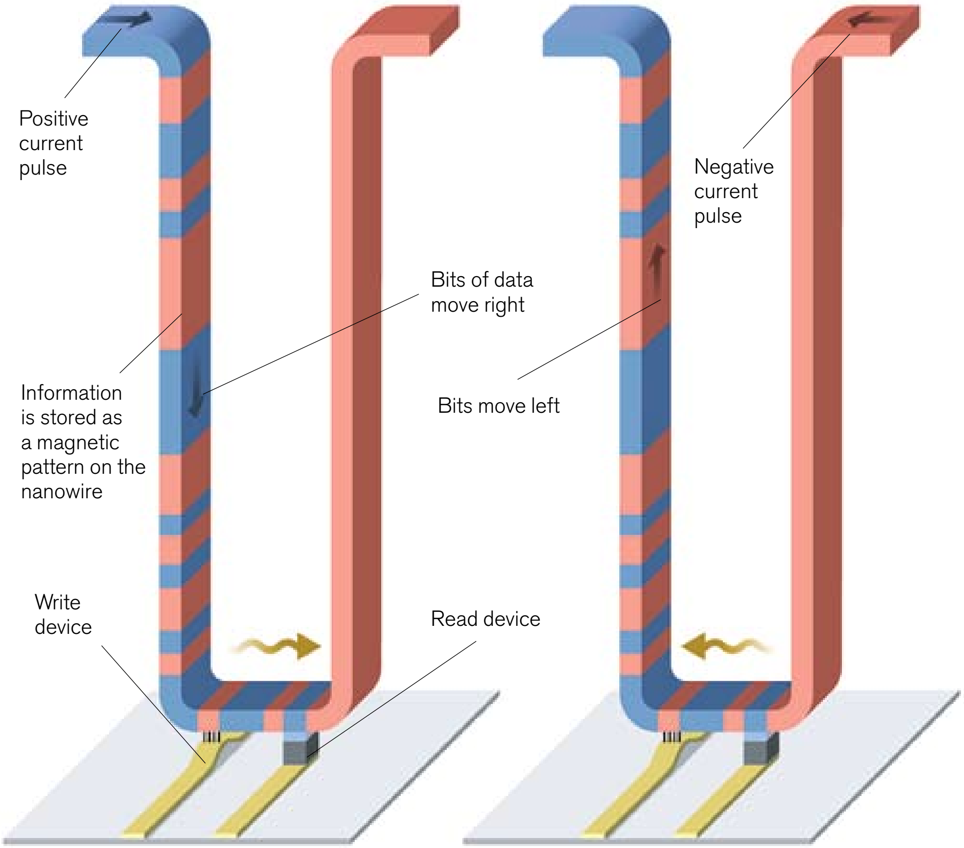
HARDWARE

Racetrack Memory

Stuart Parkin is using nanowires to create an ultradense, rugged memory chip.

When IBM sold its hard-drive business to Hitachi in April 2002, IBM fellow Stuart Parkin wondered what to do next. He had spent his career studying the fundamental physics of magnetic materials, making a series of discoveries that gave hard-disk drives thousands of times more storage capacity. So Parkin set out to develop an entirely new way to store information: a memory chip with the huge storage capacity of a magnetic hard drive, the durability of electronic flash memory, and speed superior to both. He dubbed the new technology "racetrack memory."



SPEEDING BITS In one implementation of racetrack memory, information is stored on a U-shaped nanowire as a pattern of magnetic regions with different polarities. Applying a spin-polarized current causes the magnetic pattern to speed along the nanowire; the data can be moved in either direction, depending on the direction of the current. A separate nanowire perpendicular to the U-shaped "racetrack" writes data by changing the polarity of the magnetic regions. A second device at the base of the track reads the data. Data can be written and read in less than a nanosecond. Racetrack memory using hundreds of millions of nanowires would have the potential to store vast amounts of data.

Both magnetic disk drives and existing solid-state memory technologies are essentially two-dimensional, Parkin says, relying on a single layer of either magnetic bits or transistors. "Both of these technologies have evolved over the last 50 years, but they've done it by scaling the devices smaller and smaller or developing new means of accessing bits," he says. Parkin sees both technologies reaching their size limits in the coming decades. "Our idea is totally different from any memory that's ever been made," he says, "because it's three-dimensional."

The key is an array of U-shaped magnetic nanowires, arranged vertically like trees in a forest. The nanowires have regions with different magnetic polarities, and the boundaries between the regions represent 1s or 0s, depending on the polarities of the regions on either side. When a spin-polarized current (one in which the electrons' quantum-mechanical "spin" is oriented in a specific direction) passes through the nanowire, the whole magnetic pattern is effectively pushed along, like cars speeding down a racetrack. At the base of the U, the magnetic boundaries encounter a pair of tiny devices that read and write the data *(see "Speeding Bits," above)*.

This simple design has the potential to combine the best qualities of other memory technologies while avoiding their drawbacks. Because racetrack memory stores data in vertical nanowires, it can theoretically pack 100 times as much data into the same area as a flash-chip transistor, and at the same cost. There are no mechanical parts, so it could prove more reliable than a hard drive. Racetrack memory is fast, like the dynamic random-access memory (DRAM) used to hold frequently accessed data in computers, yet it can store information even when the power is off. This is because no atoms are moved in the process of reading and writing data, eliminating wear on the wire.

Just as flash memory ushered in ultrasmall devices that can hold thousands of songs, pictures, and other types of data, racetrack promises to lead to whole new categories of electronics. "An even denser, smaller memory could make computers more compact and more

ARTHUR MOUNT; SOURCE: IBM

energy efficient," Parkin says. Moreover, chips with huge data capacity could be shrunk to the size of a speck of dust and sprinkled about the environment in tiny sensors or implanted in patients to log vital signs.

When Parkin first proposed racetrack memory, in 2003, "people thought it was a great idea that would never work," he says. Before last April, no one had been able to shift the magnetic domains along the wire without disturbing their orientations. However, in a paper published that month in *Science*, Parkin's team showed that a spin-polarized current would preserve the original magnetic pattern.

The *Science* paper proved that the concept of racetrack memory is sound, although at the time, the researchers had moved only three bits of data down a nanowire. Last December, Parkin's team successfully moved six bits along the wire. He hopes to reach 10 bits soon, which he says would make racetrack memory competitive with flash storage. If his team can manage 100 bits, racetrack could replace hard drives.

Parkin has already found that the trick to increasing the number of bits a wire can handle is to precisely control its diameter: the narrower and more uniform the wire, the more bits it can hold. Another challenge will be to find the best material for the job: it needs to be one that can survive the manufacturing process and one that allows the magnetic domains to move quickly along the wire, with the least amount of electrical current possible.

If the design proves successful, racetrack memory could replace all other forms of memory, and Parkin will bolster his status as a magnetic-memory genius. After all, his work on giant magnetoresistance, which led to today's high-capacity hard drives, transformed the computing industry. With racetrack memory, Parkin could revamp computing once more.

—Kate Greene

BIOTECH

$100 Genome

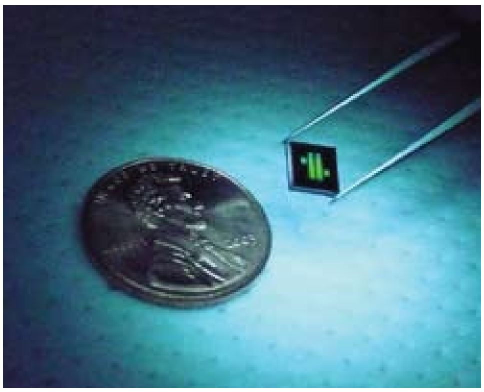
Han Cao has designed a nanofluidic chip that could lower DNA sequencing costs dramatically.

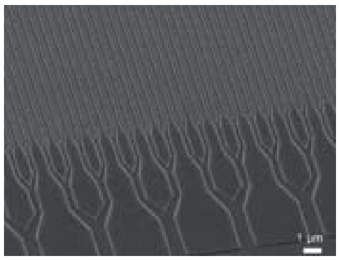
In the corner of the small lab is a locked door with a colorful sign taped to the front: "$100 Genome Room—Authorized Persons Only." BioNanomatrix, the startup that runs the lab, is pursuing what many believe to be the key to personalized medicine: sequencing technology so fast and cheap that an entire human genome can be read in eight hours for $100 or less. With the aid of such a powerful tool, medical treatment could be tailored to a patient's distinct genetic profile.

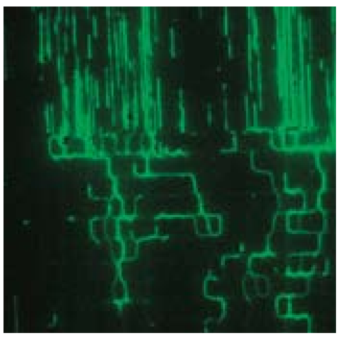
Despite many experts' doubt that whole-genome sequencing could be done for $1,000, let alone a 10th that much, BioNanomatrix believes it can reach the $100 target in five years. The reason for its optimism: company founder Han Cao has created a chip that uses nanofluidics and a series of branching, ever-narrowing channels to allow researchers, for the first time, to isolate and image very long strands of individual DNA molecules.

If the company succeeds, a physician could biopsy a cancer patient's tumor, sequence all its DNA, and use that information to determine a prognosis and prescribe treatment—all for less than the cost of a chest x-ray. If the ailment is lung cancer, for instance, the doctor could determine the particular genetic changes in the tumor cells and order the chemotherapy best suited to that variant.

Cao's chip, which neatly aligns DNA, is essential to cheaper sequencing because double-stranded







NANOSCALE SORTING A tiny nanofluidic chip (above) is the key to BioNanomatrix's effort to sequence a human genome for just $100. Thousands of branching channels just nanometers wide (top right) untangle very long DNA strands; bright fluorescent labels allow researchers to easily visualize these molecules (bottom right).

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