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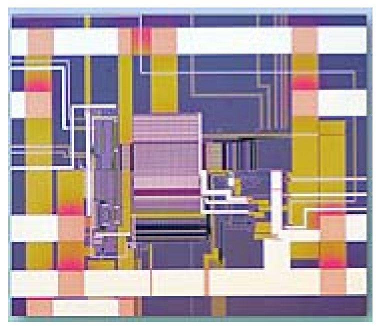
'Spin' Could Be Quantum Boost for Computers

By KENNETH CHANG

Electronic devices like radios and computers work by shuttling around the electric charge of electrons. Hence, the "electron" in "electronics."



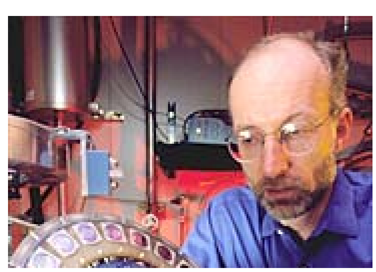
I.B.M.
The M-RAM chip, which may be on the market in a few years, could lead to computers that turn on instantly.

But besides their electric charge, electrons also have a less exploited property: "spin," an angular momentum that makes electrons act like tiny bar magnets. Researchers are beginning to tap into electrons' magnetic side as part of an emerging field known as spintronics.

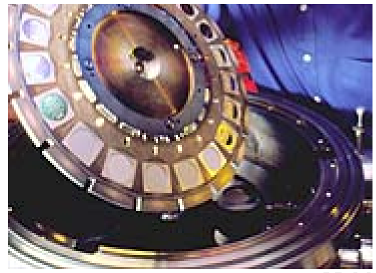
Already, spintronics has yielded a couple of uses and may eventually provide the underpinning for computers that employ quantum mechanical efforts to perform calculations.

"If you can manipulate the spin, it gives you another parameter to play with," said Dr. Mark Johnson, a research scientist at the Naval Research Laboratory in Washington.

At the Spintronics 2001 conference in Washington this month, one of the first devoted to the topic, scientists reviewed their achievements and the gaping challenges.



A couple of years ago, an early application of spintronics helped bulge the capacity of computer hard disks by making the part that reads data from the spinning platters much more sensitive to magnetic fields.



I.B.M.

Stuart Parkin, an I.B.M. researcher, works with a machine that creates magnetic tunnel junctions, the basic component of M-RAM.

"Everybody has a spintronics device on their desktop," said Dr. David D. Awschalom, director of the Center for Spintronics and Quantum Computation at the University of California at Santa Barbara.

On the horizon is M-RAM, or magneto resistive memory, which will remember data after the power is turned off, possibly eliminating the long boot-up time every time a computer is switched on. At least two commercial efforts — one by Motorola, the other by I.B.M. and Infineon of Munich — plan to begin production of M-RAM in 2004.

While improved hard disks and memory chips are useful, researchers in spintronics are still searching for something that will propel the field forward the way the transistor transformed electronics. "People have not come up with the killer application that will come onto the market tomorrow," said Dr. Sankar Das Sarma, a professor of physics at the University of Maryland.

Most researchers in the field have the same distant goal: using spintronics to build computers that take advantage of the bizarre all-possibilities-at-once nature of quantum mechanics to perform divergent calculations simultaneously.

Electrons can be thought of as tops that can spin clockwise or counterclockwise but always at one fixed speed, and the spinning generates an intrinsic magnetic field. Electron spins are in many ways ideal for representing 0's and 1's, the binary on-off language that computers use in their calculations. If the spin — the orientation of the electron's magnetic field — is pointing down, that can represent a 0. Flip the spin upward, and that represents a 1. Two spins can then be "entangled" with each other, so that neither is distinctly up or down, but a combination of the two possibilities, similar to the Schrödinger's Cat paradox in which a cat is simultaneously alive and dead.

And because the spins exist in both states at once, a spin-based quantum computer using the spins would, in theory, compute all possible answers in one pass. A conventional computer has to make each calculation separately, which can be much slower if there are many possibilities that need to be checked.

While quantum computers are probably decades away, recent experiments have begun to fill in some pieces of the puzzle, like how to line up the electrons' magnetic fields and how to flip them around at will.

In an article in the journal Science in June, researchers at Penn State and U.C. Santa Barbara led by Dr. Awschalom described how they tipped electrons by striking them with pulses of laser light of less than a trillionth of a second each.

"It's a proof of concept," Dr. Awschalom said. So far the pulses tip millions of electrons at a time. For a quantum computer, the electrons would have to be tipped one by one, a feat no one has yet accomplished.

In a second article, published in the journal Nature, also in June, the Penn State and U.C. Santa Barbara researchers showed that they were able to take electrons with lined-up spins in the semiconductor gallium arsenide and push them into an adjoining slab of zinc selenide, another semiconductor.

Notably, the electrons stayed lined up as they crossed over. One obstacle spintronics researchers have faced is that the tumult of passing from one material to another usually jumbles up the electron spins.

In an accompanying commentary in Nature, Dr. Michael L. Roukes, a professor of physics at the California Institute of Technology, said the gallium arsenide could act as a "spin battery," providing bursts of spin-aligned electrons as needed.

Another approach to creating a reservoir of spin-aligned electrons is embedding into a semiconductor cobalt or other magnetic atoms, which nudge the electron spins to one direction. Until recently, such magnetic semiconductors worked only at very low temperatures, but there are now reports of ones that remain magnetic up to 1,600 degrees Fahrenheit.

Even as they improve techniques for creating spin-aligned electrons, scientists are still looking for what to do with them. Dr. Johnson of the Naval Research Laboratory imagines reprogrammable computer chips where flipping a spin opens or closes a circuit. Instead of manufacturing a new chip, "you just go in and send it new instructions," he said.

Dr. Das Sarma of the University of Maryland suggests that M-RAM may eventually be used not just as computer memory, but as a replacement for hard disks. "In principle, you can do processing and storage in the same chip," he said. That would eliminate the lag time in retrieving data from the hard disk, a major bottleneck in current computers.

The basic concept of spintronics — adding a magnetic component to electronics — goes back decades. "There's nothing fundamentally new here," said Dr. Randall D. Isaac, vice president for science and technology research at I.B.M. "From the 60's and the 70's, people have tried to do this blend. What I find fascinating is to find the evolution of thought and techniques to get this closer and closer to a viable technology."

The first breakthrough was discovering a phenomenon known as giant magnetoresistance. In 1998, scientists in France found that by layering iron and chromium, they created a material whose electric resistance changed markedly when placed in a magnetic field.

The iron atoms also act as bar magnets, and the directions of the magnetic fields usually alternated from layer to layer.

When electric current flowed through the iron and chromium layers, the spins of the electrons continually bounced back and forth. That bouncing slowed the motion and increased the electrical resistance. When the material was placed in a magnetic field, the iron atoms all flipped to the same direction, and the electrons flowed through more smoothly.

That proved to be a sensitive detector of magnetic fields, like those used to store information on hard disks, and in 1997, I.B.M. introduced the first hard disk that took advantage of giant magnetoresistance. Before then, the capacity of hard disks had increased by about 60 percent a year. Since then, hard disk capacities have doubled every year, in large part because of the more sensitive read/write heads.

A structure known as a magnetic tunnel junction, first built by scientists at the Massachusetts Institute of Technology in 1995, forms the basic component of M-RAM. A junction consists of two magnetic layers separated by an insulator. The magnetic field of one magnetic layer always remains in one particular direction, the field in the other layer can be switched back and forth. When the fields oppose each other, little current flows across the junction, which represents a "0." When a field is switched in the one magnetic layer, resistance drops, representing a "1."

Because the atoms in the magnetic layers do not flip back and forth by themselves, the junction maintains its "0" or "1" state even when power is turned off. The speed of M-RAM should be reasonably fast, if not quite as fast as the fastest of current technologies, and it is expected to be low- power.

"All of us have in mind the holy grail of memory," said Dr. Isaac of I.B.M. "We've shown that magnetic memory works. The physics of it work. The devices work."

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