

Researchers demonstrate record-setting p-type transistor

EurekaAlert!

New design for a basic component of all computer chips boasts the highest 'carrier mobility' yet measured

CAMBRIDGE, MA -- Almost all computer chips use two types of transistors: one called p-type, for positive, and one called n-type, for negative. Improving the performance of the chip as a whole requires parallel improvements in both types.

At the IEEE's International Electron Devices Meeting (IEDM) in December, researchers from MIT's Microsystems Technology Laboratories (MTL) presented a p-type transistor with the highest "carrier mobility" yet measured. By that standard, the device is twice as fast as previous experimental p-type transistors and almost four times as fast as the best commercial p-type transistors.

Like other experimental high-performance transistors, the new device derives its speed from its use of a material other than silicon: in this case, germanium. Alloys of germanium are already found in commercial chips, so germanium transistors could be easier to integrate into existing chip-manufacturing processes than transistors made from more exotic materials.

The new transistor also features what's called a trigate design, which could solve some of the problems that plague computer circuits at extremely small sizes (and which Intel has already introduced in its most advanced chip lines). For all these reasons, the new device offers a tantalizing path forward for the microchip industry — one that could help sustain the rapid increases in computing power, known as Moore's Law, that consumers have come to expect.

Pluses and minuses

A transistor is basically a switch: In one position, it allows charged particles to flow through it; in the other position, it doesn't. In an n-type transistor, the particles — or charge carriers — are electrons, and their flow produces an ordinary electrical current.

In a p-type transistor, on the other hand, the charge carriers are positively charged "holes." A p-type semiconductor doesn't have enough electrons to balance out the positive charges of its atoms; as electrons hop back and forth between atoms, trying futilely to keep them electrically balanced, holes flow through the semiconductor, in much the way waves propagate across water molecules that locally move back and forth by very small distances.

"Carrier mobility" measures how quickly charge carriers — whether positive or

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Published on Electronic Component News (<http://www.ecnmag.com>)

negative — move in the presence of an electric field. Increased mobility can translate into either faster transistor switching speeds, at a fixed voltage, or lower voltage for the same switching speed.

For decades, each logic element in a computer chip has consisted of complementary n-type and p-type transistors whose clever arrangement drastically reduces the chip's power consumption. In general, it's easier to improve carrier mobility in n-type transistors; the MTL researchers' new device demonstrates that p-type transistors should be able to keep up.

Handling the strain

Judy Hoyt, a professor of electrical engineering and computer science; her graduate students Winston Chern, lead author on the new paper, and James T. Teherani; Pouya Hashemi, who was an MIT postdoc at the time and is now with IBM; Dimitri Antoniadis, the Ray and Maria Stata Professor of Electrical Engineering; and colleagues at MIT and the University of British Columbia achieved their record-setting hole mobility by "straining" the germanium in their transistor — forcing its atoms closer together than they'd ordinarily find comfortable. To do that, they grew the germanium on top of several different layers of silicon and a silicon-germanium composite. The germanium atoms naturally try to line up with the atoms of the layers beneath them, which compresses them together.

"It's kind of a unique set of material structures that we had to do, and that was actually fabricated here, in the MTL," Hoyt says. "That's what enables us to explore these materials at the limits. You can't buy them at this point."

"These high-strain layers want to break," Teherani adds. "We're particularly successful at growing these high-strain layers and keeping them strained without defects." Indeed, Hoyt is one of the pioneers of strained-silicon transistors, a technology found today in almost all commercial computer chips. At last year's IEDM, she and Eugene Fitzgerald, the Flemings-SMA Professor of Materials Science and Engineering at MIT, received the IEEE's Andrew S. Grove Award for outstanding contributions to solid-state devices and technology. The award announcement cited Hoyt's "groundbreaking contributions involving strained-silicon semiconductor materials."

Gatekeeping

Another crucial aspect of the new transistor is its trigate design. If a transistor is a switch, throwing the switch means applying a charge to the transistor's "gate." In a conventional transistor, the gate sits on top of the "channel," through which the charge carriers flow. As transistors have grown smaller, their gates have shrunk, too. But at smaller sizes, that type of lockstep miniaturization won't work: Gates will become too small to reliably switch transistors off.

In the trigate design, the channels rise above the surface of the chip, like boxcars sitting in a train yard. To increase its surface area, the gate is wrapped around the channel's three exposed sides — hence the term "trigate." By demonstrating that

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they can achieve high hole mobility in trigate transistors, Hoyt and her team have also shown that their approach will remain useful in the chips of the future.

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