

## Current-induced second-order nonlinear Hall effect in bulk $WTe_2$

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Second-order nonlinear Hall effect has opened up access to a deep understanding of the connection between symmetry and topological states of materials. For example, second-order nonlinear Hall effect has been demonstrated in bilayer and few-layer  $T_d$ - $WTe_2$  experimentally originating from Berry curvature dipole [1-3]. More importantly, the emergence of the second-order Hall effect generally requires broken inversion symmetry and other spatial symmetries (such as in-plane  $C_2$  symmetry) rather than broken time-reversal symmetry, which brings new avenue to nonlinear physics research and innovative concepts for devices applications [4,5]. However, this intriguing nonlinear phenomenon is smeared out in bulk counterpart of  $T_d$ - $WTe_2$  due to the preservation of  $C_2$  symmetry.

Here, we investigate the induced second-order Hall effect in bulk  $T_d$ - $WTe_2$  by applying direct current along the longitudinal direction (Fig. 1a,b). The observed second-order Hall effect is strongly dependent on the external direct current with its magnitude increasing with direct current (Fig. 1c,d). Furthermore, the direct current induced second-order Hall effect in bulk  $T_d$ - $WTe_2$  exhibits two-fold angular dependent features, which is different from that in bilayer and few-layer  $T_d$ - $WTe_2$ , but similar to third-order Hall effect observed in bulk  $T_d$ - $WTe_2$  (Fig. 1e,f). The occurrence of the second-order Hall effect in bulk  $T_d$ - $WTe_2$  is believed to be originated from several possible origins, including Berry connection polarization tensor, Drude transport, disorder scatterings. Our work outlines a potential roadmap to control the second-order Hall effect in materials where crystal symmetry forbids with both fundamental interests and technological applications.

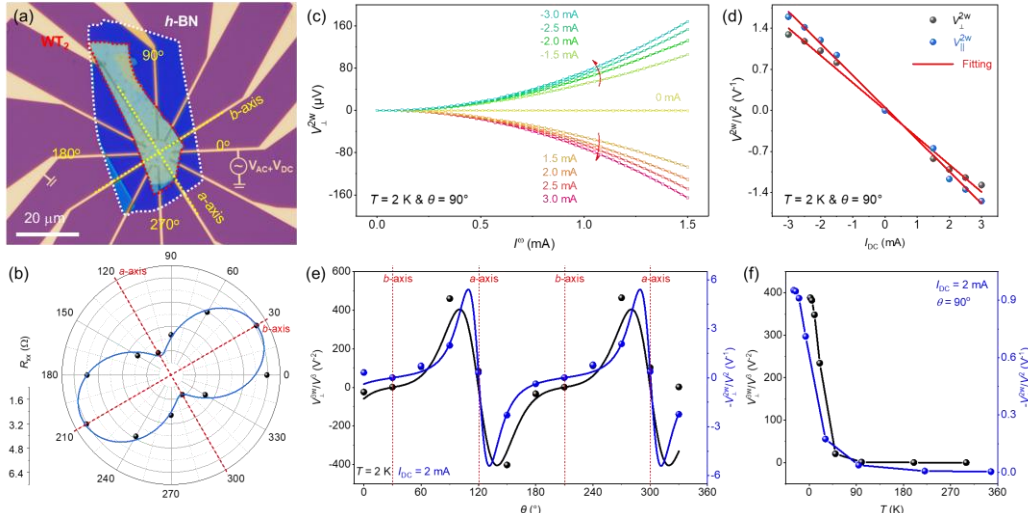


FIG. 1. DC induced nonlinear Hall effect in bulk  $T_d$ - $WTe_2$ . (a) Optical image of the bulk  $T_d$ - $WTe_2$  device. (b) Angular dependence of longitudinal first-harmonic  $R_{xx}$ . (c) Second-order Hall voltage in bulk  $T_d$ - $WTe_2$  measured under different DC. (d) The slope of  $V_{\perp}^{2\omega}$  (black spheres) and  $V_{\parallel}^{2\omega}$  (blue spheres) versus square of the longitudinal first-harmonic voltage  $V_{\parallel}^{\omega}$  as a function of applied DC. Red lines are linear fitting results (e) Angular and (f) temperature dependence of third-order (black spheres) and DC induced second-order (blue spheres,  $I_{DC} = 2$  mA) nonlinear Hall effect in bulk  $T_d$ - $WTe_2$ . The solid and dashed lines in (e) indicate the fitting results and crystalline  $a$ -axis and  $b$ -axis, respectively.

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