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University of Misan
College of Sciences
Department of Physics

(Nanotechnology for Solar cell Applications)

A Project

Submitted to the College of Science- University of Misan in Partial Fulfillment of the Requirements for B.Sc Degree of Science in Physics

by

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Shawal 1444 A.H

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Dedication

To the absent who still inspires us with the light of supplication

To the first pen that visited my finger...

To my mother's early awakenings and my father's sleeplessness, whose causes we may be on top of...

To my big point that I thought I wouldn't leave where it ends
Even replaced by a thousand lines and points.

To every professor whose share was a station of meditation, love and reconstruction of the mind....

I dedicate this research to you.

.

بسم الله الرحمن الرحيم

فَوَجَدَا عَبْدًا مِّنْ عِبَادِنَا آتَيْنَاهُ رَحْمَةً مِّنْ عِندِنَا وَعَلَّمْنَاهُ مِن لَّدُنَّا عِلْمًا* ”

”قَالَ لَهُ موسى هَلْ أَتَّبِعُكَ علي أَن تُعَلِّمَنِ مِمَّا عُلِّمْتَ رُشْدًا.

سورة الكهف، الآيات ٦٥، ٦٦.

Supervisor Certification

This is to certify that the preparation of this research entitled ("Nanotechnology for Solar cell Applications ") is prepared by (Hawraa Chasseb Asmar

Russell Ali Salman) under my supervision in the Physics department, College of Sciences, misan University as a partial fulfillment of the requirement of B.Sc Degree of Science in physics.

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In view of the available recommendations, I forward this research for debate by the Examining Committee.

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Date :

Dedication

My family : Thank you for your unconditional support with my studies. Thank you for giving me a chance to prove myself.

Acknowledgment

Thank be to God Almighty the grace of Patience and the ability to complete this work .I would like to extend my thanks and appreciation to my distinguished Prof. Dr. baqer alnashy ,who kindly supervised this work and for all the support and guidance he provided me to complete this work as it is. He has the highest expression of praise and appreciation for me. I would like thanks and appreciation to the head of the Physics Department ,Dr. Munther Abdulhassan,and all the physics faculty members ..

The approval of the discussion committee

We, the chairman and members of the discussion committee, the undersigned, have discussed the tagged research (Nanotechnology for Solar cell Applications)

The foot by the female students (Hawraa Chasseb Asmar) (Russell Ali Salman)

In view of their knowledge of the content of the research and their defense through the questions directed to them, the committee found that it fulfilled as it is considered part of the requirements for obtaining a bachelor’s degree in physics

Chairman of the Committee

Signature:

Name: Dr. Ahmed Khalaf Zughayer

Scientific title: Professor

Date: / /2023

Committee member

The name :

The scientific title :

Date: / /2023

Committee member

The name :

The scientific title :

Date: / /2023

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	one sun global air mass 1.5 (AM1.5g) light. These cells did not haveantireflective coating. InGaP: Indium gallium phosphide. GaAs: Galliumarsenide.	

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Abstract

Nanotechnology can help to address the existing efficiency hurdles and greatly increase the generation and storage of solar energy. A variety of physical processes have been established at the nanoscale that can improve the processing and transmission of solar energy. The application of nanotechnology in solar cells has opened the path to the development of a new generation of high-performance products. When competition for clean energy options is growing, a variety of potential approaches have been discussed in order to expand the prospects. New principles have been explored in the area of solar cell generation, multi-generation, spectrum modulation, thermo-photoelectric cells, hot carrier, the middle band, and many other techniques. Nanoparticles and nanostructures have been shown to enhance the absorption of light, increase the conversion of light to energy, and have improved thermal storage and transport.

The solar cell industry has grown quickly in recent years due to strong interest in renewable energy and the problem of global climate change .Cost is an important factor in the success of any solar technology. Today's solar cells are simply not enough efficient and are too expensive to manufacture for large-scale electricity generation. However, potential advancements in nanotechnology may open the door to the production of cheaper and slightly more efficient solar cells. Nanotechnology has already shown huge breakthroughs in the solar field. Quantum dots have the potential to change the world. They are a form of solar cell that is completely beyoznd anything you might imagine. Nanotechnology might be able to increase the efficiency of solar cells, but the most promising application of nanotechnology is the reduction of manufacturing cost. PVs based on CdTe, CuInGaSe (CIGS), CuInSe (CIS), and organic materials are being developed with the aim of reducing the price per watt even if that means sacrificing conversion efficiency and reliability.

Keywords: Nanomaterials; Solar cells; Organic; Inorganic; Nanopillars;

1. Introduction

The most emphasized problem of modern life in the 21. century is by far the growing energy requirement of the world. The global energy consumption is estimated to double by the year 2050; the growth of any other industry is strictly related to the resources. However, this high energy demand is conventionally met with the use of fossil fuels. The disadvantages of fossil fuels including environmental pollution and resource depletion are well-disputed and undeniable. This is why researchers have steered towards new and renewable energy resources. Solar energy is considered to be the most promising solution to the clean energy requirement of the modern world. The conversion of solar energy to electricity is achieved through solar cells. We are considerably familiar with the conventional solar cells which are installed on almost every rooftop, traffic lights, and various other places we encounter on a daily basis. These are single-crystalline silicon solar cells and make up to 94% of the solar energy market. Many photovoltaic devices including these traditional solar cells have been developed over the years however; their wide-spread use is limited by conversion efficiency and cost. Traditional silicon solar cells are often referred to as first generation solar cells. With regards to first generation solar cells, high cost, and theoretical efficiency limit (which is known as the Shockley-Quiesser limit) are the two major disadvantages. The high cost of the single–crystalline silicon solar cells is due to the production of high quality Si wafers which makes up to 40-50% of the market price. The second generation thin film solar cells were developed in order to aid the high cost of traditional solar cells.

2. Solar Energy

Solar energy is the most abundant of all energy resources and can even be harnessed in cloudy weather. The rate at which solar energy is intercepted by the Earth is about 10,000 times greater than the rate at which humankind consumes energy.

Solar technologies can deliver heat, cooling, natural lighting, electricity, and fuels for a host of applications. Solar technologies convert sunlight into electrical energy either through photovoltaic panels or through mirrors that concentrate solar radiation.

Although not all countries are equally endowed with solar energy, a significant contribution to the energy mix from direct solar energy is possible for every country.

The cost of manufacturing solar panels has plummeted dramatically in the last decade, making them not only affordable but often the cheapest form of electricity. Solar panels have a lifespan of roughly 30 years, and come in variety of shades depending on the type of material used in manufacturing.

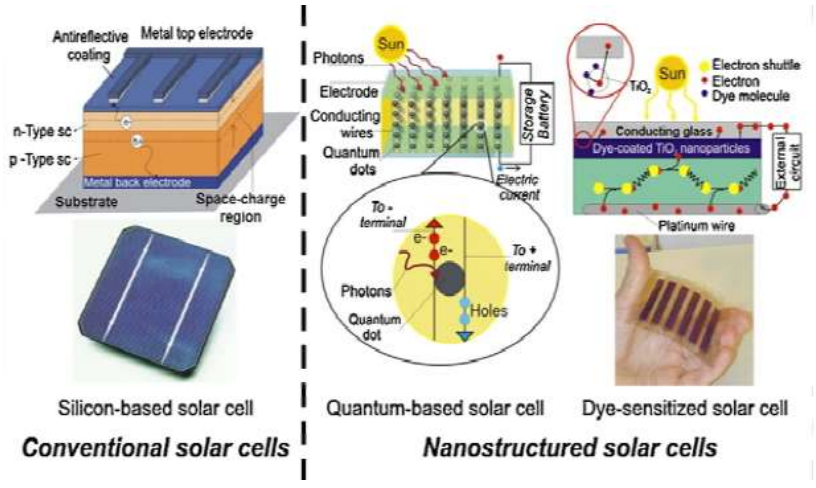

Fig. 1. Evolution of photovoltaic technology from conventional to nanostructured solar cells [3].

3. How does Nanotechnology Enhance Solar Cell?

Amorphous Si, cadmium telluride (CdTe), copper-indium-gallium-selenide (CIGS), and other compound semiconductor thin films are commonly used in second generation solar cells. However, hydrogenated amorphous silicon degenerates when exposed to sunlight hence they have a short lifetime. The CdTe and CIGS films are more efficient for the conversion of sunlight and are relatively cheap to produce, but they contain heavy metals and thus are harmful to the environment. The third generation solar cells composed of hybrid junctions, polymers, organic-inorganic hybrid assemblies, and semiconductor nanostructures are developed to improve the theoretical efficiency. The Shockley-Quiesser limit defining the theoretical efficiency of traditional solar cells was first calculated by William Shockley and Hans-Joachim Quiesser in 1981. They proposed that the maximum efficiency of a silicon solar cell would be 30% at 1.1 eV. However, later calculations have updated this limit as 33.7% at 1.37 eV. This limit is one of the most fundamental theories of solar energy systems and frequently utilized in the production of photovoltaic cells. Shockley-Quiesser limit calculations assume that; low energy photons can't be absorbed and high energy photons can only excite one electron. However, it is important to note that this limit is only valid for conventional single p-n junction solar cells. Third generation solar cells attempt to increase the efficiency limit either by utilizing the high-energy photons more efficiently, or recovering the low-energy photons normally not converted. Nanostructures are extensively studied for this purpose. Here we will examine how nanotechnology benefits solar cells technologies and the use of nanotechnology in several different solar cells including conventional thin film solar cells, dye-sensitized solar cells, carbon and polymer based solar cells, quantum dot solar cells, and extremely thin absorber solar cells.

Employing nanotechnological solutions and nanoscale structures to the solar cell systems provide promising improvements. Nanoscale systems exhibit different properties than their bulk or thin film counterparts. High surface to volume ratio of nanostructures 6, quantization effects at ≈1-20 nm scale, and variety in production methods provide several benefits to solar energy systems. Nanomaterials are utilized in multiple-junction solar cells to exceed the Shockley-Quiesser limit. In theory, a finite number of junctions results in an efficiency limit of 68% at 1-sun intensity while a triple-junction solar cell based on III-V semiconductors reaches up to 34.1% efficiency 3. However, these high-efficiency cells are far too expensive. On the other hand, nanomaterials can be used to produce layers with different bandgaps, and the multiple junctions can be solution-processed at a significantly lower cost. Furthermore, the unique properties of nanostructures are employed to provide two major improvements to the solar energy systems; optical losses and electrical performance.

4. Nanomaterial

4.1 What are Nanomaterials?

The term nanoscale refers to the dimension of 10^{-9} meters. It is the one billionth part of a meter. So, the particles whose any of the external dimensions or internal structure dimension or surface structure dimension lies in the range of 1nm to 100nm are considered as Nanomaterials.

4.2 Properties of Nanomaterials

A drastic change in the properties of nanomaterials can be observed when they are breakdown to the nanoscale level. As we go towards the nanoscale level from the molecular level, the electronic properties of materials get modified due to the quantum size effect. Change in the mechanical, thermal and catalytic properties of the materials can be seen with the increase in surface area to volume ratio at the nanoscale level.

4.3 The classification of nanomaterials

The classification of nanomaterials mainly depends on the morphology and their structure, they are classified into two major groups as Consolidated materials and Nanodispersions. Consolidated nanomaterials are further classified into several groups. The one dimensional Nano dispersive systems are termed as Nanopowders and Nanoparticles. Here the nanoparticles are further classified as Nanocrystals, Nanoclusters, Nanotubes, supermolecules,etc..

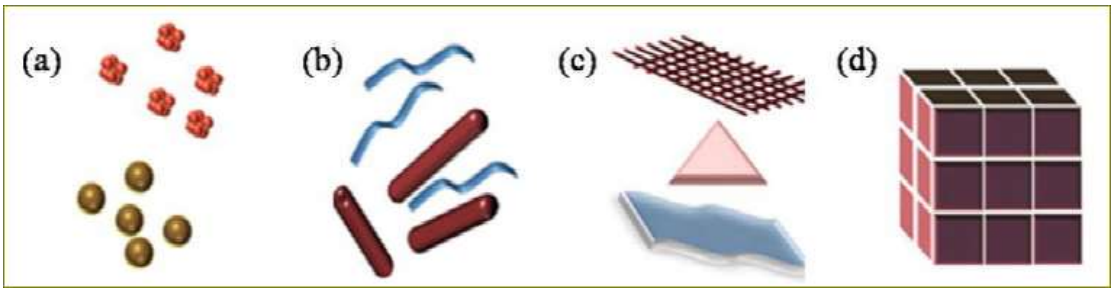

Fig. 2. Classification of Nanomaterials (a) 0D spheres and clusters, (b) 1D nanofibers, wires, and rods, (c) 2D films, plates, and networks, (d) 3D nanomaterials

5. Nanostructured photovoltaics platforms

Nanostructured PVs offer the possibility of increased surface area due to their nanostructured components without increasing the physical size of the device, whereas tailoring of their individual components is significantly easier than conventional Si-based PV as different processes occurring under illumination are decoupled. In this section we highlight the nanostructured PV platforms that have significant and encouraging power conversion efficiencies, and the potential for long term stability. The various technologies that currently satisfy these criteria, and those we will describe and discuss here include dye-sensitized solar cells, quantum dot-sensitized solar cells (QDSSCs) , colloidal quantum dot solar cells, and nanowire-based solar cells. In addition to their operational principle, we will discuss both their advantages and shortcomings, along with insights into possible improvements

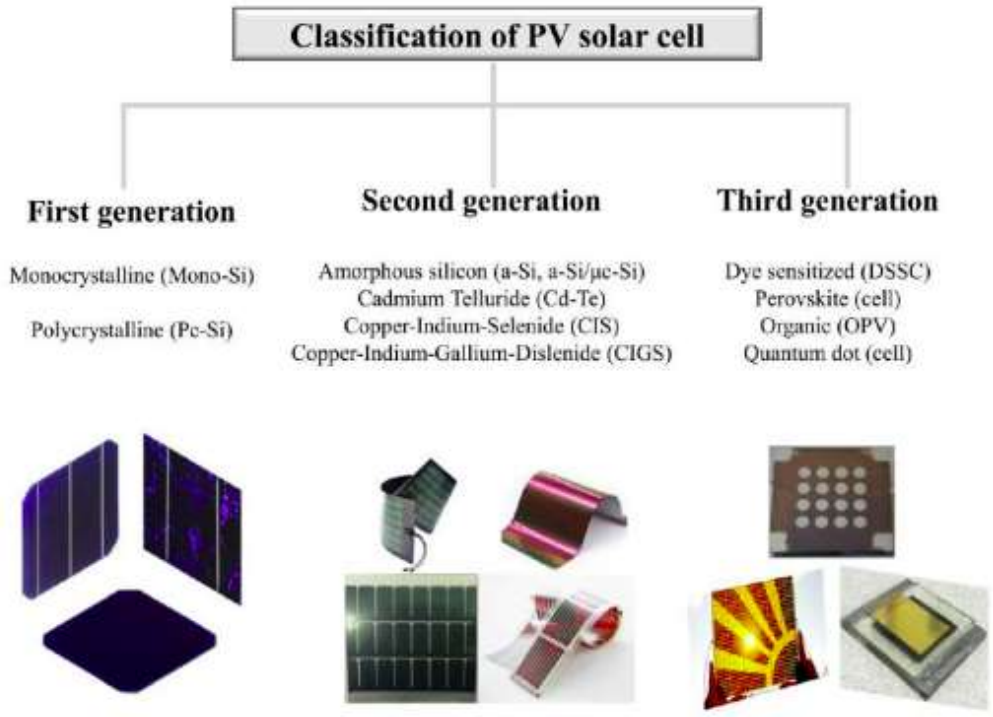

Fig. 3.. classification of photovoltaic panels generations types [5]

6. Quantum dot- solar cells

QDSSCs operate much like DSSCs. In these devices, the sensitizer layer now consists of quantum dots (QDs) instead of a dye, on a mesoporous semiconductor which serves as the ETL, such as TiO_2 or ZnO [163, 164]. The solar cell is completed by the electrolyte or HTM, and the counter electrode. As outlined in figure 4, when sunlight is incident on the QDSSC, the QDs will absorb light to generate electron–hole pairs. The electrons are then transferred from the conduction band of the QD to the conduction band of the ETL, and the holes are transferred to the electrolyte/HTM, which is typically made of polysulfides. The oxidized electrolyte is then reduced to its original state by electrons re-entering the cell from the external circuit [13, 15]. The open-circuit voltage is determined by the difference between the fermi level of the

QD/ETL system and the redox potential of the electrolyte, whereas the produced current is controlled by the sensitizing ability of the QDs and the efficiency of electron separation and extraction [13, 16]. QDSSCs have become an attractive alternative to DSSCs due to ease of fabrication, tunable spectral properties allowing for tandem architectures, improved stability over DSSCs as they can form better junctions with solid state HTMs, and the potential of multiple exciton generation by impact ionization that could increase the theoretical limit in efficiency to 44% [16–15, 17–19]. The current best efficiency recorded for QDSSCs is 11.61% [10], and while significant enhancements have been achieved in the past few years, the record efficiency is still below the record efficiency of DSSCs [15].

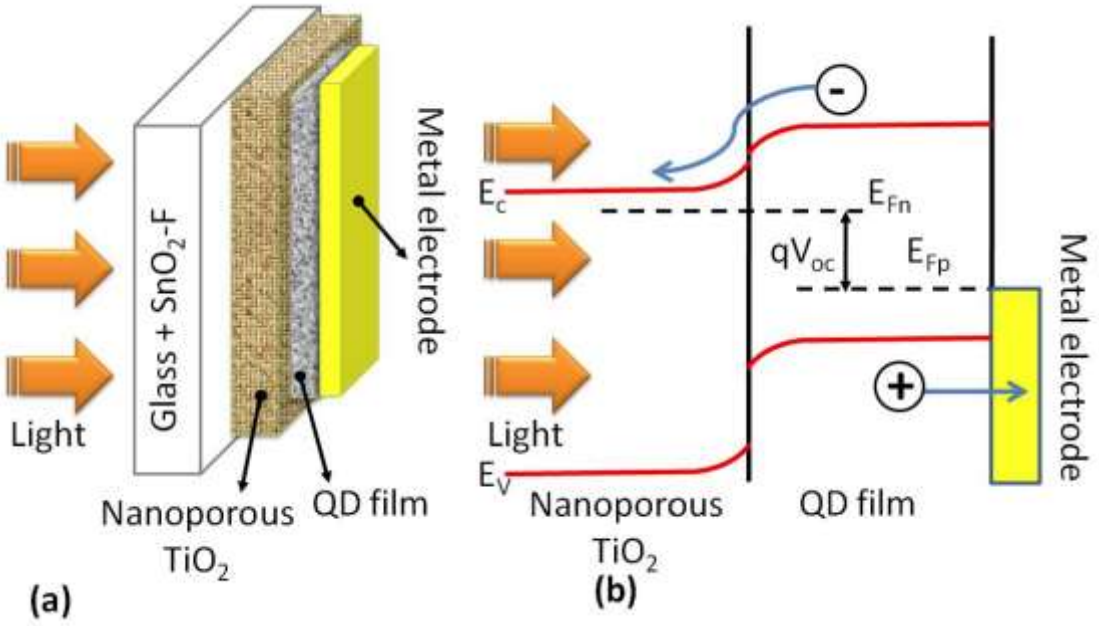

Fig. 4. (a) Schematic diagram of Depleted-heterojunction Colloidal Quantum Dots Solar Cells, (b) energy band diagram. [24].

7. Results And Discussion

7.1 Size tunable properties

Implementation of QDs offers a variety of benefits over dyes as sensitizers in a solar cell. Perhaps their biggest benefit is the ability to tune their spectral properties easily by varying the diameter of the QD, due to quantization effects present. By modifying the energy levels of the QDs, light absorption and electron injection can be tailored to match the needs of the solar cell [11, 12], whereas generation of multiple excitons by a single photon and hot electrons offer new possibilities for enhancement of device performance [11, 13].

Good QDSSC operation requires that the conduction band of the QD sensitizer be higher than the conduction band of the ETL for efficient electron transfer between the two, as the offset provides the driving force for charge transfer [13, 11]. While the open circuit voltage of the device is independent of the size of the QDs used in the sensitizer, as demonstrated in figure 5(a), the device photocurrent is directly correlated to the properties of the QDs [11]. It has been observed that smaller QDs result in higher photocurrent due to the higher conduction band as shown in figure 5(b), implying that a larger driving force will be available for electron injection to the ETL [11, 14]. However, decreasing QD size is also associated with more limited response in the visible part of the spectrum as shown in figure 5(c) [11].

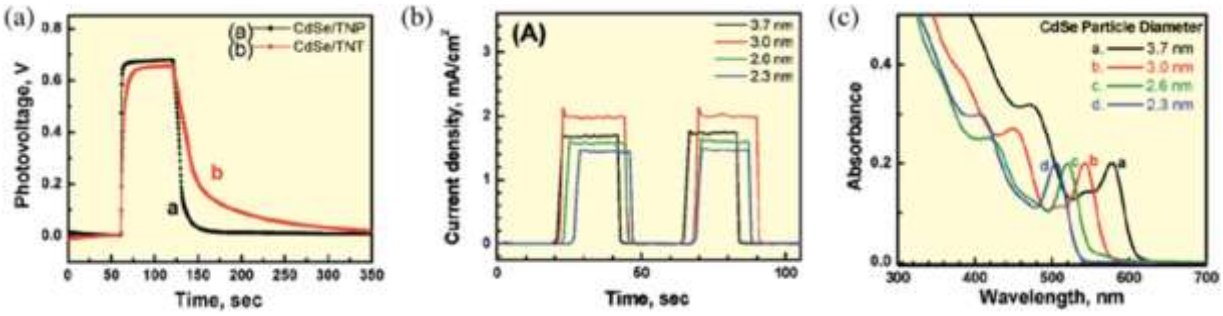

Fig. 5.. (a) Open-circuit voltage for TiO_2 nanoparticles/3 nm CdSe QDs and TiO_2 nanotubes/3 nm CdSe QDs, (b) photocurrent of TiO_2 nanoparticles/CdSe QDs of various sizes, (c) absorption spectra of CdSe QDs of various sizes. Reprinted with permission from [11]. Copyright (2008) American Chemical Society.

7.2 Colloidal QD solar cells

The first example of a solar cell employing colloidal QDs for both light harvesting and charge transport was made in 2005, using a mixture of PbS QDs and a conjugated polymer poly[2-methoxy-5-(2'-ethylhexyloxy-p-phenylenevinylene)] (MEH-PPV), which served as HTM [21]. However, the efficiency of these devices was limited by poor electron transport and after significant enhancements in the conductivity of QD films, the active layer was prepared by PbS QDs only, which was found to enhance charge carrier extraction from the active layer [26]. These devices were built as Schottky cells, as the semiconducting active layer (PbS) formed a rectifying junction with a low work function metal and the operating procedure is outlined in figure 6(a) [27]. Metals used for this purpose included aluminum, calcium, magnesium, silver, and gold. The best device efficiency achieved with such an architecture was 5.2% [28]. Nevertheless, the device performance is limited by the Fermi level at the interface which limits the open-circuit voltage, whereas illumination from the non-rectifying side of the device was required, which meant that internal quantum efficiency was low as this was far from the junction [27, 29].

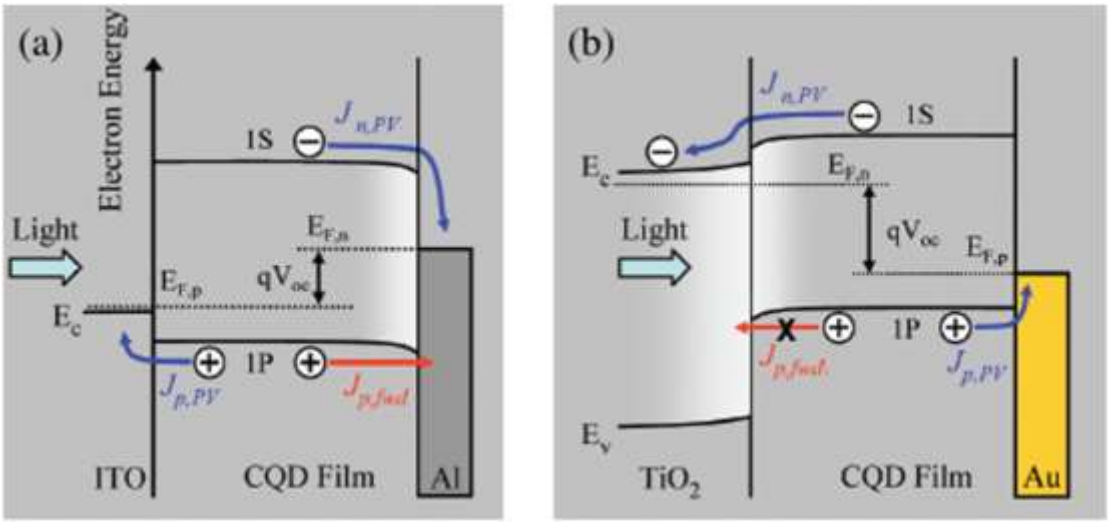

Fig. 6.. Device operation of: (a) Schottky colloidal QD solar cell, and (b) depleted heterojunction colloidal QD solar cell. Reprinted with permission from [220]. Copyright (2010) American Chemical Society

Fig. 7.. Schematic representation of hot electron transfer mechanism. (a) Excited plasmons decaying via radiative emission of photons or non-radiatively by exiting hot electrons in the metal. Localized surface plasmons can decay radiatively via re-emitted photons or non-radiatively via excitation of hot electrons in the conduction band. (b)Hot electron having energy above the Fermi level (c) Hot electrons can be transferred to the semiconductor if the electrons have energy greater than the Schottky barrier of the metal-semiconductor junction. φ_M is the work function of the metal and χ_S is the electron affinity of the semiconductor. [34] (2014) Copyright © 2014, Springer Nature. With permission of Spring

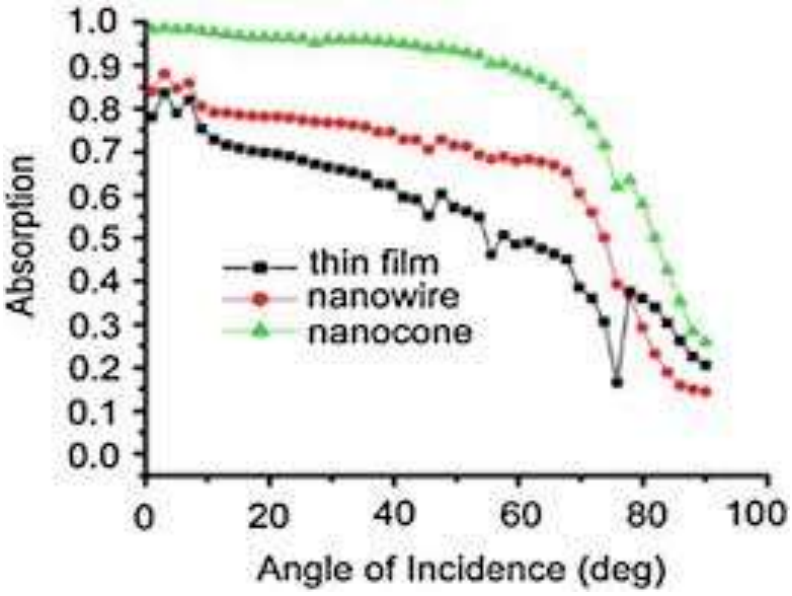

Fig. 7. Absorption of ITO/a-Si:H samples with a-Si:H thin film, nanowire arrays, and nanocone arrays as top layer over different angles of incidence at at wavelength l = 488 nm (Reprinted with permission from Ref. [28] (copyright 2011, Elsevier) and Ref. [12] (copyright 2011, American Chemical Society))

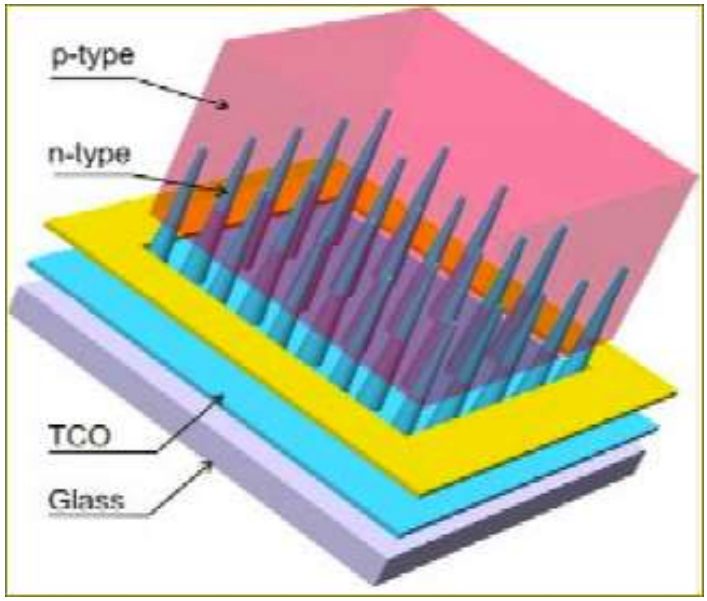

Fig. 8 Nanocones for solar cell applicqtions

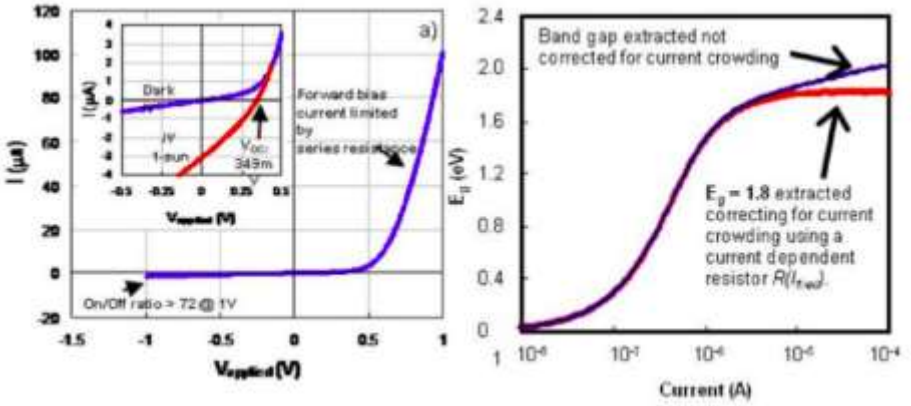

Figure 9. First results from cells using quantum effects in silicon. The band gap of the top layer containg silicon nanoparticles is about 1.8 eV (Conibeer, Green et al, 2010).

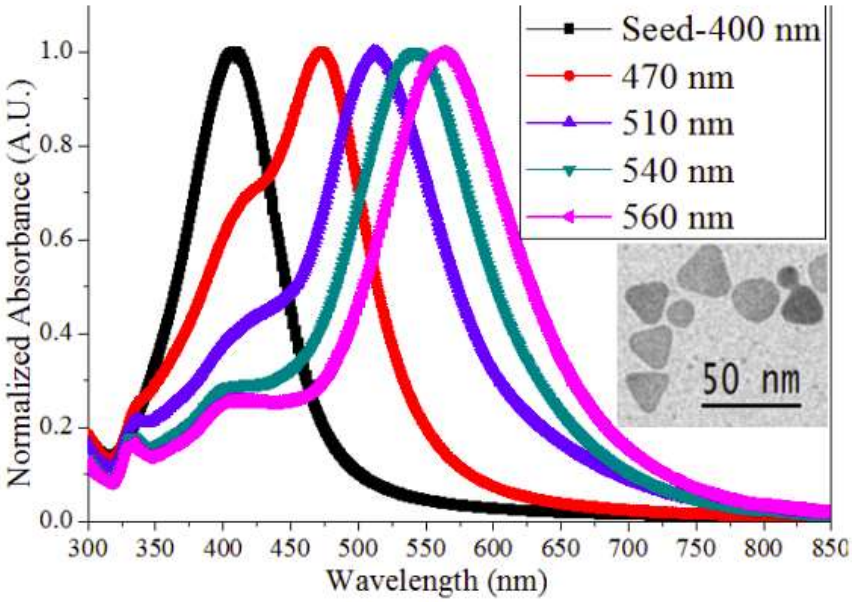

Fig. 10. shows the measured absorbance of three different sizes of lead sulfide (PbS) quantum dots suspended in toluene using dual beam spectrophotometer. Since a quantum dot bandgap is tunable depending on its size, the smaller the quantum dot the higher energy is required to confine excitons into its volume. Also, energy levels increase in magnitude and spread out more. Therefore, exciton characteristic peak is blue shifted.

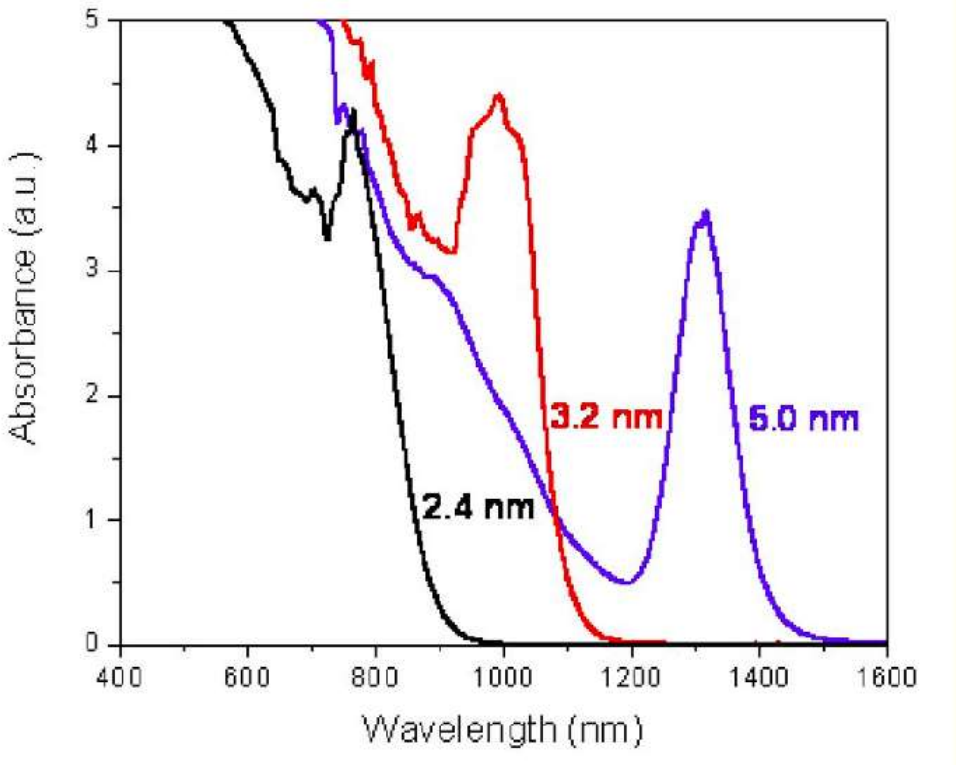

Fig. 11..Measured absorbance of three different sizes PbS quantum dot suspended in toluene [20].

7.3 Quantum dot-dye sensitized solar cells(DSSCs)

Dye sensitized solar cells DSSCs were first introduced by O'Regan and Grätzel in 1991 [14]. Their work challenged the conventional solid-state photovoltaic cells, by introducing a device that incorporated nanomaterials and separated the processes of light absorption and charge carrier transport. This new device offered the possibility of low-cost photovoltaic devices, which would provide an alternative to power generation from conventional sources.

The first example of DSSC was prepared using a ruthenium complex as sensitizer, deposited on a TiO2 (titanium dioxide) film, and employed a liquid re-dox electrolyte of tetrapropylammonium iodine mixed with iodine. This device achieved a fill factor of 0.76, and in addition to a PCE of 7.9% [14], it also demonstrated an efficiency of

12% under diffuse sunlight, revealing unexpected benefits of these devices compared to conventional silicon based solar cells. Furthermore, under conditions of low light intensity (<5 W m−2), the fill factor remained above 0.7, which is not observed for conventional devices. This was an initial indication of the absence of recombination processes that normally limit device performance in semiconductor devices. The promise shown by this first DSSC encouraged further research into the processes occurring within the device and potential enhancements of the device design to achieve higher PCE .

A typical DSSC is shown in figure 1. The device consists of a glass or plastic substrate, which is coated with a transparent conductive oxide (TCO)—common examples include indium tin oxide (ITO) or fluorine-doped tin oxide (FTO). The substrate is coated with a mesoporous oxide layer, which typically serves as the electron transport layer (ETL) that guides electrons to the anode, and TiO2 has been a particularly popular material for this purpose. Dye is deposited onto the ETL and is employed for light absorption followed by electron injection into the conduction band of the ETL. The dye is then regenerated via electron transfer from the redox electrolyte, typically an iodide/triiodide system. Finally, the triiodide formed is reduced to iodide by capture of electron from the cathode, which usually consists of platinum on TCO glass. These processes are shown in figure 1(b). Therefore, at the end of the process the device has returned to its original state [15]. While extensive research has been done on the materials incorporated in these devices, certain dyes have shown great promise. The most impressive PCE from a single sensitizer so far has been achieved by implementing porphyrin sensitizer (SM315) that has been engineered to improve its light harvesting properties, resulting in a PCE of 13.0% [16].

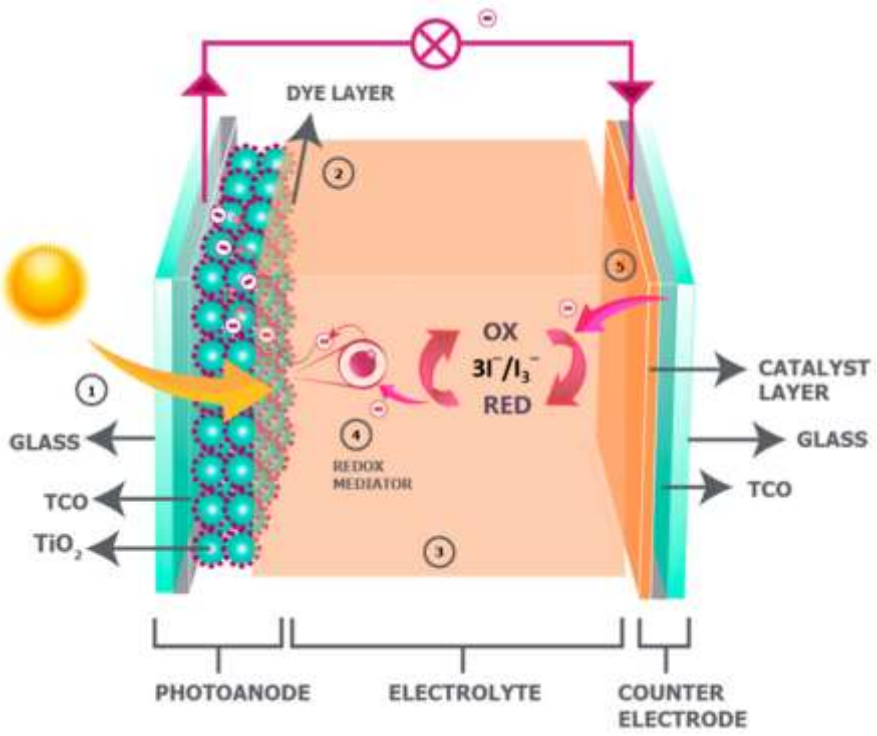

Fig. 12. Device structure of a dye-sensitized solar cell employing iodine electrolyte (employing)redox couple) as an example [11,26,29,30].

Figure 12 shows an example of the I-V characteristics of a first round study of assembled cells illuminated with a collimated beam from a hot filament lamp. In cell preparation we followed the same strategy described in section 5.6 such that after coating the photoelectrode with PbS quantum dots it was soaked in dye for an hour. Then, the electrode was rinsed with deionized water and ethanol. After that the cell is assembled and tested. The dye used was extracted from a pomegranate.

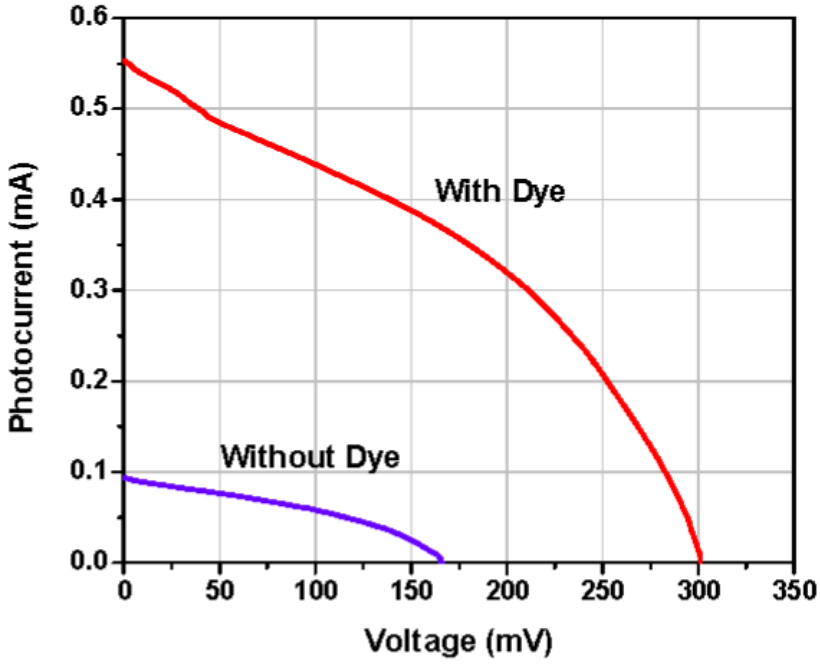

Fig. 13. I-V characteristics of typical assembled quantum dot-dye sensitized solar cell. Quantum dots average size of 2.4 nm and pomegranate dye extract used as sensitizers of TiO2 nanoporous layer.

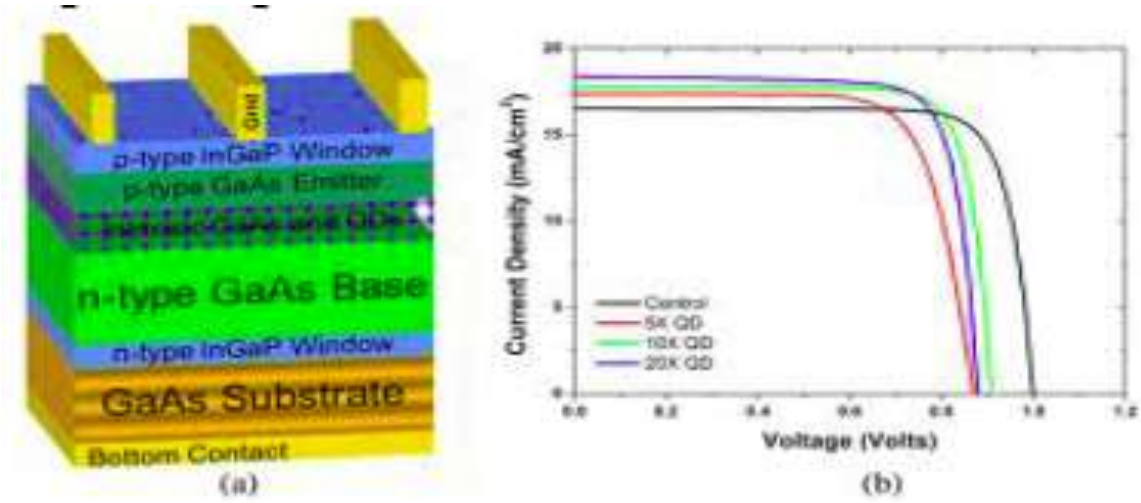

Fig. 14. a) Quantum-dot (QD)-enhanced solar-cell design concept. (b)Current density-voltage curves for control and 5–20 layer enhanced cellsunder one sun global air mass 1.5 (AM1.5g) light. These cells did not haveantireflective coating. InGaP: Indium gallium phosphide. GaAs: Galliumarsenide.

8. Conclusion

In sum, it can be seen that while the usage of nanotechnology in the construction and enhancement of solar cell efficiency is currently in the research process, it can be assumed that the transition period to the commercial arena for this field would be very near and inevitable. Seeing the tremendous promise that this sector has demonstrated in enhancing the efficiency of solar cells, the commercialization of this technology can be viewed as a major turning point in the solar cell industry. Figures 13 and 14 show the summery of application of nanotechnology in solar technolog

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الخلاصة:

يمكن أن تساعد تقنية النانو في معالجة عقبات الكفاءة الحالية وزيادة توليد الطاقة الشمسية وتخزينها بشكل كبير. تم إنشاء مجموعة متنوعة من العمليات الفيزيائية على المقياس النانوي يمكنها تحسين معالجة ونقل الطاقة الشمسية. فتح تطبيق تقنية النانو في الخلايا الشمسية الطريق أمام تطوير جيل جديد من المنتجات عالية الأداء. عندما تتزايد المنافسة على خيارات الطاقة النظيفة ، تمت مناقشة مجموعة متنوعة من الأساليب المحتملة من أجل توسيع الآفاق. تم استكشاف مبادئ جديدة في مجال توليد الخلايا الشمسية ، والتوليد المتعدد ، وتعديل الطيف ، والخلايا الكهروضوئية الحرارية ، والحامل الساخن ، والفرقة الوسطى ، والعديد من التقنيات الأخرى. لقد ثبت أن الجسيمات النانوية والبنى النانوية تعزز امتصاص الضوء ، وتزيد من تحويل الضوء إلى طاقة ، وتحسن التخزين والنقل الحراري.

نمت صناعة الخلايا الشمسية بسرعة في السنوات الأخيرة بسبب الاهتمام القوي بالطاقة المتجددة ومشكلة تغير المناخ العالمي ، وتعتبر التكلفة عاملاً مهمًا في نجاح أي تقنية شمسية. الخلايا الشمسية اليوم ليست فعالة بما فيه الكفاية وهي مكلفة للغاية لتصنيعها لتوليد الكهرباء على نطاق واسع. ومع ذلك ، فإن التطورات المحتملة في تكنولوجيا النانو قد تفتح الباب أمام إنتاج خلايا شمسية أرخص وأكثر كفاءة إلى حد ما. لقد أظهرت تقنية النانو بالفعل اختراقات هائلة في مجال الطاقة الشمسية. النقاط الكمومية لديها القدرة على تغيير العالم. إنها شكل من أشكال الخلايا الشمسية التي تتخطى تمامًا أي شيء قد تتخيله. قد تكون تقنية النانو قادرة على زيادة كفاءة الخلايا الشمسية ، ولكن التطبيق الواعد لتقنية النانو هو تقليل تكلفة التصنيع. يتم تطوير PVs على أساس CdTe و CIGS (CuInGaSe) و CIS (CuInSe) والمواد العضوية بهدف تقليل السعر لكل واط حتى لو كان ذلك يعني التضحية بكفاءة التحويل والموثوقية. إن استخدام تكنولوجيا النانو في الخلايا الشمسية الرخيصة سيساعد في الحفاظ على البيئة. مصطلحات الفهرس - تقنية النانو ، النقاط الكمومية ، الاختراقات

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تقنية النانو لتطبيقات الخلايا الشمسية

بحث مقدم إلى قسم الفيزياء - كلية العلوم- جامعة ميسان في استيفاء جزئي لمتطلبات بكالوريوس علوم في الفيزياء.

من قبل

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