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Nanowire Solar Cells: A New Era of Photovoltaic Technology

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Abstract – *Solar energy, a huge abundant mass of energy impinges on Earth. This energy is predominantly growing in today's global energy consumption. Utilizing even the smallest amount of this energy to useful forms of energy, guarantees the requirement of future energy to be secured and stored. Photovoltaic energy is one form of energy converting intense light (photons) to electricity. In addition, with Nanowire technology, the traditional photovoltaics (PVs) offers multi-bandgap materials and low material consumption-based devices. The geometry of nanowires provides more advantages in terms of lower reflection, maximum trapping of photons, tunable bandgap, and defect tolerances. This doesn't necessarily mean that the properties optimize the rated efficiency of the system, instead they provide the flexibility in offering reduced quantity materials which results in reduced cost of the overall system. Nanowires exhibit innovative optical and electrical properties. This paper further emphasizes on overview of nanowire solar cells, some studies on nanowire synthesis, then nanowire solar cell performances of different semiconductor materials and finally, nanowire fabrication methods and its applications.*

Key Words: Nanowire Solar Cells, Nanowire Synthesis, Fabrication Methods, Performances of different Nanowire based material Solar Cells, Applications.

1.INTRODUCTION

Due to the ever-growing demand and requirement for renewable energy sources and adopting them over fossil fuels is one of the toughest challenges faced by modern humankind. Solar energy because of its abundance availability and more interest being shown, there is huge focus aligned towards the development of new classes of Photovoltaic Technology. The need for increased solar cell efficiencies considering the lower cost has become apparent and because of advent of nanoscience, electronic systems with higher performances are becoming possible. Nanowire based Solar Cell research have become predominant topics within the field of science and engineering [1]. Most of the commercial solar modules are based on crystalline Si materials. However, recent advances are being made on Generation II (thin film) solar cells and Generation III, (high efficiency and low-cost Solar Cells) requires the use of nanostructures and nanomaterials-based processes. The

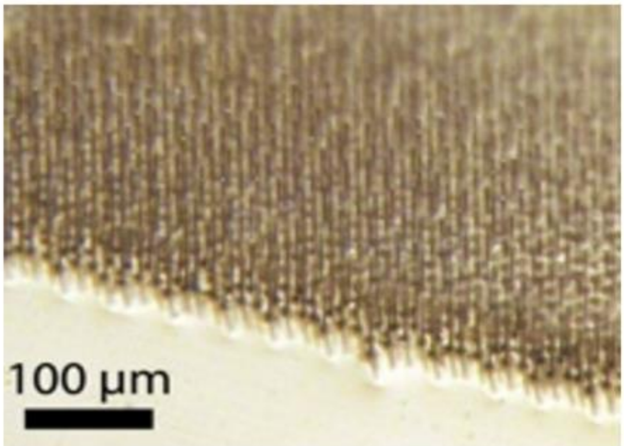

Figure-1: Nanowires (Solar Cells)

[Credit: Caltech/Michael Kelzenberg]

nanowire devices because of several improved performances and processing benefits, provides a direct path for transporting the charge carriers as afforded by the geometry of such nanostructures [3]. Nanoengineering nanowire solar cells offers more absorbing of incoming solar radiation, about 90 percent, depending upon the certain angle of incidence, which is twice the amount in comparison with traditional thin-film solar cells. Also building up of conventional solar cells requires intense temperature and more cost associated with the manufacturing process whereas nanowire based solar cells consumes only one percent of the amount required to build conventional solar cells [4]. Nanowires are the orderly arrangement of vertical stack arrays of electrodes constructed using pure semiconductor materials, basic idea being formulated is to convert photons to electrons. The potential of nanowire cells is unmatched over wafer based or thin film based solar cells. The fabrication of NW (nanowire) Solar Cells is done by Silicon, Germanium, Zinc Oxide [1]. In optimized level of configuring the device, its unlikely that current optimized rated efficiencies of nanowire solar cells exceed predicted or theoretical efficiencies. This is majorly due to the advancements not being made yet in terms of synthesis of nanowire solar cells, enhancement in the fabrication properties and complex device performances [2]. Instead, nanowire solar cells provide a pathway in doing more research to address the limits of efficiencies and bringing more of low-cost materials, also previously degraded materials and other various processing options [1]. Efficiencies of various implementations shown a steadily increase with the implementations of Nanowire Solar Cells.

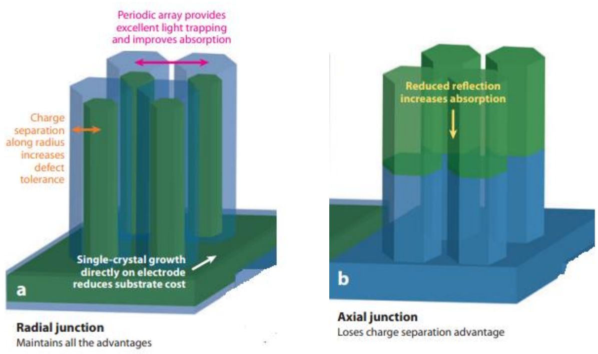

Figure-2: Periodic Arrays of Nanowires: Showing the advantages of Nanowire Geometry. [1]

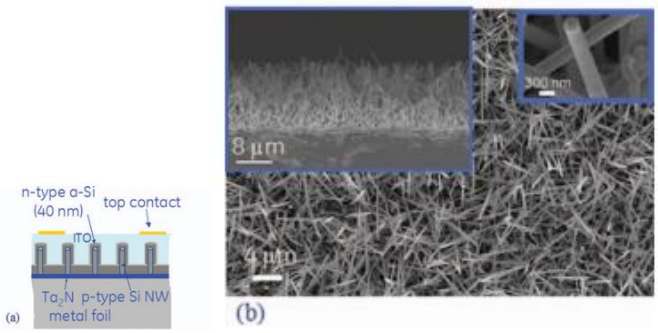

Figure-3: Structure of the Silicon Nanowire Solar Cell. (a) Schematic of Si NW solar cell, (b) SEM (Scanning electron micrograph) image [3].

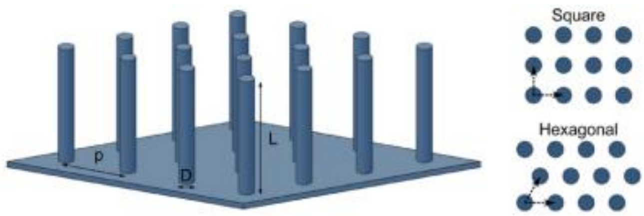

Figure-4: Geometry of arrangement of NWs. (p=array pitch, L=nanowire length, D=nanowire diameter, Square and hexagonal are the array symmetry) [5]

Solar cells made with nanowires have the toleration level up to 40 times as much high energy radiation [6]. Most of the available single junction solar cells, the total power conversion efficiency (PCE) is limited by Shockley-Queisser limit of approximately equivalent to 33%. Increasing PCE is possible with the combination of various materials along with their analysis with nanostructured materials.

2. NANOWIRE SOLAR CELL FABRICATION

The diameter of the nanowire is less than the wavelength of visible light and so the nanowire operates in the wave optics regime (Connection between waves and rays of light) [7]. The first step in the fabrication is the synthesis of nanomaterials. Synthesis is the production of chemical compounds by the reaction or combination of certain materials formulating nanowire solar cells. As nanowire exhibit various properties depending on the materials involved, controllable nanowire synthesis procedures are required. Synthesis techniques can be broadly classified into two categories, (a) Top-Down Fabrication Synthesis and (b) Bottom-Up Fabrication Synthesis [7].

2.1 Top-Down Fabrication

Lithography and chemical etching are the two approaches implemented in turning a bulk wafer to nanowire structure. Performing top-down fabrication requires large area, which is expensive and precision-based instruments often found in nanofabrication facilities. The analysis of this process is implemented from the [7].

Lithography is extensively used in the microelectronics and semiconductor industry and its is one of the most popular top-down techniques for nanofabrication. Initially, this requires the resist material deposition (poly) which acts as a photographic element, a film produces a pattern when provided exposure and development using a patterned mask. The resolution of different dimensions of photolithography is limited by the technique employed and

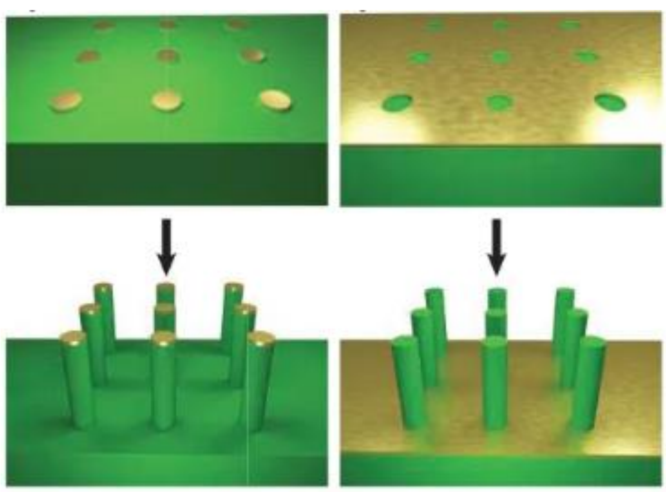

Figure-4: Top-down fabrication methods. Lithographic patterning followed by etching process [7].

the wavelength of light being used. This is not preferred for smaller nanowires. Without masking, a pattern with higher resolution is possible to achieve by using electron-beam lithography. As nanowire solar cells are the vertical stack of electrodes, to produce them persists the requirements of pattern consisting of a series of circles or holes on top of a wafer of the target intended material. Nanowires are then produced by etching the material from the wafer. Sometimes gold material is used as etch mask as its more stable. With top-down nanowire fabrication, its simpler to construct ordered arrays of nanowires forming the electrical contacts and assist in the integration of large-scale devices. The setback occurs if the desired length scale decreases thereby requires more sophisticated methods.

2.2 Bottom-Up Fabrication

Vapor Phase and Solution Phase are the two approaches often employed in the fabrication of bottom-up method.
Bottom-up process starts with the molecule assembly, its structure and the combination of these molecules forming a larger material with thousands and more of molecules embedded in a nanowire material.

In Vapor Phase, the growth of nanowires is done by nanoparticle catalysts. Most common method is vapor-liquid-solid (VLS) growth.

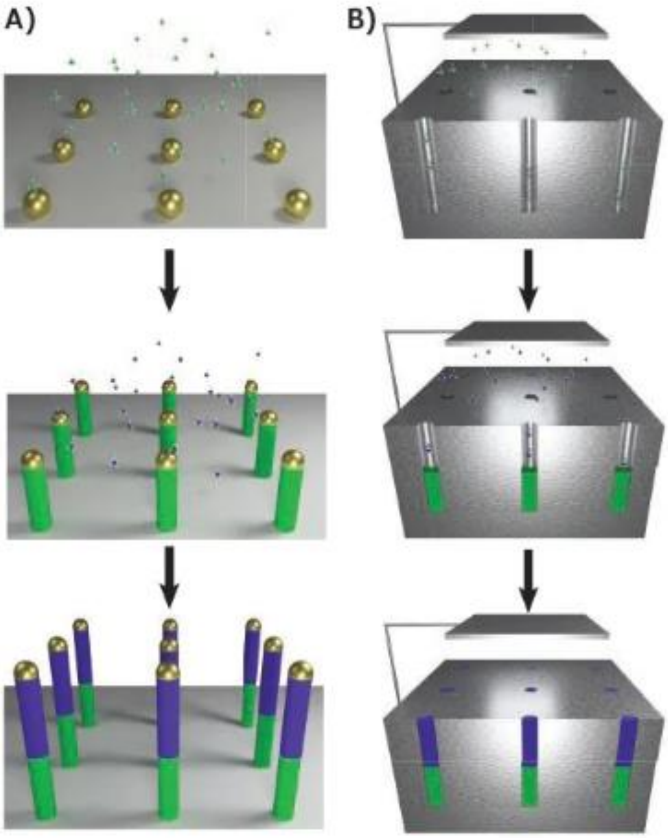

Figure-5: Bottom-up synthesis methods. (A) Vapor-phase growth of nanowires by VLS process. (B) Solution phase growth of nanowires by AAO process [7].

In Solution Phase, the growth of nanowires is done by Solution-liquid-solid mechanism. Anodic Aluminum oxide substrates are used to grow the nanowire materials. The bottom-up synthesis provides excellent control of nanowire composition during the growth of nanomaterial, producing complex nanostructures. The demerit is that, this method faces critical challenge when integrated to large-scale devices.

3. Performances of Nanowire Solar Cells

Nanowire Solar Cell Material	Growth Method	Single/array type	Efficiency (%)
GaAs	Bottom-up with Au (Gold)	Array	0.83 = ~1
GaAs	Bottom-up with Ga (Gallium)	Single vertical	40
GaAs	Bottom-up with Au (Gold)	Array	15.3
InP	Top-down	Array	17.8
GaN	Bottom-up with Au (Gold)	Array	2.73

Table-1: Nanowire Solar Cell Performances [2]

Table 1 provides the performance rubrics of various nanowire solar cells materials. In each material device, the results are listed as per to their PCE. It is shown from the table that solar cell performance has been drastically improved ranging from 1% in 2009 to 40% for single vertical nanowires as well as 15.3% and 17.8% for nanowire array synthesized with the bottom-up and top-down methods [2].

4. APPLICATIONS

As the nanowire geometrical structure provides a pathway to optimize the usage of materials to construct a photovoltaic system in a lower cost and minimal quantity when compared with building up of conventional solar cell materials. Nanowire solar cells enhances the optimality of absorption of photons from the radiated solar energy. The NW solar cells can be replaced with existing solar cells and can be used in domestic appliances requiring the consumption of electricity. The fabrication involves much simpler instruments and often requires nominal temperature. Designing the solar systems with NW solar cells is imminent.

5. CONCLUSION

The requirement of solar cells in the modern world requires the highest possible efficiency of a solar system with minimal manufacturing costs. Nanowire Solar cells exhibits the required measurement. Current solar technology limits the usage of fewer resources resulting abundant materials proning to more toxicity in the manufacturing process. The NW geometry eliminates the traditional solar practices, making a way to offer nontoxic, fewer material resources. Using NW solar cells enhances the absorption of incident light from the solar spectrum. Much of the research must be now prioritized on how the nanowire solar cells can be integrated with solar modules in framing a larger solar system, understanding nanowire geometry, its chemical stability and durability when exposed to high temperatures.

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