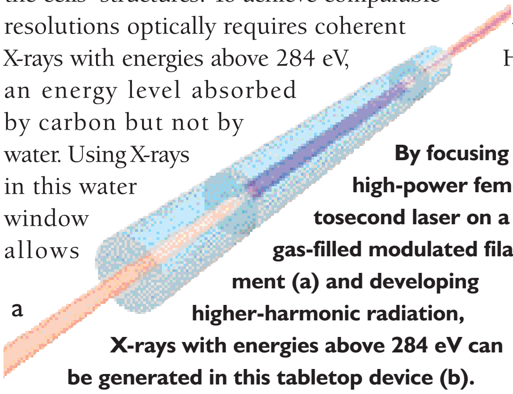
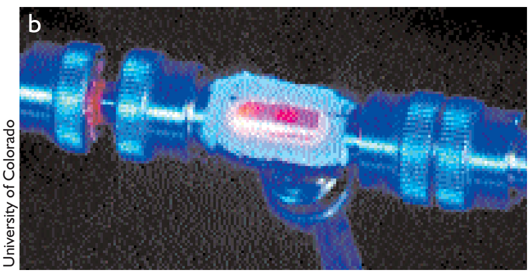
Opening the X-ray water window

Electron microscopes provide ultrahigh-resolution images of cells, but the technique requires considerable sample preparation, which takes time and can damage the cells' structures. To achieve comparable resolutions optically requires coherent X-rays with energies above 284 eV, an energy level absorbed by carbon but not by water. Using X-rays in this water window allows researchers to view cells by quick-freezing them, which preserves more of their internal structure than is possible when preparing samples for electron microscopy.





University of Colorado

By focusing a high-power femtosecond laser on a gas-filled modulated filament (a) and developing higher-harmonic radiation, X-rays with energies above 284 eV can be generated in this tabletop device (b).

Until now, the principal source of coherent X-rays has been synchrotron radiation produced by an accelerator. But such accelerator facilities typically cost around \$20 million, and for cost-effective operation, many researchers must share them.

A research collaboration between the University of Colorado at Boulder, the University of California at Berkeley, Sofia University (Bulgaria), and the Lawrence Berkeley National Laboratory has now developed a way to generate water-window coherent X-rays with a tabletop device that will cost about \$250,000 (*Science* **2003**, *302*, 95). The device focuses a laser on a gas-filled filament, which converts a fraction of the light to X-rays using higher-harmonic generation (HHG). In HHG, intense laser light strips electrons from atoms and as the field oscillates, the electrons are then slammed back into the ions, releasing higher-energy photons. The light is created over several cycles of the laser field, resulting in higher harmonics of the laser light. The harmonic light frequencies increase with the intensity of the laser and can be more than 100 times the frequency of the original light.

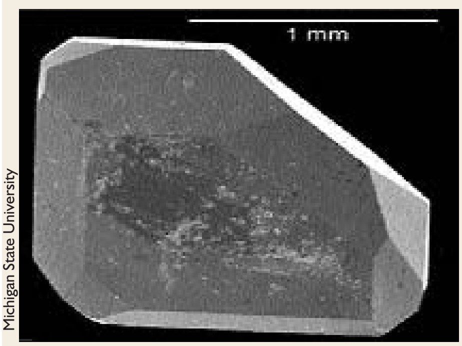
However, a basic limitation of the process has prevented HHG from efficiently generating X-ray energies as high as the water window. As the ionization fraction increases, the index of refraction starts to decrease, due to the freed electrons. This effect is dependent on the square of the wavelength of the radiation involved, so it affects light far more than it does X-rays. The difference in the index of refraction creates a relative velocity between the light and X-rays, causing them to go out of phase and undergo destructive interference before the harmonic signal can build up in the fiber. This greatly decreases the amount of light that can be generated in the highest harmonics.

To overcome this limitation, the researchers put the gas to be ionized into a waveguide whose diameter is modulated periodically every 250 μm. "Because the process is very sensitive to the laser light intensity, modulating the filament diameter limits the HHG process to a series of discrete, small regions," explains Henry C. Kapteyn of the University of Colorado. The discrete regions are small, and thus, there is not enough space for the relative velocity differences between the X-rays and the laser light to destroy the phase matching. Emissions from all of the regions add together constructively, which allows the high-energy harmonics in the water window to build up. The team's experiments showed that a flux between 10^6 and 10^8 photons/s is produced in the water-window region, which may be sufficient for biological-imaging applications.

The next steps, says Kapteyn, are to lengthen the waveguide from its present 2.5 cm to as long as 40 cm and increase laser intensity to about 5×10^{15} W/cm^2. These advances should greatly increase the intensity of the water-window X-rays and make possible significant X-ray production at energies approaching 1 keV.

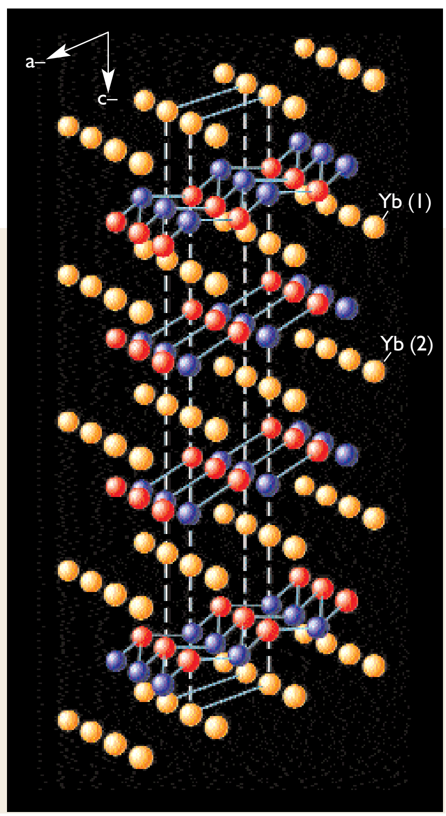
Zero thermal expansion

The vast majority of materials expand when heated, a phenomenon that often creates engineering headaches. If a



Michigan State University

Near-zero thermal expansion is exhibited by the electrically conductive intermetallic compound YbGaGe (red atoms are Ga, blue Ge, and yellow Yb) because cell constants a and b increase with falling temperature, but the c axis contracts.



Michigan State University, East Lansing, Michigan/Ian Worpole material is subjected to swift heating or cooling, as occurs in space applications or with rapid pulses of electric power, thermal expansion or contraction may exceed the strength of the material. This causes it to plastically deform and eventually fracture. A material with a tiny coefficient of expansion, or, ideally, zero thermal expansion (ZTE), would be useful for demanding applications, especially if it were an electrical conductor.

Researchers at Michigan State University in East Lansing have developed an intermetallic compound, ytterbium-gallium-germanium (YbGaGe), that exhibits near-ZTE over a temperature range of 100 to 400 K (*Nature* **2003**, *425*, 702). The phenomenon that creates this ZTE, called electronic valence transition, could prove useful in developing other such ZTE materials.

YbGaGe drew the researchers' attention because of several peculiarities in its crystal structure. For one, the Yb atoms seemed to remain in an intermediate valence state—in other words, the atoms did not appear to have given up two or three electrons, but somewhere in between.

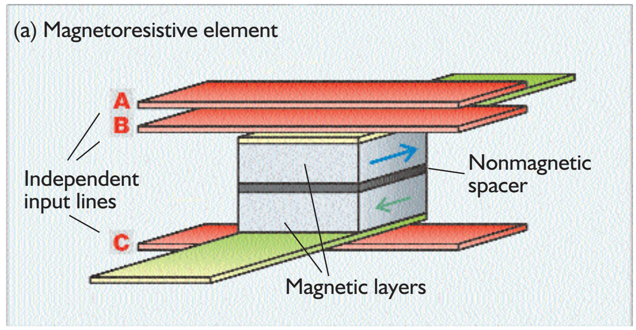
X-ray crystallographic studies showed that when cooled, one of the bonds in the crystal cell between the Yb and Ge atoms actually gets longer. As a result, the cell stretches in one direction and slightly contracts in another direction, yet it maintains almost exactly the same volume. The actual change in volume implies a thermal expansion coefficient of only 3% that of tungsten and less than 1% that of copper.

"What is happening to cause this effect is that as the compound cools, electrons drop out of the conduction band and become valence electrons of the Yb atoms," explains James R. Salvador, a member of the research team, which was led by Mercouri G. Kanatzidis. "The addition of the electrons causes the Yb atoms to grow and thus the bond length to get longer. In the meantime, the other bonds are shrinking slightly, as would normally be expected with decreasing temperature. So the net result is virtually no change in volume."

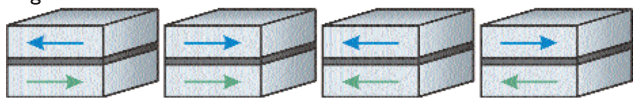
Although the compound's volume changes little with temperature, there is a substantial coefficient of thermal expansion along the axes of the crystal, which could still cause some strain in a rapidly heated or cooled part. However, along certain directions at an angle to the crystal axes, expansion or contraction would be negligible, and parts could be fabricated to take advantage of these directions of least expansion. Another limitation of YbGaGe is that its electrical conductivity is only fair, with a value at 300 K of 2.3×10^5 S/m, only 0.4% that of copper.

The researchers believe that the valence-transition phenomenon observed in this compound can probably be applied in designing other ZTE metallic compounds with similar properties, including ones with less expansion along each crystal axis and higher conductivity. Ω

(a) Magnetoresistive element



Magnetoresistive element



A	B	O
0	0	0
0	1	0
1	0	0
1	1	1

AND

A	B	O
0	0	0
0	1	1
1	0	1
1	1	1

OR

A	B	O
0	0	1
0	1	1
1	0	1
1	1	0

NAND

A	B	O
0	0	1
0	1	0
1	0	0
1	1	0

NOR

(b) Binary logic tables

Paul-Drude-Institut fuer Festkoerperelektronik, Berlin, Germany

This magnetoresistive element consists of two magnetic layers separated by a nonmagnetic spacer and three independent input lines (a). Setting the magnetic layers into one of the four parallel (logic 1) or antiparallel (logic 0) configurations produces logic tables corresponding to AND, OR, NAND, and NOR (b).

Magnetoresistor computing

As anyone who has waited for a computer to boot or load a program knows, the limiting factor on a computer's real speed is not its processor but how long it takes to transfer information in and out of memory. This problem affects not just the long-term memory on the hard drive but also the short-term memory in the random access memory (RAM). As a result, researchers have long worked on schemes to place memory devices and logic processors closer and closer together—on the same chip or even in the same device. However, one problem has been that the physical processes used to build memory devices and transistors are incompatible.

Reinhold Koch and his colleagues at Paul-Drude-Institut fuer Festkoerperelektronik (Berlin) have developed another approach based on magnetoresistors (*Nature* **2003**, *425*, 485). They combined the functions of memory and logic processing into a single device that does without transistors.

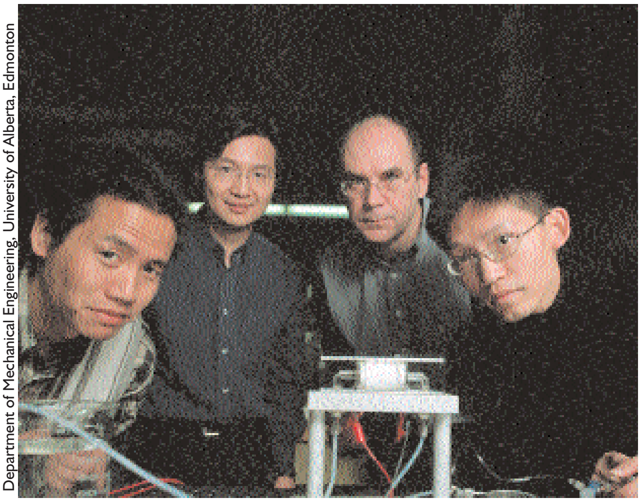
Their device is related to magnetic RAMs (MRAMs), which will soon enter the commercial market. The core of the new programmable spin-logic device—as with MRAMs—is a giant magnetoresistive element consisting of two magnetic layers separated by a nonmagnetic barrier. When the magnetization in the top and bottom layers is parallel, the resistance of the sandwich is much lower than when the two elements are magnetized antiparallel.

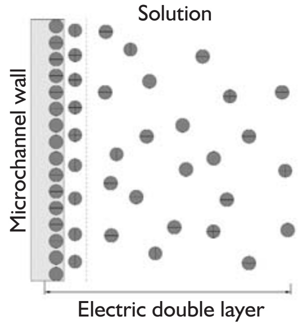
If the device is used as a memory, a current carried by an input layer can create a magnetic field to flip the magnetization of one of the layers, changing the resistance of the device. Because the magnetization is stable, this creates a nonvolatile memory, which does not require power to maintain itself. The new device uses three input lines to convert it to either a logic or memory unit, depending on the inputs. The strengths of the currents are set so that a single input current cannot switch either magnetic layer, but two inputs together will switch the top layer, and three together will switch both layers.

By using the current to preset the device into one of its four either parallel or antiparallel configurations representing the four logic functions—AND, OR, NAND, and NOR—the device can be programmed to carry out all the logical operations that transistors can do. For example, for the logical operation AND, the output will be positive only if both inputs are positive. Any device that can carry out all four logical operations can carry out any programmable computation, which is made up of a string of such logical operations.

Although laboratory experiments indicate that the new device has maximum switching speeds of only a few gigahertz, which is much slower than that of the fastest complementary-metal-oxide-semiconductor processors, Koch believes that spin-logic devices have strong compensating advantages. “Because the memories are nonvolatile, you can do parallel processing without worrying about keeping everything synchronous,” he points out, and the time saved in transferring information in and out of memory can increase the overall speed by 100 to 1,000 times compared with existing architectures.

Department of Mechanical Engineering, University of Alberta, Edmonton





A research team at the University of Alberta (Edmonton) has demonstrated a nonpolluting battery without moving parts that uses the small potential between the upstream and downstream ends when water is forced through the microchannels of porous glass.

A pressure-driven battery

For more than a century, converting the kinetic energy of water or gas to electricity, generally through a turbine, has produced by far the greatest amounts of power. Turbines, however, are not suited to small-scale electric applications, so portable operations rely on batteries, which produce energy directly from chemical reactions. But batteries have some drawbacks, most significantly in their contribution to heavy-metal pollution when they are discarded.

A Canadian engineering team at the University of Alberta (Edmonton) has invented a new method for generating electricity on a small scale from kinetic energy without using turbines or other moving parts (*J. Micromech. Microeng.* **2003**, *13*, 963). The new approach, termed an electrokinetic microchannel battery, makes use of electric double layers, a phenomenon that occurs in a conducting liquid (such as saltwater) very near a solid surface.

An electric double layer forms because many insulators, such as glasses and ceramics, have an excess of electrons on their surface. This excess attracts positively charged ions in the water, creating a thin, positively charged layer. When the water moves under pressure through a channel, the ions tend to pile up at the downstream end of the channel, while the electrons, trapped in an insulator, cannot follow them. The result is a small positive potential between the downstream and upstream ends of the channel. If these ends are connected by a conductor, a small current flows, which converts the kinetic energy of the water flow into electricity, without moving parts. (Magnetohydrodynamic conversion can do the same thing, but it requires an imposed magnetic field.)

Because the ions are confined to a thin layer—generally on the order of 1 μm—significant conversion of kinetic to electric energy occurs only when there is a large ratio of the surface area of the flow to its volume. This occurs when the fluid is forced through the microchannels of a porous material. Using a commercial porous-glass filter 20 mm in diameter, and with a pore size from 10 to 16 μm, the team produced a 1.5-μA current using tap water and a 30-cm pressure head.

Although the current produced and the energy-conversion efficiency were tiny in the initial experiments, the team calculated that it could greatly increase efficiency by using water with a higher salinity and by optimizing other factors, such as the external load resistance. “In more recent experiments, we have achieved a 1% conversion efficiency,” explains team leader Daniel Y. Kwok of the university’s department of mechanical engineering. “We are not trying hard yet to maximize efficiency. We are still in the proof-of-principle phase.” Kwok says that the battery’s main advantages are its complete lack of environmentally polluting materials and moving parts.

A major disadvantage is that the battery stores energy in the form of pressurized water, so applications could not require very high energy-storage densities. Even at 100 atm, water would have only one-sixteenth the energy density of a nickel–cadmium battery.