3-D Solar Carbon Nanotube Array

Abstract

Today, solar power is being utilized for reducing our dependence on carbon-based energy sources. It’s integrated into modes of transportation, placed on rooftops for commercial and residential energy, and built into everyday devices. However, current photovoltaic technology isn't optimal for these implementations. Solar panels aren’t very efficient, have a high initial cost, and occupy lots of valuable space to collect meager amounts of power. If solar power is to have a stronger role in supplying an abundant source of energy in the future, the panels need to be lighter, more durable, and more efficient. Our solution involves the use of three-dimensional carbon nano-structures grafted to doped indium gallium nitride layers that will greatly increase the surface area of the panel while lowering the chances for photons to deflect and escape. The nano-structures will serve as electron transports and will make the array light and durable.

3-D Solar Carbon Nanotube Array

Present Technology

A photovoltaic solar panel absorbs sunlight and converts it into electrical energy. Recently, the technology has become more available worldwide. The solar cell is coated with a semiconductor material with electrons that get excited by the thermal energy from the sun. When a photon strikes the semiconductor, there is a chance that it will knock out and replace an electron from the semiconductor. Multiple strikes create a flow of electrons which is an electrical current.

Current technology for commercially available solar cells uses a single type of semiconducting material, which is usually silicon. Commercial silicon-based solar cells are able to capture up to 20% of solar energy in the form of photons. This is partially due to the silicon atom's ability to only capture a specific range of wavelengths in the electromagnetic spectrum. A large quantity of energy is lost because of the external shape of the solar panels, which is unable to capture all of the photons. Because of the flat surface, many photons deflect off the panel without being absorbed. This is the main reason why solar panels are inefficient today.

Our project implements a three-dimensional array which will allow photons to “bounce” between ridges until they are taken in by the semiconductor. Overall, solar panels are definitely a big step towards green energy, but their limitations pose a great area for improvement.

History

The first photovoltaic event was observed in the mid 1800's by Becquerel. Becquerel observed this event when experimenting with an electrolytic cell containing two metal electrodes; this device was the world's first photovoltaic cell. In the experiment, silver chloride was placed in an acidic solution and illuminated while connected to platinum electrodes, generating a small amount of voltage and current. However, after the observation, there was no explanation for the experiment's outcome. The photoelectric effect was further studied by Einstein, who was awarded the Nobel Prize because of his explanation of the phenomena. Through his research, he discovered the notion of quanta (energy packets), which was a significant building block for the foundation of Quantum Mechanics. This physics phenomenon is observed when electrons are emitted from atoms which are exposed to energy in the form of light. To later honor Becquerel's work, the photoelectric effect is also referred to as the "Becquerel effect."

Around 20 years later in 1873 and 1876, selenium's photoconductivity was observed by two different teams of scientists. Afterwards, CharlesFritts, an American inventor, described a method to produce electricity using selenium cells in 1883. In addition, Heinrich Hertz discovered that ultraviolet light altered the lowest voltage that caused a spark between two metal electrodes in 1887. Then in the mid-20th century, Western Electric became the first company to sell and manufacture solar panels on a commercial scale. The first early successful photovoltaic powered products included devices that decoded computer punch cards and tape. Soon, more large companies started taking interest in photovoltaic cells. During the mid-20th century, Hoffman Electronics Semiconductor Division announced a commercial PV product at 2% efficiency. Each 14 milliwatt cell was priced at $25, resulting in a final cost of $1500/W. Expanding on this interest, the photovoltaic cell produced by Hoffman Electronics soon achieved 14% efficiency. The rest of the energy was lost to heat and friction.

During the space race, NASA engineers adopted large photovoltaic cells as a viable power source option for spacecraft. Thus, photovoltaic cells gained an increased interest. In fact, a 470-W Photovoltaic array was aboard the Nimbus spacecraft when it was launched in 1964. Throughout the space race, the U.S. government developed the Photovoltaic Cell Development and Research Project. Later, Exxon opened the Solar Power Corporation, which was a major research company for PV technology. Ever since their invention, solar panels have played a prominent role in the field of inexhaustible energy.

Future Technology

To make solar power a more attractive source of energy to invest in for the future, we proposed to prevent photon deflection off panels. Theoretically, the maximum efficiency for solar technology is 86 percent due to photon entropy. However, current solar panels do not come close to that. With current panels, the flat face allows photons to escape because there is a chance that they will not be taken in by the panel. The photon is only given one opportunity to make impact with the panel. If it had more collisions, there would be a higher probability for successful absorption. We came up with a ridge design that would give the photon multiple chances to "rebound". Then, we decided to bring the design to the nano-level because photons (300-500 nanometer wavelength) and electrons (2.82x10^-15 m calculated radius) are very small.

Twenty years from now, we expect 3-D printing technology to greatly improve. Currently, the printing method can create figures that are very detailed and precise out of different materials. We hope to use this for making our vision real. Our technology requires three production phases. The first phase involves creating the ridged nanostructure array. A modern 3D printer would print out a thin insulating material in the ridge pattern with etches on the surface. Then, carbon nanotubes will be laid into these etches, securing them in place.

The second phase involves growing the semiconductor. The semiconductor indium gallium nitride was originally used in making LED's. However, a new method called metal-modulated epitaxy was developed in October, 2013, which allowed for the growth of a perfect indium gallium nitride crystal layer. Before, when indium was introduced to the gallium nitride mix, it did not spread evenly, creating imperfect crystals. That is why it couldn't be used for PV technology in the past, but now, it can. A modern version of metal-modulated epitaxy would be used to grow indium gallium nitride on top of the carbon nanotube structure complex and also underneath the insulation material.

The third phase involves doping the two sheets of indium gallium nitride grown on either side of the carbon nanotube ridge structure: an upper negative sheet (N-doped) and a lower positive sheet (P-doped). Doping is a chemical process that replaces some atoms in the semiconductor material with atoms of a different element. This changes the property of the semiconductor allowing for it to capture electrons or negate them.

When a photon hits the new array, an electron from the semiconductor is pushed out into the carbon nanotube because it was replaced by the energy from the photon. This electron will travel down the carbon nanotube, which serves as an electron transport. At the end of the panel, there will be a terminal connecting it to a load. From the load, there will be another connection back to the lower positive semiconductor sheet on the array. The electron will travel to the load because it's attracted to the positive sheet. When the electron flows through the load and hits this positive layer, it will negate.

Breakthroughs

To make this concept a reality in the near future, certain advancements in manufacturing must be made. Improved 3-D printing technology would be needed to create a ridged insulation material backbone at the nanoscale. Also, a procedure to mass manufacture carbon nanotubes in long lengths will need to be developed. Lastly, the prototype requires the grafting of carbon nanotubes to a crystal-like semiconductor. These problems need to be overcome in order to make the 3-D Carbon Nanotube Array work.

3-D printers today can print out anything within certain maximum dimensions depending on their size. These printers are currently precise in the micron range (1 X 10^-3 m). Although, they can’t print at the nanoscale (1 X 10^-9 m), the technology will have to be improved in order to create the base for the ridged nano-structures.

Currently, there is no method of mass production to create long carbon nanotubes. Today, carbon nanotubes are created in short lengths and batches in the lab through different means. The highest quality nanotubes are produced through arc evaporation which requires two graphite electrodes in a helium environment. An electric current is shot from one electrode to another, slowly growing carbon nanotubes. However, these nanotubes are produced in small batches and are quite expensive. In order to make this technology viable, large batches will have to be made at once to reduce cost. Research would have to be done on how to build these nanotubes efficiently with the utmost accuracy. Mass production should not affect the quality of the nanotubes because that will reduce the efficiency of the array itself.

Researchers at the Georgia Institute of Technology have developed a method to grow indium gallium nitride with almost no imperfections in the crystal structure. The only problem is creating a method to grow the indium gallium nitride layers on carbon nanotubes and different insulators. These layers will have to be doped to create a layer that is positively charged and a layer that is negatively charged. Work already has been done to grow this semiconductor on silicon sheets. A similar process would have to be developed to grow this on carbon and different insulation materials.

A research project would have to be done to test whether the grafting changes the electrical properties of the carbon nanotubes. That could have major implications, good or bad, in terms of efficiency of the panel. Functional testing would require shooting a quantified input of photons into the panel and then using a multimeter to record power output (dependent variable). Different amounts of photons (independent variable) will have to be shot at the panel in order plot a graph and derive an equation. Efficiency can then be calculated by taking output power and dividing it by input power.

Design Process

During brainstorming, one idea was to keep silicon as the semiconductor for the technology and only focus on the electron transport aspect of the carbon nanotubes. However, the idea was scrapped after researching about indium gallium nitride, which is another semiconductor. It functions at higher temperatures, has a more uniform composition, and resembles a perfect crystal with the new epitaxy process. This new semiconductor can reach higher theoretical efficiencies compared to silicon.

The original idea for the design of the solar array was that there would only be one layer of negatively doped indium-gallium nitride on top of the carbon nanotubes. In order to make the electrons flow and create an electric circuit, there would be an area on one side of the panel with a negative charge. This would force the electrons to be repelled and flow through carbon nanotubes to the load. This idea, at first, seemed great since it was a simple design, but unfortunately, the electric current would not have an end point. There would be nothing to negate the electrons after they have passed through the load. Instead, the new idea that was proposed included two layers of doped indium-gallium nitride, the one on top with anions and one on the bottom of the insulator layer with cations. When the light hits the top layer, electrons from that layer would be displaced and would flow through carbon nanotubes due to the circuit connection leading to the bottom positive layer. This would force the electrons to go to the load on its way to the bottom layer. This schematic will actually negate the electrons at the bottom layer completing the circuit.

When we were brainstorming ideas for designs, one idea that was considered was for the shape of the carbon nanotube array to be circular, with a small opening at the top for light to go through. This was considered because there would be an improbable chance that the photons could even escape. But through some speculation, the design was changed to incorporate a flat zig-zag shaped structure because the circular shape had a small opening, which didn't allow much light to come through. Another negative is that a circular shaped panel would not be able to lay on flat surfaces, automatically preventing use for certain applications. The zig-zag shape allows more light to hit the panel at once and still prevent most of the photons from escaping the panel. Also, the zig-zag idea is better because it would be easier to manufacture. Considering the semiconductor's crystal angled structure, growing it on curved surfaces would be really hard and would be expensive.

Consequences

The use of three-dimensional carbon nanotube arrays in solar panels has major advantages for society. In a world where energy demands are growing, solar panels can provide cheap, clean, and reliable power. This innovation brings greater efficiency to photovoltaics, enabling use in many applications.

The size of a solar panel required to capture a certain amount of energy decreases, allowing integration on smaller devices such as smartphones and watches that use more energy than traditional cell phones or analog watches. It also means that it's possible to get more energy from the same sized solar panel. Another positive is that the slim nano-structures make the technology aesthetically pleasing and less bulky. This is more appropriate for vehicles and aircraft for which conventional solar panels could affect aerodynamics and weight.

The durability of the panel is a major benefit. Conventional panels can last a bit over 25 years, if they are maintained well. A single carbon nanotube is a hundred times stronger than steel at one-sixth the weight. This will allow panels to last generations with their immense durability, allowing for a long term source of energy.

On the other hand, mass producing carbon nanotubes and grafting semiconductor crystals to them would require a difficult fabrication process that might initially be expensive. The financial burden would be passed to the consumers as a result. Additionally, because the array is textured at the nanoscale, maintenance of the arrays will be difficult, as current cleaning materials cannot clean in between ridges that small. Ultimately, although there are some negative consequences, if implemented correctly with new manufacturing technology, the pros definitely outweigh the cons.

Bibliography

1. Angelica, Amara D. "Controlled Atomic-layer Crystal Growth Is 'breakthrough' for Solar-cell Efficiency." Kurzweil - Accelerating Intelligence. KurzweilAINetwork, Oct.-Nov. 2013. Web. 28 Jan. 2014. <http://www.kurzweilai.net/controlled-atomic-layer- crystal-growth-is-breakthrough-for-solar-cell-efficiency>.

2. Bellis, Mary. "Photovoltaics - Timeline of the History of Photovoltaics." About.com Inventors. About.com, 20 Dec. 2013. Web. 23 Jan. 2014. <http://inventors.about.com/od/timelines/a/Photovoltaics.htm>.

3. Burchell, Bernard. "Determining the Electron Structure." Structure and Radius of Electron. Alternativephysics, 2010. Web. 28 Jan. 2014. <http://www.alternativephysics.org/book/ElectronStructure.htm>.

4. Dimroth, Frank. "World Record Solar Cell with 44.7% Efficiency — Fraunhofer ISE."World Record Solar Cell with 44.7% Efficiency — Fraunhofer ISE. Fraunhoffer, 23 Sept. 2013. Web. 27 Jan. 2014. <http://www.ise.fraunhofer.de/en/press-and-media/press-releases/presseinformationen-2013/world-record-solar-cell-with-44.7-efficiency>.

5. Fitlow, Jeff. "New Nanotube Fibers Have Unmatched Combination of Strength, Conductivity, Flexibility (w/ Video)." New Nanotube Fibers Have Unmatched Combination of Strength, Conductivity, Flexibility (w/ Video). Phys.org, 10 Jan. 2013. Web. 28 Jan. 2014. <http://phys.org/news/2013-01-nanotube-fibers-unmatched-combination-strength.html>.

6. Kim, Hoon-sik, Eric Brueckner, and John A. Rogers. "Unusual Strategies for Using Indium Gallium Nitride Grown on Silicon (111) for Solid-state Lighting." PNAS, June-July 2011. Web. 28 Jan. 2014. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3121821/>.

7. Llorens, Dave. "Solar Panel Efficiency and the Factors That Affect It | 1BOG.org." Home Solar 101 A Homeowners Guide to Solar Solar Panel Efficiency and the Factors That Affect It Comments. Pure Energies Group Company, 2012. Web. 28 Jan. 2014. <http://howsolarworks.1bog.org/solar-panel-efficiency/>.

8. MacNeill, John. "Ultra-Efficient Solar Power." MIT Technology Review. Technology Review, 13 Apr. 2013. Web. 28 Jan. 2014. <http://www.technologyreview.com/featuredstory/513671/ultra-efficient-solar-power/>.

9. Maehulum, Mathias. "Solar Energy Pros and Cons." Energy Informative. Energy Informative, 26 June 2013. Web. 26 Jan. 2014.<http://energyinformative.org/solar-energy-pros-and-cons/>.

Maxey, Kyle. "3D Printing Trends, History." ENGINEERING.com. ENGINEERING.com Inc., Aug.-Sept. 2013. Web. 30 Jan. 2014. <http://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/6344/3D-Printing-Trends-History.aspx>.

10. Piccirillo, Clara. "Solar Panel." Decoded Science. Wordpress, 4 Jan. 2013. Web. 29 Jan. 2014. <http://www.decodedscience.com/the-most-significant-breakthroughs-in-materials- science-for-2012/23680/solar-panel>.

11. Seale, Eric. "The Photovoltaic Effect." The Photovoltaic Effect. Creative Commons, 11 July 2003. Web. 23 Jan. 2014. <http://encyclobeamia.solarbotics.net/articles/photovoltaic.html>.

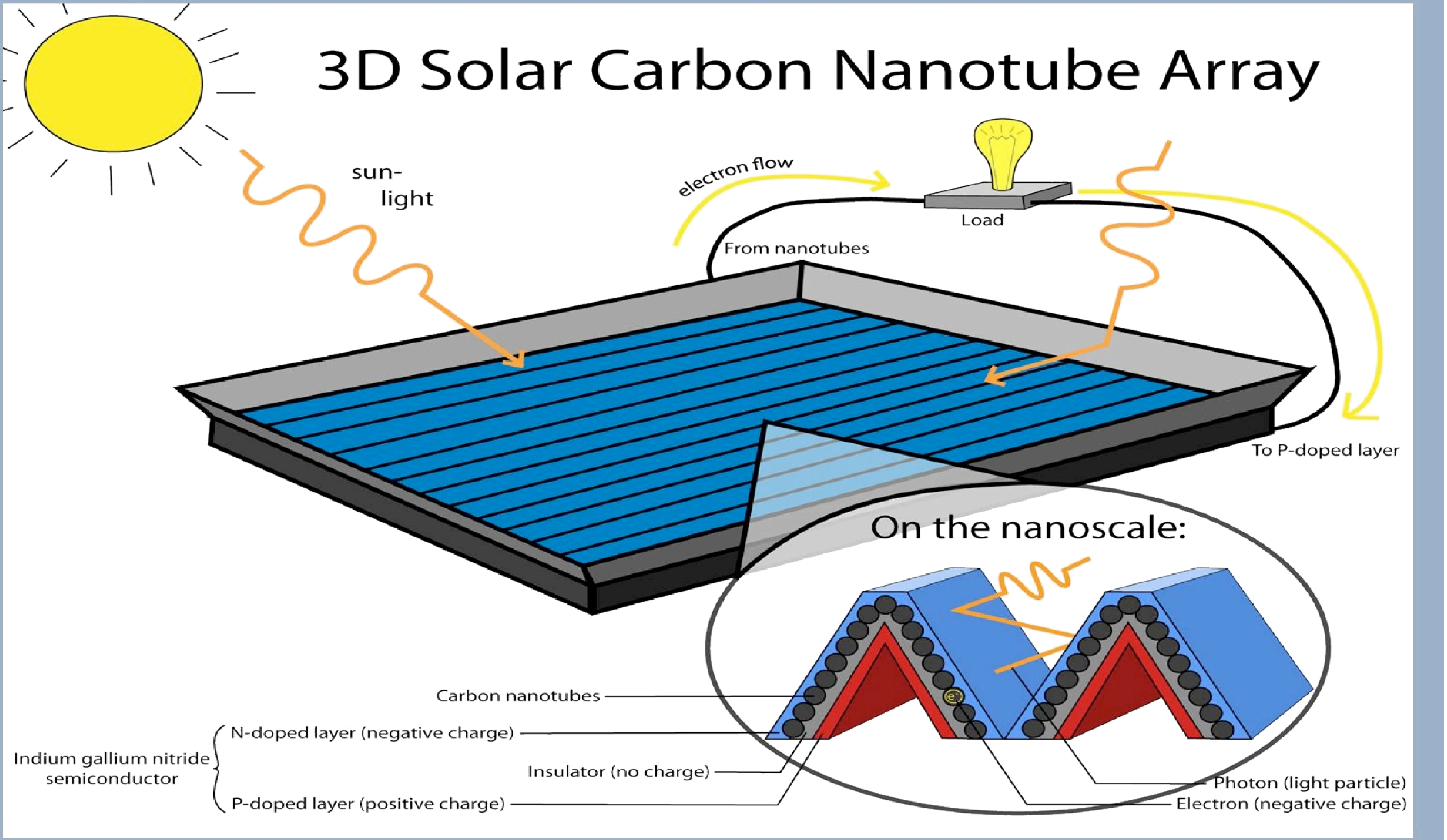
12. The Nobel Foundation."The Nobel Prize in Physics 1921". Nobelprize.org. Nobel Media AB 2013. Web. 28 Jan 2014. <http://www.nobelprize.org/nobel_prizes/physics/laureates/1921/>

13. Toothman, Jessika, and Scott Aldous. "How Solar Cells Work." HowStuffWorks. HowStuffWorks.com, 01 Apr. 2000. Web. 26 Jan. 2014.<http://science.howstuffworks.com/environmental/energy/solar-cell1.htm>.

15. Whitman, Llyod, Dr. "NSI: Nanotechnology for Solar Energy Collection and Conversion--Contributing to Energy Solutions for the Future." Nano. United States National Nanotechnology Initiative, n.d. Web. 23 Jan. 2014. <http://www.nano.gov/node/830>.

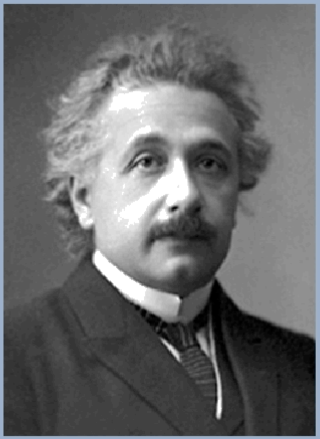
16. Whitwarm, Ryan. "New Nanomaterial Could Boost Solar Panel Efficiency as high as 80 Percent." ExtremeTech. Ziff Davis, 17 Oct. 2013. Web. 26 Jan. 2014.<http://www.extremetech.com/extreme/168811-new-nano-material-could-boost-solar-panel-efficiency-as-high-as-80>.

17. Willhite, Roger. "What Happens When Solar Cells Reach Maximum Efficiency? | Second Silicon." Secondsilicon.com. Second Silicon, May-June 2013. Web. 29 Jan. 2014. <http://secondsilicon.com/what-happens-when-solar-cells-reach-maximum-efficiency/>.


3D Solar Carbon Nanotube Array
sun-
light
electron flow
Load
From nanotubes
To P-doped layer
On the nanoscale:
Carbon nanotubes
N-doped layer (negative charge)
Indium gallium nitride semiconductor
Insulator (no charge)
P-doped layer (positive charge)
Photon (light particle)
Electron (negative charge)
e⁻

History of Photovoltaics

The first photovoltaic cell that produced electrical current from sunlight was developed in the early 19th century by Edmund Becquerel. The experimental electrolytic cell raised questions about how the phenomenon occurred. Einstein answered these questions when he discovered the photoelectric effect, which explains how photons of light affect atoms and their electrons. Later on, advanced scientific and engineering knowledge in the 20th century utilized this affect to produce commercial applications. Then, the concept of the photovoltaic cell gained importance when NASA became interested in the technology as an alternative sustainable energy source for their spacecraft. Over time, the photovoltaic cell underwent improvements and modifications which have increased it's efficiency.



Photovoltaic Technology Today

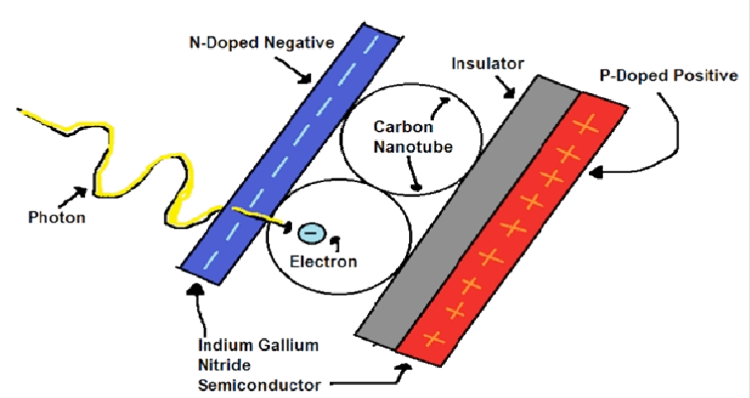
Solar panels are widely used today, and work by converting solar power to electrical energy. An electrical current is produced when the photons hitting the panel excite the electrons on it's surface. Currently, these devices are made up of semiconductor materials, the most common being silicon. Unfortunately, this technology has some negatives.

The average efficiency of a commercial solar panel is around 20%, which isn't very high. The shape of these panels are flat, rendering it difficult to capture the photons due to the high possibility that they will be reflected. Despite these difficulties, solar panels have great potential in the field of inexhaustible energy.

Future Technology

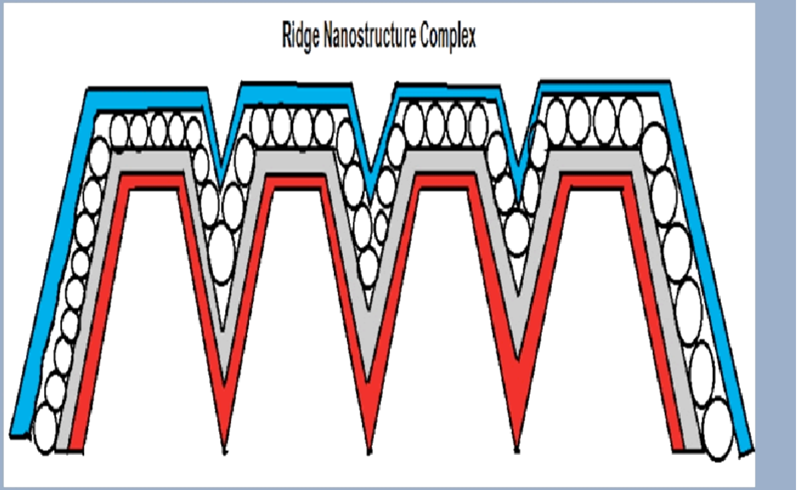
Production of the technology

1. An insulation material backbone is printed in a ridged shape structure with a future 3-D printer
2. Carbon nanotubes are laid into the grooves on the insulation structure
3. Indium gallium nitride crystal layers are grown on both sides with a modern version of metal modulated epitaxy
4. The top layer is doped negative and the bottom layer is doped positive



The technology...step by step

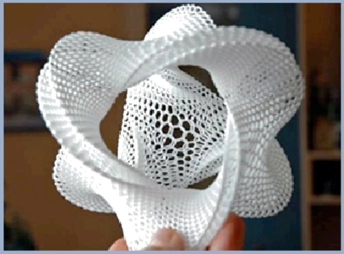
1. Photons hits the N—Doped layer which displaces electrons
2. Displaced electrons enter into carbon nanotubes and travel through them to the terminal
3. The electrons travel from the terminal to the load
4. The electrons travel from load to P—doped layer and negates with positive charge



Breakthroughs

Things that need to be developed for our technology to be produced:

- Advanced three—dimensional printer that can print accurately at the nanoscale



- Currently, 3D printers can print in accurately the micron range (1x10^-3 m)

- Need to be accurate in (1x10^-9 m) range

Created with a 3D printer

- Mass scale production method for producing long carbon nanotubes cheaply and efficiently

    -Currently produced in small batches in the lab

    -Need to be produced in large quantities and length

- Growing process similar to metal modulated epitaxy to grow the semiconductor layers

- The current epitaxy process is the only method for producing a perfect semiconductor crystal, which is needed for InGaN to be used in PV technologies

Consequences

Positive Consequences-

We believe that the new array will be durable. Carbon nanotubes are much stronger and lighter than steel, so the panels will last much longer than the ones do today. Also, they can be put onto small portable devices because they take up less space in order to produce the same amount energy . They can be implemented on modes of transportation because they don't add weight or affect aerodynamics drastically. Society will benefit from this innovation because people use electrical technology in their everyday lives.

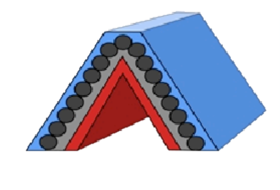
Negative Consequences-

At first, the solar arrays might initially be expensive due to the processes involved in producing them. Also, maintenance of these solar panels will be difficult because current cleaning materials cant clean between ridges that small. However, the pros definitely outweigh the cons and these problems can be overcome in the future with new manufacturing processes and technology.

Design Process

Accepted

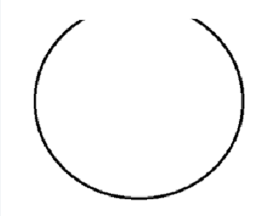
- Semiconductor Indium Gallium Nitride
  - Works just as well at higher temperatures
  - Higher theoretical efficiency than silicon technology
- Flat Ridged Array Shape
  - Allows more light to hit array while stopping most photons from escaping
  - Easier to produce: crystal structure is angled



- Two layers of InGaN: one doped positive and one doped negative
  - Electrons are able to negate at positive—doped indium gallium nitride layer

Rejected

- Continue using silicon as semiconductor and only focus on carbon nanotube transports
  - Lower theoretical efficiency
- Circular Array Shape with Top open
  - Cannot be placed on flat surfaces
  - Very little light can come through
  - Hard and expensive to produce



- Only one layer of negatively doped InGaN with negative pole
  - Electrons have nowhere to go after they reach load