Ultrahigh supercurrent density in a two-dimensional topological material

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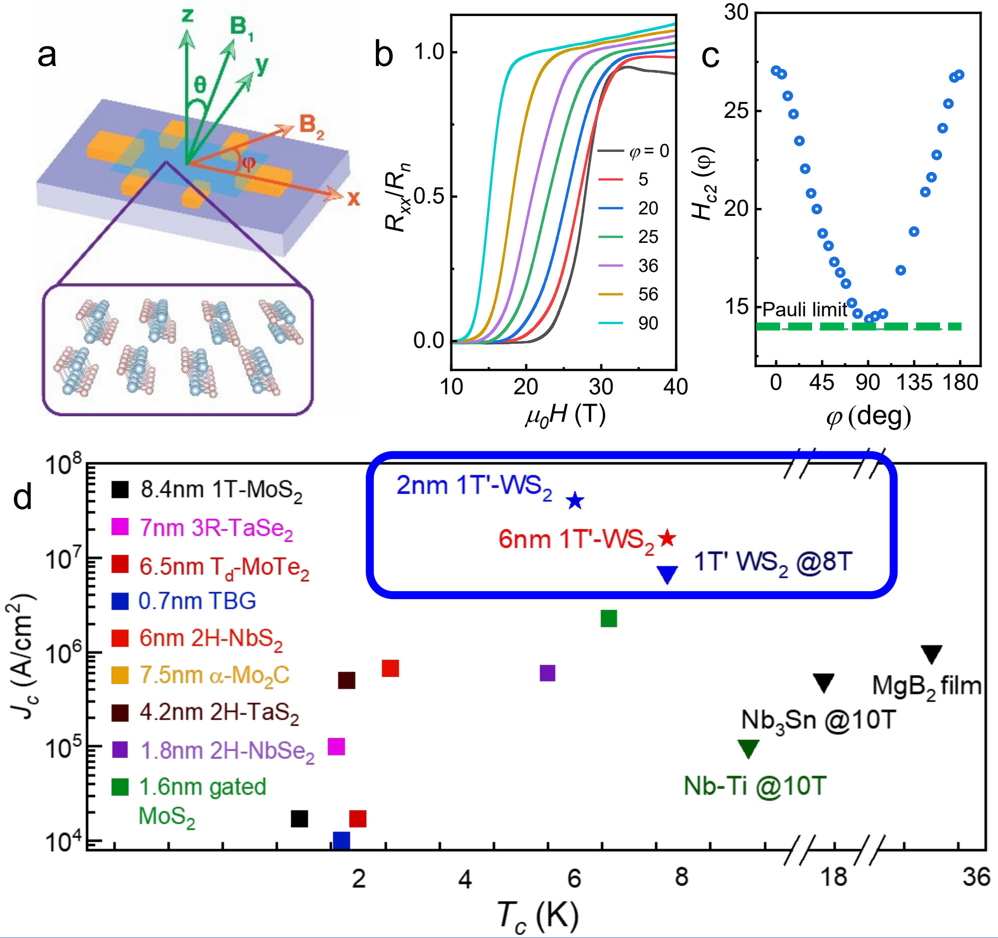
Funding Grants: Z. M. Hasan (GBMF4547；DOE/BES DE-FG-288 02-05ER46200); L. Balicas (DE-SC0002613); N. Yao (DMR-2011750); G.S. Boebinger (NSF DMR-1644779)

Since the discovery of superconductivity by Heike Kamerlingh Onnes in 1911, superconductors have revolutionized science and technology through numerous applications ranging from high-field magnets to superconducting qubits. High-field magnets, fabricated from superconductors with high critical current density, have enabled scientific discoveries across the physical, chemical, and biological sciences. *New superconducting materials that exhibit topological properties offer additional technological possibilities beyond present-day applications, opening a new frontier to implement fault-tolerant quantum information technologies*.

MagLab users discovered an unprecedentedly high superconducting critical current density (17MA/cm² at 0T) in atomically thin 1T′-WS$_2$, exceeding those of all two-dimensional superconductors reported to date. It was also discovered that 1T′-WS$_2$ features a strongly anisotropic superconducting state that is not only anisotropic with regard to in-plane and out-of-plane orientation of the magnetic field, but also within the two dimensional plane. To measure these anisotropies, the sample was rotated around different two axes with respect to the applied field direction. *The maximum in-plane critical field was found to approach 30T, which violates the Pauli paramagnetic limit by a factor of two, signaling the presence of unconventional superconductivity*.

Even under an 8T in-plane magnetic field, the J_c of 1T′-WS$_2$ is large (7MA/cm²). By comparison, critical current densities of commercial magnet building materials are much smaller: Nb-Ti alloy is 0.1MA/cm² at 10T and Nb$_3$Sn is 0.5MA/cm² at 10T. *The large J_c at zero and finite magnetic fields makes 1T′-WS$_2$ a candidate for future study on building next-generation superconducting magnets.*



a. Schematic illustration of a 1T′-WS$_2$ device and the rotation experiment setup. **b.** Magnetic field dependence of the normalized resistance of the 1T′-WS$_2$ device at T = 0.33 K with different in-plane rotation angles φ. **c.** The φ-dependence of the upper critical field. The green dashed line indicates the Pauli limit.

d. Comparison of critical current densities among 1T′-WS$_2$ (high-lighted by blue box) and other representative 2D superconductors, such as twisted bilayer graphene (TBG) and transition metal dichalcogenides. Nb-Ti and Nb$_3$Sn (used in building superconducting magnets) are included in the figure for reference.

Facilities and instrumentation used: 41 Tesla Resistive Magnets (Cell 6).

Citation: Zhang, Q.; Hossain, S.MD.; Casas, B.W.; Zheng, W.; Cheng, Z.J.; Lai, Z.; Tu, Y.H.; Chang, G.; Yao, Y.; Li, S.; Jiang, Y.X.; Mardanya, S.; Chang, T.R.; You, J.Y.; Feng, Y.P.; Cheng, G.; Yin, J.X.; Shumiya, N.; Cochran, T.A.; Yang, X.P.; Litskevich, M.; Yao, N.; Watanabe, K.; Taniguchi, T.; Zhang, H.; Balicas, L.; Hasan, M.Z., *Ultra high supercurrent density in a two-dimensional topological material,* Physical Review Materials, **7**, L071801 (2023) **doi.org/10.1103/PhysRevMaterials.7.L071801**