A brief review on materials, structures and thin film solar cell

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Abstract—The eco friendly nature, abundance and easy availability of renewable solar energy have made solar electricity production viable. The total solar irradiation that reaches to the earth is more than sufficient to full fill the energy demand of human being for a whole year. The c-Silicon, microcrystalline silicon are the leader in solar PV segment. The thin film materials are promising with CIGS being important one. The spectrum splitting method to harness more solar energy gives enhanced energy efficiency. This paper discusses about the materials and basic solar cell techniques.

Index Terms— Renewable energy, Photovoltaic cell, Thin film cell, Multijunction

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1 INTRODUCTION

The conventional method of the electricity production from fossil fuels has three limitations (a) rapid exhaustion of fossil fuel from the earth's crust, (b) increasing cost of the fossil fuels and (c) excessive emission of green house gases. The electricity production from the solar photovoltaic (PV) cell offers an alternative. The irradiations from sunlight are an unlimited source of energy which is available at no cost. Silicon is a pioneer material for manufacturing the PV cells. A silicon wafer based technology captures ~90% of today's PV electricity market but high cost restricted its widespread use. The cost effectiveness of silicon technology is improved by low temperature deposition of an amorphous silicon (a-Si) thin-film. The a-Si thin-film has high light absorption, but a single junction a-Si thin-film solar cell suffers with a poor efficiency due to defects in the material. Microcrystalline (μc) and nanocrystalline (nc) silicon films with quality near to monocrystallline silicon offers an alternative if we mix the a-Si with hydrogen. Figure 1 shows complete setup for electricity generation using solar energy. PV cells convert sunlight to direct current (DC) electricity. The charge controller work to control the power from solar panel which reverses back to solar panel and may cause panel damage. Battery system acts as storage of electric power, used when sunlight is not available (i.e. night). An inverter converts direct current (DC) into alternating current (AC).

2 NECESSITY OF SOLAR PV TECHNOLOGY

The future of the human being depends on effectiveness of energy harvesting and security. The rapid energy demand in both, developed and developing countries can only be meet by vast availability of energy sources. Currently, the major contribution towards production of this energy is obtained from fossile fuels such as coal, oil and gas. The uncontrolled use of such fossile fuels tending to deplete their reserves in the time span of next ~200 years. The environmental and climatic conditions are deteririoating continuously due to emission of carbon dioxide and other greenhouse gases by their rapid and unplanned applications. The clean fuel technologies are developed to generate power based on hydro, tidal, solar, wind, geothermal and biomass energies sources [1]. The loss of natural consumable sources like fossil fuel, harmfull nuclear radiation effects, excessasive environmental pollution are the major force for development and research of clean fuel technologies such as solar photovoltaic (PV) technology [2]. The Jawaharlal Nehru National Solar Mission (JNNSM) launched by Government of India in year 2010 set the target for installed solar power capacity as 100 GW by the year 2022 which includes installations based on solar thermal and solar PV segments [3].

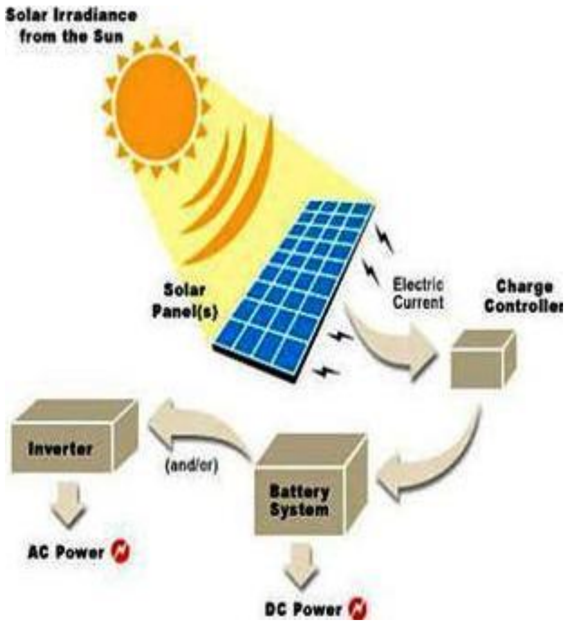

Fig. 1. Schematic of solar based electricity generation process

The data shows that incident solar radiation per day over India is around 4–7 kWh per square meter [4] with an annual radiation in the range of 1200–2300 kWh per square meter [5].

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Hence, India has a plenty of solar energy, capable of producing an estimated ~5000 trillion kW of clean energy. The power production in the country is just 13.3% of renewable power production and ~1.8% of total installed capacity [3]. To meet with demand and supply gap, this clean energy is harnessed proficiently, it can easily reduce the energy deficit situation. Thus, a huge potential exist for further deployment and exploration of solar based projects, especially the solar PV. The advantages of PV technology are abundance of light energy, ii) modularity and portability (iii) no fuel costs (iv) requires relatively low operation and maintenance costs unlike conventional power plants based on coal, oil, gas and nuclear fuel.

The process of solar electricity generation is performed by a solar cell which is basically a p-n junction (Figure 3(a)) [6]. The photo generation requires a semiconductor material as an absorber layer, which absorbs the incoming photons and generates electron-hole pairs (EHPs) in first step. The second step is to extract the generated charge carriers at the end contacts. The internal electric field due to built-in-voltage created by p-n junction of the solar cell is an important factor. The higher the built-in-voltage, the better is the charge separation. The carriers generated near the junction have poor life time in a p-n junction solar cell as it is a diffusion type device. Therefore, an application of the p-n structure alone is impractical, as high density of dopant induced defects in the doped layers destroy the electric field. Further, the p-i-n structure has been incorporated in to all PV cells for increased conversion efficiency above Shockley Queisser limit [7] of ~33%. The p-i-n structure (Figure 3(b)) creates strong drift field, thereby increasing the carrier transport length.

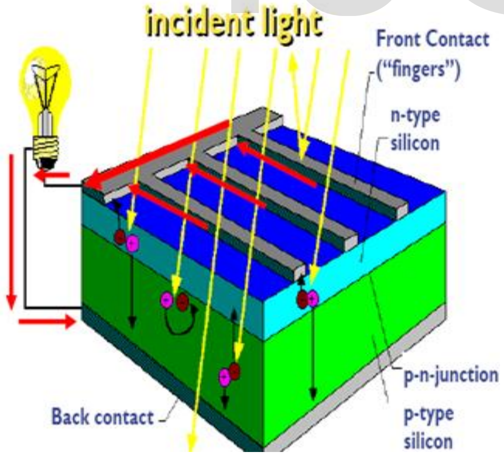

Fig. 2. Concept of conversion of light in to electricity

3 MATERIALS AND TECHNOLOGIES FOR SOLAR CELLS

The solar cell development can be classified based on the technology used and generations of development. The important technologies currently in use can be classified as silicon based cells, compound semiconductor cells, dye sensitized cells, organic/polymer solar cells. The classification of solar cells based on their generation enlists the structure of various solar cell structures used. First generation solar cells are silicon based photovoltaic cells which owns ~90% of solar cell market. Even though they have high manufacturing cost but they have high efficiency of ~25%. Second generation solar cells includes thin film solar cells which are cost effective than first generation silicon solar cells but have lower efficiency. The advantage of this generation of solar cells is their flexibility i.e. they are very light weight and have easy processing.

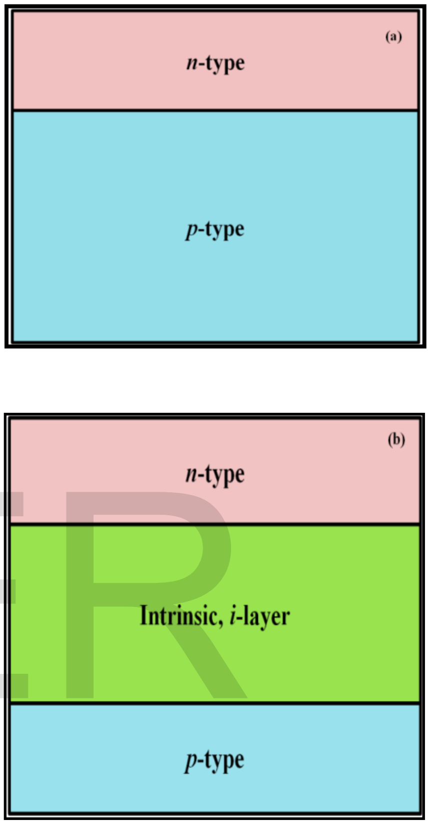

Fig. 3. (a) p-n junction solar cell (b) p-i-n solar cell [2]

Copper Indium Gallium Selenide (CIGS), Cadmium Telluride (CdTe), amorphous silicon (a-Si) are the three most widely commercialized thin film solar cells. They all are direct band gap materials which enable the use of very thin material [8]. The third generation solar cells includes technologies like quantum dot technology, tandem/multi junction cells, hot-carrier cells, up conversion and down conversion technologies, and solar thermal technologies [9]. The perosvskite solar cells are the new entrants in the field of solar arena with high efficiency of ~ 20%.

The crystalline silicon (c-Si) widely is used material for PV due to high cell efficiency, mature knowledge base of production methodology, easy availability, non-toxicity, and excellent stability proven by long term field applications [10,11]. An uneconomic production of c-Si wafer, indirect band gap, poor light absorption leading to thick cells and long energy payback period are the detrimental factors.

The optical absorption coefficient of Si based materials is shown in Figure 4 [11]. The highest absorption is shown by intrinsic amorphous Si (a-Si) in visible light range than all other Si based materials. This is one of the prime reasons for application of this material in initial stages of thin film solar cell development. However, the intrinsic a-Si has extremely high density of dangling bonds and hence high defect density ~10^{21} cm^{-3}. These defect states are held responsible for poor conductivity of these films. hydrogen (H_2) acts as passivating agents to these dangling bonds.

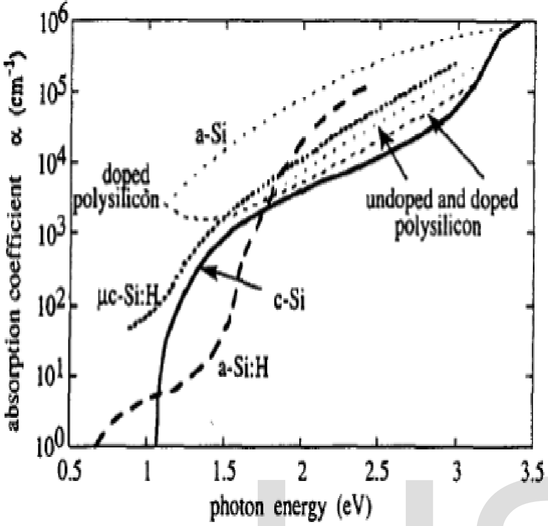

Fig. 4. A typical absorption coefficient vs photon energy for Si based PV materials

Figure 5 shows the schematic of atomic structure of c-Si, hydrogenated amorphous silicon (a-Si:H) and hydrogenated microcrystalline silicon (µc-Si:H). The a-Si:H is a short range order material, consisting of a covalent random network of Si-Si and Si-H bonds as compared to c-Si where each Si atom is covalently bonded to four neighboring Si atoms. Due to hydrogenation, a reduction in the defect density to ~10^{15-16} cm^{-3} is observed in a-Si:H [12,13]. The a-Si:H behaves as a direct band gap material and its red light absorption is much higher then c-Si, therefore, a very thin layer (~100 times thinner) than the c-Si solar cells is obtainable [14].

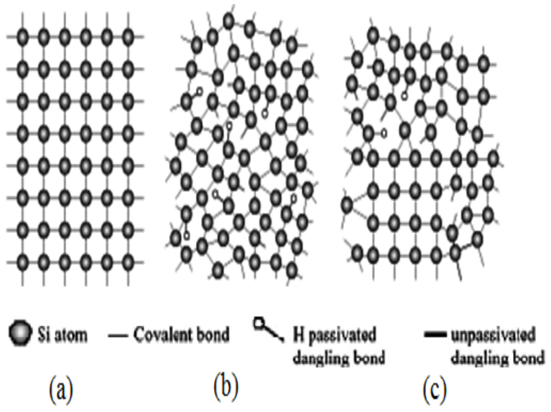

Fig. 5. Schematic diagram of the atomic structure of (a) c-Si (b) a-Si:H (c) µc-Si:H

Cadmium Telluride (CdTe)

CdTe is stable crystalline compound formed from cadmium and tellurium. It is mainly used as the semiconducting material in cadmium telluride photovoltaics. It is sandwiched with cadmium sulfide to form a p-n junction solar PV cell. Bulk CdTe is transparent in the infrared, from close to its band gap energy (~1.5 eV at 300 K, infrared wavelength of about 830 nm) out to wavelengths greater than 20 µm. CdTe is a direct band gap material like CIGS with a large absorption coefficient, and a stable compound. Figure 6 shows the efficiency chart of CdTe solar cell and its typical structure. [15]. The present efficiency demonstrated by CdTe solar cells is ~22%.

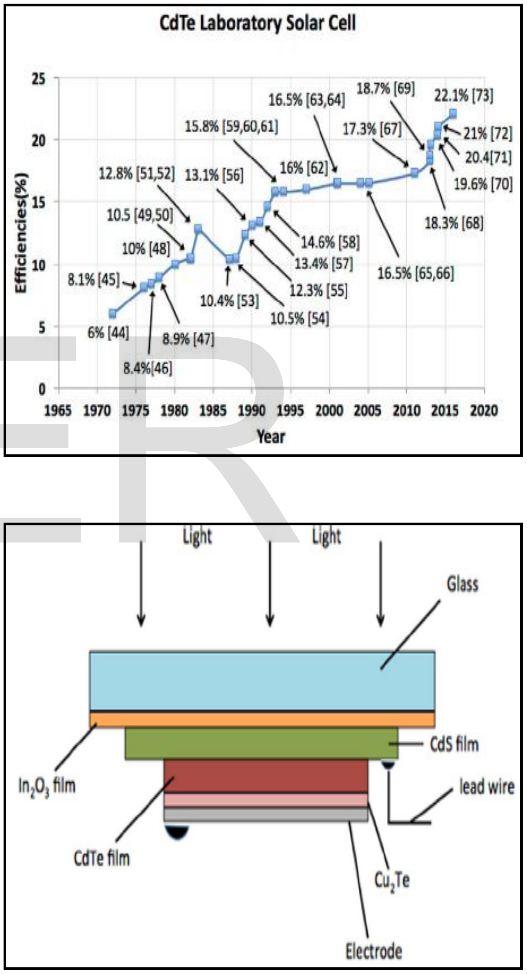

Fig. 6 (a) CdTe solar celll efficiency chart (b) Structure of CdTe solar cell

Copper Indium Gallium (di) Selenide (CIGS)

It is a I-III-VI semiconductor material composed of copper, indium, gallium, and selenium The chemical formula of CIGS is CuIn(1-x)Ga(x)Se2 where the value of x can vary from 0 (pure copper indium selenide) to 1 (pure copper gallium selenide). CIGS is a tetrahedrally bonded semiconductor, with the chalcopyrite crystal structure, and a band gap varying continuously with x from about 1.0 eV (for copper indium selenide) to about 1.7 eV (for copper gallium selenide).

Figure 7 shows time frame in which the efficiency of the CIGS cells increased from 4.5% to 22.3%. The p-type Cu(InGa)Se2 forms the main junction with n-type CdS, which serves as the buffer layer. An intrinsic zinc oxide layer lies on top of the CdS and the n-type ZnO:Al layer functions as the front contact. The substrate used is soda lime glass. [15]

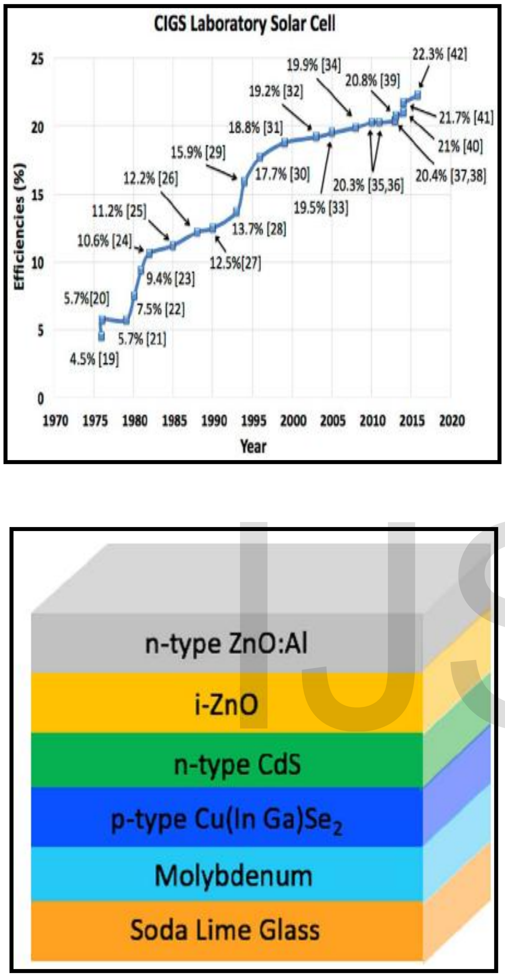

Fig. 7. (a) CIGS cell efficiency chart (b) Structure of CIGS cell

Cadmium Sulfide (CdS)

It is an inorganic compound as yellow solid. A direct band gap semiconductor (gap 2.42 eV) whose conductivity increases when irradiated (as a Photoresistor). When combined with a p-type semiconductor it forms the core component of a photovoltaic (solar) cell.

Multi junction solar cell

The concept of spectrum splitting is efficiently shown by multi junction solar cells for improved solar spectrum utilization. The higher enrgy photons are absorbed by top most cell and the lower energy photons are absorbed by lower band gap solar cell. Multi junction cell can be fabricated either by mechanical stacking of various layers or each semiconductor layer can be monolithically grown on top of the other layers [16]. The multi junction solar cell is fabricated by GaInP, GaAs layers on Ge substrate or multilayers of silicon materials on different substrate. Figure 8 shows the concept of multi junction solar cells. Most promising design improvement in multijunction solar cell is increasing number of junctions. Figure 9 shows structures of different multijunction solar cells. The micromorph solar cell, double junction and triple junction solar cells are few examples of multijunction solar cells.

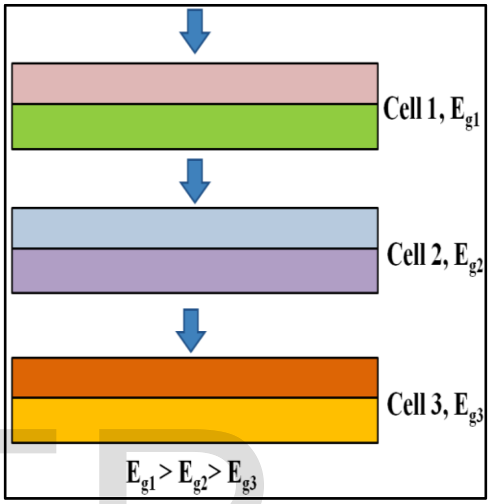

Figure 8: Multi-Junction concept

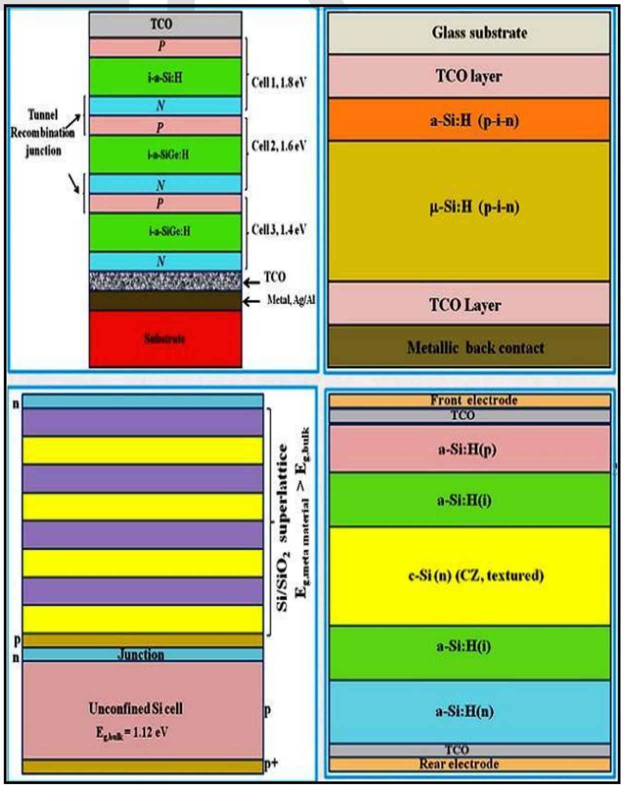

Figure 9: Solar cell structures of different Multijunction solar cells

4 CONCLUSION

Renewable energy is most promising source of energy. It has more benefits compared to other forms of energy like fossils fuels and petroleum deposits. The solar photovoltaics is the leader in clean energy generation. The silicon based material, especially c-Si solar cell have captured ~90% of solar PV market. Thin solar cells are gaining importance but poor efficiency is a concern. The CIGS and CdTe are promising one with efficiency of the order of ~20% but toxicity of cadmium is a concern. The spectrum spliiting and utilizing the solar spectrum efficiently is a concept to enhance efficiency of solar cells. Research on solar cell and solar energy is has a future worldwide.

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