Scientists create single device capable of dual transistor operation

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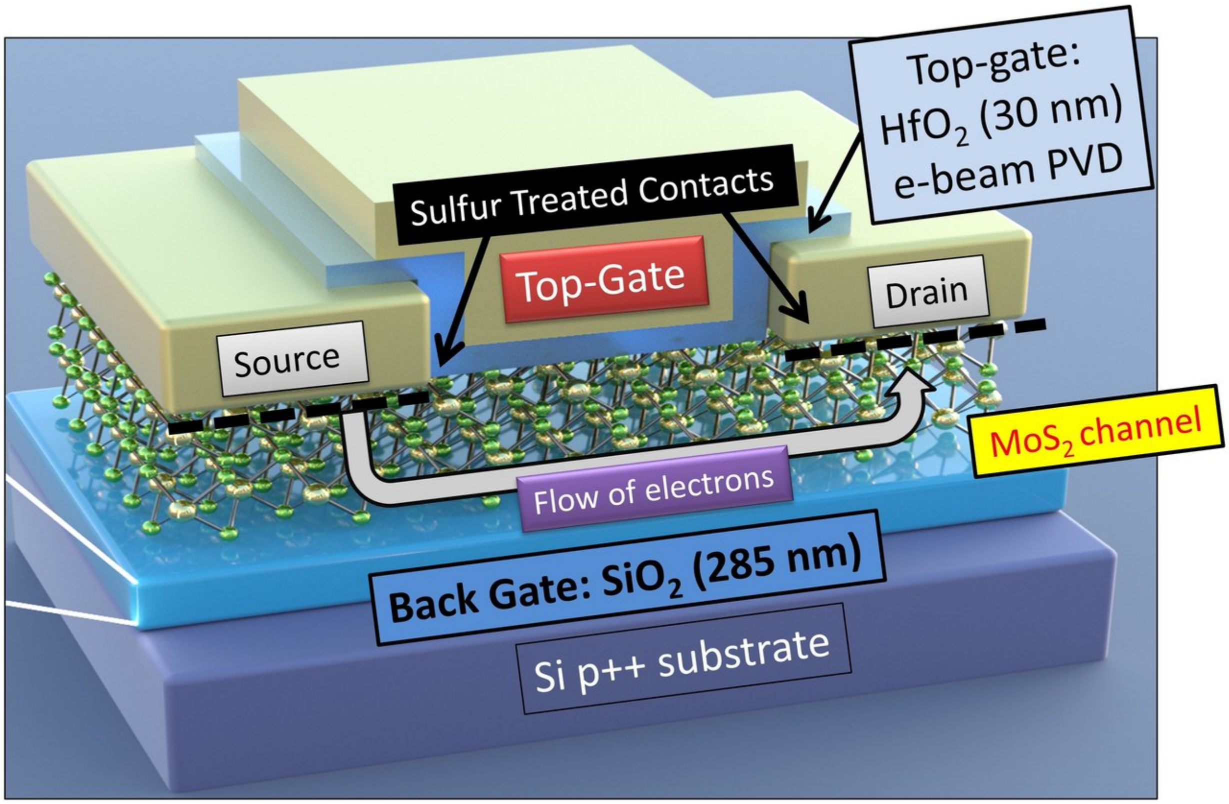

Credit: Bhattacharjee et al.

Transistors, the building blocks of modern devices, act like electronic switches controlling the flow of current across circuits. In the last few decades, they have shrunk more than 1000 times in size, making devices such as laptops and smartphones faster and more compact.

As they grow smaller, however, they are also consuming and wasting more power. The most common type of transistors called MOSFETs cannot abruptly switch from on to off, and therefore leak current even after the device is turned off—the smaller they are, the more power they waste. Recent alternatives called tunnel FETs are expected to waste much less power but are more suited for low-performance devices such as watches or notebook computers.

For the first time, scientists at the Indian Institute of Science (IISc) have combined these two different types of transistors into a single device that can easily switch between power-efficient and high performance modes, depending on the need. The device has a special type of metal-semiconductor junction which can be tweaked to make it behave either like a MOSFET or a tunnel FET.

"You have flexibility," says Shubhadeep Bhattacharjee, Ph.D. student at the Centre for Nano Science and Engineering, IISc and first author of the paper published in *Applied Physics Letters*. "Using the same device, you can have either high performance which compromises on power, or an optimal performance, low-power operation. Think of it as using the same car as either a Tata Nano or a Mercedes Benz."

The first transistors were palm-sized, but today they are several thousand times smaller than the width of a human hair. "The good thing about this miniaturization is that we are now able to cram more functions within a small area," says senior author Navakanta Bhat, Chair, Centre for Nano Science and Engineering, IISc. Which is why smartphones are able to do more today than what many earlier computers were capable of.

Transistors such as conventional MOSFETs, used in almost all electronics gadgets today, typically work like floodgates in a dam. They have a source, a drain, and a gate that controls the flow of electrons between the two. When the gate is in the OFF position, there is a large energy barrier between the source and the drain which prevents electrons from crossing over. When a voltage is applied, the gate is turned on, the height of the barrier is reduced, and electrons are able to jump over it. The smaller the supply voltage needed to turn the transistor on, the more efficient the device.

However, scientists have been unable to bring down the supply voltage for MOSFETs proportionately with transistor size, because of a fundamental design flaw. A factor called subthreshold swing—which determines the minimum gate voltage required for the transistor to switch from on to off—restricts the supply voltage to a certain lower limit of about 1 volt. This means that the maximum efficiency that MOSFETs can achieve will be severely limited, no matter what size they are. "This is a fundamental limitation imposed by physics, since the number of electrons capable of jumping the barrier is governed by Boltzmann statistics," says Bhat.

To overcome this limitation, scientists have tried using transistors called tunnel FETs, where, instead of the *height*, the *width* of the electron barrier is reduced to a point where electrons are able to "tunnel" through the barrier instead of jumping over it. Tunnel FETs can operate at lower supply voltages and are much more efficient. But they also have a disadvantage: the desired output—the current flowing when the transistor is on—is greatly reduced.

In this study, for the first time, the researchers designed a hybrid device capable of switching between MOSFET and tunnel FET modes by using two gates instead of one, and a special type of electron barrier called Schottky junction. The Schottky barrier is created when a metal and semiconductor are joined under certain conditions. The researchers used specific design processes to create a Schottky junction where the height and width of the barrier can be adjusted independently. Sulphur treatment was used to enable this contact engineering. In addition, the gate material was deposited using e-beam evaporation, instead of the conventional atomic layer deposition method.

The dual-gated device was able to operate at a voltage lower than possible with conventional MOSFETs, greatly reducing power consumption. This would enable reduction of operating voltage to less than half a volt. It also showed superior performance compared to current state-of-the-art tunnel FETs.

The new composite design offers much more flexibility in transistor function than previously possible, and may improve the efficiency of electronic devices significantly, the authors say.

More information: A sub-thermionic MoS2 FET with tunable transport, published in *Applied Physics Letters*, October 2017 (Featured among Editor's picks). aip.scitation.org/doi/full/10.1063/1.4996953

Provided by Indian Institute of Science

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