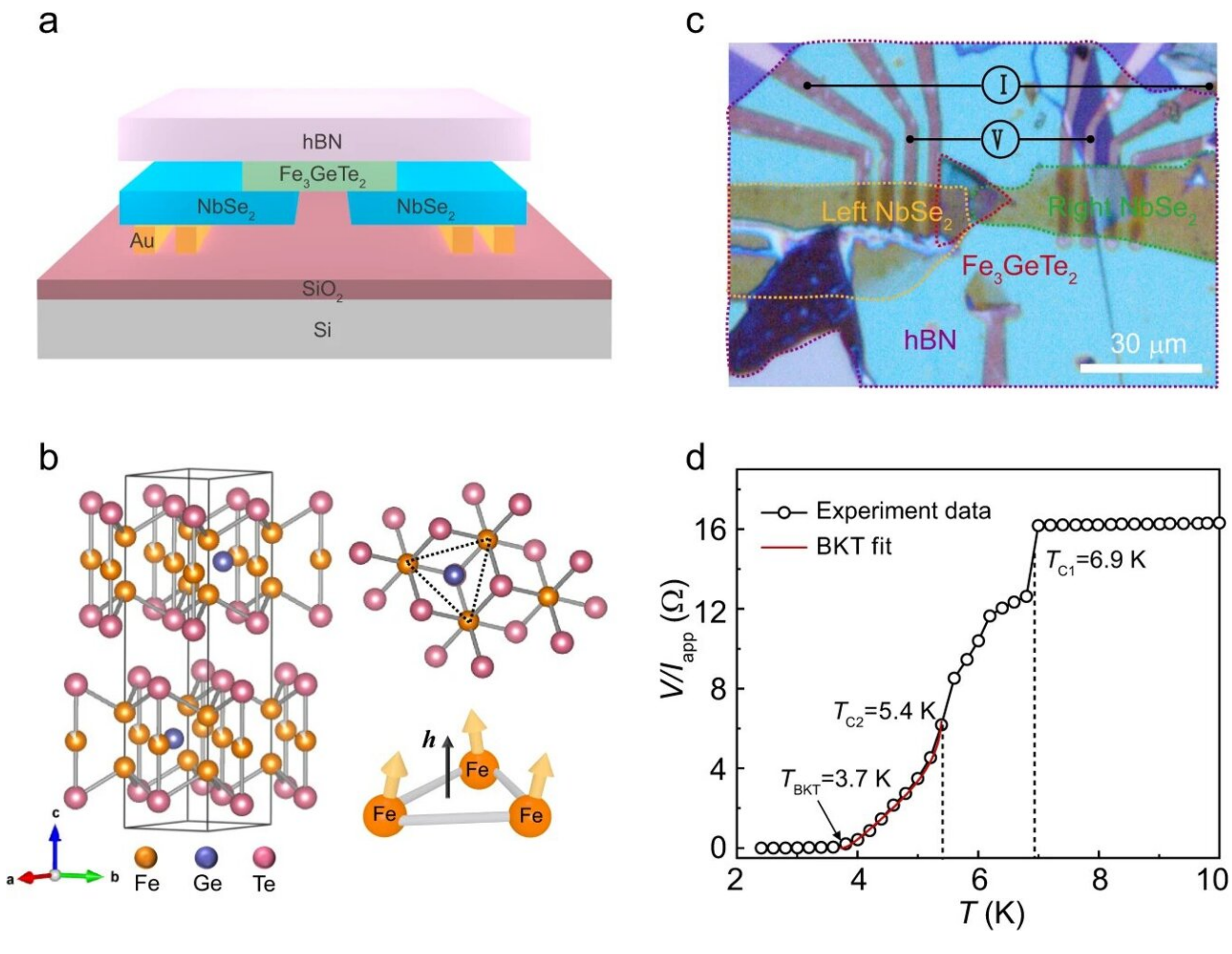
Team discovers long-range skin Josephson supercurrent across van der Waals ferromagnet

May 8 2023, by Liu Jia



S/F/S device architecture and temperature-dependent resistivity. **a** Schematic illustration of a S/F/S lateral Josephson junction. **b** Schematic diagram of the atomic structure of Fe_3GeTe_2, where showing noncoplanar spin textures with a fictitious field of *h* in a frustrated triangular lattices. **c** Optical image of the

S/F/S device. **d** Temperature dependence of the S/F/S resistance by a four-terminal measurement and the applied current (I_{app}) is 10 μA. Three transitions are identified, with the first two T_{c1} = 6.9 K from superconducting $NbSe_2$, and T_{c2}~5.4 K from the proximity-induced superconducting transition of the S/F bilayers at each end of the S/F/S. The red solid line represents the BKT transition using the Halperin–Nelson equation for fitting, which gives the third transition with a BKT temperature T_{BKT} = 3.7 K. Source data are provided as a Source Data file. Credit: *Nature Communications* (2023). DOI: 10.1038/s41467-023-37603-9

In a study published in *Nature Communications*, Prof. Xiang Bin's group from University of Science and Technology of China of the Chinese Academy of Sciences, in collaboration with Assoc. Prof. Wang Zhi from Sun Yat-sen University, discovered the long-range skin Josephson supercurrent across a van der Waals ferromagnet.

They bridged two spin-singlet superconductors $NbSe_2$ (S) by constructing the van der Waals ferromagnet metal Fe_3GeTe_2 (F), and observed long-range supercurrent in the lateral Josephson junction (S/F/S) for the first time, which exhibits astonishing skin characteristics.

Ferromagnetism and superconductivity are two antagonistic macroscopic orderings. When the singlet supercurrent enters the ferromagnet, rapid decoherence of the Cooper pairs will be triggered.

However, spin-triplet supercurrents induced in the vicinity of superconductor/ferromagnet interfaces enable transport without energy dissipation over long distances in ferromagnets, which has been proved theoretically and experimentally in recent years. This provides a more desirable method for constructing quantum devices without dissipation.

Earlier research focused on the construction of superconducting

Josephson junctions with coupled bulk ferromagnets to achieve the observation of spin-triplet currents and the control of spin and charge degrees of freedom. However, there are few reports on the observation of spin-triplet supercurrents and related studies of interfacial properties based on heterojunctions of two-dimensional (2D) van der Waals (vdW) materials.

The researchers constructed lateral vdW Josephson junctions of S/F/S by bridging two singlet vdW superconductors $NbSe_2$ with vdW ferromagnet Fe_3GeTe_2 (F). The electrical properties of the S/F/S with different junction channel lengths have been studied by low-temperature electrical tests. The results showed a zero-resistance state of the S/F/S and a long-range Josephson supercurrent (~ 300 nm).

The zero-temperature superconducting critical current tends to decay with increasing channel length and disappears completely when the channel length increases to 450 nm.

More interestingly, the response of the long-range superconducting critical current to an external magnetic field perpendicular to the supercurrent channel presented a periodic oscillation pattern, which is similar to double-slit interference, rather than the conventional Fraunhofer periodic oscillation stripe. This result confirmed the existence of a Josephson supercurrent with a long-range skin feature in S/F/S that is distinctive from the Josephson superconducting current of conventional bulk channels.

Additionally, the researchers proposed two possible mechanisms for the skin feature of the long-range supercurrent. First, the Rashba spin-orbit coupling induced by the mirror symmetry breaking on the Fe_3GeTe_2 surface, when interacting with ferromagnetism and the s-wave superconductivity of $NbSe_2$, may lead to 2D topological superconductivity on the Fe_3GeTe_2 surface.

Second, the magnetic inhomogeneity caused by the non-coplanar structure of Fe atoms in Fe_3GeTe_2 promotes the transformation of spin-singlet Cooper pairs into spin-triplet pairs at the surface through spin-rotation and spin-mixing, and then forms a long-range Josephson supercurrent.

The S/F/S design of the noncoplanar structure provides a new perspective to explore the interaction between ferromagnetism and superconductivity. The novel physical properties presented by this noncoplanar structure provide a platform for potential applications of new quantum functional devices in 2D superconducting spintronics and the realization of topological superconductivity.

More information: Guojing Hu et al, Long-range skin Josephson supercurrent across a van der Waals ferromagnet, *Nature Communications* (2023). DOI: 10.1038/s41467-023-37603-9

Provided by Chinese Academy of Sciences