

Linear and circular magnetic dichroism in angle-resolved hard X-ray photoemission from Heusler compounds

Heusler compounds have attracted scientific and technological interest and are now widely used as materials for magneto-electronic devices [1]. One major technology where Heusler compounds are used is on tunneling magneto resistive (TMR) junctions. To develop high performance spintronic devices, it is essential to clarify the electronic structures of these films and compare them to bulk materials. Hard X-ray photoelectron spectroscopy (HAXPES) is a powerful method to probe both chemical states and electronic structure of bulk materials and buried layers in a non-destructive way [2]. The combination of HAXPES with polarized radiation for excitation significantly extends its applicability. The use of linearly *s* and *p* polarized light in HAXPES enables the analysis of the symmetry of bulk electronic states [3]. In the present study the valence band electronic structure of NiMnSb bulk material was investigated by means of HAXPES and linear dichroism. The *2p* core level of a thin exchange biased thin film of Co₂FeAl as used in TMR devices was studied by means of HAXPES combined with circular magnetic dichroism.

The polarized HAXPES experiments were performed at BL47XU using 7.94 keV linearly and circularly polarized photons for excitation. Horizontal (*p*) polarization was obtained directly from the undulator without any additional polarization optics. An in-vacuum phase retarder based on a 300- μ m-thick diamond crystal was used to produce vertical, linearly *s*-polarized light or circularly σ^+ or σ^- polarized light, all with a degree of polarization above 90%. Gracing incidence ($\alpha=88^\circ$) – normal emission ($\theta=2^\circ$) geometry was used that ensures that the polarization vector was nearly parallel (*p*) or perpendicular (*s*) to the surface normal or that the polarization vector σ coincides with the magnetization. The energy resolution was set to 150 meV and was verified by spectra of the Au valence band at the Fermi energy. For further details of the experiment see [3,4].

Figure 1 compares the valence band spectra and calculated electronic structure of NiMnSb. The density of states exhibits a typical 4-peak structure in the energy range of the *d* states as well as the split-off *s*-band with *a*₁ symmetry. These structures are clearly resolved in the spectra. The sum of the polarization-resolved spectra corresponds to a spectrum with unpolarized photons. The width of the *d*-part of the density of states (0...5 eV) corresponds to the width of the measured spectra. The spectrum exhibits a rather high intensity in the *a*₁-part below -7 eV that is caused by the higher cross section for *s*-states

compared to *d*-states at high excitation energy. The intensity of the *d*-states is governed by the states localized at the Ni atoms. It is evident that striking differences appear in the spectra if the polarization is changed from *p* to *s*. The spectra indicate that the *a*₁ states have a higher intensity for *p* polarization and the *s* polarization result in a higher intensity in the energy range of the *d*-states. In particular, the intensity of the Ni 3*d* states at -2 eV is enhanced and the structure of the density of states becomes better resolved under illumination with *s* polarized photons. These observations show that the symmetry of the states can be explored using linearly polarized photons [3].

Figure 2 shows the Fe 2*p* and the “shallow” core level of a deeply buried Co₂FeAl film underneath

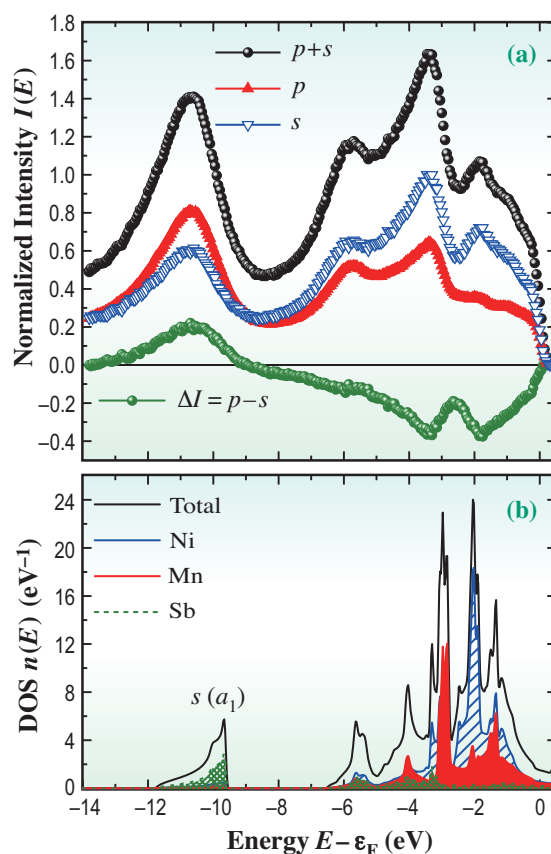


Fig. 1. Electronic structure and polarization-dependent photoelectron spectra of NiMnSb. (a) Spectra obtained with *s* and *p* polarized light together with the sum and difference and (b) total and partial density of states (DOS).

10 nm of MnIr. The differences in the spectra taken with opposite helicity of the photons at a fixed direction of magnetization are very pronounced. The spin-orbit splitting of the Fe 2*p* states is clearly resolved, as expected. If going from 2*p*_{3/2} to 2*p*_{1/2}, the dichroism changes its sign across the 2*p* spectra in the series - + + - what is typical for a Zeemann-type *m_j* sub-level ordering. Details of the MCDAD reveal, however, that the situation is more complicated. For such complex multilayer structures the situation becomes complicated in the way that the signals from all the elements contained in the system are detected. One still notices strong signals from the buried elements even though the ferromagnetic Co₂FeAl layer lies underneath the antiferromagnetic IrMn layer. As expected no MCDAD is observed for the Ir and Mn states. A non-vanishing asymmetry is clearly observed only for Co and Fe signals that are

just the ones being responsible for the ferromagnetic properties of the system. The asymmetry of 50% in the Fe 3*p* signal is huge. At the Co 3*p* it is well detected even though the direct spectra overlap with Ir states.

Overall, the high bulk sensitivity of HAXPES combined with linearly and circularly polarized photons will have a major impact on the study of the magnetic phenomena of magnetic materials. It will allow an element-specific study of the magnetism of buried layers and make feasible the investigation of the properties of magnetic layers not only at the surface but also at buried interfaces. The results obtained with circularly polarized photons confirm the possibility to distinguish between localized or itinerant character of the magnetic moments in complex compounds. The symmetry of valence states can be determined when using linearly polarized photons.

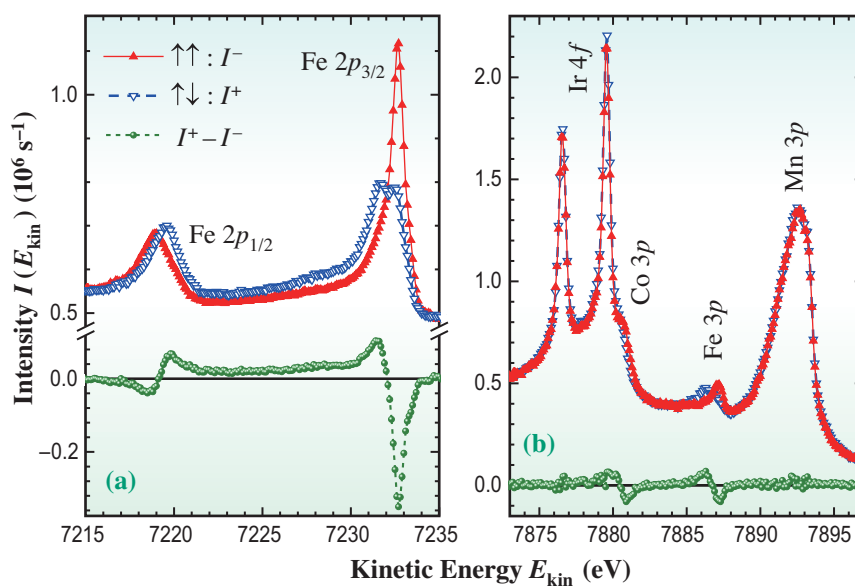


Fig. 2. High kinetic energy core level spectra and MCDAD from Co₂FeAl underneath a 10 nm thick IrMn film. (a) Fe 2*p* core level; (b) shallow core levels. [4]

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