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NANOTECHNOLOGY: GATEWAY TO RENEWABLE ENERGY

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Abstract

Nanotechnology is the science of engineering and technology which is implemented in nm measurements from 1 to 100 nanometers (nm). The materials based on nanotechnology shows characteristic properties because of the quantum mechanical theory. Nanotechnology helps to produce more robust substances which require decreased energy, reducing the wastage and promising high efficiency. The new photoelectric materials allow the production of solar panels and hybrid semiconductor molecular devices. At the nanoscale, the quantum mechanical effects come into play with increased surface area that influences on the properties of the material. The photon propagation dramatically gets changed according to the size and periodicity of the transient structure approaches the wavelength of visible light. During the propagation, the variable dielectric constant and the rules of quantum mechanics mentions about the limit of the energy as well as wavelength. Photonic crystals have effect over the propagation of the photon in two-dimensional and three-dimensional structures depends on the wavelength of the propagated light in visible as well as infrared region. These structures have been widely studied as tools for advanced nanostructure materials. Researchers are particularly interested in infrared wavelengths and motivate new potential applications photonics properties reveals the the idea for making new devices using the idea of confinement. Nanotechnology has shown a promising development in the renewable energy sector. Potential advances lead to the development of cheaper as well as efficient solar cells. The application of nanotechnology reduces production costs by providing economic solar cells with greater efficiency as current technology. Solar cells use nanotechnology to absorb sunlight which can be interconvert to electricity and helps to preserve the environment.

Keywords: Environment, Nanomaterials, Nanotechnology, Solar cells, Quantum dots.

Introduction

Nanotechnology helps with design and manufacture of 2^{nd} generation and 3^{rd} generation solar cells. Nanomaterials improve the photo conversion efficiency with technologies like thin film, nanowires, quantum dots and other nanostructures. Nanotechnology promises efficient nano-enhanced PV cells cheaper with nanostructures [1]. Nanomaterials has potential to improve the performance of each layer of cell with more conductive electrodes, more efficient absorbers and more transparent coatings. Various nanomaterials are applied for high performance n-type and p-type semiconductors by novel solar cells. Electron transport is improved by addition of nano particles to the matrix.

The development in area of science of interactions, addition of nanoparticles and its function in solar photovoltaic cells is still going on. Small perfect crystals are the building blocks of photovoltaic cells produced on the basis of nanoscience. Nano whiskers as new antireflective coating are being experimented. The location and range of wavelengths that can absorb more sunlight is increased by the use of sensitizing dyes [2]. Quantum dots can generate multiple electrons per photon without obstructing electron transfer. The photovoltaic cells are made a promising pursuit by the applications of nanotechnology. Nanostructured solar cells have large surface-volume ratios for allowing increased sensitizers loading and the potential of an increased number of current producing electron transfer chemical reactions since the specific surface area of the nanostructure could be improved by 1000 times comparing with bulk material.

Currently nanotechnology beat performance barriers and improves conversion and collection of solar energy. Nanotechnology identifies a number of nanoscale physical phenomena's that helps in improving the collection and conversion of solar energy. Nanostructures and nanoparticles seem to enhance the light absorption, conversion of light to electricity and thereby providing better transport and thermal storage [3]. Solar panels which have self-cleaning glass keeps the panel deprived of dirt and debris and it guarantees in receiving as much of the incident solar energy by PV cells. This technique effectively helps the conventional cells to perform at peak efficiency, is an indirect application of nanotechnology to solar panels.

The "Solar Window" fabrication technology allows flexible solar cells created by screen-printing and spraying with organic semiconductors which create thin film photovoltaic cells. Dye sensitized PV cells imply nanotechnology by the use of a solidified dye which prevent leakage but at the same time is effective in capturing solar energy and thus gives a viable lifetime for the cell [4]. The goal was to utilize the benefits of nanotechnology for improving energy conversion and storage phenomenon at the nanoscale, enhancing nanoscale characterization of electronic properties and assist to facilitate economical nanomanufacturing.

Quantum dot sensitized solar cells

The quantum dot sensitized solar cells apply nanotechnology and quantum mechanics theory for enhancing the performance of ordinary solar cells. Quantum dot sensitized solar cell is solar cells design that utilizes quantum dots as a photovoltaic material for photon absorption. Quantum dots which are semiconducting particles, which reduced the size less than the exciton Bohr radius and the electrons energy exist in them become finite similar to energies of that an atom [5]. By changing the size, the energy levels can be tuned which in turn result in tuning of the band gap. The dots are found to be of different size of varying range, which allow to access various band gaps. In typical wet chemistry preparations, the tuning is done by altering the duration of synthesis or by varying temperature.

Band gap of quantum dots are varied along energy levels of wide range by changing the size. The property of tuning the bandgap makes quantum dots desirable for solar cells. Half of the solar energy getting on to earth is infrared, mostly near infrared region. A quantum dot solar cell can access infrared energy, and this can be made used in multi-junction solar cells, in which different materials are used for efficiency improvement by gathering multiple portions in the solar spectrum [6]. Several excitons could be generated upon absorption of a single, energetic photon in a quantum dot. The quantum dot is tuned to liberate various electron-hole pairs on a lower energy as an alternative to one pair at high energy known as "carrier multiplication" (CM) or "multiple exciton generation" (MEG), which increases efficiency via increased photocurrent.

Quantum dots diameter ranges from 2 to 10 nm, that shows energy levels of an electron excited within the QD are discrete. The quantum dot size varies the bandgap and the energy difference between an excited electron within its hole and outside its hole [7]. So, the absorbed energy by electrons in a quantum dot from high-energy photons can be transferred through the excited electron and the electron-hole can be loaded with electron at low energy [8]. Solar cells consist of most important part that is the quantum dots which adsorbs the incoming photons of light and can send out the useful energy, shown in Figure 1.

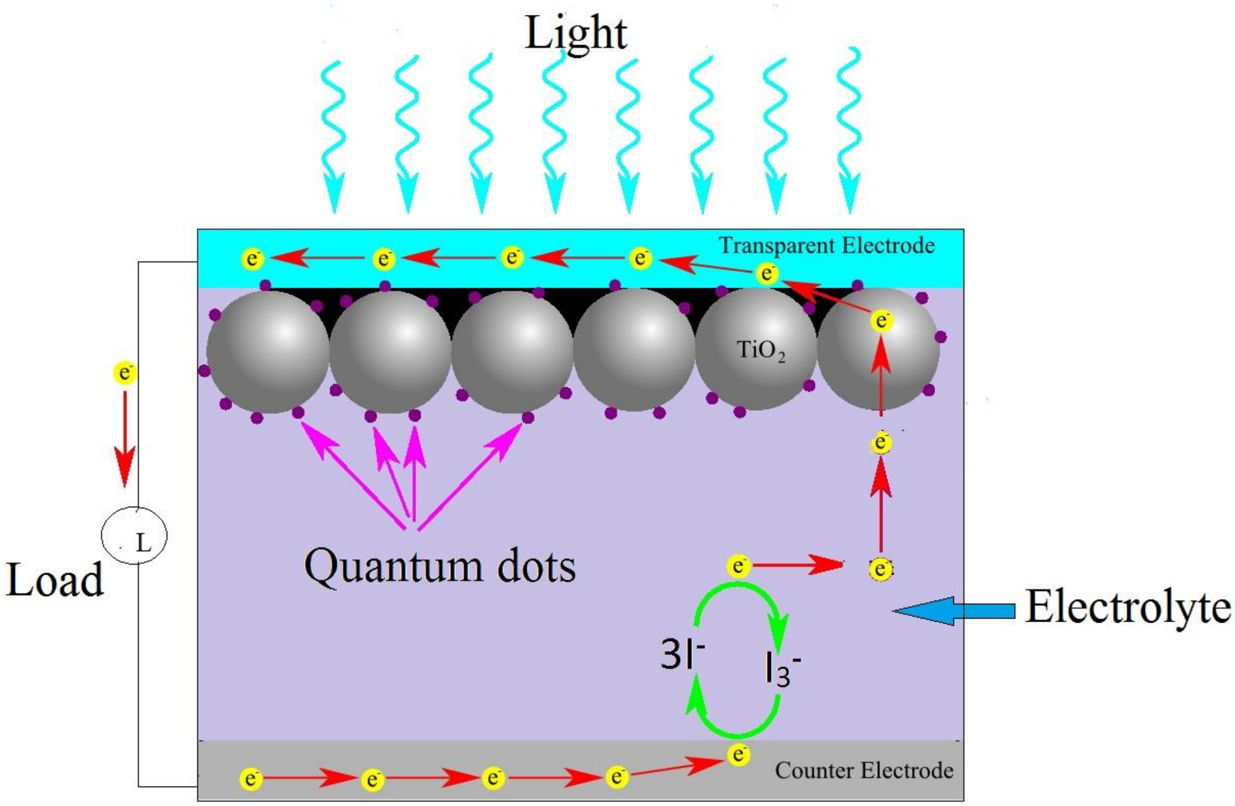

Figure 1. Quantum dot sensitized solar cell

The quantum dot sensitized solar cell works by the photon of light that travels into the cell strikes a quantum dot particle and will raise the electrons energy in the quantum dots. These excited electrons will be injected into the titanium dioxide and will be travelled through the electrodes conducting surface and will form some holes in quantum dots that are to be filled by other electrons. Quantum dots take electrons from electrolyte for filling of these holes while electrons from counter electrode are taken by electron depleted electrolyte. This led to the creation of a cell voltage, and it will in turn induce current. In solar cell, titanium dioxide provides a path for the excited electron to depart the quantum dot, and the electrolyte (usually an iodide solution) allow lower-energy electrons to fill the holes left out by the excitons. This electron flow creates current [9].

For deposition of QD, large surface area is provided by wide bandgap nanostructures such as nanowires, nanorods, mesoporous nanoparticles and nanotubes. Mesoporous films consisting of crystals with nanometer diameter and are sintered together forming a continuous network. Insitu and ex-situ are the two fundamental techniques used for QD sensitization on nanostructured wide bandgap semiconductors. Successive Ionic Layer Adsorption and Reaction (SILAR) and Chemical Bath Deposition (CBD) are the in-situ methods extensively used for sensitization of QDs on nanostructured wide bandgap semiconductors to offer high surface coverages [10]. The wide bandgap semiconductor and QDs direct connection can lead to effective charge injection to the wide bandgap materials from the QD. The pre-synthesized QDs are either linked to wide bandgap semiconductor via molecular linkers or direct ex-situ deposition without molecular linker [11]. But bifunctional molecular linker's chemical nature has a vital role in the separation of charge and in efficiency of conversion of light to electric power in cell. In ex-situ method, the QDs surface coverage on the wide bandgap nanostructured oxide is commonly poor. For efficient operation of solar cell, better absorption of light followed by effective charge separation is needed.

The commonly used electrolytes in QDSCs are organic electrolyte which is aqueous with polysulfide and I^-/I_3^- redox couple. Counter electrodes are usually platinized TCO/ITO layers combination with the redox electrolytes. In case of polysulfide electrolyte, Pt counter electrode result in a low fill factor and Au is alternatively used. The QDs low stability in corrosive electrolytes, requirement for enhanced charge extraction from the QD and recombination by surface traps can beat by passivating the surface of QD contacting with the electrolyte with protective coatings. Inorganic amorphous coatings are deposited onto mesoporous wide bandgap semiconductor electrodes improve the performance of solar cell.

Effect of titanium dioxide on solar cells

Titanium dioxide is the natural oxide of titanium. It occurs in nature as anatase, brookite and rutile forms. The stable and common form is the rutile form. Brookite and anatase forms on heating can be changed to rutile form [12]. Anatase and rutile forms have tetragonal crystal systems and brookite forms have orthorhombic crystal system. It has lot of applications in pigments used (because of high refractive index and brightness, n=2.7) in paint, sunscreen, food colouring and in photocatalytic applications (narrows bandgap energy from 3.2 to 2.45 eV) under UV light [13]. Nanocrystalline TiO_2 has been studied intensively for diverse applications. Recent interest is towards the photocatalytic applications of TiO_2 where particle size, phase, shape and degree of crystallinity of the Titania have vital role [14]. The naturally occurring oxides mined and used are commercial titanium sources. Other minerals like leucoxene ores or rutile beach sand and ilmenite can also be used for metal mining. Conventionally the sol-gel method is used for TiO_2 synthesis, which forms amorphous titania and crystallinity is obtained by thermal treatments [15]. Methologies of synthesizing crystalline TiO_2 without the post treatments are rare. By altering reaction heating rates, we obtain rutile, anatase, and brookite multiphase Titania nanowires and nanotubes. Anatase Titania is a thermally stable compound even at high temperatures. In the chloride process, crude titanium dioxide is purified by converting to titanium tetrachloride. Carbothermal chlorination and Becher process are other methods for upgrading ilmenite. With relevance to nanotechnology, the production of titanium dioxide is done by solvothermal synthesis. Anatase Titania can be converted to anatase nanotubes and nanoribbons by hydrothermal synthesis which is of potential interest as photocatalysts and catalytic supports.

Significance of titanium dioxide nanostructures

Titanium dioxide nanoparticles are ultrafine titanium dioxide produced in the rutile and anatase forms and maintains strong ultraviolet absorption characteristics and photocatalytic activity. Current application of titanium dioxide nanostructures includes photocatalytic degradation of environmental contaminants, dye-sensitized solar cells and solid-state lithium batteries. Other important \applications are in the fields of liquid phase and gas phase catalysis, biosensors, electroplating of composite coatings, photocatalytic coatings on glass tube, opacifier in ceramic glazes, as inorganic UV- absorber, to disinfect and killing cancer cells, for treatment of microcystin, for air purification and antibacterial/antifouling coatings, to create self-cleaning building materials, in sunscreen technologies and lipsticks, in pigments, paints, cements, windows, tiles, sterilizing, hydrolysis catalyst, for micro-optoelectronic applications such as solar cells and light emitting diodes [16].

Under ultraviolet (UV) irradiation, anatase form of Titanium dioxide exhibits photocatalytic activity. In TiO_2, the positive holes having huge oxidative potential can form hydroxyl radicals by oxidizing water . TiO_2 directly oxidizes organic materials or oxygen. Titanium dioxide contained in nanoparticle and thin film form is effective for use as photocatalyst in production of energy which can split water into oxygen and hydrogen to use hydrogen as fuel [17]. The efficiency of this method can be enhanced by doping oxide with carbon and by adding disorder to the lattice structure of surface layer of titanium dioxide nanocrystals result in infrared absorption. The photocatalytic antimicrobial coatings in the form of thin films applied to surfaces and furniture in hospitals which are infected with fungi, bacteria and viruses. Titanium dioxide coated glass exposed to sun exhibit the superhydrophilicity phenomenon result in anti-fogging coatings and self-cleaning glass development. Remediation of wastewater or detoxification is an industrial application of TiO_2.

Currently solar cell is consisting of anode with porous layer of titanium dioxide nanoparticles which led to formation of more porous structure with large surface area . In UV region, TiO_2 can only absorb a small number of solar photons**.** In conduction band of the TiO_2 electrode, the excited electrons get injected resulting in the oxidation of photosensitizer such as dye or quantum dots. The injected electrons in the conduction band of TiO_2 are translocated between nanoparticles of TiO_2 with diffusion toward the electrons and back contact glass substrate and through the circuit reach counter electrode at the end. The solar cells efficiency depends on the TiO_2 electrode Fermi level [18]. The rate of photon absorption depends on the sensitized TiO_2 layer absorption spectrum and the solar flux spectrum and the maximum possible photocurrent is determined by the expansion over the solar flux spectrum and the absorption spectrum. Titanium dioxide nanoparticles with mesoporous anatase wall are preferred. It is the most commonly used crystalline phase of TiO_2 for photochemical applications and so preferred for photo catalysis. Mesoporous TiO_2 has attracted much attention because of its high surface-to-volume ratio [19]. It can hold the the quantum dots in place and can establish a pathway for traveling of electrons from the quantum dots to the electrodes conducting layer. By considering smaller area, the titanium dioxide has large surface area to hold large number of the quantum dots.

Nanoscience and nanotechnology research bring new chemical and physical properties of nanomaterials of TiO_2, and new opportunities are provided for the TiO_2 based solar cells development [20]. Mesoporous TiO_2 film having large surface area that can largely improves the power conversion efficiency (PCE) [21]. Solar cells mostly consist of mesoporous metal oxide layer composed of TiO_2 nanoparticles network which can be sintered together for establishing electronic conduction [22]. An enhancement in surface area can be provided by mesoporous titania architecture resulting in high surface area for adsorption of sensitizer. In TiO_2, the injected electrodes are collected at the conducting glass surface through transport across the disordered network of TiO_2 nanoparticles [23]. The interaction of TiO_2 with surrounding environment such as electrolytes and sensitizers have relevant impact on the interfacial properties, PV performance and charge transfer kinetics.

The metal oxide layer sensitization with quantum dots (QDs) such as CdSe, CdS, PbS, InP and Bi_2S_3 have attained relevant consideration for the promising photovoltaic devices [24]. The band gap tuning of QD can done through controlling the size of nanoparticle, which makes absorbtion of visible response and the energies together at the interfaces of surrounding media and the QDs. The overall efficiency of the device and the ability for harvesting light of the photoanode can be increased by improving the high extinction coefficients of QDs [25]. For adsorption of quantum dots, a mesoporous structure is provided for the metal oxide. The levels of bandgap edges have to be adjusted with respect to the electrolytes and quantum dots because the voltage generation mainly depends on the band edges.TiO_2 is more stable, non-toxic and highly abundant compared to other metal oxides. TiO_2 have suitable band adjusts for injection of electrons from most quantum dots and high electronic mobility for photogenerated electron collection. TiO_2 is robust, stable, non-hazardous and reliable [26]. Due to its high stability, the electron drift is maximum as the charge transport is concerned. The thermodynamic efficiency limit of the QDSCs can be increased by multiple exciton formation by absorption of a single photon in QDs, making QDSCs an effective alternative in photovoltaic applications.

The light harvesting effect of QDs has ensured the adequate potential to prepare excellent performing solar cells and one of the reasons behind QDSCs average conversion efficiency is the the existence of surface traps on the QDs [27]. The recombination in device which is trap mediated can be increased by surface traps which can act as recombination centers. The recombination processes and injection are affected by surface states in QDs. The surface traps operate as recombination centers moreover enhance trap mediated recombination in the device. The QDs surface states influence the injection and recombination. The in-situ synthesis of QDs on TiO_2 surface creates well-organized charge injection into the TiO_2 material from the QD [28]. This method ensures more loading of QD photoanodes and progressively more photocurrents, however QDs gained a broad size distribution and poor crystalline quality. Either linker molecules connect presynthesized QDs to the TiO_2 nanostructure or directly deposited in the absence of linker molecules on TiO_2 but the injection of electron from QDs to TiO_2 is comparatively less with linker molecules comparing with the direct deposition QDs. In addition, the recombination of charge between the TiO_2 electrons, the hole transport material also comprise electron loss since large area of the surface of TiO_2 is in direct contact. An ideal TiO_2 structure balances between the minimal recombination with the need of screening effect increase and the desired surface area for the light absorption. The larger amount of TiO_2 particles might direct to improved photon absorption as well as decreased carrier-migration distance due to enhanced light trap consequently improving the device performance. The application of wide band gap materials thin layer coating passivates surface states, and the internal charge recombination is reduced but also obstructs the tunneling of hole and it will reduce transfer of charge. Hence an effective control of the TiO_2 coating width is critical for device performance optimization.

Titanium dioxide nanomaterials have shown compatibility with modern technologies thus it can be used in solar energy conversion to electricity. The continuous innovations in the modifications and synthesis of nanomaterials of titanium dioxide have applications and relevent properties in the photovoltaic filed with performance improvement. Apart from that, novel concepts based newly developed devices have expanded the titanium dioxide application range and also intended new requirements for titanium dioxide properties. The major advancement of nanomaterials of titanium dioxide to photovoltaics include the polymer-inorganic hybrid solar cells, dye-sensitized solar cells, perovskite solar cells, inorganic solid-state solar cells and quantum dot-sensitized solar cells.

TiO_2 nanomaterials take part an important responsibility in efficient and low expenditure photovoltaic technologies. The charge transferring depend on the properties of titanium dioxide interface and nanomaterials of titanium dioxide in the photovoltaic devices. The chemical and physical properties of nanomaterials of titanium dioxide are maintained through modification of nanocrystal structure, shape, size and organization. The interface properties of titanium dioxide can be maintained through the interaction between surrounding elements and TiO_2, including charge transport materials, additives, light harvesters and interfacial modifiers [29]. By sensible control of the interfacial and intrinsic properties of the nanomaterials of TiO_2, great advancement has made in controlling the energy distribution, light harvesting, charge transfer, charge transport and separation properties in the devices and it can fairly boost the performance of the devices. Efforts are taken for development of large-scale preparation of high-quality, cost-effective nanomaterials of titanium dioxide and transformative technology to be aware of marketing economically feasible solar panels with vast range of application [30]. Sunlight can be concentrated in nanowires due to a resonance effect. This effect will result in more efficient solar cells, which in turn allows conversion of more sunlight energy into electricity. It is understood that future research efforts on innovative materials and key interfaces will create the titania-based solar cells as a new PV energy source.

Conclusion

Green chemistry makes use of few principles that can decrease the use and formation of harmful substances in the design, manufacture, application and disposal of chemical products. In recent times, development of green chemistry methods designed for synthesis of nanoparticles has become a major focus. Novel and enhanced synthesis technique provide improved environmental performance on principles of green chemistry. Nanoparticles prepared by green way are more stable and have low toxicity. The benefits of nanotechnology can be utilized for improving energy conversion and storage phenomenon at the nanoscale, enhancing nanoscale characterization of electronic properties and assist to facilitate economical nanomanufacturing.

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