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Local-spin-selective X-ray absorption and X-ray magnetic circular dichroism of MnP

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Abstract

The local-spin-selective X-ray absorption spectrum and the magnetic circular dichroism (MCD) spectrum are measured at the manganese K edge of MnP. A comparison of the two techniques makes it possible to determine the energy dependence of the Fano factor. It is found that the Fano factor is -4% at the edge while it decreases to values lower than 1% at all energies more than 7 eV above the edge.

1. Introduction

To study magnetic effects with X-ray absorption spectroscopy, two techniques have been developed: local-spin-selective X-ray absorption and X-ray magnetic circular dichroism (MCD). Local-spin-selective X-ray absorption has been exploited for the first time by Hämäläinen and coworkers [1]. In this technique the K edge X-ray absorption spectrum is measured by detecting the Kβ X-ray emission ($3p \rightarrow 1s$) decay channel at two different energy positions. By selecting, respectively, a spin-up and a spin-down peak of the Kβ X-ray emission spectrum one is able to obtain a local-spin selectivity in the manganese K edge absorption spectrum [2]. The difference between spin-up (μ_+) and spin-down (μ_-) spectra is given as: $\mu_+ - \mu_- = [R_+^2 \rho_+] - [R_-^2 \rho_-]$, where $R_\pm$ are the matrix elements and $\rho_\pm$ the density of states. The use of a core spectrum for the spin selectivity implies that the spin is referenced to the local situation in the solid. For a ferromagnet this is equivalent to an externally referenced technique.

X-ray MCD effects have been observed for the first time by Schutz and coworkers [3]. The difference between left (μ_L) and right (μ_R) circular X-rays is proportional to the difference in the spin polarization of the empty states multiplied with their matrix element. ($\mu_L - \mu_R = P\{[R_+^2 \rho_+] - [R_-^2 \rho_-]\}$). The proportionality factor is the so-called Fano factor (P), which originates from the spin–orbit coupling of the final states of p-symmetry [4]. The Fano factor can be determined directly from a comparison of the local-spin-selective X-ray absorption spectrum and the X-ray MCD spectrum:

$$P(\omega) = \frac{\mu_L(\omega) - \mu_R(\omega)}{\mu_+(\omega) - \mu_-(\omega)}. \tag{1}$$

Due to the coherence of the 1s X-ray absorption and $3p \rightarrow 1s$ X-ray emission processes the 1s life time broadening (FWHM = 1.5 eV) disappears for local-spin-selective X-ray absorption [5]. For a sharp peak in the Kβ decay spectrum the broadening is given by the life time of the 2p final states (FWHM = 0.8 eV). A detailed analysis of the Kβ X-ray emission spectra and a comparison with a theoretical density of states is given in Ref. [6].

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2. Experiment

The local-spin-selective X-ray absorption experiment was carried out on the X25 hybrid wiggler beam line at NSLS. A double crystal Si(2 2 0) monochromator with a resolution of 0.7 eV (FWHM) was used. The Kβ X-ray emission was analyzed with a Rowland circle spectrometer equipped with a spherically bent Si(4 4 0) crystal with a resolution was 0.3 eV [5]. The X-ray MCD experiment was performed at the energy dispersive beamline of the DCI storage ring at LURE. A curved Si(1 1 1) dispersive monochromator with a resolution of 1.2 eV (FWHM) was used. Right circularly polarized X-rays were selected by positioning a 1 mm vertical slit at 3 mrad below the synchroton orbit plane [6].

The two local-spin-selective X-ray absorption spectra are given at the bottom of Fig. 1 for spin-up (solid) and spin-down (dashed). Their difference is indicated in the top spectrum with the open circles. If one normalizes the absorption spectra to 1.0 the difference reaches a maximimum of + 4% at 6543.5 eV. In the difference spectrum a shoulder is visible at 6538.5 eV. The middle spectrum shows the X-ray absorption spectrum measured with circularly polarized X-rays. The spectrum measured with the opposite magnetization direction is not visibly different. The X-ray MCD effect (multiplied by 50) is indicated at the top with the solid dots. It has a maximum difference of − 0.08%.

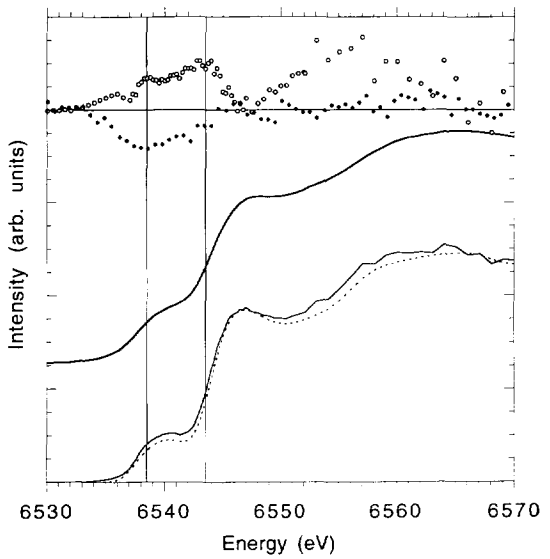

Fig. 1. Bottom: The local-spin-selective X-ray absorption spectra for spin-up (solid) and spin-down (dashed). Middle: The X-ray absorption spectrum taken with transmission. Top: Comparison of the local-spin-selective X-ray absorption difference spectrum (open circles) and the X-ray MCD spectrum (solid points; multiplied with 50).

It can be seen that both the local-spin-selective X-ray absorption spectrum and the X-ray MCD spectrum show relatively large effects between 6535 and 6545 eV. For X-ray MCD the effect diminishes at higher energies. According to Eq. (1), by dividing both spectra the energy dependence of the Fano factor is found. The Fano factor reaches its highest value (− 4%) at the edge and decreases to a value lower than 1% for all energies 7 eV above the edge.

Acknowledgements

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