Carbon Nanostructures in Organic Photovoltaic Cells for Solar Energy

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One of the challenges of the 21st century is to find alternative sustainable and efficient sources of energy, one of the possibilities being solar energy. The current method adopted worldwide for harnessing this type of energy is the use of silicon-based photovoltaic cells due to their conversion efficiency and durability (Dubacheva 2012). However, these solar cells are expensive and have several other undesirable traits in their widespread deployment, such as the great amount of energy and environmentally harmful chemicals that go into the production of silicon (Schwarzburger, 2010). Organic photovoltaic solar (OPV) cells do not have as high an energy conversion efficiency as silicon photovoltaic cells, but they do not have these undesirable traits and due to their capacity for high-speed production, costs can be reduced to be significantly lower than that of silicon-based photovoltaic cells. Carbon nanostructures have very interesting properties in electrical conductance and as such, their applications in OPV cells have been extensively researched.

A solar cell works like a diode that is connected to a circuit. P-type and n-type materials are joined together and form a p-n junction. Some of the delocalized electrons in the n-type material move to the p-type material to occupy some of the holes and create a depletion region that prevents further flow of electrons. In a photovoltaic cell, an absorbed photon of sunlight creates an electron-hole pair and the built-in potential sweeps electrons through the cell, producing an electric current in an external circuit. This is how sunlight is harnessed to create electricity ("How a Photovoltaic Cell Works", 2011).

OPV cells follow the same general layout of an ordinary solar cell with a layer that transports holes and another that transports electrons. Typical structures of single and tandem layer OPV cells are shown in Figure 1 below. The transparent electrode, commonly made of indium tin oxide (ITO), allows light to pass through to the active layer of the cell where photons are absorbed and electrons are excited (Dubachev, 2012). Electrons travel to their respective transport layer, which is the electron transport layer. Interfacial buffer layers, like the hole-transport layer, are crucial to the overall performance of the cell as they are essentially what transports charges around, and while there is current research to find improved active layers, there are also challenges to be faced in improving these interfacial layers. For

da Vinci's Notebook (ISSN 1923-5720) is sponsored by the
College of Physical and Engineering Science, University of Guelph, Canada.

example, the use of a current material called PEDOT-PSS as the interfacial buffer layer for selective hole transport improves the efficiency of the cell, but because of its acidic nature, it is a source of cell degradation over long-term operation (Dubacheva 2012).

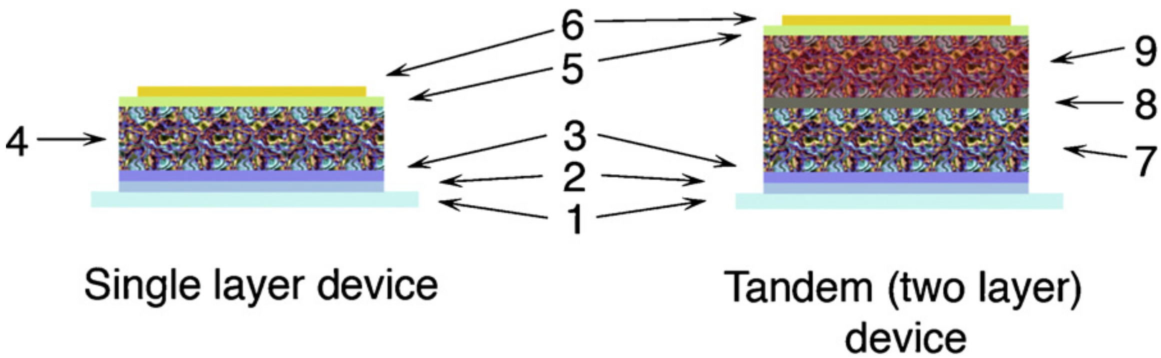

Figure 1 "Schematic design of single (left) and tandem (right) OPV cells. Layer composition: 1, transparent substrate; 2, transparent electrode; 3, hole-transport layer; 4, active layer in a single cell; 5, electron transport layer; 6, top electrode; 7, first active layer in tandem design; 8, charge recombination layer; 9, second active layer in tandem design." (Dubacheva *2012).*

Fullerene Interfacial Layer

Fullerenes have high electrical conductance and can be used as an interfacial layer to transport electrons more efficiently and improve charge separation and collection (Guldi & Sgobba, 2011). When electrodes made of a metal with a high work function are used, then injecting holes into the metal is thermodynamically preferred, and using a fullerene monolayer at the interface will complete the circuit as it readily accepts and transports the removed electrons from the metal electrodes to produce these holes (Dubacheva 2012). In an inverted OPV cell, where the holes are collected by the interfacial layers at the top electrode and electrons are collected at the transparent electrode, a fullerene derivative can be used at the transparent electrode as a buffer layer and related experiments have shown an improvement on the overall efficiency of the devices (Dubacheva 2012).

Carbon Nanotube Layers

It has been shown that thin film carbon nanotubes (CNTs) incorporated into the interface between the PEDOT-PSS layer and active layer, or the PEDOT-PSS layer and transparent electrode produces a device with promising energy conversion efficiencies (4.9%) for an OPV cell (Dubacheva 2012). An interesting thing about CNTs is that they can be grown vertically from a substrate by chemical vapour deposition. If grown on a plastic substrate, then there exists a possibility of fabricating flexible OPV devices.

CNTs can also be used to make transparent and electrically conducting electrodes to replace ITO, which would improve OPV cell efficiency because of the intrinsic high mobility property of CNTs. However, such advances are slowed by the current availability of

CNTs and their purity in sufficient quantities (Dubacheva 2012).

Graphene

Graphene is a single layer of graphite. It is the most promising of all the carbon allotropes for solar energy conversion because it has remarkably high electron mobility at room temperature, is incredibly transparent, and is flexible. With these properties, it has a high potential for use as a transparent electrode and also as a cathode and as a photosensitizer, which converts light into electricity (Das 2014). It has also been shown that a graphene oxide layer can be used to replace the interfacial PEDOT-PSS layer (Dubacheva 2012). This addresses the problem of PEDOT-PSS being detrimental to the longevity of the device due to its acidic nature. The numerous applications that graphene has in OPV cells gives graphene-based OPV devices a theoretical energy conversion efficiency of 12%, just 3% less than silicon-based photovoltaic cells (Dubacheva 2012). However, graphene was only isolated in 2004, so much research is still being conducted to investigate how to implement graphene in the best way possible.

Conclusion

Current solar cells are expensive and producing sufficient material for widespread deployment is a great environmental burden. As such, carbon nanostructures to be used in OPV cells have been extensively researched resulting in promising discoveries. Fullerenes and CNTs could replace current materials used in solar cells such as the ITO electrode and the electron transport layer. CNTs can also be used to enhance the energy conversion efficiency of OPV cells by incorporating them between layers in the cell. The most promising carbon allotrope is graphene, which can replace many of the current materials used in OPV cells, including the PEDOT-PSS hole-transport layer. Graphene can be a cost-effective and abundant material that will help replace silicon-based PV cells in the future.

References

Das, S., Sudhagar, P., Kang, Y., & Choi, W. (2014). Graphene synthesis and application for solar cells. *J. Mater. Res.,* 29 (3) 299-319.

Dubacheva, G.V., Liang, C.-K., & Bassani, D.M. Functional monolayers from carbon nanostructures – fullerenes, carbon nanotubes, and graphene – as novel materials for solar energy conversion. (2012) *Coordination Chemistry Reviews*, 256 (21-22) 2628-2639.

Guldi, D.M., & Sgobba, V. Carbon nanostructures for solar energy conversion schemes. (2011) Chem. Commun., 47 (2) 606-610.

How a Photovoltaic Cell Works. (2011). Retrieved December 7, 2015, from http://solardat.uoregon.edu/download/Lessons/Appendix_E_HowSolarCellsWork.p df

Schwarzburger, H. (2010). Photovoltaic news and PV jobs. Retrieved December 7, 2015, from http://www.pv-magazine.com/archive/articles/beitra_100001055/86/?#axzz3u4dacVmg/the-trouble-with-silicon-