



Rolling Towards Renewability by Studying Photovoltaic Solar Cells and the Comparison of their Performance under Enhanced Illumination

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Abstract - This paper presents a comparative study of photovoltaic solar cells in terms of their production cost, manufacturing methods and the performances under environmental conditions. In this study photovoltaic solar cells are categorized on the basis of the material used i.e. Silicon based solar cells (e.g. mono-crystalline, multi-crystalline, amorphous and micro crystalline forms) the polycrystalline compounds (some of the examples are copper indium disulphide, copper gallium indium diselenide, and Cadmium telluride, copper gallium indium diselenide) and the Organic Solar cells (e.g. polymers, dyes and fullerenes etc.) .It is found that the overall performance of the Silicon based solar cells is much better than the organic and polycrystalline compounds. It is also reported that the quantum efficiency of the Organic solar cells is around 0.1% under $1 \times 10^{-4} \text{ W/cm}^2$ intensity. Thin film silicon solar cells and crystalline silicon solar cells are performing better than the amongst all available options for harnessing the solar energy into the electrical energy if cost is not only the criteria for consideration.

Key words: Photovoltaic solar cell, organic solar cells, inorganic solar cells, thin film silicon solar cells, solar insulation, quantum efficiency.

I. INTRODUCTION

In the present scenario, Silicon is generally used in manufacturing the commercial solar cells. The Silicon is generally of different types such as mono crystalline,

polycrystalline and amorphous. Silicon photovoltaic phenomenon which has been used in aerospace technologies in 1954 has been first came into knowledge in 1839. In 1990, the organic photovoltaic solar cells came into existence. Appearance of the several types of organic materials based solar cells in the recent time raises the probability of less expensive solar cells that can be made on flexible substrate. Some of the well-known differences between the photo conversion mechanism of the organic photovoltaic cells and inorganic photovoltaic IPV cells is that light absorption in OPV cells leads to the production of exciton mobile excited states while in IPV cells it leads directly to the creation of free electron-hole pairs. This difference, however, has fundamental, and under-appreciated, outcomes for the theoretical explanation of the photo conversion process and for efforts to optimize the performance of OPV cells.

II. SILICON BASED SOLAR CELLS TECHNOLOGY AND ITS EVOLUTION

Edmund Bequrel discovered the photovoltaic effect from the platinum electrodes immersed in electrolyte, after the discovery of photovoltaic effect by Edmund Bequrel, the photovoltaic effect has been observed by William Adams et.al. detects the photovoltaic effect in a sample of Se (Selenium) placed between two metallic electrodes. This was the first solid photovoltaic device. The photovoltaic effect in the photovoltaic device

produces from the association of selenium and metal. After them so many photovoltaic devices was developed by various researchers but one thing was common in each of these early cells was that they were comprised of metal electrode/semiconductor/ semitransparent thin metal electrode with a bottle neck to transmit incident light. This limitation, results in less power conversion efficiency ~ 1%.

In the 1950 PV cells achieved first practical application. In 1954, the first high-power silicon PV cell, has been developed by Pearson and Bell Lab scientist Chapin Fuller which used a p-n junction and reported a PCE of 6%.[1] This beautiful achievement compelled the New York Times to forecaste that solar cell would be able to harness the“limitless energy of the sun.”

In 1958, the first time PV technology was practically utilized a PV based radios appeared on the US Vanguard I space satellite.

In 1976 RCA laboratories scientist Carlson and Wronski developed a first amorphous silicon photovoltaic cell.

In 2001 Konarka’s flexible introduced a thin film technology which leads to complete green energy solution.

In this period, various PV cells made of different materials like cadmium sulphide, gallium arsenide, cadmium telluride, and indium phosphide. But silicon based pv cells are the most promising option than the other as cadmium is a toxic element while GaAs-based PV cells are very expensive and indium is rare.

Thin film technology can replace the si pv cells technology in order to reduce the cost of production, amorphous or microcrystalline silicon were used. Also in this period various researchers conducted experiment on the tandem cell structures and for the tuning of bandgap of semiconducting materials to improve power conversion efficiency.

III. SILICON SOLAR CELLS

The indirect energy gap of Silicon at room temperature is 1.1 electron volt (eV) approximately. In

the indirect energy band gap the optical absorption coefficient observed low value $\approx 100\text{cm}^{-1}$. This signifies that several hundred microns thick ($\gg 1\mu\text{m}$) silicon is required to absorb most of the incident light.. To contribute to the photocurrent, the electron hole pairs produced by the light should be able to spread up to that distance to reach the electric field in the depletion region of the junction. For using silicon in PV solar cells, the manufactures now used to purify the Silicon by themselves as there is a fast growth in the PV sales over last 6 years [8]. Fig. 2.1 shows the cross sectional view of the schematic diagram of the conventional silicon solar cell. A boule of silicon sows the boron doped p-type monocrystalline silicon wafer using Czochralski and the pn junctionformed by diffusing phosphorus impurities into water. Screen printed silver contact fingers are used on the n-type surface to make both electrical contact and to permit light to be conveyed to the junction region.

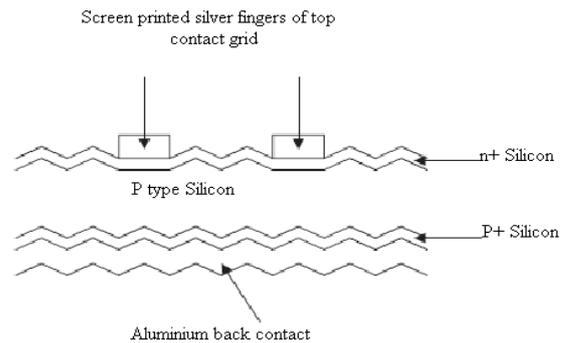


Fig. 3.1 Schematic cross-sectional diagram of a silicon solar cell with screen printed contacts.

Crystalline silicon devices and modules have dominated production and sales from 1954 to 2000. Although the sale of silicon solar cell has continued to grow rapidly the market share of monocrystalline silicon products has actually reduced to approximately 40% of sales volume due to increased competition from devices based on the use of Multicrystalline silicon. The cells sold have the efficiency ranging from 10% to 16%, the more sophisticated design resulting in the higher efficiency devices.

Multicrystalline silicon solar cell are used to make the best module generally have efficiencies 2-3% less than those of crystalline silicon and cost approximately 80% of that of crystalline silicon cells to produce. The market share of this product (55%) has



continued to increase over the past 5 years and it still increasing.

Thin films of amorphous silicon are produced using the chemical vapour deposition of gases containing silane (SiH_4), usually “PECVD” [19] or “hot wire CVD” [20]. For continuous production and diverse use has been allowed by depositing layers onto flexible substrates e.g. plastics and thin metallic sheets and onto rigid substrates such as glass.

An alloy of hydrogen and silicon (5-20 atomic % hydrogen) a Si-H (Hydrogenated amorphous silicon) is taken as a material in solar cells in which hydrogen plays a very important use in passivating the dangling bonds which produces output from the silicon atoms random arrangement. An optical absorption coefficient $\pm > 105 \text{ cm}^{-1}$ and a direct optical energy band gap of 1.7 eV of hydrogenated amorphous for photons with energies which is greater than energy band gap. This shows that by reducing the usage of the materials and hence cost, most of the incident light is absorbed using few microns of the materials. To reduce the lifetime and mobility of minority carriers in amorphous silicon doping is found quite useful.

The properties such as high optical absorption coefficients, have direct energy band gaps and have good values of minority carrier lifetime and mobilities are possessed by the polycrystalline compounds such as Phosphide (InP), Gallium antimonide (GaSb) and Gallium Arsenide (GaAs) which makes them an efficient materials for making highly efficient solar cells. The liquid encapsulated Czochralski method or Bridgmann method can be used to produce single crystals of these materials.

Due to high absorption of coefficient the solar radiation with energy higher than that of the band gap is absorbed efficiently at a surface distance of about few micrometers. For single-junction conversion of the solar spectrum the near optimum band gap values has been analyzed.

InP has a band gap of 1.34 eV and GaAs has a band gap 1.424 eV. The minority carrier diffusion length of InP , L_n (for Zn doped p- InP wafers) in the range 2-30 mm depends on the density possessed by the doping.

IV. SOLAR CELLS BASED ON THE USE OF POLYCRYSTALLINE COMPOUNDS

The optimum energy bandgap for photovoltaic solar energy conversion is 1.5 eV given by Loferski in 1956 [9]. CdTe , has a direct energy bandgap near to this value, and a high optical absorption coefficient for photons with energies greater than the energy bandgap ($\pm > 105 \text{ cm}^{-1}$) made the CdTe a promising PV material [12,13]. It was also observed that a very thin layers which is few microns thick, were all that would be needed to absorb most of the incident light, minimizing material costs.

Also because a long minority carrier diffusion length would not be required (as most of the light would be absorbed in the depletion region) polycrystalline layers deposited using low cost processing methods might be adequate for producing efficient cells. CdS has an energy bandgap of 2.42 eV, which is sufficiently wide to transmit most of the solar spectrum to the device junction. It is also one of the few wide energy bandgap materials that can be strongly doped (n-type) minimizing series resistance problems.

V. LIMITATIONS OF THE POLYCRYSTALLINE COMPOUNDS

- The disadvantage of using Polycrystalline compounds in photovoltaic devices is the very high cost of producing device quality substrates or epitaxial layers of these compounds.
- Crystal imperfections, including unwanted impurities, severely reduce device efficiencies and alternative lower cost deposition methods cannot be used.
- These materials are also easily cleaved and are significantly weaker, mechanically, than Si.
- Materials possessing high density has a disadvantage in terms of weight. To take advantage of the high absorption coefficients very thin cells can be manufactured.
- These drawbacks led to them being considered as unpromising materials for single junction, terrestrial, solar cells.
- It was primarily due to their potential for space applications that development of Polycrystalline compound based devices was undertaken.

- The potential for high conversion efficiencies together with radiation resistance in the demanding environment of space power generation mitigated against the high materials cost.

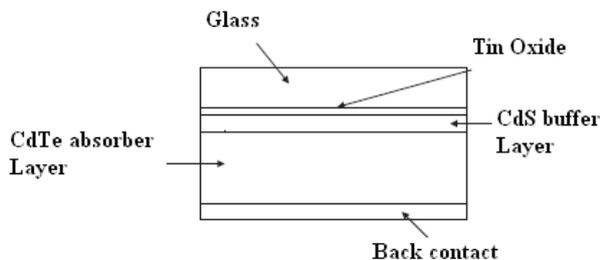


Fig. 5.1 Block Diagram of CdS/CdTe device structure

VI. ORGANIC PV CELL

The organic materials that are of most interest are molecular and polymeric semiconductors and fullerene (C₆₀) and its derivatives [14-20]. The former materials are well known for their use in organic LEDs. The potential advantages of using these materials include simplicity of deposition processes that can be used, e.g. many of the materials are solution processible such that spin coating of substrates is possible, and that all-polymer-devices should be flexible and hence easy to use for a wide range of applications. The cell structure used for most of these devices starts with an indium tin oxide coated glass substrate which also acts as the transparent top electrode to the device. A layer (or layers) of light absorbing organic material (or materials) is deposited onto indium tin oxide. The device is completed by depositing a back contact (usually a metal) onto the organic material(s). Initial studies just used one absorbing material between the two co-planar electrodes; however, carrier collection is poor resulting in low device efficiencies.

Following types of organic PV cells are developed

6.1 Single layer Organic PV Cell

The single layer device structure of Organic PV cells is composed of a transparent electrode/organic photosensitive semiconductor/electrode. In 1994 R. N. Marks et al. developed a structure of 50-320 nm thickness of poly (p-phenylene vinylene) (PPV) which was sandwiched between an ITO and a low work

function cathode. And they reported the quantum efficiency around 0.1% under 1×10^{-4} W/cm² intensity.[2] This efficiency is very low in comparison with the single crystalline silicon. It is due to the carrier mobility of semiconducting organics which was around 10-3 cm²/V·s, while the mobility of single crystalline silicon is about 10³ cm²/V·s order.

This indicates that the photogenerated charges in semiconducting organics require more time to be collected from electrodes. The slow charge transport itself decreases the efficiency of the Organic PV cell, but also increases the recombination chance of charges in the device.

The other problem of generating low efficiency is the Organic PV cells exciton formation, which are strongly bound dipole charges of photo excited semiconducting organics.[3]

It was known that the excitons are more efficiently dissociated at the interface between donor and acceptor, and a bilayer Organic PV cell was developed by inserting an acceptor layer between a donor semiconducting organic and a cathode.

6.2 Bilayer Organic PV Cells

In the Bilayer Organic PV cell structure an additional electron transporting layer is found than in the single layer Organic PV structure. This structure was first observed by C. W. Tang in 1985 and the device structure was composed of indium tin oxide (ITO)/copper phthalocyanine (CuPc)/ perylene tetracarboxylic derivative (PV)/ silver (Ag)[7]. It is observed that the reported efficiency of bilayer Organic PV cells is still lower than that of inorganic PV cells. This is due to the reason that intrinsically short exciton diffusion length of excitons in organic semiconductors, which are typically around 10-20nm.[4-5]

6.3 Bulk Heterojunction Organic PV Cells

Bulk heterojunction Organic PV cells, which have an intermixed composite of donor and acceptor having a much larger interface area between donor and acceptor in comparison with the bilayer organic PV cells. The best performance from the optimized blend OPV cell was 4.4%.



VII. LIMITATIONS OF THE ORGANIC PV CELLS

- Exciton generation: Almost all spectrum of light can be converted by the polymers and polymer composites i.e. organic pv cells into the excitons, their mobility remains poor. These generated electrons and holes pair can only travel very short distances (appx.10-20nm) before their recombination. and also Organic photovoltaic possess very poor transport characteristics.
- Transparency: For the exciton generation very thin film is required and due to this thin film a specific amount of light is lost because of transparency. The solution was present in the antireflection coating and it became very costlier step which become unsuccessful.
- Oxidation: To protect from the oxygen contamination in the polymers and composites controlled lab conditions are required.

VIII. COMPARISONS OF SOLAR CELLS PERFORMANCES

S.No.	Performance Criterion	Si-based Solar Cells	Polycrystalline Compound based Solar Cells	Organic Compound based Solar Cells
1.	Module Efficiency (normal)	(i) Monocrystalline Si- 10-16% (ii) Polycrystalline Si-16-18% (iii) Amorphous Si-<10%	CdS/CdTe devices with efficiencies > 10% 16.5% (NREL)	<5%
2.	Module Efficiency(Intense illumination)	(i) Monocrystalline Si-10% (ii) Polycrystalline Si-15-16% (iii) Amorphous Si-<5%	CdS/CdTe devices with efficiencies d 10%	d 5%
3.	Manufacturing Cost	High	Comparatively low	Very Low
4.	Stability	10 years if commercially used	d 10 years	10-15 years
5.	Nature	Non Toxic	Toxic	Non Toxic
6.	Environmental issues	-	-	Ecofriendly
7.	Occurrence	Easily available	Rare	Available in abundance
8.	Energy band gap	Mono crystalline and Multicrystalline Si 1.12 eV Amorphous Si-1.7 eV).	1.5 eV	d 1.5 eV

Table 8.1 Comparison of Solar Cell Performances

IX. CONCLUSION

In this paper we discussed about the different material suited for the production of solar cell devices their performances are tabulated. During the study we observed that the Si PV technology is the most acceptable one pv technology either crystalline Si based or amorphous Si based because of the better efficiency and stability than the other materials, if cost is not taken

into consideration. While the Polycrystalline compound based solar cells like CdTe is doing better in the field of PV technology but they are not eco-friendly and toxic in nature and energy payback time is also very low. As far as organic compound based solar cells are considered then they are not much efficient.



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