Scientists study the types of carbon nanotube 'stuffing'

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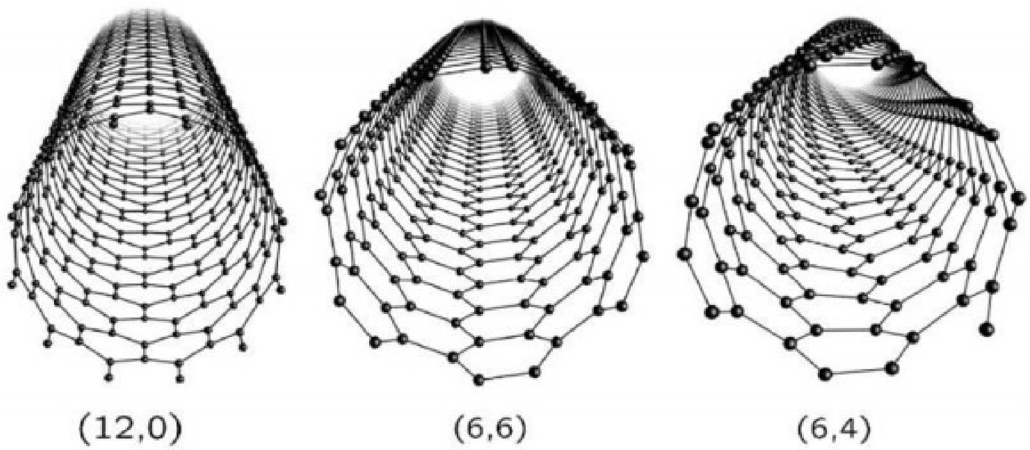

Schematic representation of the three types of the single-walled carbon nanotubes. The black dots correspond to the carbon atoms, and the lines between them show the relations between the carbon molecules. Credit: *Progress in Materials Science*

Marianna Kharlamova of the Lomonosov Moscow State University Department of Materials Science examined different types of carbon nanotube "stuffing" and classified them according to the influence on the properties of the nanotubes. The researcher's work was published in the journal *Progress in Materials Science*.

"A detailed systematic study of 430 works was conducted, most of which had been published during the last five years, as the area under study is actively developing," says Kharlamova. Apart from analytical systematization of the existing data, the author considered the band theory of solids, the theoretical basis of such studies, which describes the interaction of the electrons in a solid.

The many faces of carbon: diamonds, balls, tubes

Carbon exists in several allotropic modifications, and can be found in different structures. It forms coal and carbon black, diamond, graphite, graphene, fullerenes and others. Organic chemistry is based on carbon, which forms the backbone of organic molecules. In diamonds, the carbon atoms are aligned in strictly specified positions in a crystal lattice, which leads to its hardness. In graphite, the carbon atoms are arranged in hexagonal layers resembling honeycombs. Each layer is weakly interacting with layers above and below, so the material is easily separated into flakes that look like pencil marks on paper. IOne such layer of hexagons rolled into a tube is a carbon nanotube.

A single-walled nanotube comprises a single rolled layer, and a multi-walled nanotube resembles a Russian matryoshka doll, consisting of several concentric tubes. The diameter of each tube is a few nanometers, and the length is up to several centimeters. The ends of the tubes are closed by hemispheric "caps"—halves of fullerene molecules—fullerenes are another form of elemental carbon resembling soccer balls stitched together from hexagons and pentagons. To make and fill the carbon nanotube is much more challenging than to stuff a wafer curl, for instance. To tailor these structures, scientists use laser ablation techniques, thermal dispersion in an arc discharge or vapor deposition of hydrocarbons from the gas phase.

SWNT is no cookie

What is so special about them, then? The properties of the graphite, including electrical conductivity, ductility, and metallic shine, are reminiscent of metals. But the properties of carbon nanotubes are quite different. They have applications in electronics (as components of prospective nanoelectronic devices—gates, memory and data transmission devices etc.) and biomedicine (as containers for targeted drug delivery). The conductivity of carbon nanotubes can be changed depending on the orientation of the carbon hexagons relative to the tube axis, on what is included in its wall besides carbon, on which atoms and molecules are attached to the outer surface of the tube, and what they are filled with. Additionally, single-walled carbon nanotubes (or SWNTs) are surprisingly tear-proof and refract light in a particular way.

Kharlamova was the first to classify types of nanotube "stuffing" according to their impact on the electronic properties of SWNTs. The authMarianna or considers a particular method of filling SWNTs as the most promising for tailoring their electronic properties.

"This is due to four main reasons," Kharlamova says. "Firstly, the range of substances that can be encapsulated in the SWNT channels is wide. Second, to introduce the substances of different chemical natures into the SWNT channels, several methods have been developed, from the liquid phase (solution, melt), the gas phase, using plasma, or by chemical reactions. Third, as a result of the encapsulation process, efficient filling of SWNT channels can be achieved, which leads to significant change in the electronic structure of the nanotubes. Finally, the chemical transformation of the encapsulated substances allows controlling the process of tailoring the electronic properties of the SWNTs by selecting an appropriate starting material and conditions of the nanochemical reaction."

The author herself conducted experimental studies of the filling of nanotubes with 20 simple substances and chemical compounds, and revealed the influence of "stuffing" on the electronic properties of nanotubes. She found the correlation between the temperature of the formation of inner tubes and the diameter of the outer tubes, and explained which factors influence the degree of the nanotubes' filling.

More information: Marianna V. Kharlamova, Advances in tailoring the electronic properties of single-walled carbon nanotubes, *Progress in Materials Science* (2016). DOI: 10.1016/j.pmatsci.2015.09.001

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