Solar "Nanoforest" Creates Artificial Photosynthesis [1]
Artificial photosynthesis is a process that seeks to imitate plants’ natural ability to take energy from the sun and create renewable and sustainable energy sources. It does so by utilizing the sun to break water into hydrogen and oxygen, a process called water splitting. Scientists have been looking into the use of nanotechnology as a means of producing artificial photosynthesis to yield hydrogen. A nanotechnology which functions in a way similar to chloroplasts in green plants offers the possibility of cheaply producing hydrogen in an effective and efficient manner.
The artificial photosynthesis process hinges in part on replicating the \( Z \)-scheme electron transport chain of oxidation half-reactions and water reductions by using nanowires. The nanoforest's integrated nanosystem of silicon (Si) and titanium dioxide (TiO\(_2\)) semiconductor nanowires absorb sunlight. Reactive ion etching (RIE) was used to create the Si nanowire arrays, but electroless etching and chemical vapor deposition are also methods of creating such arrays. Hydrothermal synthesis was used to create the TiO\(_2\) nanowires. Platinum nanoparticles were loaded onto the Si nanowires and iridium oxide nanoparticles were loaded onto the TiO\(_2\) nanowires to make certain that the Si and TiO\(_2\) nanowires would operate together in acidic electrolyte. Arrays in the nanosystem are composed of heterostructures that resemble miniature nanoforests (Figure 1). The structure was designed for performance optimization as the dense arrays create larger surface areas for reactions that will create fuel and limit sunlight reflection.

References


2. Citekey </span><a href="http://dx.doi.org/10.1021/nl401615t">10.1021/nl401615t</a>[<span>/bib]. As sunlight falls on the nanowires, the Si and TiO\(_2\) absorb differing sections of the solar spectrum. Photo-excited electron-hole pairs are produced in the Si and TiO\(_2\). The electrons in the Si nanowire reduce protons thereby creating hydrogen after traveling to the surface. Meanwhile, the holes in the TiO\(_2\) oxidize water thereby creating oxygen. An ohmic contact, an electrical junction between two conductors, is located between the nanowires and is a point where the majority of the charge carriers recombine to finish relaying the replicated \( Z \)-scheme.


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Development Stage:

- Off-Market [20]
Key Words:

- Artificial Photosynthesis [5]
- Water Splitting [4]
- nanowire heterostructure [21]
- Silicon [6]
- Titanium Dioxide [7]

Mechanism:

- Active Nanostructure [22]

Summary:

The integrated nanosystem comprised of a nanowire [10]-based heterostructure has advantages over past technologies due to its integrated nature, yet individually positioned components. The modular design of the system allows for replacement of individual components which will help when other anodes [23] are investigated. The system operates most like a chloroplast within a plant, where separate components efficiently convert sunlight into energy. Previous technologies have not used a combined system approach for direct water splitting [4] through the use of the sun [2] and this nanosystem is the first fully integrated and functional means of completing this process [1].

References


Function:

- Energy Production [27]

Material:

- Silicon [28]

Benefit Summary:
The fully integrated nanosystem is 0.12 percent efficient at using the sun’s energy in a process of artificial photosynthesis [5] to create the fuel source hydrogen [1]. Alterations to the nanosystem are being explored to potentially increase this efficiency and make it more comparable to that of a plant (3-6% efficiency) [2]. Inorganic nanowires are utilized which can add durability to the system without great cost [3]. The integrated nanosystem also has a modular design due to its individually placed components. This design of individually placed components within a system reduces costs of entire system upgrades because certain parts can be replaced at specific times, making the prospect of mass manufacturing and commercialization more cost effective.

References


Benefit:

- Improved Environmental Quality [35]
- Resource Efficiency [36]

Risk Summary:

Silicon [8] (Si) nanowires have been shown to be biocompatible and non-cytotoxic to human cells [1]. However, titanium dioxide [7] (TiO2 [8]) nanoparticles [12] have been shown to possess toxic effects with modification of the titanium dioxide [7] into a nanowire [10] raising concerns about disruption of the cell’s recycling function in lysosomes[2], leading to cell death[3]. Inhalation of TiO2 [8] nanoparticles [12] causes neutrophils in the lungs to increase, but is not seen as having as having a great cancer risk<bib>10.1016/j.scitotenv.2008.09.028</bib>. Human cell lines have had genotoxic and cytotoxic responses to these nanoparticles [12]. Changing the shape of a TiO2 [8] material from one of a nanoparticle [37] to one of an elongated rod causes an alteration in toxicity as phagocytic cells have even greater difficulty processing the new configuration. More research needs to be conducted on the specific health [38] risks posed by using TiO2 [8] nanowires [2].

In addition to negative impacts on human health [38], the use of TiO2 [8] nanomaterials can have serious environmental consequences. TiO2 [8] nanoparticles [12] have been shown to cause oxidative damage in bacteria [39] , and crustaceans through the creation of reactive oxygen species[4]. Nano- TiO2 [8] also aggregates in soil [40] and groundwater to a greater extent if
divalent cations are present [5]. Therefore, replacing TiO2 [8] nanowires with other more efficient and environmentally safer photoanodes would decrease risks of the integrated nanoforest system.

References

1. Citekey 10.1002/adma.200401362 not found
2. Hamilton RF [41], Wu N [42], Porter D [43], Buford M [44], Wolfarth M [45], Holian A [46]. Particle length-dependent titanium dioxide nanomaterials toxicity and bioactivity [47]. Particle and Fibre Toxicology [Internet]. 2009 ;6(1):35. Available from: http://www.particleandfibretoxicology.com/content/6/1/35 [48]

Risk Characterization:

- Complex [65]

Risk Assessment:

- Ecological Risks [66]

Facility:

- Energy Systems [67]

Activity:

- Energy Production [68]
Challenge Area:

- Energy Efficiency

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