Tuning Ising Superconductivity with Layer and Spin-Orbit Coupling in Two-Dimensional Transition Metal Dichalcogenides

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Introduction

Superconductivity in the presence of strong spin-orbit coupling (SOC) is predicted to lead to novel electronic phases in two dimensions. The addition of broken inversion symmetry is expected to enforce a significant portion of spin-triplet Cooper pairs. Experimental progress in isolating and protecting atomically-thin, superconducting transition metal dichalcogenide (TMD) crystals has enabled investigations of these intriguing phenomena in the two-dimensional limit. In particular, a novel superconducting phase resulting from strong SOC and broken inversion symmetry known as "Ising superconductivity" has been measured in monolayer (1L) TaS_2 [1] and $NbSe_2$ [2], revealed by low-temperature and high-field measurements of the parallel upper critical field, $H_{c2||}$, which is significantly enhanced over the paramagnetic limit. These measurements have raised several important questions about the precise nature of this state, such as the importance of the triplet fraction of pairing, the origin of the upper critical field, and the possibility of supporting unconventional and/or topological superconducting phases.

Experimental

We performed magnetotransport measurements on single- and few-layer TaSs and $NbSe_2$ devices in both Cell 9 and Cell 12 as a function of the temperature and the magnetic field, taking great care to ensure the precise parallel orientation of the two-dimensional plane of the superconductors with respect to the field.

Results and Discussion

Figure 1 shows our results for the upper critical field of atomically-thin TaS_2 and $NbSe_2$ in parallel fields, extracted from temperature- and field-dependent measurements of the resistance. The upper critical fields are significantly larger than the predicted paramagnetic limit, $H_{c2||}/H_P$ »1, for all devices measured. Comparing 1L TaS_2 and $NbSe_2$, we find that the enhancement above H_P is larger for TaS_2 than $NbSe_2$ due to the larger SOC in the former— strong evidence that SOC is at the origin of the enhancement. Interestingly, few-layer samples also appear to possess enhanced $H_{c2||}$, with the dependence on the number of layers N being fairly weak for N >1. Due to the particular symmetries of few layer TMD crystals, this result suggests that these materials possess extremely weak interlayer coupling relative to the SOC.

Conclusions

In 2017, we performed the first measurement of the transition temperature of 1L TaS_2, with T_{c0} = 3 K. Our high-field measurements performed at the NHMFL point to 1L TaS_2 having the highest parallel upper critical field of any intrinsically superconducting TMD. Furthermore, these measurements suggest that TaS_2 may be an excellent candidate for topological and/or triplet superconductivity in two dimensions.

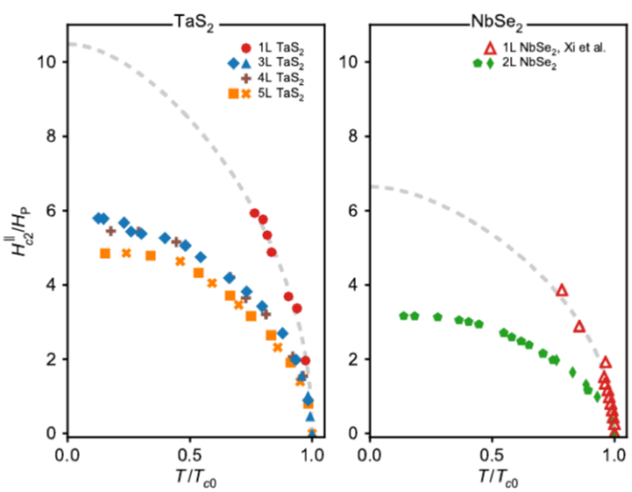

Fig.1 Upper critical field in the parallel orientation for (left) 1, 3, 4, and 5-layer TaS_2 and (right) 2-layer $NbSe_2$. Triangles show 1-layer $NbSe_2$ data from Ref. [2]. Field axes are normalized to the paramagnetic limit, H_P =1.84T_{c0} [T/K], about 5.5 T for both 1-layer materials. Dashed line shows a fit to the 1L data using a standard pair-breaking theory [3], allowing extrapolation to lower temperatures and higher fields (outside the field range of cells 9 and 12).

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References

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