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Soft x-ray resonant photoemission study of filled skutterudite superconductor $PrPt_4Ge_{12}$

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1 Introduction

$PrPt_4Ge_{12}$ is a novel filled skutterudite superconductor reported in 2008 [1]. This compound exhibits a superconducting transition temperature (T_c) of 7.9K, being unexpectedly high among the filled skutterudite superconductors containing Pr 4*f* electrons. The reduced gap value ($2\Delta/k_BT_c$) estimated from a specific heat jump was 4.7, which classifies $PrPt_4Ge_{12}$ into a strong coupling superconductor. More recently, muon-spin rotation and specific heat measurements down to very low temperature suggest point-like node in the superconducting gap [2]. In contrast, NMR studies of $LaPt_4Ge_{12}$, its non 4*f* counterpart, suggests a conventional BCS-type superconductivity [3]. In order to understand the exotic superconducting properties in $PrPt_4Ge_{12}$, it is important to investigate the role of 4*f* electrons in $PrPt_4Ge_{12}$.

2 Experiment

Polycrystalline samples of $PrPt_4Ge_{12}$ and $LaPt_4Ge_{12}$ were prepared by a conventional arc-melting method. It was confirmed that they consisted of a single phase of $PrPt_4Ge_{12}$ or $LaPt_4Ge_{12}$ by analyses using an X-ray diffractometer. T_c of $PrPt_4Ge_{12}$ and $LaPt_4Ge_{12}$ samples determined from magnetic susceptibility measurements were 7.9 and 8.2 K, respectively.

Soft x-ray resonant photoemission spectroscopy (SXRPES) and soft x-ray absorption spectroscopy (XAS) were carried out at BL2C, KEK-PF, measured at 20 K and under an ultrahigh vacuum of better than 1 x 10^{-10} Torr. PES measurements were done with a SES2000 analyzer with total energy resolutions setting to 200-300 meV depending on the photon energies. XAS measurements with a total electron yield mode were also performed for the same samples. Clean sample surfaces for SXRPES and XAS measurements were obtained with *in-situ* fracturing of samples at 20 K.

3 Results and Discussion

The results of the bulk sensitive Pr 3*d*→4*f* SXRPES performed at BL2C, KEK-PF shown in Fig. 1 [4]. We found that the spectral shape of the off-resonance spectrum (A in Fig. 1(b)) can be explained by band structure calculations. In the on-resonance spectrum (E), the peak at the binding energy of 4.5 eV can be a Pr $4f^1$ final state, and another enhanced peak near the Fermi level (E_F) indicated with a thick bar possibly corresponds to intermediate states. Absence of a strong peak at E_F in the on-resonance spectrum confirms the localized-like nature of Pr 4*f* electrons. These results from SXRPES studies support the fully localized treatment of Pr 4*f* and the dominant Ge 4*p* character of the states at E_F.

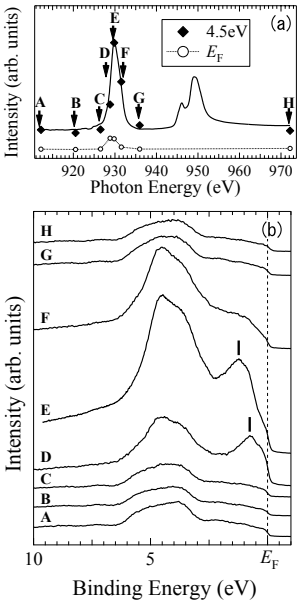

Fig. 1: (a) Pr 3*d*→4*f* XAS and (b) SXRPES spectra of $PrPt_4Ge_{12}$ across Pr 3*d*→4*f*. SXRPES spectra denoted with A-H are measured at photon energies indicated by arrows A to H on the XAS spectrum, respectively. Open circles and filled diamonds are the intensities at E_F and 4.5eV binding energy of the SXRPES spectra.

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