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Solar Cell to Photovoltaic Power Generation

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Abstract: *In renewable energy research, solar energy, along with wind, water and geothermal energy sources has got accelerating interest due to degrading environmental conditions. Solar energy is renewable, abundant and pollution free. Solar cells are the means to convert light energy from sun to electrical energy using photovoltaic effect. This made the need to advance the research and manufacture solar cells and photovoltaic arrays, as once installed solar panels produce zero emissions as they convert sunlight directly into electrical energy. However, Silicon abundantly available material has the disadvantage of high cost due to extensive wafer processing required. This gave way to research of new materials and technologies. Here, a review is done to better understand the various generations of solar cell material technologies to ease their flexibility in various applications.*

Key Words: *Renewable energy; Solar cells; Photovoltaic effect; Solar cell material technologies.*

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I. Introduction

Global energy demands are continuously increasing. To reduce the impact on climate owing to excess dependence for energy on non-renewable energy sources, the need for solar cell with higher efficiency and greater power handling capability is felt. In 1954 Calvin Fuller, Gerald Pearson and Daryl Chapin made effort and produced the first silicon solar cell. Solar cells work on the principle of photovoltaic effect. When sunlight falls on the pn junction, electron hole pair (EHP) generation takes place, which are swept apart by the built in electric field, leading to flow of electric current in the load connected. Solar cells are packed behind a glass sheet as they require protection from the environment. When more power is required than a single cell can deliver, cells are electrically connected together to form photovoltaic modules, or solar panels. Materials presently used for photovoltaic cells include monocrystalline silicon, polycrystalline silicon, amorphous silicon, Cadmium Telluride, and Copper Indium Gallium Selenide / Sulphide.

II. Solar cell materials

This short review is about the solar cell materials of first, second and third solar cells' generation. Silicon semiconductors materials, Cadmium Telluride, Copper Indium Gallium Selenide/ Sulphide, Dye Sensitized Solar Cells, Perovskite Solar Cells etc all are promising choices. Silicon cells are most abundantly available. Continuous research in material technology has led to third generation solar cells, which are based on nano-technology.

Wafer based Solar Technology (First Generation): Pure silicon is obtained from silicon dioxide by using metallurgical techniques. The first generation solar cells are based on monocrystalline Silicon (mono-Si) or polycrystalline Silicon (poly-Si) wafer. Mono-Si is made using Czochralski method. There can be one layer of light absorbing material i.e. single junction or there can be multiple junctions of light absorbing materials. The junction is formed by doping pure silicon with phosphorous and consequently boron to produce a semiconductor capable of current conduction. The upper layer of solar cell is made of thin p-type layer material. This thin layer allows ease in light absorption. Solar cells made of mono-Si have higher efficiency of 24.4% [1] as compared to poly-Si with 19.8%. Poly-Si surface is coated with thermally grown oxide so as to limit its detrimental electronic processes. The defects in poly-Si reduce the efficiency as border defects occur. Maximum power and efficiency of poly-Si cells decreases with cell temp and temperature coefficient of efficiency, while maximum output power is negative.

Thin film technology (Second Generation): The second generation solar cells are based on thin film technology in which different materials like amorphous silicon, Cadmium-Telluride, Cadmium Indium Selenide or thin Si films on Indium Tin oxide are produced. These are most commercially used in photovoltaic power stations, and have better performance in cloudy conditions. Material combinations of Cu/ In/ Ga/ Se called as CIGS-cells, and III/ V semiconductors like GaAs are applied. Most thin - film solar cells are sandwiched by putting two panes of glass, making a module. Silicon solar panels use only one pane of glass while thin –film panels are approximately twice heavy as crystalline silicon pane. Cadmium Telluride (CdTe), Copper Indium

Gallium Selenide (CIGS) and amorphous silicon (a-Si) are the thin -film technologies often used. Cadmium telluride and a-Si and other thin film materials are also the choices.

(i)Amorphous Silicon: It has various varieties such as amorphous Silicon Nitride (a-SiN), amorphous Silicon Germanium(a-SiGe), microcrystalline Silicon (μ-Si) and amorphous Silicon carbide(a-SiC). It is commonly used in desktop computers and calculators. Very thin layer of a-Si is grown on substrate material. Due to amorphous structure, Silicon exhibits a higher bandgap of 1.7eV which results in higher light absorption[2]. A transparent conducting oxide (TCO) is incorporated to allow light to reach the junction and also reduce series resistance. Using only metal fingers results in reduction of efficiency due to heat generation. Hydrogenated amorphous Si (a-Si:H) cells have higher efficiency, however lesser than mono-Si. The efficiency of a-Si cells lies in the range of 8 to 10%.

(ii)Cadmium Telluride (Cd-Te) and Cadmium Sulphide Thin film solar cell: It is one of the promising materials in thin film technology that has less cost, lower life cycle GHGs emission, lower carbon footprint and lower heavy metal emission than traditional solar cell technology. In this a junction of Cd-Te and CdS is developed over a glass substrate. However, the effects of lattice mismatches on epitaxy need to be understood prior to manufacturing. Typical value of efficiency is from 15 to 20%. Luminescent downshifting can be used to improve a poor quantum efficiency.

(iii)Copper Indium Gallium Di-Selenide (CIGS) Solar cell: It is a quaternary direct band gap semiconductor composed of Copper, Indium, Gallium and Selenium. It has higher efficiency than Cd-Te cell and its efficiency of 22.8% [3]competes with crystalline Si.

Third Generation

(i)Hybrid Solar cells: This technology is based on combination of amorphous and crystalline forms of Silicon. It has high manufacturing complexity but Wu et al (2005)[4] found that using a maximum power point controller could be used to interface amorphous Si cell to crystalline Si cell and result in high performance to cost ratio. Its efficiency ranges from 17 to 26%.

(ii)Nanocrystal based Solar cells: These solar cells involve latest material engineering technologies and continuous enhancements in device structure using novel fabrication techniques. They are also called as Quantum dots (QDs) solar cells made of transition metal groups in nanometer dimensions. They achieve typical efficiency in the range of 16 to 17 %. Typical QDs have a structure consisting of core and different layers are deposited to reduce interaction between between EHP generated and surface of nanoparticle. With the latest developments in nanocrystal based solar cell development, there will be a cost reduction and higher efficiency will be achieved.

(iii)Polymer Solar cells: These are built with serially linked thin functional layers on polymer foil. Conducting/ conjugate polymer are used to draw energy from the sun. Polymeric graphitic nanocomposites show excellent electrical and mechanical properties, good charge transport capabilities. Integrating carbon based nanomaterials provides operating levels similar to Si- based cells and find various applications due to their increased flexibility and lightweight.

(iv)Dye Sensitized Solar cells: These are still considered to be in preliminary stage of development. The major components in DSSCs are semiconductor electrodes, redox mediator, dye sensitizer and counter electrode. P-type NiO and N-type TiO_2 are the semiconductor electrodes. The two electrodes are separated by dye molecules. When sunlight penetrates transparent electrode and reached the dye layer, it excites the electrons which reach TiO_2 layer and a current conduction path through load is established. They have maximum reported efficiency of 14%. When organic dyes are used, such DSSCs are referred as organic solar cells. They are preferred for solar windows and glass walls of buildings. DSSCs have photosensitive nano TiO_2 coatings and visible optically active dyes, this provides DSSCs various colours.

(v)Pervoskite Solar cells: Perovskite structure was first discovered in mineral Perovskite (CaTiO3) having cubic lattice nested octahedral layered structure[5]. The perovskite materials have high charge mobility, lifetime and diffusion length. This leads them to have efficiency at par with crystalline Si.

(vi)Multijunction Solar cells: This technology takes advantage of the variation in band gap of different materials. The main idea is to increase the overall efficiency by combining the efficiencies of multiple junctions. The materials of different band gaps are aligned so that the band gap decreases from top and each junction converts a part of energy of solar spectrum into electrical energy. The materials are deposited using thin film technology in accordance with their bandgaps.

III. Performance and Efficiency of Solar Cells

The performance and efficiency of a solar cell can be known through two parameters i.e. Fill factor (FF) and Conversion efficiency (η). Fill factor is defined as the ratio of product of maximum voltage and maximum current to the product of short circuit current and open circuit voltage. Conversion efficiency is defined as the ratio of maximum power to the input solar power.

$$FF = \frac{V_m I_m}{V_{OC} I_{SC}}$$

$$\eta = \frac{P_m}{P_{in}}$$

IV. Conclusion

Climate change is occurring at a rapid pace. It is occurring due to GHGs emission and increasing carbon footprint owing to extensive use of non-renewable energy sources. Renewable energy source is the dire need of hour. It has been observed that the efficiency of multi-junction monocrystalline solar cell is greater than multicrystalline solar cells. Traditional Silicon cells have a quite high efficiency compared to Cd-Te thin-film cells, but very pure silicon is needed. Amorphous silicon and polycrystalline silicon are gaining popularity at the expense of single crystal silicon. Solar trackers can be used to track the movement of the sun to increase the time solar cells face sun. Additional innovations including minimizing shade and focusing sunlight through prismatic lenses are also put to use. This involves layers of different materials that absorb light at different frequencies, thereby increasing the amount of sunlight effectively used for electricity production. Innovations in solar cell technology to reduce the cost of energy and increase the application of solar cells are being done which include developing and manufacturing cheaper alternatives to the expensive crystalline silicon cells to have sustainable development.

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