'Valleytronics' advancement could help extend Moore's Law

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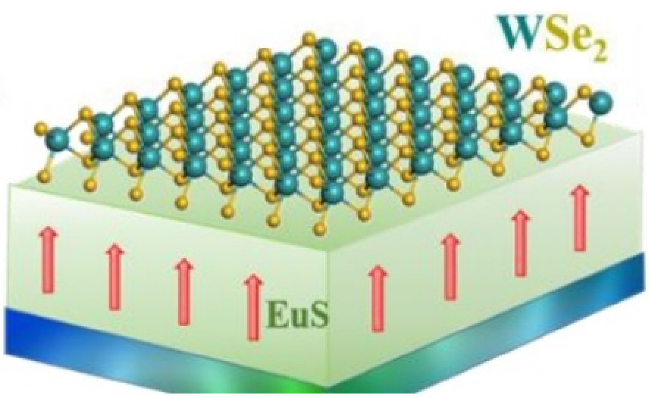

A two-layered heterostructure, with a 10 nanometer thick film of magnetic EuS (europium sulfide) on the bottom and a single layer (less than 1 nanometer) of the transition metal dichalcogenide WSe2 (tungsten diselenide) on top. The magnetic field of the bottom layer forced the energy separation of the valleys in the WSe2. Credit: *Nature Nanotechnology*.

In the world of semiconductor physics, the goal is to devise more efficient and microscopic ways to control and keep track of 0 and 1, the binary codes that all information storage and logic functions in computers are based on.

A new field of physics seeking such advancements is called valleytronics, which exploits the electron's "valley degree of freedom" for data storage and logic applications. Simply put, valleys are maxima and minima of electron energies in a crystalline solid. A method to control electrons in different valleys could yield new, super-efficient computer chips.

A University at Buffalo team, led by Hao Zeng, PhD, professor in the Department of Physics, worked with scientists around the world to discover a new way to split the energy levels between the valleys in a two-dimensional semiconductor.

The work is described in a study published online today (May 1, 2017) in the journal *Nature Nanotechnology*.

The key to Zeng's discovery is the use of a ferromagnetic compound to pull the valleys apart and keep them at different energy levels. This leads to an increase in the separation of valley energies by a factor of 10 more than the one obtained by applying an external magnetic field.

"Normally there are two valleys in these atomically thin semiconductors with exactly the same energy. These are called 'degenerate energy levels' in quantum mechanics terms. This limits our ability to control individual valleys. An external magnetic field can be used to break this degeneracy. However, the splitting is so small that you would have to go to the National High Magnetic Field Laboratories to measure a sizable energy difference. Our new approach makes the valleys more accessible and easier to control, and this could allow valleys to be useful for future information storage and processing," Zeng said.

The simplest way to understand how valleys could be used in processing data may be to think of two valleys side by side. When one valley is occupied by electrons, the switch is "on." When the other valley is occupied, the switch is "off." Zeng's work shows that the valleys can be positioned in such a way that a device can be turned "on" and "off," with a tiny amount of electricity.

Microscopic ingredients

Zeng and his colleagues created a two-layered heterostructure, with a 10 nanometer thick film of magnetic EuS (europium sulfide) on the bottom and a single layer (less than 1 nanometer) of the transition metal dichalcogenide WSe2 (tungsten diselenide) on top. The magnetic field of the bottom layer forced the energy separation of the valleys in the WSe2.

Previous attempts to separate the valleys involved the application of very large magnetic fields from outside. Zeng's experiment is believed to be the first time a ferromagnetic material has been used in conjunction with an atomically thin semiconductor material to split its valley energy levels.

"As long as we have the magnetic material there, the valleys will stay apart," he said. "This makes it valuable for nonvolatile memory applications."

Athos Petrou, a UB Distinguished Professor in the Department of Physics, measured the energy difference between the separated valleys by bouncing light off the material and measuring the energy of reflected light.

"We typically get this type of results only once every five or 10 years," Petrou said.

Extending Moore's law

The experiment was conducted at 7 degrees Kelvin (-447 Fahrenheit), so any everyday use of the process is far in the future. However, proving it possible is a first step.

"The reason people are really excited about this, is that Moore's law [which says the number of transistors in an integrated circuit doubles every two years] is predicted to end soon. It no longer works because it has hit its fundamental limit," Zeng said.

"Current computer chips rely on the movement of electrical charges, and that generates an enormous amount of heat as computers get more powerful. Our work has really pushed valleytronics a step closer in getting over that challenge."

More information: Enhanced valley splitting in monolayer WSe2 due to magnetic exchange field, *Nature Nanotechnology* (2017). nature.com/articles/doi:10.1038/nnano.2017.68

Provided by University at Buffalo