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High-energy x-ray core-level spectroscopy for $PrFe_4P_{12}$

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In our previous study, we observed a very strong Pr $4f$ spectral intensity just below the Fermi level in $PrFe_4P_{12}$ by means of the bulk-sensitive high-resolution photoemission spectroscopy [1]. The strong spectral intensity is interpreted as a Kondo resonance arising from the hybridization between the Pr $4f$ and P $3p$ states. The rare-earth $3d$ core-level spectroscopy by means of the hard x-ray light source enables us to investigate not *surface-sensitive* but *bulk-sensitive* Pr $4f$ electronic structures because of the large escape depth of photoelectrons in solid as well as the valence band photoemission spectroscopy by means of the soft x-ray light source. In order to obtain a deeper insight into the bulk electronic structures of $PrFe_4P_{12}$, we have carried out the x-ray core-level spectroscopy using the high-energy synchrotron radiation light source up to $h\nu = 5450$ eV at European Synchrotron Radiation Facility (ESRF).

The contribution of $|f^3\rangle$ configuration is obviously seen in Pr $3d$ core-level spectra of $PrFe_4P_{12}$, $PrSn_3$, and Pr metal. Among them, $PrFe_4P_{12}$ has much larger $|f^3\rangle$ intensity than others due to the stronger c-f hybridization. Configuration interaction cluster model calculations reproduce the Pr $3d$ core-level spectra of both well hybridized and localized Pr compounds. Difference of the estimated $4f$ electron numbers between high and low $h\nu$s indicates the larger c-f hybridization strength in the bulk than near the surface. Furthermore, the results of the calculations predict that the Kondo effect observed in $PrFe_4P_{12}$ and $PrSn_3$ originates from the mixing of $|4f^n\rangle$ and $|4f^{n+1}\rangle$ configurations in contrast with the mixing of $|4f^n\rangle$ and $|4f^{n-1}\rangle$ configurations in Ce (n=1) compounds.

[1] A. Yamasaki, S. Imada, T. Masuda, T. Nanba, A. Sekiyama, H. Sugawara, T. D. Matsuda, H. Sato, C. Sekine, I. Shirotani, H. Harima, and S. Suga, Acta phys. Polonica B **34**, 1035 (2003).