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A review: Solar cell current scenario and future trends

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Abstract
In recent years solar cell technology has achieved tremendous growth as sustainable source of energy. In last few years photovoltaic industries have emerged with an annual growth of 40%.Solar cells are renewable pollution free source of electrical energy which can easily replace traditional fossil fuels. In this article we have reviewed the previous and current status of various generations of solar cells and discussed about their future trends and aspects.

Keywords: Solar cell current scenario, cell technology, energy

INTRODUCTION

Solar energy is the most promising source of energy of modern era. It has a biggest advantage over the conventional power generation systems that the sunlight can be directly converted into solar energy with the help of solar cells. This type of electrical energy production methods is cost effective, generates no toxic materials, and follows green approach [1]. The modern photovoltaic technology follow the principle that, each cell consists of two different layers of semiconducting materials i.e. p type material and n type material. When photon of appropriate energy strikes this combination of materials an electron by acquiring energy from photon moves from one layer to another and consequently generates electricity. Modern technologies are using this phenomenon for production of solar cells but less efficiency and high cost are major setback for them.

In previous many years silicon wafer has been the prominent material used for fabrication of solar cells but due to high cost and low efficiency it has gradually lost the interest of researchers, now days thin film solar cell technology has completely replaced the silicon wafer technology. The present article focuses on importance of multi junction solar cell, in which combination of semiconductor materials which captures a large range of photon energies [2-6].

At first current solar cell design and performance will be presented and future design improvements will be suggested such as optimization of existing triple junction design, increasing number of junctions in solar cell, or quantum dot incorporation into the layers. Finally the conclusion will be given on high efficiency and cost effectiveness of multi junction solar cells.

Various kinds of solar cells and current technological trends

Over the past half century crystalline silicon solar cells were used widely but various types of cells have been developed, which are more efficient and cost effective. The efficiency of various important cells has been given in the table 1 given below

Table1. Best efficiencies reported for different types of solar cells.

Solar cell type	Efficiency	Laboratory/Institution
Crystalline Si	24.7	University of New south Wales
Multi Crystalline Si	20.3	Fraunhofer institute of solar energy system
Amorphous Si	10.1	Kaneka
HIT cell	23	Sanyo Corporation
GaAs cell	26.1	Radboud University Nijmegen
InP Cell	21.9	Spire Corporation
Multi junction cell	40.8	National Renewable Energy Laboratory
CdTe	16.5	National Renewable Energy Laboratory
CIGS	19.9	National Renewable Energy Laboratory
$CuInS_2$	12.5	Hahn Meitner Institute
DSSC	11.1	Sharp
Organic solar cell	6.1	Gwangju Institute of Science and Technology

In the above table, we have listed different types of solar cell technologies which are currently in use along with some new concepts which are yet to be made practical. For convenience they are grouped as silicon based cells, cells based on compound semiconductors, dye sensitized cells, organic/polymer solar cells and some new concepts.

Another mode of classification of solar cells is based on their generation. First generation solar cells are silicon based photovoltaic cells which still owns 86% of solar cell market. Even though they have high manufacturing cost but they have high efficiency.

Second generation solar cells thin film solar cells which are cost effective than first generation silicon solar cells but they have lower efficiency. The advantage of this generation solar cells is their flexibility i.e. they are very light weight and can be used for various applications such as solar panel. Various materials used for second generation solar cells are copper indium gallium selenide, Cadmium telluride (CdTe), amorphous silicon and micro amorphous silicon.

The third generation solar cells include non semiconducting technologies like quantum dot technology tandem/multi junction cells, hot-carrier cells, up conversion and down conversion technologies, and solar thermal technologies.[7]

Organic solar Cell

In 1985 first time Ching Tang demonstrated a fully organic cell prepared by perylene pigment combined with Copper phthalocyanine (CuPc) with an efficiency of 1% [8]. In mid 1990s Messiner obtained another organic solar cell prepared by cell structure with C-60 doped ZnPc layer with efficiency exceeding 1% [9].The conversion of solar energy in to electrical energy is more effective in hetero junction based on conjugated polymer/C-60, so using these materials first PV devices based on MEPPV and C-60 were fabricated and investigated [10-13]. Recently Alan Heeger and Kwanghee lee and colleagues have developed tandem organic solar cell based on polymer-fullerene composite with energy efficiency of 6.5% [14].

Mesoscopic Cells or Dye sensitized cells (DSCs)

In early 1990s Michel Gratzel and coworkers form Swiss federal institute of technology designed mesoscopic cell or nanocrystalline dye sensitized solar cell using interpenetrating network of nanoscale titanium dioxide (TiO2) covered with monolayer of sensitizing dye molecules with efficiency of 12% [15-16]. The limitization of DSCs is poor optical absorption characteristics in near infrared region. Present sensitizers' posses' poor optical absorption resulting in low conversion efficiency.

Tandem nanocrystalline dye sensitized solar cell

The tandem nanocrystalline dye sensitized solar cell construction is based on several different layer of dye with comparatively narrow absorption bands. Latest development in this field is PV tandem cell comprising a nanocrystalline DSC at top cell for high energy photons CIGS cell for low energy photons could reach 15% energy conversion efficiency [17].

Fabrication of present day multi junction 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 molecular organic chemical vapor deposition (MOCVD) [18-19] . The present day multi junction solar cell is fabricated by GaInP, GaAs, layers on Ge substrate .Such triple junction solar cell usually contains about 20 layers. A photon of wavelength less than 650 nm and passes through GaInP and GaAs layers is not captured efficiently, so large amount of spectrum is absorbed by Ge layer which results in difference between potential of top two layers and bottom two layers of about 0.3 eV [20].

Future design improvements

Existing layer's design optimization

Since disordered GaInP has higher band gap as compared to ordered GaInP (1.88 eV vs. 1.78 eV), so the disordered material has been used as the top layer in the triple junction cell for improving its efficiency [21-22].Moreover if the top layer of GaInP is thickened current production will increase and overall multi junction cell would generate higher matched current and thus more power. If GaS (band gap 1.25 eV) is layered instead of GaInP then it would collect large current and will reduce the amount of photon transferring to the Ge layer and thus increasing the efficiency [21, 23]

Increasing number of junction

Another most promising design improvement is increasing number of junctions in solar cells. Four junction cells has already been reported with band gap of 1.0 eV [18], for this purpose GaInNAs has been mostly studied and it can be grown with matching lattice. But even four junction cells are not able to improve efficiency than three junction solar cells. Five and six junctions cells are designed to partitioned the solar spectrum in to narrower wavelength ranges than triple junction cells which allows sub cells to better current matched to the lower current sub cell [18,21,24].

Inclusion of semiconductor nanostructures

In recent years it has been experienced and experimentally verified that many nanostructures such as quantum dots, nano wires, nano tubes, nanorods, super lattice, and quantum wires can improve photovoltaic efficiency by tailoring the properties of previously used materials and can reduce cost due to their self- assemblance property [25-34].

Quantum dots InAs of size 5nm, 10nm, 12nm have band gaps of 1.071 eV, 0.553eV, 0.045eV respectively [35]. The quantized states can act as intermediate states for better absorption of photons in solar cells and mixture of quantum dots of various sizes can be used for harvesting maximum proportion of incident light. Theoretically a single QD intermediate band can improve efficiency up to 63.2 % of ordinary cell and can improve the conversion efficiency up to 31 % for single junction device [28].

CONCLUSION

At present most solar cells are fabricated using III-V group compounds and II-VI group compounds with widening band gaps. Currently available photovoltaic devices are triple junction solar cells with GaInP, GaAs, and Ge layers which give conversion efficiency of about 30 % which is less than half of the efficiency maximum theoretical efficiency of 86.6% [36]. In current work it has been presented that the current design of multi junction photovoltaic can be improved by design optimization of existing layers, by increasing number of junctions in structure of present solar cell, by inclusion of nanostructures which can improve conversion efficiency by tailoring the properties of existing materials. New approaches and concepts of nanotechnology may also improve the multiple junction devices by controlling the growth, band structures and defects. Currently solar energy is expensive source of energy but with use of multi junction high efficiency solar cells with innovative concepts can accelerate the field of photovoltaic.

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