Orbital Crossing with Spin Flip Found in Noncentrosymmetric Metals

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ABSTRACT

In noncentrosymmetric metals, the antisymmetric spin orbit interaction resolves spin degeneracy of electronic bands and therefore a Fermi surface splits into two pieces. In the metals belonging to a certain point group, however, the spin degeneracy recovers at the special symmetry points. Here, we found the orbital crossing phenomenon in which a carrier transfers from one split Fermi surface to the other one at a degenerate point. We further estimated the probability of crossing the orbital and revealed that the estimation allows us to judge the occurrence of spin flip at the degenerate point.

INTRODUCTION

When most of elementary solid state physics textbooks introduce the energy band or the Fermi surface of electron, they usually ignore the degree of freedom of spin for simplicity. However, considering noncentrosymmetric materials that lack a space inversion symmetry, the spin-degenerate bands split owing to the antisymmetric spin orbit interaction. This produces two similar, but different in volume, Fermi surfaces as shown in Fig. 1(a), for example. In such a case, spin orientations depend on the wave vector $\boldsymbol{k}$, forming *spin texture* in $\boldsymbol{k}$-space (see, e.g. Fig. 1(b)). It is generally difficult to detect this spin texture.

Recently, we observed an orbital crossing between doubly split Fermi surfaces via the de Haas-van Alphen (dHvA) effect in noncentrosymmetric Yb_4Sb_3 [1]. Furthermore, we successfully revealed that this orbital crossing is associated with the spin texture from the analysis of probability of the orbital crossing.

ORBITAL CROSSING

The dHvA effect is a quantum oscillation of magnetization which arises under the condition of strong magnetic fields with sufficiently low temperatures. The frequency of the oscillation, with respect to inverse magnetic field, is proportional to the extremal cross-sectional area of the Fermi surface. In noncentrosymmetric metals consisting of a pair of split Fermi surfaces, as shown in Fig. 1(a), a composite dHvA oscillation with two close frequencies is expected to be observed. However, we actually detected three additional oscillations in Yb_4Sb_3. Their frequencies are between the two frequencies expected from the extremal areas of the split Fermi surfaces. These extra-oscillations indicate that electrons transfer from an orbit on one Fermi surface to an orbit on the other paired Fermi surface during cyclotron motion.

This observation is similar to so-called magnetic breakdown [2]. In the case of magnetic breakdown, Fermi surfaces are separated by a small energy gap. Electrons jump this gap via a tunnel effect. On the other hand, in the case of Yb_4Sb_3, the energy gap is inherently zero on a specific symmetry axis. Therefore, electrons could change orbit at this degenerate point (as indicated by the black dot in Fig. 1(a)). We call this change of the orbit *orbital crossing*.

SPIN FLIP AT THE CROSS POINT

Although orbital crossing is similar to magnetic breakdown, they are different physical phenomena. The most significant difference is that the orbital crossing could be accompanied by spin flip. As shown in Fig. 1(c), when an electron passes through the cross (degenerate) point,

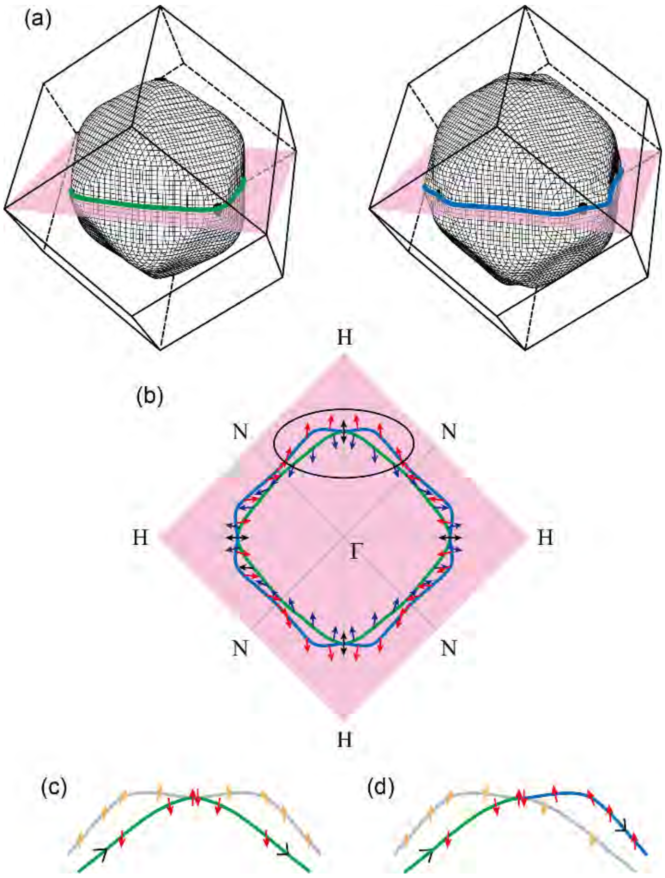

Fig. 1: (a) A Fermi surface pair of Yb_4Sb_3. (b) Cross section of the Fermi surface pair in (a) for the magnetic field applied along <100> direction, shown as the pink plane. The orbit for each Fermi surface is colored by green and blue. There are four degenerate (cross) points on the ΓH axis. The arrows indicate the effective local field at each $\boldsymbol{k}$, corresponding to the spin direction. (c) and (d) Detailed views of the circled part in (b) at an enlarged scale for the cases of inner-to-inner path (c) and of inner-to-outer path (d).

the spin direction does not change or changes continuously. On the other hand, as shown in Fig. 1(d), when an electron changes orbit at the cross point, i.e. the orbital crossing occurs, the spin direction suddenly changes to the opposite direction. We estimated the probability of the orbital crossing from the amplitudes of the dHvA oscillations, and found that such a spin flip takes place on a specific Fermi surface pair for a specific field direction.

PROBING SPIN TEXTURE BY DHVA EFFECT

The existence of orbital crossing in noncentrosymmetric metals has been known for a long time [3]. However, there have been few studies thus far. The novelty of this study is finding that orbital crossing with spin flip depends on the Fermi surface and the magnetic field direction [4]. This indicates that the dHvA effect is a good probe to detect novel properties associated with the spin texture in noncentrosymmetric metals. Our finding will provide deeper understanding of spin texture resulting from the antisymmetric spin orbit interaction.

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