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Nano-Technology Applications in Solar Energy

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Abstract

The introduction of the nanomaterials in the solar industry will have amazing affects. Already these technologies have been utilized to increase efficiency of solar plans while decreasing their costs. If their technological advances continue to take place, and if these nanomaterials are used in all solar products, solar energy could become the cheapest from of energy available, surpassing oil and coal. Nanotechnology is being used in several ways. The Nano solar company has created a panel that uses a nano coating to increase the surface area of panels. This is similar to the nanofibers that other companies are using to also increase surface area. Nano tubular Titania Photoanodes can increase light absorption and decrease surface impurities of solar panels. The Rensselaer Researchers have invented a nanotechnology that not only boosts surface absorption, but also can track the sun for constant peak light. And quantum dots have been used experimentally to increase efficiency. Currently solar energy's biggest problem is the high cost compared to other options. Combined with its relatively low efficiency, it is easy to see why it is not more prominent in today's world. However, the introduction of nanotechnology solves those major problems, and may be the solution to our global energy crisis.

Keywords - Photovoltaic; Nanofibers; Quantum Dots; Nanotubular Titania Photoanodes; Carbon Nanotubes.

I. INTRODUCTION

With the increase of greenhouse gas production, [1] scientists have been looking for an affordable alternative energy. Although much alternative energy exists, their main downfalls are efficiency and affordability. The introduction of nanotechnology into this field could help to eliminate those problems. Specifically, with solar energy, nanotechnology has helped to push the industry to a place where it can potentially be competitive with other, more common forms of energy. Greenhouse gas emissions are at an all-time high. CO2 emissions are up by 500% since the 1950s. [1] Although scientists are still debating the exact impacts these emissions have on our atmosphere and environment, most all are in agreement that there is in fact an impact. Combine that with the fact that our main source of energy up to now has been coal and other fossil fuels, both limited resources, and it is clear that something must change. Scientists and researchers all over the world have been searching for solutions to our global energy crisis, and although alternative energy sources have existed for a while now, none are widely used yet. Without a change in our current energy usage, not only will we one day reach the point where there is no more oil to use, we will also have done unknown damage to our planet. The emission of CO2 and other dangerous

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gases can lead to a "greenhouse effect." This would cause an increase in global temperature, melting polar ice caps, and global flooding.

II. Environmental Issues

One possible solution to this global energy crisis is solar energy. The sun is an endless resource, providing nonstop energy that is ready for use. Solar panels do not emit CO_2 and have no waste products. Currently, we are not taking advantage of this unlimited energy source. Australia, for example has about 15,000 times more energy falling on the surface than the country's energy usage. The use of solar energy as the India's main energy source could help to end our dependence on foreign oil. It would also help to de-centralize our energy sources. In doing so, natural disaster and foreign controversy would not have a negative impact on our nation's energy.

III. Conventional Approaches

A. How Solar Works

Solar panels consist of an array of photovoltaic cells. These cells are what convert sunlight into electricity. In conventional methods, these cells are made up of semi-conductor, usually silicon. When sunlight hits the cell, it is absorbed by the semiconductor and can "knock" an electron loose. Electric fields are used to direct electrons to create a flow of current, making electricity. [2] This current can be drawn off the cell to use externally.

Solar cells are not made with pure silicon. Impurities are imperative for the photovoltaic cells to work. Due to the fact that its outer electron shell only has 4 electrons, silicon atoms covalently bond with other atoms to create crystalline structures. If an atom with 5 electrons in its outer shell were introduced, say phosphorus, there would be an extra electron not being bonded with the silicon atoms. Since the protons in the nucleus of the atoms have a strong enough positive charge, it holds that extra electron in place, until energy from the sun is added, and the electron is able to break free of that bond.

This process of adding impurities is called doping, and this is a negative, or N-type dope. To balance out the extra electrons added by the phosphorus atoms, a positive, or Ptype dope must also exist. This is done by adding another atom with only 3 valence electrons, like boron. Doing this creates "holes" in the crystalline structure. Eventually a balance can be reached between the positive holes and negative electrons, creating an electric field. (see figure 2.1) This diode allows electrons to flow from negative to positive, but not the other way around. [2] When a photon hits the cell, it excites the electron-hole pair and frees if from the diode. The positive hole will go to the positive side, and the negative electron moves to the negative side. The movement of the electron creates the current.

Besides the silicon, two other layers of the solar cell are very important. First, there is an antireflective coating. Reflected photons will not provide energy, therefore this coating can increase the efficiency of the cell. There is also a glass cover plate to protect the photovoltaic cells from the elements. For a cross-section diagram of a solar cell see figure 2.2. [2]

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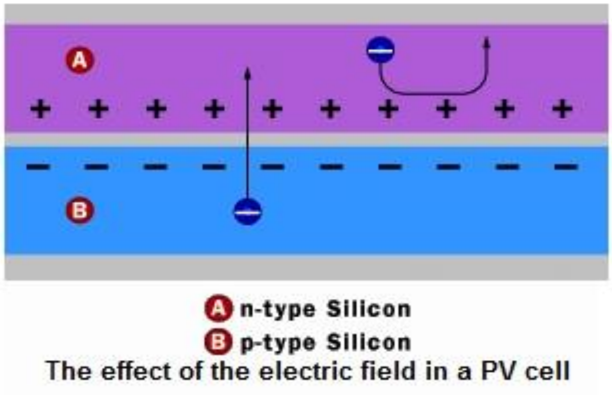

Fig 2.1

B. Current Solar Panel Technology

There are two types of solar panels. The first is made with silicon wafers, and the second is thin-film cells. Silicon wafers are generally considered the first generation or first phase of solar panels. It was the first type of solar panel on the market. The next step up was the second generation thin-filmed photovoltaic panels. Single crystal and multi-crystalline silicon wafers currently dominate the market; it is estimated that the multi-crystalline method accounts for 63% of it. Refer to section [III A] for how these silicon-based solar cells work.

There are many downsides to the traditional silicon crystal type of solar panel. First, they are not very efficient. Average efficiency of single-crystal wafers ranges between 18%-21%. For multi-crystalline wafers, efficiency is much lower, 13%-14%. However, this method is more commonly used because it is relatively lower in cost per watt than single-crystals.[3] The more important downside to silicon wafers is the cost. Currently, it costs about $4/W for solar energy which is too high to be competitive with any cheaper form of energy.

Prices are so high because silicon is an expensive commodity. Not only that, during the manufacturing process, as much as 70 percent of silicon is wasted.[4] One way to bring this cost down would to be to use less silicon. Currently most silicon wafer cells are between 200-250 µm thick. If this thickness were reduced, and less silicon is used, the price would decrease. This is the idea that drove the creation of thin-filmed photovoltaic cells.

Thin-film photovoltaic cells use an amorphous-Si or a polycrystalline-Si deposited on glass. In this form, silicon can absorb the solar spectrum more efficiently than in crystal form. It also only uses between 1-10 µm of silicon.[3] This creates a significant decrease in the price of the solar panels. In fact, using thin film technology, it is possible to reach the $1/W mark to make solar a competitive form of alternative energy. However, there is a downside. Thin-filmed solar panels tend to be less efficient, and have a shorter life

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span. However, combining this technique with nanotechnology, solar can become more efficient and cost effective than ever before.

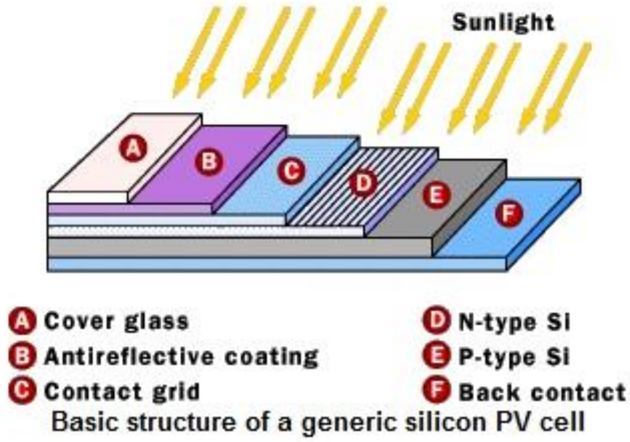

Fig 2.2

IV. Nanotechnology based Approaches

A. Nanotechnology Application

Nanotechnology has been applied to the solar industry in several different ways. There are many companies and universities currently researching the various ways that nanotechnology can help to boost solar panel efficiency, as well as decrease the panel costs. In most techniques, nanosized particles are used to increase the surface area of the photovoltaic cells, allowing them to take in more sunlight and energy, thus increasing their efficiency. The first commercial company to integrate a nano product to their solar cells was the Nano solar company.

According to Nano solar, silicon wafer cells were the first wave in solar technology. The second wave was thin-filmed cells, successfully producing solar panels that were 100 times thinner, and still as efficient as the silicon wafer cells. Nano solar’s product, which they refer to as the third wave, is called Power Sheet cells. Compared to current prices between $3 and $4 per watt, the Power Sheet cells are available at just 30 cents per watt. For the first time in history, solar could be cheaper than burning coal. Power Sheet cells are a type of thin-film panel, with the coating the thickness of a sheet of paint. The technology behind this has been around for years, however, Nano solar was the first company to manufacture and mass produce the Power Sheets.[5] Although the technology is similar to that of thin-film photovoltaic cells, there are a few key differences. First, Nanosolar uses a metal foil substrate, instead of depositing the films on glass or stainless steel. This can increase the yield by up to 20%. They developed a low-cost, high-performance electrode, increasing efficiency and decreasing overall costs. They also use a technique called individual cell matching and sorting. Normally, and bad or electrical mismatched cell would result in a decrease in panel yield and efficiency distribution. With thin-film on glass technology, a bad cell would result in a bad panel. However, with the cell-sorting technology, only that one cell is lost. [5] Next, they use high-yield, continuous roll-to-roll processing. This “allows large quantities of material to be processed with equipment that leaves a small footprint.” [5] Finally, they developed high-powered, high-current panels at a lower cost. This first commercially available nanotechnology solar product is a huge step for the solar industry. If, in fact, solar could become less expensive than coal, there is a much greater chance of solar become the main form of energy in the United States, and the world.

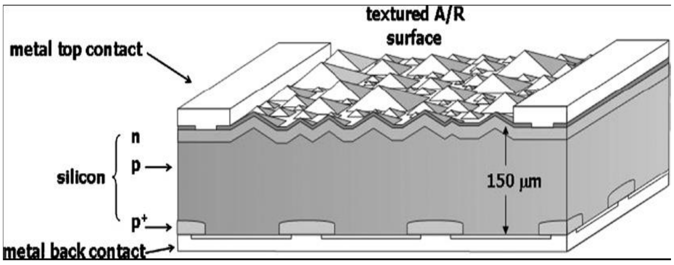

Fig 2.3

B. Different Nanomaterials

Researchers at the University of California San Diego, have been growing "photovoltaic" hairs, or nanofibers, on solar cells. These nano hairs being grown by UCSD are products of a process known as electrospinning. This process involves applying an electric field to a drop of fluid. The setup of an electrospinning device is shown in Figure 3.1. These hairs allow for a much larger surface area than the panels. Because of the shape and close grouping of these hairs, quantum mechanics principles can be applied. In this case, electrons are more easily separated from their hole counterparts. These cells also offer a clear pathway to the electrodes, reducing energy loss and making the panels more efficient. The weakness however, is polymer degradation. According to Paul Yu, an electrical engineering professor at the University of California San Diego, "The polymers degrade quickly when exposed to air. Researchers around the world are working to improve the properties of organic polymers."[6]

C. Titania Photoanodes

The University of Arkansas at Little Rock has developed another new nanotechnology solar cell. It uses titania photoanodes to convert solar energy into hydrogen fuel cells. According to researchers, this has an 80% increase in efficiency. [16] Other institutions have studied the same technique. Both North-eastern University and the National Institute of Standards and Technology have discovered a way to use titanium nanotubes to boost solar cell efficiency. Like with the nanofiber process, the use of titanium nanotubes creates more surface area, which can then increase efficiency. The energy could then be used to create hydrogen gas from water, which would be a "pollution free fuel that can be stored and shipped." [7]

In their approach, the NIST attempted to integrate carbon into the nanotubes. On its own, titania only absorbs light in the ultraviolet region, and adding carbon would help to absorb visible light as well. While researching a way to achieve this, they noticed that the titanium nanotubes contained traces of potassium ions left behind by the fabrication process. Test results showed that the same amount of hydrogen could be produced with only half the energy from the potassium cells.

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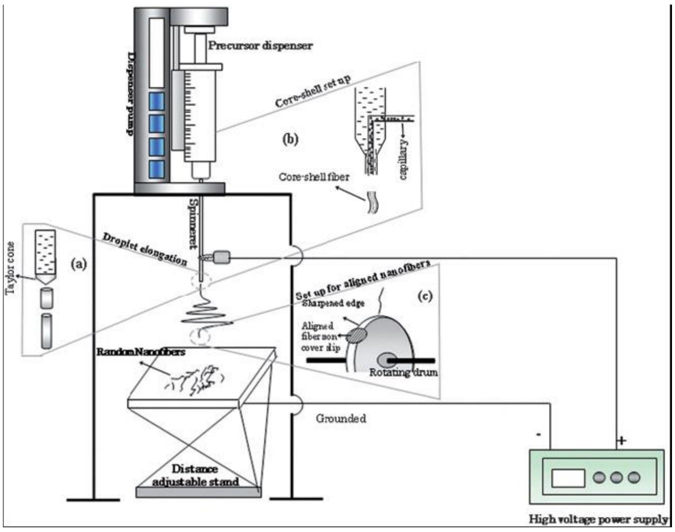

Fig 3.1Schematic of electrospinning set up to obtain random nanofibers.
(a) Enlarged view of formation of fiber starting from the Taylor cone. (b)
Set up to obtain aligned nanofibers using rotating drum with sharp edge.
(c) Set up to obtain core-shell nanostructures

D. Boosting Efficiency

Students in the Nano-engineering department at Rensselaer have discovered a way to create a 96% efficient solar panel. This is 75% more efficient than any solar panel on the market. This high efficiency is done in two ways. First, it has an antireflective coating on the panel, to allow more sunlight to be absorbed. Current technology reflects almost 1/3 of the sunlight. With the antireflective coating, that sunlight can be turned into energy. Antireflective coatings have been around for a while. The truly remarkable feat that Rensselaer accomplished was using a nano-coating to follow the suns movements, so the panel would be in the optimum location all day long.

As the sun moves across the sky, the angle at which sunlight hits conventional solar panels changes. There is a specific angle that will create optimal conditions of photon absorption. Several products on the market allow for a slow moving mechanism to mimic the movement of the sun, but this mechanism requires energy as well. The way that Rensselaer solved this problem was by layering 7 antireflective coatings on top of each other. Each new layer could enhance the layers below it, and it would help to "bend" the sunlight.

These layers consist of silicon dioxide and titanium dioxide nano-rods, positioned at an oblique angle (see figure 3.2). A good analogy is that "each layer looks like (and functions like) a dense forest where sunlight is 'captured' between the trees. Using chemical vapour disposition, the nano-rods can be attached to a silicon substrate. Shawn- Yu Lin, a physics professor at Rensselaer said, "This nano-engineering coating could be applied to nearly any photovoltaic material for use in solar cells. These two huge gains move solar power forward to being cost-effective for mass production."[8]

E. Quantum Dots

Using quantum dots to enhance solar cells has many advantages. First, there is a size quantization property that "allows one to tune the visible response and vary the band offsets to modulate the vectorial charge transfer across different sized particles."[9] Also, quantum dots allow for one photon to excite multiple electrons, increasing the amount of energy produced for the same amount of sunlight.

F. Other Nanotechnologies

These five techniques are the main ones being developed currently, but many other companies are developing their own nanotechnology to enhance solar energy. Scientists are studying carbon nanotubes to see if there is a way to increase efficiency in photovoltaic cells. Arizona State University is building arrays of nano-sized antenna like structures to capture the sun's energy. In this technique, strands of DNA are painted onto nanostructures, allowing the structures to self-assemble based on their natural chemical properties. This layer of nanostructures would function as a thin-film, and could be used as a solar panel. This technology is still in the development phase, but shows promise.[10]

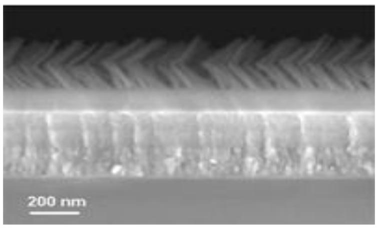

Fig 3.2

V. NANOTECHNOLOGY IMPLICATIONS

A. Synthesis of Nanoparticles

The creation of nanoparticles is still a relatively new field. Scientists are still unsure as to the health risks of synthesizing particles. Especially with the development of these new technologies, it is still relatively unknown what implications may arise.

Although there is little data available on the synthesis of nanoparticles, there is some information on the development of carbon nanotubes, a nanostructure that could be used in solar panels. The effects of inhaling carbon nanotubes is similar to asbestos, substance that is known to cause a deadly organ membrane cancer known as mesothelioma. This cancer develops from the fact that the particles are small and long in shape. Multi-walled carbon nanotubes are especially dangerous, because they can maintain their high aspect ratio. When these particles are inhaled, they are absorbed into the lungs and create scar tissue. The body continues to build new cells over the nanoparticles, and this leads to the cancer. It can take between 30 and 40 years for the symptoms to appear. Because of this, it is especially difficult to determine the dangers of carbon nanotubes, since they are still a relatively new discovery.[11]

Other nanomaterials may have similar health risks. A study done by the University of California San Diego in 2002 showed that quantum dots also have potential dangers. Quantum dots composed of cadmium selenide nanoparticles can lead to cadmium poising.[12] Other studies show that quantum dots could enter the body through cuts and open wounds. However, more research needs to be done to discover the full effects.

B. Energy Conversion Efficiencies

The main problem with current and future solar technologies will always be 'efficiencies'. Adding nanotechnology to the equation is one way that scientists believe they can boost efficiency. As seen above, efficiency of solar panels can range anywhere from 14% to 96%. If there is a way to mass produce a 96% solar panel, then solar could become the most efficient and cost effective form of energy available.

Creating a solar panel in space is one proposed way to gain efficiency in the solar industry. Without the atmosphere blocking the sun's rays, a much larger amount of solar energy could be collected. Satellites with solar panels already exist, but these are used purely to power those satellites. The issue with attempting to provide adequate power from space is in the transfer of that energy to the ground. Currently there is no way to efficiently transfer that energy, and until technology is advanced enough to do this, solar panels in space is not a viable option.[12]

C. Lifetime Expectancy

Current photovoltaic cells have a relatively long lifetime. Because they are so expensive, the panels need to last long enough to recoup their initial investment. Atypical silicon wafer panel can last between 30 and 40 years.

One of the major downsides of nanotechnology is a shortened lifetime on the panels. Some companies, like Nano solar, still offer a long warranty on their products. For their PowerSheets, they guarantee 25 years. Since these new panels are so much cheaper than older panels, this is still a long enough lifespan to make the investment cost effective. The other nanotechnologies do not guarantee as long of a lifetime. Nano fibres are one such technology that is still unable to last. The degradation of polymers is still a major problem, and until resolved, these technologies cannot be considered viable. That being said, nanotechnology is still a relatively new field, and the possibilities for improvement are endless.

D. Cost and Time of Investment

With the introduction of nanotechnology, the cost of solar could become low enough to make it competitive with other forms of energy. Currently, a home solar system takes 40 years to make the investment cost effective. This high time of investment is the main reason home owners and average consumers are unwilling to invest in solar energy. The reduction of this time of investment is the only way to make solar energy a viable commercial energy form. As shown above, nanotechnology is a promising introduction that could lead to this happening.

VI. CONCLUSIONS

Nanotechnology is an exciting new field. It has many positive applications, including the advancement of the solar energy industry. It is clear that the global energy crisis will continue to be a problem unless significant measures are taken. The addition of nanotechnology to the solar industry is one possible way to end this crisis. With affordable, efficient, environmentally friendly energy available, CO2 and other greenhouse gas emissions can be lowered, and the effects of global warming can be stopped.

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