Lecture 1. Nano Forms of Carbon. Quantum Confinement in Carbon Nanomaterials. Raman Spectroscopy of Nanocarbons.

The purpose of the lecture: to familiarize masters with the nano forms of carbon, the role of quantum confinement in carbon nanomaterials.

Expected results: knowledge of the role and importance of nano forms of carbon.

Though carbon has been known for thousands of years, during the last three decades three new forms of carbons have been discovered and the inventors of two of them (C60 and graphene) have won the Nobel Prize. Some of the novel nanostructures are illustrated in Figure 1. The classical example of closed shell stabilization of carbon nanostructures is the formation of C60 molecules and other fullerenes by electric arc evaporation of graphite discovered by Smalley, Kroto, and Curl in the year 1985. Subsequently the team won the Nobel Prize in chemistry in the year 1996. The diameter of a single C60 fullerene molecule is 1.4 nm. Here stabilization is achieved by the formation of closed shell structures that obviate the need for surface heteroatoms to stabilize the dangling bonds, as in the case of bulk crystals of diamond and graphite.

Other forms of carbon are carbon nanotubes or elongated fullerenes, either closed at both ends or only at one end. Although various carbon cages were studied, it was only in 1991 when Iijima observed for the first time tubular carbon structures. The nanotubes consisted of up to several tens of graphite shells, so-called multiwalled carbon nanotubes (MWCNTs) with adjacent shell separation of ~0.34 nm, diameters of ~1 nm, and a large aspect ratio. Two years later Iijima and Ichihashi and Bethune et al. synthesized singlewalled carbon nanotubes (SWCNTs).

Nanocarbons, which have been obtained by controlling the structure in nanometer scale as well as the bonding nature of carbon atoms, can provide the highly functional advanced performances, which are difficult to obtain from conventional carbons.

Fullerenes and carbon nanotubes and graphene are unique in the larger family of nanocarbon- based materials as interrelated prototypes for zero-dimensional quantum dots (fullerenes), one-dimensional quantum wires (CNT), and two-dimensional quantum wells (graphene).

Likewise carbon nanotubes, which are capped at each end by half of fullerene (Semispherical sheet), have aroused great interest in the research community because of their exotic electrical and mechanical properties. The unique properties of fullerenes and carbon nanotubes described in the following chapters are expected to be of interest for practical applications.

Early during his pioneering work, Bacon in 1960 synthesized graphite whiskers that he described as scrolls, using essentially the same conditions as for the synthesis of carbon nanotubes except for the use of helium pressures higher by an order of magnitude to synthesize the scrolls. It is believed that the cross-sectional morphology of multiwalled nanotubes and carbon whisker scrolls is different.

Vapor-grown carbon fibers, which were accidently found inside furnaces containing hydrocarbon gases and CO for melting metals, are typically several nanometers in diameter, several microns in length with a tubular microstructure. The formation of these filaments at relatively low temperatures <1000°C, in presence of metal catalysts can be a source of cheap high modulus carbon fibers for reinforcement in composites.

Carbon nano-onions (CNOs), which consist of concentric graphitic shells, represent another new allotropic nanophase of carbon materials. CNOs have already been shown to offer a variety of potential applications such as solid lubrication, electromagnetic shielding, fuel cells, heterogeneous catalysis, gas and energy storage, and electro-optical devices owing to their outstanding chemical and physical properties. According to a recent study, CNOs can also be used to produce ultrahigh-power micrometer-sized supercapacitors due to their accessible external surface area for ion adsorption.

Direct current (DC) arc discharge between graphite electrodes is one of the versatile processes to produce a variety of carbon nanomaterials besides fullerenes and carbon nanotubes.

These include different forms of carbon nanostructures like carbon soot, carbon nanoshells, metal encapsulated carbon shells, sea urchins, bucky onions, helical coils, spinning cones, and nanohorns.

Formation of carbon nanoshells during the arc discharge process demonstrates that it is possible to encapsulate metal nanoparticles inside the shells for potential applications in magnetic nanoparticles as data storage, ferrofluids, confinement of radioactive waste, and targeted drug delivery nanocapsules. A host of publications on this aspect are available.

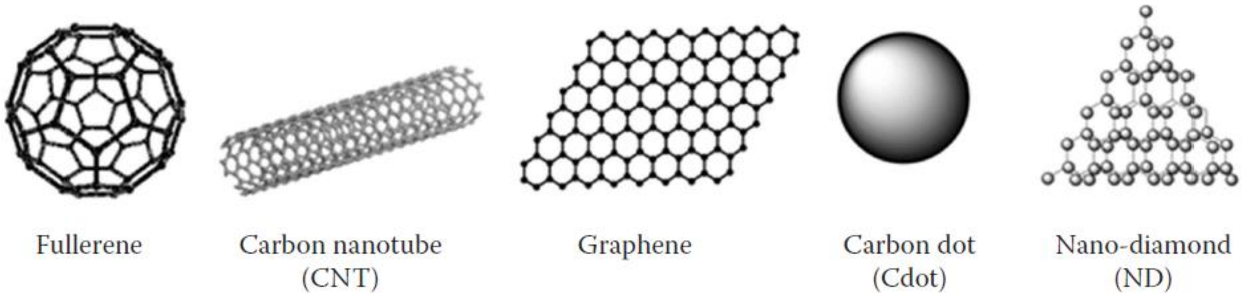

FIGURE 1. Nanoforms of carbon, from left, o-D fullerene, 1-D carbon nanotube, 2-D graphene, carbon dot, and nanodiamond.