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Laser-excited ultrahigh-resolution photoemission study of anisotropic s-wave superconductor YNi_2B_2C

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Abstract

We have performed laser-excited ultrahigh-resolution photoemission spectroscopy of $Y(Ni_{1-x}Pt_x)_2B_2C$ ($x = 0.0$, 0.2) and numerical simulation using s, anisotropic s and even s + g symmetry to study the superconducting gap anisotropy in borocarbide supercodnuctors. We observed the reduction of gap anisotropy in the $x = 0.2$ sample in comparison to the $x = 0.0$ sample, confirming the anisotropic s-wave gap. We also found that the spectrum of $x = 0.0$ at 3.5 K cannot be fitted well with the s + g-wave symmetry, implying that the s + g symmetry is too simple to describe over all supercodncuting gap electronic structure of borocarbides.

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Keywords: Anistropic s-wave superconductorp; Antiferromagnetic superconductor; Photoemission spectroscopy

1. Main text

In nonmagnetic borocarbide superconductor RNi_2B_2C (R = Lu, Y), various experimental results [1,2] have shown the existence of a large superconducting (SC) gap anisotropy with s-wave SC gap symmetry, in spite of phonon-mediated superconductivity [3,4]. Recently, even the direction and type of node have been discussed from field-angle-dependent thermal conductivity and ultrasonic attenuation for all the symmetrically independent elastic modes [5,6]. But the mechanism of SC gap anisotropy has not been clarified, yet.

In this paper, utilizing laser-excited ultrahigh-resolution photoemission spectroscopy [7] enabling us to measure with higher-energy resolution, more bulk sensitivity, and lower sample temperature, we study anisotorpic s-wave superconductor YNi_2B_2C and discuss its SC gap anisotropy.

Single crystals of $Y(Ni_{1-x}Pt_x)_2B_2C$ ($x = 0.0$ and 0.2) were prepared from a floating zone method [8]. The DC susceptibility measurement indicated that SC transition temperature T_c of the crystals ($x = 0.0$ and 0.2) are 15.4 and 12.1 K, respectively. The energy resolution of all PES measurements was set to 1.5 meV.All the photoemission measurements have been done for insitu fractured surfaces.

Fig. 1 shows normalized SC PES spectra of $Y(Ni_{0.8}Pt_{0.2})_2B_2C$ and YNi_2B_2C near E_F at 3.5 K plotted as a function of binding energy/peak position. The spectrum of $x = 0.0$ has a lower peak intensity and a gentler slope of the leading edge with a larger intensity at E_F compared with those of $x = 0.2$. The variation of SC spectra are more clearly observed than those of our previous study [2].

To verify SC gap function of $Y(Ni_{0.8}Pt_{0.2})_2B_2C$ and YNi_2B_2C, we have tried numerical simulations. In Fig. 2 (a), we show $Y(Ni_{0.8}Pt_{0.2})_2B_2C$ spectrum at 3.5 K (open

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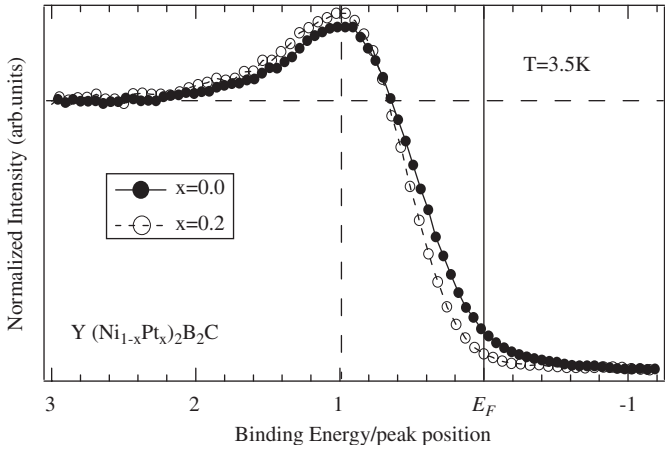

Fig. 1. Normalized photoemission spectra of $Y(Ni_{0.8}Pt_{0.2})_2B_2C$ (open circles) and YNi_2B_2C (filled circles) as a function of binding energy/peak position.

circles) and fitting results with an isotropic s-wave Dynes function [9] (connected line). With the values of $\Delta = 1.75\,\text{meV}$ and $\Gamma = 0.14\,\text{meV}$, the fitting result well reproduces the spectrum, indicating that $Y(Ni_{0.8}Pt_{0.2})_2B_2C$ has a s-wave SC gap symmetry. In Fig. 2 (b)–(d), YNi_2B_2C spectra at 3.5 K are shown together with numerical calculation results with (b) isotropic s-wave, (c) anisotropic s-wave ($\Delta(\theta) = \Delta_{min} + (\Delta_{max}\text{-}\Delta_{min})\ |\cos 2\theta|$ ($\Delta_{min} = 0$)) and (d) s + g-wave ($\Delta(\theta,\phi) = 1/2\Delta(1 + \sin^4\theta\cos(4\phi))$) [10]. Calculated spectra are shown with the best fitting values of (b) $\Delta = 2.35\,\text{meV}$ and $\Gamma = 0.30\,\text{meV}$, (c) $\Delta = 2.80\,\text{meV}$ and $\Gamma = 0.04\,\text{meV}$ and (d) $\Delta = 4.20\,\text{meV}$ and $\Gamma = 0.03\,\text{meV}$.We find that the calculated spectra using anisotropic s-wave can reasonably reproduce the experimental results than using an isotropic s-wave. This indicates a reduction of SC gap anisotropy in $Y(Ni_{0.8}Pt_{0.2})_2B_2C$ in comparison to YNi_2B_2C due to disorder and thus provides experimental evidence for anisotropic s-wave SC gap symmetry of borocarbide supercodncutors [11], consistent with our previous study [2]. On the other hand, we found that the fitting results using s + g-wave symmetry cannot explain the measured spectrum successfully. This implies that the s + g symmetry might not be a suitable one to describe over all SC gap electronic structure of borocarbides. This implies importance of taking the complicated electronic structures of borocarbides into consideration when the s + g wave symmetry is used for analyzing the anisotropic SC gap.

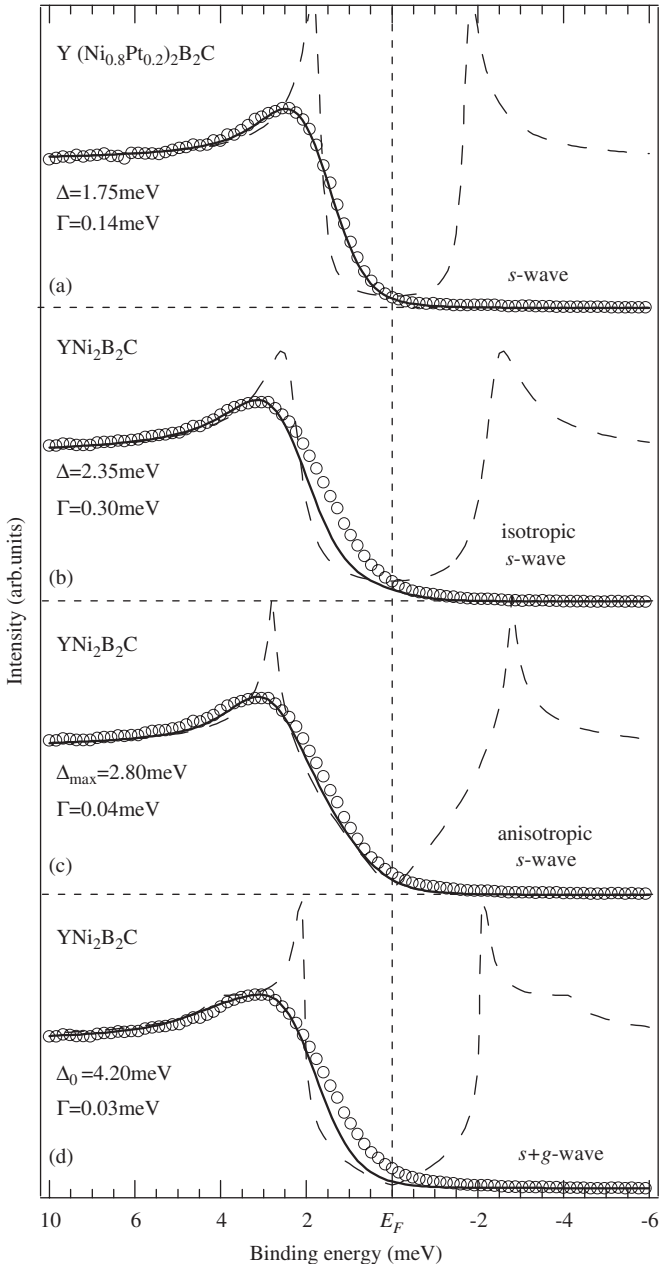

Fig. 2. Numerical calculation results for (a) $x = 0.2$ and (b)-(d) $x = 0.0$ using (a), (b) isotropic s-wave, (c) anisotorpic s-wave and (d) s + g-wave Dynes functions (connected line) together with the raw spectra of $Y(Ni_{0.8}Pt_{0.2})_2B_2C$ and YNi_2B_2C (open circle).

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