Nano Focus

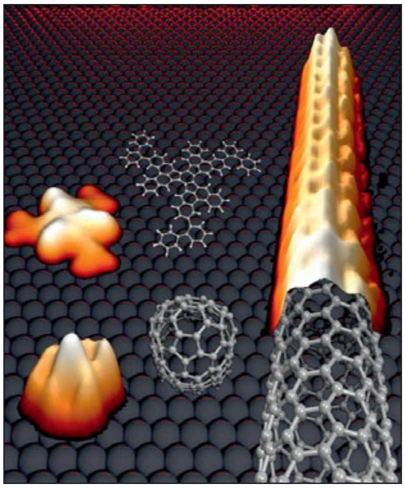
Precursor molecules enable custom-made CNTs

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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drive the robot forward, the researchers shortened one of the scaffold's pillars, causing the crossbeam to bend slightly and the muscle cells to exert differential force on the pillars.

This bio-bot is no cheetah: it moves at a relatively slow pace of around 1.5 body lengths per minute. However, Bashir hopes that the concept could ultimately be incorporated into a more complex machine with neural connections regulating the muscle cells. "Our next step is working to integrate neurons into the structure, so you could provide a signal to the neuron and the neuron would control the movement," he said.

"It's clear that there's an opportunity to take technological advances and combine them with what nature has developed to come up with ways of making things that are even better," said Ali Khademhosseini, a bioengineer at Harvard-MIT's Division of Health Sciences and Technology who was not involved in the research. "I think [this experiment] opens up a lot of new possibilities."

Laurel Hamers

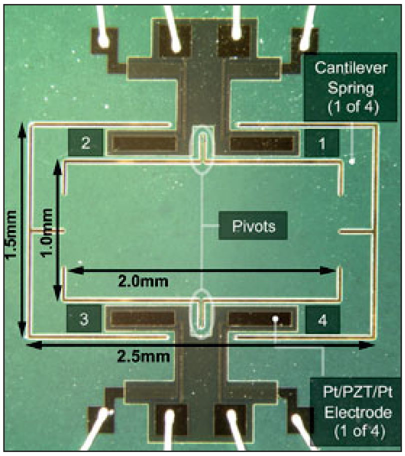
Bio Focus

Fly-inspired PZT sound detector

A team of researchers at The University of Texas at Austin (UT Austin) has developed a tiny prototype device that mimics the hearing mechanism of a parasitic fly, the yellow-colored *Ormia ochracea*. This development may be useful for a new generation of hypersensitive hearing aids. Described in the July 22 online edition of *Applied Physics Letters* (DOI: 10.1063/1.4887370), the 2-mm-wide device uses piezoelectric materials, which turn mechanical strain into electric signals. The use of these materials means that the device requires very little power.

The space between the ears of insects is typically so small that sound waves essentially hit both sides simultaneously. However, the *O. ochracea* has an unusual physiological mechanism in which the sound phase shifts slightly when the sound goes in one ear and when it goes in the other. The fly, whose ears are less than 2 mm apart, has an ear structure that resembles a tiny teeter-totter seesaw about 1.5 mm long. Teeter-totters, by their very nature, vibrate such that opposing ends have a 180° phase difference, so even very small phase differences in incident pressure waves force a mechanical motion that is 180° out of phase with the other end. This effectively amplifies the four-millionths of a second time delay the *O. ochracea* experiences in its hearing.

Neal Hall, an assistant professor in the Electrical and Computer Engineering Department at UT Austin, and his graduate student Michael Kuntzman built a miniature pressure-sensitive teeter-totter in silicon that has a flexible beam and integrated piezoelectric materials. By using multiple piezoelectric sensing ports, the researchers enable numerous vibration modes which then amplify the interaural time and level differences such as the fly experiences. The use of piezoelectric materials was their original innovation, and it allowed them to simultaneously measure the flexing and the rotation of the teeter-totter beam. Simultaneously measuring these two vibration modes allowed the researchers to replicate the fly's special ability to detect sound direction in a device essentially the same size as the fly's physiology.



A photograph of the biologically inspired microphone taken under a microscope, providing a top-side view. The tiny structure rotates and flaps about the pivots (labeled), producing an electric potential across the electrodes (labeled). Credit: N.Hall/UT Austin.

Bio Focus

Conducting polymers utilized to overcome electrode limits in ionic transport systems

The transport of particles through a fluid by an electric current, known as electrokinetics, is a process used in a number of well-known applications such as gel electrophoresis and drug delivery systems. These types of ionic conductors operate based on the interaction of a direct current (DC), applied between metal electrodes and charged ions suspended in a fluid. This process, however, can have a number of critical drawbacks such as the production of chemical side products or gases that may impede particle movement. Moreover, the charge limitations of typical metal electrodes present the largest handicap to current technology in this field.

As reported in the August 13 issue of *Advanced Materials* (DOI: 10.1002/adma.201401258; p. 5143), Magnus Berggren and his research team from Linköping University in Sweden have built a four-diode full-wave rectifier for the transport of ionic species using conducting polymer electrodes to overcome this considerable restriction. Conducting polymers can be used to improve electrode capacity by increasing effective electrode area; however, most conducting polymers cannot withstand prolonged DC, necessitating alternating current (AC) operation. The AC acts just as it would in an electrical circuit, producing a periodic reversal in the direction of particle flow that would produce no

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