SYNTHESIS OF QUANTUM DOTS AND MESOPOROUSE OF TiO FOR SOLAR SELLS

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Məqalədə qünəş elementlərdə (QE) qünəş enerjinin çevrilməsini yaxşılaşdırmaqda nanotexnologiyanın inkişafı haqqında qəsa məlumat verilir. QE-də istifadə üçün kvant nöqtələrin CdSe, $CuInS_2$, PbSe orta qadağan zonalı materiallarda sintezi müzakirə edilir. Bu kvant nöqtələri fotovoltaik çevriçilərdə (FVÇ) böük istifadə potensiala malikdirlər. Kvant nöqtələr işıqı adi FVÇ fərgli olaraq daha enli spektrdə udurlar, orta qadağan zonaya malikdirlər və hər bir udulmuş foton üçün üç elektron əmələ gətirir. Diqər tərəfdən mezoməsaməli TiO nazik təbəqədən istifadəsi çox böyük daxili səthi tə'min etdir, o isə QE istifadə olunan materialların azalmasına qətirib çıxarır. Bu QE çox perspektivdirlər, ona qörə ki materialların açağı qiymətinə malikdirlər və xüsusi avadanlıq tələb olunmur.

В статье дается краткий обзор развитию нанотехнологии для улучшения преобразования солнечной энергии в солнечных элементах (СЭ). Рассматривается синтез квантовых точек в области промежуточной запрещенной зоны в CdSe, $CuInS_2$, PbSe для использования в СЭ. Эти квантовые точки имеют огромный потенциал для применения в фотовольтаических преобразователях (ФВП). Квантовые точки поглощают свет в более широком спектре, чем традиционные ФВП, имеют промежуточную запрещенную зону и могут образовывать целых три электрона на каэдый поглощенный фотон в противоположность обычному ФВП, в котором образовывается один электрон на каждый поглощенный фотон. С другой стороны, применение также покрывающей пленки TiO с мезопористой структурой также обеспечивает огромную внуреннюю площадь поверхности, поэтому приводит к уменьшению количества материала необходимого в СЭ. Эти СЭ являются очень перспективными, потому что имеют меньшую стоимость материала и не требуют специального оборудования для изготовления.

There is a brief review in given paper about progress of nanotechnology for improvement of solar energy transformation in solar cells. The synthesis of quantum dots of CdSe, $CuInS_2$, PbSe for use in intermediate-bandgap solar cells are considered. These quantum dots have huge potential for photovoltaic applications. Quantum dots absorb light in a larger spectrum than traditional PVs, have an intermediate bandgap and can produce as many as three electrons for every photon absorbed from the sun - traditional PVs only produce up to one electron per photon absorbed. On other hand, also application of the mesoporous nature of the covering TiO film provides an enormous internal surface area, therefore reducing the amount of material needed in the cell. These cells are extremely promising because they are made of low-cost materials and do not need elaborate apparatus to manufacture.

1. BACKGROUND

Today's world energy demands are satisfied mainly via the combustion of fossil fuels. Of the 210 million barrels of oil equivalent per day used worldwide, about 85 million barrels come from oil: the rest comes from coal (23%). gas (17%), biomass (17%). some fission (5%). little hydroelectric (6%) and almost none from renewable resources. It is estimated that by 2050 we will need twice the amount of energy that we are burning or consuming today (about 14 Terawatts, TW). By then it is expected that the world's population will use from today's 6.3 billion people to 9 billion people. Relying on fossil fuels (oil. coal and natural gas) to 'feed" the world's future energy needs is not a responsible environmental option, since there is some evidence that the combustion of fossil fuels is the main cause of the high levels of greenhouse gases such as carbon anhydride (CO:) that are accumulating in the atmosphere, with consequent dramatic worldwide climatic changes [1].

Therefore, there is an urgent need for energy resources alternative to fossil fuels. Of these, renewable energy sources (solar, wind, geothermal. hydro etc.) are an option. However, tremendous technology breakthrough will need to occur in the next years to make the conversion of these energy resources an efficient and economically viable option.

Solar energy is an excellent example. Every day the Earth is hit by 165,000 TW of solar power [2]. The problem is obviously solar energy collection, conversion, storage and distribution, winch needs to be efficient and cost-effective. Current solar panels have about 25% energy conversion efficiency, but they are very expensive. Since solar light is only available during part of the day, suitable storage solutions also need to be found.

Another alternative energy source is hydrogen, but hydrogen fuel cell technology will have to face a number of issues (e.g., hydrogen extraction, hydrogen storage, fuel cell lifetime and cost, just to mention few) before a hydrogen economy can become a reality. Solving the future energy challenges does not only require advancements in the field of energy conversion and storage, but also energy saving, considering how much energy is wasted today using conventional incandescent lights. Nanotechnology not only has the potential to solve many of the issues that the energy sector is facing, but its application to this sector has already resulted in advanced research projects and some commercial realities.

Among the renewable sources of energy, solar energy holds a great potential. The main problem associated with this form of energy is not its supply, but the development of devices that will allow for its efficient and cost-effective conversion into electric current. Presently, solar energy conversion is done using solar photovoltaic cells (PV) devices made of semiconductors that generate an electric current when illuminated.

2. NANOTECHNOLOGY

The Nanotechnology is the art and science of building stuff that does stuff at the nanometer scale. This definition is therefore inclusive of science in speaking of nanotechnologies; for our purposes here reference to nanotechnology will include science in its fold. Nanomaterials have been used for centuries – from the use of nanometer-size gold particles for red stained glass to soot from candles in inks etc. Nanoparticles can be both man-made and naturally occurring. What is different today is that technological advancements have enabled us to see these materials and begin to understand how their shape and size can be used to good effect, and with this ability, we can begin to change them so that they are more exploitable. This development is best summed up by The Royal Society and the Royal Academy of Engineering, UK – they define Nanotechnology as the ability to measure, see, manipulate and manufacture things between 1 and 100 nanometers (1 billionth of a meter)—is seen as the driver of a new industrial revolution emerging with the development of materials that exhibit new properties and potential new risks and benefits at this tiny scale. But in other fields, such as biochips the objects have dimensions in the range of hundreds of nanometres. Nanomaterials are categorized according to their dimensions (see table):

Table.

Nanomaterials categorized based their dimensions

Nanomaterial dimension	All three dimensions < 100 nm	Two dimensions < 100 nm	One dimension < 100 nm
Nanomaterial type	Nanoparticles, quantum dots, nanoshells, nanorings, microcapsules	Nanotubes, fibres, nanowires	Thin films, layers and coatings

Nanotechnology is a platform technology that utilizes the inherently unique properties of matter that arise at the nanoscale. Applications of this technology can be found in areas of material sciences, medicine, energy, environment, communications and electronics among others. The enormous international S&T investment in nanotechnology research has evolving, and potentially endless possibilities. Researchers continue to find new applications for nanomaterials. Whether it is using carbon nanotubes to make vehicle composites stronger than steel, but lighter (thereby improving fuel economy), or creating medicines that can target and treat specific cells in the body, or purifying water at point of use, nano could revolutionize some sectors.

Nanotechnology (NT) has the potential to revolutionize the entire energy sector both in terms of finding new resources and maximizing the utilization of existing ones.

In terms of maximizing current energy resources, NT offers two main approaches. First, an ability to *secure more* resources at a cheaper cost (for example, retrieving more than 95% of the oil out of the well). Several examples of how NT achieves this goal include subsurface sensors that can be used to improve both the discovery and the recovery of hydrocarbons; better materials to make it easier, cheaper and faster to extract oil. Corrosion problems caused by bacteria during oil production can be solved with the help of self-assembled layers that contain silver nanoparticles which in turn inhibit or kill the corrosive bacteria. NT also offers alloys and additives that increase material performance, making drilling bits and pipes stronger, more wear-resistant, and lighter, thus decreasing drilling costs.

3. SOLAR ENERGY AND PHOTOVOLTAICS

The main two problems of current PV are efficiency and cost. The efficiency of a PY depends on the type of semiconductor it is made of, and on its absorbing capacity. All semiconductors adsorb only a precise 'energy window' (the 'band gap") which is just a fraction of the entire solar energy available. Presently, maximum energy conversion efficiency (around 25%) in a PV cell is obtained when this is made of crystalline Si. This excellent conduction material has the main drawback of being very expensive to produce, which is reflected in the high cost of current PVs. Alternative, cheaper materials, such as TiO_2 can be used in PV technology; this material is less conductive, so it leads to cheaper PVs. but with lower energy conversion efficiencies.

Nanotechnology can be used to introduce alternative materials and fabrication methods to produce cells with tailored adsorption characteristics, whilst retaining acceptable conversion efficiency (10-15 %) and reduced cost. Examples are crystalline solids with a controlled conductivity band gap to optimize energy absorption and highly ordered thin films. Increase of PV absorption rates can also be obtained using multi-junction solar cells, i.e. stack of thin-film semiconductors with band gaps of different energies, and 'sensitized semiconductors", where surface attachment methods are used to attach some other strongly absorbing specie. These type of cells, called dye-sensitized cells [3] or Gräztel cell from the name of its inventor, belong to the group of thin-film solar cells and use complex dye molecules (sensitizer) attached to the surface of a wide-band-gap mesoporous oxide semiconductor like TiO_2.

Different from classical thin-film cells where light is absorbed in a semiconductor layer, absorption occurs in the dye molecules. The dye molecules act in some way like an antenna, meaning that more of the light of a particular colour can be captured but also that a wider range of colours of light can be absorbed compared to pure TiO_2, this way increasing the efficiency of the device.

The mesoporous nature of the oxide provides an enormous internal surface area, therefore reducing the amount of material needed in the cell. The TiO_2 films are produced from a nanoparticle suspension (which is synthesised to form a stable porous material). Specific synthetic dyes have been designed with a matching of the energy levels in the dye and the titanium oxide, (increasing the efficiency of transfer of the photon energy absorbed by the dye to the titanium oxide and consequently to be used to generate power). These cells are extremely promising because they are made of low-cost materials and do not need elaborate apparatus to manufacture. Current scale up of production utilizing polymer materials and roll to roll continuous production has the potential to produce the large areas of solar cell required to capture significant amounts of solar energy.

An important nanotechnology discovery that has a great potential to increase the efficiency of solar cells was reported in May 2006 by a team of the Los Alamos National Laboratory. Researchers from this group found that when nanoparticles of less than 10 nm in diameter made of lead and selenium (PbSe nanoparticles) are illuminated with light they adsorb one photon of light but produce up to three electrons [4]. When today's photovoltaic solar cells adsorb one photon of sunlight, the energy gets converted to one electron, and the rest of the photons energy is lost in heat. Therefore PbSe nanoparticles produce at least twice the electrons compared to conventional semiconductors, a process known as “carrier multiplication”. This nanotechnology discovery could boost the efficiency from today's solar cells of 20-30% to 65%.

4. QUANTUM DOTS AND SOLAR CELLS

Quantum dots (QD) are another class of nanomaterials that are under investigation for making more efficient displays and light sources (QD-LEDs). These are nanoscale semiconductor particles characterized by emitting a specific colour based on the size of the nanoparticle. A minute change in particle size results in a totally different colour they emit; for instance a 6 nm-diameter particle would glow red, while another of the same material but only two nanometers wide would glow blue. Light emission from a QD is monochromatic, therefore is very pure. As a consequence, their use in displays would lead to images with exceptional image quality.

The most exciting property of QD-LEDs, though, is that they use much less power than currently employed LCDs. This arises from the fact that QD-LEDs are not colour-filtered. A LCD display is powered by a fluorescent lamp that is colour-filtered to produce red, green and blue pixels. Thus, when a LCD screen displays full white colour, two-thirds of the light is absorbed by the filters. QD emit light, rather than filtering it, so for this reason QD-LEDs are expected to be more energy efficient. In June 2006, QD Vision announced a first proof of concept of a quantum dot display [5].

The NASA Glenn Research Center has been investigating the synthesis of quantum dots of CdSe and $CuInS_2$ for use in intermediate-bandgap solar cells. Using quantum dots in a solar cell to create an intermediate band will allow the harvesting of a much larger portion of the available solar spectrum. Theoretical studies predict a potential efficiency of 63.2%, which is approximately a factor of 2 better than any state-of-the-art devices available today [6]. This technology is also applicable to thin-film devices--where it offers a potential four-fold increase in power-to-weight ratio over the state of the art.

Intermediate-bandgap solar cells require that quantum dots be sandwiched in an intrinsic region between the photovoltaic solar cell's ordinary *p*- and *n*-type regions. The quantum dots form the intermediate band of discrete states that allow subbandgap energies to be absorbed. However, when the current is extracted, it is limited by the bandgap, not the individual photon energies. The energy states of the quantum dot can be controlled by controlling the size of the dot. Ironically, the ground-state energy levels are inversely proportional to the size of the quantum dots.

Dr. Ryne P. Raffaelle and et.al. [7] have prepared a variety of quantum dots using the typical organometallic synthesis routes pioneered by Ba Wendi et al., in the early 1990's [8]. The most studied quantum dots prepared by this method have been of CdSe. To produce these dots, researchers inject a syringe of the desired organometallic precursors into heated triocytlphosphine oxide (TOPO) that has been vigorously stirred under an inert atmosphere. The solution immediately begins to change from colorless to yellow, then orange and red/brown, as the quantum dots increase in size. When the desired size is reached, the heat is removed from the flask. Quantum dots of different sizes can be identified by placing them under a "black light" and observing the various color differences in their fluorescence.

Unlike previous work in this area, NASA Glen Research Center used single-source precursor molecules in this synthesis process. $CuInS_2$ precursor molecules were prepared using a metasthesis reaction of an organoindium reagent in a nonaqueous solution. The precursors were used in the same process just described to produce nanoscale CuInS quantum dots for photovoltaic applications.

Nanotechnology research is a huge area of contemporary research and has exciting potential in a number of industries from medicine to materials science to energy generation. Today, we'll look at two potential applications of nanotechnology for energy generation. Both offer some pretty incredible numbers and are certainly exciting to think about.

Jesse Jenkins [9] first focus on "quantum dots", tiny nano-scale (generally smaller than 10 nanometers) semi-conductor crystals of materials like Cadmium-selenide (CdSe) or Lead-selenide (PbSe). These quantum dots have huge potential for photovoltaic applications because, as semiconductors, they can, like the silicon in traditional PVs, absorb photons from solar radiation and release electrons to generate electricity. However, while silicon-based PVs absorb a small fraction of the energy in the sun - the best achieve efficiencies of only ~33% and most operating around 10-15% - and radiate the remaining portion as waste-heat, quantum dots could theoretically convert up to 65% of incoming solar radiation into electricity. Quantum dots absorb light in a larger spectrum than traditional PVs, have an intermediate bandgap and can produce as many as three electrons for every photon absorbed from the sun - traditional PVs only produce up to one electron per photon absorbed. Furthermore, as they absorb more of the solar energy, they release less in the form of heat, solving some of the heat-managment issues associated with traditional PV designs.

Paras N. Prasad from University of Buffalo Institute for Lasers, Photonics and Biophotonics explains: "Current solar cells act only in the green region, thus capturing only a fraction of the available light energy. By contrast, we have shown that these lead selenide quantum dots can absorb in the infrared, allowing for the development of photovoltaic cells that can efficiently convert many times more light to usable energy than can current solar cells."

Prasad and the UB Institute for Lasers have recently patented two new efficient and highly scalable chemical synthesis method for the production of quantum dots. One method is used to produce quantum dot-polymer nanocomposites that absorb photons in the infrared region for use in photovoltaics. The second method produces quantum dots for medical applications where they are used as non-toxic luminence probes that allow bioimaging unprecedented details.

Quantum dots could be used to manufacture extremely efficient thin-film PVs. Because of the efficient photon harvesting ability of quantum dots, in the immediate future Yudhisthira Sahoo will be able to incorporate a few different types of quantum dots simultaneously into a plastic host material so that an efficient and broad band active solar device is possible [Yudhisthira Sahoo, UB Department of Chemistry].

Needless to say, if a cheap, efficient and scalable manufacturing process for quantum dot-based thin-film PVs operating at ~60% efficiency could be developed, and the reasearchers at UB seem to be on the right track, we would see a true revolution in photovoltaic power.

5. SOLAR ENERGY STORAGE AND SAVING

Storage of electrical power is critical for making solar energy a primary power source. The best place to provide this storage is locally, near the point of use. Ideally every house, every business, even- building should have its own local electrical energy storage device, an uninterruptible power supply capable of handling the entire needs of the owner for 24 hours. If tins were done using today's lead-acid storage batteries, such a unit for a typical house capable of storing 100 kilowatt hours of electrical energy would take up a small room and cost over S10.000. Through advances in nanotechnology. it may be possible to shrink an equivalent unit to the size of a washing machine, and drop the cost to less than $1,000 [10].

Solar energy can also be used as a heating source to produce hot water, and heat home and offices. Since the Sun is a variable source that produces a diffuse energy, controlling the incident solar radiation is difficult because of its changing position. Nanotechnology can be used to fabricate complex nano-structured mirrors and lenses to optimize solar thermal collection as well as aereogels with nanopores to be used as transparent and thermally isolating material for the cover material of solar collectors.

Energy saving can be achieved in numerous ways, such as improving insulation of residential homes and offices; use more efficient lighting; and using lighter and stronger materials to built devices, which then would require less energy to operate. Also, a large portion of energy is lost during its transport, so there is a need for a more efficient electric grid to transport energy.

Nanotechnology can potentially be applied to all of these energy saving materials and technologies. One example is nanoporous aerogels to improve thermal insulation. A commercial example is represented by Aspen Aerogels products. This company produces flexible aerogel nanoporous insulation blankets (e.g. Cryogel™) designed for cryogenic applications (for instance, for insulating pipes and tanker ships) [11]. These insulation blankets can be cut as normal textiles, installed faster than traditional materials, and their low thermal conductivity allows for less material usage. Additionally, the Aspen's product are resistant to compression and inherently hydrophobic so they can be exposed to water for long periods without damaging the product outstanding thermal properties.

Another important application of nanotechnology in the area of energy saving is the production of more efficient lighting devices. Conventional incandescent lights are not energy efficient, a large portion of their energy being dispersed in heating. Solid state light devices in the form of light emitting diodes (LEDs) are attracting serious attention now as low-energy alternatives to conventional lamps. The need is to engineer white-light LEDs as a more efficient replacement for conventional lighting sources.

One proposed solution is to use a mixture of semiconductor nanocrystais as the intrinsic emitting layer for a LED device. Simply mixing several colours of nanocrystais together to achieve white light is a possibility, but this would result in an overall reduction of device efficiency through self-adsorption between the various sizes of the nanocrystal. An important result that can potentially resolves this problem came recently from the work of some researchers from the Vanderbilt University. They found that crystals of cadmium and selenium of certain size (called 'magic sized" CdSe) emit white light when excited by a UV laser [12], a property that is the direct result of the extreme surface-to-volume ratio of the crystal. This material could therefore be ideal for solid state lighting applications.

CONCLUSION

We have considered the progress of nanotechnology for improvement of solar energy transformation in solar cells. The synthesis of quantum dots of CdSe, $CuInS_2$, PbSe for use in intermediate-bandgap solar cells are analysed. These quantum dots have huge potential for photovoltaic applications. Quantum dots absorb light in a larger spectrum than traditional PVs, have an intermediate bandgap and can produce as many as three electrons for every photon absorbed from the sun - traditional PVs only produce up to one electron per photon absorbed. Increase of PV absorption rates can also be obtained using multi-junction solar cells. On the other hand, also application of the mesoporous nature of the covering TiO film provides an enormous internal surface area, therefore reducing the amount of material needed in the cell. These cells are extremely promising because they are made of low-cost materials and do not need elaborate apparatus to manufacture.

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