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Electronic structure of impurity systems by resonant soft-X-ray ARPES: Application to the diluted magnetic semiconductor GaMnAs

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A fundamental benefit soft-X-ray ARPES (SX-ARPES) in the energy range around 1 keV is the photoelectron escape depth increasing by a factor of 3-5 compared to the conventional VUV-ARPES. Furthermore, this region covers the 2p and 3p core levels of the transition and rare earth metals, respectively, which brings another benefit of the elemental and valence-state specificity achieved through resonant photoemission. These spectroscopic properties of SX-ARPES, combined with advanced instrumentation since recently available at the ADRESS beamline of SLS, have enabled the move of this technique from bulk materials to buried heterostructures and impurities.

We illustrate first applications of resonant SX-ARPES to impurity systems with the diluted magnetic semiconductor (Ga,Mn)As, which is considered as the paradigm spintronics material. Despite more than a decade of intense research and various theoretical approaches ranging the p-d exchange to double-exchange models, the mechanism of ferromagnetism in (Ga,Mn)As still remains obscured. Our resonant SX-ARPES experiments on the Mn 2p absorption edge have for the first time unambiguously identified the Mn 3d-derived impurity band (IB) inducing the ferromagnetism as located about 300 meV below the valence-band maximum and hybridized with the light-hole band of the host GaAs. These findings conclude the long disputed picture on the (Ga,Mn)As valence band structure. The non-dispersive character of the IB and its energy alignment relative to the GaAs bands unveil its origin as a split-off Mn-impurity state predicted by the Anderson model. Responsible for the ferromagnetism in (Ga,Mn)As is the transport of hole carriers in the IB. Our experiments are further extended to (InFe)As showing the ferromagnetism induced by doped electron carriers. These examples illustrate an enormous application potential of SX-ARPES to a wide range of functional materials from bulk systems to heterostructures and impurities.

[1] M. Kobayashi et al, http://arxiv.org/abs/1302.0063

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