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A Review on Comparative Studies of Diverse Generation in Solar Cell

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Abstract:

The light from the sun is a non-vanished renewable source of energy which is totally free from the environmental pollution. It can be easily compensate the energy which is drawn from the non-renewable sources of energy like as fossil fuels and petroleum deposits which is present below the earth. Solar energy has experienced phenomenal development and growth in recent years because of technological improvements resulting in cost reductions and government policies which is supportive of renewable energy development and utilization. In 19th century the timeline of solar cells begins when it is observed that the presence of sunlight is capable of generating usable electrical energy. Solar cells have been used in many applications.

In this review paper, we have reviewed a progressive research and development in the solar cell from one generation to Other, and discussed about their future trends and its aspects. The article also tries to emphasize the various practices and methods to promote the research in solar cell and their benefits as a solar energy.

***Keywords* —** Solar Cells, Generation of Solar cell, Renewable Energy

I. INTRODUCTION

Solar energy is radiant light and heat which is coming from the "Sun" a non renewable energy source which is used as a range of ever-evolving technologies such as solar power heating, photovoltaic cell, solar thermal heat energy, solar architecture, molten salt power plants and in process of artificial photosynthesis. It is a very important tool or source of renewable energy and its different technologies are broadly classified such as either in passive solar or in active solar depending on how they absorb or capture and distribute solar energy or it's conversion into solar power. Good quality solar energy techniques contain use of photovoltaic cell system, concentrated solar power and solar water heating to strap up the energy. Inert solar techniques include orient a building to the sun, select materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air. Renewable energy sources have found its way in the global energy market; it is due to increase in conventional fuel prices, degradation to environment caused by the combustion of fossil fuels. Every morning sun sends its tremendous quantity of energy in the form of heat and radiations called solar energy and solar radiations. Solar energy is a immeasurable source of energy which is available without no cost [1]. The major advantage of solar energy over other conventional power generators is that the sunlight is directly harvest into solar energy by using small and tiny photovoltaic (PV) solar cells system [2]. The Sun is assuming as a big spherical gaseous cloud which is having the presence of hydrogen and helium atoms. Environmentally clean and benign energy system like Heat and Power System which is based on photovoltaic linear concentrators which is an interesting option in urban India. Cost efficiency is a important constraint in measuring the achievement of any new technology. The present literature survey is showing pertaining to the earlier works in view of optimized energy markets and scenarios, conceptual development and techno economics of hybrid PV/T systems.

One of the major compensation of solar energy is that it is free reachable to common people and available in abundant amount in comparison with that of the price of various fossil fuels and oils in the past decade [3]. Moreover, solar energy system needs significantly lower manpower, expenses as compared with conventional energy production technology. The solar energy is easily, freely available everywhere, there is an initial expenditure required on the equipments for harvesting this energy with the development of solar cells, panels and modules [4]. The solar cells system does not produce any noise during their operation. Various the large power pumping devices produce intolerable sound pollution, and therefore they create very much disturbance to the society [5]. Due to the reduce in amount of renewable energy resources, the per watt cost of solar energy equipment have become more significant in the last decade, and is absolutely set to become economical in the coming years and develop as better technology in view of both cost and applications [6].

II. SOLAR CELLS

Previously solar cell or photovoltaic cell are termed as a "solar battery" [7] is an electrical tool that directly convert the energy of light into electricity by the photovoltaic effect, which is a chemical and physical occurrence [8]. It is form of photoelectric cell, which is defined as a device whose electrical character such as voltage, current, and resistance, which is vary when exposed to light. Solar cells are the important parameters of photovoltaic (PV) modules, or it is also known as solar panels. Solar cells or systems are also known as photovoltaic, irrespective of whether the basis of it is sunlight and artificial light. They can also be used as a a photodetector such as infrared detectors, detecting light and also other electromagnetic radiation which is near to the visible range, or measuring light intensity.

The mechanism for the working of a photovoltaic (PV) cell system needs three basic requirements:

1. Absorption of light, generation of either electron-hole pairs/excitons.
2. Separation of charge carriers of opposite types.
3. Separate extraction of these carriers to an external circuit.

The photovoltaic (PV) effect was first coined by Sir Alexander-Edmond Becquerel in 1839 [9]. Afterward, in 1946 the first modern solar cell made of silicon was invented by Russel Ohl [10]. In advance photovoltaic solar cells are thin silicon wafers which convert sunlight energy into electrical power. The modern photovoltaic (PV) technology is mainly on the basis of the principle of electron hole creation in each cell system which is composed of two different type of layers (p-type and n-type materials) of a semiconductor material, as shown in Figure 1. In this type of arrangement of the structure, when a photon of sufficient energy impinges on the p-type and n-type junction, an electron is ejected by gaining energy from the striking photon and moves from one layer to another. This creates an electron and a hole in the process and with this process electrical power is generated [11]. The different type of materials used for photovoltaic solar cells system contains mainly in the form of silicon (single crystal, multi-crystalline, amorphous silicon), cadmium-telluride, copper-indium-gallium-selenide, and copper-indium-gallium-sulfide. On the basis of these materials, the photovoltaic solar cells systems are categorized into different classes as shown in the Figure 2.

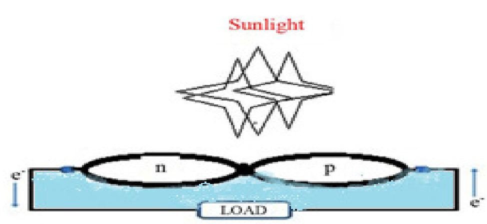

Figure 1: Schematic Representation of semiconductor p-n junction solar cell under load.

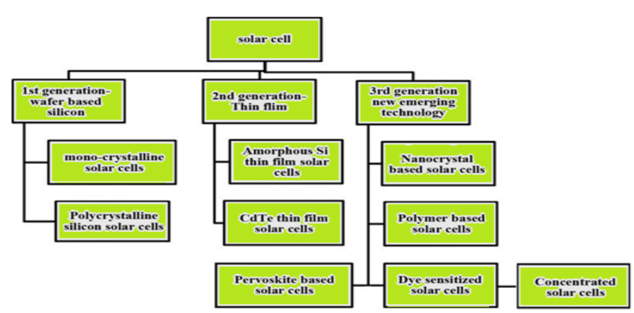

Figure 2: Different Category of Photovoltaic Solar Cells

III. SOLAR CELL WORKING MECHANISUM

Photons in the light of sun hit the solar panel and are absorbed by semiconducting materials, such as silicon. Electrons get excited from their current molecular or atomic orbital. Once they get excited an electron can either disperse the energy as heat and return to its orbital or go through the cell until it reaches the electrode. The current get flows through that material to cancel the potential and this electricity is captured. The chemical bonds of the material are fundamental for this process to work, and usually silicon is used in two layers, one layer being doped with boron, the other phosphorus. These layers have different chemical electric charges and subsequently both drive and direct the current of electrons [12]. An array of solar cells are able to convert solar energy into a functional amount of direct current (DC) electricity. An inverter can also able to convert the power to alternating current (AC). The most frequently known solar cell is configured as a large-area p–n junction made from silicon. Other type of solar cell are organic solar cells, dye sensitized solar cells, perovskite solar cells, quantum dot solar cells etc. The illuminate sides of a solar cell generally have a transparent conducting film to allow light to enter into active material and to collect the generated charge carriers. Likewise, films with high transmittance and high electrical conductance such as indium tin oxide, conducting polymers or conducting nanowire networks are used for the purpose [13].

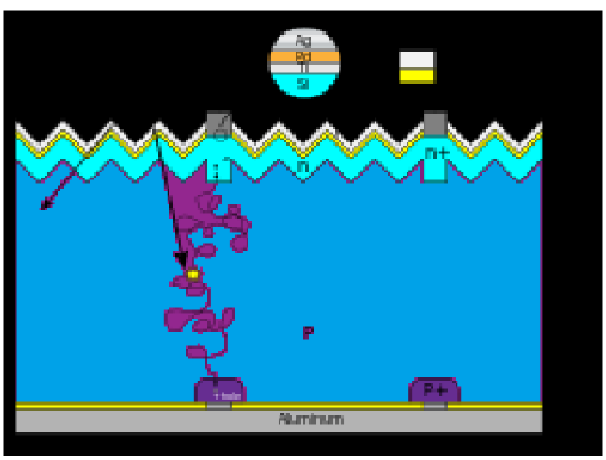

Figure 3: Schematic Representation of working mechanism of solar cell

IV. Different Generations of Photovoltaic Solar Cells

First Generation Solar Cell:

Generally 1st generation's solar cells include

a. Single Crystal Solar Cells

b. Multi Crystal Solar Cells.

This are the oldest and the mostly common used technology type due to high efficiencies. 1st generation solar cells are produced on wafers.

4.1. First Generation Solar Cell—Wafer Based:

As it is already mentioned in the literature, the first generations of solar cells are formed on silicon wafers. It is a very oldest and the most promising technology due to it's high power efficiencies. The silicon wafer based technology is further categorized into two sub classes named as.

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

4.1.1. Single/Mono-Crystalline Silicon Solar Cell:

Mono crystalline solar cell, as the name indicates, it is manufactured from a single crystals of silicon by a process called Czochralski process [14]. During it's manufacturing process, Si crystals are sliced from the big sized ingots. These large single crystal productions require precise processing as the process of "recrystallizing" of the cell is more expensive and multi process. The efficiency of mono-crystalline single-crystalline silicon solar cells ranging between 17% - 18%.

4.1.2. Polycrystalline Silicon Solar Cell (Poly-Si or Mc-Si):

Polycrystalline (PV) cell modules are generally collected of a number of different crystals, coupled to one another in a single cell. The processing of polycrystalline Si solar cells is more economical, which can be produced by cooling graphite mold filled containing molten silicon. Polycrystalline Si solar cells are now currently the most accepted solar cells. They are believed to occupy most up to 48% of the solar cell production worldwide during 2008 [15]. During solidification of the molten silicon, various crystal structures are formed. Though they are slightly cheaper to fabricate compared to monocrystalline silicon solar panels, yet are less efficient ~12% - 14% [16].

4.2. Second Generation Solar Cells—Thin Film Solar Cells:

Most of the thin film solar cells and a-Si are the second generation solar cells, and are more economical in comparison to that of first generation of silicon wafer solar cells. Silicon-wafer cells have light absorbing layers up to 350 μm thick, while thin-film solar cells have very thin light absorbing layers, generally of the order of 1 μm thickness [17]. Thin film solar cells are classify into three different types:

1) a-Si.
2) CdTe.
3) CIGS (copper indium gallium di-selenide).

4.2.1 Amorphous Silicon Thin Film (a-Si) Solar Cell:

Amorphous silicon (a-Si) is the non-crystalline form of silicon used for solar cells and thin-film transistors in LCDs. Used as semiconductor material for a-Si solar cells, or thin-film silicon solar cells, it is deposited in thin films onto a variety of flexible substrates, such as glass, metal and plastic. Amorphous silicon cells generally feature low efficiency, but are one of the most environmentally friendly photovoltaic technologies, since they do not use any toxic heavy metals such as cadmium or lead. As a second-generation thin-film solar cell technology, amorphous silicon was once expected to become a major contributor in the fast-growing worldwide photovoltaic market, but has since lost its significance due to strong competition from conventional crystalline silicon cells and other thin-film technologies such as CdTe and CIGS. Amorphous silicon differs from other allotropic variations, such as monocrystalline silicon—a single crystal, and polycrystalline silicon, that consists of small grains, also known as crystallites.

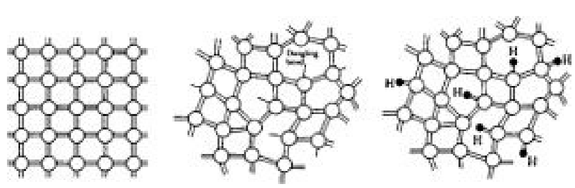

Figure 4: Schematic structures of crystalline silicon, amorphous silicon, and amorphous hydrogenated silicon

Amorphous Si (a-Si) PV modules are the primitive solar cells that are first to be manufactured industrially. Amorphous (a-Si) solar cells can be manufactured at a low processing temperature, thereby permitting the use of various low cost, polymer and other flexible substrates. These substrates require a smaller amount of energy for processing [18]. Therefore, a-Si amorphous solar cell is comparatively cheaper and widely available. The "amorphous" word with respect to solar cell means that the comprising silicon material of the cell lacks a definite arrangement of atoms in the lattice, non-crystalline structure, or not highly structured. These are fabricated by coating the doped silicon material to the backside of the substrate/glass plate. These solar cells generally are dark brown in colour on the reflecting side while silverish on the conducting side. The main issue of a-Si solar cell is the poor and almost unstable efficiency. The cell efficiency automatically falls at PV module level. Currently, the efficiencies of commercial PV modules vary in the range of 4% - 8%. They can be easily operated at elevated temperatures, and are suitable for the changing climatic conditions where sun shines for few hours [19].

4.2.2 Cadmium Telluride (CdTe) Thin Film Solar Cell:

Cadmium telluride (CdTe) photovoltaics describe a photovoltaic (PV) technology that is based on the use of cadmium telluride, a thin semiconductor layer designed to absorb and convert sunlight into electricity. Cadmium telluride PV is the only thin film technology with lower costs than conventional solar cells made of crystalline silicon in multi-kilowatt systems. Among thin-film solar cells, cadmium telluride (CdTe) is one of the leading candidate for the development of cheaper, economically viable photovoltaic (PV) devices, and it is also the first PV technology at a low cost [20]. CdTe has a band gap of ~1.5 eV as well as high optical absorption coefficient and chemical stability. These properties make CdTe most attractive material for designing of thin-film solar cells. CdTe is an excellent direct band gap crystalline compound semiconductor which makes the absorption of light easier and improves the efficiency. It is generally constructed by sandwiching between cadmium sulfide layers to form a p-n junction diode. The manufacturing process involves three steps: Firstly, the CdTe based solar cells are synthesized from polycrystalline materials and glass is chosen a substrate. Second process involves deposition, i.e., the multiple layers of CdTe solar cells are coatedon to substrate using different economical methods. It is already mentioned that CdTe has a direct optimum band gap (~1.45 eV) with high absorption coefficient over 5 × 1015/cm. Therefore, its efficiency usually operates in the range 9% - 11%. CdTe solar cells can be made on polymer substrates and flexible. However, there are various environmental issues with cadmium component of solar cell. Cadmium is regarded as a heavy metal and potential toxic agent that can accumulate in human bodies, animals and plants. The disposal of the toxic Cd based materials as well as their recycling can be highly expensive and damaging too to our environment and society. Therefore, a limited supply of cadmium and environmental hazard associated with its use are the main issues with this CdTe technology [21].

4.2.3 Copper Indium Gallium Selenide (CIGS) Solar Cells:

A copper indium gallium selenide solar cell (or CIGS cell/CI(G)S or CIS cell) is a thin-film solar cell which is used to convert sunlight into electrical power. These solar cells get manufactured by depositing a thin layer of copper, indium, gallium and selenide on glass or plastic backing, along with electrodes on the front and back to collect current. As these material having a high absorption coefficient and strongly absorbs sunlight, a much thinner film is to be required than of the other semiconductor materials. CIGS is one of three mainstream thin-film PV technologies, the other two being cadmium telluride and amorphous silicon. Like these type of materials, CIGS layers are thin enough to be flexible and also allowing them to be deposited on flexible substrates. On the other hand as all of these technologies normally use high-temperature deposition techniques, the best performance normally comes from the cells deposited on glass, although advances in low-temperature deposition of CIGS cells have been erased much of this performance difference. CIGS outperforms polysilicon at the cell level, however its module efficiency is still lower, due to a less mature up scaling [22].

4.3. Third Generation Solar Cells

Third generation solar cells are the new promising technologies but are not commercially investigated in detail. Most of the developed 3rd generation solar cell get categorized into following types which are:

1) Nano crystal based solar cells.
2) Polymer based solar cells.
3) Dye sensitized solar cells.
4) Concentrated solar cells.

4.3.1. Nano Crystal Based Solar Cells:

Nanocrystal solar cells are those solar cells which is based on a substrate with a coating of nanocrystals. Nanocrystal based solar cells are commonly known as Quantum dots (QD) solar cells. The nanocrystals are typically based on silicon, CdTe or CIGS and the substrates are generally silicon or various organic conductors. The quantum dot solar cells are a variant of this approach, but take advantage of quantum mechanical effects to extract further performance. These type of solar cells are made up of a semiconductor, from transition metal groups as they are of size of nanocrystal range made of semiconducting materials. QD is just a name of the crystal size ranging typically within a few nanometers in size, for example, materials like porous Si or porous TiO2, which are generally used in QD [23]. According to the advancement of nanotechnology, these type of nano crystals of semiconducting material are generally used to replace the semiconducting material in bulk state such as Si, CdTe or CIGS. This idea of the QD based solar cell with a theoretical formulation were employed for the design of a p-i-n solar cell over the self-organized in As/GaAs system [23]. Commonly, these type of nanocrystals are mixed into a bath and coated onto the Si substrate. These crystals rotate very fast and flow away due to the centrifugal force. In conventional method these type of compound semiconductor solar cells, generally a photon will excite an electron there by creating one electron-hole pair [24].

4.3.2. Polymer Solar Cells:

Polymer solar cells (PSC) are generally flexible solar cells due to the polymer substrate. The first PSC were invented by the research group of Tang et al. at Kodak Research Lab. A PSC is consist of a serially connected thin functional layers which is coated on a polymer foil or ribbon. It functions usually as a combination of donor (polymer) and a acceptor (fullerene). There are different types of materials for the absorption of sunlight, including organic material like a conjugate/conducting polymer [25]. In 2000, Heeger, MacDiarmid, and Shirakawa fetched the Nobel Prize in Chemistry for the discovering a new category of polymer materials known as conducting polymers. The PSC and the other organic solar cells operate on same principle known as the photovoltaic effect, i.e., where the transformation of the energy occurs in the form of electromagnetic radiations into electrical current [26]. Yu et al. mixedpoly [2-methoxy-5-(2'-ethylhexyloxy)-p-phenylene vinylene] (PPV), C60 and its other derivatives to develop the first polymer solar cell and obtained a high power conversion efficiency [27]. This process is responsible for the development of a new age in the polymer materials for capturing the solar power. After significantly optimizing the parameters, researchers achieved efficiency over 3.0% for PPV type PSCs [28]. These unique properties of PSCs opened a new gateway for new applications in the formation of stretchable solar devices including textiles and fabrics [29]. A modern recycling concept known as polarizing organic photovoltaics (ZOPVs) was also developed for increasing the function of liquid crystal displays utilizing the same polarizer, a photovoltaic device and proper light conditions/solar panel [30].

4.3.3. Dye Sensitized Solar Cells (DSSC):

A dye-sensitized solar cell (DSSC, DSC, DYSC or Grätzel cell) is a low-cost solar cell belonging to the group of thin film solar cells. The main principle of it is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photo electrochemical system. The modern version of a dye solar cell, also known as the Grätzel cell, was originally co-invented in 1988 by Brian O'Regan and Michael Grätzel at UC Berkeley and this work was later developed by the aforementioned scientists at the École Polytechnique Fédérale de Lausanne until the publication of the first high efficiency DSSC in 1991.Michael Grätzel has been awarded the 2010 Millennium Technology Prize for this invention. DSSCs based solar cells generally employ dye molecules between the different electrodes. The DSSC device consists of four components: semiconductor electrode (n-type TiO_2 and p-type NiO), a dye sensitizer, redox mediator, and a counter electrode (carbon or Pt) [31]. The DSSCs are having attention due to the simple conventional processing methods like printing techniques, are highly flexible, transparent and low cost as well. The novelty in the DSSC solar cells arise due to the photosensitization of nano grained TiO_2 coatings coupled with the visible optically active dyes, thus increasing the efficiencies greater than 10% [32]. However, there are certain problems like degradation of dye molecules and hence stability issues. This is due to poor optical absorption of sensitizers which results in poor conversion efficiency. The dye molecules generally degrade after exposure to ultraviolet and infrared radiations leading to a decrease in the lifetime and stability of the cells. Moreover, coating with a barrier layer may also increase the manufacturing more expensive and lower the efficiency.

4.3.4. Concentrated Solar Cells:

Concentrator photovoltaics (CPV) (also known as Concentration/Concentated Photovoltaics) is a photovoltaic technology that generates electricity from sunlight. Concentrating photovoltaic (CPV) has been established since the 1970s [33]. It is the recent technology in the solar cell research and development. The main principle of this concentrated cells is to collect a large amount of solar energy onto a tiny region over the PV solar cell, as shown in Figure 5. The main principle of this technology is based upon optics, by using large mirrors and lens arrangement to focus sunlight rays into a small region on the solar cell. The converging of the sunlight radiations which produces a large amount of heat energy. This heat energy is further driven by a heat engine controlled by a power generator with integrated. CPVs have shown their promising nature in solar world [34]. They are classified into low, medium, and high concentrated solar cells depending on the power of the lens systems [35]. Concentrating photovoltaic technology have the following merits, such as solar cell efficiencies >40%, absence of any moving parts, no thermal mass, speedy response time and can be scalable to a range of sizes.

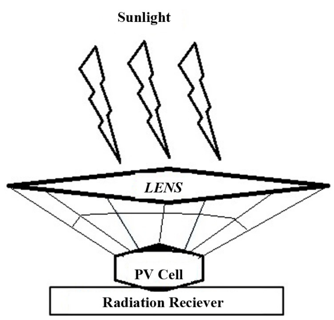

Figure 5: Schematic of concentrated solar cell

4.3.5. Perovskite Based Solar Cell: A **perovskite solar cell** is a type of solar cell which having a perovskite structured compound, most commonly a hybrid organic-inorganic lead or tin halide-based material, as the light-harvesting active layer. Perovskite materials such as methylammonium lead halides are cheap to produce and simple to manufacture. Solar cell efficiencies of such type of devices which manufactured by using these type of materials have increased from 3.8% in 2009 to 22.7% in late 2017, making this the fastest-advancing solar technology. They have high potential of achieving even higher efficiencies and the very low production costs. Perovskites are a class of compounds which are defined by the formula ABX3 where X represents a halogen such as I–, Br–, Cl–. and A and B are cations of different size. Perovskite solar cells are recent discovery among the solar cell research and possess they have several advantages over conventional silicon and thin film based solar cells. The perovskites based solar cells can have efficiency up to 31% [36]. There is a prediction that these perovskites also play an important role in next-generation electric automobiles batteries, according to an interesting investigation recently performed by Volkswagen. However, current issues with perovskite solar cells are their stability and durability. The material degrades over time, and hence a drop in overall efficiency. Therefore more research is needed to bring these cells into the market place.

V. CONCLUSION

This review paper is proposed to provide a brief summary for those researchers who are interested in solar energy technologies and as a reference for those who want to invest or work in this field. We all know that "Solar energy is free and is the only energy that is sustainable forever," Kanatzidis said. "If we know how to harvest this energy in an efficient way we can raise our standard of living and help preserve the environment." Solar power generation has been developed as one of the most demanding renewable sources of electricity now-a-days. These solar energy techniques having several advantages as compared to other forms of energy like fossils fuels and petroleum deposits. It is an alternative source of energy which is promising and consistent to meet the high energy demand of world now-a-days. Though the methods of utilizing solar energy are simple, yet need an efficient and durable solar material. Technology based on nano-crystal QD of semiconductors based solar cell can theoretically convert more than sixty percent of the whole solar spectrum into electric power. The polymer base solar cells are also a viable option. However, their degradation over time is a serious concern. There are various challenges for this industry, including lowering the cost of production, public awareness and best infrastructure. Solar energy is the need of the day and research on the solar cells has a promising future worldwide.

REFERENCES

[1] Chu, Y. and Meisen, P. (2011) Review and Comparison of Different Solar Energy Technologies. Report of Global Energy Network Institute (GENI), Diego.

[2] McEvoy, A., Castaner, L. and Markvart, T. (2012) Solar Cells: Materials, Manufacture and Operation. 2nd Edition, Elsevier Ltd., Oxford, 3-25.

*[3] Rana, S. (2013) A Study on Automatic Dual Axis Solar Tracker System using 555 Timer. International Journal of Scientific & Technology Research, **1**, 77-85.*

[4] Bertolli, M. (2008) Solar Cell Materials. Course: Solid State II. Department of Physics, University of Tennessee, Knoxville.

[5] Grisham, L.R. (2008) Nuclear Fusion in: Future Energy, Improved, Sustainable and Clean Options for our Planet, Edited by Trevor M. Letcher, 2nd Edition, Elsevier Ltd., Amsterdam, 291-301.

[6] Wall, A. (2014) Advantages and Disadvantages of Solar Energy. Process Industry Forum, 7 August 2013. Web. 2 February 2014.

[7] Shockley, William; Queisser, Hans J. (1961). "Detailed Balance Limit of Efficiency of p-n Junction Solar Cells" (PDF). Journal of Applied Physics. ***32*** *(3): 510. Bibcode: 1961 JA P. ... 32 ..510S.*

[8]. Solar Cells. chemistryexplained.com.

[9] Yadav, A. and Kumar, P. (2015) Enhancement in Efficiency of PV Cell through P&O Algorithm. International Journal for Technological Research in Engineering, ***2****, 2642-2644.*

[10] Castellano, R. (2010) Solar Panel Processing. Old City Publishing Inc., Philadelphia. [11] Srinivas, B., Balaji, S., Nagendra Babu, M. and Reddy, Y.S. (2015) Review on Present and Advance Materials for Solar Cells. International Journal of Engineering Research-Online, ***3****, 178-182.*

[12]. Solar Cells. chemistryexplained.com

[13]. Kumar, Ankush (2017-01-03). "Predicting efficiency of solar cells based on transparent co-nducting electrodes". Journal of Applied Physics. ***121*** *(1): 014502.*

[14] Dmitrijev, S. (2006) Principles of Semiconductor Devices. Oxford University Press, Oxford.

[15] Saga, T. (2010) Advances in Crystalline Silicon Solar Cell Technology for Industrial Mass Production. NPG Asia Materials, ***2****, 96-102. http://dx.doi.org/10.1038/asiamat.2010.82*

[16] Jayakumar, P. (2009) Solar Energy Resource Assessment Handbook. Renewable Energy Corporation Network for the Asia Pacific.

[17] Chopra, K.L., Paulson, P.D. and Dutt, V. (2004) Thin-Film Solar Cells: An Overview. Progress in Photovoltaics, ***12****, 69-92.*

[18] Imamzai, M., Aghaei, M., Hanum Md Thayoob, Y. and Forouzanfar, M. (2012) A Review on Comparison between Traditional Silicon Solar Cells and Thin-Film CdTe Solar Cells. Proceedings of National Graduate Conference (Nat-Grad 2012), Tenaga Nasional Universiti, Putrajaya Campus, 8-10 November 2012, 1-5.

[19] Types of Solar Panels, Grein Energy. Published 22 April 2015.

[20] Maehlum, M.A. (2015) Energy Informative The Homeowner's Guide To Solar Panels, Best Thin Film Solar Panels—Amorphous, Cadmium Telluride or CIGS? Last updated 6 April 2015.

[21] Yogi Goswami, D. and Kreith, F. (2007) Handbook of Energy Efficiency and Renewable Energy. CRC Press, Boca Raton.

[22]. Green, Martin A., et al. "Solar cell efficiency tables (version 50)." Progress in Photovoltaics: Research and Applications 25.7 (2017): 668-676.

[23] Sethi, V.K., Pandey, M. and Shukla, P. (2011) Use of Nanotechnology in Solar PV Cell. International Journal of Chemical Engineering and Applications, ***2****, 77-80.*

[24] Andorka, F. (2014) CIGS Solar Cells Simplified. Solar Power World. http://www.solarpowerworldonline.com/2014/01/cigs-solar-cells-simplified/

[25] Razykov, T.M., Ferekides, C.S., Morel, D., Stefanakos, E., Ullal, H.S. and Upadhyaya, H.M. (2011) Solar Photovoltaic Electricity: Current Status and Future Prospects. Solar Energy, ***85****, 1580-1608. http://dx.doi.org/10.1016/j.solener.2010.12.002*

[26] Hoppe, H. and Sariciftci, N.S. (2008) Polymer Solar Cells. Advances in Polymer Science, ***214****, 1.*

[27] Dubey, S., Sarvaiya, J.N. and Seshadri, B. (2013) Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World: A Review. Energy Procedia, ***33****, 311-321. http://dx.doi.org/10.1016/j.egypro.2013.05.072*

[28] Ganesh, B.N.V.S. and Supriya, Y.V. (2013) Recent Advancements and Techniques in Manufacture of Solar Cells: Organic Solar Cells. International Journal of Electronics and Computer Science Engineering, ***2****, 565-573.*

[29] Alex, C., Mayer, Shawn, R., Scully, Brian, E., Hardin, Michael, W., Rowell and Michael, D. McGehee (2007) Polymer-Based Solar Cells: A Review. Materials Today, ***10****, 28-33.*

*[30] Brabec, C.J., Shaheen, S.E., Winder, C. and Sariciftci, N.S. (2002) Effect of LiF/Metal Electrodes on the Performance of Plastic Solar Cells. Applied Physics Letters, **80**, 1288. http://dx.doi.org/10.1063/1.1446988*

*[31] Zhu, R., Kumar, A. and Yang, Y. (2011) Polarizing Organic Photovoltaics. Advanced Materials, **23**, 4193-4198.*

*[32] Suhaimi, S., Shahimin, M.M., Alahmed, Z.A., Chyský, J. and Reshak, A.H. (2015) Materials for Enhanced Dye-Sensitized Solar Cell Performance: Electrochemical Application. International Journal of Electrochemical Science, **10**, 28-59.*

*[33] Liang, M., Xu, W., Cai, F.S., Chen, P.Q., Peng, B., Chen, J. and Li, Z.M. (2007) New Triphenylamine-Based Organic Dyes for Efficient Dye-Sensitized Solar Cells. The Journal of Physical Chemistry C, **111**, 4465-4472.*

*[34] Barnes, P.R.F., Anderson, A.Y., Koops, S.E., Durrant, J.R. and O'Regan, B.C. (2009) Electron Injection Efficiency and Diffusion Length in Dyesensitized Solar Cells Derived from Incident Photon Conversion Efficiency Measurements. The Journal of Physical Chemistry C, **113**, 1126-1136.*

*[35] Mohanta, P. R., Patel, J., Bhuva, J. and Gandhi, M. (2015) A Review on Solar Photovoltaics and Roof Top Application of It. International Journal of Advanced Research in Science, Engineering and Technology, **2**, 2394-2444.*

*[36] Ahn, N., Son, D.-Y., Jang, I.-H., Kang, S.M., Choi, M. and Park, N.-G. (2015) Highly Reproducible Perovskite Solar Cells with Average Efficiency of 18.3% and Best Efficiency of 19.7% Fabricated via Lewis Base Adduct of Lead(II) Iodide. Journal of the American Chemical Society, **137**, 8696-8699.*