Momentum Microscopy: Exploring the Mysteries of Topology in Quantum Materials

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1. Introduction

The evolution in technology continuously asks for novel materials. In this context quantum materials are considered a key resource for the 21st century, taking us from the silicon age into the "quantum age". Quantum materials promise a wealth of novel phenomena with respect to electrical transport, superconductivity, magnetism or multiferroicity. Often their electronic properties are linked to non-generic quantum effects, caused by topology or chirality.

A characteristic feature of emergent or quantum materials is the competition of various spin-dependent interactions, such as spin-orbit coupling and exchange interaction. In addition, there may be a breaking of time-reversal and/or inversion symmetry at play. As a consequence, topological materials may range from metals to insulators. In close to the Fermi level, this situation leads to peculiar electronic dispersions associated with Dirac and Weyl points, eventually also resulting in complex spin textures in momentum space. In order to understand the physical properties of quantum materials on a fundamental level, we need to explore these electronic states in detail and disentangle the role of the various interactions. This holds for both the static behavior, as well as fast and ultrafast time responses.

2. Experimental Approach

We employ an advanced electron spectroscopic approach, which is able to map the entire Fermi surface and explicitly takes the electron spin as an experimentally measurable quantity into account. This momentum microscopy technique employs a two-dimensional spin filter and uses synchrotron radiation [1]. As shown in the presentation and in Fig. 1, it provides detailed insight into the spin-resolved electronic states throughout the entire Brillouin zone. A second instrument for laser-driven studies of ultrafast dynamics in condensed matter systems is currently under construction in our group.

3. Results

Among others we investigated "simple" single-crystal systems to detail the role of the individual interactions and symmetry-breaking mechanisms. One of them is the heavy metal W(110) [[2]], which has a strong spin-orbit coupling. There we observe several states with Dirac-like dispersion, which are derived from *d*-electrons. In panel (a) we show the experimental geometry and spin-resolved Fermi surface momentum map. The dashed contour indicates the outline of the surface Brillouin zone of W(110), together with high-symmetry points. Panels (b–d) show full 3D (k_x, k_y, E_B) spin-resolved momentum maps (photon energy hν=50eV), cutting along the indicated directions in the W(110) Brillouin zone as a function of binding energies E_B ($E - E_F$ from 0 to 1.7 eV). Measured intensities and spin polarization are encoded using the displayed 2D color code, where the spin polarization P_y is indicated by red and blue colors, and the color saturation encodes the intensity. Panel (e) depicts schematically the three observed Dirac states for W(110): one appears at the Γ point and two coexist at $k_y = \pm 0.4 \text{Å}^{-1}$.

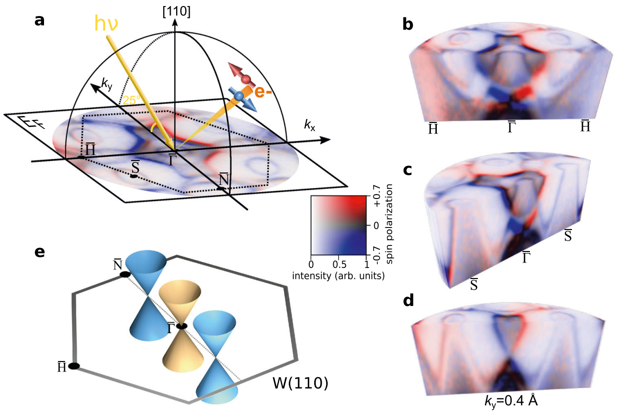

Figure 1: Multiple *d*-derived Dirac fermions in the heavy transition metal W(110).

Further studies on ferromagnets concerned nonlocal spin-dependent electronic correlation effects in Co(001) [3]. Even Fe(100) exhibits several interesting phenomena, such as a symmetry breaking due to the magnetization direction [**?**], or a topological phase transition [5]. The current activities concern spin-resolved momentum microscopy studies on several Dirac and Weyl semimetals, such as $MoTe_2$ and $NiTe_2$[6].

References

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