Manipulating interlayer magnetic coupling in van der Waals heterostructures

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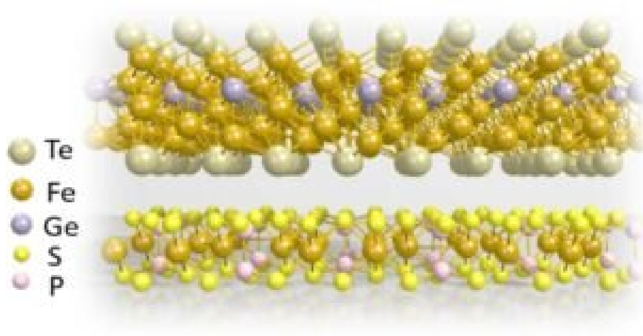


A heterostructure constructed with antiferromagnetic lower layer ($FePS^3$) and ferromagnetic upper layer (Fe_5GeTe_2). Credit: *Nano Letters*

An RMIT-led international collaboration has observed, for the first time, electric gate-controlled exchange-bias effect in van der Waals (vdW) heterostructures, offering a promising platform for future energy-efficient, beyond-CMOS electronics.

The exchange-bias (EB) effect, which originates from interlayer magnetic coupling, has played a significant role in fundamental magnetics and spintronics since its discovery.

Although manipulating the EB effect by an electronic gate has been a significant goal in spintronics, until now, only very limited electrically-tunable EB effects have been demonstrated.

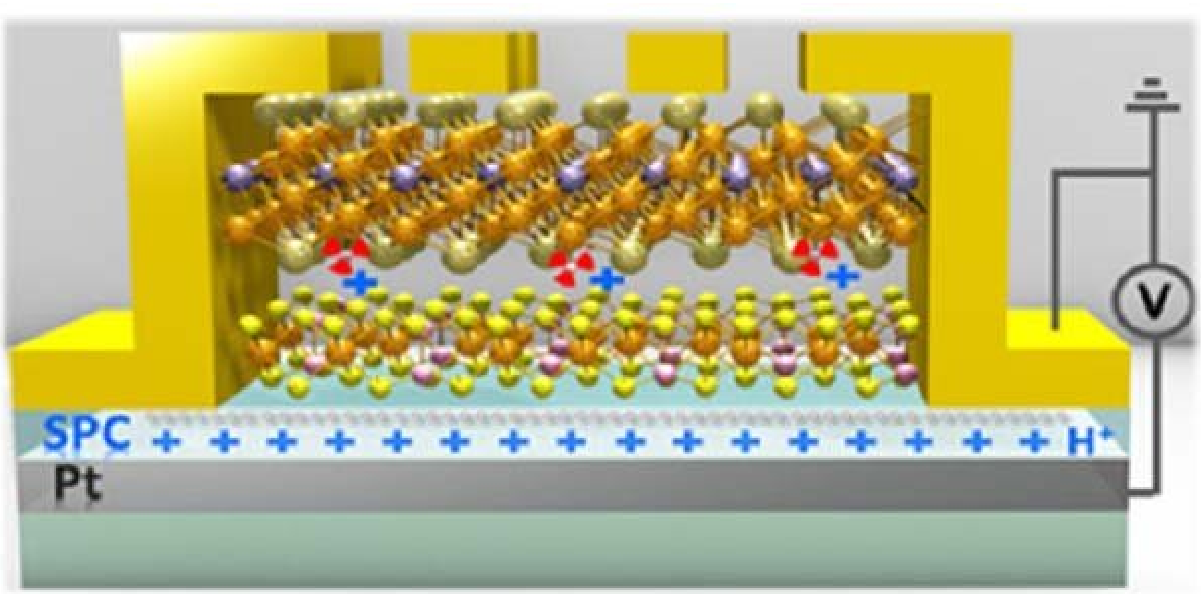
Electrical gate-manipulated EB effects in AFM-FM structures enable scalable energy-efficient spin-orbit logic, which is very promising for beyond-COMS devices in future low-energy electronic technologies.

The "blocking" temperature of the EB effect can be effectively tuned via an electric gate, which would allow the EB field to be turned "ON" and "OFF" as well in future spintronic transistors.

The FLEET-led collaboration of researchers at RMIT University (Australia) and South China University of Technology (China) confirm for the first time the electric control of EB effect in a vdW heterostructure.

Realization of exchange bias effects in AFM-FM heterostructures

The emergence of vdW magnetic materials boosts the development of vdW magnetic and spintronic devices and provides an ideal platform for exploring intrinsically interfacial magnetic coupling mechanisms.



The device: a solid-proton field-effect transistor (SP-FET) mounts the AFM-FM heterostructure within electric contact (gold), mounted on a solid protonic conductor (SPC) and gate electrode (Pt). Credit: *Nano Letters*

Manipulating the EB effect, which originates from the AFM–FM interface coupling induced unidirectional anisotropy, by an electronic gate is a significant goal in spintronics. To date, very limited electrically tunable EB effects have been experimentally demonstrated in some oxide multiferroic thin film systems. Although vdW magnetic heterostructures have provided improved platforms to investigate EB effects, these heterostructures have not exhibited electrical gate-controlled EB effects yet.

"We had obtained much experience in vdW heterostructure-based nano-devices and we decided it was time for us to utilize some methods, such as electric gates, to control magnetic properties in FM/AFM bilayers," says the study's first author, FLEET Research Fellow Dr. Sultan Albarakati (RMIT).

"Moreover, we are familiar with proton intercalation, which is an effective tool for modulating materials' charge density."

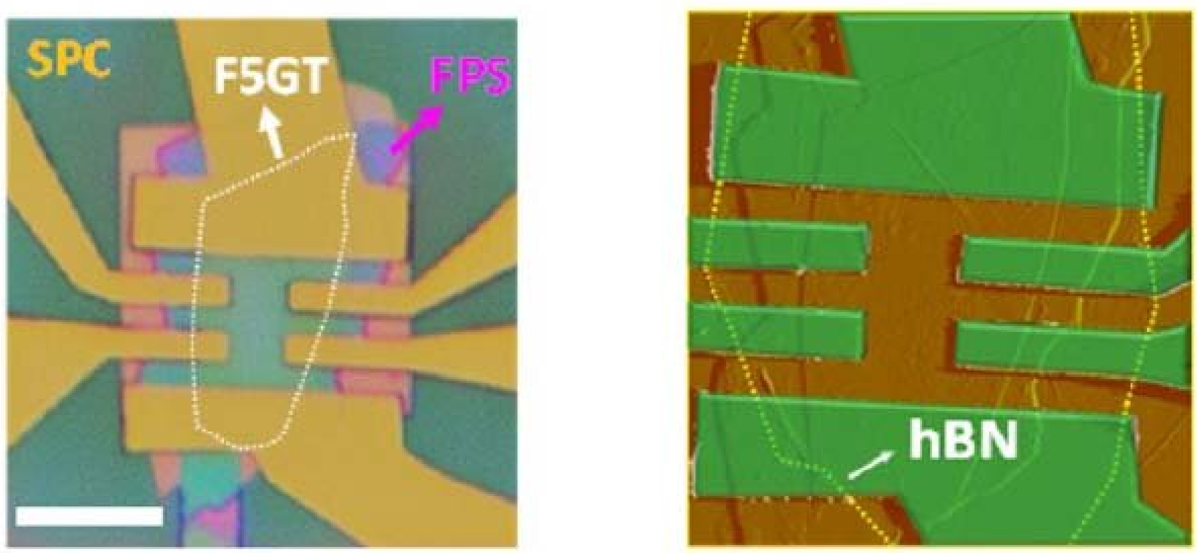
The team designed a nano-device structure with a tri-layer of FM/AFM/solid proton conductor, and chose a vdW material with higher Neel temperature, $FePS_3$, to serve as the AFM layer.

"The choice of FM layer was a bit tricky," says co-author Dr. Cheng Tan (RMIT).

"Based on our previous results, the EB effect could occur in proton-intercalated Fe_3GeTe_2, while in Fe_5GeTe_2 (F5GT) of various thicknesses, the proton intercalation cannot result in any EB effects. Hence, we choose F5GT as the FM layer," says Cheng.

Thus the resulting heterostructure comprised:

- Antiferromagnetic (AFM) layer $FePS_3$ (FPS)
- Ferromagnetic (FM) layer Fe_5GeTe_2 (F5GT)



Imaging the device via optical microscope (left) and atomic force microscope (right). Credit: *Nano Letters*

Generally, the EB effect is regarded as an interface effect and would be expected to diminish if the thickness of the FM layer is increased. While the thinner F5GT nano-flakes (