Current-induced nuclear spin polarization in topological insulators at high bias currents

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Three-dimensional topological insulators (3DTIs) are bulk-insulating while hosting spin-momentum locked surface states. Through hyperfine interactions, such surface currents can polarize the nuclear spin system [1], and conversely nuclear spin polarization can induce an electric response with an inductive character in the surface states [2]. This effect scales with the number of participating nuclear spins, making 3DTIs promising for microelectronic applications that call for scalable inductive elements. Here, we present a unified experimental study of current-induced nuclear spin polarization in the 3DTI $(Bi_{1-x}Sb_x)_2Te_3$. While this material is nuclear spin-rich, achieving a finite nuclear polarization requires high bias currents that introduce competing effects such as Joule heating and electrostatic self-gating. We disentangle these contributions through complementary measurements of in-plane magnetoresistance, nonreciprocal transport, and bias-dependent quantum corrections. We identify a bias-dependent offset in the in-plane magnetoresistance that is consistent with an effective Overhauser field generated by nuclear spin polarization [3]. Our results establish experimental constraints for observing nuclear spin polarization in topological insulators and clarify the role of parasitic transport effects at high bias. Nevertheless, direct experimental access to the nuclear spin subsystem will be crucial to fully establish the role of nuclear spins in nonequilibrium transport and the inductive response of topological surface states.

References

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Figures

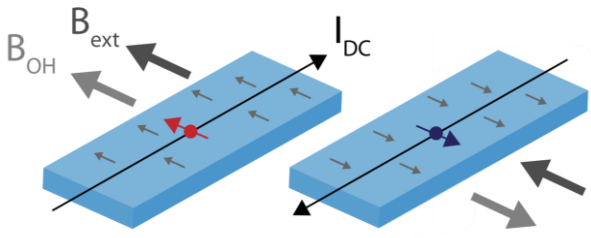

Figure 1: Spin-momentum locked surface currents in a 3DTI generate a nonequilibrium nuclear spin polarization via hyperfine interactions. The resulting Overhauser field (B_{OH}) adds to an external in-plane magnetic field (B_{ext}) and offsets the magnetoresistance.

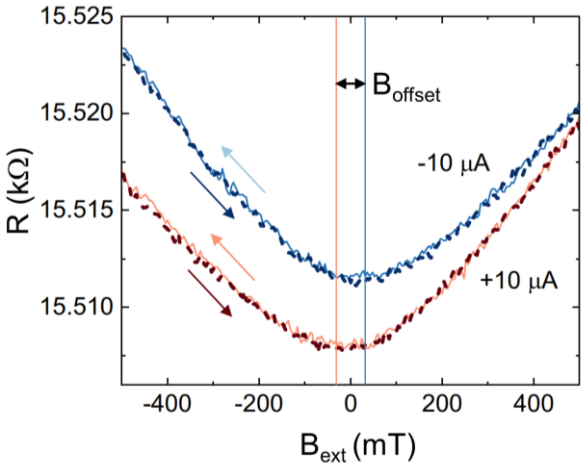

Figure 2: Resistance of $(Bi_{1-x}Sb_x)_2Te_3$ in an in-plane magnetic field, measured using positive and negative DC bias currents. Reversing the bias offsets the traces in magnetic field.