Silver and Gold: Powering the Future

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Abstract

Silver and Gold: Powering the Future proposes a new material that will act as an addition to current photovoltaic cells. Modern cells absorb light in the spectrum 500 nm to 700 nm at a 14% efficiency. Our additive, a layer of colloid consisting of polyhedron shaped gold/silver nanoparticles, will absorb light in the 700 nm to 1100 nm spectrum and convert the energy into current using the photoelectric effect. The transparent colloid layer will be placed on top of the light acceptors of modern cells, allowing the entire 500 nm to 1100 nm spectrum to be absorbed. This greater absorption will result in an increased efficiency of cells, allowing for smaller and more accessible solar power plants and encouraging homeowners to switch to solar power.

Silver and Gold: Powering the Future

Present Technology

Nanoparticles, particles that are between 1 and 100 nanometers in size, are leading the way in current technological research. Among them, gold nanoparticles are the subject of much current research involving electricity.

Researchers at the University of Pennsylvania have created a method to generate electricity from light by using gold nanoparticles. This method implements a glass coated with the nanoparticles that has electrodes on both sides. A light is then shone onto the gold-covered glass. This creates surface plasmons, oscillation of electrons between the surfaces of the two materials, which allows for a current to be induced across the gold molecules, generating electricity. This method of generation is not very efficient, but researchers claim that through adjustment of particle size and shape efficiency can be increased.

There are three main shapes of gold nanoparticles, all of which were researched by the University of Pennsylvania scientists. They are nanoshells, nanospheres, and nanorods. Each of these can be produced in a variety of different sizes, which affects their absorption spectra. The absorption spectra of any given one of these particles is narrow, only about 50 nanometers, and generally lies within the 550-650 nanometer range (Jain). This means that gold nanoparticles of these shapes cannot utilize the majority of the light spectrum to generate electricity. For more electricity to be generated, the absorption spectrum must be wide. This requires that the particles have a shape, size, and material that allows for the absorption of a wide portion of the light spectrum.

One such combination of shape, size, and material is just now starting to be researched. Polyhedron shaped gold and silver nanoparticles were synthesized by researchers at the

University of Texas in July of 2009. Not much is known about these particles except that their absorption spectrum is 700 to 1100 nanometers, much wider than those of previously made gold nanoparticles. An added benefit of this shape is that the absorption spectrum does not greatly overlap the absorption spectrum of present day silicon photovoltaic cells, which is from 500 to 700 nanometers. Regrettably, these newly engineered shapes contain defects due to their method of production. The defects result in non-uniform particles, which can lead to absorption spectra that differ from what is expected, or in breakage of the particle. Current research wishes to expand upon this shape and develop a more reliable method for synthesis.

History

The mechanism for producing current in a photovoltaic cell, the photoelectric effect, has been known for well over a century. Scientist Edmund Becquerel first discovered the effect in 1839 while experimenting with wet cell batteries. He noticed that the metals and semiconductor materials in his batteries would produce a small current when they were exposed to light. This phenomenon was later implemented by electrician Charles Edgar Fritts in 1883 to manufacture his Selenium Wafer solar cell (Craddock 52). The Selenium Wafer cell consisted of a thin sheet of selenium covered with a layer of thin gold wires and a film of glass. His primitive cell could only generate current at an efficiency of less than one percent, but he was no Einstein.

Then, Einstein released his theory explaining the photoelectric effect in 1905, for which he received the 1921 Nobel Prize in Physics. Einstein concluded that light consists of individual light quanta, called photons, which contain energy proportional to the wavelength of the light. These photons, according to Einstein, interact with electrons in metals, causing the electrons to gain energy. When electrons gain enough energy, when the light is of the proper wavelength, electrons can become removed entirely from their atoms. These free electrons are what produced the current in Becquerel’s batteries.

Photovoltaic cell technology continued to be improved upon, using Einstein's theory and Fritts's original design. The next major breakthrough occurred at Bell Telephone Laboratories in 1954 by researchers Calvin Fuller, Darryl Chapin, and Gerald Pearson. Their photovoltaic module closely resembled Fritts's in that it consisted of very thin layers of semiconductor. The Bell module used silicon instead of selenium, which was then altered by a process called doping. Doping adds impurities to the material, which creates an electric field. When the doped semiconductor is exposed to light, the released electrons are captured by conductors that are attached to the positive and negative sides of the semiconductor's electric field. This flow of electrons is the current produced by the cell, and is determined by the amount and frequency of light, as well as the surface area of the cell.

To produce a current, the light that the photovoltaic (PV) cell is exposed to must be of a frequency greater than the band gap of the semiconductor. The band gap is the minimum frequency of light, or the minimum amount of energy, required to dislodge an electron completely from its atom. Electrons can absorb light of any frequency higher than their band gaps. With this in mind, scientists created a new type of PV cell, called multi-junction cells. These modern cells are made of layers, or junctions, of semiconductors with different band gaps. The material with the highest band gap is placed on top so it can absorb the photons with highest energy. Photons of lower energy are able to pass down to lower junctions, allowing an increase in the amount of absorbed light. NASA's multi-junction cells have been found to produce current at an efficiency of 35% when exposed to concentrated sunlight under laboratory conditions (Knier).

More commonly used cells only have a single-junction made of silicon; a semiconductor made of gallium-arsenide is used by NASA in its triple-junction cells. Silicon cells in a laboratory test in 1989 produced current at an efficiency of 23% and gallium-arsenide at an efficiency of 26% ("Solar Cells"). The record high of 42.3% efficient was achieved in October of 2010 by a triple-junction gallium cell. The efficiency observed by commercial cells, though, is extremely low. Current single-junction cells have efficiencies of around 14.1%, some companies boasting 14.4%. Because of this low efficiency level, the size of solar plants needs to be extremely large, which limits the accessibility of solar energy. If efficiency can be improved, smaller plants will be possible. Thus, solar energy can be utilized more readily in urban areas and by individual property owners.

Future Technology

Our proposal is to merge a revolutionary new material with pre-existing photovoltaic cell technology to increase the efficiency and energy output of the cells. By utilizing the gold/silver polyhedron shaped nanoparticles along with the concept of energy retrieval developed by the University of Pennsylvania, we will be able to drastically improve photovoltaic cell efficiency. This will be implemented through the creation of a colloidal solution, similar to colloidal gold, in which polyhedron shaped gold/silver nanoparticles will be suspended in an aqueous medium.

Our colloidal solution will be applied to a quartz substrate, unlike the glass used by the University of Pennsylvania team. Quartz is a more suitable substrate, as posited by Einstein in his experiments, because it contains fewer imperfections than glass. The coated substrate will be placed on top of the semiconductor material of a PV cell and attached to conductors. The colloid will be transparent, as to not impede excess photons flowing through it and onto the cell underneath. The nanoparticles will be close to the quartz surface, so when light shines on them, surface plasmons will induce a current, and electricity will be generated and collected. The photons not absorbed by the nanoparticles will be free to travel through the colloid and substrate and onto the semiconductor of the PV cell, where they will be collected and used to produce even more current.

If a layer of our gold/silver polyhedron shaped nanoparticle solution were to be added to modern PV cells, the amount of the spectrum that would be absorbed would drastically increase. The silicon and gallium-arsenide material contained in current cells utilize the 500 to 700 nanometer wavelength portion of the spectrum. Our nanoparticle solution is able to utilize the 700 to 1100 nanometer wavelengths. This means that more energy will be able to be extracted from the light because more photons will be available for absorption. This is similar to the way multi-junction cells can absorb a greater portion of photons; the top layer absorbs the highest energy wavelengths and allows lower energy photons to pass through.

Our revolutionary new material could be applied to both silicon single-junction cells and multi-junction cells that are currently in use to improve their efficiency. Silicon single-junction based solar panels have an efficiency of around 14%. To add our colloid to cells like these that are already functioning, electrodes must be placed on opposite sides of the panel frame to receive the current produced by the colloid. Then, the solution must be adhered to the inner side of the protective plate. The plate would need to be replaced by quartz to allow for the greatest number of photons to be accepted by the cell, and for the greatest number of surface plasmons to be induced.

The same method could be applied to already working multi-junction cells. The only difference in implementation between these cells is that multi-junction cells are thinner than silicon cells, so the quartz substrate size would have to be adjusted. Multi-junction cells are more efficient than single-junction to start with, some up to 40% efficient, but their absorption spectrum is still the same as the single-junction cells. Thus, the efficiency of both types of cells will increase with the addition of colloidal gold/silver nanoparticles.

Breakthroughs

The current production of this technology is hindered by a few technological obstacles. Firstly, the defects that occur in the production of polyhedral nanoparticles must be removed. The method used to produce this shape of nanoparticle involves silver "seed" particles. These seeds are placed in a growth medium of ascorbic acid and other chemicals. After 20 hours, gold nanostars form around the silver seeds. They are called nanostars because the particles form peaks in either a hexagonal or a triangular shape, depending on the amount of ascorbic acid in the solution. The defects of the nanoparticles exist between peaks and affect the spectra of absorbable light (Mayoral 2).

At the moment, researchers are unsure where the defects originate, but we have two theories. To begin with, the nanoparticle growth solution undergoes gentle mixing during the 20 hour growth period. Uneven mixing or agitation that is too strong could cause particles to collide and break. The other possible cause is the concoction of chemicals in the growth medium. The amount of ascorbic acid greatly affects the shape of the particles, so it only follows that slight alterations in concentrations of other substances could affect the shape as well. Before polyhedron shaped gold/silver nanoparticles can be effectively used to produce a current, technology must advance enough to produce uniform and defect-free particles.

Another breakthrough that must occur is the production of the actual colloid. Current gold colloid that is made of nanospheres, nanorods, and nanoshells is usually made of water, which can easily freeze. Our colloidal solvent must be one that has a very low freezing point so it can withstand year-round use. It should preferably be a gel so the solution stays in place without leaking onto the rest of the PV cell. Most importantly, the colloid has to be transparent so sunlight can pass through and onto the semiconductor. This colloid has to be invented before production of our cells can occur.

Design Process

Before deciding upon our gold/silver nanoparticles idea, we had a few other proposals for improving the efficiency of solar panels. Our first notion was to utilize prisms to refract light before it reached the solar cells. We had researched PV cells enough to conclude that semiconductors produce current in proportion to the energy, or the wavelength, of the light they receive. We also knew that different semiconductors have different band gaps, or different ranges of wavelengths, they could actually absorb. Our hypothesis was that by refracting white light into its component wavelengths, we could effectively filter light into the optimal wavelength for use by the cells. The prism could refract a single beam of white light into multiple beams of colored light for use by an array of PVs, each containing different semiconductors, which would respond better to their respective wavelengths.

Unfortunately, the optimal wavelength for absorption for PV cells is consistent among the commonly used semiconductors. Optimal absorption falls in the range 500 nm to 700 nm, which is a majority of visible light. The differences in band gap effects the lowest wavelength absorbable, not the most effective range of wavelength. The multi-junction cell already uses this principle to produce current more efficiently, so we were forced to search for another idea.

While reflecting on our failed prism idea, we envisioned a second idea. Since photovoltaic cells do not absorb 100% of the light that comes in contact with them, some is reflected. If this reflected light could be shone back onto the panel, we proposed that efficiency would be increased. We hypothesized that if reflective particles, basically small mirrors, were to be suspended in a solution, some of the light reflected off of the solar cells could be reused.

However, the small mirrors would have a negative effect as well. Just as light reflected off of the panels would be bounced back in by the mirrors, light coming in from the sun would be reflected away. This would decrease the amount of light that is available for use in electricity production. Although some efficiency may be gained through the use of more of the light that enters the cell, overall efficiency would be reduced by the mirrors because less total light would be able to enter.

Our third idea came from biology, specifically photosynthesis. We researched the Photosystems of plant chloroplasts, the multi-protein structures that absorb light and transfer excited electrons to the electron transport chains of the organelle. Light is absorbed by the reaction center of the Photosystem and an excited electron is released. It is captured by the primary acceptor of the ETS and its energy is utilized as NADHP by ATP synthase, another protein, to produce ATP ("Step"). Then, the Photosystem splits a molecule of water into H^+ and O_2 to gain back the lost electron. We proposed isolating Photosystems in a solution and collecting the released electrons with a conductor.

This idea was another lamentable failure. After researching semiconductors, we learned that they work best in cooler temperatures. The reaction splitting water in the Photosystem produces a lot of heat, which would damage the efficiency of our PV cells. Also, a constant supply of water would be necessary to maintain the Photosystems. The addition of water pumps and water-level meters would likely use up any extra electricity produced by the Photosystems, as well as make the PV cell more complicated and expensive.

Consequences

The switch from oil and coal to greener energy sources is the struggle of our generation. By making solar cells more efficient, more people will be encouraged to switch from oil and gas. The effects on the environment will be drastic. Power plants will produce less greenhouse gasses and nonrenewable resource consumption will decrease. Increased solar cell use will lessen the effects of global warming and decrease smog in the air, improving the environment. Gold/silver cells will hasten the switch from nonrenewable to renewable power because they will allow solar power to compete in production with current sources.

Conversely, gold/silver cells might negatively affect the environment. These new cells use precious metals in their production, the consumption of which could cause a higher demand for gold and silver. Mining companies would have to search for new gold and silver deposits, most likely in untouched parts of the world. This would lead miners to ecological preserves, where destructive mining could ruin the habitat and cause extinctions. In order to produce gold/silver PVs, serious legal steps must be taken to preserve the land above gold and silver deposits.

The chemicals needed to produce these cells could also devastate the environment. The growth medium for the nanoparticles contains compounds of chlorine and CTAB, a common surfactant. The disposal of this solution might have unforeseen effects on our ecosystems.

Additionally, PV cells and their storage batteries contain lead, sulfuric acid, and cadmium telluride (“Disadvantages”). These toxic substances are released into the atmosphere during production and may leach into the soil of landfills after disposal. The proper air treatments at production plants and the proper disposal of cells will be vital to maintaining a clean environment.

On a more positive note, solar energy is growing increasingly popular in areas like the Mojave Desert of Nevada, where sunlight is intense and land is almost uninhabited. Current solar cells are so inefficient that huge tracts of land are required for these plants to generate enough power to compete with oil, coal, and water-powered plants. With the implementation of our new technology, PVs will become much more efficient. Fewer cells will be required to generate the same amount of power, so plants will not need to be as large. Solar power will be a possibility for urban centers; where once a multi-acre plant was needed, soon only a few lots or rooftops will suffice. Homeowners will be able to power their homes with fewer cells, decreasing the cost of switching to solar power.

Another advantage is the higher demand for solar cells. New production facilities will be required to manufacture the cells, and jobs will be created by the new industry. Technicians will be needed to fix cells, workers will be needed to make the cells, and engineers will be needed to design the new power grids. Jobs like these will be a much needed relief, especially with unemployment so high. Unfortunately, the cost of this production might discourage people from purchasing cells. In twenty years, as the cost of oil, coal, and natural gas rise, the cost of solar panels most likely will not be a significant issue.

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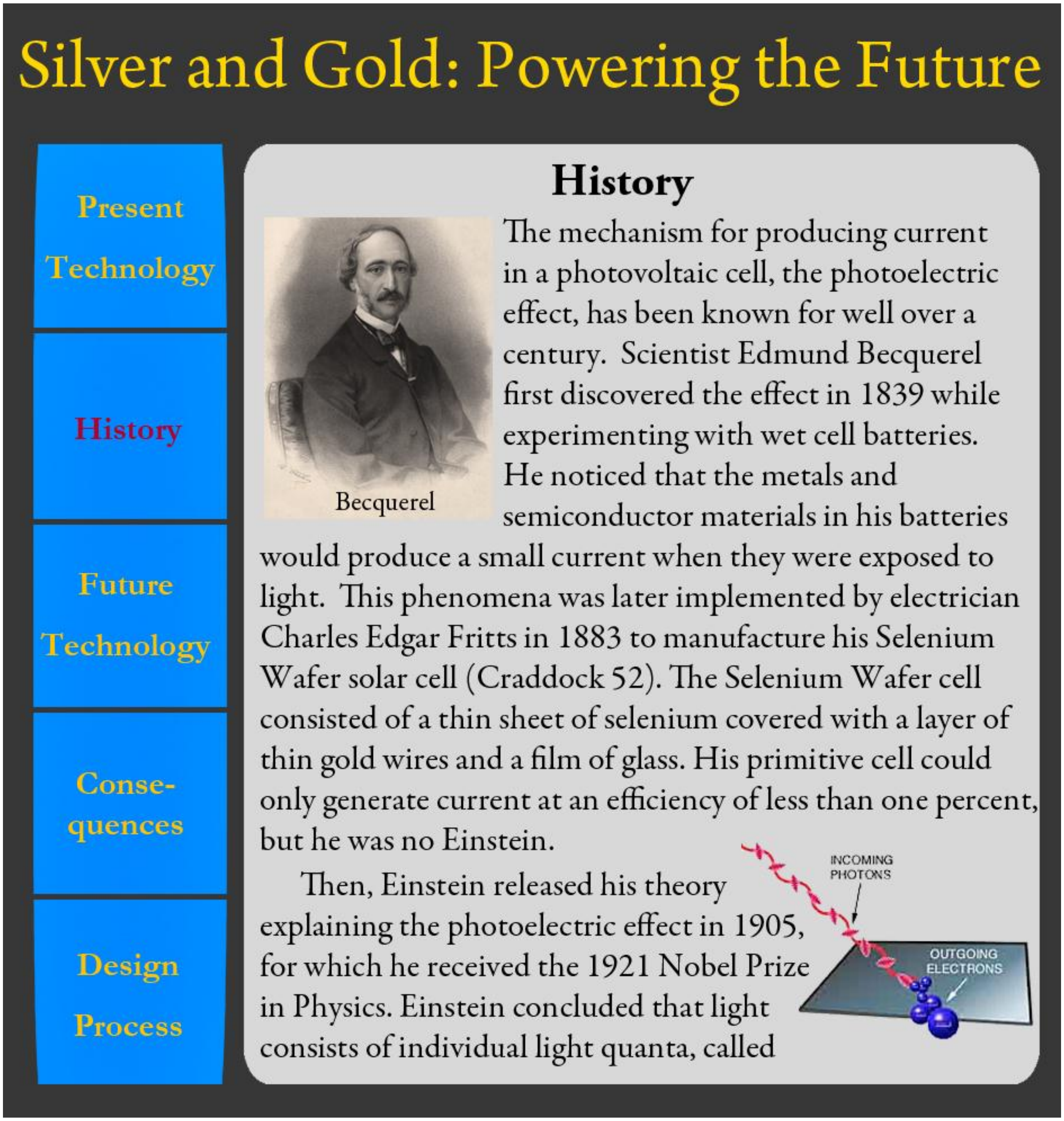

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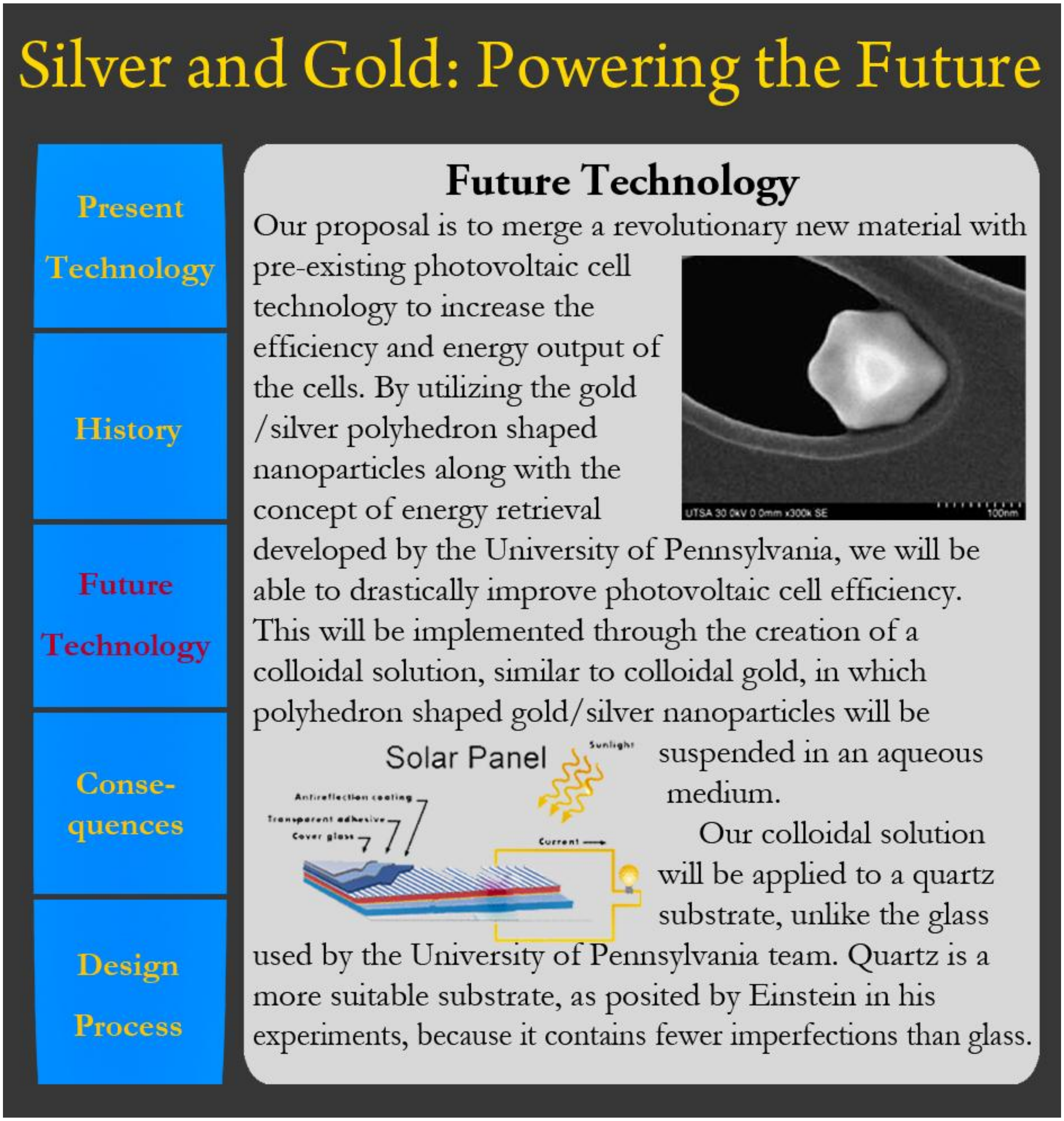

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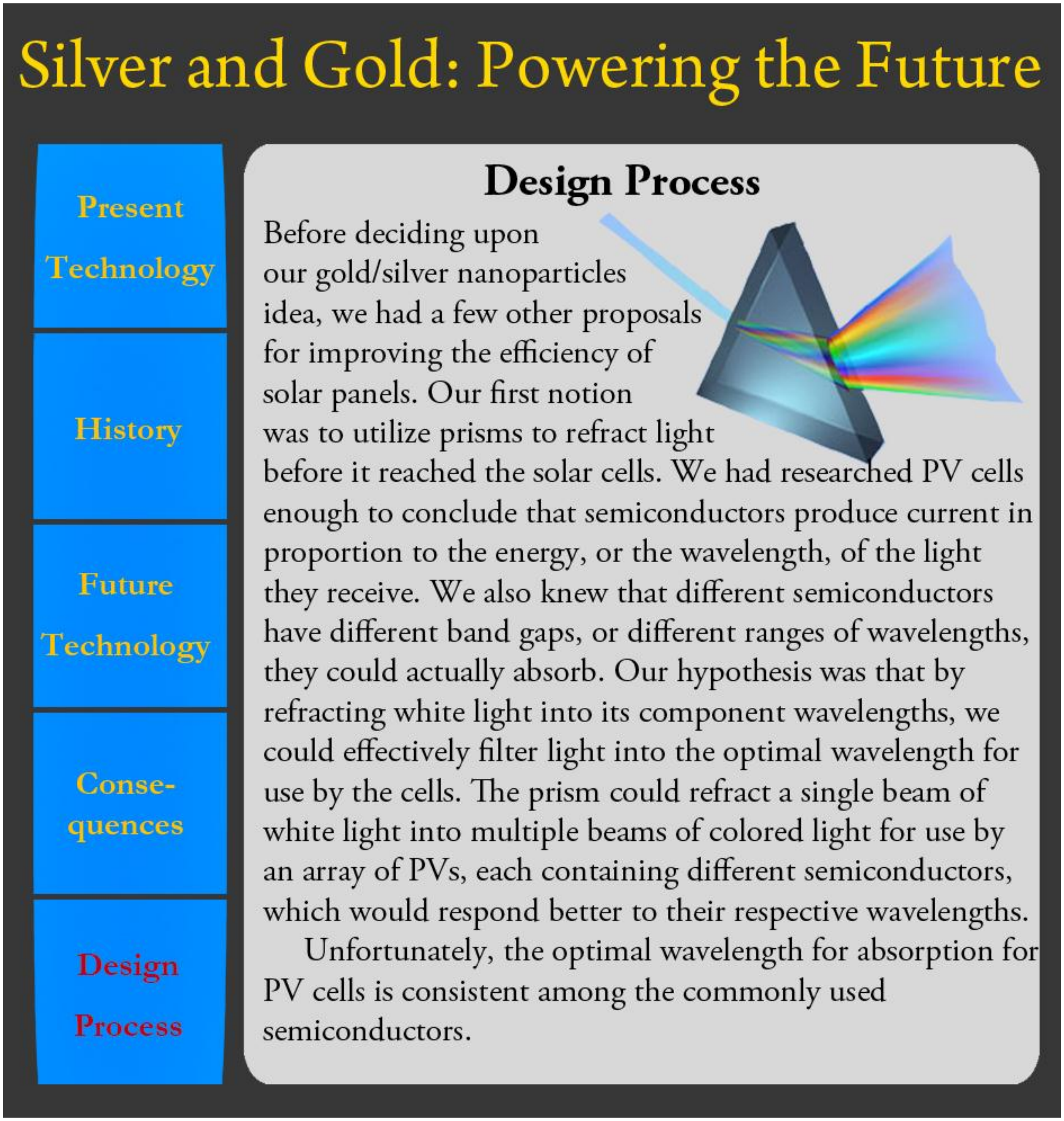

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