A Review on Different Types of Materials Employed in Solar Photovoltaic Panel.

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***Abstract*— This paper gives brief introduction about the solar cell materials, steps and the procedure followed during the fabrication of silicon solar cell, materials used in the a fabrication of the solar cell and the classification of the solar cells based on the materials and generation. Also it describes the study of different types materials used in PV system. Finally different types of solar cells are compared according to their efficiency, cost and life span.**

Keywords*— solar cell elements, Fabrication, solar cell materials first generation solar cells, second generation solar cells, Emerging photovoltaic's, Monocrystalline, Epitoxial, polycrystalline, ribbon, CdTe, CuIdGaS, Amorphous, Gallium arsenide thin film, Perovskite, DSSC, polymer solar cells, efficiency, cost per watt, life span.

I. INTRODUCTION

Renewable energy resources contribute to major part of energy consumed in the world. Solar cells play a major role in the renewable energy resources. Solar cells are the devices that convert solar energy directly into electricity via photovoltaic effect. Solar panel has been used increasingly in recent years to convert solar energy to electrical energy. The solar panel can be used either as a stand-alone system or as a large solar system that is connected to electricity grids. Only some materials exhibit the property of the photoelectric effect. Therefore the selection of materials for the manufacturing of solar cell plays an important role in the efficiency and performance of the solar cell[5].

Everyday sun sends out tremendous amount of energy in the form of heat and radiations called solar energy. Solar energy is a limitless source of energy which is available at no cost. The major benefit of solar energy over other conventional power generators is that the sunlight can be directly harvested into solar energy with the use of small and tiny photovoltaic (PV) solar cells [15].

Solar cells are the basic building block of the solar panel. Solar cells are the devices that convert solar energy directly into electricity via photoelectric effect. Photovoltaic converters is the another name for solar cells. Photovoltaic conversion is the process of direct conversion of the light energy into electricity at atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of the light and release free electron. When free electrons are captured, electricity is generated [18].

The working mechanism of solar cells is based on the three factors: (1) Adsorption of light in order to generate the charge careers, holes (p-type) and electrons (n-type). (2) Separation of charge careers. (3) The collection of charge careers at the respective electrodes establishing the potential difference across the p-n junction. The generation of voltage difference noticed at the p-n junction of the cell in response to visible radiation is utilized to do the work [6].

II. KEY ELEMENTS OF SOLAR CELL

Solar cell is a semicondutor device sensitive to light made up of pn junction formed by the p-type and n-type materials. A single solar cell is made up of following elements.(1) substrate .(2) emitter. (3) electrical contacts (4) anti-reflective coating.

A. Substrate

It is the unpolished p-type wafer referred to as p region base material. P type semiconductor is formed by doping silicon with trivalent impurity such as Boron, Gallium, Indium and Aluminium. Silicone semiconductor has 4 electrons in its valence band and Trivalent dopant has outer electrons one less than silicon, so during the combination, one free space is left out which is a positive charge carrier referred as hole. The photos are absorbed in the p-layer, it is designed in such a way that it can absorb large amount of photons and free up as many electrons as possible. The design of p-layer must also keep the electrons away from meting up with holes and recombining with them before they can escape from the PV cell [1].

B. Emitter

The emitter formation involves the doping of Silicon with pentavalent impurities such as phosphorous, Arsenic and Antimony. However for solar cell applications phosphorous is widely used as impurity. Pentavalent impurities have 5 electrons in their valance band, so while doping with silicon one electron is left out which acts as negative charge carrier [1].

C. Electrical contacts

These are essential a photovoltaic cell since they bridge the connection between the semiconductor material and external electrical load. Usually it consists of layer of Aluminium or Molybdenum metal. (1)Front contact: Current collection grid of metallic finger trip arranged in such a way that photon energy falls on n-region defused layers. When the light falls on the solar cell a current of electrons flows over the surface, to collect the maximum current the contact must be placed across the entire surface of solar cell. This is done with a grid of metal strips or fingers. (2) Back contact: It is the metallic conductor completely covering the back; it is located on the side away from the incoming light [1].

D. Anti-reflective coating

Anti-reflective coatings are applied to reduce surface reflection and maximize cell efficiency. The solar glass and silicon solar cell manufacturing. It helps to reduce the reflection of desirable wavelengths from the cell, allowing more light to reach the semiconductor film layer, increasing solar cell efficiency. When a thin-film nano-coating of antireflection coating of silicon-dioxide (SiO2) and titanium di-oxide (TiO2) is applied, there seems to be an increase in cell efficiency by 3-4%. [1]

III. FABRICATION OF SILICON SOLAR CELL.

The fabrication of silicon solar cell includes the following steps: (1) purifying the silicon: The silicon dioxide of either quartzite gravel or crushed quartz is placed into an electric arc furnace. A carbon arc is then applied to release the oxygen. The products are carbon dioxide and molten silicon. This simple process yields silicon with one percent impurity, useful in many industries but not the solar cell industry. The 99 percent pure silicon is purified even further using the floating zone technique. A rod of impure silicon is passed through a heated zone several times in the same direction. This procedure "drags" the impurities toward one end with each pass. At a specific point, the silicon is deemed pure, and the impure end is removed. (2)Making silicon wafers: From the boule, silicon wafers are sliced one at a time using a circular saw whose inner diameter cuts into the rod, or many at once with a multiwire saw. Only about one-half of the silicon is lost from the boule to the finished circular wafer more if the wafer is then cut to be rectangular or hexagonal. Rectangular or hexagonal wafers are sometimes used in solar cells because they can be fitted together perfectly, thereby utilizing all available space on the front surface of the solar cell. After the initial purification, the silicon is further refined in a floating zone process. In this process, a silicon rod is passed through a heated zone several times, which serves to 'drag" the impurities toward one end of the rod. The impure end can then be removed. Next, a silicon seed crystal is put into a Czochralski growth apparatus, where it is dipped into melted polycrystalline silicon. The seed crystal rotates as it is withdrawn, forming a cylindrical ingot of very pure silicon. Wafers are then sliced out of the ingot. The wafers are then polished to remove saw marks. (3)Doping: The traditional way of doping silicon wafers with boron and phosphorous is to introduce a small amount of boron during the Czochralski process. The wafers are then sealed back to back and placed in a furnace to be heated to slightly below the melting point of silicon (1,410 degrees Celsius) in the presence of phosphorous gas. The phosphorous atoms "burrow" into the silicon, which is more porous because it is close to becoming a liquid. The temperature and time given to the process is carefully controlled to ensure a uniform junction of proper depth. A more recent way of doping silicon with phosphorous is to use a small particle accelerator to shoot phosphorous ions into the ingot. By controlling the speed of the ions, it is possible to control their penetrating depth. (4) Placing electrical contacts: Electrical contacts connect each solar cell to another and to the receiver of produced current. The contacts must be very thin so as not to block sunlight to the cell. Metals such as palladium/silver, nickel, or copper are vacuum-evaporated through a photo-resist, silkscreened, or merely deposited on the exposed portion of cells that have been partially covered with wax. All three methods involve a system in which the part of the cell on which a contact is not desired is protected, while the rest of the cell is exposed to the metal. After the contacts are in place, thin strips ("fingers") are placed between cells. The most commonly used strips are tin-coated copper. (5) Antireflective coating: Pure silicon is shiny, it can reflect up to 35 percent of the sunlight. To reduce the amount of sunlight lost, an anti-reflective coating is put on the silicon wafer. The most commonly used coatings are titanium dioxide and silicon oxide, though others are used. The material used for coating is either heated until its molecules boil off and travel to the silicon and condense, or the material undergoes sputtering. In this process, a high voltage knocks molecules off the material and deposits them onto the silicon at the opposite electrode. Yet another method is to allow the silicon itself to react with oxygen- or nitrogen-containing gases to form silicon dioxide or silicon nitride. Commercial solar cell manufacturers use silicon nitride. (6) Encapsulating of cell: The finished solar cells are then encapsulated; that is, sealed into silicon rubber or ethylene vinyl acetate. The encapsulated solar cells are then placed into an Aluminium frame that has a Mylar or tedlar backsheet and a glass or plastic cover [17].

IV. SOLAR CELL MATERIALS.

Solar cells are typically named after the semiconducting material they are made of. These materials must have certain characteristics in order to absorb sunlight. Some cells are designed to handle sunlight that reaches the Earth's surface, while others are optimized for use in space. Solar cells can be made of only one single layer of light-absorbing material (single-junction) or use multiple physical configurations (multi-junctions) to take advantage of various absorption and charge separation mechanisms.[6]

A. Classifications of solar cell materials.

1) First generation: The first generation cells are also called conventional, traditional or wafer-based cells. They are made of crystalline silicon, the commercially predominant PV technology, that includes materials such as polysilicon and monocrystalline silicon.[7]

a) Monocrystalline silicon: Monocrystalline silicon (mono-Si) solar cells are more efficient and more expensive than most other types of cells. The corners of the cells look clipped, like an octagon, because the wafer material is cut from cylindrical ingots, that are typically grown by the Czochralski process. Solar panels using mono-Si cells display a distinctive pattern of small white diamonds.[8] The following benefits are (1) Efficiency is high in range of 15-24% as they are fabricated from the heighest grade silicon, making them cost effective in long term. (2)Low installation cost. (3)Space efficient. (4)Non-hazardous to environment (5) Greater heat resistance. (6)Long life.

b) Epitoxial silicon: Epitaxial wafers of crystalline silicon can be grown on a monocrystalline silicon "seed" wafer by chemical vapor deposition (CVD), and then detached as self-supporting wafers of some standard thickness (e.g., 250 µm) that can be manipulated by hand, and directly substituted for wafer cells cut from monocrystalline silicon ingots. Solar cells made with this "kerfless" technique can have efficiencies approaching those of wafer-cut cells, but at appreciably lower cost if the CVD can be done at atmospheric pressure in a high-throughput inline process. The surface of epitaxial wafers may be textured to enhance light absorption.[9]

c) Polycrystalline silicon: Polycrystalline silicon, or multicrystalline silicon (multi-Si) cells are made from cast square ingots large blocks of molten silicon carefully cooled and solidified. They consist of small crystals giving the material its typical metal flake effect. Polysilicon cells are the most common type used in photovoltaics and are less expensive, but also less efficient, than those made from monocrystalline silicon[8]. The followings are the benefits: (1)The production process is simple. (2)Cost effective. (3)Reduces silicon waste compared to monocrystal panels.[10]

d) Ribbon silicon: Ribbon silicon is a type of polycrystalline silicon it is formed by drawing flat thin films from molten silicon and results in a polycrystalline structure. These cells are cheaper to make than multi-Si, due to a great reduction in silicon waste, as this approach does not require sawing from ingots. However, they are also less efficient.[11]

e) Mono-like-multi cryastaline silicon: They are also called cast-mono, this manufactoring process uses polycrystalline casting chambers with small "seeds" of mono material. The result is a bulk mono-like material that is polycrystalline around the outsides. When sliced for processing, the inner sections are high-efficiency mono-like cells (but square instead of "clipped").[12]

2) Second generation: Second generation cells are thin film solar cells, that include amorphous silicon, CdTe and CIGS cells and are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics or in small stand-alone power system.[12]

a) Cadmium telluride: Cadmium telluride is the only thin film material so far to rival crystalline silicon in cost/watt. However cadmium is highly toxic and tellurium (anion: "telluride") supplies are limited. The cadmium present in the cells would be toxic if released. However, release is impossible during normal operation of the cells and is unlikely during fires in residential roofs.A square meter of CdTe contains approximately the same amount of Cd as a single C cell nickel-cadmium battery, in a more stable and less soluble form.[12]

b) Copper Indium Gallium selenide: Copper indium gallium selenide (CIGS) is a direct band gap material. It has the highest efficiency (~20%) among all commercially significant thin film materials (see CIGS solar cell). Traditional methods of fabrication involve vacuum processes including coevaporation and sputtering. Recent developments at IBM and Nanosolar attempt to lower the cost by using non-vacuum solution processes.[12]

c) Silicon thin film(Amorphous silicon): Silicon thin film cells are mainly deposited by chemical vapour deposition (typically plasma-enhanced, PE-CVD)from silane gas and hydrogen gas. Depending on the deposition parameters, this can yield amorphous silicon (a-Si or a-Si:H), protocrystalline silicon or nanocrystalline silicon (nc-Si or nc-Si:H), also called microcrystalline silicon[14].Amorphous silicon is the most well-developed thin film technology to-date. An amorphous silicon (a-Si) solar cell is made of noncrystalline or microcrystalline silicon. Amorphous silicon has a higher bandgap (1.7 eV) than crystalline silicon (c-Si) (1.1 eV), which means it absorbs the visible part of the solar spectrum more strongly than the higher power density infrared portion of the spectrum. The production of a-Si thin film solar cells uses glass as a substrate and deposits a very thin layer of silicon by plasma-enhanced chemical vapor deposition (PECVD).[13]

d) Gallium arsenide thin film: The semiconductor material Gallium arsenide (GaAs) is also used for single-crystalline thin film solar cells. Although GaAs cells are very expensive, they hold the world's record in efficiency for a single-junction solar cell at 28.8%. GaAs is more commonly used in multijunction photovoltaic cells for concentrated photovoltaics (CPV, HCPV) and for solar panels on spacecrafts, as the industry favours efficiency over cost for space-based solar power. Due to the following reasons GaAs is able to achive high power conversion efficiency.[14]. (1)GaAs bandgap is 1.43ev which is almost ideal for solar cells. (2)Because Gallium is a by-product of the smelting of other metals, GaAs cells are relatively insensitive to heat and it can keep high efficiency when temperature is quite high.

e) Multijunction cells: Multi-junction cells consist of multiple thin films, each essentially a solar cell grown on top of another, typically using metalorganic vapour phase epitaxy. Each layer has a different band gap energy to allow it to absorb electromagnetic radiation over a different portion of the spectrum. Multi-junction cells were originally developed for special applications such as satellites and space exploration, but are now used increasingly in terrestrial concentrator photovoltaics (CPV), an emerging technology that uses lenses and curved mirrors to concentrate sunlight onto small, highly efficient multi-junction solar cells. By concentrating sunlight up to a thousand times, High concentrated photovoltaics (HCPV) has the potential to outcompete conventional solar PV in the future. A triple-junction cell, for example, may consist of the semiconductors: GaAs, Ge, and GaInP2. GaAs based multi-junction devices are the most efficient solar cells.[15]

3) Third generation (emerging photovoltaics):

a) Perovskite solar cells:

The organic-inorganic perovskite, RNH3PbX3 (X = Cl, Br, I; R = Me, etc.), can function as a light absorption layer. A device of the perovskite solar cell is solution processible for fabrication at low cost. The organic-inorganic perovskites RNH3PbX3 are easily prepared from HX salts of organic amines and lead halides[2].

b) Dye sanitized solar cells (DSSC): The DSSC is a liquid-type device that involves nanoporous titanium oxide (TiO2) as a semiconducting electrode, organic dye-sensitizer and an electrolyte solution containing a redox component. This is expected to be a low cost solar cell, because there is a simple device structure compared with other solar cells[13]. The DSSC is usable under conditions with weak light. Thus, it is expected that the DSSC may be installed in a room. A ruthenium complex with a bipyridine ligand is one popular organic dye for solar cells. DSSC's can be engineered into flexible sheets and although its conversion efficiency is less than the best thin film cells, its price to performance ratio may be high enough to allow them to compete with fossil fuel electrical generation. The photogenerated electrons from the light absorbing dye are passed on to the n-type TiO_2 and the holes are absorbed by an electrolyte on the other side of the dye[4]. The circuit is completed by a redox couple in the electrolyte, which can be liquid or solid [2]. The followings are benefits: (1)Low cost (2)Good price to performance ratio (3)Operate in low light and at wider angle. (4)Operate at lower internal temperatures. (5)Mechanical robustness and long life[3].

c) Organic/polymer solar cells: Organic solar cells and polymer solar cells are built from thin films (typically 100 nm) of organic semiconductors including polymers, such as polyphenylene vinylene and small-molecule compounds like copper phthalocyanine (a blue or green organic pigment) and carbon fullerenes and fullerene derivatives such as PCBM. They can be processed from liquid solution, offering the possibility of a simple roll-to-roll printing process, potentially leading to inexpensive, large-scale production[10]. In addition, these cells could be beneficial for some applications where mechanical flexibility and disposability are important. Current cell efficiencies are, however, very low, and practical devices are essentially non-existent. Energy conversion efficiencies achieved to date using conductive polymers are very low compared to inorganic materials. The active region of an organic device consists of two materials, one electron donor and one electron acceptor. When a photon is converted into an electron hole pair, typically in the donor material, the charges tend to remain bound in the form of an exciton, separating when the exciton diffuses to the donor-acceptor interface, unlike most other solar cell types. The short exciton diffusion lengths of most polymer systems tend to limit the efficiency of such devices. Nanostructured interfaces, sometimes in the form of bulk heterojunctions, can improve performance[2].

TABLE I. EFFICIENCY OF DIFFERENT TYPES OF SOLAR CELLS

Cell materials	***Theoretical efficiency (%)***	***Practical efficiency (%)***	***Cost/watt (INR)***	***Life Span in years***
Monocrystalline silicon[10]	20-26	12-18	48	25
Copper Indium Gallium selenide	20	14	45	12
Gallium arsenide thin film	28.8	22	29	18
Amorphous silicon[10]	12-14	5-12	40	15
Cadmium telluride	15-16	5-10	39	20
Gallium arsenide[21]	26-32	18-25	18	20
Ribbon grown silicon	8-10	<10	25	14
Bifacial[21]	19.8-21.4	13	11	30
Perovskite[22]	23	20	10	20

Conclusion

Among these materials, Gallium arsenide solar cell having highest efficiency but life span is less. The Monocrystalline silicon solar cells are economical in long term with good efficiency which has made highly marketable. Polycrystalline cell also exhibits efficiency close to the Monocrystalline with same life span and less cost which made economical over ling term. Solar power generation has been developed as one of the most demanding renewable sources of electricity. It has several advantages compared to other forms of energy like fossils fuels and petroleum deposits. It is an alternative which is promising and consistent to meet the high energy demand. 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.

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References

[1] Shobh Nath Singh, “Non-Conventional Energy Resources” Pearson publications, pp. 128–147, 2018.
[2] TCI CHEMICALS (https://www.tcichemicals.com/pdf/F2033E.pdf)
[3] Materials Science and Application (http://www.scirp.org/journal/msa)
[4] Solar cells: In Reasearch and Applications (http://dx.doi.org/10.4236/msa.2015.612113)
[5] Williams, Neville. “Chasing the Sun”: Solar Adventures Around the World. New Society Publishers. pp. 84, 2005
[6] Jones, Geoffrey, Bouamane, Loubna (2012). "Power from Sunshine": A Business History of Solar Energy. Harvard Business School. pp. 22–23.
[7] Sunny Uplands, “Alternative energy will no longer be alternative". The Economist. 21 November 2012. Retrieved 28 December2012.
[8] Mann, Sander A, de Wild-Scholten, Mariska J, Fthenakis, Vasilis M, van Sark, Wilfried G.J.H.M.; Sinke, Wim C. "The energy payback time of advanced crystalline silicon PV modules in 2020: a prospective study". Progress in Photovoltaics: Research and Applications.
[9] Baldwin, Sam Energy Efficiency & Renewable Energy: Challenges and Opportunities. Clean Energy SuperCluster Expo Colorado State University. U.S. Department of Energy
[10] http://solarbotics.net
[11] "Radiation energy transducing device". Mori Hiroshi, Hayakawa Denki Kogyo KK. 1961-10-03
[12] Gevorkian, Peter (2007). Sustainable energy systems engineering: the complete green building design resource. McGraw Hill Professional
[13] Dye Sensitized Solar Cells. G24i.com (2 April 2014). Retrieved 20 April 2014.

[14] Deyo, J. N., Brandhorst, H. W., Jr., and Forestieri, A. F., Status of the ERDA/NASA photovoltaic tests and applications project, 12th IEEE Photovoltaic Specialists Conf., 15–18 Nov. 1976
[15] What is a solar panel and how does it work?". Energuide.be. Sibelga. Retrieved 3 January 2017
[16] Cuevas, A.; Luque, A.; Eguren, J.; Alamo, J. del (1982). "50 Per cent more output power from an albedo-collecting flat panel using bifacial solar cells". Solar Energy.
[17] How products are made (http://www.madehow.com/Volume-1/Solar-Cell.html)
[18] Bullock, Charles E. and Peter H. Grambs. Solar Electricity: Making the Sun Work for You. Monegon, Ltd., 1981.
[19] Komp, Richard J. Practical Photovoltaics. Aatec Publications, 1984
[20] Making and Using Electricity from the Sun. Tab Books, 1979
[21] Martin, Chris (30 December 2016). "Solar Panels Now So Cheap Manufacturers Probably Selling at Loss". Bloomberg View. Bloomberg LP. Retrieved 3 January 2017
[22] INDIA MART (https://m.indiamart.com/proddetail.php?i=9241798312)
[23] BIJLI BACHAO (https://www.bijlibachao.com/solar/solar-panel-cell-cost-price-list-in-india.html)