts an electron from the valence band to conduction band. But if less, then it does not extract. Also, there is an important point that if the incident photon has energy more than the band gap energy, it will extract an electron; but along with that, it releases the extra amount of energy as heat which is a loss to the system. Thus, there is an electron in the conduction band and a hole is created in the valence band. Now, when the semiconductor is connected across an external load, the mobile electron moves through the external circuit to the load and in turn, again comes back to the valence band to fill up the hole created earlier; and in that way, again an electron moves to the conduction band. In this way, the flow goes on [22].

2. Solar Cell Characteristic Equations

Solar Cell I-V Characteristic Curves show the current and voltage (I-V) characteristics of a particular photovoltaic (PV) cell, module or array giving a detailed description of its solar energy conversion ability and efficiency. Knowing the electrical I-V characteristics (more importantly P_{max}) of a solar cell, or panel is critical in determining the device's output performance and solar efficiency. Solar cells produce direct current (DC) electricity and current times voltage equals power so that we can create solar cell I-V curves representing the current versus the voltage for a photovoltaic device. Solar Cell I-V Characteristics Curves are a graphical representation of the operation of a solar cell or module summarising the relationship between the current and voltage at the existing conditions of irradiance and temperature. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible. Solar Cell I-V Characteristic Curves are graphs of output voltage versus current for different levels of insolation and temperature and can tell us a lot about a PV cell or panel's ability to convert sunlight into electricity. The most important values for calculating a particular panel's power rating are the voltage and current at maximum power.

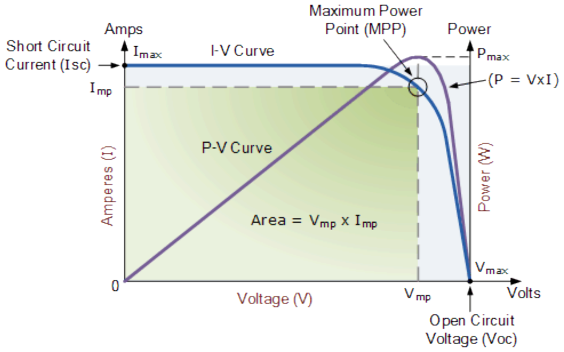

Figure 2: Solar Cell I-V Characteristic Curve

Figure 2 shows the I-V characteristics of a typical silicon PV cell operating under normal conditions.

The I–V characteristic equation for solar cell is as mentioned in eqn. (1):

$$I = I_L - I_0(e^{\frac{qv}{nkT}} - 1) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where I_L is the light generated or load current; I_0 is dark saturation current (depends on the recombination of the solar cell)
$q = 1.6 \times 10^{-19}$ C (q is the charge of an electron)
k (Boltzmann constant) = 1.38×10^{-23} J / Kelvin

The cell current at various irradiance levels can be expressed as in eqn. (2):

$$I(G) = \left(\frac{G}{G_0}\right) I(G_0) \quad \text{......} (2)$$

Where, G_0 (photogeneration rate) = 1 kW/m^2 at AM1.5

The power extracted from a PV cell is as mentioned in eqn. (3):

$$P_{cell} = V_{cell} \times I_{cell} \quad \text{......} (3)$$

The open circuit voltage (V_{oc}) is logarithmically dependent on the cell illumination level and the short circuit current (I_{sc}) is linearly dependent on the cell illumination level. V_{oc}, i.e. the maximum voltage available from a solar cell, occurs when no current is flowing through the solar cell. I_{sc}, i.e. the maximum current flows through the solar cell, when the voltage is not present across the solar cell (i.e., short-circuited cell).

V_{oc} (measures the amount of recombination) can be expressed as in eqn. (4):

$$V_{oc} = \left(\frac{nkT}{q}\right) \times \ln\left(\frac{I_L}{I_o} + 1\right) \quad \text{......} (4)$$

where 'n' is the ideality factor and it is the measure of how closely the diode obeys the ideal diode equation.

The short-circuit current I_{sc} (due to collection and generation of light carrying charges) is expressed as in eqn. (5):

$$I_{sc} = qG(L_n + L_p) \quad \text{......} (5)$$

where L_n and L_p are the electron and hole diffusion length respectively.

The Fill Factor (FF) in eqn. (6) characterizes the non-linear electrical behaviour, thus determines the quality of the solar cell.

$$FF = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}} \quad \text{......} (6)$$

where V_{mp} is the maximum voltage and I_{mp} is the maximum current.

The maximum power output from the solar cell can be written as eqn. (7):

$$P_{max} = (I_{sc} \times V_{oc} \times FF) \quad \text{......} (7)$$

The power conversion efficiency can be expressed as in eqn. (8):

$$\eta = \frac{I_{sc} \times V_{oc} \times FF}{P_{input}} \quad \text{......} (8)$$

3. Types of Solar Cells

Basically, here we will discuss only the following three types of solar cells: Mono or single crystalline (sc-Si), Multi or poly crystalline (mc-Si), and thin film solar cells (TFSC). Crystalline silicon is the most common type of solar cell among all those that we have. The reason behind it is that silicon is abundant and non-toxic; which is made of Sn sand. But, its major disadvantage is that the absorption of light by silicon is relatively weak, which in turn necessitates having a high thickness of the silicon layer in order to absorb the light efficiently and appropriately. Also, silicon is brittle material, which limits the lower boundary on its thickness. Along with that, the doping of silicon must be done in a clean environment to control the impurities if any. Because of this thickness limitation only, the material cost and thus the construction cost of silicon solar cells goes high. However, due to its inherent quality of lower defect density at the junctions, it has the highest energy conversion efficiency till date.

The sc-Si and mc-Si solar cells are very similar in their performance. The basic difference is that mc-Si based solar cells have slightly lower efficiency in compared to sc-Si based devices due to the difference in the defect structures, which are developed during the directional solidification or ingot casting in mc-Si while the crystal growth process was going on. It also leads to premature recombination of electrons and holes in mc-Si [22]. Along with that, sc-Si solar cells are more efficient in warm weather. So, as the temperature goes up its solar electricity output does not degrade severely as in mc-Si solar cells (in practice, the difference is very small) [7]. Hence, sc-Si is less expensive than mc-Si. Also, there is a provision that if we want to eliminate the waste during wafer slicing, continuous ribbon growth technologies such as Edge Film-fed Growth (EFG) and a process called String Ribbon could be adopted[22].

TFSC is a second-generation solar cell whose basic advantages are as follows: it is flexible; it involves a low-cost economy in terms of raw materials [21]. It has less weight per unit of power [7]. It shows good performance under low light conditions like during partial shading or in extreme heat, its mass production capability with varied sophisticated deposition techniques (like-homo, hetero and Schottky). It shows high light absorption capacity due to its extremely small thickness with small diffusion length, and its high recombination velocity makes it the cheapest type of solar cell in comparision to sc-Si and mc-Si solar cells (1st generation) solar cells. But, a little amount of disadvantage is that it is somewhat less efficient, requires more space for orientation [10] and has fast degradation which implies shorter life span in comparision to (sc-Si and mc-Si). TFSCs are basically made of materials such as amorphous silicon (a-Si), cadmium telluride (CdTe) and cadmium indium gallium selenide (CIGS) or cadmium indium selenide (CIS). It is comprised of several layers consisting of different elements like the absorbing layer, an oxide layer, which is transparent and conducting (TCO) or called as transparent conducting oxide, a window layer, and rear metal contact layer [22]. The properties of all of these layers and its interfaces are the optimum factors that affect the actual efficiency of the cell.

Again, we have organic and inorganic thin film solar cells. Organic solar cells are several times thinner than inorganic solar cells, thus have high absorption capacity; so it has a slightly higher efficiency. Along with that, organic solar cells have a higher affinity for chemical modification or one can say that via chemical synthesis techniques, several arrangements or modifications could be done at molecular level adjustments (better than atomic level arrangements) [4]. But, if we see the energy required to dissociate the excited states or excitons (formed by the absorption of photons), it is approx 0.5 eV for organic, whereas few milli eV for inorganic. Some examples of organic solar cells are fullerene, polypyrrole, polyaniline, etc. Some examples of inorganic solar cells are CdS, CIGS, cadmium selenide (CdSe), etc. Along with that, by combining organic matter and inorganic matter, one more types of solar cell called biohybrid solar cells had been developed by the researchers [12,13]. Hence, the organic photovoltaic devices have the advantage of low weight, good flexibility, semitransparent, easily gets integrated into other products, less manufacturing cost, shorter period of energy payback, etc. [3,16].

The voltage rating (V_{mp} / V_{oc}) of the crystalline is around 80% to 85% whereas for thin film is around 72% to 78% [10]. Along with that, the temperature coefficient and fill factor value of the thin film is lower than a crystalline silicon [10]. As the absorbing layer gets thinner; its light-absorbing capacity goes on enhancing. Hence, TFSC is a journey to attain the highest efficiency level that could be achieved from light. We have two types of configurations for the thin film: the superstrate and the substrate as shown in Figure 3. The main difference between these is that the substrate, which provides a layer of support to the thin film cell. Superstrate type has a transparent glass substrate, e.g. CdTe. Substrate type has a non-transparent substrate (metal or metallic coating on a glass/plastic), e.g. CIGS/CIS. Substrate type is cheaper comparatively [22]. But, the major disadvantage of the CdTe and CIGS is that cadmium is toxic which causes environmental problems; as well as Indium and Gallium are very rare metals that are available.

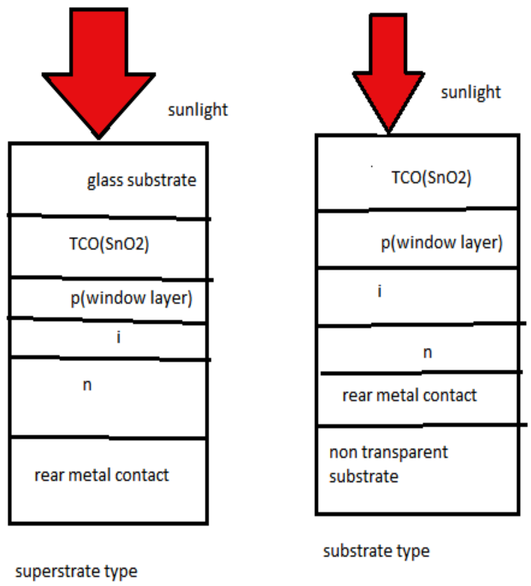

Figure 3: Types of configurations [22]

4. Losses of Incident Light Over the PV Cell

The whole portion of the incident light over the PV cell is not converted into electrical energy as shown in Figure 4. A major amount of it gets lost due to the following reasons. Since, every differently composed PV material has a specific range of spectral bandwidth that it is suited for, hence if the bandwidth of light incident does not match with the particular cell requirement, then the PV cell does not absorb that light; instead, that light creates only heat on the surface of the cell, which is not purpose. Recombination, resistive heating, electrical resistance losses or the electrical interconnects, shadowing, module inefficiency, optical reasons like scattering and reflection (highest loss) at the surface of the solar cell are also the factors that contribute to the system loss. By creating cohesive (well bonded) surfaces and interfaces within the solar cells, the losses during manufacturing could be prevented [22]. With a motto to improve the light trapping or light absorption, manufacturers try to modify the design of a solar cell in such a way that whatever the light enters its path length, should be there as long as possible for better absorption of light by the cell [5]. Actually, here in order to improve the absorption of light, the top contact coverage layer surface of the solar cell has to be minimized in order to reduce the amount of area that blocks light from reaching the cell [20]. Practically, only about 25% to 29% of the incident light energy can be converted into electrical energy.

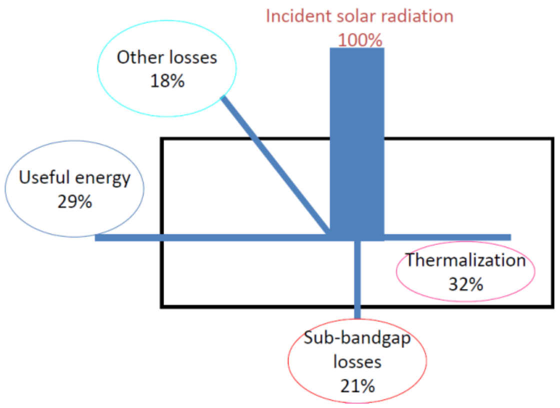

Figure 4: Losses in a solar cell [9]

5. Antireflection Coatings

The prime objective of the antireflection technique is to trap more light in compared to that the cell could originally do. A coating of anti-reflecting material is provided on the very top layer of the solar cell in order to reduce the optical losses (normally reflection) when the light is incident on the surface of the cell. The coating layer may be mono or double depending on the user requirement. If the amount of light, which is reflected back could be reduced to an optimum level or reducing the surface recombination, then only the absorbing level as well the conductivity level of the cell could be increased and in turn, the efficiency level could be enhanced to a certain extent. Monolayer coating, generally of SiN_x or SiO_2, has the lowest reflectivity but it shows its good result only within a certain small bandwidth. And, the double layer coating is formed by combining SiN_x and SiO_2. Double layer coating is created by oxidizing the Si surface first at high temperature and then a Plasma-Enhanced Chemical Vapor Deposition (PECVD) coating of SiN_x is applied to it. A better quality of SiN_x is obtained if it is deposited by employing high-frequency PECVD. (TCO) also performs as an anti-reflection coating or as a conductive electrode, which creates voltage depending on the photoelectric effect. It has a wide bandgap and it is transparent for the visible light [22], e.g. indium doped tin oxide, Aluminium doped zinc oxide, etc. Along with that, at the bottom, reflecting coating layer should be used to a certain extent such that there would be a total internal reflection of the absorbed light and hence more absorption and thus higher conductivity [22].

5.1 Types of Antireflection Coating Methods

(a) An antireflection technology, where the black silicon coating (black colour absorbs more light even at lower angles with very less reflectivity [11]) is provided on the top the solar cell is catalysed in order to create a layer where the refractive index gradually changes when the light is incident on it. Here the motto behind is to create a layer of nanostructures whose light absorbing wavelength limit is less than the wavelength of incident light. Along with that grading is done across the thickness of the silicon layer. This small modification in the refractive index of the coating layer enables the light to penetrate further into the cell instead of being reflected away; thus the light absorption is enhanced [23].

(b) Pyramidal texturing (in Figure 6) is one more antireflection technology, which etches away the material used on the top of the solar cell in order to create very small pyramid-like structures. Now, when light (photon) incident on these pyramidal structures, it either gets absorbed or reflected onto another pyramid, creating another opportunity for the photon to get absorbed as much as possible. By this way, these pyramids effectively enhance the chance for the photon to get absorbed. Generally, TMAH (Tetra Methyl Ammonium Hydroxide) is used with the silicon surface with the motto to create reliable pyramidal structures. Now a better idea is that if both the black silicon and pyramidal texturing method is combined as shown in Figure 5, then the light absorption could be doubly enhanced. It decreases the amount of blue light recombination as well as it creates an even better antireflection possibility. However, passivation and difficulty in large-scale applications are its two weaknesses [21].

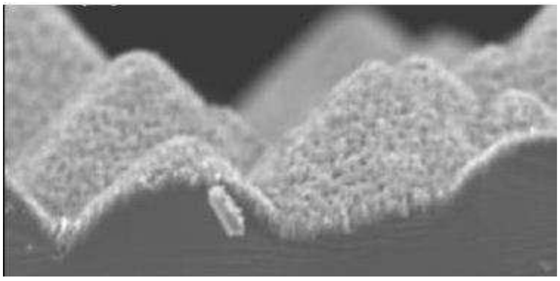

Figure 5: Cross section of black silicon with pyramid architecture [22]

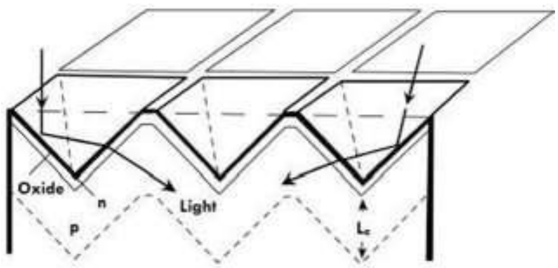

Figure 6: Inverted pyramid structure [22]

(c) One more method of antireflection technology that appears almost similar to the pyramidal texturing methods is moth-eye texturing, which employs the idea of formation of pillars with narrowed structural orientation as appears in moth eyes, as shown in Figure 7. But, this moth eye creation process is an expensive step, because pillar-like structures with higher ratios are difficult to create and align [22].

Figure 7: Moth texture [23]

(d) One more method is to form a bump and sponge-like nanostructures by growing a thin layer of (SiO_2) on triacetate polymers in as shown in Figure 8. Here the (SiO_2) provides dual protection; it enhances performance as well as provides a protective layer to the nanostructures that are developed [22].

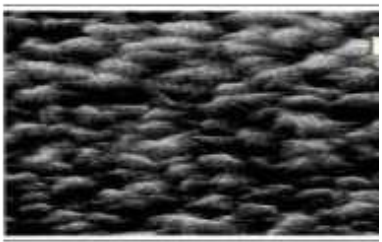

Figure 8: Bump structure [22]

(e) We have one more option for the antireflection method and that is to use a large grain size (SnO_2) thin film over the top layer as shown in Figure 9. Due to its rough surface texture, it improves the light trapping by the solar cell [22].

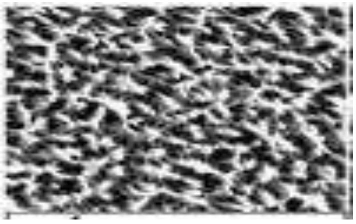

Figure 9: Thin film of SnO_2 on top layer [22]

6. Plasmonics

Generally, errors arise when the thin film solar cells trap light and plasmonics acts as a solution to the said problem as shown in Figure 10. Plasmonics are actually defined as the resonant oscillations of free or conducting electrons collectively between a metal and a dielectric or positive and a negative permittivity materials, which is stimulated by incident light as a source thus resulting into a resonant frequency [15]. It is also broadly described as the interaction of conducting electrons (charges with the EM waves). When the wavelength of incident light converges with the wavelength of the oscillatory wave, i.e. Plasmon, then it leads to higher absorption of photons. These plasmons act like dipoles. Here, the wave is only due to the oscillation of nano particles that happens due to the interaction between the charges. Size, shape, and dielectric properties of the medium are the factors, on which the formation of surface plasmon wave depends. An ideal plasmon wave does not have nodes in the semiconductor. Metals formed of noble gas compounds are best applicable for the nano particles when used for the PV purposes because it shows resonance in the infrared and visible frequencies [22].

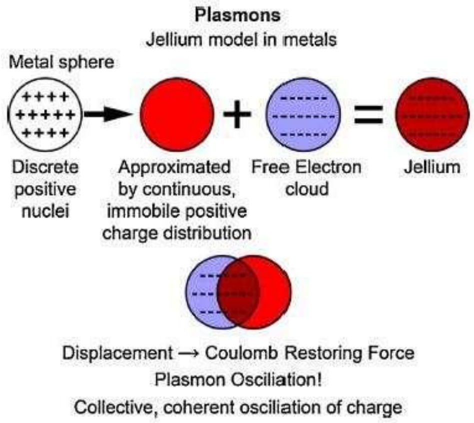

Figure 10: Plasmon [22]

7. Negative Index Metamaterials (NIM)

NIM is a method of improving light absorption and reducing the light reflecting back. It is an artificially man made material whose observed properties are not seen in nature. It refracts the incident light on the same side of the normal to the surface (opposing the standard rule of light refraction) as shown in Figure 11. A small change in the geometry of the NIM structures causes the refractive index to become positive; it implies that structures exhibiting NIM property are extremely sensitive to its geometry. Actually, NIMs are the improved version of fishnet structure (as shown in Figure 12), which is a combination of a cross and a circle employed for linear polarizations arbitrarily. Within the improved structure, the current density is very high, thus it leads to a high magnetic resonance [22].

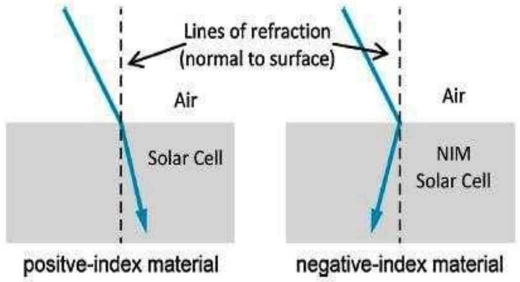

Figure 11: NIM refraction property [22]

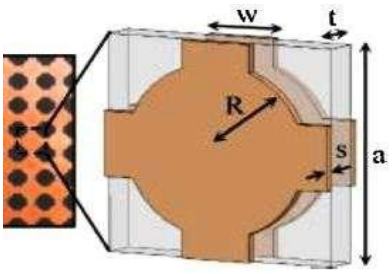

Figure 12: NIM fishnet structure [22]

8. Solar Multijunctions

The construction of practically powered PV modules becomes possible by changing the material from amorphous silicon (a-Si) to amorphous silicon hydrogenated (a-Si:H), because a-Si:H is well suited for doping and alloying with other materials and fabrication of junction devices. But, a single junction (a-Si:H) solar cell faces the problem of degradation of the material when induced by the light for a long time. Thus, it leads to the reduction in the energy conversion efficiency in the very initial stage of operation of the solar cell and following to it that solar cell then stabilizes at a lower efficiency (approximately 30% less than the initial value). So, one possible solution could be the use of a thin intrinsic layer in order to generate a high internal electric field and lessen the sensitivity to the distortions appeared. But, this thin intrinsic layer, further results in the reduction of absorption of light or energy by the solar cell. However, this amount of reduction in efficiency due to a low amount of light absorption could be compensated to some extent by the multiple p-i-n structures, which is composed of several amorphous silicon layered structures as shown in Figure 13. Thus, a heterodyne junction is created by using multiple p-i or i-n junctions. The mc-Si has a higher electron mobility as well as a high light absorption coefficient due to the presence of silicon crystallites. Multijunctions are best suited for concentrator solar plants [22].

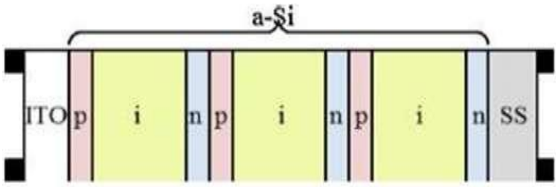

Figure 13: Multilayered a-Si solar cell [22]

Now, in order to connect the multijunctions, wafer bonding and layer transfer processes are used. In wafer bonding [22] (interface made is very strong), the two materials that are required to be bonded to be atomically flat. After that, they are pressed together and heated up, and due to their planarity property atoms are allowed to diffuse between the materials; as a result of which current easily passes through it thus enhances the efficiency. And, the other method is the layer transfer processes [22], in which the crystalline films are grown on an expensive substrate (reusable) and then moved to create the multijunction.

9. Environmental Impact on Solar Cell

(i) Effect of dust on the PV cell's performance:

The minute solid particles whose size is less than 500 nm in diameter are regarded as dust. Once the dust is deposited on the cell, it attracts more dust to be deposited; so better is that the already deposited dust has to be removed as fast as possible. The dust settlement on solar module depends on the tilted angle and the finishing of the surface of the module, as well as humidity and wind speed prevailing in the environment at that moment. If the modules are tilted at a large angle, then a lesser amount of dust is deposited; and thus the drop in transmittance reduces. Fine dust particles are more dangerous than the coarser dust particles. High wind speed leads to high deposition of dust on the module; thus leads to the deterioration of the module. Along with that higher humidity level enhances the dew formation on the top of the module, and if in that period wind flows with fine dust; then the highest amount of dust will get deposited; hence the poor output of the module [19].

(ii) Effect of wind velocity on PV cell performance:

With the increase in the air velocity, the temperature of the solar cell drops, which implies a better PV cell efficiency [19]. However, as mentioned earlier, high wind speed leads to dust deposition on the module. There is another side to it called shading, which happens due to the scattering of dust as well as nearby particles due to high wind speed; thus, leads to poor performance of the solar system as depicted by the in eqn. (9).

$$\text{Performance Ratio} = \frac{P_{mean} \times P_{max}}{\frac{G}{100}} \quad \text{..........} \ (9)$$

where, P_{mean} = mean power output (W);
P_{max} = maximum power output (W)

(iii) Effect of Humidity on PV Cell Performance

As mentioned earlier, high humidity leads to dust deposition on the module. Along with that, there are two directions, which need to be monitored [19]. The first side is that the effect of water vapour particles on the irradiance level of sunlight and the second way is the humidity ingression in the solar cell enclosure. Light after hitting the water droplets may be refracted, reflected or diffracted. There is a non-linear effect of humidity on the irradiance of sunlight as shown in Figure 14. Moreover, irradiance creates little variations in a non-linear manner and creates large variations linearly as shown in Figure 15. This non-linearity is due to the non-uniform distribution and wide range of the size of water vapour particle. Also, the scattered angle is inversely proportional to the size of water vapour particles.

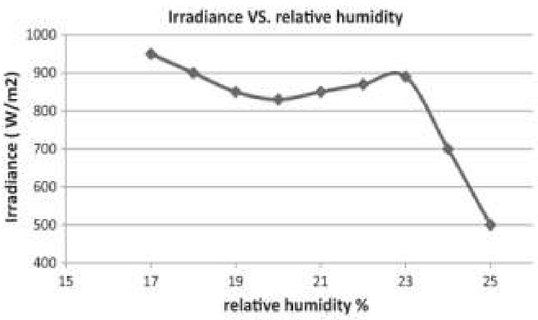

Figure 14: Solar irradiance v/s Relative Humidity [19]

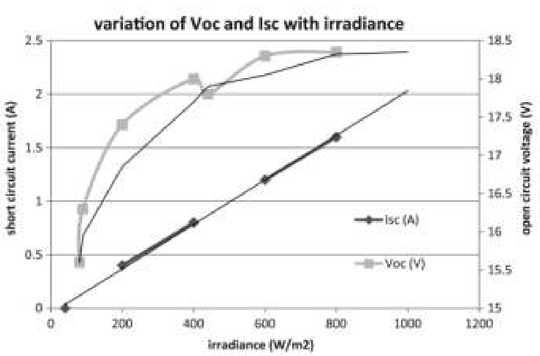

Figure 15: V_{oc} and I_{sc} v/s Solar irradiance [19]

10. Reliability of PV Cell

The necessary parameters that are required in order to determine the break-even characteristics of PV modules are reliability and longevity. All those etching steps that are adopted in order to remove the cracks or defects that are formed during the wafering process while manufacturing if fails in its performance, then the module shows problems in its operation. Here we can not discard the situation of performance degradation by the solar cell in the interfaces completely; it will be present even in a very small scale also; because always a heat is generated on the cell when the photon is incident on it or we can say heat is a by-product of photon energy conversion. In order to obtain a cell with good reliability conditions; the interfaces that we have in the solar cells must be robust against the thermal cycling. Cracks may also be seen during the mechanical movement of the solar cell like when the cell was being installed or maybe during transportation. Sometimes, cracks may also appear due to the moisture seepage caused by rain; thus, dew gets into any slight cracks hence percolate into the cells ultimately leads to the non-uniformity of the interfaces; in turn the performance of the solar cell deteriorates, e.g. light absorption capacity gets reduced, moisture absorption increases hence critically damages the cell. A large amount of heat and UV radiation is developed on those multijunctions that are applied in concentrator solar systems, which in turn, the lifetime of the cell diminishes. So, as a solution to achieve the reliability conditions or to avoid the cell failure, the material used for the construction must have the properties like- robustness, durability, heat resistant, water resistant, flexibility [22].

11. Cost

The cost required in order to construct a solar cell governs by both the reliability and efficiency of the solar cell. The cost incurred is subdivided into Short-term cost and Long-term cost [22]. Short-term cost includes the cost of buying the raw materials cost, installation as well as transportation, then manufacturing cost, reliability testing cost. Long-term cost is basically based on life expectancy of the solar cell which involves the cost of maintenance like replacing the cells after prolonged use. Ultimately, our main aim is to determine the solar cell with the best design and least cost as much as possible without sacrificing efficiency and reliability. But, there is a general logic that the cells with high efficiency are more costly. Likewise, cadmium is too toxic; tellurium and indium are so rarely found that it cannot provide a strong support to the total energy production. Hence, a trade-off will always be there in order to maintain balance between efficiency, reliability and cost. Energy payback is a very complicated metric to calculate, because of the large variance in data obtained. Payback period varies from one cell to the other depending on factors like- type of raw material used, installation location, reliability, and manufacturing processes. The standard lifetime for a solar cell is generally 30 years (bulk production of solar cell always has a lesser efficiency than a cell that is developed in a lab, because when constructed in bulk it generates heat which further reduces the efficiency of the solar cell). Applications of solar cells include power plants, homes, commercial uses, ventilation systems, remote applications, solar cars, solar lightings, etc. [11].

12. Market Share and Efficiency

If we look on market share with present efficiency levels (as obtained from the website of National Renewable Energy Laboratory (www.nrel.com). In 2013, TFSC accounted for about 9%. In 2015, TFSC accounted for about 9(+7)%. Rest of the per cent is occupied by crystalline silicon (sc-Si and mc-Si). PCE, i.e. power conversion efficiencies of different types are shown in Figure 16. Some of the current solar cell manufacturing market leaders are mentioned here [14].

For crystalline silicon: Sharp, Kyocera, Suntech, etc.
For a-Si: Sharp, United Solar, Fuji Electric, etc.
For CdTe: First Solar, Antec Solar
For CIGS: Day Star, Shell Solar, Wurth Solar, etc.

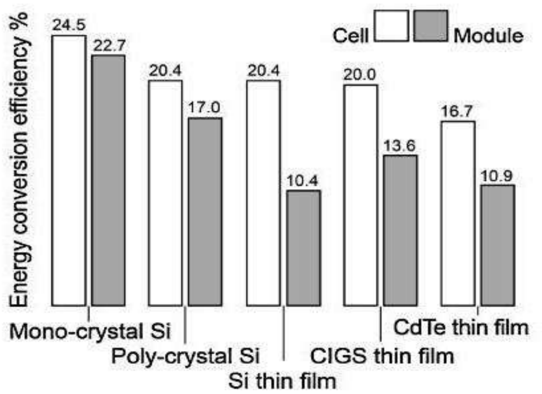

Figure 16: Power Conversion Efficiency (PCE) [22]

13. Conclusion

In this review, the basics on p-n junction and further formation of a solar cell, along with the necessary characteristic equations have been discussed. The types of solar cells have been discussed in detail, with more concentration of work on thin-film solar and its different contributions due to its several advantages. However, every system has a loss associated with it. Few more methods were discussed like antireflection coating, multijunction, negative index metamaterials, plasmonics in order to construct a cell in such a way that its light absorption capacity gets enhanced in turn efficiency. Also, we came to know how the solar cell or a module responds towards the environmental impacts, e.g. dust, wind velocity and humidity. A review of the analysis has also been done in order to determine the reliability or longevity as well as the cost incurred. And finally, we have mentioned about the market share and the efficiency chart as obtained from the National Renewable Energy Laboratory.

The combination of the following factors determines the performance of solar cells: Radiation at the site, Losses in PV systems, Amount of light absorbed and reflected, Temperature and climatic conditions, Design parameters of the plant, Inverter efficiency, Module Degradation due to ageing, etc. [23].

Efficiency, in decreasing order, can be arranged as:
sc-Si > mc-Si > thin film
The cost in decreasing order can be arranged as:
sc-Si > mc-Si > thin film.

Additionally, thin film solar cells have an approximate lifetime of 20 years and Crystalline solar cells have an approximate lifetime of 25-30 years lifetime. In, India, the Government is carrying out a mission under the name of Jawaharlal Nehru National Solar Mission (JNNSM). Its objective is to create a policy framework for the creation of 20,000 MW from solar source by 2022 [23].

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