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Advances in Solar Cell Technology: An Overview

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Abstract: **Progress in the field of solar cell technology starting with first generation and second generation solar cells is discussed here by considering different materials on which these technologies are based. The efficiencies attained with different new age solar cell technologies, limitations in their commercial application have been summarized. This paper is an overview of the advances in solar cell technology and comparison of the performance of different types of solar cells.**

Index Terms: **efficiency of solar cell, perovskite solar cell, quantum dot solar cell, solar cell technology, solar photovoltaics**

I. Introduction

Along with food, clothes and shelter, energy is also basic need of new age man. After industrial revolution the need for energy in various fields went on increasing. Rather, the mechanization and industrialization in Europe and America were geared up with the invention of steam power and electrical power. Conventional energy sources based on fossil fuels are extensively used for years all over the world which has led to better quality of life, but it has also created harmful effects on the environment. The fossil fuel resources are fast depleting and the need for alternative energy sources is recognized by all developed as well as developing countries.

Apart from sources of energy based on fossil fuels there are sources based on water power, nuclear energy, wind energy, tidal energy, geothermal energy, solar energy and biomass which are contributing for electric power generation for commercial and non-commercial purposes.

Solar energy is inexhaustible, environmentally clean, free and available in adequate quantities in almost all habitable parts of the world. Main problems encountered in its application are large collecting areas required and variation in the availability of the energy with time; so collection and storage of solar energy requires large initial investments.

The solar energy is utilized in two ways 1) photothermal and 2) photovoltaic. In first case the heat from solar radiation is either directly used for applications such as drying, water heating, space heating etc. or is converted into electricity. In photovoltaic conversion, the devices called as solar cells directly convert the solar radiation falling on them into electricity. Increasing the efficiency of solar cells and limiting the production cost is the key factors on which most of the research in this area are based upon.

II. Different Solar Cell Technologies and Other Efficiencies

Solar cell technologies can be broadly divided as 1) solar cells based on Silicon 2) thin film solar cells 3) multijunction solar cells and 4) next generation solar cells.

Theoretical maximum solar cell efficiency value for homojunction cells can be about 29% (Sukhatme, S. P. & Nayak, J. K., 2018) assuming incident global radiation to be AM1.5 under a clear sky ($1000 W/m^2$) and with band gap energy in the range 1.1eV to 1.7eV. Many semiconductors like Si, GaAs, CdTe have band gap in this range. However, even with sustained research and development the highest reported values (2) from laboratories for solar cells and PV modules can barely reach the maximum theoretical values.

The efficiency values (Green, M.A. *et al*, 2016; Sukhatme, S. P. & Nayak, J. K., 2018) attained in laboratory with some first generation and second generation solar cells are listed in Table I for comparison purpose.

A. Crystalline Silicon Solar Cells

Both single crystal and multicrystalline, are widely popular because silicon is abundant and non-toxic. With increasing production of solar PV cells and with need to reduce their cost, multicrystalline Silicon is used for commercial modules, though its efficiency is lower.

Due to high cost of making crystalline silicon, thin film cells based on a hydrogenated alloy of amorphous silicon (denoted by a-Si:H) have been commercialized.

B. *Thin Film Solar Cells*

Table I. Efficiency values attained in laboratory with some first generation and second generation solar cells. Measurements under global AM1.5 spectrum (1000 W/m^2) and at cell temperature 25^0 C (Green, M.A. et al , 2016; Sukhatme, S. P. & Nayak,J. K., 2018)

Type of Solar Cell	Area (cm^2)	Efficiency %
Silicon (single crystal)	143.7	25.6
Silicon (multicrystalline)	242.74	21.3
Silicon (amorphous)	1.001	10.2
Gallium arsenide GaAs (multicrystalline)	4.011	18.4
Thin Film:		
Cadmium telluride CdTe	1.0623	21.0
Copper indium gallium diselenide CIGS	0.9927	21.0
Gallium arsenide GaAs	0.9927	28.8

Technology has helped to reduce the cost as compared to Silicon wafer based technology due to less material requirement. Other advantages of thin film modules are, they can be made in large sizes and can be mounted on curved surfaces with use of suitable substrates. However, the efficiencies of thin film solar cells are lower as compared to wafer based cells.

C. *Multijunction Solar Cells*

Based on amorphous silicon as well as compound semiconductors from group III and V elements of periodic table have shown greatly improved efficiencies. However, their manufacturing is expensive. An efficiency of 40.7% has been reported (King, R. R. *et al*., 2007) for a three-junction GaInP⁄ GaInAs⁄ Ge cell under the standard spectrum for terrestrial concentrator solar cells at 240 suns (24.0W/cm^2, AM1.5D, low aerosol optical depth, 25°C). Multijunction cells based on III-V compounds are primarily used with solar concentrators, mainly providing power in space applications.

Gallium arsenide (GaAs) is a compound semiconductor which has replaced silicon in many applications due to high efficiency. GaAs solar cells have been made in various forms: thin film, single crystal, multicrystalline and multijunction. The thin film GaAs single junction solar cells have shown efficiency of 28.8% in laboratory and multicrystalline GaAs solar cells have shown 18.4 %. Thin film GaAs solar cell modules have shown 24.1% efficiency in laboratory (Green, M.A. *et al*, 2016). Multijunction solar cells with GaAs have shown efficiency of 31.6 % (Green, M.A. *et al*, 2016). Other advantages of GaAs are: its bandgap 1.42eV is close to ideal value for PV applications, its high performance in high temperature environment and better resistance to radiation. All these characteristics make it suitable for use in space applications and solar concentrators (Sukhatme, S. P. & Nayak,J. K. ,2018).

D. *The Next Generation Solar Cells*

The next generation solar cells include: Perovskite solar cells, organic solar cells, dye sensitized solar cells, kesterite solar cells and quantum dot solar cells.

1) *Pervoskites*

Perovskites are a group of compounds having crystal structure similar to a mineral called perovskite which is composed of calcium titanate (CaTiO3). Perovskite solar cells are based on organometallic halides. They have been recently reported with efficiency 25.5 % in single-junction architectures and 29.1% in silicon-based tandem cells (https://www.nrel.gov/pv/cell-efficiency.html). Perovskite solar cells are the fastest-advancing solar technology with the potential of achieving even higher efficiencies at low production costs. However, the commercialization of this technology faces certain issues, like stability against moisture and oxygen (Bryant, D. et al , 2016; Chun-Ren Ke, J., et al, 2017), heating under applied voltage (Yuan, Y., et al, 2016), photo-unstability (Juarez-Perez, Emilio J. et al, 2019) , mechanical fragility (Rolston, N., et al, 2016) and environmental concerns due to toxicity of lead halides used in perovskite solar cells.

2) *Organic Solar Cell*

Organic solar cell or plastic solar cell is thin film cells which use organic semiconductors. The advantages of this type of cell are: they are inexpensive, flexible, light weight and involve solution based processing. But these cells suffer from low efficiency. Various architectures and different materials have been tried with organic solar cells. Recently efficiency for organic photovoltaics of 17.3% was reached via tandem structure (Chen, Y., et al, 2018).

3) *Dye Sensitised Solar Cells (DSSC)*

Dye sensitised solar cells (DSSC) or Gratzel cells are photoelectrochemical cells. The cell consists of photoanode, sensitizer, electrolyte and counter electrode. The sensitizer can be an organic dye, inorganic dye or metal-organic dye. The DSSC has attracted the attention mainly because it is simple to make using conventional roll-printing techniques and most of the materials used are low-cost. Conversion efficiencies of over 11% and 15% have been obtained with single junction and tandem cells, respectively, in the laboratory (Nazeeruddin Md. K., et al, 2011).

4) *Kesterite Solar Cells*

Kesterite solar cells are based on two synthetic compounds copper zinc tin sulphide (Cu2ZnSnS4) (CZTS) and copper zinc tin selenide (Cu2ZnSnSe4) (CZTSe). The optical and electronic properties of CZTS and CZTSe are similar to CdTe and CIGS. However, the advantage with CZTS and CZTSe is they do not contain toxic or rare earth elements like cadmium and indium respectively. Efficiency of 7.6% has been reported with CZTS cell and 9.8% CZTSe cell (Green, M.A., et al, 2016). Some loss mechanisms limiting the performance of these cells are dominant interface recombination, high series resistance and low minority carrier lifetime (Mitzi, D. B. et al, 2011).

5) Quantum Dots

Quantum dots are a special class of semiconductors, which are nanocrystals, composed of periodic groups of II-VI, III-V or IV-VI materials. Quantum dot solar cells (QD) are structures with tunable bandgap to match the spectral distribution of solar spectrum, which reduces cost/ watt ratio of solar electricity. QDs offer the advantages like: they can be moulded into a variety of different types, in two-dimensional (sheets) or three-dimensional arrays; they can be processed to create junctions on inexpensive substrates such as plastics, glass or metal sheets; they can easily be combined with organic polymers and dyes (Jesim, K. E., 2015). Recently scientists at the University of Queensland achieved 16.6% efficiency by synthesizing a quantum dot solar cell from a halide perovskite (Hao, M., et al, 2020). U.S. National Renewable Energy Laboratory (NREL) set the previous record for quantum dot cell efficiency in 2017 at 13.4%, working with a similar lead halide perovskite (Sanehira, E. M. et al, 2017).

III. Future Trends

Continuous research and development in the field of solar photovoltaics is providing innovative materials to harvest maximum solar energy. Not only the materials but design of the products also plays important role in commercial application of the technology. Many interesting applications have been realised and some are expected in near future like : floating solar farms, where photovoltaic panels floating on reservoirs, dams and other water bodies save on large land area occupied by solar panels (Choi, Y. K., et al, 2016) ; building integrated photovoltaics (BIPV) blend into building architecture in the form of roofs, canopies; photovoltaic glasses act as energy generating device as well as allow natural light inside houses and offices (Biyik,E. et al, 2017; Norton, B. et al, 2011); anti-solar panels working exactly opposite to conventional solar panels i.e. by using heat radiated from earth's surface so that energy can be generated around the clock (Deppe, T. & Munday, J. N., 2020) and perhaps the most promising would be solar paint with quantum dot solar cells and perovskite solar cells (Abbas, M. A. et al , 2017; Bishop, J. E. et al 2020; Park, S. H. et al 2020).

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