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Analysis of solar cell current scenario and future trends

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Abstract
The development is basically hindered by the cost and efficiency. In order to choose the right solar cell for a specific geographic location, we are required to understand fundamental mechanisms and functions of several solar technologies that are widely studied. In this paper, I have reviewed a progressive development in the solar cell research from one generation to other, and discussed about their future trends and aspects.

Keywords: Analysis, solar, cell current, trends

Introduction
The major benefit of solar energy over other conventional power generators is that the sunlight can be directly harvested into solar energy with the use of small and tiny photovoltaic (PV) solar cells [1–3]. The Sun is assumed as a big spherical gaseous cloud made up of hydrogen and helium atoms. This big spherical gaseous cloud is mainly composed of several hydrogen nu lei combining to form helium energy with the emission of energy from the fusion of the hydrogen nuclei in inner core of the Sun via nuclear fusion as shown in Figure 1.

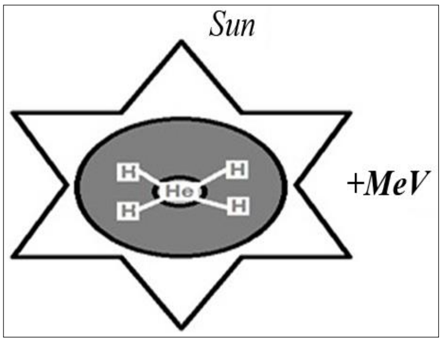

Fig 1: Nuclear fusion reaction: source of solar energy

$${}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n + 3.27Mev$$

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$${}_1^2H + {}_1^3H \rightarrow {}_2^4He + {}_0^1n + 17.59Mev \quad (2)$$

During this process of fusion, four hydrogen atoms combine to form one helium atom with a loss of mass which is radiated as thermal energy [4].

There have been an enormous amount of research activities to harvest the Sun’s energy effectively by developing solar cells/panels with high conversion efficiencies. The photovoltaic conversion efficiency is referred to the efficiency of solar PV modules, and is defined as the fraction of Sun’s energy that can be converted into electricity.

Solar panels are a huge collection of tiny solar cells arranged in a definite geometrical shape to produce a given amount of power supply. The storage of solar power is still has not been achieved successfully. Currently the radiation efficiency of solar panel is up to 22% [5]. There are many solar photovoltaic batteries available which are usually more expensive and bulky. These are more suitable for small scale or household solar needs compared to large solar plants [6, 7].

First generation solar cell

As it is already mentioned, the first generation solar cells are produced on silicon wafers. It is the oldest and the most popular technology due to high power efficiencies. The silicon wafer based technology is further categorized into two subgroups named as [8, 9, 10].

- Single/ Mono-crystalline silicon solar cell.
- Poly/Multi-crystalline silicon solar cell.

Single/mono-crystalline silicon solar cell

Mono crystalline solar cell, as the name indicates, is manufactured from single crystals of silicon by a process called Czochralski process [11]. During the manufacturing process, Si crystals are sliced from the big sized ingots. These large single crystal productions require precise processing as the process of "recrystallizing" the cell is more expensive and multi process. The efficiency of mono-crystalline single-crystalline silicon solar cells lies between 17% - 18% [12].

Polycrystalline silicon solar cell (Poly-Si or Mc-Si)

Polycrystalline PV modules are generally composed of a number of different crystals, coupled to one another in a single cell. The processing of polycrystalline Si solar cells is more economical, which are produced by cooling a graphite mold filled containing molten silicon. Polycrystalline Si solar cells are currently the most popular solar cells. They are believed to occupy most up to 48% of the solar cell production worldwide during 2008 [13]. During solidification of the molten silicon, various crystal structures are formed. Though they are slightly cheaper to fabricate compared to monocrystalline silicon solar panels, yet are less efficient ~12% - 14% [14].

Second generation solar cells

Most of the thin film solar cells and a-Si are second generation solar cells, and are more economical as compared to the first generation silicon wafer solar cells. Silicon-wafer cells have light absorbing layers up to 350µm thick, while thin-film solar cells have a very thin light absorbing layers, generally of the order of 1µm thickness [15]. Thin film solar cells are classified as;

- A-Si.
- CdTe.
- CIGS (copper indium gallium di-selenide).

Amorphous silicon thin film (a-Si) solar cell

Amorphous Si (a-Si) PV modules are the primitive solar cells that are first to be manufactured industrially. Amorphous (a-Si) solar cells can be manufactured at a low processing temperature, thereby permitting the use of various low cost, polymer and other flexible substrates. These substrates require a smaller amount of energy for processing [16]. Therefore, a-Si amorphous solar cell is comparatively cheaper and widely available. The "amorphous" word with respect to solar cell means that the comprising silicon material of the cell lacks a definite arrangement of atoms in the lattice, non-crystalline structure, or not highly structured. These are fabricated by coating the doped silicon material to the backside of the substrate/glass plate. These solar cells generally are dark brown in color on the reflecting side while silverish on the conducting side [17].

The mainissue of a-Si solar cell is the poor and almost unstable efficiency. The cell efficiency automatically falls at PV module level. Currently, the efficiencies of commercial PV modules vary in the range of 4% - 8%. They can be easily operated at elevated temperatures, and are suitable for the changing climatic conditions where sun shines for few hours [18].

Cadmium telluride (CdTe) thin film solar cell

Among thin-film solar cells, cadmium telluride (CdTe) is one of the leading candidate for the development of cheaper, economically viable photovoltaic (PV) devices, and it is also the first PV technology at a low cost. CdTe has a band gap of ~1.5 eV as well as high optical absorption coefficient and chemical stability. These properties make CdTe most attractive material for designing of thin-film solar cells.

Copper indium gallium di-selenide (CIGS) solar cells

CIGS is a quaternary compound semiconductor comprising of the four elements, namely: Copper, Indium, Gallium and Selenium. CIGS are also direct band gap type semiconductors. Compared to the CdTe thin film solar cell, CIGS hold a higher efficiency ~10% - 12%. Due to their significantly high efficiency and economy, CIGS based solar cell technology forms one of the most likely thin film technologies.

Nano crystal based solar cells

Nanocrystal based solar cells are generally also known as Quantum dots (QD) solar cells. These solar cells are composed of a semiconductor, generally from transition metal groups which are in the size of nanocrystal range made of semiconducting materials. QD is just a name of the crystal size ranging typically within a few nanometers in size, for example, materials like porous Si or porous TiO_2, which are frequently used in QD. The structure of the QD solar cells are shown in Figure 2.

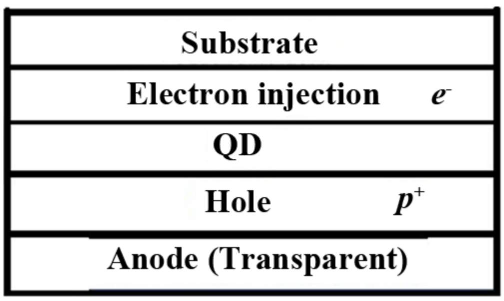

Fig 2: A schematic of Quantum dot (QD) layer

With the advance of nanotechnology, these nanocrystals of semiconducting material are targeted to replace the semiconducting material in bulk state such as Si, CdTe or CIGS. This idea of the QD based solar cell with a theoretical formulation were employed for the design of a p-i-n solar cell over the self-organized in As/Ga As system. Generally, the nanocrystals are mixed into a bath and coated onto the Si substrate. These crystals rotate very fast and flow away due to the centrifugal force. In conventional compound semiconductor solar cells, generally a photon will excite an electron there by creating one electron-hole pair. However, when a photon strikes a QD made of the similar semiconductor material, numerous electron-hole pairs can be formed, usually 2 or 3, also 7 has been observed in few cases.

Polymer solar cells

Polymer solar cells (PSC) are generally flexible solar cells due to the polymer substrate. The first PSC were invented by the research group of Tang *et al*. at Kodak Research Lab. A PSC is composed of a serially connected thin functional layers coated on a polymer foil or ribbon. It works usually as a combination of donor (polymer) and a acceptor (fullerene). There are various types of materials for the absorption of sunlight, including organic material like a conjugate/conducting polyme. In 2000, Heeger, MacDiarmid, and Shirakawa fetched the Nobel Prize in Chemistry for the discovering a new category of polymer materials known as conducting polymers. The PSC and other organic solar cells operate on same principle known as the photovoltaic effect, i.e., where the transformation of the energy occurs in the form of electromagnetic radiations into electrical current. Yu *et al*. mixedpoly [2-methoxy-5-(2'-ethylhexyloxy)-p-phenylene vinylene] (PPV), C60 and its other derivatives to develop the first polymer solar cell and obtained a high power conversion efficiency. This process triggered the development of a new age in the polymer materials for capturing the solar power.

Dye sensitized solar cells (DSSC)

Recent research has been focused on improving solar efficiency by molecular manipulation, use of nanotechnology for harvesting light energy. The first DSSC solar cell was introduced by Michel Gratzel in Swiss federal institute of technology. DSSCs based solar cells generally employ dye molecules between the different electrodes. The DSSC device consists of four components: semiconductor electrode (n-type TiO_2 and p-type NiO), a dye sensitizer, redox mediator, and a counter electrode (carbon or Pt). The DSSCs attractive due to the simple conventional processing methods like printing techniques, are highly flexible, transparent and low cost as well. The novelty in the DSSC solar cells arise due to the photosensitization of nano grained TiO_2 coatings coupled with the visible optically active dyes, thus increasing the efficiencies greater than 10%. However, there are certain challenges like degradation of dye molecules and hence stability issues. This is due to poor optical absorption of sensitizers which results in poor conversion efficiency. The dye molecules generally degrade after exposure to ultraviolet and infrared radiations leading to a decrease in the lifetime and stability of the cells. Moreover, coating with a barrier layer may also increase the manufacturing more expensive and lower the efficiency.

Perovskite based solar cell

Perovskites are a class of compounds defined by the formula ABX_3 where X represents a halogen such as I−, Br−, Cl−. and A and B are cations of different size. Perovskite solar cells are recent discovery among the solar cell research community and possess several advantages over conventional silicon and thin film based solar cells. Conventional Si based solar cells need expensive, multiple processing steps and require high temperatures (>1000˚C) and vacuums facilities. The perovskites based solar cells can have efficiency up to 31%. It can be predicted that these perovskites may also play an important role in next-generation electric automobiles batteries, according to an interesting investigation recently performed by Volkswagen. However, current issues with perovskite solar cells are their stability and durability. The material degrades over time, and hence a drop in overall efficiency. Therefore more research is needed to bring these cells into the market place.

Advances in Energy Storage

Since the sunlight is not always available, all these businesses of PV solar cells may not work at night and a lot of electricity will go unused. Therefore energy storage is an important factor in solar cell market. A comparison and summary of various types of solar cells is summarized in Table 1.

Table 1: A comparison of various types of solar cells

Cell type	Crystalline silicon		Thin Film			Third Generation				Perovskites
	Monocrystalline	Polycrystalline	CdTe	CIGS	Amorphous Silicon	Nanocrystal	Dye Sensitized	Polymer	Concentrated	
Efficiency	14% - 17.5%	12% - 14%	9% - 11%	10% - 12%	4% - 8%	7% - 8%	≈10%	≈3% - 10%	≈40%	31%
High temperature performance	Not good at high temperatures	Not good at high temperatures	Good in cool as well as high temperature conditions	Good in cool as well as high temperature conditions	Good in cool as well as high temperature conditions	Excellent thermal stability	Not good in high temperature conditions	Not good in high temperature conditions	Excellent thermal stability	Excellent thermal stability
Size	Significantly less volume to produce the same amount of power	Significantly less volume to produce the same amount of power	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a specialized range of product design	Offering a wide range of product design from flexible, light durable
Cost	Two times more expensive compared to thin-film.	Two times more expensive compared to thin-film.	50 percent less expensive than conventional silicon cells	50 percent less expensive than conventional silicon cells	50 percent less expensive than conventional silicon cells	50 percent less expensive than conventional silicon cells	50 percent less expensive than conventional silicon cells	50 percent less expensive than conventional silicon cells	50 percent less expensive than conventional silicon cells	50 percent less Expensive than conventional silicon cells
Additional detail	Oldest PV technology	Economical choice	Toxic due to Cd	Some CIGS have impressive 20% efficiency	Needs long installation time and large space	Needs short installation time and large space	Needs short installation time and large space	Needs short installation time and small space	Needs long installation time and large space	Latest technology. Needs short installation time and minimum space

Several energy storage devices are available in the market but those are highly expensive and a short life span. Recently, in 2014, The world's first solar cell energy storage is introduced by Wu and his co-workers at Ohio State University. This device not only can store energy but can also reduce the costs of renewable energy by 25%, relying on a new aqueous, rechargeable lithium-oxygen battery used in sunlight.

Conclusion

In this paper, the methods of utilizing solar energy are simple, yet need an efficient and durable solar material. Technology based on nano-crystal QD of semiconductors based solar cell can theoretically convert more than sixty percent of the whole solar spectrum into electric power. The polymer base solar cells are also a viable option.

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