

The Impact of Carbon Nanotubes and Graphene on Electronics Industry

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INTRODUCTION

A great technological opportunity has been introduced with the discovery of carbon nanomaterials where carbon nanotubes and graphene are their main representatives, which are completely involved in the science, technology and applications on new electronic devices, as an interesting alternative to those devices based on conventional semiconductor materials. They have attracted significantly attention of the scientific and industrial communities thanks to their unique electrical, optical, thermal, mechanical, and chemical properties. Nevertheless, carbon nanotubes and graphene due to their insignificant size, these require be homogeneously embedded into dielectric and light-weight, matrices, which are regularly of the polymeric type giving place to polymer-matrix composite materials (Das, 2013). Several models have been developed to predict the behavior of electrical conductivity of these composite materials based on carbon nanomaterials (Vargas-Bernal, 2013). Various chemical strategies for achieving synthesis of these composites have been proposed around the world, but these are not studied in this paper. The future trend in electronics industry consists in using individual carbon nanotubes and graphene sheets or set of them to design devices, circuits or systems. A lot of electronic devices have been fabricated based

on carbon nanotubes and graphene: field-effect transistors, diodes, analog and digital circuits, sensors (biosensors, gas sensors, etc.), solar cells, batteries, supercapacitors, flexible displays, etc. In this paper, the impact of the carbon nanotubes and graphene in electronic devices (discrete devices and/or integrated circuits), optoelectronic devices, photovoltaic devices, energy storage devices, and sensors, is briefly reviewed. This paper has been divided as follows: basic concepts about carbon nanotubes and graphene are described in section entitled Background. Next, different applications in the electronic industry are discussed in section entitled Applications of the Carbon Nanotube and Graphene. A comparison between the performance of the carbon nanotubes and graphene is presented in the next section. Future research directions are described in an additional section. Finally, conclusions about this study are given in the end section.

BACKGROUND

Carbon nanomaterials possess unique properties that can be exploited electrical, thermal, chemical and mechanically to provide applications in areas such as composite materials, energy storage and conversion, sensors, drug delivery, field emission devices, and nanoscale electronic components.

Three different morphologies between carbon nanomaterials can be distinguished: carbon nanotubes, fullerenes and graphene. Carbon nanotubes and graphene have been used more extensively in the electronic industry. Next, a brief description of their properties is made with the purpose of knowing the advantages of these materials for electronic applications. The basic concepts of each type of material have been separated for a better description.

Carbon Nanotubes

A carbon nanotube can be defined as a set of cylinder-shaped graphite sheets. Carbon nanotubes (CNTs) can be categorized by the number of graphite layers in their structure: Single-Wall Nanotubes (SWNTs) containing a single layer (see Figure 1), Double-Wall Nanotubes (DWNTs) with two layers, and Multi-Wall Nanotubes (MWNTs) that contain more of two layers (see Figure 2). Two main physical properties are associated directly with electronic applications: high thermal and electrical conductivity (Vargas-Bernal, 2012). Carbon nanotubes and their compounds exhibit extraordinary electrical properties useful for electronic organic materials, and can be used for a wide range of new and existing applications such as conductive plastics, flat-panel displays either as flexible displays or touch screens, micro- and nano-electronics (transistors), radar-absorbing coating, ultra-capacitors, solar cells, batteries with improved lifetime, hydrogen storage cells, conductors, smart textiles, electrochemical sensors, biosensors, and gas sensors. A more detailed study of their properties is found in Vargas-Bernal, 2012.

Graphene

Graphene is a two-dimensional allotrope of carbon with hexagonal lattice in atomic-scale, as shown in Figure 3 (Vargas-Bernal, 2015c). This material is a thin layer of pure carbon where each atom has four bonds, one σ -bond with each of its three neighbors and one π -bond that is oriented out the plane. Just

as the carbon nanotube, graphene has many extraordinary properties such as 100 times stronger than steel by weight, conducts heat and electricity with great efficiency and is almost transparent. From the electronic point of view, it presents the effect of a bipolar transistor, ballistic transport of electrical charge, and large quantum oscillations. A lot of electronic devices have been developed

Figure 1. Structure of the single-wall carbon nanotube (SWNT)

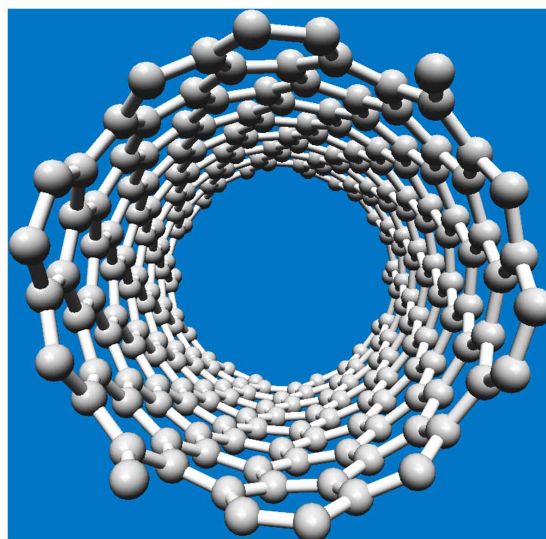
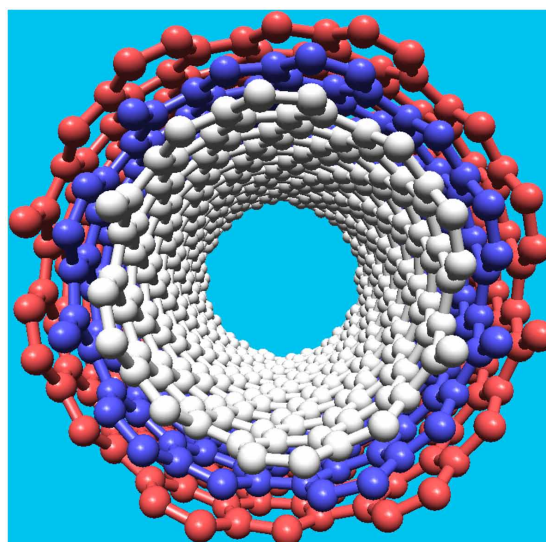


Figure 2. Structure of the multi-wall carbon nanotube (MWNT)



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