nism. "These are 'Russian matryoshka doll-like' structures," Ruoff said. "One nanotube is nested inside of another, which is inside of another, and so on. For the MWCNTs we mechanically loaded, there would be typically 10 to 40 nested cylinders."

"Our method of 'nano-welding' these onto the cantilever tips, which are our 'fingers' for holding and pulling, is to focus the electron beam onto the MWCNT, where it is loosely attached by the relatively weak van der Waals forces to the cantilever tips," said Ruoff. "Doing this causes residual hydrocarbon gases in the electron microscope to be decomposed and to build up a small carbonaceous deposit. This deposit is the strong attachment that holds the nanotubes in place during the experiment."

The method needs further development, he said. About one-half of the MWCNTs attached in this manner still broke at the attachment site rather than within the loaded nanotube section after the load was applied. But the other half represented 19 separate MWCNT tensile-loading experiments.

Ruoff said, "Since the attachment is to the outermost shell, and the interaction between these nested nanotubes in a multiwalled nanotube is relatively weak, one might expect that the outermost shell will carry the load and break, with pullout of the inner shells then occurring immediately after the break. This is exactly what we observed."

"When we take account of the lower density of carbon nanotubes as compared to high-grade steels, the outer shell is about 50 to 60 times stronger. This suggests that there are future applications for very lightweight, high-strength cables and composites, where the carbon nanotubes are the load-carrying element," Ruoff said.

V_2O_5 Nanofibers Used in Fabricating Field-Effect Transistor

G.T. Kim, J.G. Park, and Y.W. Park of Seoul National University, and J. Muster, V. Krstic, S. Roth, and M. Burghard of the Max-Planck Institute in Stuttgart have demonstrated that vanadium pentoxide (V_2O_5) nanofibers can be readily deposited in controllable densities on chemically modified Si/SiO_2 substrates. The feasibility of using these nanofibers for electrical conduction in nanoscale devices is being investigated. Current attempts to use carbon nanotubes for this purpose suffer from the tendency of the nanotubes to form in dense networks, requiring potentially damaging ultrasonic treatment to separate the individual fibers. The deposition of V_2O_5 nanofibers requires no such separation step.

As reported in the April 3 issue of *Applied Physics Letters*, nanofibers of V_2O_5 of molecular thickness are synthesized from ammonium(meta)vanadate and an acidic ion exchanger. To fabricate a field-effect transistor (FET), the nanofibers are deposited on a Si/SiO_2 substrate, and 15-nm-thick Au/Pd electrodes are patterned on the surface 100 nm apart using electron-beam lithography. A 300-nm-thick layer of thermally grown SiO_2 insulates the electrodes from a back gate consisting of the substrate doped with As^+ ions. The measured resistance of the V_2O_5 fibers connecting the electrodes ranged between 200 MΩ and 300 MΩ. This relatively high resistance limits the performance of the FET in its present version; further investigation using fibers with higher conductivity (such as VO_2 or V_2O_3) is planned.

Ultrafast Laser Pulses Facilitate Storage and Retrieval of Quantum Phase Information in Cesium Rydberg States

Using ultrafast lasers and a beam of cesium atoms, physicists at the University of Michigan have created a database that stores and retrieves data in atomic quantum phases. As reported in the January 21 issue of *Science*, a computer randomly assigned data values to one quantum state of a single cesium atom. Using an ultrashort pulse of intense laser light, the scientists stored the information in the assigned quantum state by flipping the quantum phase or inverting the quantum wave for that state. Less than 1 ns later, the same atom was hit by a second laser pulse, which located the stored data by amplifying the flipped quantum state and suppressing all other states in the wave packet. The laser pulse used to store the data was produced by filtering a 100-fs laser pulse centered approximately on $\lambda = 785$ nm. The cesium atomic states interrogated were Rydberg *p*-states, with principal quantum numbers ranging from $n = 29$ to $n = 38$.

Philip H. Bucksbaum, the Otto Laporte Professor of Physics at Michigan, said that L.K. Grover, in a 1997 paper published in *Physics Review Letters*, speculated that quantum 2-state data registers would be a faster, more efficient way to search and retrieve data than the classical binary system currently used because the rules of quantum mechanics allow a search in many locations simultaneously. "We test-

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Portland, OR 97223 USA
Tel: 503.624.0315 • Fax: 503.624.0735
www.ktekintl.com
E-mail: science@ktekintl.com
Circle No. 16 on Inside Back Cover

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ed one of his algorithms and confirmed Grover's idea," Bucksbaum said.

"It is important to keep this study in perspective," he said. "Quantum phase data storage is a new concept. Most researchers are using the spin of a quantum particle as a storage medium. Our work may turn out to be a step on the pathway to a viable quantum computer system or it could be a complete dead-end. The field is still too new to know which approach will succeed."

John Reffner Receives 2000 Williams-Wright Award

John A. Reffner, technical director of SensIR Technologies, has been named recipient of the 2000 Williams-Wright Award from the 2000 Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy held in March in New Orleans, Louisiana. He is being honored for his work toward the development of infrared microspectroscopy (IMS).

In collaboration with colleagues, Reffner raised the standards for Fourier transform infrared spectroscopy (FTIR) microscopes and expanded the applications of IMS, which led to the development of new infrared microscopes and rapid advances in infrared microanalysis, spectral mapping, and quantitative microspectroscopy.

Reffner received his PhD degree from the University of Connecticut, where he was assistant director of the Institute of Materials Science and a member of the chemistry faculty. He has held research and scientist positions at B.F. Goodrich, W.C. McCrone Associates, American Cyanamid, and Spectra-Tech. He joined SensIR Technologies in 1998. Since 1974, Reffner has served as forensic consultant to the Connecticut State Police. He is a Fellow of the Academy of Forensic Science and serves on the editorial board of the *Journal of Forensic Science.* He is a member of several scientific and professional associations, including the Coblentz Society and the Society of Applied Spectroscopy.

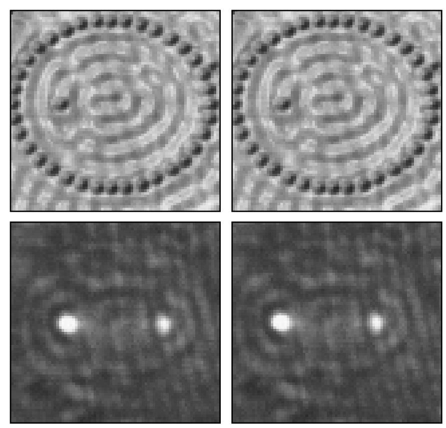
This award has been presented by the Coblentz Society since 1978.

Circle No. 10 on Inside Back Cover

"Quantum Mirage" May Enable Atom-Scale Circuits

As computer-circuit features shrink toward atomic dimensions, the behavior of electrons changes from being like particles described by classical physics to being like waves described by quantum mechanics. For example, on such small scales, tiny wires do not conduct electrons as well as classical theory predicts. Therefore, quantum analogues for many traditional functions must be available if nanocircuits are to achieve the desired performance advantages of their small size. Researchers at IBM Almaden Research Center have discovered a way to transport information on the atomic scale that uses the wave nature of electrons instead of conventional wiring. They call this phenomenon the "quantum mirage" effect.

Physicists Hari C. Manoharan and Christopher P. Lutz and IBM Fellow Donald M. Eigler, lead researcher on this project, describe their research in the February 3 issue of *Nature.* Using a low-temperature scanning tunneling microscope (STM), they created the quantum mirage by first moving several dozen cobalt atoms on a copper surface into an ellipse-shaped ring. The ring atoms acted



This four-part composite image shows the "quantum mirage" effect in action. When a magnetic cobalt atom is placed at a focus point of an elliptical corral (upper left), some of its properties also appear at the other focus (lower left), where no atoms exist. In this case, a change in the surface electrons due to the cobalt's magnetism—the Kondo resonance—appears as a bright spot at each focus. When the cobalt atom is placed elsewhere within the ellipse but not at a focus point (upper right), the mirage disappears (lower right), and the Kondo effect is detected only at the cobalt atom itself. The corral is made of 36 cobalt atoms positioned on a copper [111] surface.

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