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A review of the emerging technologies in solar cells: Dye-sensitized solar cells and quantum dot-sensitized solar cells

Yuantai Chiang

Shanghai World Foreign Language Academy, Shanghai, 200233, China

yuantaijiang_2024@stu.swfla.org

Abstract. In the current energy crisis, more efficient and clean energy sources are needed to help move the primary energy source away from fossil fuels. Fossil fuels are one of the main contributors to greenhouse gas emissions and are shown to be unsustainable. Efforts have been made in many fields surrounding renewable energy sources, with wind power, hydropower, and nuclear power being the well-known ones. Solar power is another field that has shown tremendous promise in being a clean, renewable energy source. Dye-sensitized solar cells(DSSCs) and quantum dot-sensitized solar cells(QDSSCs) have significantly advanced over the past 30 years. They are showing great potential as the production cost for DSSCs drops and the efficiency of QDSSCs rises with every passing year. This article shows the primary working mechanism of the two solar cells, compares them, and discusses their prospect of them.

Keywords: Solar Cells, Dye-sensitized Solar Cells, Quantum dot-sensitized solar cells, stability of solar cells

1. Introduction

Currently, most of the world still relies on fossil fuels for energy generation. Fossil fuels are finite. They replenish at a prolonged speed and are not renewable. Moreover, as fossil fuels are significant sources of greenhouse emissions, we face the challenge of moving away from fossil fuels. The task is not to be underestimated, as the current energy generation system is essentially built around the consumption of fossil fuels. A transition to using renewable energy has to be done with haste. Renewable energy is energy replaced at a greater rate than the consumption rate and can be treated as a relatively infinite energy source.

There are a lot of renewable energy sources. The most widely known ones are wind, solar, hydro, tidal, biomass, and geothermal. This article places its focus on solar energy. The sun is the most prominent source of energy that comes to mind. The sun gives off approximately 173000 TW of energy annually [1]. Solar power is the act of converting the sun's power into energy that can be better utilized. This can be achieved using solar cells. Solar cells use the photovoltaic effect and convert the sun's power into electricity. The emerging solar cell technology gave way to all kinds of solar cells with varying efficiency, lifespan, and cost of production. This article will discuss two specific types of solar cells: dye-sensitized solar cells (DSSCs) and quantum dot-sensitized solar cells (QDSSCs).

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2. Dye-sensitized Solar Cells

Dye-sensitized solar cells (DSSCs) are thin film solar cells invented in 1988 by Michael Grätzel and Brian O'Regan. As the name would imply, the solar cell takes advantage of the property of the sun-sensitized dye to generate electricity. It was discovered in the 1960s that when certain dyes are illuminated when connecting to oxide electrodes, electricity can be generated [2]. Based on this process came the invention of the first DSSC. Michael Grätzel was later awarded the 2010 Millennium Technology Prize for his invention of DSSC. DSSCs are known for their low manufacturing cost and are the focus of much research.

The dye-sensitized solar cells consist of a mesoporous oxide layer [3]. The layer is made up of nanometer-sized particles. These particles are typically TiO2, though other wide-band gap oxides are sometimes also used. These particles are heated but not to the point of liquidation. Instead, the particles fuse. Doing so allows the layer to conduct electricity—a monolayer of charge transfer dye. The two layers are enclosed in an organic electrolyte by two slaps of fluorine-doped tin oxide (TPO) glass, which acts as transparent electrodes. When the dye is exposed to sunlight, the photon hits the dye. The dye then becomes excited, and the electron from the dye moves into the TiO2.

Moreover, since the TiO2 layer is connected to a circuit via the electrodes, the electrons will follow the circuit and generate an electric current. Afterward, the electrons move back into the electrolyte, and the electrolyte donates them back into the dye, restoring the dye to its original state with no permanent damage. The process is then repeated.

The most important trait that the DSSCs possess is their low production cost, ease of processing, and flexibility. The current price of DSSCs is not ideal as it is much higher than the cost of energy production via fossil fuel [4]. However, the price of DSSCs is still subject to change as the cost of production will drop with higher production [5]. Therefore, the current price of DSSCs should not be seen as a significant concern. The cost of DSSCs comes mainly from their dyes. The dyes approximately account for 50-60% of the total production cost of DSSCs. As more dye options are invented, the price may be lowered. For example, betanin is sometimes used as the dye, and it has proven to drive down the production cost as betanin is considered a natural dye and is in abundance [6]. Natural dyes refer to the dyes that are made from plants. Though the current non-natural ruthenium-based dyes have shown great promise in their performance in tests, their staggering cost of them is not desirable [7]. The environmental impact of DSSCs, too, must be taken into consideration. Energy payback time (EPBT) is the time needed for an energy system to produce the energy needed to make the system. A lower EPBT is preferred as the energy would pay back its production cost quickly. The current EPBT for DSSCs can be further improved by changing the FTO glass with polyethylene terephthalate [8]. Furthermore, because of DSSCs' already low energy demand during production, EPBT can be lowered to 0.73 years.

One of the factors judging solar cells is their power conversion efficiency. The power conversion efficiency should be higher. A higher power conversion efficiency can effectively lower the EPBT of DSSCs. Researchers worldwide have been working on ways to optimize DSSCs' power conversion efficiency. For example, the distance of the dye's pigment molecules to the dye skeleton and the mesoporous oxide layer's surface can affect the DSSCs' performance. A shorter distance could be conducive to electron transfer. This then results in the power conversion efficiency of DSSC being higher [9].

Another factor to be taken into consideration is their stability. DSSCs can be very fragile. They are susceptible to any changes in their environment. For example, temperature and humidity can drastically decrease the output of DSSCs, rendering them incredibly ineffective when placed in extreme environments. This limits the usefulness of DSSCs. For DSSCs to be practical, the stability of DSSCs must be improved upon. There are currently multiple studies on optimizing the stability of DSSCs. The study has shown that making I- ions the electron donors to the dye cations can increase the stability of DSSCs [10]. The choice of dye is also crucial to the stability of the DSSCs. More specifically, if pigments found in dyes have a structure with more extended R groups, it can lead to the binding of pigment molecules with mesoporous oxide layers, thereby improving stability [11]. That said, in many cases, the source of the solar cells' degradation comes from the solar cells themselves. Due to the high energy difference within the solar cells, the electrodes are degraded by the electrolyte itself [12].

DSSCs can be modified to be flexible. The only component limiting cells' flexibility is the FTO glass electrode. Replacing the FTO glass electrodes with transparent conductive plastic film can rid the DSSCs of their rigidness [13]. They are allowing DSSCs to be employed in more portable power sources. However, this newfound flexibility comes at a cost to the DSSCs as the flexible dye-sensitized solar cells (FDSSCs) suffer from reduced conversion efficiency and tend to be less stable than the DSSCs made of FTO glass. Even so, the FDSSCs prove to be helpful and hold great potential.

3. Quantum Dot-sensitized Solar Cells

Quantum dot-sensitized solar cells (QDSSCs) were originally an offshoot of DSSCs. However, as QDSSCs utilize quantum dots, QDSSCs have a larger surface area. This increase in surface area makes the QDSSCs more conducive to light absorption. This leads to QDSSCs having a greater power conversion efficiency in theory [14]. The typical QDSSCs consist of three parts: a photoanode, a counter electrode, and an electrolyte. The idea was to use quantum dots in place of the dye in DSSC so that the bandgap could be tuned, granting manufacturers a wider variety of materials to use in making the cells. This causes the potential conversion efficiency of QDSSCs to be greater than that of DSSCs. However, the stability of QDSSCs still needs improvement as QDSSCs are not as stable as other types of solar cells.

Quantum dots (QDs) are semiconducting nanocrystalline materials [15]. When illuminated, quantum dots send an electron from the valance band to the conductance band. The gap between these two sets of energy levels is referred to as bandgap. The bandgap depends on the size of the quantum dots. This means that researchers can control the bandgap size in the QDSSCs by changing the quantum dots size. Moreover, since a higher energy level is not favorable, the electron sent to the conductance band will return to the valance band and release the difference in energy between the two bands. This is the primary process in the production of energy using QDSSCs.

The most significant barrier limiting QDSSCs is that QDSSCs are very unstable. Like their predecessor DSSCs, QDSSCs also suffer from low stability. At the very beginning, QDSSCs were using the standard electrolyte of the standard configuration of the DSSCs, which was an electrolyte using iodine/iodide redox couple [17]. However, the semiconductor QDs are unstable in the iodine/iodide electrolyte, resulting in a redesign of the QDSSCs' structure [18]. The two solar cells should be treated differently to account for their design differences. Studies have shown that polysulfide redox can make semiconductors in electrolyte stable for longer [19]. However, liquid electrolyte is not the only one showing great potential; salt-based solid-state electrolytes like benzimidazolium salt have also shown excellent stability. Moreover, the solid-state electrolyte even showed a power conversion efficiency of 4.26% [20]. While stability is improving, QDSSCs still need to be more stable.

The efficiency of QDSSCs has seen significant improvement, with the power conversion efficiency increasing from a neglectable 1.35% [21] to an impressive 18.1% [22].

This increase in power conversion efficiency can be attributed to many factors—for example, the advancement made in the recombination of semiconductor nanoparticles. The future of QDSSCs holds great potential, with their efficiency moving more towards the theoretical power conversion efficiency of 40%.

4. Conclusion

Recent technological advancements indicate the viability of commercializing these solar cells. Though their stability still needs work, the low cost of production, satisfactory power conversion efficiency, and good energy payback time mark them as essential technologies for the future of energy. However, this conclusion is only obtained through preexisting papers, and more research is needed for a better and more conclusive result. Still, the dye-sensitized solar cells and the quantum dot-sensitized solar cells hold great potential. If this trend in technological advancements were to continue, the mass commercialization of the two kinds of solar cells would be fast approaching.

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