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## Technique Turns Computer Chip Defects Into an Advantage

***Physicists at Ohio State University have discovered that tiny defects inside a computer chip can be used to tune the properties of key atoms in the chip.***

The technique, which they describe in the journal *Science*, involves rearranging the holes left by missing atoms to tune the properties of dopants -- the chemical impurities that give the semiconductors in computer chips their special properties.

Though the technique is currently limited to the laboratory, it could prove valuable to industry in the future, as the continued miniaturization of cell phone and computer chips makes the performance of individual atoms in a semiconductor more important.

"The effect we discovered is probably already going on inside the devices we use every day -- it's just not being controlled," said Jay Gupta, Assistant Professor of Physics at Ohio State and Principal Investigator on the project. "Once industry takes this effect into account, our discovery could not only enable future computers with faster speeds, but could also enable new paradigms for computing -- based, for example, on quantum mechanics."

The initial discovery happened in the summer of 2008 as then-graduate student Donghun Lee was carefully measuring how the properties of dopant atoms depended on the arrangement of other nearby atoms. Lee and Gupta were peering at the common chip material gallium arsenide using a Scanning Tunneling Microscope (STM), a type of electron microscope that can image surfaces with atomic resolution and position single atoms using a strong electric field.

Researchers commonly nudge atoms with an STM's electric field to rearrange them. In the case of these chip materials, the rearrangement process was like playing a sliding tile puzzle, Gupta explained; they rearranged the vacancies -- empty holes, considered defects -- in the material.

For example, they found that an arsenic vacancy on the surface of the material -- like the missing tile in a puzzle -- could be effectively moved by nudging an arsenic atom into a different nearby hole, thus resulting in a new hole where the arsenic atom used to be.

The hole left by the arsenic atom has its own electric field, and the researchers studied the influence of this field on nearby dopants -- in this case, manganese atoms. They noticed that the dopant's energy level dropped when the hole was moved nearby, and increased when it was moved away.

Dopants are important in semiconductor devices such as computer chips because they enable very sensitive control over the current flow, depending on temperature and applied voltage. The dopant's energy is the key parameter that determines this ability.

Following the initial discovery, Gupta says it took over a year of additional experiments to understand the effect.

He explained the gist: "A dopant's ability to donate an electron or take it away depends on its binding energy, and by creating a vacancy near the manganese, we were tuning its binding energy. You could say we made the manganese act like a different atom, even though it was physically the same."

While chip makers aren't likely to employ STMs in their production lines anytime soon, Gupta believes that they could take advantage of the discovery in a practical way -- by manipulating tiny electric fields across the metal electrodes that already exist on top of chips.

Manufacturers may be interested in this technique for not only improving current chip technologies in the short term, but also for developing new chip designs in the long term.

Today, a single chip may contain only a few dozen dopant atoms that are critical to its performance. As chips get smaller, the performance of every atom will count even more, and techniques such as Gupta's that can control individual dopant atoms could become very important.

In the future, a computer's logic controls and memory could both be integrated on a single chip, if semiconductor materials could be made magnetic at room temperature and above; those technologies are still under development. Computers powered by such chips would theoretically use less power, and never need rebooting.

Manganese-doped gallium arsenide is a prototypical magnetic semiconductor, which is why Gupta and Lee are now exploring how they might control the magnetic interaction between two or more manganese atoms using their discovery.

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