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Anisotropic superconducting gap in the iron-based superconductor $BaFe_2(As_{1-x}P_x)_2$

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Introduction

In the iron-based superconductors, most of the experimental studies have so far indicated that the superconducting (SC) gap is nodeless and opens on the entire Fermi surfaces (FSs) in contrast to the *d*-wave SC gap in the high-T_c cuprate superconductors. However, some systems such as $BaFe_2(As_{1-x}P_x)_2$ [1] show signatures of line nodes in the SC gap. Experimental determination of the presence or absence of line nodes in momentum space is a crucial test of the order parameter symmetry and, hence, of the pairing mechanism. In a laser angle-resolved photoemission (ARPES) study of $BaFe_2(As_{1-x}P_x)_2$ by Shimojima *et al.* [2], nearly anisotropic, FS-independent superconducting gaps around the Z point have been identified. However, a recent study by Zhang *et al.* [3] has reported the observation of a horizontal line node on the outer hole Fermi surface around the Z point. In order to resolve the controversy, in this work, we have performed a systematic ARPES study of $BaFe_2(As_{1-x}P_x)_2$.

Experimental condition

High-quality single crystals of $BaFe_2(As_{1-x}P_x)_2$ with x=0.3 (T_c= 30 K) were grown using the self-flux method. Angle-resolved photoemission (ARPES) experiments were carried out at BL 28A of Photon Factory (PF). A Scienta SES-2002 analyzer and a circularly-polarized light were used with the total energy resolution of ~8-10 meV. The crystals were cleaved *in situ* at T=8-13 K in an ultra-high vacuum of ~5 x10^{-11} Torr.

Results and Discussion

In order to investigate the possible existence of line nodes on the electron FSs, a photon energy of hν =40 eV with a circularly polarized light was used as shown in Fig. 1. Energy distribution curves (EDCs) at Fermi momentum k_F below (T=13K) and above (T=35K) Tc for the inner electron FSs are plotted in Fig. 1(a). The energy shifts of the crossing point between the EDCs below and above T_c. are plotted in Figs. 3(c). These plots indicate that the inner FS has a gap minimum at the edge of the FS (θ_{FS}~0 or 180°). Although the minimum gap value appears to be finite, it should be remembered that ARPES has finite k_z resolution (inverse of the photoelectron meanfree-path ~0.5 nm) and, therefore, that a finite gap may appear even at a nodal k_F point unless the line node is directed in the vertical (k_z) direction. Therefore, the deep gap minima in the inner electron FSs are suggestive of line nodes.

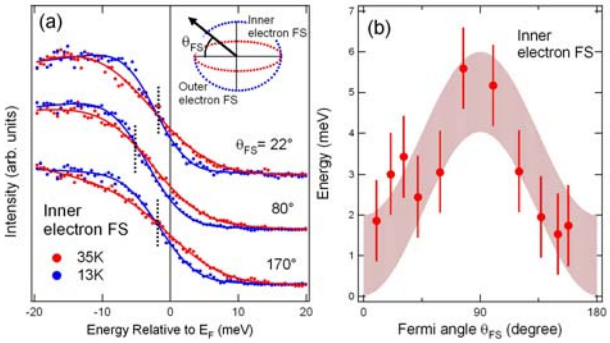

Fig.1: Superconducting gap anisotropy observed on the electron FSs around the X point in $BaFe_2(As_{1-x}P_x)_2$ (x=0.30, T_c=30K). (a) EDCs at k_F taken below (T=13K) and above (T=35 K) Tc for the inner FS. The Fermi angle is defined so that the direction from X to Γ is θ_{FS}=0°. Vertical bars indicate the crossing energy between the spectra below and above T_c. (b) Energy of the crossing point for the inner FSs are plotted as a function of Fermi surface angle θ_{FS}.

References

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