Controllable Biped Walking Device Constructed from DNA

Recent literature contains many accounts of the fabrication and isolation of molecular machines. Some, like synthetic DNA devices, even display a certain degree of controllable motion, although it is essentially intramolecular and therefore limited. The precise control of a range of motion in fabricated molecular devices remains a challenge. Recently, however, W.B. Sherman and N.C. Seeman at the Department of Chemistry, New York University, achieved controlled molecular motion relative to an external substrate.

As reported in *Nano Letters* (Web release date, April 22), Sherman and Seeman synthesized and demonstrated a molecular walking motor built from DNA. The nanodevice consists of two components that are connected only by labile hydrogen bonds. The researchers term the first component the "footpath"—a rigid structure composed of a DNA motif known as a triple crossover, in which three DNA double helices are linked to each other, twice each, in an essentially coplanar arrangement. The second component is the "biped," which is composed of two double helices linked by three short, flexible, single strands of DNA that are not complementary to any other single-stranded DNA in the system. In addition, each biped helix contains a single strand of DNA termed a "foot" by the researchers. Similarly, each of the footpath's three domains contains single-stranded DNA "footholds." Sherman and Seeman selected the sequences of feet and footholds to minimize complementarity between them (i.e., to prevent them from hydrogen-bonding to each other directly). Observation was made possible with the use of psoralen molecules that were attached to the ends of the feet, linking the foot strands covalently to their respective set and foothold strands.

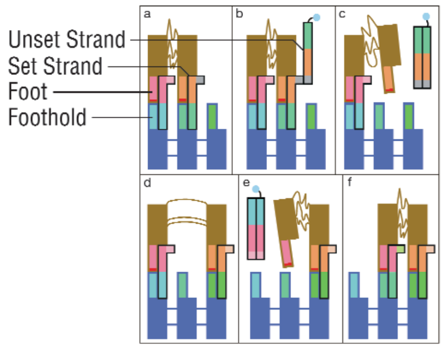

Figure 1. Schematic depicting a biped system taking a full step. Matching colors represent complementary sequences between strands. The red section at the end of each foot represents psoralen, and the blue circle represents the biotin group responsible for removing the unset complex.

Sherman and Seeman used a previously developed system of "fuel strands" to power their device, that is, to make the biped walk. "Set strands" are single-stranded DNA molecules with a sequence region complementary to the foot and another sequence region complementary to the foothold. The addition of a set strand attaches a foot to a foothold whereas the addition of an "unset strand," which has a higher affinity for the set strand than either the foot or the foothold, detaches a foot from a foothold. Figure 1 depicts the biped taking a full step, which involves five states (Figure 1a, 1c–1f). In the initial state (Figure 1a), the left foot and right foot are attached to the left and middle footholds, respectively, by set strands. The addition

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of the proper unset strand frees the right foot from the middle foothold, although it is still tethered to the left foot (state 2, Figure 1c). The addition of a set strand results in the right foot attaching to the right foothold (state 3, Figure 1d). The flexible linkers must be long enough to extend from the left to the right foothold, a gap of about 2 nm. Similar unset and set steps remove the left foot from the left foothold (state 4, Figure 1e) and attach it to the middle foothold (state 5, Figure 1f). The researchers verified each of the states by illuminating the structures with UV light, which resulted in covalent bonds between single-stranded DNA (due to the presence of the psoralen), and then performing polyacrylamide-gel electrophoresis.

Sherman and Seeman said that their device has precise bidirectional control and that a longer gait can be achieved with longer footpaths, which might also accommodate multiple, independently addressable bipeds and multipeds. They said that rotational motion can be achieved with circular footpaths. The researchers envision applications such as the transportation of loads and the winding or threading of polymers. In addition, Sherman and Seeman believe that "algorithmically generated set strands could drive a device on a 2D footpath so that the positions of the feet could represent the state of a DNA-computational machine."

STEVEN TROHALAKI

Bi_2O_3-Coated Zinc Oxide Nanoparticles Yield High-Quality Ceramics

Polycrystalline ceramic zinc oxide (ZnO) varistors, which include an intergranular bismuth-rich phase, are known to show excellent nonlinear current–voltage properties. These materials are typically made by sintering physically mixed precursors and thus often have poor microstructural uniformity and porosity. F. Yuan of the Chinese Academy of Sciences and the Korean Research Institute of Chemical Technology and H. Ryu, also of the Korean Research Institute, have found that sintering ZnO nanoparticles that have been uniformly coated with Bi_2O_3 results in ZnO ceramic varistors with perfect and homogenous ZnO grains, each of which is completely surrounded by a uniform Bi_2O_3 layer.

As described in the April issue of the *Journal of the American Ceramic Society* (p. 736), Yuan and Ryu used predesigned nanoparticles as precursors to prepare the ceramic varistors. The researchers precipitated a $Bi(NO_3)_3$ solution onto a slurry of basic carbonate-of-zinc and after calcination obtained ~30–50-nm-sized ZnO nanoparticles with homogenous Bi_2O_3 coatings. These particles were then sintered at 1150°C for 1 h to obtain the ZnO ceramics.

Yuan said, "The major advantage of this process is that ZnO nanoparticles coated with Bi_2O_3 can give a uniform liquid phase environment for every ZnO particle." The ceramics prepared from these precursors exhibited uniform grain size ranging from 3–5 μm for samples with 1 wt% Bi_2O_3 to 8–10 μm for samples with 3 wt% or 5 wt% Bi_2O_3.

The eutectic temperature for the ZnO–Bi_2O_3 system is ~740°C; above this temperature, a liquid phase is formed. In using the preformed, coated particles, each ZnO particle is in a homogenous medium, thus the ZnO grains grow homogeneously and perfectly. The researchers observed that above 3 wt% of Bi_2O_3 there is a continuous skeleton of the bismuth-rich phase completely surrounding the perfectly formed ZnO grains. They also determined that the ZnO grains do not grow once the bismuth-rich phase has formed a continuous grain boundary surrounding the ZnO grains. The lack of porosity and good grain condition as well as the excellent grain-boundary properties are expected to have favorable effects on the varistor properties under high current.

SARBAJIT BANERJEE

Bandgap of Semiconducting Nanotubes Shrinks in High Magnetic Fields

A team of researchers headed by Richard Smalley at Rice University has discovered that the bandgap of semiconducting single-walled carbon nanotubes (SWNTs) shrinks monotonically as a function of magnetic flux densities up to 45 T (Figure 1). The findings confirm quantum mechanical theories offered more than four decades ago by Aharonov and Bohm. According to lead researcher Junichiro Kono, an assistant professor of electrical and computer engineering at Rice, the SWNTs will likely become metals at >100 T.

A magnetic flux passing through a mesoscopic ring structure modifies the quantum states and the dynamics of electrons in the ring. Quantum-interference effects, manifested, for example, as oscillations in magnetoresistance, occur when the phase coherence length exceeds the circumference. However, a magnetic flux passing through SWNTs interacts with them in a different fashion than would occur with a mesoscopic ring, because the SWNTs have a periodic lattice potential along the circumference of the nanotube.

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