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Carbon Nanotubes for Enhancing the Efficiency of Solar Cells

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Abstract: ***The modern world is continually experiencing volatility in energy costs, in addition to ever-increasing environmental concerns besides tight budget climate. These pressures have helped to incite development of long-term strategies that guarantee reliable, cost-effective and sustainable energy supply for the large scale solar production systems in a more efficiency-guaranteeing fashion. The continuing pressure on available resources calls for sustainability in the use of these resources and maximization of efficiency in environmentally-friendly energy sources such as solar energy. Large scale solar production systems have become vital alternatives in helping to foster the agenda of sustainable development that has currently become the focal point of increased attention in all sectors, including the energy sector. Bearing all these into consideration, the main aim of this research study will be to investigate how efficiency of solar cells can be enhanced through the use of carbon nanotubes.***

Keywords: Carbon nanotubes,CNT-Silicon cells, Solar cells, crystalline solar cell, amorphous solar celland thin film solar cells

1. Introduction

1.1 Research Background

The modern world is continually experiencing volatility in energy costs, in addition to ever-increasing environmental concerns besides tight budget atmosphere. These pressures have facilitated incitement for development of long-term strategies that guarantee reliable, cost-effective and sustainable energy supply for the large scale solar energy generating systems that do not cause carbon dioxide pollution or environmental degradation. The continuing pressure on available resources calls for sustainability in the use of these resources such as energy. Large scale solar power plants are increasingly gaining attention as possible vital alternatives in helping to foster the agenda of sustainable development that has currently become the focal point of increased attention in all sectors, including energy sector. With respect to sustainable development, four main areas are of great interest. These domains include Economics, Politics, Culture and Ecology. The Ecological field is one of the most exigent areas in the field of sustainability, with majority of the other categories not receiving even satisfactory levels. With respect to economics, the idea is that the amount of power generated when CNTs are used should be of such value that the levels of costs incurred in production are not only low but also lower than alternative solar generation efficiency boosting techniques.

Within the ecological sphere, nearly every aspect correlates with agriculture. This includes aspects like energy and food that greatly interrelate with agriculture. Water and environment too are highly correlated with agriculture. Therefore, it is imperative to investigate and explore various efficiency-focused techniques that aim at satisfying the sustainability standards and which mainly focus on ensuring high efficiency in solar power generation. The CTN model is among the most prominent techniques that have drawn attention of experts and researchers as a possible effective alternative for boosting efficiency in various types of solar cells. Solar power plants used for commercial purposes are used to generate power with the aim of attaining higher and sustainable levels of energy outputs and guard them (the solar system as a whole and solar cells in particular) against harsh effects of oxides, inefficiencies in photo-electrochemical conversion and barriers to carrier transport.

1.2 Statement of the problem

The large scale solar power plants provide the benefit of all year round generation of power in regions where solar energy can be tapped from the sun all year round and offers another benefit of environmental friendliness. While a greater energy production output can be attained in polymer-based solar systems, greater demand for the renewable energy necessitates development of mechsnisms that make the solar energy production more efficient by increasing conversion factor and reducing resistance to carrier transfer. Furthermore, according to Suzuki, Yamaguchi, Kumagai, and Yanagida, (2003) the carbon nanotubes stood as significantly superior counter electrode in solar systems that utilized dye-sensitized solar cells. And according to Nam et al (2010), elimination of oxide layers comprises the greatest element to achieving greater photoconversion efficiency rates when single wall carbon nanotubes (SWCNTs) are employed as the main carbon electrode. When SWCNTs were used and oxides eliminated, the study findings indicated that the conversion factor went higher and that the conversion stood at 45% or more making carbon nanotubes to be considered as a significant improvement to the efficiency of solar cells. This implies that energy conversion in the commercial solar plants has been given emphasis in recent times with the purpose of achieving high levels of efficiency in energy generation of the solar cells and that carbon nanotubes or CNTs are at the center of the consideration.

In this case, considerations for a statistical assessment have been made aiming to achieve a better level of understanding of photoconversion efficiency management aspects in the polymer-based solar power systems. The overall energy demand in the global perspective has been on a steady rise with estimations putting demand for solar power to an ever-increasing level in the future as the graph below indicates.

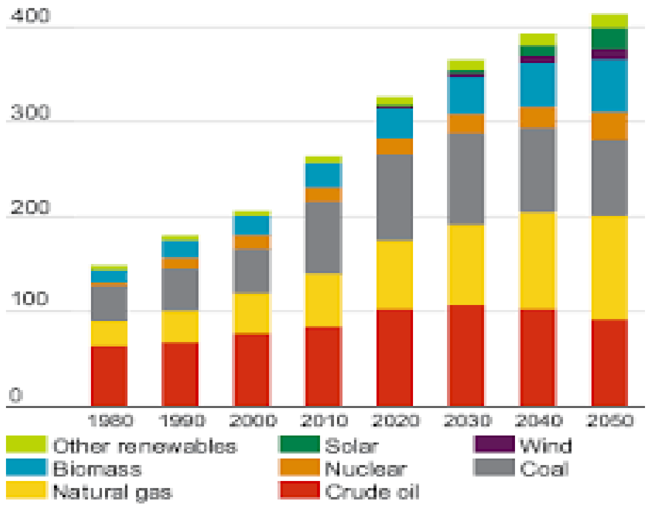

Figure 1: Energy Future Demand

The above graph clearly indicates a steady increase in energy demand for energy in the future and clearly shows that demand for solar energy will shoot greatly in the future in the global and national energy markets (IEPA, 2015). These statistics and figures clearly show the need to investigate and come up with strategies that are aimed at ensuring sustainability in efficiency of the solar power systems to guarantee steady energy supply within the global energy market.

2. Literature Review

2.1 Categorization of Solar Cells

According to Jamwal and Vaid(2015) point out that there are three basic cateogires of solar cells and these categories include the crystalline solar cell, the amorphous solar cell and thin film solar cells. The authors (Jamwal&Vaid, 2015) further note that the emergence of carbon nanotubes (CNTs) had enhancement of overall conductivity of the solar cells as the main driving force. Given that carbon nanotubes are the darkest material ever produced, they can capture solar energy more efficiently as they have the capacity of absorbing extremely high amounts of solar energy when compared to traditionally used materials. Moreover, according to Suzuki et al (2003)when heterojunction solar cells are built using CNTs, they are built using inorganic semiconductor such as silicon. In such a scenario, Mallajosyula, Iyer, and Mazhari, (2010) observe that the main object or function of the CNTs is to act as charge separation as well as charge collector and carrier.

Interestingly, Jamwal's and Vaid's (2015) study noted that when an electrolyte such as HNO3 was added to the CNT-Silicon interface, the performance efficiency of CNT-Silicon cells was boosted with a factor between 6% and 12%. This implies that boosting efficiency of solar cells where CNT-Silicon interface is used would be achieved by applied nitric acid electrolyte.

2.2 Efficiency in Charge Transport

An aspect that has extensively been highlighted in past studies and existing literature is charge transport. In one study, Kongkanand et al (2007) investigated carbon nanotube scaffolds as means of improving efficiency in photo-electrochemical solar cells. According to the study findings, single wall CTN (SWCNT) design when used as conducting gibbets in a TiO_2 semiconductor-based photo-electrochemical cell has the capacity of significantly boosting the photoconversion efficiency. Furthermore, the study findings showed that the photoconversion efficiency achieved when SWCNT is used comes to a factor of 2. In the study, the researchers dispersed titanium dioxide particles on thin SWCNT layers with the aim of improving photo-induced charge separation as well as improvement of transport of carriers to the charge collecting electrode surface. This study by Kongkanand et al (2007) provides a foundational block for the current study by initially laying emphasis on single-walled CTN as vital alternative to improvement of efficiency in solar cells. Nonetheless, the authors point out, in their findings, that attainment of Fermi level equilibrium between the SWCNT and the TiO_2 systems is extremely fundamental and that attainment of this equilibrium between the two systems has a major impact on boosting efficiency so that whenever there is charge equilibration between the SWCNT system and the TiO_2system the photoelectrochemical output or performance of the nanostructured semiconductor based solar cells is improved.

In the study by Suzuki, Yamaguchi, Kumagai, and Yanagida, (2003), the researchers investigated the possibility of three materials working as most efficient counter electrode in solar power system involving dye-sensitized solar cells. The study findings demonstrated that when SWCNTs were employed as the main carbon electrode, the achieved conversion of the system stood at about 4.5%, which is basically comparable to the conversion efficiency achieved via the use of Grätzel-kind dye-sensitized solar cells where the counter electrode mainly comprises fluorine-doped tin oxide of platinum variant. The results of this study by Suzuki et al (2003) are comparable to those achieved by Nam et al (2010), which investigated enhancement of performance of dye-sensitized solar cells using either screen printing method or via chemical vapor deposition.

Moreover, the study findings indicated that when elimination of oxide layers was well achieved, the conversion factor went higher and that the conversion stood at 45% or more making carbon nanotubes to be considered as a significant improvement to the efficiency of solar cells. This is in line with the observation made by Khan, Ikeda, and Matsumura (2014), who point out that presence of oxides can greatly limit the general efficiency of the solar cells and undermine the conversion rate of the entire solar power generation system when the oxides build up on the surface of the layers. The study by Khan, Ikeda, and Matsumur (2014) mainly focused on evaluating efficiency "in solar cell by chemically

processed hierarchically stacked debundled pristine carbon nanotubes" (Khan, Ikeda, & Matsumura, 2014, p. 406).
The study by Mallajosyula, Iyer, and Mazhari (2010) investigated the role played by single-walled carbon nanotubes in boosting efficiency of polymer-based organic solar cells. To ensure removal of oxygen molecules from the SWNT surface, the researchers applied hydrogen fluoride vapor; noting that there is always the presence of natural oxide within the surface of the silicon even at room temperature and the presence of this oxide layer can act as a barrier to improved performance of the solar cells.

To further boost the efficiency of the cells, the researchers removed other residual molecules through constantly applying electric current to the carbon nanotubes. This study by Mallajosyula, Iyer, and Mazhari, (2010) is vital for providing a foundational understanding for the current study by not only directing and further cementing the importance of dealing oxides in solar cells but by also showing that removal of other residues is just as important given that these residual molecules compromise efficiency of the cells.

In the study (Alturaif, ALOthman, Shapter, &Wabaidur, 2014), which explored the useof carbon nanotubes with polymers in solar cells, the researchers found that CNTs have a significant positive impact on the efficiency of solar cells in terms of conversion and photoelectrochemical performance. However, one area that this study plays a major contributing role to the current proposed study is its emphasis on the need to ensure reduced internal resistance, which in turn works to guarantee improved fill factor. Just as in the study by Khan, Ikeda, and Matsumura (2014), the study by Alturaif et al (2014) also demonstrated the significance of establishing photoelectrochemical components that boost charge separation and carrier transport. The two studies complement each other well in various areas of the topic at hand and provide sufficient encouragement for the ongoing topic of the possible use of carbon nanotubes as a mechanism for improving efficiency in solar cells.

3. Research Methodology

The study will use critical literature review as the main study methodology. According to Jesson and Lacey (2006), critical literature review is a methodology where the researcher mainly takes an interpretivistic epistemological approach to a problem through synthesis of the results of existing studies. To ensure rigor and quality, the study will combine positivist with interpretivism elements as Jesson and Lacey (2006) admonition.

The aims of the study will be achieved by critically evaluating the other forms of efficiency enhancement for solar system efficiency concepts and highlighting their drawbacks in order to provide a philosophical rationale upon which the CNTs model can be developed. The approach includes a cost-benefit-analysis of the CNT concept in comparison to the traditional methods. Closing with recommendations, the study will highlight the opportunities available for future research undertakings.

Through this method and with specific focus on the proposed study objectives, the prospects in solar cells performance enhancement using CTN will be investigated and evaluated by critically evaluating past studies that have focused on the topic under study. This undertaking will yield a summary of various main categories of performance enhancement for solar cells. These are: low impact energy performance, medium impact performance and high impact on the energy demand reduction. Subsequently, the high impact prospects have been further investigated with the aim of assessing their cost effectiveness in addition to measuring the energy saving of each investigated opportunity.

The economic feasibility of every proposed performance enhancement prospect will also be appraised using a simple payback period time method. Founded on the results gained from the performance enhancement examination and the critical review of literature, the various pathways for managing solar energy systems will be discussed for polymer-based and other types of solar cell based on standard temperate climatic condition to hot and arid climatic condition and tropic climatic conditions. For each condition (whether polymer or non-polymer), the most promising options will be suggested in a conduit for effective performance enhancement to enable large scale solar energy generation. In addition, and where appropriate, the impact of each suggested technique on the environment is evaluated by investigating the carbon-dioxide emission reduction.

4. Summary of Possible Ethical Issues

As with any research undertaking of this kind, there are a few ethical issues that have to be addressed since ethical conduct is a very vital element of a sincere academic undertaking like this project. However, given that the study will not involve direct respondents from field-based study, issues related to participant protection are not relevant to this study. Nonetheless, while this study will mainly involve critical review of literature as the main methodology, the main ethical standard will comprise gaining permission for the study and the permission to use material sources. As already mentioned, the issue of ethical conduct is very important for any scientific understanding such as this. For that reason, the researcher will ensure that where necessary, sources of data are informed and appropriate permission granted for use of data where applicable.

5. Conclusion

The broad conclusion of this study is successfully achieved by investigating the opportunities for improving solar energy generation through carbon nanotubes as means for efficiency enhancement with the aim of incorporating the sustainability concept. Within this broad conclusion, the following specific conclusions are achieved from the study:
1) Investigation of energy generation efficiency within large scale solar power generation system
2) Investigation of efficiency-enhancing strategies and evaluation of the economic sustainability or feasibility of the proposed techniques.
3) Evaluation of the carbon nanotubes (CNTs) model as a multidimensional efficiency boosting prospect that can

work as the most effective and economic opportunity for enhancing efficiency of solar cells.

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