Evolving Catalytic Routes for Carbon Nanotube and Graphene Growth

Mark H. Rümmeli
Leibniz Institute for Solid State and Materials
Research Dresden (IFW Dresden) Dept. 12
Helmholtzstrasse 20, D-01069 Dresden, Germany

Abstract

Nanomaterials are of enormous fundamental interest, both from the point of view of discovering new physical phenomena as well as for their exploitation in novel devices. It is for these reasons that new nanostructures are being synthesized, functionalized and examined with respect to their special optical and electronic properties. Carbon nanotubes have a broad spectrum of interesting properties, which are relevant for technological applications. They are used for field emission and gas storage and are discussed as basic elements for future electronic devices in nanoscience and technology. Because of their nanometric dimensions and their interesting electronic properties, single walled carbon nanotubes (SWNT), in particular, are considered attractive structures toreplace the semiconductor components essential in integrated circuits. The application of carbon nanotubes for producing transistors or saturable absorbers has been extensively studied; however for such applications isolated semiconducting tubes are needed. Conversely, isolated metallic nanotubes are desirable as nano-conductors. The direct synthesis of SWNT of a particular electronic form, and of a particular chirality is still lacking. Graphene is also a remarkable material with incredible electrical and mechanical properties which was isolated more recently. This has made graphene the “new rising star” in nano-carbon based materials due to its exciting properties at the nanoscale, e.g. high charge carrier mobility. In addition, when existing as narrow strips or ribbons (ca. 10 nm wide) a band gap opens making them excellent candidates for field effect transistors. Hence, apart from the exciting possibilities in discovering new physics from these 2D structures, they offer tantalizing opportunities for the development of high speed (and even flexible) molecular electronics.

In order to integrate graphene in to electronics it needs to be fabricated in large areas or in highly defined ways (e.g. nanoribbons), better still, in a manner suited to current complimentary metal oxide semiconductor (CMOS) technology. Graphene synthesis routes which are directly compatible with current Si technology are limited.

The more popular routes to synthesize carbon nanotubes and graphene are based on the use of catalysts and these are usually metallic catalysts. Despite the success of metal catalysts

they have certain drawbacks; they can be toxic and cause problems in clean room environments. In addition, in the case of nanotubes, they can be quite difficult to remove and in the process of removing them, the nanostructures themselves are often damaged. Over the last few years the use of ceramics, in particular oxide catalyst systems have begun to emerge for carbon nanotube synthesis. These exciting new catalyst systems suggest some contemporary concepts regarding their growth need reevaluating.

Moreover, many of the oxides used as catalysts are often implemented as supports in Supported catalytic growth of carbon nanotubes and raise the question as to whether such supports may actually participate in the growth of the carbon nanotubes? Recent studies suggest the oxides can play an active role in the catalytic decomposition of the hydrocarbon feedstock and in the formation of sp2 carbon. This latter point is particularly pertinent to graphene because it suggests the possibility of growing graphene directly on oxide surfaces. The CVD synthesis of grapheme directly on oxides dispenses the need to transfer graphene after synthesis, as is the case with metal catalysts. Early investigations have shown nano-graphene can be formed directly over oxide surfaces using simple CVD routes. Another emerging route is a catalyst “free” route in which no catalyst material is required. Some argue the carbon structures themselves fulfill the catalytic role.