Ultrahigh supercurrent density in a two-dimensional topological material

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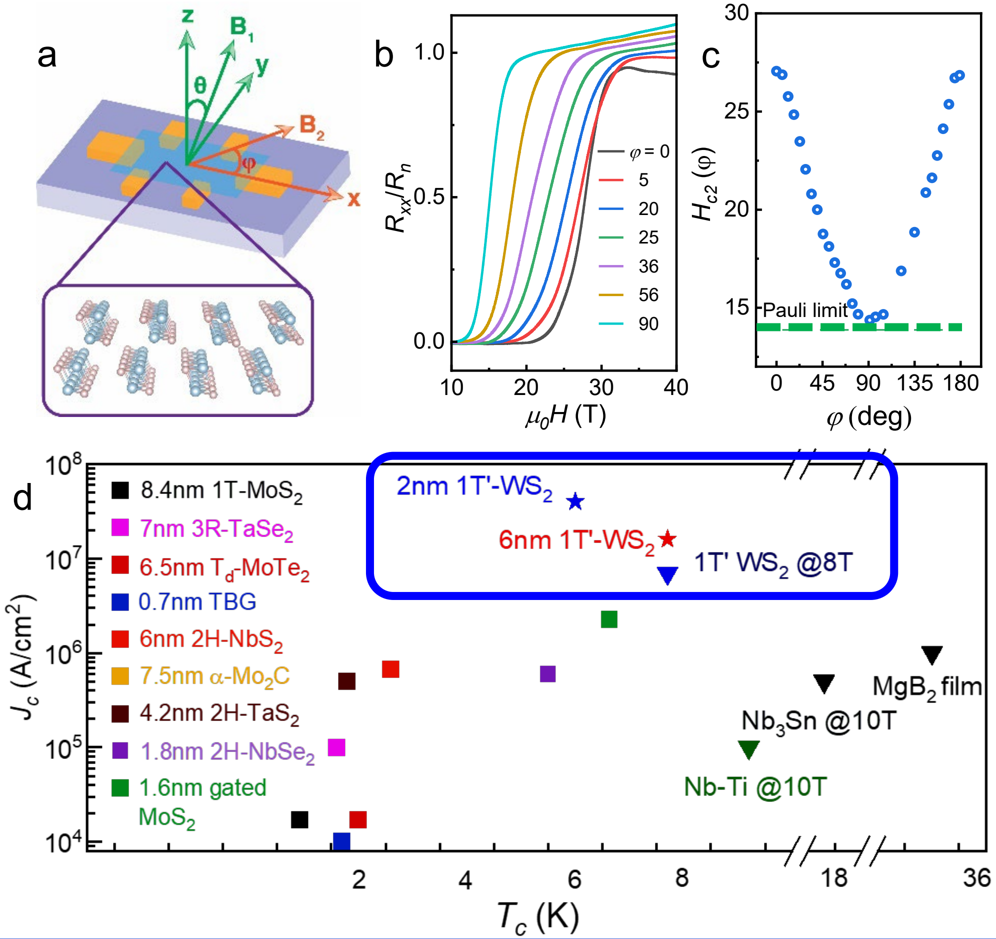
Since the discovery of superconductivity by Heike Kamerlingh Onnes in 1911, superconductors have revolutionized science and technology through numerous applications ranging from high-field magnets to superconducting qubits. High-field magnets, fabricated from superconductors with high critical current 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/cm^2 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/cm^2). By comparison, critical current densities of commercial magnet building materials are much smaller: Nb-Ti alloy is 0.1MA/cm^2 at 10T and Nb_3Sn is 0.5MA/cm^2 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_3Sn (used in building superconducting magnets) are included in the figure for reference.

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

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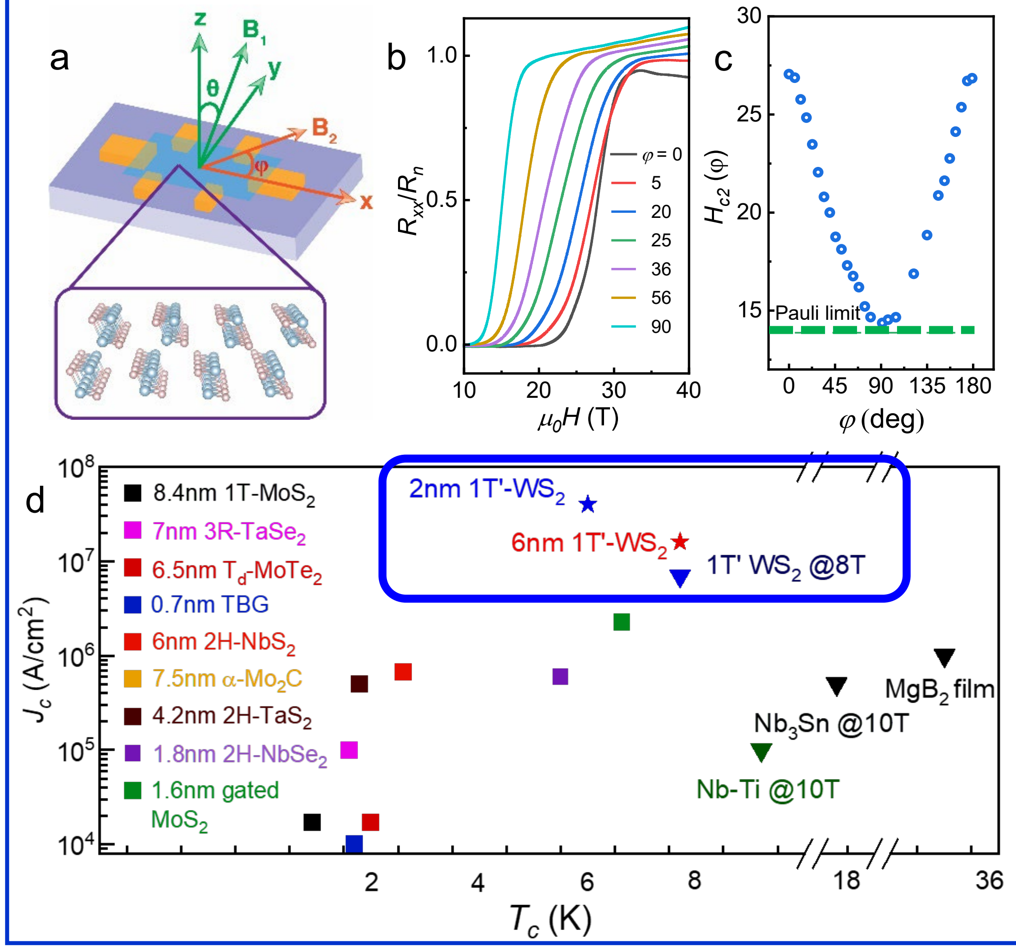
What is the finding? *The combination of extremely high DC magnetic fields up to 41T and an in-situ sample rotation stage allowed the observation of a strongly anisotropic superconducting state that had not been observed previously*. Additionally, MagLab users found in this material (1T′-WS_2) an unprecedentedly high superconducting critical current density (17MA/cm^2 at 0T) that exceeds all other known two-dimensional superconductors (blue box in **Figure d**). The band structure obtained via angle-resolved photoemission spectroscopy and first-principles calculations points to 1T′-WS_2 possessing a Z_2 topological invariant.

Why is this important? *High supercurrent densities in materials result in machines and devices that are efficient and much smaller, such as high-field magnets and high-performance superconducting spintronics*. Furthermore, the simultaneous presence of topology and superconductivity in 1T′-WS_2 *establishes 1T′-WS_2 as a topological superconductor candidate which is a favorable environment for non-Abelian anyons that could enable the construction of a fault tolerant topological quantum computer.*

Why did this research need the MagLab? To observe the anisotropic superconducting state with high critical field, it was necessary to cool the sample down to 0.3K and apply very high magnetic fields (well above 30T). *Indeed, the MagLab's 41T resistive magnet with its high-precision in-situ rotator was essential to this experiment.*



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