A Study on Modern Innovations in Nano Technology for Harvesting Solar Energy and Energy Storage

Bagyalakshmi Shanmugam[1] and Sujeen Raj Kumar[2]
1. Department of Physics, Sri Ramakrishna Institute of Technology,Coimbatore,Tamil Nadu, INDIA
2. Department of Electrical and Electronics Engineering, Sri Ramakrishna Institute of Technology, Coimbatore , Tamil Nadu, INDIA
bagyaphy@gmail.com; sujeenrajkumar5@gmail.com

Abstract
A nanotechnology is a robust tool for the solar system, which gives assistance to efficient, sustainable energy conversion, storage and conservation, in terms of adapting the interaction of light with materials and sanctioning the processing of low-cost semiconductors into devices such as photovoltaic devices. Passive solar systems, Supercapacitor, Solar collector, fuel cell, photo catalysis and solar photovoltaic and dye-sensitized solar cells are of major parts of solar systems, which used the nanomaterials in their systems. Nanomaterials are used as electrodes and electrolytes in various energy storage devices and they are becoming progressively important in areas such as electrochemical sensing, energy harvesting and storage. Nanomaterials have large surface-area-to-volume ratio compared to other bulk materials. Nanotechnology is an emerging technology that provides an increasing resource to resolve the problems related to energy because of their smaller than 100 nm which provides the way to detect, store and exchange energy.

The different types of modern solar collecting technologies that use the nano- materials effectively and successfully have been discussed. We have concentrated on the applications of nanotechnology for different solar energy storage systems. Then we insisted on how nanotechnology substantially contributes to improve the performance of solar cell technologies. Finally, this review focus on how nanotechnology has played a wide role in bringing in sustainable energy from solar radiation.

Keywords: Solar Cells, Nanotechnology, Energy Storage Devices.

Introduction
The term "nanotechnology" was described as a method of division, union and deformation of materials by one atom or one molecule". The unusual physical, chemical and biological properties can appear in materials due to the nanoscale. Those properties may differ from the characteristics of bulk materials and individual atoms or molecules. Additionally, the thought that nanotechnology includes structures exhibiting quantum mechanical aspects, such as quantum dots. However, it explicitly indicates not only the miniaturization but also the specific manipulation of atoms and molecules to produce and control the properties of the nanomaterials/nano systems[1]. Nanotechnology can significantly increase the result of energy storage, generation and performance. Several experts think that the sun is the only applicant that can give a fully detailed answer to the energy crisis.

Hence, solar cells can be viewed as an important renewable energy resource once their production cost has decreased to an affordable level compared with other accessible energy sources[2]. Sequentially, technologies in a solar cell have evolved into various generations. Solar cells in first-generation are based on a single crystalline semiconductor wafer. Solar cells of Second-generation manipulate the formation of an inorganic thin film in the cell arrangement. They are higher cost-effective to produce, but the power, which is less than 15% in solar cells made of amorphous thin-film and the performance is lower compared to single junction crystalline solar cells.

Currently, the essence is on the solar cells in current-generation that can produce economic, highly efficient cells. In this study, we have focused on the applications of nanotechnology for different solar systems. Furthermore, we have highlighted how nanotechnology significantly gives to improving the performance of solar cell technologies.

Significance of Renewable energy through nanotechnology: Most importantly, renewable energy is sustainable and its sources never dry out as well as require less maintenance than fossil fuel generators. One problem of renewable energy is the difficulty in producing electricity as large as those produced by traditional fossil fuel generators. Another drawback is the reliability of supply as it relies on weather for its source of power. The renewable energy sources that can be utilized for effective energy harvesting are solar energy, tidal power, hydropower, geothermal power, biomass etc.[3]

Solar Cells Generations: The energy produced by the sun is an essential renewable energy source for its production and minimizes the emission of greenhouse gasses. The amount of solar energy collected by the Earth from the Sun is enormous. The first generation of solar cells consists of high-quality materials with high production costs and relatively high efficiencies. It consists of single and polycrystalline silicon and germanium doped with phosphorus and boron. Silicon solar cell gives high efficiency which is costly but stable and durable. The silicon wafers made of crystalline materials consist of a large area of single layer p – n junction diode. Solar cells in an earlier generation are the most effective solar cells available for domestic use, which estimate for around 80 percent of all solar panels. The photovoltaic cells in second-generation consist of thin-film solar cell materials, such as cadmium telluride (Cd Te), copper indium gallium di selenide (CI-GS), amorphous silicon (a-Si) and cadmium sulfide (CdS), etc. The second-generation solar cells have lower efficiencies and lower production costs when related to first-generation solar cells. The efficiencies are 16.5% for Cd Te and 18.4% for CIGS. However, photovoltaic cell (PV) based on Cd Te and CIGS has the best efficiencies of 10.7% for Cd Te and 13.4% for CIGS.[4] The solar cells of third-generation transformed the constraints of single-junction devices and lead to high efficiency for the same production costs compared to first and second-generation solar cells.

The most developed third-generation solar cells are quantum dot sensitized solar cells, solar cells of dye-sensitized and polymer solar cells. Dye-sensitized solar cells are based on dye molecules, a metal oxide semiconductor, electrolytes and conducting electrodes. Polymer solar cells are flexible and use conducting polymers as electrodes. Although their efficiency is very low, there is a great possibility for the improvement of their efficiency by research[4]. The cost is very low and fabrication processes are simple in third-generation solar cells when compared to other technologies. Solar cell technology in Fourth-generation combines the low cost and the polymer thin film flexibility with the novel inorganic nanostructures stability to enhance the electronic and optical properties.

Solar cells in Fourth-generations based on inorganic materials give improved power conversion efficiency than third-generation solar cells. Establishment of active inorganic nanomaterials improves the harvesting of solar energy and the administration of electrical charges within these solar cells improves efficiency and lifetime stability.

Generation of electricity through photovoltaic solar cells: Solar Cell turns light energy into electrical energy. A solar cell is fundamentally a p-n junction diode. To transform light energy into electrical energy, it employs a photovoltaic effect. An extremely thin layer of p-type semiconductor is developed on a nearly thicker layer of n-type semiconductor. When light arrives at the p-n junction, the light photons can quickly penetrate the junction, into a very thin p-type layer. To create a number of electron-hole pairs, the photon provides adequate energy to the junction. The incident light discloses the thermal equilibrium state of the junction. The free electrons can quickly reach the n-type side of the junction from the depletion region.

Furthermore, the holes in the depletion region can soon arise to the p-type side of the junction. Because of the barrier potential of the junction, the free electrons coming to the n-type side, cannot pass the junction. Thus, the holes once reach the p-type side cannot further cross the junction due to the same potential barrier of the junction. The concentration of electrons is higher in the n-type junction and the concentration of holes also larger in the p-type junction, the p-n junction will work as a tiny battery cell. A voltage known as photo voltage is set up. A small current passing through it if a small load is connected across the junction. The materials which are employed for this need must have a band gap of 1.5 eV.

Generally utilized materials for solar cells are-GaAs, CdTe, Silicon and CuInSe2. Standards for Materials to be utilized in Solar Cell should have band gap from 1eV to 1.8eV, high optical absorption and high electrical conductivity. The raw material requirement should be abundant and the cost of the material must be less. Solar Cell's advantages are no pollution will be related to it and last for a long time, with `no maintenance cost. Disadvantages of Solar Cells are installation high cost, low efficiency. Generation in Solar Systems is used to charge wristwatches, batteries, in light meters, to power calculators and, spacecraft to provide electrical energy.[5]

Optical Properties of nanomaterials for applications in solar cells: Nanomaterials revealed the optical and electronic properties of materials at the scale of nano meters. Many materials forms of nanomaterials include nanoparticles, nanorods, nanofibers, nanowires, QDs, nanotubes, nanosheets and nanopores lead to a tremendous amount of applications. The nanoscale materials offer extraordinary physical, chemical and optical properties, because of an increase in the area surface to volume ratio. As an example, gold (Au) nanoparticles color shows variations with changes in the size of the nanoparticles, this property presents them with an outstanding nominee in the healthcare division. The novel nanomaterial's physical properties comprise adaptability in bandgap energy and the size of nanoparticles can be easily varied, a significant reduction in the recombination of charge carriers leading to a path shorter to travel for photon-generated carriers. For PV applications these properties offer them very appealing. Nanomaterials transform solar energy by making the photo voltatic devices to trap light and to collect carriers of light. Certainly, nanoparticles can make devices of Photo Voltaic Cell to improve the optical absorption of active layers and to overcome the loss of charge carrier while transport. Structures of nanomaterials include a large surface area in dye-sensitized solar cells.

New studies showed nanostructured semiconducting materials in the form of nanowires, nano cones, etc displayed enhanced absorption of a photon and an increase in the effectiveness of collecting the photo-carrier. For renewable energy applications, Nanostructured inorganic material-based PV devices such as solar cells made of quantum dots are the prime technology. Stability, absorption properties, lifetime and efficiency with less dependence on manufacturing equipment are also, advantages of inorganic solar cells [6].

Nanotechnology in the fabrication of solar cells: The advantages of Nanomaterials in the fabrication of solar cells are listed below as production costs are decreased as a result of practicing a low-temperature process rather than using a high-temperature vacuum deposition process to produce conventional solar cells made with the semiconductor crystalline material, hard crystalline panels can be used instead of adjustable rolls to minimize the cost of installation. Researchers studied solar cells thick sheets of graphene manufactured from single-molecule and molybdenum diselenide materials.

They observed this type of solar cell could produce up to a thousand times as much more power than traditional solar cells. They also produced a solar cell employing zinc oxide nanowires coated with graphene. The low cost of flexible solar cells can be produced with great efficiency. Scientists used the Aerotaxy method to grow gold nanoparticles using semiconducting nanowires. To align the nanowires on a substrate, self-assembly techniques are used to form a solar cell. e a solar cell, titanium dioxide nanoparticles, silver nanowires and a polymer were combined so it incorporates infrared light, it is used in windows which is about 72 percent transparent to visible light [7].

Advancements in solar cells composed of nanomaterials: Nanoporous germanium flexible layers were to produce lesser weight solar cells for electronic applications. To produce low-cost solar cells nanotubes made of Titanium dioxide filled with a polymer were used . Some scientists combined carbon nanotubes and buckyballs along with graphene to produce solar cells. To form solar cells of more powerful efficiency lead selenide quantum dots merged with titanium dioxide. Researchers developed a method to confine light in organic solar cells so the more electrons will be created.

This is achieved by making the organic layer much slimmer than the wavelength of light and the organic layer is sandwiched between a mirror layer and a rough layer so the light waited in the solar cell for a longer time and excite more electrons. Low-cost solar cells can be produced using Semiconductor nanoparticles employed in a printing process of low temperature. To produce low cost flexible solar panels using nanowires which is of light-absorbing were embedded in a flexible polymer film was fabricated. For spray painting, the surface of a car can be turned into a solar cell. These solar cells are composed of cadmium sulfide nanowires coated with copper sulfide that can be applied to make Organic solar cells. On windows or other building materials, Solar cells can be established as a coating.

Achievements of Nanotechnology in the storage and production of Energy: Nanotechnology is significantly utilized in numerous applications to improve the efficiency and new methods of the generation of energy.The ways of using nanotechnology to produce more cost-effective and efficient energy. Reviewers have confirmed that devices can produce steam with high energy efficiency when sunlight focused on nanoparticles. In areas of emerging countries without electricity for utilization such as purifying water or sterilizing dental instruments, the "steam solar device" is designed to get practiced.

Further, nanoparticles also designed to run powerplants by generating steam from sunlight. To produce high-efficiency light bulbs a nano-designed polymer film is employed. So the newly designed bulbs have the benefit of signifying shatterproof and double the performance of fluorescent light bulbs. The high-efficiency LEDs utilizing nano-sized arrays structures such as plasmonic cavities also produced. Another plan under construction is to modernize intense light bulbs by circling the traditional filament with a crystalline material so visible light turned into infrared radiation.To construct windmill blades, carbon nanotubes embedded in epoxy is used. Carbon Nanotube-filled epoxy is employed to make more powerful and blades of lesser weight. The quantity of electricity generated by every windmill is increased due to longer blades.

Generating electricity from waste heat. Scientists reported that nanosheets can construct cells to produce electricity when the two cell surfaces at various temperatures. These sheets made of nanotubes create electricity from dissipated heat which is being covered around pipes, like cars exhaust tube. The graphene layers were synthesized so the binding energy of hydrogen was increased to the graphene surface in a fuel container, occurring in tremendous amount storage of hydrogen and makes it a lower weight fuel container. Others also showed nanoparticles made of sodium borohydride can effectively store hydrogen. To charge mobiles and other electronic devices. Nanofibers made of piezoelectric materials are fabricated which are so adaptable enough to wear like clothing[8,9].

Current Advances in applications of nanotechnology in Fuel Cells: Catalysts like methanol or hydrogen act with fuels that create hydrogen ions. The expensive catalyst such as platinum is employed in this process. Nanotechnology is used to create more efficient membranes that permit hydrogen ions to progress through the cell, this makes them develop slighter weight and long-life fuel cells. To substitute batteries in devices such as or computers or laptops, Tiny fuel cells such as direct methanol fuel cells are designed.

Also, with a Direct Methanol Fuel Cell inject a new cartridge of methanol into the device than charging by using the normal battery. DMFC's are produced to serve greater than normal batteries. Nanoplate catalyst utilizing lead and platinum having extended lifetime and a huge level of reduction of oxygen was reported by researchers. Efforts also are taken to reduce the quantity of platinum required to act as a catalyst in fuel cells. they also found platinum nanoparticles spacing which affects the behavior of catalysts, can be controlled by changing the of the platinum nanoparticle packing density. The catalyst is constructed from a sheet of cobalt nanoparticles coated with graphene is used which is much less expensive than catalysts made of Platinium[10,11].

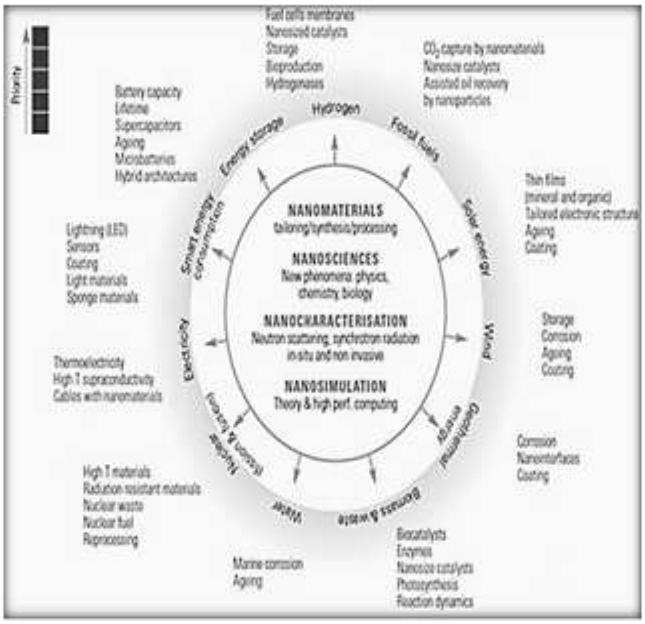

Figure 1: Implementation of Nanotechnology in various fields

To produce hydrogen, a protein shell encapsulated by an enzyme that can function either as a catalyst of a fuel cell. To produce nanoplatelets produced by graphene flakes through ball-milling in the presence of chlorine, bromine or iodine which are edge-halogenated possess good catalytic properties and used as an alternative for costly platinum catalyst in fuel cells. Nanoparticles of cobalt - platinum combined catalyst shows higher catalytic activity than pure platinum. Scientists reported a proton shift layer is fabricated using silicon with vesicles of approximately 5 nm in diameter capped by a porous silica layer to store water in the nanopores. When hydrogen molecules merge with the acid besides the nanopores wall forming acidic solution, it provides an easy pathway for ions of hydrogen through the membrane and showed better conductivity of hydrogen ions in situations of moderate humidity than the older used membrane of fuel cells[12,13].

Inventers studied the storage of hydrogen in graphene which is of single atom thick made of carbon sheets. They used plasma treatment to increase this bonding energy because the hydrogen shows high bonding energy than carbon and also due to graphene greater surface area. So, the graphene greatly stores hydrogen by a minimum of 15 %. Researchers also presented gold nanoparticles can be utilized to generate hydrogen from solar energy. Gold nanoparticles act a photocatalyst for hydrogen generation.

Implementation of Nanotechnology in Batteries: Researchers found lithium metal batteries of greater potential and quicker charging are developed by using films of carbon nanotube than normal lithium-ion batteries. Carbon nanotubes which are of silicon-coated are also used in Lithium-ion batteries[14,15]. Li-ion battery's capacity is increased if we use the silicon as the anode materials. Silicon is placed on nanotubes to prevent damage to the anode when the silicon grows.

They also fabricated a technique using graphene cages around silicon nanoparticles. The object is when the silicon grows in the nanoparticles it settles in the graphene crate without deteriorating the anode. Scientists also showed catalyst obtained from carbon-nanotubes doped of nitrogen, preferably than using platinum which stores larger energy. They also practiced the utilization of carbon nanotubes in electrodes to enhance the power density of capacitors. In graphene possessing an extremely high surface area and very feeble electrical resistance, the carbon nanotubes are grown to make as an electrode.

Batteries in hybrid cars use nanotubes for applications in Ultracapacitors to collect the electrical charge. To improve the charge/discharge rate and a lifetime of Li-ion batteries, Battery anodes utilizing silicon nanoparticles covering with titanium disilicide. When lithium titanate employed in batteries with electrodes improves the charge/discharge capacity. Carbon nanofibers, graphene on the surface of anodes are widely used as an electrode to make highspeed recharge in lithium-ion battery electrodes.

Conclusion

Because of a globally rising power need, managing climatic changes due to continuously increasing carbon dioxide emissions, as well as the rarity of fossil fuels, the development and demand of sustainable methods for power generation related to the resolve the common primary hurdles of humanity is required. The huge effort at political and economic levels is needed to renew the present energy system. Developing efficiency and new methods through nanotechnological experience perform a pivotal role in the necessary modification in the energy sector.so in this review we studied about the various nanomaterials applications used in energy sector, hydrogen storage and fuel cells[16].

Recent Innovations In Solar Cell Technology: Concerning the prospect of solar energy solar cells composed of perovskite exist significant. still, the material deteriorates fast, seriously restricting its performance and stability across time. scientists have determined that supplementing a little quantity of fluoride to the perovskite gives a protecting coating, improving the stability of the solar cell. researchers have increased the productivity of material which forms the base for future solar cells. like silicon-based solar cells, perovskite solar cells are composed of a mix of inorganic and organic molecules that together capture light and convert it into electricity. perovskite photovoltaic devices are easy, cheaper than silicon and flexible. investigators have formed a new kind of solar cell that combines two distinct layers of the sunlight-absorbing element to collect a wider area of the sun's energy. the advancement could begin to photovoltaic cells that are more effective than in solar-power installations, the unique cell uses a layer of silicon semi-transparent layer of a material called perovskite, which can incorporate particles higher-energy of light. tandem perovskite solar cell with high efficiency was developed to answer the world energy crisis.

Acknowledgement

We render ours sincere thanks to our institution Sri Ramakrishna Institute of Technology Coimbatore who helped and supported a lot to pursue our research in this field. We wish to acknowledge with appreciation to all the supporting authors for their interest, help and expertise as illustrated in their fields of interest. It is of their great effort and contribution that makes the publication.

References

1. Ashby M.F., Ferreira P.J. and Schodek D.L., Nanomaterials and nanotechnologies: an overview, 1–16 **(2009)**

2. Zäch M., Hägglund C., Chakarov D. and Kasemo B., Nanoscience and nanotechnology for advanced energy systems, *Curr Opin Solid State Mater Sci*, **10**, 132-143 **(2006)**

3. Serrano E., Rus G. and García-Martínez J., Nanotechnology for sustainable energy, *Renewable and Sustainable Energy Reviews*, **13**, 2373–84 **(2009)**

4. Green M.A., Third generation photovoltaics: advanced solar energy conversion, *Physics Today*, **57**, 71–2 **(2004)**

5. Mao Y. and Chen X., Selected nanotechnologies for renewable energy applications, *Int J Energy Res*, **31**, 619-636 **(2007)**

6. Xia Y., Yang P. and Sun Y., One-dimensional nanostructures: synthesis, characterization and applications, *Adv Mater*, **15(5)**, 353-389 **(2003)**

7. Guo K.W., Green nanotechnology of trends in future energy: a review, *Int J Energy Res*, **36(1)**, 1-17 **(2015)**

8. Saidur R., Leong K. and Mohammad H., A review on applications and challenges of nanofluids, *Renewable and Sustainable Energy Reviews*, **15**, 1646–68 **(2011)**

9. Chaar E.L. and Zein N., Review of photovoltaic technologies. *Renewable and Sustainable Energy Reviews*, **15**, 2165–75 **(2011)**

10. Guo C.X., Guai G.H. and Li C.M., Graphene based materials: enhancing solar energy harvesting, *Advanced Energy Materials*, **1**, 448–52 **(2011)**

11. Khan F.I., Hawboldt K. and Iqbal M.T., Life cycle analysis of wind- fuel cell integrated system, *Renew Energy*, **30(2)**, 157-177 **(2005)**

12. Mao Y. and Chen X., Selected nanotechnologies for renewable energy applications, *Int J Energy Res*, **31(6-7)**, 619-636 **(2007)**

13. He Y., Wang S., Ma J., Tian F. and Ren Y., Experimental study on the light-heat conversion characteristics of nanofluids, *Nanosci Nanotechnol Lett*, **3(4)**, 494-496 **(2011)**

14. Ho T.X., Kosinski P., Hoffmann A.C. and Vik A., Effects of heat sources on the performance of a planar solid oxide fuel cell, *Int J Hydrogen Energy*, **35(9)**, 4276-4284 **(2010)**

15. Du H.Y., Graphene nanosheet–CNT hybrid nanostructure electrode for a proton exchange membrane fuel cell, *Int J Hydrogen Energy*, **37(24)**, 18989-18995 **(2012)**

16. Karimi G., Jamekhorshid A., Azimifar Z. and Li X., Along-channel flooding prediction of polymer electrolyte membrane fuel cells, *Int J Energy Res*, **35(10)**, 883-896 **(2015)**

17. Liu Z.H., Hu R.L., Lu L., Zhao F. and Xiao H., Thermal performance of an open thermosyphon using nanofluid for evacuated tubular high temperature air solar collector, *Energy Converter Manage*, **73**, 135-143 **(2013)**

18. Tyagi H. and Khullar V., Application of nanofluids as the working fluid in concentrating parabolic solar collectors, Conference: 37th National and 4th International Conference on Fluid Mechanics and Fluid Power, At IIT Madras, Chennai, India **(2010)**.