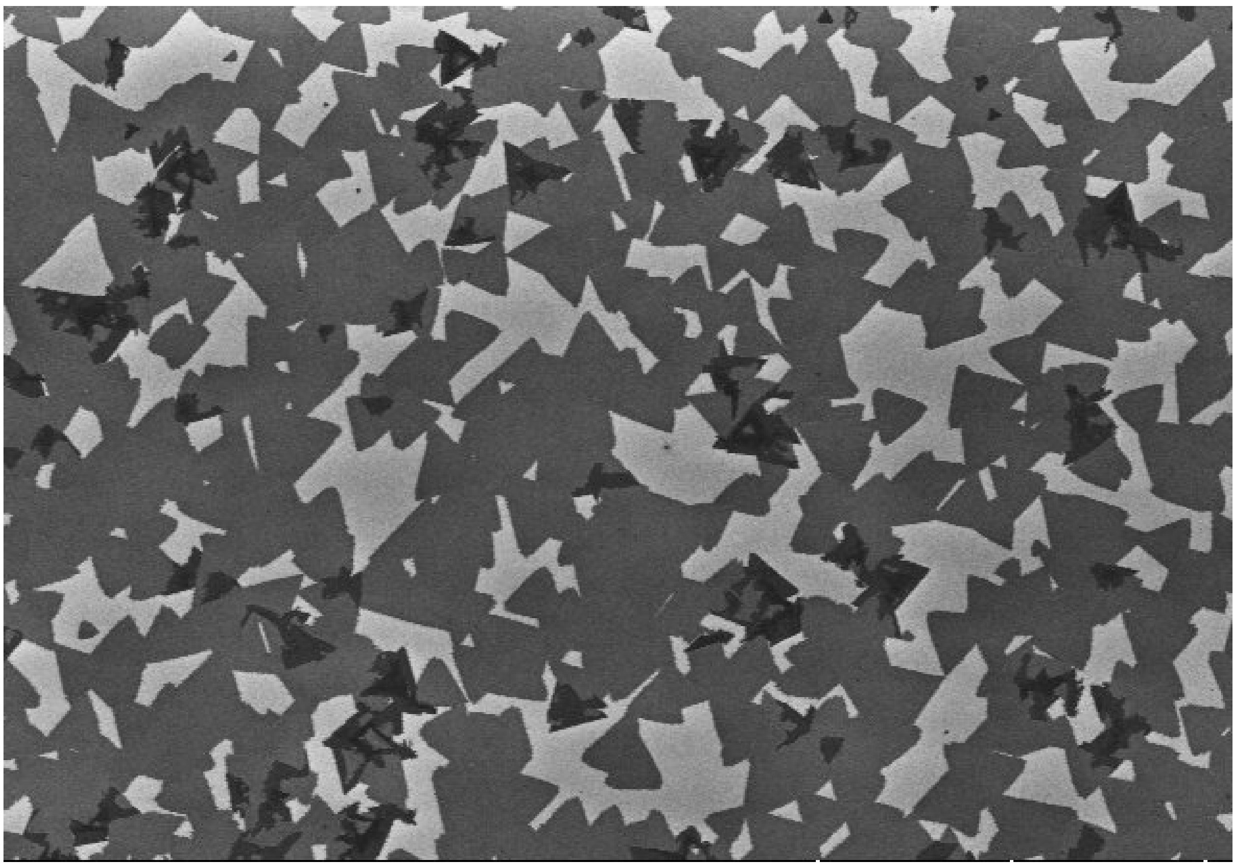
# 'Valley states' in this super-thin material could potentially be used for quantum computing

September 23 2019, by Charlotte Hsu



A scanning electron microscope image shows tungsten disulfide grown on a sapphire substrate (light area). The medium gray area shows monolayer tungsten disulfide and the dark area shows multilayer tungsten disulfide. After growing the tungsten disulfide on the sapphire, researchers transfer it onto europium sulfide. Credit: Chuan Zhao / University at Buffalo

New research on two-dimensional tungsten disulfide ($WS_2$) could open the door to advances in quantum computing.

In a paper published Sept. 13 in *Nature Communications*, scientists report that they can manipulate the electronic properties of this super-thin material in ways that could be useful for encoding quantum data.

The study deals with $WS_2$'s energy valleys, which University at Buffalo physicist Hao Zeng, co-lead author of the paper, describes as "the local energy extrema of the electronic structure in a crystalline solid."

Valleys correspond with specific energies that electrons can have in a material, and the presence of an electron in one valley versus another can be used to encode information. An electron in one valley can represent a 1 in binary code, while an electron in the other can represent a 0.

The ability to control where electrons might be found could yield advances in quantum computing, enabling the creation of qubits, the basic unit of quantum information. Qubits have the mysterious quality of being able to exist not just in a state of 1 or 0, but in a "superposition" related to both states.

The paper in Nature Communications marks a step toward these future technologies, demonstrating a novel method of manipulating valley states in $WS_2$.

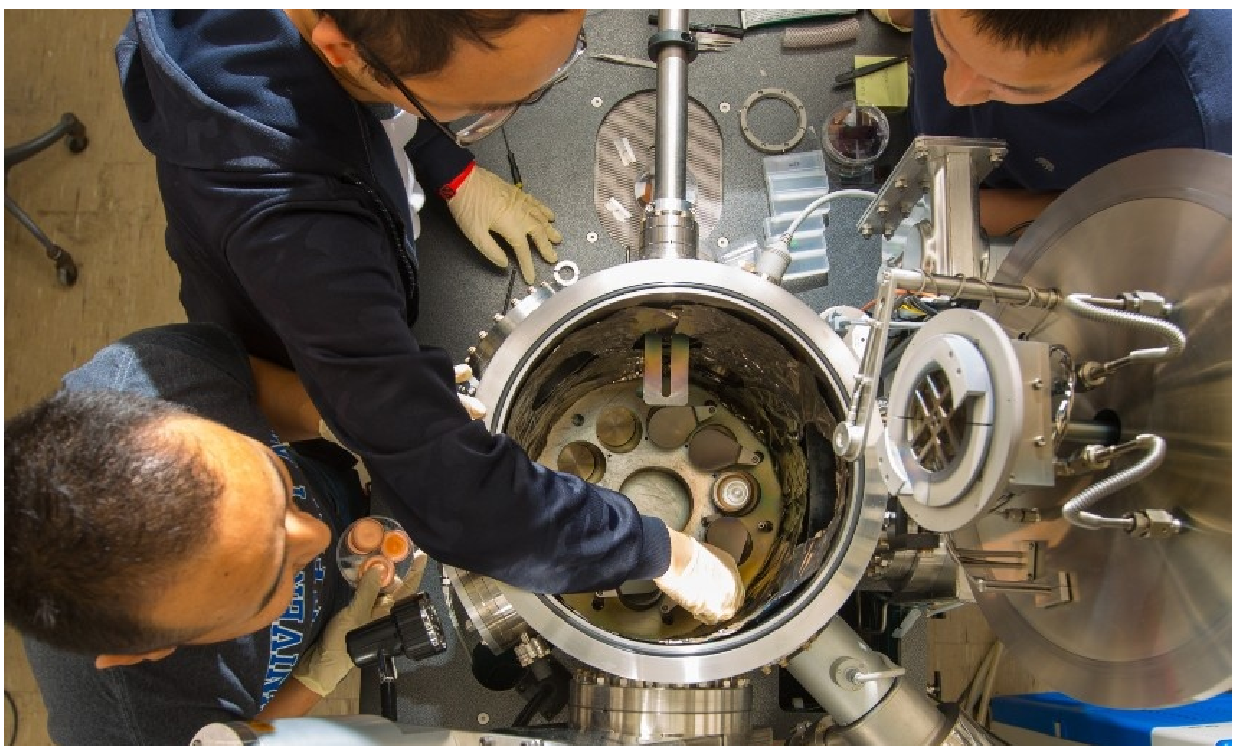
Zeng, Ph.D., professor of physics in the UB College of Arts and Sciences, led the project with Athos Petrou, Ph.D., UB Distinguished Professor of Physics, and Renat Sabirianov, Ph.D., chair of physics at the University of Nebraska Omaha. Additional co-authors included UB physics graduate students Tenzin Norden, Chuan Zhao and Peiyao

Zhang. The research was funded by the National Science Foundation.

## Shifting tungsten disulfide's energy valleys

Two-dimensional tungsten disulfide is a single layer of the material that's three atoms thick. In this configuration, $WS_2$ has two energy valleys, both with the same energy.

Past research has shown that applying a magnetic field can shift the energy of the valleys in opposite directions, lowering the energy of one valley to make it "deeper" and more attractive to electrons, while raising the energy of the other valley to make it "shallower," Zeng says.



UB researchers work with a dual chamber thin film deposition system that can be used to synthesize thin film materials. In the new study, this machine was used to create europium sulfide films and tungsten trioxide, a precursor for 2D tungsten disulfide. Credit: Douglas Levere / University at Buffalo

"We show that the shift in the energy of the two valleys can be enlarged by two orders of magnitude if we place a thin layer of magnetic europium sulfide under the tungsten disulfide," Zeng says. "When we then apply a magnetic field of 1 Tesla, we are able to achieve an enormous shift in the energy of the valleys—equivalent to what we might hope to achieve by applying a magnetic field of about a hundred Tesla if the europium sulfide were not present."

"The size of the effect was very large—it was like using a magnetic field amplifier," Petrou says. "It was so surprising that we had to check it several times to make sure we didn't make mistakes."

The end result? The ability to manipulate and detect electrons in the valleys is greatly enhanced, qualities that could facilitate the control of qubits for quantum computing.

## Valley states as qubits for quantum computing

Like other forms of quantum computing, valley-based quantum computing would rely on the quirky qualities of subatomic particles—in this case electrons—to perform powerful calculations.

Electrons behave in ways that may seem odd—they can be in multiple places at once, for instance. As a result, 1 and 0 are not the only possible states in systems that use electrons in valleys as qubits. A qubit can also be in any superposition of these states, allowing quantum computers to explore many possibilities simultaneously, Zeng says.

"This is why quantum computing is so powerful for certain special tasks," Zeng says. "Due to the probabilistic and random nature of quantum computing, it is particularly suitable for applications such as artificial intelligence, cryptography, financial modeling and quantum mechanical simulations for designing better materials. However, a lot of obstacles need to be overcome, and we are likely many years away if scalable universal quantum computing ever becomes a reality."

The new study builds on Zeng and Petrou's prior work, in which they used europium sulfide and magnetic fields to alter the energy of two valleys in another 2-D material: tungsten diselenide ($WSe_2$).

Though $WS_2$ and $WSe_2$ are similar, they responded differently to the "valley splitting" exercise. In $WS_2$, the valley that got "deeper" was analogous to the valley in $WSe_2$ that became "shallower," and vice versa, creating opportunities to explore how this distinction could provide flexibility in applications of the technology.

One characteristic that both materials share could benefit quantum computing: In both $WS_2$ and $WSe_2$, electrons populating the two energy valleys have opposite spins, a form of angular momentum. While this trait is not necessary for creating a qubit, it "provides certain protection of the quantum states, making them more robust," Zeng says.

**More information:** Tenzin Norden et al. Giant valley splitting in monolayer WS2 by magnetic proximity effect, *Nature Communications* (2019). DOI: 10.1038/s41467-019-11966-4

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