Increasing Efficiency in Solar Energy Systems: Graphene-Based Panels and Batteries

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***Abstract*— This literature review discusses the use of graphene as a material to increase the efficiency and performance of batteries and solar panels. These improvements may allow to considerably increase their characteristics and benefits, in order to make a more efficient use of the energy generated and stored in solar panels, improving its obtention and later use. This paper analyzes and explains how this efficiency upgrade can be possible by means of graphene. The improvements analyzed are in line with the United Nations' Sustainable Development Goal of ensuring clean energy for all.**

***Resumen*— La presente revisión de la literatura aborda el uso del grafeno como material para aumentar la eficiencia y rendimiento de baterías y paneles solares. Estas mejoras pueden permitir aumentar considerablemente sus características y prestaciones, para así aprovechar aún más la energía almacenada y generada por paneles solares, mejorando su obtención y uso. En este trabajo se analiza y se explica cómo esta mejora en la eficiencia puede ser posible por medio del grafeno. Las mejoras analizadas están en línea con el Objetivos de Desarrollo Sostenible de las Naciones Unidas de asegurar el acceso a energías limpias para todos.**

I. Introduction

Currently the use of non-renewable energies is a big problem for the environment; for this reason, it is essential to use renewable energies to a greater extent and stop depending on fossil fuels. On a global scale, creating new, more efficient systems to capture and store energy can be very favourable to meet the users' energy demand. In turn, this may help achieve a sustainable alternative to current energy requirements. The increase in the use of renewable energies such as solar energy is in line with the engineering aim set by the United Nations Sustainable Development Goals Report (SDG). In this respect, SDG number 7 highlights the need of "ensuring access to affordable, reliable, sustainable, and modern energy for all" [1, p.40]. It is therefore necessary to use new materials that offer better performance, have less environmental impact and reduced costs that facilitate large-scale production of solar energy systems. Graphene-based solar panels and batteries may therefore help achieve these goals.

The purpose of this paper is to discuss ways to increase the efficiency of photovoltaic devices and batteries using graphene as the main element to increase system performance in obtaining solar energy. For this, the paper will briefly address the concept, structure, properties, preparation methods of graphene and its application in lithium-ion batteries for efficient energy storage and solar panels to obtain energy.

In order to achieve this aim, this paper is organized in the following way. Firstly, this paper introduces how a lithium-ion battery works. Secondly, improvements to lithium-ion batteries with graphene are discussed. Thirdly, the paper presents how a solar panel works. Fourthly, improvements to solar panels with graphene are analyzed. Lastly, there will be a brief analysis of the perspective of the mass production of graphene for solar panels and batteries in the future.

II. Working Principles of Lithium Batteries

To understand how graphene can improve the efficiency of lithium-ion batteries, first it is necessary to explain the way they work. Fig. 1 describes the components and their arrangement in a lithium-ion battery.

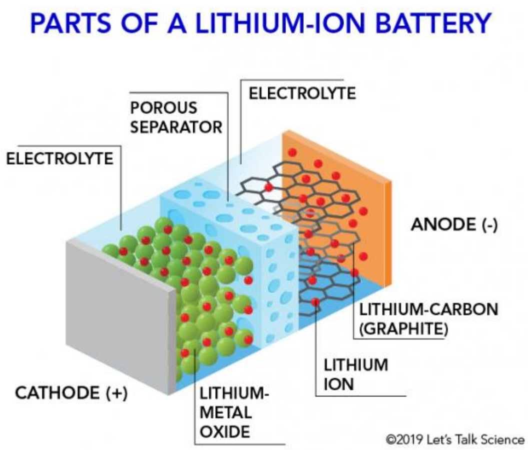

Fig. 1. Components of a lithium-ion battery. [2]

Lithium-ion batteries have a simple operating principle. In the graphite part, the lithium ions are found in an unstable state together with the electrons released by the lithium oxide. When there is a charge between the cathode and the anode, these lithium atoms will pass through the electrolyte and the separator to join the lithium oxide where the lithium atoms obtain a stable state. The function of the electrolyte is to allow only the lithium ions to pass through, forcing the electrons to flow from the anode to the cathode. This generates an electric current that will circulate through a load located between them, as shown in Fig. 2.

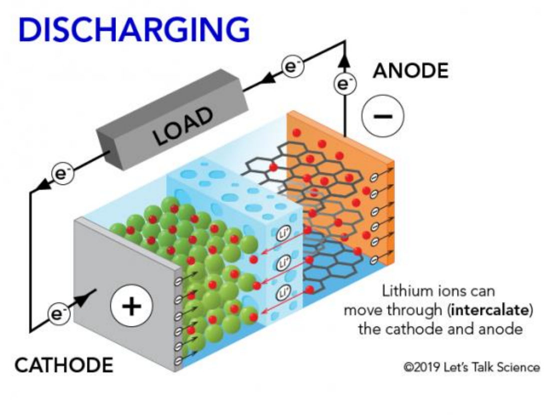

Fig. 2. Current flow in lithium-ion battery. [2]

To charge the battery, a current must be applied between the anode and the cathode in order to replace the lithium ions and electrons in the graphite part [3].

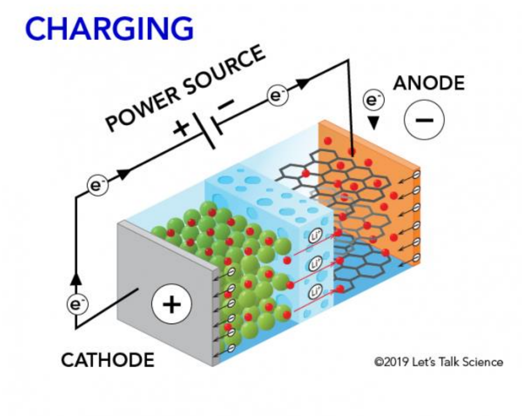

Fig. 3. Charging a lithium-ion battery. [2]

These types of cells work well today but, in the future, they will have a greater presence in, for example, vehicles and energy storage systems. This is why finding ways to achieve even better performance is an important task, due to it is use on a massive scale, making small improvements can make a big difference.

III. IMPROVEMENTS IN LITHIUM-ION BATTERIES WITH GRAPHENE

Since the discovery of graphene, multiple applications have been found that improve the performance of certain devices, and lithium-ion batteries are no exception. The way to improve lithium-ion batteries with graphene is to replace graphite with it, producing several improvements.

Graphene in the anode of the batteries will be an excellent material with several improvements. It provides thermal and chemical stability to the cell, which will give it greater reliability in harsh environments. It will also reduce the size of batteries because it has higher capacity in the same volume. More charging cycles mean extending the useful life of the batteries. The physical properties of graphene make the battery lighter. The high flexibility coefficient of graphene will also solve the dilation problems during battery charging and discharging [4].

IV. WORKING PRINCIPLE OF SOLAR PANELS

The energy of sunlight that reaches the earth in one minute can supply the world's electricity consumption for a full year [5]. For that reason, humanity has tried to make use of that renewable energy that we receive every day, which can solve many of the problems that society faces.

To capture this energy, a solar cell or photovoltaic (PV) cell is necessary. A PV cell "is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon" [5, p.94].

To use this energy, the help of the second most abundant element on earth, sand, is needed. Sand has to be converted into silicon crystals, which must go through a complex purification process to obtain silicon with 99.999% purity, to be used in solar panel cells.

Silicon has a semiconductor property that makes it possible to capture photons from the sun. If its structure is analyzed, the atoms are linked to each other, therefore, the electrons do not have freedom of movement through the material. This problem has been solved by doping silicon with phosphorus atoms [6], as shown in Fig. 4. This allows the electrons, when they have enough energy, to move freely within the structure. This type of doping is known as N-type doping.

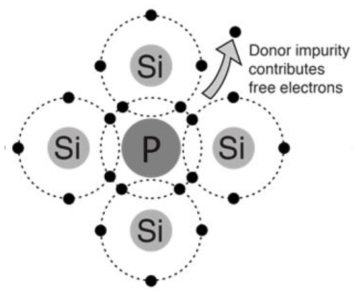

Fig. 4. N-type doped molecule. [7]

When the light hits this compound, the electrons gain photonic energy allowing them to move freely. However, the movement of electrons is random, i.e. it does not produce any flow of energy; therefore, it does not produce electric current. For the electron to flow unidirectionally, a driving force is needed, and this can be produced by a P-N junction. This junction is represented in Fig. 5.

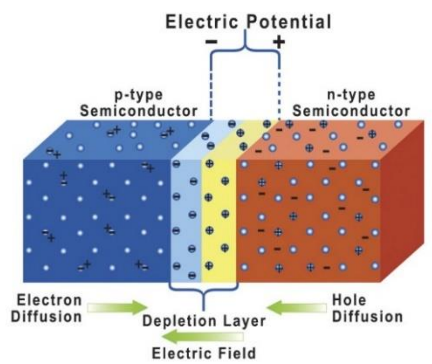

Fig. 5. Doped silicon P-N junction. [8]

Like N-type doping, boron is injected into pure silicon, forming P-type doping, as it can be seen in Fig. 6. This produces spaces called holes so that electrons that are free in the N-type semiconductor can flow to the P-type semiconductor and occupy this free space.

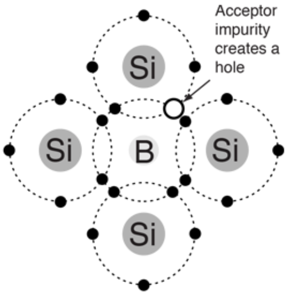

Fig. 6. P-type doped molecule. [7]

By joining these materials, a small shift of electrons from the N-type material to the P-type material occurs. This creates a depletion region [9], where there are no free electrons and no holes, as can be seen in Fig. 7. Due to this behavior of the material, the N side is positively charged, and the P side is negatively charged, producing a potential difference and this induces an electric field, which leads to the formation of the necessary electromotive force to make the charges flow.

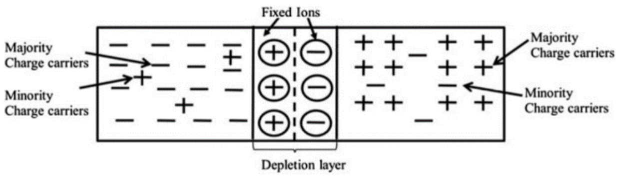

Fig. 7. Depletion layer in p-n junction [9]

When the light hits the N region of the junction, it penetrates and reaches up to the depletion region. This photonic reaction generates, in the depletion region, electron-hole pairs. The electric field drives the generated electrons and holes out of the depletion region. This effect causes the concentration of electrons in the N region and the holes in the P region to become so high that a potential difference develops between them [9].

If the N region and the P region are connected, as in Fig. 8, by means of a charge, the electrons will begin to flow in one direction. An electric flow will take place through the charge and the electrons will recombine with the holes in the P region. In this way, a photovoltaic cell can supply a direct current, although it is a low voltage, approximately 0.5 volts.

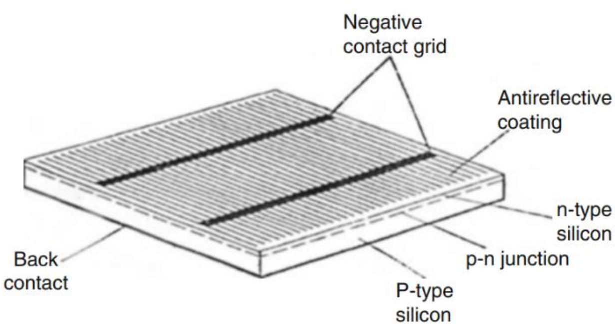

Fig. 8. P-N junction solar cell [9]

Because of this, a solar panel is made up of many photovoltaic cells, which are arranged in series and parallel to increase the voltage and current that the solar panel will supply. In turn, a solar panel is made up of different layers; one of them is a layer of cells interconnected with each other. To protect these, there are two eva rubber sheets as protection against shocks, vibrations, dirt and humidity.

Photovoltaic panels have a low operating cost per KWh produced, compared to other energy generation methods. However, the biggest problem is the capital cost, which is approximately 6 times higher than that of other traditional methods, such as thermal energy. Although, over the years, photovoltaic technology is decreasing its production cost, as shown in Fig. 9, its efficiency is beginning to stagnate. For this reason, this paper will analyze the possibility of adding graphene in production, to increase its efficiency.

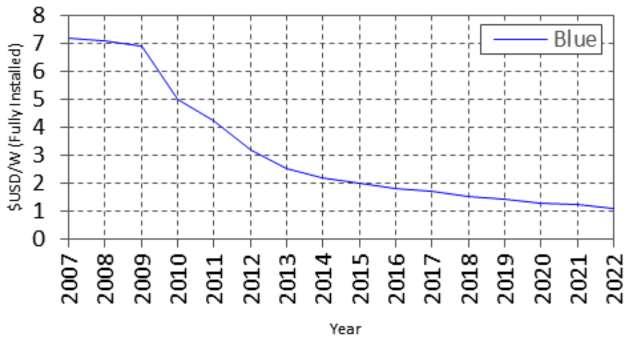

Fig. 9. Price per W of Fully Installed Solar PV 2007–2022 [10]

V. Improvements to Solar Panels with Graphene

Solar panels can be improved by means of graphene and silicon. Graphene is considered a very interesting material in photovoltaics since it is an ultra-thin material, it has high mechanical resistance and it has high transparency and good conductivity. Graphene acts as a transparent conductive electrode which collects carriers generated by other semiconductors. In turn, due to its excellent light absorption and relatively easy manufacturing process, silicon is a good alternative to produce Graphene-Silicon (G-Si) solar cells since high efficiency and low cost could be achieved [11].

In recent times, the production of Graphene-Silicon cells has been thoroughly investigated. They are complex materials to produce due to their monatomic structure. Through various processes, the researchers managed to develop graphene-silicon (G-Si) photocells, improving their properties by including carbon nanotubes within the graphene structure (CeG-Si). In order to considerably increase their efficiency, they also added anti-reflective materials, such as Titanium Oxide (TiO2) to increase the absorption of solar cell light [11].

The best obtained graphene-silicon solar cells have seen power conversion improvements of up to 15.2%, achieving better efficiency values compared to current solar cells.

VI. Conclusion

In conclusion, the graphene implementations presented in the paper are aligned with the aim of the chosen goal. As it has been developed along this paper, the implementation of graphene to solar panels and batteries may increase its efficiency. This, in turn, is aligned with the Sustainable Development Goal of ensuring sustainable energy for all. After reviewing the literature, the following conclusions have been reached.

The methods described in this paper are not totally profitable for the current industry. Obtaining graphene by means of current methods is expensive and makes this material for laboratory use only. New methods are expected to be researched on so as to reduce the costs of production. Also, new technologies may provide a better sustainable use of energy for the industrial production of graphene.

For these reasons, it can be thought that, in the not-too-distant future, there will be a greater generation of electrical energy through solar energy. The wide range of possibilities offered by the different batteries and panels can be adapted to multiple applications, such as vehicles, installations in small places, etc. The results of this investigation are in line with the aims of the SDG number 7. These improvements with graphene increase the possibility of achieving the proposed goal. An increase in the efficiency of solar energy systems, which could satisfy the present demands and requirements.

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