Graphene: The Material Transforming the World of Photovoltaics

A New, Flexible, and Inexpensive Photovoltaic Solar Cell

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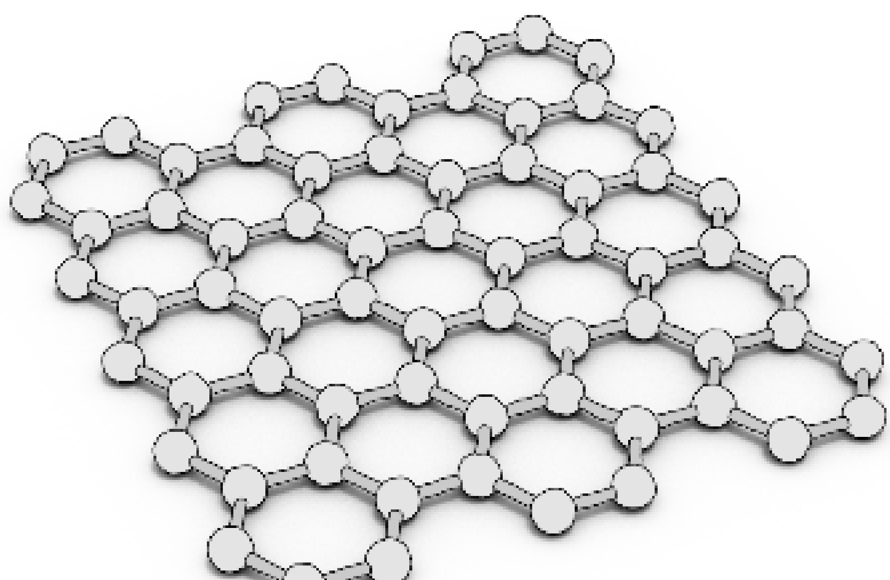

Abstract

Ethiopia is a country which suffers from the lack of an effective energy grid. Based on population statistics of 2012, approximately 76% of people in Ethiopia do not have enough access to electricity. Although Ethiopia relies heavily on hydroelectric sources of energy such as dams, these prove to be unreliable; however, photovoltaic solar cells would be an ideal energy conversion application for the country since it is situated near the equator, which would provide an abundance of sunlight to power the solar cells. More effective solar cells would greatly improve Ethiopia's situation. Previous studies have shown graphene can play beneficial roles by enhancing electron transport. Therefore, the combination of graphene and a material with a band gap and distinct properties, such as molybdenum diselenide ($MoSe_2$) deposited on top of the graphene, should prove to produce a promising solar cell that will be new, flexible, and inexpensive to manufacture.

Background on Ethiopia

Ethiopia, a country in East Africa, is situated just above the equator. Ethiopia is the second most populous country in Africa with 102 million as of 2016; however, it is one of the poorest nations in Africa, with a per capita of $783. The Ethiopian government ambitiously aims to reach lower-middle-income status by 2025.[1] In this country, power outages are common despite large investment in hydroelectric power dams.[2] In 2011, it was determined that over 96% of Ethiopia's electricity was from hydropower.[3] Ethiopia has an installed generation capacity of 4,206 MW, with 3,743 MW (89%) coming from hydroelectric power, 337 MW (8%) from wind power, and 126 MW (3%) from thermal power.[4] Despite these efforts, as of 2015, about 76% of the Ethiopian population does not have access to electricity.[5] In May of 2018, a nationwide power cut occurred after a technical fault at a massive hydroelectric dam, Gibe III. The Gibe III dam, established in 2016, serves as Ethiopia's main source of power, and is described as Africa's biggest dam.[6] Many areas are still without power as a result of the technical fault at the dam. It seems that Ethiopia's large investment in hydroelectric power dams proves to be inefficient and unreliable. Given Ethiopia's position above the equator, where sunlight is in abundance, it is reasonable that solar cells would be an excellent source of power that would prove to be much more effective than hydroelectric, wind, or thermal power sources. A new photovoltaic solar cell that is inexpensive and effective would be a promising solution to Ethiopia's energy crisis.

Graphene

Graphene was first isolated in 2004 by scientists Andre Geim and Kostya Novoselov who used a Scotch tape method to isolate graphene.[7] They were awarded the Nobel Prize in Physics in 2010 for their groundbreaking experiments of the two-dimensional carbon allotrope, graphene.[8] Because graphene is a monolayer of graphite, or carbon atoms, a million sheets of graphene would equal the thickness of a strand of hair.[7] Graphene is the thinnest and strongest material in the world yet discovered.[9] It is considered the most outstanding material due to its superb chemical and physical properties, and has great potential in revolutionizing modern electronics and devices.

Graphene as a replacement for ITO

Transparent electrodes are a necessary component in many modern devices, including photovoltaics. Traditionally, this role has been well served by doped metal oxides, the most common of which is Indium Tin Oxide, or ITO. While ITO is the most widely used, recently, advances in nano-materials research have opened the door for other transparent conductive materials, each with unique properties, including graphene.[10] Graphene can serve as a substitute for ITO in photovoltaics and is shown to be a better option than ITO. The table shown below provides a comparison of properties between ITO and graphene.

TABLE 1. ITO and Graphene Properties Comparison

ITO	Properties	Graphene
Lets through almost 90% of light	**Transparency**	Very high transparency of 97.7% (1 layer) [12]
Limited flexibility (brittle)	**Flexibility**	Excellent flexibility [13]
Good	**Conductivity**	Good [14]
Rare metal	**Rarity**	Common
High cost (price has risen) [11]	**Price**	Inexpensive for production
Light	**Weight**	Super lightweight (planar density = 0.77 mg/m2) [12]
Yes	**Bandgap**	No

As shown by the data in Table 1, graphene has superior properties than ITO that would result in more effective solar cells that would create an effective energy grid, particularly for countries like Ethiopia with less financial means.

Previous studies using graphene as a support for energy conversion

A study performed in 2011 showed that the use of reduced graphene oxide (RGO) has proved useful in collecting and transporting charge applications like photoelectrochemical solar cells. The study found RGO sheets to be good electron acceptors, which shows that graphene has good conductivity. The ability of RGO to store and shuttle electrons can be used to develop graphene as catalyst assemblies. The study also noted the enhanced degradation rate of RGO-TiO_2 as compared to that with TiO_2 alone in these systems. The only explanation for the enhanced degradation rate would be due to the presence of the graphene and the role it is playing. This enhanced rate highlights the beneficial role of graphene sheets: The graphene facilitated dispersion of catalyst particles, improved charge separation within the RGO-TiO_2 composite, and increased concentration of the organic molecules near the catalyst surface.[15]

A second study performed in September of 2017 demonstrated that the incorporation of graphene (Gr) with ZnO results in a fast charge recombination and transport rate between the conducting electrode and semiconductor nanostructures. The high conductivity of Gr makes it a great material to accept charge carriers and to promote the electron transfer rate. Looking at Table 2 below, it can be determined that the Gr-ZnO NC (nanocomposite semiconductor film) photoanode successfully reached high power conversion efficiency (PCE). The Gr-ZnO NC photoanode produced the highest photoelectrical conversion efficiency (η) at 7.01% compared sole ZnO due to its good electrode-electrolyte contact of Gr-ZnO NC.[16] This would not have happened without the beneficial presence of the graphene.

TABLE 2. Comparison between Previously Published Works and Our Work

Reference	Photoanode	Thickness (μm)	PCE (%)
Our work	Gr-ZnO NC	3	7.01
[13]	ZnO HSN	3.5	2.25
[14]	Iodine-doped ZnO HSN	8	4.5
Our work	ZnO	3	3.48
[10]	ZnO HSN	10	3.51
[15]	ZnO HSN	10	4.4
[16]	ZnO HSN	27	5.34

Effendi, N. A. S.; Samsi, N. S.; Zawawi, S. A.; Hassan, O. H.; Zakaria, R.; Yahya, M. Z. A.; Ali, A. M. M. *Studies on graphene zinc-oxide nanocomposites photoanodes for high-efficient dye-sensitized solar cells* 2017.

Molybdenum Diselenide and Graphene

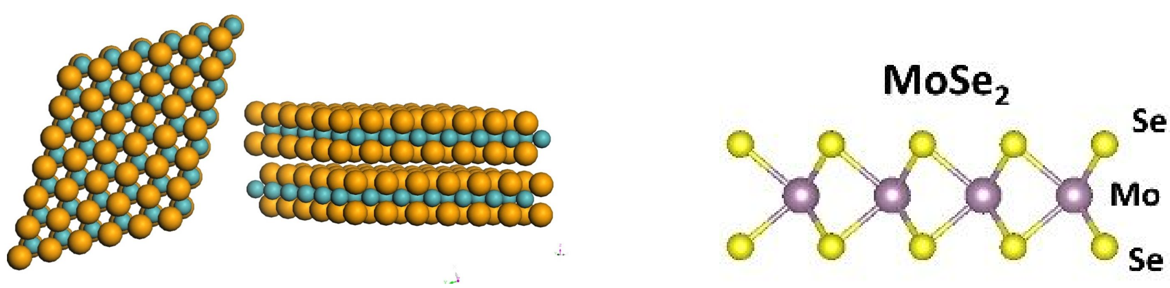

FIGURE 1. Structure of $MoSe_2$

Eftekhari, A. Molybdenum diselenide (MoSe2) for energy storage, catalysis, and optoelectronics https://www.sciencedirect.com/science/article/pii/S2352940716302475 (accessed Aug 2, 2018).

Molybdenum diselenide ($MoSe_2$) is a semiconductor with its layers stacked together via Van der Waals interactions. $MoSe_2$ can be exfoliated into thin 2D layers[17] and has band gap of ~1.5 eV.[18] The layered structure of $MoSe_2$ plus the size and electrical conductivity of Se provide a good opportunity for hosting counterions in electrochemical energy storage systems. Furthermore, the tunable band gap of $MoSe_2$ has made it a promising candidate for photocatalysis and photoelectrochemical solar cells.[19] Because of these properties, $MoSe_2$ could be used in combination with graphene to create effective photovoltaic solar cells; since graphene does not have a band gap, it needs to be used with another material that contains a band gap in order to create a working circuit for a solar cell.

Figure 2 is a schematic diagram showing how graphene and $MoSe_2$ would work in a photovoltaic solar cell and how the circuit would be completed. The band gap from the $MoSe_2$ creates the excitron, and the graphene helps to inject that excitron through the circuit.

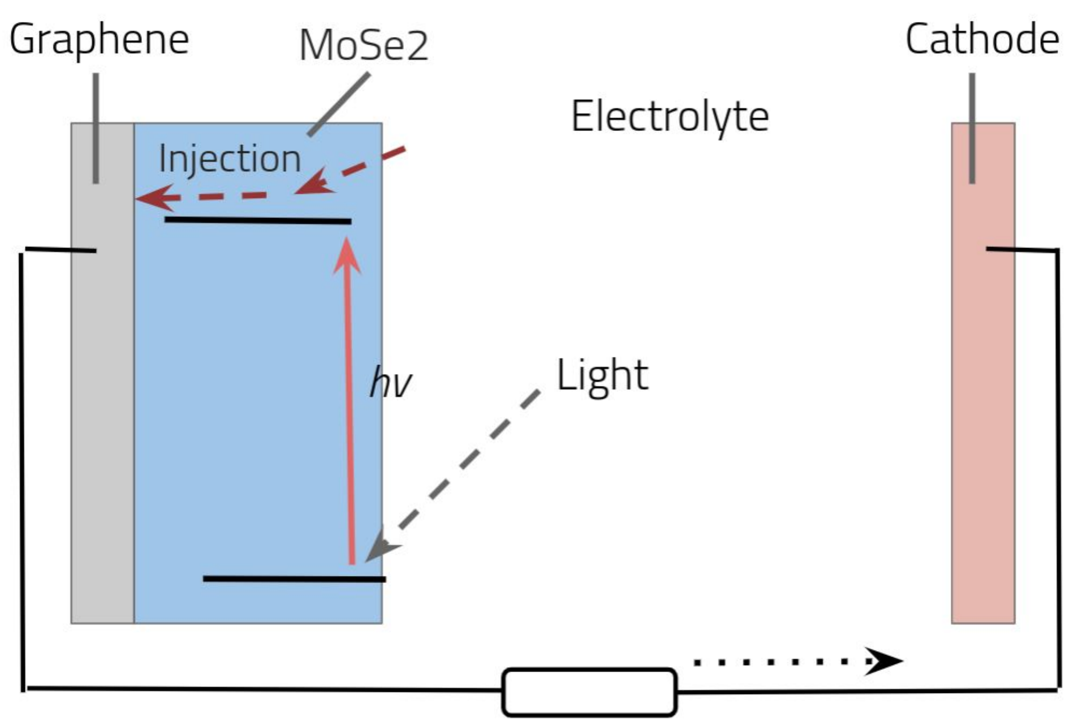

FIGURE 2. Schematic Representation of Graphene and $MoSe_2$ Solar Cell

Conclusion

By looking at previous studies that have shown graphene playing beneficial roles in enhancing electron transport, graphene, in combination with molybdenum diselenide ($MoSe_2$) deposited on top of the graphene, can prove to produce an effective solar cell. With graphene effectively promoting the transport of $MoSe_2$ electrons, the product would result in a new, flexible, and inexpensive photovoltaic cell. Moreover, a thin sheet of $MoSe_2$ on top of a monolayer of graphene would reduce the weight of the entire system. This novel technology would be able to greatly assist countries struggling with an effective power grid, such as Ethiopia.

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