Chapter 6
Main Allotropes of Carbon: A Brief Review

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ABSTRACT

Carbon allotropes can be classified according to the carbon atom hybridization. In principle, there are different ways, based on various parameters, such as range dimensionality, type of chemical bonds, etc. which can be used to classify carbon nanostructures. Classifications vary function of the field of nanostructure applications. In a point of view, one can classify the carbon allotropes by the type of carbon atom hybridation. This chapter is a brief review introduction to some major allotropes: graphene/graphite, carbon nanotubes, diamond and amorphous carbon. In addition, Chemical Vapor Deposition (CVD) techniques, frequently used for synthesizing these structures are discussed. The influence of some important experimental parameters on the growth of high quality diamond and diamond-like carbon DLC are also investigated.

INTRODUCTION

Carbon is one of the most important natural elements in the Periodic Table which never stops to surprise the world with its various allotropes (see Figure 1). There exist millions of different compounds with fantastic chemical and physical properties of its different forms (Balaban, 2015). This unique element among all the other ones, has four valence electrons, two in the 2s sub-shell and two in the 2p sub-shells, and four vacancies in its outer shells, with a ground state electron distribution of $1s^2\ 2s^2\ 2p^2$. Such atomic arrangement enables it the building of several allotropic forms in solid state, such as graphene (Monajjemi, 2014), graphite (Matsumoto et al., 2009), diamond (Khalaj et al., 2010; Atefi et al., 2010; Shahsavari et

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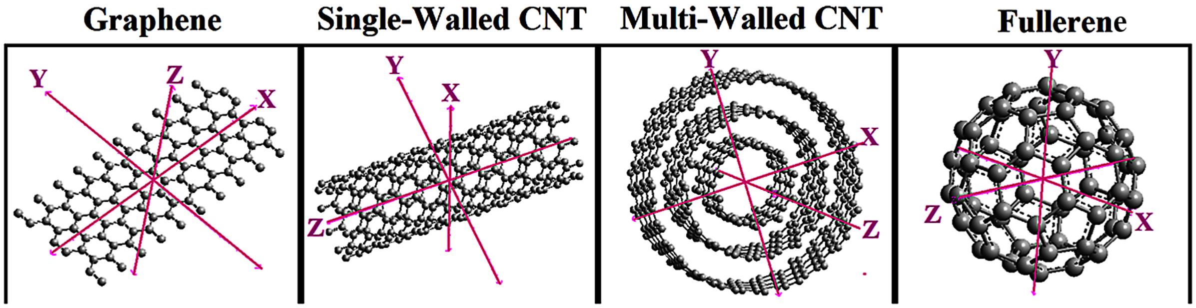
Figure 1. Some of the carbon allotropes



al., 2011; Khalaj et al., 2012a), diamond-like carbon (Khalaj et al.,2012b; Vaghri et al., 2011), fullerene (Komatsu et al., 2005), carbon nanotubes (Shams et al., 2012) and carbon nanowalls (Vizireanu et al., 2010), etc. The different types of carbon allotropes have a great influence on material's properties, some of them existing in the nature (either on earth or extraterrestrial) but also in the synthesized molecules. More than 100 years ago, when Edison used a hot incandescent carbonaceous filament in his experiment, many forms of carbon have been prepared or discovered in laboratory.

In this chapter, there is a short description on some of the main allotropes of carbon. In addition, a particular view to diamond, in both theoretical and experimental outlook, is provided. Overall, a great variety of materials are formed by carbon, ranging from crystalline to amorphous structures (Khalaj et al., 2010). The two famous primary crystalline forms of the carbon are the diamond (100% of sp^3 bonding) and graphite (with 100% of sp^2 bonding), while the amorphous carbon contains a mixture of sp^3 and sp^2 bonding. Graphite is the most stable phase of carbon (in a large range of conditions); it is made of hundreds of thousands of layers of the planar polyhex network. By scrolling a graphene sheet, a carbon nanotube can be formed (even the process is not so simple).

CARBON ALLOTROPES

Graphite and Graphene

One of the oldest known carbon allotrope is the graphite, a term derived from the Greek word "graphein", to write (Allen et al., 2010). Graphite is made of carbon atoms which form a continuous three-connected sp^2 polyhex network, with the bond strength of 524 KJ/mol. The fourth valence electron is bonded to an electron of the adjacent plane by a much weaker metallic-like bond; it results in a structure with a large anisotropy in the crystal. Graphite is commonly produced by CVD and is often referred to as pyrolytic graphite. The structure of layer by layer which has a strong bonding in each sheet and weak bonding between layers make it suitable to use in pencils (Dreyer et al., 2010; Geim et al., 2007). Scanning electron microscopy (SEM) image in Figure 2 shows a graphite layer, partly removed by Quanta 3D FEG's high-current FIB. Automated FIB sectioning recipes enable accurate cross-sectioning and low damage sample cleaning. Image shows the graphite deposited on Ni substrate; it was also analyzed by the Energy-dispersive X-ray spectroscopy (EDX), as shown in Figure 2.