Electrically controlled exchange-bias effect discovered in magnetic van der Waals heterostructures

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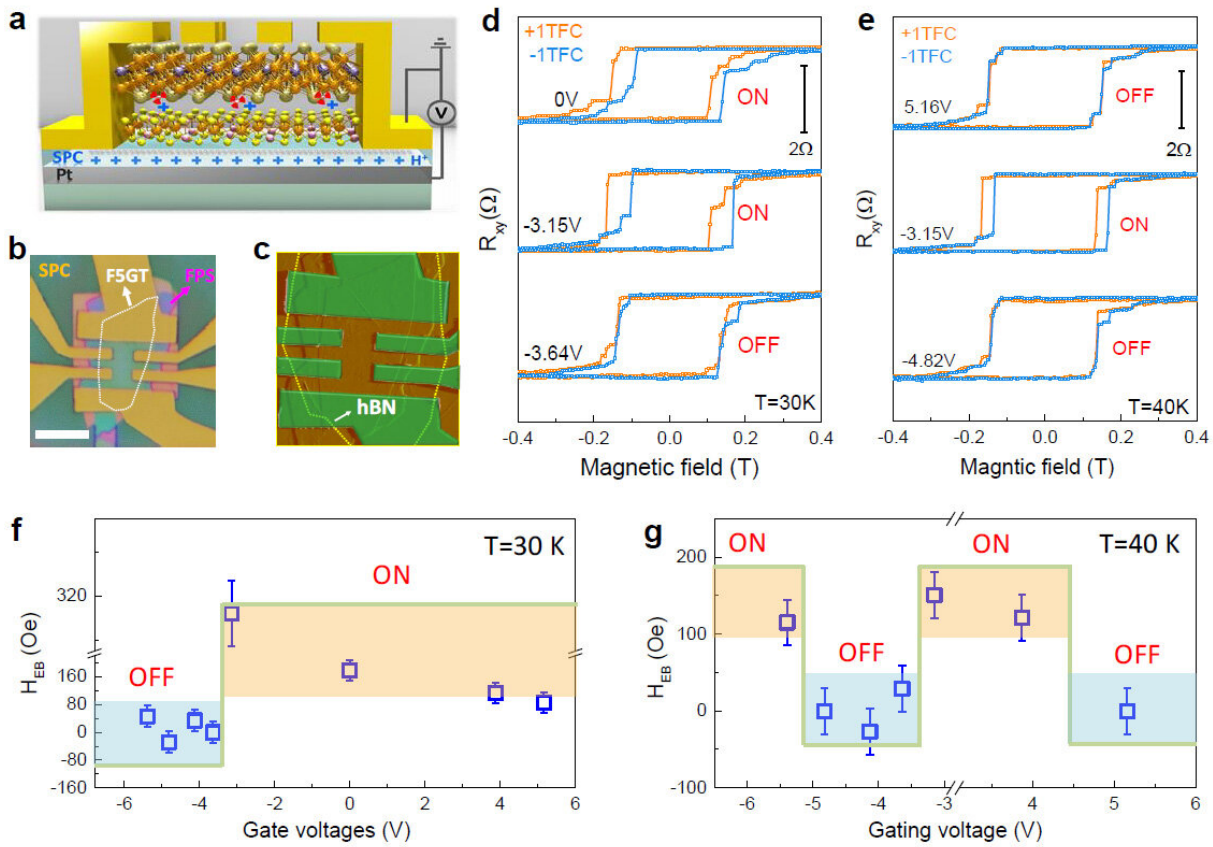

(a) Schematic of the solid proton field effect transistor. (b, c) Optical and atomic force microscope images of heterostructure device. (d, e) Gate-dependent exchange bias effects at T = 30 and 40 K, respectively. (f, g) Amplitudes of the exchange bias effects under various gating voltages at T = 30 and 40 K, respectively. Credit: Zheng Guolin

Van der Waals (vdW) ferromagnets are the building blocks of vdW heterostructure devices such as vdW ferromagnetic (FM)-antiferromagnetic (AFM) heterostructures and vdW FM-ferroelectric heterostructures. These vdW heterostructure devices have attracted a lot of attention due to their promising applications in modern spintronics.

However, the interface coupling of a vdW heterostructure is weak due to the large vdW gap, which impedes the development of this burgeoning area. Understanding of how to electrically tune the interface coupling in vdW heterostructure device remains elusive.

Recently, professor Zheng Guolin from the High Magnetic field laboratory at the Hefei Institutes of Physical Science at the Chinese Academy of Sciences (CAS), collaborating with professor Lan Wang from Royal Melbourne Institute of Technology University, experimentally studied the interface coupling in $FePS_3$-Fe_5GeTe_2 van der Waals heterostructures via proton intercalations.

This is the first time scientists discovered that the interface coupling induced exchange bias effect can be electrically controlled via gate-induced proton intercalations, which provide a promising way to manipulate the interface coupling in many more vdW heterostructures.

The results were recently published in *Nano Letters*.

In this research, the team fabricated $FePS_3$-Fe_5GeTe_2 vdW heterostructure devices (with the thickness of FM layer Fe_5GeTe_2 between 12-18 nm) and showed that the weak exchange bias effects below 20 K developed due to the interface magnetic coupling.

However, when they put the heterostructure devices onto the solid proton conductors, the blocking temperature (where the exchange bias effect disappeared) was boosted up to 60 K. Moreover, the observed exchange bias effect can be electrically switched "ON" and "OFF" due to the intercalations or de-intercalations of the protons under a gate voltage.

Interestingly, the magnetic properties of the top Fe_3GeTe_2 layer—including coercivity, anomalous Hall resistivity and Curie temperature—didn't change during the whole gating process, revealing that the proton intercalation has a very limited impact on FM layer.

Further theoretical calculations based on density functional theory demonstrated that the proton intercalations mainly affected the magnetic coupling at the interface as well as the magnetic configurations in AFM layer, leading to a gate-tunable exchange bias effect.

More information: Sultan Albarakati et al, Electric Control of Exchange Bias Effect in FePS3–Fe5GeTe2 van der Waals Heterostructures, *Nano Letters* (2022). DOI: 10.1021/acs.nanolett.2c01370

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