Semiconducting Behavior in DNA Device Detected by Triple-Probe

Deoxyribonucleic acid (DNA) is considered by some to be the ideal building block for nanoelectronic circuits, and, consequently, the electronic behavior of these molecules has attracted significant interest. It has been reported that the electrical characteristics of DNA can vary from those of an ohmic conductor to those of a wide-bandgap semiconductor. To better understand the carrier transport in DNA, a team of researchers at Fujixerox Co.'s Corporate Research Center in Kanagawa-ken, Japan, have developed a probing system for measuring the electrical properties of DNA molecules and other nanoscale samples.

As reported in the October 8 issue of *Applied Physics Letters*, H. Watanabe and coworkers have measured the electrical properties of a three-terminal single-molecule DNA device with a triple-probe atomic force microscope (T-AFM). A single DNA molecule was connected to the T-AFM with three carbon nanotube (CNT) electrodes, corresponding to a source, drain, and gate terminal. In addition to demonstrating the measurement capabilities of their T-AFM, the researchers showed that a salmon sperm DNA double strand was semiconducting.

The T-AFM system is comprised of a nanotweezers setup and a conventional AFM system equipped with a conductive, 8-nm diameter multiwalled CNT (MWCNT) probe. The nanotweezers, two 8-nm-diameter MWCNTs connected to a 100-nm-diameter glass needle, were used to position submicron DNA samples with 1–2-nm accuracy. A double strand of salmon sperm DNA was deposited on a SiO_2/Si(100) substrate, and a single-walled CNT (SWCNT) was deposited through the T-AFM adjacent to the DNA molecule to serve as the gate terminal. A three-dimensional piezo-actuator was used to position the nanotweezers such that the two CNT probes grabbed the salmon sperm DNA molecule and served as the source and drain terminals. To avoid the problems associated with electrostatic attraction of the probes both to each other and the substrate, the researchers employed a method whereby the CNT probes were continuously vibrated. When the sample was in the proper location, the vibrations were stopped and the nanotweezer probes were allowed to attain a fixed closed position and grab the sample. The MWCNT AFM probe was then used to apply a bias voltage to the SWCNT gate terminal.

The current-voltage (*I-V*) curves, which were measured at a source-to-drain distance of 25 nm in room temperature dry nitrogen, were nonlinear, indicating semiconducting behavior. Furthermore, the voltage gap decreased with increasing gate bias voltage, indicating a conductance rise and demonstrating the switching characteristics of the gate-biased DNA molecule.

"While additional studies to further clarify carrier transport mechanisms in DNA are ongoing," said Watanabe, "we anticipate that DNA will play a major role in the future of advanced biosensors and molecular electronics."

STEFFEN K. KALDOR

Lattice-Expanded C_{60} Achieves T_c of 117 K

Scientists J.H. Schön, Ch. Kloc, and B. Batlogg at Lucent Technologies/Bell Labs have shown that C_{60} can act as a superconductor at temperatures as high as 117 K, raising hopes for inexpensive current loss-free electronic devices based on organic compounds. Practical applications include quantum computers. The discovery is described in an article published on-line on August 31, 2001, by the journal *Science* on the Science Express Web site (www.sciencexpress.org), with the print version appearing in *Science* **293** (2001) p. 2432.

It is now understood that expanding the lattice of C_{60} increases the density of states at the Fermi level, leading to the increase of T_c. The expanded lattice can be achieved by intercalation of trihalomethane CHX_3 with C_{60} crystals. The researchers intercalated C_{60} single crystals with $CHCl_3$ and $CHBr_3$ in a solution to form co-crystals. The lattice parameter increased from 14.16 Å for undoped C_{60} to 14.28 Å and 14.43 Å for $C_{60}/CHCl_3$ and $C_{60}/CHBr_3$, respectively. Field-effect devices were created and researchers induced high densities of electrons or holes by gate doping. Since the hole-phonon interaction seems to be stronger than the electron-phonon interaction and the density of states in the valence band is higher than in the conduction band, the T_c for hole doping is higher than for electron doping. When the hole density reached approximately one hole per molecule, superconductivity above 1.7 K was observed. More holes led to higher values of T_c, and the value of T_c depended on the size of the intercalant molecule and the hole concentration. The highest T_c of 117 K was observed in $C_{60}/CHBr_3$ with 3–3.5 holes per C_{60} molecule. The research team also found that the increase of T_c with increased spacing between the C_{60} molecules follows the general trend of alkali-metal-doped C_{60}, which is explained in terms of the increased density of states at the Fermi level. The team suggests that if the lattice parameter can be further increased by ~1%, a T_c exceeding 150 K may result.

The only other known superconductors that work at this and higher temperatures are copper oxide superconductors. These, however, have other problems. The physics that governs copper oxide superconductors is nonconventional and not well understood, and they are highly anisotropic and granular, which makes it difficult to fabricate useful devices. The C_{60} superconductors, on the other hand, according to the researchers, are less expensive, the physics is better understood since they seem to act as conventional superconductors, and they have a potential for practical devices.

SHIMING WU

Superconducting Quantum Interference Device (SQUID) on MgB_2 Thin Films Close to a Reality

Researchers from the University of Twente in the Netherlands have fabricated a superconducting quantum interference device (SQUID) circuit based on thin films of MgB_2, a newly discovered non-copper oxide superconductor with a critical transition temperature (T_c) of 39 K. The advantages of this material for electronic applications include the large charge-carrier density, isotropy of the material, and strong links at grain boundaries. The technology to fabricate Josephson junctions in these high-quality films is essential for practical circuits.

Because of the post-annealing step involved in preparing the MgB_2 films, the conventional tri-layer Josephson junctions could not be easily constructed. Fortunately, the weak links in a SQUID circuit can also be realized on a single-layer film by creating nanobridges in a superconducting ring.

As described in the October 1 issue of *Applied Physics Letters*, the researchers deposited thin films of 200-nm MgB_2 on MgO substrates by pulsed laser ablation in a two-step *in situ* process. Standard photolithography and argon ion-beam milling were used to pattern the SQUID ring and contact paths on the film. The structure contained two striplines into which nanobridges were structured by direct focused-ion-beam (FIB) milling. The dimensions of the nanobridges were 70 nm wide by 150 nm long and 150 nm high. The T_c of the structure was found to be 22 K.

The critical current of the SQUID at T = 4.2 K is 1.5 mA, which corresponds to a critical current density of 7×10^6 A/cm^2. At 10 K, a modulation voltage of 30 μV was observed. Voltage modulation was observed up to 20 K. The structures are very stable over time and are insensitive to thermal cycling or exposure to moisture.

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The results demonstrate that high-quality superconducting structures can be realized on a length scale <100 nm in *in situ* fabricated MgB_2 films. Furthermore, the results show that the chemical reactivity and volatility of magnesium do not limit FIB processing of structures on the nanoscale level. MgB_2 ring structures incorporating nanobridges display Josephson quantum interference effects, which form the basis for the creation of an all-MgB_2 SQUID. According to the researchers, "This result is an essential step toward sensors and electronic circuits based on this novel superconductor."

SHIMING WU

Antimicrobial Materials for Medical Implants Prepared Using Sol-Gel Techniques

Researchers in the Department of Chemistry at the University of North Carolina—Chapel Hill have synthesized stable and tunable NO-releasing siloxane polymer films for use as potential medical implant coatings. The coatings were designed and characterized by Mark Schoenfisch and graduate students Brian Nablo and Ta-Yung Chen. The researchers prepared NO-releasing sol-gel materials by combining various amounts of isobutyltrimethoxysilane (iBuTMOS) and (3-trimethoxysilylpropyl) diethylene-triamine (DET3), casting thin films of the mixture onto glass slides, and then exposing the slides to high pressures of NO. The researchers demonstrated that these materials controllably released low levels of NO, a potent antibacterial agent, and prevented the adhesion of *Pseudomonas aeruginosa* bacteria. According to Schoenfisch, "Localized NO release may prove to be an effective strategy for lessening the frequency of biofilm formation and implant-related infections." *P. aeruginosa* was selected for the study because it is a well-characterized, medically relevant bacterium known to actively form biofilms.

As reported in the October 3 issue of the *Journal of the American Chemical Society*, the NO-releasing materials were prepared by the addition of three mole equivalents of water to a mixture of iBuTMOS and DET3. The mixture was then stirred for 5 min before casting onto glass slides. The sol-gel-coated slides were allowed to gel, dry, and age for 5–7 days under ambient conditions. The amine group moieties were then converted to diazeniumdiolates (NO donors) by exposure to 5 atm of NO for 72 h. NO chemiluminescence studies showed that the gels released NO continuously for up to 24 h. The amount of NO released was tuned by adjusting the fraction of DET3 in the sol.

To test the bacterial adhesion resistance of the NO-releasing coatings, the sol-gel-modified glass slides were exposed to *P. aeruginosa* for 30 min followed by fixing and staining the adhered cells. Opacity measurements of the slides revealed that the number of adhered cells was reduced by a factor of 2 for 15% DET3 gels and by a factor of 4 for 45% DET3 gels compared to control slides without NO-release capabilities. In addition, reduced cell adhesion was not observed on control slides exposed to solutions of NO_2^-, demonstrating that the NO, and not nitrite, NO's major oxidation product, is responsible for the reduced cell adhesion.

To test the stability of the films, the Si content from phosphate-buffered saline soak solutions was measured as a function of sol-gel immersion time. The Si concentrations in the soak solutions were extremely low, indicating minimal loss of Si from the aminasilane precursors which are covalently linked to the polymer backbone and thereby indicating satisfactory material stability.

These studies show that the NO-releasing materials could inhibit or even prevent bacterial growth on medical implants. Schoenfisch said that complete inhibition of cell adhesion was not achieved because this study was performed at relatively low NO-release rates and high concentrations of cells. His group is currently investigating the effectiveness of the films to reduce the adhesion of other medically relevant bacterial species.

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