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Storage of Solar Energy and Use of Photovoltaic Cells

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Abstract—*Current commercialized solar cells possess the disadvantages- of being harmful to the environment, lower efficiency and high maintenance problems, which has lead us to the possibility of utilizing organic photovoltaic cells that manage to curb all the mentioned problems. Our objective of the paper is to create a solar tree, which produces 20-50% more power than a uniform array of photovoltaic panels. In the solar tree, the organic solar panels will replace the leaves and the trunk will act as a super battery used to store the solar energy collected. We also test the different morphology of the solar panels as to determine the optimum shape and colour pigment that can absorb maximum solar radiation. We have taken help from the science of Biomimicry to maximize the output of the entire tree by arranging the solar panels as per Fibonacci sequence. To solve the general problems associated with lithium-air battery, we plan to use an alternate approach of forming nanolithia- nanostructures that act as a catalyst for the chemical reactions that take place. By selecting an appropriate stable electrolyte and optimal cell design, we exhibit a battery with high capacity and rate values. For this battery we estimate an energy density value that is much higher than those offered by the current technology, which results in more than 90% overall efficiency of the process. Solar power battery storage could be the answer to more solar powered battery homes in the near future and big savings on energy bills.*

1. INTRODUCTION

It is an established fact that utilization of renewable energies and resources such as wind, hydroelectricity, biomass, and solar is being encouraged globally as quintessential priority. Currently, 75% of the total fossil fuels utilization is for heat and power production, while other 25% for transportation and fuel, and a very small proportion for chemicals and materials.

According to the World Energy Assessment conducted in 2000 by the United Nations Development Program, annual capacity of power generation through solar energy was 1,575-49,837 exajoules; which is considerably higher than 559.8 exajoules, the world energy consumption in 2012. According to National Renewable Energy Laboratory, the sunlight emitted on earth in just one hour is sufficient to power the annual energy needs of the globe. In 2015, solar energy was the fastest growing energy sector with a 33% rise as reported by Bloomberg [1].

Then first evidence of usage of solar power can be mapped back to 700 BC [2]. However, it was in the early 1950s that we saw the photovoltaic being developed into the solar cells. In 1954, Daryl Chapin, Calvin Fuller, and Gerald Pearson made the first solar cell at Bell laboratories using a semiconductor with p-n junction which gave 6 % conversion efficiency [3].

To exploit the potential of solar power, we intend to create a solar tree, the structure of which will be as follows:

- The position of leaves on the tree will be taken up by solar panels. Thus, inspired by the Science of Biomimicry we arrange them using Fibonacci sequence to optimize their function.
- The position of trunk of the tree shall be replaced by a lithium-air super battery. In this super battery, nanometer sized lithium and oxygen particles are embedded in cobalt oxide lattice.

Instead of regular solar cells, we have used organic solar cells, which provide better efficiency along with less pollution and waste generation. The basic principle is consistent, which is conversion of electromagnetic radiation (light energy) to electrical energy (current and voltage), viz a viz the photovoltaic effect. The organic material used is a conjugated polymer. The potential advantages of polymer solar cells are numerous including flexibility, processing ability, low material cost, and independence on scarce resources.

On the other hand, recent developments in the field of science and technology and improved standards of modern life call for an improvement in cell technology as well. A lithium-air battery has 4-5 times the capacity of lithium-ion battery, charges quickly and has low discharge voltage. In the proposed structure, Nano scale Lithia particles of amorphous nature form the cathode and are embedded in cobalt oxide, which enables charging and discharging processes between solid reaction products of lithium and oxygen without any gas evolution.

2. ORGANIC PHOTOVOLTAIC CELLS

2.1 Cell Configuration

The polymer solar cell converts light into electricity, by absorption of photons of varying wavelengths and converting

into a flux of charged particles. The organic semiconductor, the active layer of the solar cell, has a band gap of specific gap energy (E_{BG}) that denotes the energy difference between the valence electrons and the nearest free electrons. This can also be termed as the difference between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO). Light photons with energy greater the band gap of the semiconductor (E_{BG}) is necessary to excite an electron from the HOMO to the LUMO state.

$$E_{PHOTON} \geq E_{BG}$$

The electron excitation due to the absorption of light from the HOMO to the LUMO state leaves an unoccupied valence state behind, called a 'hole'. This creates a certain potential energy difference between this excited electron-hole pair.

In order to activate the generation of electricity, the charge carriers must be separated and collected at electrodes at the opposite end with different polarity. To break the electron hole pair (exciton) bond, a secondary semiconductor is present in the active layer. It has a lower lying LUMO energy level, such that it facilitates electron transfer between the two semiconductors. Due to this phenomena, the semiconductor with the highest LUMO is termed as the electron donor where all the electrons are generated. The other semiconductor is termed as electron acceptor all the electrons generated are transferred here. The condition for electron transfer will be favorable if the following condition is satisfied.

$$E_{DONOR} - E_{ACCEPTOR} \geq E_{EX},$$

where E_{EX} is the exciton bond energy[4]

The exciton has a very short lifespan before it collapses and the electron recombines with the hole. Therefore distance between the generation site of exciton and a donor/acceptor interface must be of the order of 5-10 nm [5]. Consecutively, the photons need to traverse a certain thickness of the order 100nm of active layer so that it can be absorbed. The above mentioned event makes the structure of active layer considerably important for the efficiency of the polymeric solar cell.

There is no preferred direction for the internal fields of separated charges, that is, the electrons and holes created within the volume have no net resulting direction they should move. Therefore, selective layers are added between the heterojunction layer and the electrodes to allow selective transport of the charges to the corresponding electrode [6].

Specific number of photons are required to balance the number of light photons that are absorbed with the energy that is lost. These considerations establish the optimum band gap of the semiconductors and the theoretical cell efficiency limit. This was demonstrated by Shockley and Queisser in their research study explaining the 'detailed balance limit [7].

2.2 The Layer Stack

The different layers of the solar cell are formed by placing them in a certain order. The materials needed in the solar cell stack are; a proactive layer in the center to absorb light, which split the incident photons into electrons and holes, a selective charge collection layer for selectively transporting either electrons or holes, and two extracting electrodes for withdrawing the charges from the cell. One of the electrodes has a transparent electrode to allow the light to pass through it and reach the proactive layer.

2.3 Geometries

Organic solar cells are separated into two wide categories depending on their cell geometry, namely normal and inverted geometry. The major point of difference between the two geometries is the direction of flow of charge. In a normal geometry the light passes through the substrate and transparent electrode on the positive electrode further being absorbed by the semiconductor in the active layer. In the inverted geometry, the position of the charge collection layers and the electrodes are exchanged with each other, which results in the negative electrode having the transparent electrode, with electron collection layer between electrode and the proactive layer as shown in figure 1.

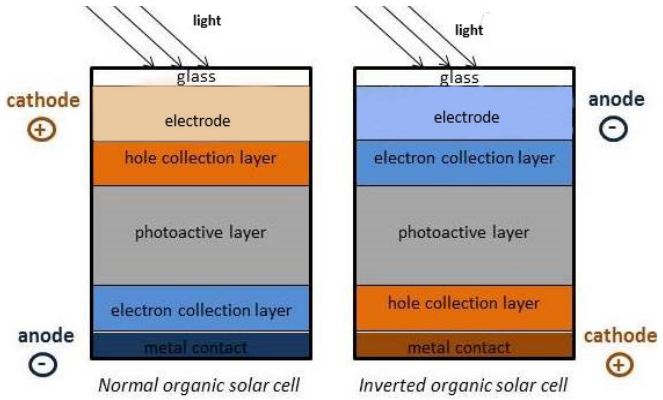

Figure 1

2.4 Surface Spectroscopy

Visible absorption is relatively more dominant for energy considerations than ultraviolet (UV) absorption. Almost 40% of solar energy belongs to the visible spectrum while ultraviolet rays provides only about 4% of the solar energy [8].

When a light photon with an inherent frequency is incident upon a surface, the electrons of that surface absorb the energy of the photon, thereby setting into vibrational motion. This happens provided the electrons of the surface have same vibration frequency as the impinged light. These vibrations cause the neighboring atoms to interact and convert the vibrational energy into electrical energy. Therefore, the selective absorption of light photon by a colour occurs because

the natural frequency of the light matches the frequency at which electrons in the atoms of that colour vibrate. Since different colors have different vibration frequencies, they selectively absorb wavelengths of the same frequency.

The absorption coefficient of different coloured surfaces can be seen in Table 1. Based on this data we can design organic photovoltaic that leads to optimal absorption of the light.

Table 1: Correlation of absorption and colors

Surface colour	Absorption Coefficient (approximated)
White smooth	0.25 - 0.40
Grey to dark grey	0.40 - 0.50
Grey to dark grey	0.50 - 0.70
Dark brown to blue	0.70 - 0.80
Dark blue to black	0.80 - 0.90

3. NANOLITHIA BATTERY

The phase change and the gas evolution between the gas and the condensed phase is needed at the cathode. This causes the nucleation and the phase growth changes with large overpotential to increase drastically, thereby damaging chemo-mechanical properties that affects cycling nature. In this paper we discuss an oxygen anion-redox cathode that does not consume or emit O_2 (gas). The phase changes are restricted to condensed phases only. LiO_2, metastable at room temperature, is stabilized by interfacial wetting [9] with a substrate. Surface science and metal-organic chemistry, shows that the oxygen molecule can be adsorbed as superoxide, peroxide, or as a surface coating [10]. Fabrication of an all condensed cathode is possible for a fully sealed battery as no gas (O_2) is released.

3. 1Nanolithia cathode with O_2 Evolution

Nanolithia composite (NC) is prepared as 33 wt% Co_3O_4 (nanoporous substrate) filled it with 67 wt% Li_2O. Cathode provides structural integrity by switching between the condensed state of lithium oxide, lithium peroxide, and lithium superoxide, thus stabilizing the nanoporous skeleton. Increased transport and catalytic activity reduce the overpotential significantly. The following reactions apply to the NC cathode:

$$Li_2O_2+2Li^++2e^-=2Li_2O\ U1^o=2.86V\ (1)$$

$$LiO_2+3Li^++3e^-=2Li_2O\ U2^o=2.88V\ (2)$$

Li_2O weight determines the theoretical capacity of Li_2O/LiO_2, which is 1,341Ahkg^{-1}. Despite considering the weight of Co_3O_4 the NC cathode involves much higher capacity than the present cation redox-based systems.

Okuokademonstrated a matching redox reaction between Li_2O and Li_2O_2 indicating the practicality of using lithium oxide/lithium peroxide cathode [11]. However, it proposed a drawback of generation of gas (O_2) when charging. In this work, a shuttling (a certain species carries dissolved electrons between cathode and anode through the electrolyte) process in the ethylene carbonate/diethyl carbonate (EC/DEC) electrolyte can automatically shunt the voltage automatically and prohibit the oxygen generation. Full cell similar to lithium batteries with economical EC/DEC electrolyte, when compared to Li–sulfur battery, can achieve equivalent energy densities, higher voltage, 5 times lower energy loss, and stable cycling [12].

Chemical synthesis process followed by calcination at 300^{o}C enabled to achieve a close contact of Li_2O and Co_3O_4. Selected-area electron diffraction (SAED) and energy dispersive spectroscopy (EDS) showed a mixture of Co_3O_4 and Li_2O, where maximum nanoparticles of Li_2O are sphere-like, surrounded by a nano crystalline Co_3O_4 particles. Here oxygen in the condensed nanolithia from is less than 3nm away from Co_3O_4 particle. Interfacial wetting largely affect its electrochemical stability and kinetics. The NC cathode has a discharge plateau of ~2.55V at a rate of 120 Akg−1. The initial discharge capacity was 502 Ahkg−1, then increased to 587Ahkg−1 in a few cycles when charged to 615 Ahkg−1. It showed that even after 200 cycles the discharge capacity loss was only about 4.9%. The charge plateau consists of two parts- part I, initially at 2.80V and slowly increasing to 2.91V, might be due to lithium oxide conversion to lithium peroxide/superoxide, while part II, nearly constant at 2.94V, and is due to a shuttling mechanism in the electrolyte. No gas (O2 or CO2) production and the voltage increasing 2.95V by charging at a constant current of 120Akg−1 was indicated by in-situ differential electrochemical mass spectrometry (DEMS). DEMS was also performed under different charging currents. When charged at 500Akg−1, 1,000Akg−1 and 2,000Akg−1, the shuttling produced the final shunting voltages of 2.96V, 3.04V and 3.14V, respectively signifying that a rise in current increases the voltages of redox and shuffle plateau [13]. The DEMS shows no O_2 generation over a range of overcharging period. Contrastingly, when charged at 5,000Akg−1, the voltage continuously increases evolving O_2 gas once the capacity reaches 250Ahkg−1. When the shuttling material in the electrolyte cannot carry current of a large magnitude, the shuttling proves inadequate suppress the increase of the voltage.

3.2 Battery Performance

A lithium-matched full cell was tested and the capacity loss was only 1.8% after 130 cycles despite having a lower capacity, which shows that the cycling nature compared to Li metal cells was more stable [14]. This demonstrated that the solid-electrolyte interphase (SEI) is highly stable during cycling, even if a SEI layer is collected on the cathode surface and the volume nanolithia change is significantly large.

4. CONCLUSION

As per our aim of the paper, we have created a theoretical model of solar tree structure. Research made in the respective

fields has provided satisfactory results. It is a noteworthy breakthrough achieved in cell technology and further research is imminent, which shall provide solution to the existing problems faced with the model.

Starting with the cell configuration, we have substantiated the advantages of organic solar cells over the regular ones. The use of conjugated polymer as organic material makes our project in compliance with the initiative of GREEN ENVIRONMENT. As established, the active layer structure is crucial for the polymeric solar cell efficiency. Future prospect includes trying different types of polymers and achieving the lowest possible band gap for optimum design and maximum theoretical efficiency, which in turn leads to utmost absorption of photons in the active layer. The geometry of the solar cell can be decided as per the requirement for the direction of flow of charge.

The discovery of lithium-air super battery has fueled the application opportunities for solar power. We can achieve five times the energy capacity with about $1/5^{th}$ the weight as that compared to a lithium-ion battery. The initial problems encountered with the open cell configuration, such as phase change of oxygen and high difference between charging and discharging voltages have been overcome with our proposed nanolithia structure.Simply by halting the phase change of oxygen, the theoretical capacity and life cycle of the super battery improved significantly, with tests showing only about 1.8% degradation over 130 cycles.

We believe, with appropriate research into our proposed model, the solar tree will be able to achieve the aim of powering homes and vehicles with solar radiation on a daily basis.

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