Nano Focus

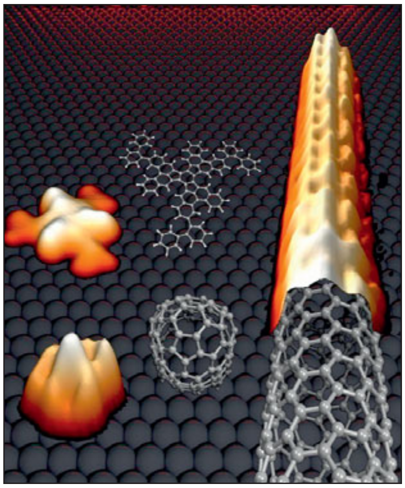
Precursor molecules enable custom-made CNTs

With their unusual mechanical, thermal, and electronic properties, carbon nanotubes (CNTs) promise the ability to construct the next generation of smaller and faster electronic and electro-optical components. To achieve this goal, however, the CNTs must exhibit specific properties that depend on their structures. However, current production methods lead to a mixture of different CNTs, as characterized by a "chiral index" that describes the way the graphene sheet is wrapped.

As described in the August 7 issue of *Nature* (DOI: 10.1038/nature13607; p. 61), researchers have now developed a new method that can be used to produce single-walled carbon nanotubes (SWCNTs) with a single, pre-specified structure. Led by Martin Jansen, Director Emeritus at the Max Planck Institute for Solid State Research, and Roman Fasel, head of Empa's Nanotechnology Department and titular professor at the Department of Chemistry and Biochemistry of the University of Bern, the research team also confirmed that these nanotubes have identical electronic properties.

By depositing the precursor molecule $C_{96}H_{54}$ on a Pt(111) surface, and using surface-catalyzed cyclodehydrogenation, the researchers formed ultrashort singly capped (6,6) "armchair" nanotube seeds. They then used ethanol as a carbon feedstock gas to epitaxially elongate the seeds up to a few hundred nanometers. Out of 100 precursor monomers, more than 50% adopted the desired configurations. "Most importantly," the researchers reported, "the condensation products of precursor molecules exhibiting 'wrong' conformations cannot act as seeds for the subsequent CNT growth process via epitaxial elongation, and thus will not affect the selectivity of SWCNT formation."

The researchers have thus proven that they can unambiguously specify the growth and thus the structure of long SWCNTs using custom-made molecular seeds. The SWCNTs synthesized in this study can exist in two forms, which correspond to an object and its mirror image. By choosing the precursor molecule appropriately, the researchers were able to influence which of the two variants forms. Depending on how the honeycomb atomic lattice is derived from the original molecule—straight or oblique with respect to the CNT axis—it is also possible for helically wound tubes, that is, with right- or left-handed rotation, and with non-mirror symmetry to form. And it is precisely this structure that then determines the electronic, thermoelectric, and optical properties of the material. In principle, the researchers can therefore specifically produce materials with different properties through their choice of the precursor molecule.



An end cap is produced from planar carbon, which forms the seed for the growth of a carbon nanotube. The calculated computer images on the left were supplemented with images taken with a scanning tunneling microscope, as seen on the right. © Empa/ Juan-Ramon Sanchez.

Bio Focus

3D-printed robots powered by skeletal muscle

Though C-3PO and R2D2 in Star Wars are fictional, these personable machines match our traditional view of robots as rigid, often metallic devices.

The latest real-world robots might not be able to save the galaxy, but they do have an advantage over their on-screen counterparts: recent advances in tissue engineering have allowed the construction of biologically inspired robots from soft tissues instead of hard materials, creating highly responsive machines that more closely mimic actual biological functions like locomotion.

In the latest example of this technology, a team of researchers from the University of Illinois at Urbana-Champaign (UIUC) and the Massachusetts Institute of Technology (MIT) has created a three-dimensional (3D) printed biological robot powered by skeletal muscle tissue that can move across a surface like an inchworm. Their results, published on July 15 in *Proceedings of the National Academy of Sciences* (DOI: 10.1073/pnas.1401577111; p. 10125), demonstrate the potential of forward engineered machines to enhance our understanding of biological systems.

Previous biological machines have used cardiac muscles to power locomotion. However, "cardiac muscle cells self-pace—they move on their own. If you want to actually control the motion, you want to use skeletal muscle cells," said Rashid Bashir, a bioengineer from UIUC and the leader of the research team.

Using 3D printing technology, the team of researchers created a scaffold—two rigid pillars connected by a pliant beam. An extracellular matrix made of collagen and fibrin proteins placed over the scaffold provided structure for the embryonic muscle cells, which self-assembled into a muscle strip over a period of a week to create a bio-bot.

An external electrical pulse mimicking a neural signal caused the muscle to contract and the robot to move—when the device was lopsided. "To get a directional movement, you somehow have to break symmetry. Either the force that's generated has to be asymmetric, or the structure has to be asymmetric," Bashir said. To create asymmetry that would

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