Intrinsic supercurrent non-reciprocity coupled to the crystal structure of a van der Waals Josephson barrier

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The non-reciprocal behavior in dissipative current flows, known as the diode effect, has played a central role in modern electronic devices and circuits. In conventional schemes, non-reciprocity along the current direction arises from spatial inhomogeneity. Recently, it has been shown that when inversion and time-reversal symmetries are both broken, and in combination with a spin-orbit interaction (SOI), even spatially homogeneous systems can provide for diode functionality. By implementing this magneto-chirality with superconductors and matching the superconducting gap with the SOI energy, one can achieve a directional, non-dissipative, supercurrent flow, which is a prerequisite for the realization of future superconducting quantum devices. To date, only a few methods have been developed to intrinsically and/or extrinsically break the inversion symmetry and its mechanisms, especially whether intrinsic or extrinsic, remain elusive.

Here we demonstrate a substantial supercurrent non-reciprocity in a van der Waals (vdW) vertical Josephson junction (JJ) formed with a T_d-WTe_2 barrier and $NbSe_2$ electrodes that clearly reflects the intrinsic crystal structure of T_d-WTe_2. In combination with time-reversal symmetry breaking by applied magnetic field, an inherently inversion symmetry breaking of WTe_2 barrier can provide a non-reciprocal supercurrent in $NbSe_2$/WTe_2/$NbSe_2$ vdW JJs. The magneto-chiral characteristics with respect to a mirror plane of WTe_2, identified angular-resolved polarized Raman spectroscopy, strongly support the crystal structure reflected supercurrent non-reciprocity in $NbSe_2$/WTe_2/$NbSe_2$ vdW JJs. The diode efficiency of the JJs show linear scaling behavior with WTe_2 barrier thickness up to critical thickness, which is predicted theoretically for ballistic JJ. It shows that the supercurrent non-reciprocity of the JJs can be likely related to charge transport mechanism in barrier. Furthermore, we demonstrate a tunable magneto-chirality in twisted WTe_2 double barrier JJ via twist-angle engineering. Our results show that 2D materials promise vertical Josephson diodes with high efficiency and tunability and our approach can be extended to other low-symmetric and twisted vdW systems for accelerating the development of 2D superconducting devices and circuits.