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Review Article

Progress Review on Advancement of Solar Cell Nano-technology in Harvesting Clean Energy

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Abstract

Everyday events of a world populace are extremely dependent on energy. Unpaid environmental air pollution of exploration of non-renewable energy, the cosmos is dramatically shifting from consuming non-renewable energy to renewable energy. If properly designed components are used, solar energy is a clean green energy resource that produces effective utilization. That is, the efficiency of generous energy harvesting devices protocol is very essential. The world is unable to custom renewable energy effectively owing to the absence of effective efficient solar energy harvesting devices. Because our intention is focused on effective and more recent nano-particles maze those are used in harvesting solar energy. The reviewer tried to summarize various research works that are conducted on the modifications of solar panels through nano-particles. Accordingly, a large percentage of nano-particle atoms resides on their surfaces than in their interiors. The surface interactions of the particular particle atoms dominate its behavior. They often have different characteristics and properties than larger masses of the same material. The nano-particles incorporated into various solar cell films revealed special promise to both enhance efficiency and lower total cost.

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1. Introduction

Energy plays a key role in the socio-economic, technological, and political development of any nation. Inadequate supply of energy restricts socio-economic activity, limits the expansions of technological advancement like the growth of industries, economic growth and it adversely affects the quality of life. It is widely accepted that there is a strong correlation between socioeconomic development and the energy availability of a given nation. Renewable energy sometimes referred to as "clean" or "green" energy, is a booming novelty that is bringing down energy charges and conveying its promise of a detergent, greener future. Across the world, solar and wind generation are breaking record after a greatest as they slowly start to penetrate national electricity grids without bargaining on electricity. Renewable energy sources are slowly but surely displacing "dirty" energy sources, such as fossil fuels (e.g., coal and oil) in the power segment and offering the benefit of lower emissions and pollution levels (Zippini & Vang, 2020; Zhu et al., 2019).

The major benefit of solar energy over other conventional power generators is that the sunlight can be directly harvested into a solar cell or photovoltaic (PVC). The sun is assumed as a big spherical gaseous cloud made up of hydrogen and helium atoms. During the process of fusion, hydrogen atoms combine to form helium atoms with a loss of mass which is radiated as thermal energy (Daghbouj et al., 2020). The radiant energy produced by fusion reactions is free from any pollutant, gases, or other reaction by-product and also it is the major driving force of all clean energy technology. The photovoltaic conversion efficiency is referred to the efficiency of solar PVC modules and is defined as the fraction of the sun's energy accumulated in the form of chemical energy in the tiny solar cells that can be converted into electricity. Solar panels are also a huge collection of tiny solar cells arranged in a definite geometrical shape to produce a given amount of power supply (Yoon et al., 2015; Zhang et al., 2018).

Owning to the sun is extensively sending out an incredible amount of energy in the form of heat and radiations, the energy conversion desires more powerful and very efficient materials. In this regard, a tremendous amount of research drudgery has been conducted to improve the efficiency of solar panels. This review is encompassing on cost-effective and the progress of the recent research work conducted to improve the productivity of green energy harvesting materials.

2. Results and Discussion

2.1 Solar Cells

The photovoltaic (PV) effect was first observed by Alexandre-Edmond Becquerel in 1839. Subsequently, in 1946 the first modern solar cell made of silicon was invented by Russel Ohl (Yadav & Kumar, 2015). Earlier photovoltaic solar cells are thin silicon wafers that transform sunlight energy into electrical power. The modern photovoltaic technology is based on the principle of electron-hole creation in each cell composed of two different layers (p-type and n-type materials) of semiconductor material, as shown in Figure 1. In this arrangement of the structure, when a photon of sufficient energy impinges on the p-type and n-type junction, an electron is ejected by gaining energy from the striking photon and moves from one layer to another. This creates an electron and a hole in the process and by this process, electrical power is generated (Srinivas *et al.,* 2015).

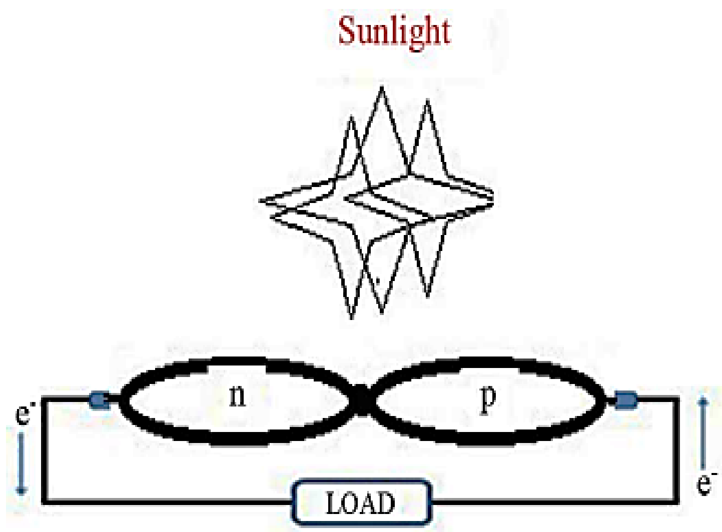

Figure 1: The semiconductor p-n junction solar cell under load (Smith et al., 2018).

The various types of materials applied to manufacture PVC include silicon (single crystal, multi-crystalline, amorphous silicon) (Tripathy *et al.,* 2016), cadmium-telluride copper-indium-gallium-selenide, and copper-indium-gallium-sulfide (Bagher *et al.,* 2015; Srinivas *et al.,* 2015). Depending on these materials, the PVC is categorized into various classes as discussed in the following sections (Figure 2).

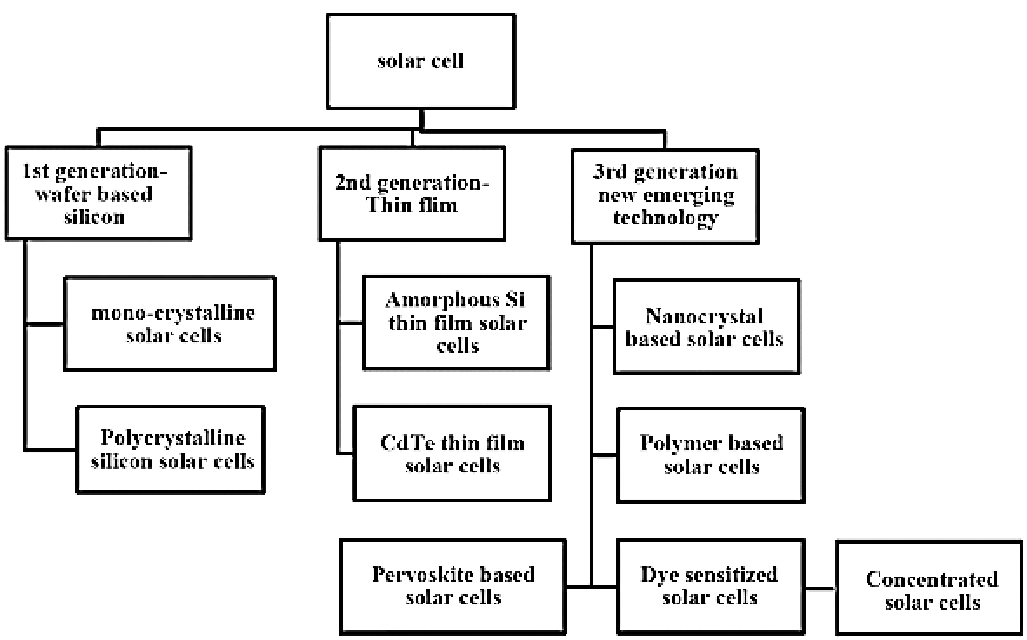

Figure 2: Various types of solar cell technologies and current trends of development (Srinivas et al., 2015)

2.2. First Generation (welfare) solar cells

2.2.1. Single/Mono-Crystalline Silicon Solar Cell

Mono crystalline solar cell is manufactured from single crystals of silicon by a process called Czochralski process. During the process, silicon crystals are sliced from the big-sized ingots. The large single-crystal productions require precise processing as the process of "recrystallizing" the cell is more expensive and multi-process. Rendering to the report of Zhao, *et al*, 2016 and Benick *et al*, 2017 the efficiency of these solar cells lies between 17% - 18%.

2.2.2. Polycrystalline Silicon Solar Cell (Poly-Si or Mc-Si)

Polycrystalline PV modules are generally composed of some 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 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 (Huang *et al.*, 2018). During solidification of the molten silicon, various crystal structures formed. Though they are slightly cheaper to fabricate compared to nanocrystalline silicon solar panels, they are less efficient lies between ~12% - 14% (Maehlum, 2015; Philipps *et al.*, 2015).

2.3 Second Generation (Thin Film Solar Cells)

2.3.1 Amorphous Silicon Thin Film (a-Si)

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. These solar cells generally are dark brown on the reflecting side while silverish on the conducting side. The main issue of a-Si solar cells is their poor and almost unstable efficiency (Ahn *et al.*, 201 5). Bagher *et al.* (2015) report indicate that the efficiency of these PV modules varies in the range of 4% - 8%; they can be easily operated at elevated temperatures, and are suitable for the changing climatic conditions where the sun shines for a few hours.

2.3.2. Cadmium Telluride (CdTe) Thin Film Solar Cell

In this class, cadmium telluride is one of the leading candidates 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 with a high absorption coefficient of 5 × 1015/cm as well as a high optical absorption coefficient and chemical stability (Hendi *et al.*, 2017). Ramos *et al.* (2017) also reports that the CdTe cell is an excellent direct band gap crystalline compound semiconductor which makes the absorption of light easier and improves the efficiency. It is generally constructed by sandwiching between cadmium sulfides layers to form a p-n junction diode. As per the report of Kapadnis *et al.* (2020) the manufacturing process of CdTe cell involves three steps: Firstly, the based solar cells are synthesized from polycrystalline materials, and glass is chosen as a substrate. The second process involves deposition, i.e., the multiple layers of CdTe solar cells are coated on to substrate using different economical methods and its efficiency is range from 9% - 11%. Even though CdTe solar cells can be made easily on polymer substrates and flexible with high efficiency, according to Maani *et al.* (2020) finding's there are various environmental issues with cadmium component solar cells due to cadmium being regarded as heavy metal and potential toxic agent that can accumulate in human bodies, animals and plants.

2.3.3. Copper Indium Gallium Di-Selenide (CIGS)

CIGS is a quaternary compound semiconductor comprising of four elements, namely: Copper, Indium, Gallium, and Selenium. CIGS is also a direct band gap type semiconductor. Compared to the CdTe thin-film solar cell, CIGS holds 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 (Tina, 2015; Ong *et al.*, 2018). Powalla *et al. (*2018), findings demonstrate that the processing of CIGS is done through certain techniques like sputtering, evaporation, electrochemical coating, printing, and electron beam deposition. Besides this, the sputtering can be a two or multi-step process involving deposition and subsequent interaction with selenium later or can be a one-step reactive process. However, evaporation is similar to sputtering in the sense that it can be used in a single step, two-step, or multiple processing steps. The substrates for CIGS material can be chosen from the glass plate, polymers substrates, steel, aluminium, etc. The advantages of CIGS thin-film solar cells include their prolonged life without considerable degradation and enhanced efficiency.

2.4 Third Generation Solar Cells

2.4.1 Nano Crystal Based Solar Cells

Nano crystals 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 nano crystals range made of semiconducting materials. QD is just a name of the crystal size ranging typically within a few manometers 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 is shown in Figure 2. With the advance of nanotechnology, these nano crystals 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 was employed for the design of a p-i-n solar cell over the self-organized in As/GaAs system. Generally the nano crystals 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 thereby creating one electron-hole pair (Lin et al., 2019).

2.4.2 Polymer Solar Cells

Polymer solar cells (PSk8C) are generally flexible solar cells due to the polymer substrate. A PSC is composed of serially connected thin functional layers coated on a polymer foil or ribbon. It works usually as a combination of the donor (polymer) and acceptor (fullerene). There are various types of materials for the absorption of sunlight, including organic material like a conjugate/conducting polymer (Srinivas *et al.,* 2015). The PSC and other organic solar cells operate on the 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. 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 polymer materials for capturing solar power. As indicated in Zhao *et al.* (2016) research work, after significantly optimizing the reactions parameter like temperature the efficiency of the cells achieved over 3.0%. They also concluded that these unique properties of PSCs opened a new gateway for new applications in the formation of stretchable solar devices including textiles and fabrics.

2.4.3 Dye Sensitized Solar Cells (DSSC)

Recent research has been focused on improving solar efficiency by molecular manipulation, the use of nanotechnology for harvesting light energy. DSSCs based solar cells generally employ dye molecules between the different electrodes. The DSSC device consists of four components: a semiconductor electrode (n-type TiO2 and p-type NiO), a dye sensitizer, a redox mediator, and a counter electrode (carbon or Pt) (Suhaimi *et al.*, 2015). The DSSCs are 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 arises due to the photosensitization of nano grained TiO2 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 the 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 manufacturing more expensive and lower the efficiency (Sharma *et al.*, 2018).

2.4.4 Concentrated Solar Cells

As Philipps et al. (2015) and Mohanta et al. (2015) noted, the concentrated photovoltaic (CPV) has been established since the 1970s. It is the newest technology in solar cell research and development. The main principle of this cell is to collect a large amount of solar energy onto a tiny region over the PV solar cell, as shown in Figure 3. The principle of this technology is based on optics, by using large mirrors and lens arrangement to focus sunlight rays onto a small region on the solar cell. The converging of the sunlight radiations thus produces a large amount of heat energy. This heat energy is further driven by a heat engine controlled by a power generator integrated. It can be classified into low, medium, and high concentrated solar cells depending on the power of the lens systems (Mohanta et al., 2015). Concentrating photovoltaic technology has the following merits such as solar cell efficiencies (>40%), absence of any moving parts, no thermal mass, speedy response time, and can be scalable to a range of sizes.

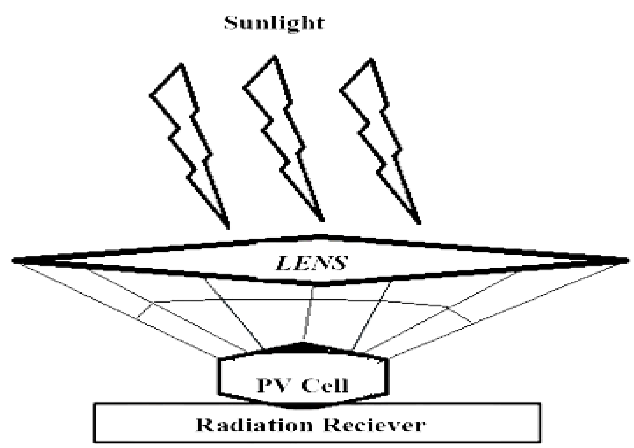

Figure 2. Schematic of concentrated solar cell (Liu *et al.*, 2015)

2.4.5 Perovskite Based Solar Cell

The appearance of perovskite solar cells newly has brought new hope to the solar cell industry due to their unbelievable improvement of the power conversion efficiency

(PCE), which can now exceed 20.0% within seven years of fabulous research. The efficiency and stability of PSCs depend strongly on the morphology and type of materials selected as the electron transport layer (ETL) in the device (Noh et al., 2018). According to the report of Ren et al., 2020, two-dimensional Ruddlesden–Popper phase (2DRP) perovskites are known to exhibit improved photostability and environmental stability compared with their three-dimensional (3D) counterparts. The 3D unambiguously demonstrates that a sulfur–sulfur interaction is present for a new bulky alkylammonium, 2-(methylthio) ethylamine hydrochloride (MTEACl). In addition to a weaker van der Waals interaction, the interaction between sulfur atoms in two MTEA molecules enables an (MTEA)2(MA)4Pb5I16 (n =5) perovskite framework with enhanced charge transport and stabilization. The 2DRP perovskite solar cells significantly improved efficiency and stability. Cells with a power conversion efficiency as high as 18.06% (17.8% certified) are achieved, along with moisture tolerance for up to 1,512 h (under 70% humidity conditions), thermal stability for 375 h (at 85 °C), and stability under continuous light stress (85% of the initial efficiency retained over 1,000 h of operation at the maximum power point).

2.5 Advances in Energy Storages

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. Several energy storage devices are available in the market but those are highly expensive and a short life span. Recently Harvard University researchers developed a new type of battery based on organic molecules called Quinone. It is found in plants and is economical in a sense that it can store sunlight energy for a couple of days (Bagher et al., 2015).

3. Conclusion and Recommendation

The nano materials are promising for the future growth and developments of solar cell technologies. The unsocial and the most arduous to generate electricity from a renewable source is solar radiation is mostly enhanced through these materials. Besides this, the nanoparticle materials have also several advantages like being friendly to the environment compared to other customs of energy like fossils fuels and petroleum deposits. It is an alternative that is promising and consistent to meet the high energy demand. Though the methods of utilizing solar energy are simple, but yet desire more efficient and very durable solar panels. Technology-based on nano-crystal quantum dot (QD) of semiconductors and perovskite-based solar cells can theoretically convert more percent of the whole sun radiations spectrum into electric power. Conversely, perovskite solar cells have stripy on the disputes of the stability and durability, that is, the material degrades over time, and hence a drop in overall efficiency. Therefore more research work should be conducted to bring these cells into the market. Polymer-based solar cells are also a viable option. However, their degradation over time is a serious concern. There are various challenges for this industry, including lowering the cost of production, public awareness, and best infrastructure. Perovskite solar cells are attracting more attention in solar cell industry technology due to their credible amount of power conversion efficiency, long duration time, photo-stability, and environmental friend.

Declarations

Conflict of interest, author declares that there is no competing interest.

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