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# Resonant Photoemission Spectroscopy of $RFe_4P_{12}$ (R= La, Ce, Pr)

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## Introduction

Ternary intermetallic compounds $RFe_4P_{12}$ (R= rare earth element) with the filled skutterudite structure exhibit various interesting properties. According to the measurements on a high quality single crystal [1], $CeFe_4P_{12}$ shows the complex temperature dependence of resistivity unexpected for a simple single-gap semiconductor; $PrFe_4P_{12}$ exhibits the Kondo-like anomalies in the transport properties. We investigated the electronic states of $RFe_4P_{12}$ (R= La, Ce, Pr) by the high-resolution resonant photoemission spectroscopy. In this paper, we report the Pr 4*f* spectra of $PrFe_4P_{12}$.

## Experimental

The photoemission experiments were performed using synchrotron radiation at the beam line BL-11D of the Photon Factory, High Energy Accelerator Research Organization (KEK). The instrumental resolution was about 65 meV. The samples were cooled to 20 K.

## Results and Discussion

Figures 1 shows the resonant photoemission spectra of $PrFe_4P_{12}$ and the Pr 4*f* spectrum obtained by subtracting the resonance minimum spectrum ($h\nu$ = 115 eV) from the resonance maximum spectrum ($h\nu$ = 124 eV). In the 115 eV and 124 eV spectra, the intense band located at the binding energy of ~0.7 eV is mainly due to the Fe 3*d* band. In the 4*f* spectrum, the peaks located at ~4.6 eV and ~0.5 eV correspond to the $f^1$ and $f^2$ peaks, respectively. Furthermore, a weak additional structure was observed at 2.6 eV and the $f^2$ peak shows the complicated multiplet structure. To assign these structures, we calculated the multiplet structure of the $4f^2$ configuration using Cowan's code [2]. The Vertical bars in Fig. 1 indicate the calculated multiplet components.

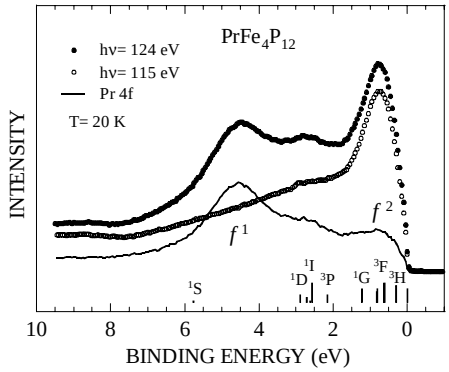


Figure 1: Resonant photoemission spectra of $PrFe_4P_{12}$. The solid line and vertical bars indicate the Pr 4*f* spectrum and the calculated multiplet components, respectively.

For Pr compounds, data for the high-resolution photoemission spectrum are sparse. We have measured the 4*f* spectra of $PrSn_3$ with a high Kondo temperature ($T_K$) and a weakly hybridization system $PrAl_2$ as the reference samples. Figure 2 shows the Pr 4*f* photoemission spectra in the vicinity of the Fermi energy. As can be seen from Fig. 2, the intensity of the $f^2$ peak for $PrFe_4P_{12}$ is stronger than those for the reference systems. This indicates the strong hybridization between the Pr 4*f* and the valence band states.

In all the spectra, the structures due to the $^3H_4$ state were observed at ~0.06 eV. For $PrFe_4P_{12}$ and $PrAl_2$, the $^3H_4$ peaks were observed as a shoulder. On the other hand, the spectrum of $PrSn_3$ with a high-$T_K$ exhibits the $^3H_4$ peak as the peak structure. According to the experimental and theoretical results of the Ce 4*f* spectrum of a Kondo system [3], the spectral shape of the $f_{5/2}{}^1$ peak ascribed to the tail of the Kondo resonance peak varies from a shoulder to a prominent peak with increasing $T_K$. The shoulder structure for $PrFe_4P_{12}$ is similar to the feature observed in the very low-$T_K$ Ce system. Thus, we infer that $PrFe_4P_{12}$ is not a high-$T_K$ system.

## References

[1] H. Sato *et al*., Phys. Rev. B **62** (2000) 15125.
[2] R. Cowan, *The Theory of Atomic Structure and Spectra* (University of California Press, verkeley, 1981)
[3] F. Patthey *et al*., Phys. Rev. B **42** (1990) 8864.

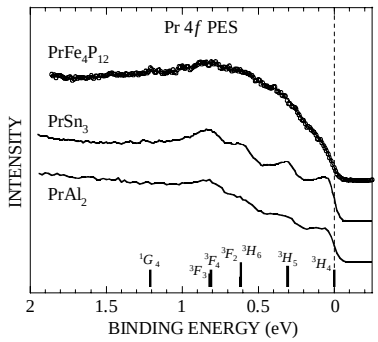


Figure 2: Pr 4*f* photoemission spectra of $PrFe_4P_{12}$, $PrSn_3$ and $PrAl_2$.

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