Recent Developments of Solar cells with the Application of Nanotechnology

K.Sivakumar[1], A.Thiyagarajan[2]

[1]*Assistant professor, Department of E.C.E., Dhanalakshmi Srinivasan College of Engineering, Coimbatore, India*

[2]*Assistant professor, Department of E.E.E., Karpagam Institute of Technology, Coimbatore, India*

[1]siva.jece@gmail.com

[2]thiyagarajanaruchamy@gmail.com

Abstract— **Power generation using photovoltaic (PV) systems is being an important role among the renewable energy sources. Presently, solar cells are not enough efficient and more expensive. The efficiency of a PV system depends on the absorbing capacity of the semiconductor. Nanotechnology can be used to improve the efficiency of PV and the most assured application of this reduction of manufacturing cost. The absorption of PV can be increased by using stack of thin film semiconductors with band gaps of different energies. By using nanotechnology, solar cell would protect the environment with low cost. This paper discusses an overview of the recent solar cell technologies with the application of nanotechnology.**

Keywords— **Solar cell, Nanotechnology, Renewable energy.**

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I. Introduction

Solar energy has a great potential among the renewable energy sources. Photovoltaic of solar cells are used to convert to the energy of the sun into electric current. The solar cells are made of semiconductor material. It is necessary to explain the operation of solar cell uses. When sun light hits the solar cells, energy is absorbed and that allows electron flow in silicon. The different impurities such as phosphorus or boron are added to establish an electric field. This field allows electrons to flow in one direction and it is known as electricity. The main drawbacks of solar cells are inefficiency and their manufacturing cost. In this, the drawback of inefficiency is almost unavoidable because the falling light or incoming photons should have the energy, called the band gap energy used to knock out the electrons. If the photon has more energy compared to band gap, then that energy will be gone as heat. The above main two effects contributes in the loss of around 70 percent of the radiation energy incident on the solar cell [1].

Nanotechnology can be used to increase the efficiency of solar cells but that promises in the reduction of manufacturing cost. It is used to fabricate complex nano-structured mirrors and lenses to optimize solar energy harvesting and aereogels with nanopores to be used as thermally isolating material for the cover material of solar collectors.[6],[8] .The solar cells which has a nano rods could convert sunlight into energy without losses. The Fig.1 shows the structure of solar cells with nano rods.

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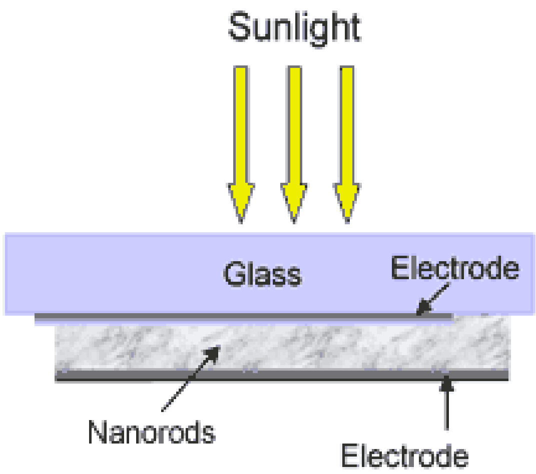

Fig.1 Structure of solar cell with nano rods [1]

The various nano-structured materials have been investigated potential applications in solar energy. In solar cell, thin film promises to improve efficiency and reduce total cost. The main advantages of thin film are categorized with less loss and reducing size [11]. First, due to multiple reflections, the effective optical path for absorption is very larger than usual film thickness. Second, the electrons and holes which are generated by the light need to move over a shorter path that results recombination losses are mostly reduced and the thickness of absorber layer in nano-structured solar cells can be thin as 150 nm in place of several micrometers in conventional thin film solar cells.[1]

The main purpose of depositing thin film on an optical surface is to provide environmental protection and improve optical performance. This is most cost-effective solution and uses a less support on active component which is applied as a thin coating. The thin film solar cell technology is based predominantly on deposited amorphous silicon (a-Si) thin films, CuInSe2 (CIS), and its higher band gap variant Cu(In/Ga)Se2 (CIGS) and CdTe. The thin film solar cells use very small deposition material and can be deposited on a variety of low cost substrates as stainless steel and flexible surfaces.

II. Dye-Sensitized Nanocrystalline Solar Cell

Currently, maximum energy conversion efficiency in a PV cell is acquired from Crystalline Silicon (Si). Even it is a good conducting material has the main drawback of very expensive that reflected in high cost of recent PVs.Alternatively, TiO_2 can be used in Photovoltaic and it is less conductive [4].

Increment of PV absorption rate can be acquired by using multi-junction solar cells with band gaps of different energies and sensitized conductors. This type of cells is known as dye-sensitized cells. In this, dye molecules attached to the surface of wide band gap mesoporous oxide semiconductor like TiO_2. The Fig.2 shows the operation of dye-sensitized electrochemical photovoltaic cell.

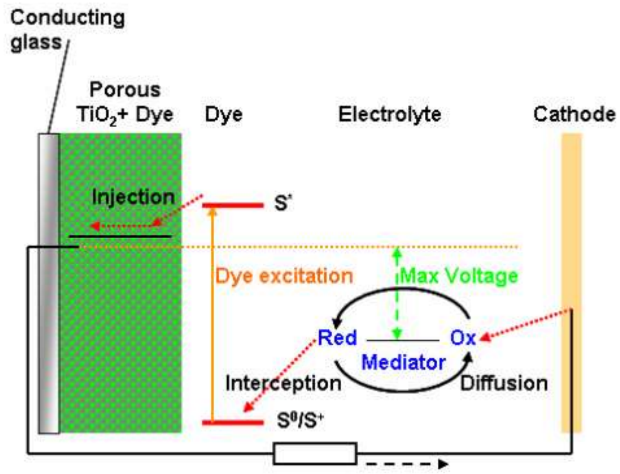

Fig.2 Operation of dye-sensitized electrochemical photovoltaic cell

The dye molecules acts like an antenna to capture the light of a particular colour and also wide range of colour of light can be absorbed compared to the TiO_2.This is a way to increase the efficiency of the device.

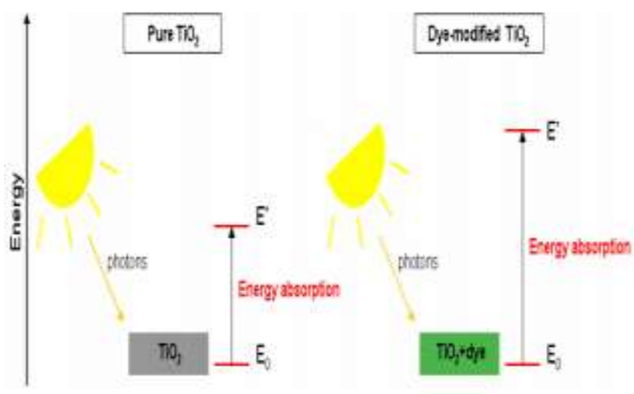

Fig.3 Difference between solar light absorption in pure titanium and a mesophorous dye-sensitised titanium oxide.

Fig.3 shows the Difference between solar light absorption in pure titanium and a mesophorous dye-sensitised titanium oxide.The mesoporous nature of the oxide gives a huge internal surface area so that reducting the amount of material is needed in the solar cell. To increase the efficiency of transfer of the photon energy absorbed by the dye to the titanium oxide and that is used to generate power. These cells assures because that are low cost materials and reduced size.

III. Semiconductor Quantum Dots(QD)

This is a one of the method for the increase of the conversion efficiency of solar cells with the use of semiconductor quantum dots (QD). In this method, the band gaps can be adjusted to convert longer wave light and that can increase the efficiency of the solar cells. At present, quantum dot solar cells are still subject, to basic research. In the material systems of Quantum dots solar cells, III/V-semiconductors and other material combinations such as Si/Ge or Si/Be Te/Se are considered.[4] Fig.4 shows the Typical quantum dot cell.

The main advantages of these Si/Ge QD solar cells are:

1) Higher light absorption in particular in the infra -red Spectral region,
2) Compatibility with standard silicon solar cell production (in contrast to III/V semiconductors),
3) Increase of the photo current at higher temperatures,
4) Improved radiation hardness compared with conventional solar cells.[4]

Suppose, a solar cell made of quantum dots is placed on top of an ordinary silicon cell, its absorption starts to “kick in” where the silicon cell absorption starts to fall off. Such a cell Configuration is called a tandem solar cell because the two devices work in series manner. The result is that the overall efficiency rises because more light is absorbed.

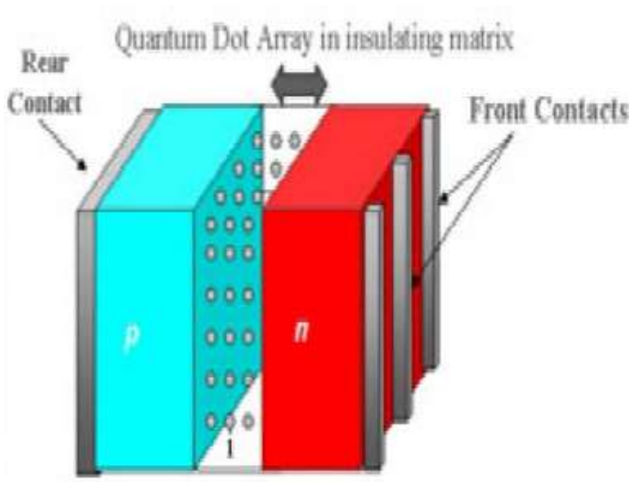

Fig.4 Typical quantum dot cell

The theoretical Estimatation of the efficiency exhibits in the range from 30% to 35% in sunlight.

IV. Silicon Based Photovoltaic Devices

Silicon based PV is a leading technology and 85% of solar panels made out of silicon .Silicon is a most available element in the earth and produced form natural sand in form of silicon oxide(SiO_2).

a) Crystalline Silicon (c-Si)

In this type of solar cells, boron is used as a dopant to produce a p-type crystal and it is then sliced into wafers. A polishing process is carried out on the wafers. To obtain a p-n junction, phosphorous is used as n-type dopant on the wafer. Doping process of this material can be done by one of the following techniques i.e., vapour phase (expose to N2), solid phase (CVD of PO2) or directly by ion implantation. An efficiency of 27.6% was achieved for silicon devices.

b) Multicrystalline Silicon.

Multicrystalline Silicon material is produced by a casting process in which molten Si is poured into a mould. Fig.5 shows the Large block of multicrystalline Si from a melt. The Si material is sliced into wafers after the melting process. These wafers are produced from casting process, but that are not as efficient as c-Si due to the improper in crystal structure, grain boundaries and contamination from crucible. The present lab efficiency of multicrystalline silicon is about 25%.

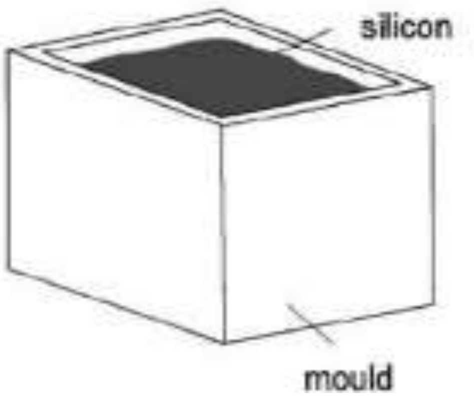

Fig.5 Large block of multicrystalline Si from a melt

Multicrystalline silicon and c-Si have a indirect gap so that light absorption is very weak in both.

c) Amorphous Silicon (a-Si)

This material is composed of randomly oriented Si atoms in a homogenous layer instead of a crystal structure. In a-Si, the absorption of light is higher and leading to a use of thin layers. For this reason a-Si is also among the thin film solar cells and has a direct bandgap[7]. The film is produced by decomposition of silane (SiH_4) and can be deposited on a wide range of substrates. The main disadvantages in all a-Si based solar cells is a reduction in efficiency during their first few hundred hours of illumination, known as Staebler-Wronski effect. To reduce recombination losses, a p-i-n structure is used which consists of thin p- and n-doped layers at the front and rear part.[3]

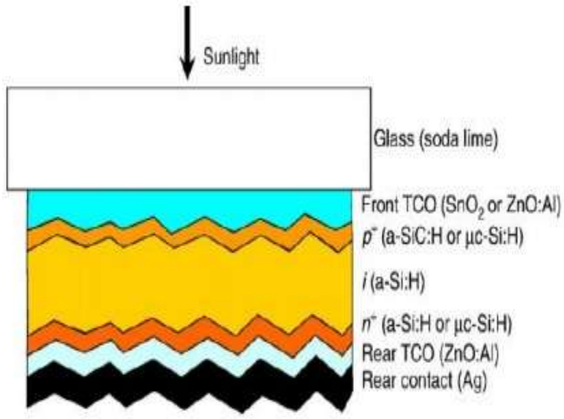

Fig.6 structure of p-i-n a-Si:H solar cells on a glass substrate

At the centre, an intrinsic layer is used which serves as the light or photon absorbing layer as shown in Fig.6. Ag contact fingers which are used to make a contact to the n-type surface by screening method. Al paste is to make a contact at the back p-type surface.

V. Thin Films Solar cells

This is a second generation solar cells and it groups into four technologies such as a-Si, CdS/Cu_2S, CdTe and CIGS. CdTe and CIGS thin films solar cells are currently under in research. CIGS-based solar cells are currently best with a record efficiency of 20.3% and 15% for small scale laboratory and module respectively .The another technology, CdTe-based solar cells have achieved a laboratory and module efficiency of 17.3% and 13.4%[2]. Some of the advantages of these technologies include lower material requirements, variety of processing methods and lightweight modules. A thickness of thin film solar cells is sufficient(2-4µm_ for light absorption, whereas c-Si needs to be more thick(180-300µm) to absorb all incident radiation efficiently. Due to the thinner layer produced, this leads to the faster processing steps and provides reducing in manufacturing cost.[5]

a) CdTe

CdTe thin film solar cell consists of two semiconducting layers. A CdS layer serves as the n-type window material with energy bandgap, E_g = 2.42 eV and a CdTe layer (absorber) deposited on top with E_g = 1.45 eV. Cadmium sulphide (CdS) is among the binary compounds of group II-VI family and its thin films are mostly used in various materials such as light emitting diodes (LEDs), solar cells, electronic and optoelectronic devices.

Cadmium telluride (CdTe) thin film based PV devices one of the suitable materials for use in PV structures such as sensors, nano-devices, solar cells and other electronic devices. Fig.7 shows the Basic structure of the glass/ChS/CdTe/metal solar cell. The specific advantages of it makes one of the primary participant in the field of PV energy conversion. It includes the ideal bandgap energy of 1.45 eV for the achievement of the theoretical maximum photovoltaic conversion efficiency of 31% and a high optical absorption coefficient of over 99% of the incident sunlight with only about 2 µm of active thickness.

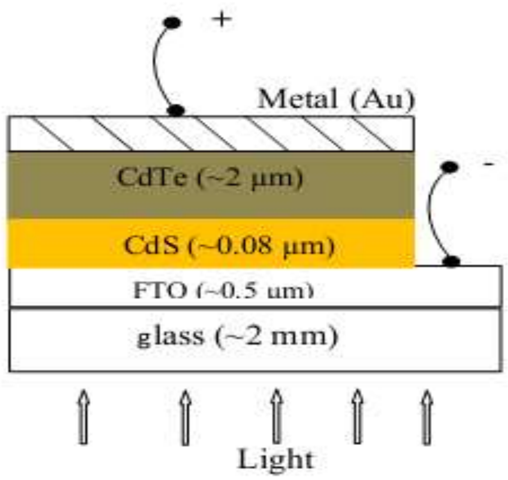

Fig 7: Basic structure of the glass/ChS/CdTe/metal solar cell

The basic structire of the CdS/CdTe solar cell structure is shown in Fig.7.The device structure is then a simple n-p heterojunction with an ohmic contact at the p-CdTe/metal interface. CdTe solar cells is very stable and produce clean energy.

b) CIGS

This configuration provides the highest efficiency in favorable process conditions and it requires an additional layer to protect the cell surface as shown in fig.8.

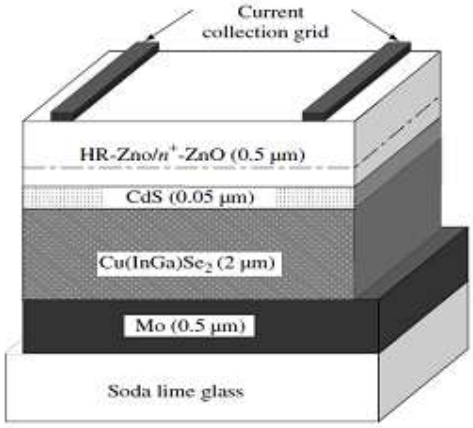

Fig.8 Basic structure of the CIGS solar cell

The efficiency of CIS- based superstrate solar cells did not exceed 5% because of indesirable interdiffusion of Cd into CIS(or CIGS) during the elevated temperature.To overcome this problem replacing CdS with undoped ZnO and co-evaporating Na_xSe during CIGS deposition. By this addition of composition grading in absorber layer,12.8% efficiency cells can be developed. This co-evaporation of Na_xSe for incorporation of sodium in CIGS is essential for high-efficiency cells, as the ZnO front contact acts as diffusion barrier for Na from the glass substrate and leads to a low net carrier densityin CIGS.

c) Multi-junction solar cells

The absorption of light can be increased efficiently by using multi-layered cells. The theoretical value conversion efficiency of 86.6% can be achieved using a multi-layer structure. Different band gap materials are used, with each layer absorbing different range of energies photon. Fig.9 shows the diagram of Multi layer solar cells connected in series.

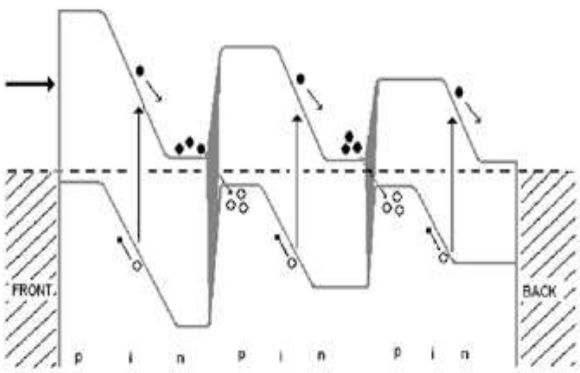

Fig.9 Multi layer solar cells connected in series

. At the front solar structure high energy photon are absorbed and lower energy are absorbed in rear of this structure [9].

By using a tunnel-junction, a series connection can be done and by making contact of the conduction band of one device and the valence band. The main disadvantages of using this connection is a substantial recombination at the interfaces in which electron and hole are created and recombine again. But the parallel connection gives the good result.

d) Transparent Conducting OXIDES (TCOs)

Transparent Conducting Oxides (TCOs) are suitable for a various applications due to their high transparency and near-metallic electrical conductivity. This is key components in most optoelectronic devices. TCOs are used as a current collector in solar cells. In this, Tin oxide is mainly used for making good electrical contact and is often doped with either indium or fluorine to achieve high conductivity

e) Organic solar cells

These solar cells consist of two organic layers of two organic materials. One of these materials be an organic dye or a semiconductor polymer that provides electron and the other used as a electron acceptor. Indium tin oxide is used as transparent anode in this device and aluminium doped zinc oxide (ZnO) is probed. Fabrication techniques of organic solar cells are simple and manufacturable on a large scale. The major disadvantages of cost of these cells are expensive because of polymers used so far. Poor stability of these cells are major concern and encapsulation techniques need to be developed.[4]

VI. IMPROVING SOLAR CELL WITH NANOTECHNOLOGY

The main drawback of solar cell is high cost and inefficient but using nanotechnology should be able to reach high efficiency.The improvement in solar cell performance can be described by the fact that the efficiency is highly affected in long-wavelength region with the increase of intrinsic region thickness[6]. When the intrinsic region thickness is increased more photons are absorbed in long wavelength illumination, Thus a greater percentage of electron-hole pairs would be created from the absorbed photons.

In Solar cell ,quantum dots to coat the nanoparticles but in conventional materilas which one photon generates only one electron. Quantum dots have the ability to convert high energy photons into multiple of electrons. In the working of quantum dot that produce three electrons for each photon of sunlight that hits the quantum dots. The electrons will move from the valence band to conduction band and dots will catch more spectrum of light waves. Thus the result of conversion efficiency increases as 65 percent [9]. Fig.10 shows the Solar cell enhanced with Quantum-dot.

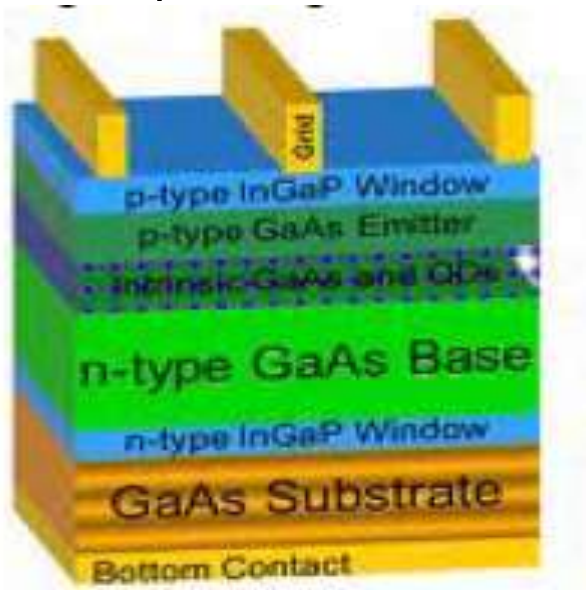

Fig.10 Solar cell enhanced with Quantum-dot(QD) [4]

A hot carrier cells can be used with quantum dots. A photon supplies extra energy is lost as a heat but with a hot carrier cells these extra energy of photons result in higher energy electrons which produces higher voltage. The movement of electrons through the particle network is the main issue in achieving higher photo conversion efficiency in nanostructured electrode. The use of CNT network support for light collecting semiconductor particles by assisting the electron movement to the collecting electrode [10].

If CNTS is attached in Cdse and CdTe that can induce charge transfer process under visible light irradiation. Enhancement of interconnection between the titanium dioxide particles and MWCNTs in the porous titanium dioxide film can be the cause for the improvement in short circuit current density.

VII. COST MINIMIZATION BY NANOTECHNOLOGY

To reduce installation cost in solar cell that can achieved by creating flexible rolls temperature vaccum deposition process and reduced manufacturing costs as a result instead of crystalline panels. Nanotechnology might be able to increase the efficiency of solar cells, but that assuring in reduction of manufacturing cost.

The Fig.11 shows the solar cell, which utilizes nanorods to convert light into electricity. These new type of plastic solar cells use tiny nanorods dispersed within in a polymer.

The nanorods behave as wires because when they absorb light of a specific wave-length they generate electrons. These electrons flow through the nanorods until they reach the aluminium electrode where they are combined to form a current and are used as electricity.

Fig.11 Solar cell utilizes nanorods to convert light into electricity [1]

These types of cells are lower in cost to manufacture than the conventional one because these are not made from silicon which can be expensive. In another way, manufacturing of these cells does not require expensive components. The other main feature of these cells is that the nanorods can be tuned to absorb the different wave-lenghts of light. This process increases the efficiency of the solar cell because of large amount of incident light can be utilized. A theoretical comparison of different photovoltaic cells is given in Table.I.

TABLE.I THEORETICAL COMPARISON OF DIFFERENT PHOTOVOLTAIC CELL EFFICIENCY

Description	CdTe	CIGS	a-Si	Multijunction
	Semiconductor is deposited directly on glass			
Efficiency (Production)	10%	12%	7%	36%

PV including amorphous silicon, cadmium telluride (CdTe),copper indium deselenide (CIS) and copper indium gallium deselenide materials (CIGS). These thin film material could offer substantial PV devices price reductions costs.

VIII. CONCLUSION

Solar energy conversion technology can be enhanced by implementing nano scale materials such as quantum dots, multilayer of ultrathin nanocrystalline materials and the availability of sufficient quantities of raw materials. The efficiency of solar cells should be improved without any compromise on the processing cost of these devices is the main objective. Nanotechnology assists with the films gives a promise in enhancing the efficiency of solar energy conservation and also reducing the manufacturing cost. The efficiency can be improved by increasing the absorption efficiency of the light. The different technologies of solar cell with the application of nanotechnology are mainly focused on cost reduction. By these new trends in the developments of solar cells, the solar energy will reach a greater stage and that has to be properly channelized to meet the energy demand.

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