Temperature and substitution dependence of extremely low-energy photoemission spectra on $Sm_{1-x}Eu_xB_6$

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SmB_6 and YbB_{12} have been well known as valence fluctuating (VF) Kondo semiconductors (insulators) and intensively studied because of their physical properties. The Kondo semiconductors behave as metals with localized *f* magnetic moments at high temperatures (*T*), whereas they develop a narrow hybridization gap (~10 meV) at the Fermi level (E_F) at low *T*. It is thought that the gap formation originates from the hybridization of the narrow *f* band with broad itinerant valence-bands, but the mechanism of the gap is still controversial.

In our previous hard x-ray photoemission (HAXPES) studies for the Lu substitution Kondo semiconductor alloys $Yb_{1-x}Lu_xB_{12}$ [1], we have found from the *T* dependence of the Yb 4*f* spectral analyses that the 4*f* lattice coherence plays important roles for developing the gap. The gap for YbB_{12} is suggested to be rapidly closed by the Lu substitution of $x = 0.125$ due to the collapse of the 4*f* lattice coherence. On the other hand, our HAXPES study for the Eu substitution alloys $Sm_{1-x}Eu_xB_6$ shows that the *T* dependence of the Sm^{2+} 4*f* spectra for $x = 0.15$ is qualitatively similar to that for pure YbB_{12}. Thus, it is expected from our HAXPES results that a finite gap is still open for $Sm_{0.85}Eu_{0.15}B_6$, although the 4*f* lattice coherence could be broken by the Eu substitution. In order to directly investigate the existence of the gap, we have performed the extremely low-energy photoemission (ELEPES) study on $Sm_{1-x}Eu_xB_6$ (x = 0, 0.15, and 0.5). The ELEPES spectra for $x = 0.15$ and 0.5 were measured by use of synchrotron radiation ($h\nu$ = 7 eV) at UVSOR-II BL7U and those for $x = 0$ and 0.5 were measured with the Xe I ($h\nu$ = 8.4 eV) resonance line. The energy resolution was set to ~6 meV in all measurements.

Figure 1 shows the *T* dependence of the ELEPES spectra near E_F for x = 0, 0.15, and 0.5. According to the photoionization cross section [2], the observed spectra are dominated by the non-4*f* (Sm and/or Eu 5*d* and B 2*sp*) states. For $x = 0$, we find that a so-called leading-edge of the spectra is on the occupied side, which indicates the existence of the finite gap. In addition, the prominent peak is observed at ~15 meV, which is comparable to that due to the magnetic excitation observed by neutron scattering measurements for SmB_6 [3]. With increasing *T* from 5 to 200 K, The spectral weight on E_F increases and the peak shits toward the higher binding energy side. It should be noted that the spectra for $x = 0.15$ show the essentially equivalent *T* dependence for $x = 0$, which indicates that $Sm_{0.85}Eu_{0.15}B_6$ is still a Kondo semiconductor against the collapse of the 4*f* lattice coherence. In contrast, the spectra for $x = 0.5$ show no prominent peak and thus a typical metallic thermal behavior. These ELEPES results indicate that SmB_6 is a “robust” Kondo semiconductor against a rare-earth substitution, which is significantly different from YbB_{12}.

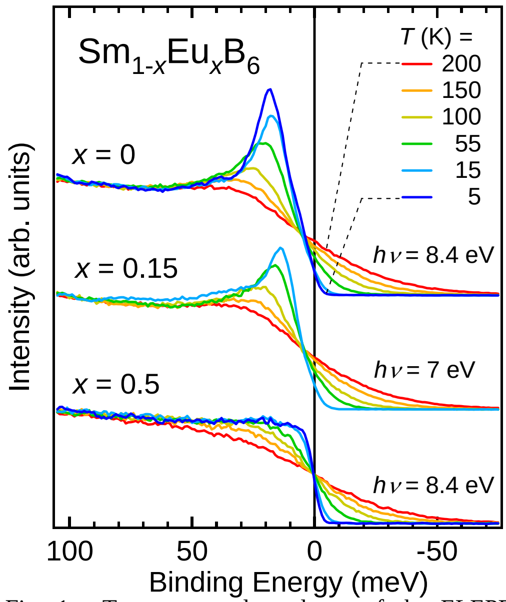

Fig. 1. Temperature dependence of the ELEPES spectra near E_F for $Sm_{1-x}Eu_xB_6$.

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