J. Mountain Res. P-ISSN: 0974-3030, E-ISSN: 2582-5011 DOI: https://doi.org/10.51220/jmr.v19-i1.59
Vol. 19(1), (2024), 609-613

Recent Advancements In Nano-Enhanced Solar Technologies

Neelam Sinha[1] • Piyush Sinha[2*]

[1]*Dept. of Physics, S.D. College, Muzaffarnagar*
[2] *Dept. of Physics, H.N.B. Garhwal University, B.G.R Campus, Pauri*

*Corresponding Author Email id: piyushs03@gmail.com

Received: 13.04.2024; Revised and Accepted: 30.06.2024

Abstract: Nanotechnology offers promising solutions to overcome current efficiency challenges of solar energy devices and significantly enhances both the generation and storage capabilities of solar energy. Numerous physical phenomena have been identified at the nanoscale that can enhance the processing and transmission of solar energy. Utilizing nanotechnology in solar cells has paved the way for the creation of advanced, high-performance products. As demand for clean energy options continues to rise, various strategies are being explored to broaden the scope of potential approaches. In the present research article, the role of nanotechnology in solar photovoltaic systems is explored with the emphasis in investigating the recent advancements in solar technology using nanoparticles such as self-cleaning solar panels, dye-Sensitized solar cells, Quantum dot sensitized solar cells, Perovskite-sensitized solar cells and the effect of silicon nanoparticles on the efficiency of solar cells is studied as well.

Keywords: solar energy • solar cells • silica • titanium dioxide • quantum dots • perovskite • nanotechnology

Introduction

In the fast developing world of rising population and with the high pace of technological advancements there is a consistent need of energy to match the growing demands. It is presumed that the demand of energy will be doubled by the year 2050, hence there is an urgent need to develop alternative energy resources (renewable) which are free from conventional fossil fuels. Out of all types of non-conventional energy sources solar energy is catching up fast to become major energy contributor. With the rise in global adoption of solar technologies, there is a growing need for research and development aimed at enhancing their functionality. Solar panels generate electricity by capturing light energy, with each layer serving a crucial role in their efficiency. Enhancements in these features promise to make solar technology more accessible, cost-effective, and ubiquitous worldwide. Key areas of improvement include enhancing light absorption, reducing manufacturing expenses, enhancing adaptability to diverse conditions and increasing power output from solar modules. Nanotechnology plays a pivotal role in driving advancements in these areas.

Nanomaterials are the materials which have a physical size between 1nm-100nm. The small size of these particles results in a large surface-to-volume ratio (Goldstein et al, 1992). The surfaces of these materials have dangling bonds that interact with neighbouring molecules, resulting in lower melting points, higher solubility, and greater chemical stability compared to bulk materials. The quantum tunnelling effect causes these materials to have quantized or discrete properties, allowing for optimization or alteration of their optical and intrinsic properties, such as the Bohr radius and migration distance. Nanomaterials can also lower manufacturing costs by enabling the modification of less expensive materials to meet application requirements. The maximum theoretical conversion efficiency for crystalline silicon and that of cadmium telluride (CdTe) has been found below 30% while for triple junction compound semiconductor materials such as gallium arsenide (GaAs), indium gallium arsenide (InGaAs) and indium gallium phosphide (InGaAs), the highest energy conversion efficiency has been achieved up to 37.9%, which is encouraging.

Nanotechnology has been crucial in enhancing solar cells by improving light absorption, energy conversion, and overall efficiency. This can be achieved by coating the solar cell components such electrodes and wafers with transparent nanomaterial dyes. However, due to larger surface to volume ratio of nanomaterials, such modified solar cells may develop agglomeration and increased side reactions.

Some of the recent progressions of Nano-enhanced solar applications are discussed here.

Before discussing the added value of nanomaterials in solar cells, it is essential to understand the basic mechanism of how solar cells work. A solar cell is an electronic device, essentially a P/N junction, that converts sunlight into electricity. This phenomenon, known as the photovoltaic effect, was discovered by Edmond Becquerel in 1839. Not all materials are suitable for use in solar cells; the key requirement is the ability to convert the visible spectrum of sunlight into electricity. This occurs through the creation of electron-hole pairs when the material absorbs photons with energy equal to or greater than its energy gap (Pode et al, 2011), as illustrated in Fig.1. A basic solar cell consists of a P/N junction, where a P-type semiconductor has an excess of holes and an N-type semiconductor has an excess of electrons. These excess electrons and holes move in opposite directions creating electric potential which can be connected in an electric circuit to achieve current flow. This process will continue until equilibrium is reached that is when all electron-hole pairs are formed.

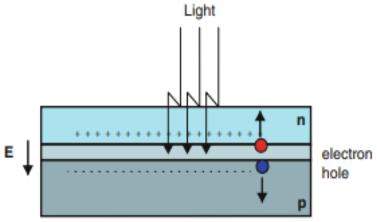

Fig.1 Structure of a basic solar cell and the effect of light on the cell

Nano-Coatings for Solar Panels

In this technology, solar panels are treated with a protective coating designed to prevent the accumulation of dust and dirt. Regions characterized by industrial and rural activities tend to have higher levels of airborne pollution and dust, increasing the likelihood of panel contamination. When panels become dirty, the layer of dust obstructs sunlight penetration, reducing light absorption and subsequently diminishing charge generation and overall panel efficiency.

Additionally, solar panels are susceptible to surface damage such as scratches and moss-related issues, further impeding performance. To address these challenges, scientists and researchers have engineered nano-coatings that can be applied to the panel surface, offering enhanced protection and performance.

These coatings serve to deter dust and dirt from adhering to the panel surface, facilitating their easy removal to prevent sunlight blockage. Moreover, they impede the growth of moss or lichens, effectively self-cleaning the panels. Additionally, these coatings offer protection against winter conditions by preventing the accumulation of ice or snow and safeguarding against scratches and superficial damage. Furthermore, nano-coatings possess the added benefit of being anti-reflective, enhancing light transmittance through the panels. Solar modules treated with nano-coatings have demonstrated efficiency gains of 7-12%. The anti-reflective nature of the coating also enables the utilization of solar technology in regions with low sunlight or weak radiation, yielding respectable power outputs from such installations.

Dye-Sensitized Solar Cells (DSSCs): A transparent conducting oxide layer, such as Fluorine-doped Tin Oxide (SnO2:F, FTO) or Indium Tin Oxide (ITO) (Weili et al., 2010), a photo-anode, a sensitizer dye, electrolytes like Iodide-Triiodide, and counter electrodes coated with catalysts like Platinum are used in the construction of these solar cells. This technology involves coating the photo-anode with Ruthenium (II) dye (N719) nanoparticles. The photo-anode is usually made from nano-enhanced TiO2 (Jiang et al, 2012).

The combination of these nano-enhanced materials (Rattanavoravipa et al, 2008) absorbs light more effectively. The light can be understood as packets of photons or photon energy. When it falls on the surface it gets absorbed by the electrons present causing it to excite from its original highest occupied molecular orbit to lowest unoccupied molecular orbit. This is very similar to valence band and conduction band of semiconductors. These excited electrons then act as charge carriers. These excited electrons interact with Ruthenium (II) dye (N719) nanoparticles leading to the further oxidization of dye. The dye is brought back from its oxidized state after receiving an electron from the electrolyte thus allowing it to participate in conduction again. The counter electrode, coated with a Platinum catalyst, replenishes the electrolyte that donated the electron. Meanwhile, the electrons excited from the dye are transferred and accumulated at the photo-anode (TiO2) terminal. In this way the electrons continuously gets recycled making the process seamless (Fig. 2). The working of these Dye-sensitized Solar Cells closely follow the photosynthesis process found in nature. The DSSCs are also more eco-friendly than the conventional silicon solar cells.

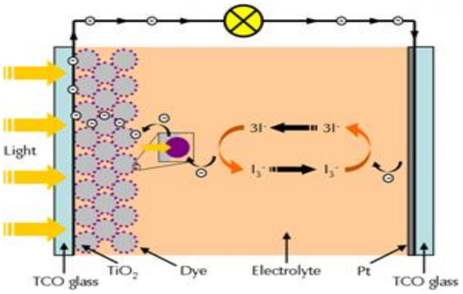

Fig. 2 Schematic representation of DSSC

These cells are also flexible, making them adaptable to various surfaces, but their efficiencies are relatively low, averaging around 12%. However, ongoing advancements in optimizing nanoparticles in DSSCs show promise for increasing their efficiency, potentially making them commercially competitive in the coming years.

Quantum-Dot Sensitized Solar Cells (QDSSCs): These solar cells are one of the promising solar cell technologies similar to the DSSCs which drew more and more attention due to the significantly improved photovoltaic performance. The novel nanocrystal QD sensitizer that is employed is the main distinction between QDSSCs and DSSCs. It has been discovered that key characteristics of QDs, such as their size-tunable band gap, incredibly adaptable solution processing methods, ability to produce multiple excitons (MEG) when exposed to intense photons, and superior photostability over organometallic sensitizers, are appropriate for building extremely stable and highly effective solar cell devices (Kamat P.V, 2008, 2013). The characteristics of charge transfer that occur at the interface between the photo-anode, sensitizer dye, and electrolyte are significantly impacted by this difference. Another notable distinction is that QDSSCs have a faster recombination lifetime, which increases the likelihood of higher recombination, which is a serious drawback. The sensitizers for QDSSCs (Kim et al, 2015) (Ruhle et al, 2010) are quantum dots made of materials such as cadmium chalcogenide nanoparticles (CdS, CdSe, CdTe), lead chalcogenide nanoparticles (PbS, PbSe) and ZnSe.

The attachment of QDs to the metal oxide surface is crucial, and Huang et al. (2014) found that the short chain organic ligand mercapto propionic acid (MPA) is an effective candidate in the charge transfer process. The power conversion efficiency (PCE) of QDSCs has been observed to have significantly improved over the last 15 years, rising from less than 1% to nearly 13%. These are economically feasible and have adjustable bandgaps that support a broad range of spectrums. In comparison to DSSCs, QD sensitizers have a higher extinguishing coefficient, and QDSSCs operate on the same principle as the DSSCs depicted in Fig. 3 (Zhenxiao et al, 2014).

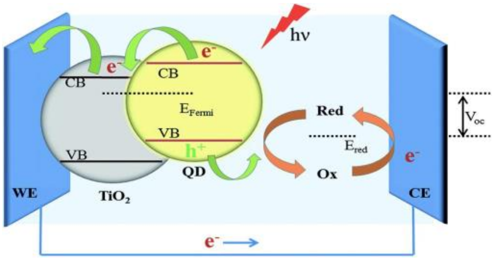

Fig. 3 QDSCs: the schematic illustration of the device structure

Perovskite-Sensitized Solar Cells (PSCs):

These cells have garnered significant research attention in recent years due to their exceptional light absorption properties, robust tolerance to internal defects (Jun, 2017), efficient charge carrier mobility, long lifetimes of charges, cost-effectiveness, and scalability in industrial applications. Perovskite Solar Cells (PSCs) adopt an ABX3 structure, where A, B, and X components interlace in a lattice formation.

These cells are characterized by their minimal thickness, which reduces heat losses. They consist of a transparent conducting oxide (TCO) layer like Fluorine tin oxide (FTO), metal electrode and a photo-anode. Its main component perovskite layer composed of Calcium titanate (CaTiO3) compound is sandwiched between electron transport layer (ETL) and hole transport layer (HTL)

In PSCs, the perovskite layer absorbs photon energy, generating excitons that can either recombine or produce current. These excitons which can either be electrons or holes are captured by ETL and HTL respectively. While holes are transported to and collected by the metal electrode, electrons are transported to the TiO2 anode layer and collected by the FTO.

PSCs have a large dielectric constant, high optical coefficients, and low binding energy, which facilitate the transfer of electrons and holes and raise the short-circuit current density (Jsc) and open-circuit voltage (Voc). This contributes to an average efficiency of up to 33%. Additionally, PSCs have been developed on flexible substrates, enhancing their adaptability to various surfaces.

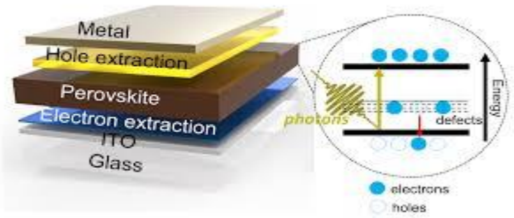

Fig 4. Schematic diagram of a perovskite solar cell

Conclusion

In summary, the application of nanotechnology to improve the construction and efficiency of solar cells is currently in the research phase. However, it is anticipated that the transition to commercialization in this field is imminent and practically inevitable. Given the significant potential demonstrated by this sector in enhancing solar cell efficiency, the commercialization of this technology represents a pivotal moment in the solar cell industry. The various technologies that are covered in this article such as Nano-coatings, DSSC'S, QDSSCS, and Perovskite-Sensitized Solar Cells have provided insights into how nanotechnology can influence solar technology. Significant advancements and refinements are in progress for these applications, suggesting that the synergy between nanotechnology and solar technology could potentially offer cutting-edge, cost-effective, and efficient power generation in the decades ahead.

References

Akl A.A, Afify H.H. (2008) Growth, microstructure, optical and electrical properties of sprayed CuInSe2 polycrystalline films. Mater Res Bull 43:1539–1548

Chiappafreddo P, Gagliardi A (2010) The photovoltaic market facing the challenge of organic solar cells: economic and technical perspectives. Transit Stud Rev 17:346–355. doi:10.1007/s11300-010-0148-0

Goldstein A.N, Echer C.M, Alivisatos A.P (1992) Melting in semiconductor nanocrystals. Science 256(5062):1425–1427

Huang J, Xu B, Yuan C, Chen H, Sun J, Sun L, Agren H (2014) Improved performance of colloidal CdSe quantum dot-sensitized solar cells by hybrid passivation. ACS Appl Mater Interfaces 6(21):18808–18815

Jiang C.Y, Koh W.L, Leung M.Y, Chian S.Y, Wu J.S, Zhang J (2012) Low temperature processing solid state dye sensitized solar cells. Appl Phys Lett 100:113901

Jun Kang (2017). High Defect Tolerance in Lead Halide Perovskite CsPbBr3". The Journal of Physical Chemistry Letters. 8 (2): 489–493

Kamat P.V. (2008) Quantum dot solar cells. Semiconductor nanocrystals as light harvesters. J Phys Chem C 112(48):18737–18753

Kamat P.V. (2013) Quantum dot solar cells. The next big thing in photovoltaics. J Phys Chem Lett. 4(6):908–918

Kim M.R. and Ma D, J. (2015**)** Quantum-Dot-Based Solar Cells: Recent Advances, Strategies, and Challenges Phys. Chem. Lett., 6, 85–99.

Pode R, Diouf B (2011) Solar lighting, green energy and technology. Springer, Berlin/Heidelberg. doi:10.1007/978-1-4471-2134-3_2

Rattanavoravipa T, Sagawa T, Yoshikawa S (2008) Photovoltaic performance of hybrid solar cell with TiO2 nanotubes arrays fabricated through liquid deposition using ZnO template. Sol Energy Mater Sol Cells 92:1445–1449

Ruhle S, Shalom M and Zaban A, (2010) Quantum-Dot-Sensitized Solar Cells. Chem. Phys. Chem., 11, 2290–2304.

Shengli Zhu, Guoquiang Xie, Xian Jin Yang, Zhenduo Cui (2013) A thick hierarchical rutile TiO2 nanomaterial with multilayered structure. Mater Res Bull 48:1961–1966

Tauc J (2005) Optical properties of amorphous semiconductors and solar cells. In: Yu PY, Cardona M (eds) Fundamentals of semiconductors: physics and materials properties. Springer, Berlin/Heidelberg, pp 566–568. ISBN 3-540-25470-6

Wanzhu Cai, Xiong Gong, Yong Cao (2010) Polymer solar cells: recent development and possible routes for improvement in the performance. Sol Energy Mater Sol Cells 94:114–127

Weili Yu, Bin Xu, Qingfeng Dong, Yinhua Zhou, Junhu Zhang, Wenjing Tian, Bai Yang (2010) A two-step method combining electrodepositing and spin-coating for solar cell processing. J Solid State Electrochem. 14:1051–1056.

Zhenxiao Pan, Ivan M.S, Qing S, Hua Z, Yan. L, Ke. Z, Jin W, Zinhua Z, and Juan B. (2014) High- efficiency “grren” quantum dot solar cells, J Am Chem Soc. 136(25):9203-10