

**Photoemission of Pr-, Nd- and Sm-filled skutterudites**

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Among the skutterudite compounds  $RT_4X_{12}$  ( $R$  = rare earth,  $T$  = transition metal,  $X$  = pnictogen), largest  $X$  cage is realized in  $ROs_4Sb_{12}$ , leading to various interesting properties. Electronic states of  $CeOs_4Sb_{12}$ , which shows Kondo insulating behavior[1], and  $PrOs_4Sb_{12}$ , which shows heavy-fermion superconductivity[2], have been studied by photoemission[3,4], and the roles of the  $R4f$  electronic states in the physical properties have been discussed.

In  $SmOs_4Sb_{12}$  was found heavy electron state, which is robust to the magnetic field[5]. In order to get information about Sm  $4f$  state, and also about the hybridization between the  $4f$  state and the conduction band ( $c$ - $f$  hybridization), we have performed bulk-sensitive photoemission[6]. Hard x-ray Sm  $3d$  core-level photoemission indicates that the Sm valence number shows a crossover from a larger high-temperature value to a smaller low-temperature value and also that Sm is kept in the valence fluctuation state throughout. The observed temperature dependence of the Sm valence number is not qualitatively different from that observed by Sm  $2p$  photoabsorption[7]. Furthermore, Sm  $4f$  state is shown to make a large contribution to the electronic states at the Fermi level through the  $c$ - $f$  hybridization.

$NdOs_4Sb_{12}$  has been reported to show ferromagnetism and possible Nd-based heavy-fermion behavior[8]. Sm  $3d$  photoabsorption and soft x-ray photoemission have been carried out[9]. The results suggest that Nd is mainly trivalent in the bulk. Nd divalent components are, however, clearly observed in Nd  $3d$  photoemission and Nd  $3d$ - $4f$  resonant photoemission. High-resolution study suggests the existence of quasiparticle peak caused by the  $c$ - $f$  hybridization near the Fermi level.

We have also studied the electronic states of  $PrRu_4P_{12}$ , in which the metal-insulator (M-I) transition at 60 K was discovered a decade ago[10]. It has been shown[11] that the effective  $c$ - $f$  hybridization strength is significantly large but does not change across the M-I transition. This indicates that the  $c$ - $f$  hybridization nature is highly stable across the M-I transition accompanied by the Ru and P displacement and the CDW formation.

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