Electronic Structure of $RuSr_2R(Cu_{1-x}M_x)_2O_8$ (R=Gd, Eu and M=Ni, Zn)

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The ruthenium-based layered copper oxide, $RuSr_2RCu_2O_8$ (Ru-1212), where R is small rare-earth ions like Gd and Eu, has attracted intensive investigation over the last decade because of the unconventional appearance of high-temperature superconductivity (T_C = 20 – 50 K) below long-range magnetic ordering (T_M = 100 – 150 K) [1]. Recently, D.C. Ling et al. [2] have reported the impurity induced influence both on superdonductivity and ferromagnetism for the Ni- and Zn-substituted Ru-1212. The Cu substitution by Zn exhibits the contrast reduction rate of transition temperature, T_C, between RuGd-1212 (rapid) and RuEu-1212 (slow), respectively, while Ni melts regularly the superconductivity regardless of the kind of base materials (Gd and Eu). In contrast to the pair-breaking effects by Ni and Zn impurities, the magnetic ordering, T_M, increases in RuGd-1212 as doped regardless of the kind of impurities while it decreases in RuEu-1212.

In order to elucidate the doping effects, the electronic structure of RuR-1212 (R=Gd, Eu) and doped samples has been investigated by using photoemission spectroscopy (PES), which were performed at the beamline 08A equipped with an OMICHRON EA125 hemishperical analyzer with a base pressure better than $1x10^{-9}$ mbar. The ranges of photon energy were used between 50 and 160 eV, which energy resolution is approximately between 150 and 300 meV. For clean surface, we scraped the sample in-situ using a diamond file.

Figure 1 shows the valence-band spectra obtained at the hν = 130 eV. The main valence-band in the range of 1-8 eV represnet the Cu 3d partial spectral weights (PSW's) because the hν = 130 eV is above the Cooper minimum of the Ru 4d cross section (~ 100 eV). However, the contribution of oxygen still remains at this photon energy due to the ratio of photon ionization cross section between Cu ($2+:3d^9$) and O ($2-:2p^4$) is 0.67 : 0.32 under the consideration of the formula units.

Two satellites around 9-13 eV are not due to the contamination like CO. They have main contribution from the hybridization of Cu and Gd (Eu) 4f with oxygen. The Gd and Eu 4d → 4f resonance occur around 140-160 eV photon energy. The PSW's of Gd and Eu 4f states are localized at 8.4 eV (FWHM = 2.8 eV) and 7 eV (FWHM =3.3 eV) with very weak features near E_F, respectively.

Upon doping, the peak (indicated by arrow) around 3-4 eV for RuEu-1212 and 5-7 eV for RuGd-1212 increases and broadens, respectively. The difference clarifies the doping dependence which was taken by subtracting the valence band of doped sample from that of undoped RuR-1212 (R=Gd and Eu). They are in good agreement with the calculations [3]. Note that the bandwidth and shape is clearly different between RuGd-1212 and RuEu-1212 supporting the different spin state due to different amount of mixed Cu valence states, in fact Cu^{2+} and Cu^{3+}.

Inset displays that the spectral weights near the Fermi energy, E_F. The chosen photon energy, hν = 60 eV, is above the Ru 4p → 4d resonance, which is known to occur around 52 eV photon energy. The intensity decreases along with doping for RuGd-1212 while the case of RuEu-1212 has no significant change. This indicates why the transition temperature, T_C, of superconductivity is suppresed by the impurity doping.

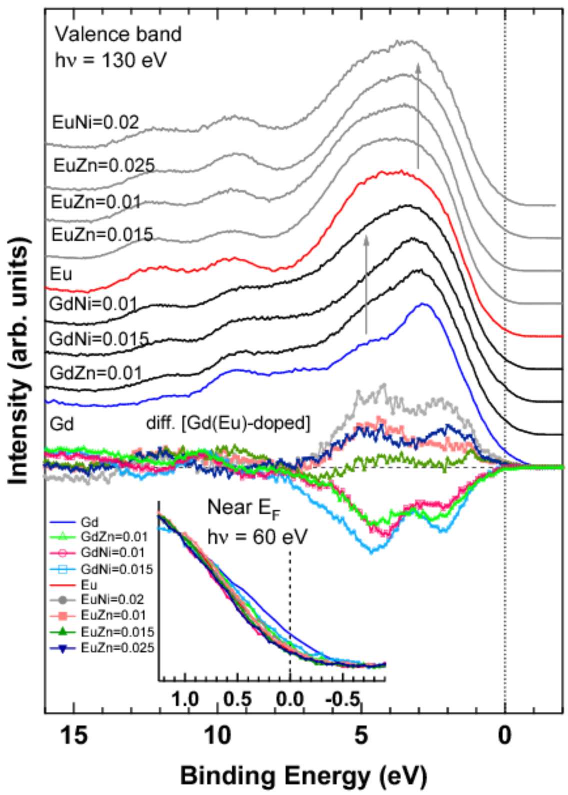

Fig. 1: hν = 130 eV valence-band spectra. The difference was taken by subtracting the valence band of doped sample from that of undoped RuR-1212 (R=Gd and Eu). Inset shows the spectra near E_F at hν = 60 eV.

References

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