Colossal enhancement of spin-caloritronic unidirectional magnetoresistance in a Weyl ferromagnet at room temperature

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Unidirectional magnetoresistance[1] (UMR) is a novel spintronic feature in nano-science, which has been intensively studied in hopes of realizing all-electrical magnetization direction detection devices[2]. However, cryogenic temperatures and/or high magnetic fields have been required to achieve noticeable effects. Here, we exploit the high heat-to-charge conversion efficiency of the Heusler alloy Weyl semimetal Co2MnGa[3,4] to produce a colossal enhancement of the room temperature UMR ratio, when compared with conventional ferromagnets. As shown in Fig. 1(a), the dependence of both the longitudinal and transversal resistance on the magnetization angle was analyzed, for magnetic field scans along three perpendicular planes. The even and odd components of the resistance were extracted measuring for positive and negative dc currents, where we found the longitudinal odd part, attributable to UMR, depends linearly on the current density, as shown in Fig. 1(b). In addition, a comparison of the UMR ratio measured for different material is shown in Fig. 1(c), where a two order of magnitude enhancement is observed in Co_2MnGa thin films.

We reveal that Joule-heating-originated vertical thermal gradients[5]—combined with the large anomalous Nernst effect (ANE) in this topologically-non-trivial material, thought to be originated in a large Berry Curvature distribution around the Fermi energy, associated with Weyl points[6]—converge into the manifestation of a strong UMR in nano-scaled wires. Finite-elements temperature distribution simulations were performed to estimate the temperature gradient, reaching a very good agreement with independent direct measurements of the anomalous Nernst thermopower. Furthermore, the size scaling trend indicates further improvement is expected when the dimensions are reduced. Finally, we demonstrate the operation of a prototype non-volatile all-electrical memory device based on the enhanced UMR in Co2MnGa. Our results open up new horizons of using thermoelectric voltages in novel materials for magnetization direction detection.

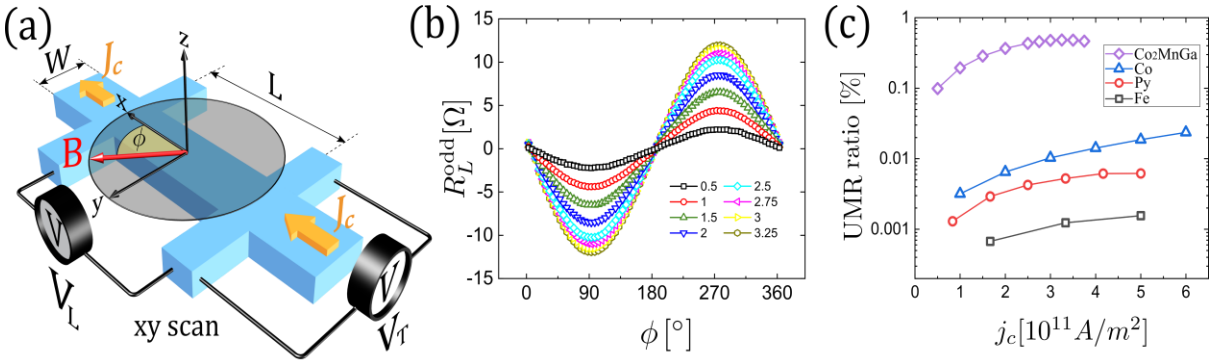

Figure 1: (a) Schematics and geometry of a magnetic field angular dependence experiment in a Hall Bar device. (b) Odd-in-current component of the longitudinal resistance for an xy scan for several current densities, in units of 10^{11} A/m^2. The UMR manifests in this component, showing a 360° periodicity on the magnetization direction. (c) Current dependence of the UMR ratio measured for 200 nm-width and 30 nm-thick Hall bars made of different ferromagnetic materials. An enhancement of up to 2 orders of magnitude is observed for Co_2MnGa, when compared to conventional ferromagnets.

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