Using a carbon nanotube, Cornell researchers make an oscillator so small it might weigh a single atom

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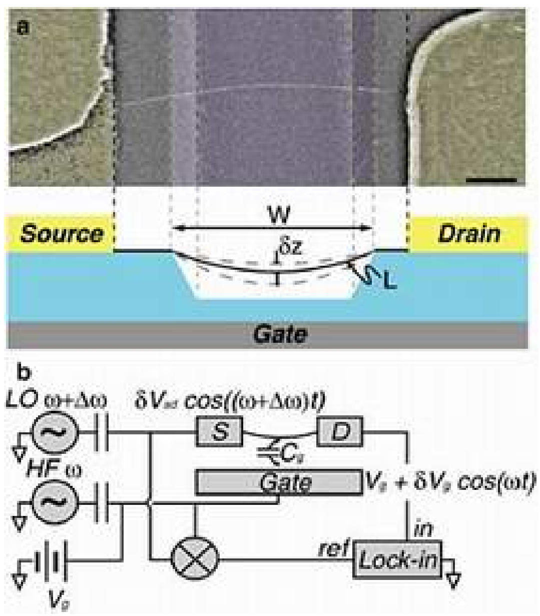

Using a carbon nanotube, Cornell University researchers have produced **a tiny electromechanical oscillator that might be capable of weighing a single atom**. The device, perhaps the smallest of its kind ever produced, can be tuned across a wide range of radio frequencies, and one day might replace bulky power-hungry elements in electronic circuits.

Recent research in nanoelectromechanical systems (NEMS) has focused on vibrating silicon rods so small that they oscillate at radio frequencies. By replacing the silicon rod with a carbon nanotube, the Cornell researchers have created an oscillator that is even smaller and very durable. Besides serving as a radio frequency circuit element, the new device has applications in mass sensing and basic research.

Paul McEuen, Cornell professor of physics, Vera Sazonova, Cornell graduate student in physics and Yuval Yaish, a visiting scientist in the Laboratory of Atomic and Solid State Physics (LASSP) at Cornell, report on the device in the latest issue (Sept. 16, 2004) of the journal Nature.

Image: Scanning electron microscope photo of a single carbon nanotube suspended over a silicon trench, and a schematic drawing of the device as seen in cross-section. Below, a diagram of the circuit. Copyright © Cornell University

Carbon nanotubes are cylinders of carbon atoms arranged in a hexagonal pattern similar to that in the geodesic domes created by architect, inventor and mathematician Buckminster Fuller. Materials with this structure are called fullerenes in his honor, and fullerene spheres are known as buckyballs. A nanotube can be thought of as an elongated buckyball.

The Cornell device consists of a carbon nanotube from one to four nanometers in diameter and about one-and-a-half micrometers long, suspended between two electrodes above a conducting silicon plate. (A nanometer is one-billionth of a meter, the length of three silicon atoms in a row; a micrometer is one-millionth of a meter.) The tube is not stretched tight, but hangs like a chain between two posts in a shallow curve called a catenary.

The tube itself is a conductor, and when a voltage is applied between the tube and the underlying plate, electrostatic force attracts the tube to the plate. An alternating voltage sets up vibration as the tube is alternately attracted and repelled. A static voltage applied at the same time increases the tension on the tube, changing its frequency of vibration just as tightening or loosening a guitar string changes its pitch. The entire assembly of tube and plate behaves as a transistor, so the tube's motion can be read out by measuring the current flow. Experimenting with various sizes and lengths of tubes, the researchers have made oscillators that tune over a range from 3 to 200 megaHertz (millions of cycles per second).

Such a tunable oscillator could be used as a detector in a radio-frequency device such as a cellular phone, which must constantly change its operating frequency to avoid conflicts with other phones.

Like their larger cousins, nanotube oscillators also could be used for mass sensing. Since the frequency of vibration is a function of the mass of the vibrating string, adding a very small mass can change the frequency. Silicon rod oscillators have been used to weigh bacteria and viruses. "This is so much smaller that mass sensitivity should be that much higher," McEuen said. "We're pushing the ultimate limit, maybe weighing individual atoms."

The researchers conducted their measurements in a vacuum. If air or any other gas were present, the gas molecules would adsorb, or collect in a condensed form, on the surface of the tube, changing its mass. So, McEuen says, nanotube oscillators could be used as gas detectors.

One drawback, he points out, is that at present there is no way to mass-produce carbon nanotubes.

McEuen looks forward to studying the fundamental physics of the device. When cooled to cryogenic temperatures, he says, the nanotube acts like "a skinny quantum dot," or a sort of box full of electrons. "We can study the influence of individual electrons hopping on and off," he says. "What happens when you have a quantum dot that can wiggle?"

The Nature paper is titled "A Tunable Carbon Nanotube Electromechanical Oscillator." Other co-authors are Hande &†uml;stünel, a graduate student in physics, David Roundy, a LASSP postdoctoral associate and Tomás A. Arias, Cornell associate professor of physics. The work was funded by the National Science Foundation (NSF) and the Microelectronics Advanced Research Program (MARCO) Focus Center on Materials, Structures and Devices supported by the Semiconductor Research Corporation. The devices were fabricated at the NSF-funded Cornell Nanoscale Facility.

Source: Cornell University