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A Practical Method to Correct the Saturation Effect in XMCD Spectra

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I report a simple method to correct the saturation effect in absorption spectra measured in total electron yield (TEY) mode. It does not require additional measurements of the X-ray penetration depth. In order to check the reliability of the method, X-ray magnetic circular dichroism (XMCD) spectra for polycrystalline Fe were measured at two different incident angles, and then processed with the method. The two resultant XMCD spectra were identical, and their sum rule analysis produced the ratios of orbital magnetic moment to spin magnetic moment, which were very close to the well-known value.

Keywords : X-ray absorption spectroscopy, X-ray magnetic circular dichroism, saturation effect

1. Introduction

For decades, X-ray magnetic circular dichroism (XMCD) has been an important tool of magnetics due to its unprecedented abilities to measure the magnetic properties with elemental specificity and to separate the orbital and spin magnetic moments. These abilities support researches exploring the microscopic origin of the magnetic properties of transition metal and rare earth compounds [1-5]. XMCD spectrum is the difference between two absorption spectra of circularly polarized X-ray with opposite directions of magnetization. The absorption spectra have been exclusively measured by an indirect method to detect the total electron yield (TEY) because of its simplicity and high sensitivity. Usually it is accepted that TEY is proportional to the absorption coefficient to a large extent. Nevertheless, the problem of saturation effect cannot be avoided in the quantitative analysis of orbital magnetic moment using TEY [6, 7]. This problem is caused by the large variation in X-ray penetration depth across the resonant absorption edges, and the relative intensities of prominent peaks in the TEY spectrum are reduced by the effect.

The saturation effect has been studied extensively and is expressed by the following equation [6]:

$$Y(t,\ \theta)=C\frac{1}{1+\lambda_e/\lambda_x\cos\theta}(1-e^{-t(1/\lambda_e+1/\lambda_x\cos\theta)})\mu \qquad (1)$$

Here, Y is TEY, μ the absorption coefficient, θ the photon incident angle from the surface normal direction, λ_e the electron sampling depth, and λ_x the X-ray penetration depth. The proportionality constant C is given by $C=I_oG\lambda_e/\cos\theta$, where the electron gain function G is proportional to the photon energy [8]. As shown in this equation, the effect is described explicitly but the actual application of this equation is not straightforward because it requires the X-ray penetration depth of the sample at all relevant photon energies and the TEY spectra are recorded in an arbitrary unit. Thus, the saturation correction has been made in only a limited number of works, in which the penetration depth was obtained through an independent experiment of measuring the transmission of a thin film on a semitransparent film or measuring the photoluminescence of a transparent substrate in the visible region [9-11]. However, such data are usually not available since their determination requires a different set of samples grown on a special substrate as well as an additional set-up for the measurement of the other yields.

In this work I suggest a new method to correct the saturation effect. Only the theoretical values of the X-ray penetration depth outside the region of resonant edges (before and after the edges) are used to calculate the theoretical electron yield and match it with the measured electron yield in the same unit, thereby eliminating the necessity of the independent transmission measurement. The reliability of this method is also confirmed by applying it to the XMCD spectra measured on an isotropic Fe polycrystal at two different angles before the sum rule

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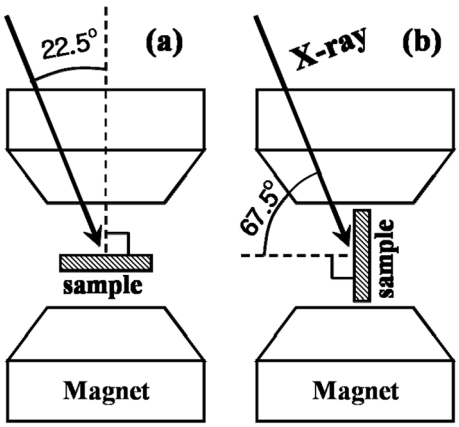

Figure 1. Configuration of XMCD measurements: (a) θ=22.5° and (b) θ=67.5°.

analysis.

2. Experiment

The XMCD measurements were conducted at the Pohang Light Source (PLS) Magnetic Spectroscopy beamline 2A. All measurements were taken with left-circularly polarized X-rays with an energy resolution of 0.2 eV in the TEY mode. An electromagnet was used to flip the magnetic field of 1 T at every photon energy point. The Fe polycrystal was *in-situ* scraped just before the measurement to remove the contamination layer on the surface. Two XMCD spectra at Fe $L_{2,3}$ absorption edges were obtained at two different photon incident angles of 22.5° and 67.5°, as shown in Figure 1. All the spectra were normalized by the intensities of the incident photon beam, which were measured by using an Au grid in front of the XMCD chamber.

3. Analysis

The two electron yield spectra at two different incident angles are compared in Figure 2(a). As Fe polycrystal is isotropic magnetically, it should produce the same XMCD spectrum at all incident angles. However, as shown in this figure, the spectrum at the higher glancing angle of 67.5° suffers more seriously from the saturation effect, and the respective integrations of each spectrum (panel (b)) converge at different values, which correspond to the ratios of the orbital magnetic moments [1]. Furthermore, their signs are opposite. Therefore, the saturation correction is essential for the quantitative sum rule analysis.

The theoretical values of the X-ray absorption coefficient μ_c can be obtained easily from the literature [12]. However, they need to be changed to the corresponding

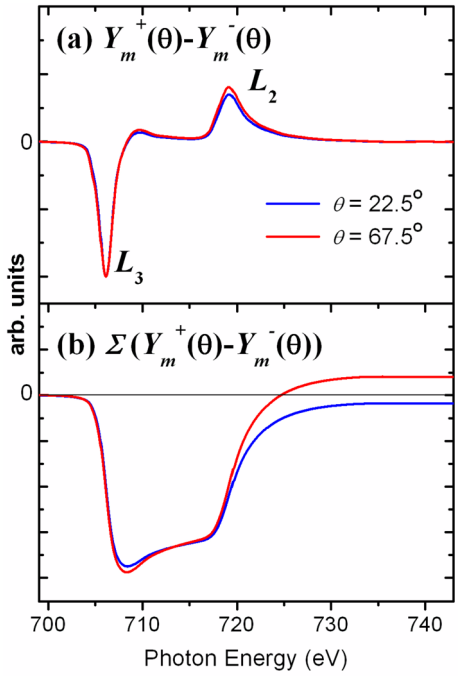

Figure 2. (colour online) Comparison of two TEY spectra for Fe $L_{2,3}$ edges at two different incident angles. (a) The XMCD spectra do not coincide even though the sample is isotropic. (b) The integrations of the XMCD spectra are saturated differently, misleading that there is an orbital anisotropy in the Fe polycrystal.

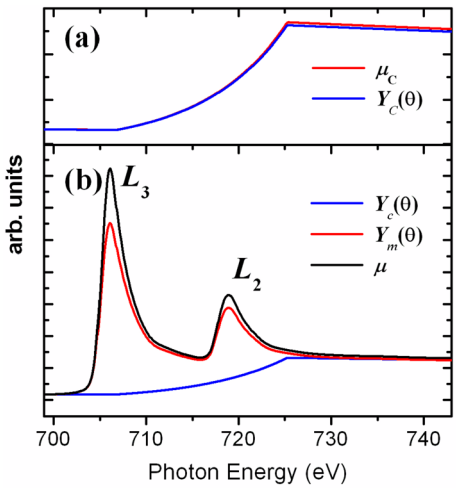

Figure 3. (colour online) (a) Theoretical absorption spectrum and the calculated TEY considering the saturation effect. (b) TEY and saturation-corrected absorption spectra.

values of electron yield $Y_c(\theta)$ at the incident angle θ by inserting them into equation (1). In the photon energy region around the resonant edges, abnormal excitation processes occur that prevent the theory from producing reliable values, as shown in Figure 3(a). However, the values outside the resonant region agree well with the

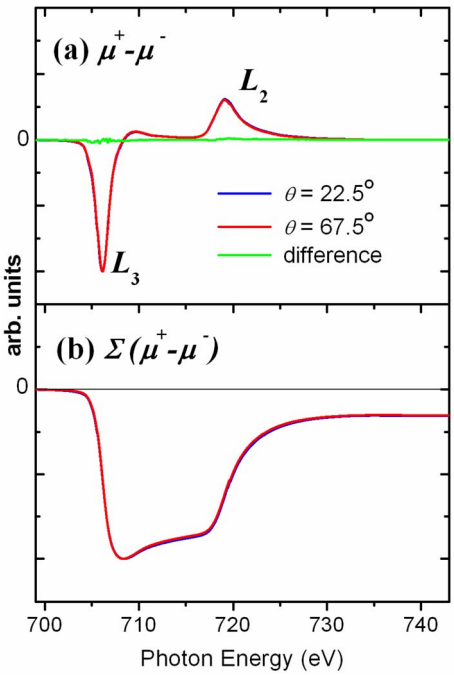

Figure 4. (colour online) Comparison of two XMCD spectra at two different angles after saturation correction. (a) The XMCD spectra do not exhibit any noticeable features in the difference spectrum. (b) The integrations of the XMCD spectra produce the same values for the orbital and spin magnetic moments.

measured ones [6] and can be used to fix the scale of the measured electron yield by subtracting a constant value ΔY from the measured spectrum. ΔY is determined as the value which makes the step-jump ratio across the absorption edges in the measured spectrum coincide with that of $Y_c(\theta)$. Then the factor C required to make both ends of $Y_c(\theta)$ and $Y_m(\theta)$ meet can also be determined. This process is physically meaningful because the contribution from the stray photon beam and higher harmonics is unavoidable in actual measurement. The contribution is merely assumed to be constant in the photon energy range concerned. So $Y_m(\theta)$ can then be inserted into equation (1) to obtain the saturation-corrected absorption spectrum μ, as shown in Figure 3(b).

The same values of $\Delta Y(\theta)$ and $C(\theta)$ are also used to correct the saturation effect in the XMCD spectra. The resultant spectra for two different photon incident angles are shown in Figure 4. The two spectra coincide very well and there is no noticeable structure in the difference spectrum between them. Consequently, their sum rule analysis produces the same value of 0.043 as the ratio of the orbital magnetic moment to the spin magnetic moment, m_o/m_s, which perfectly agrees with the well-known value for bulk Fe [1].

4. Conclusion

The saturation correction of XMCD spectra was made with a new method that can be applied without any additional measurement of the X-ray penetration depth, which is not available in most XMCD setups. The validity and accuracy of the method were confirmed by application to two differently saturated XMCD spectra.

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References

[1] C. T. Chen, Y. U. Idzerda, H.-J. Lin, N. V. Smith, G. Meigs, E. Chaban, G. H. Ho, E. Pellegrin, and F. Sette, Phys. Rev. Lett. **75**, 152 (1995).
[2] W. L. O'Brien, T. Droubay, and B. P. Tonner, Phys. Rev. B **54**, 9297 (1996).
[3] J. Stöhr, J. Magn. Magn. Mater. **200**, 470 (1999).
[4] J.-Y. Kim, T. Y. Koo, and J.-H. Park, Phys. Rev. Lett. **96**, 047205 (2006).
[5] J.-S. Lee, J.-Y. Kim, J. H. Shim, B. I. Min, K.-B. Lee, and J.-H. Park, Phys. Rev. B **76**, 060403(R) (2007).
[6] Reiko Nakajima, J. Stöhr, and Y. U. Idzerda, Phys. Rev. B. **59**, 6421 (1999).
[7] Susana Gota, and Martine Gautier-Soyer, Phys. Rev. B **62**, 4187 (2000).
[8] J. Stöhr, *NEXAFS Spectroscopy*, Vol. 25 of Springer Series in Surface Science (Springer, Heidelberg, 1992).
[9] D. J. Huang, C. F. Chang, J. Chen, H.-J. Lin, S. C. Chung, H.-T. Jeng, G. Y. Guo, W. B. Wu, S. G. Shyu, and C. T. Chen, J. Electron Spectrosc. Relat. Phenom. **137-140**, 633 (2004).
[10] M. Kallmayer, H. Schneider, G. Jakob, H. J. Elmers, K. Kroth, H. C. Kandpal, U.Stumm, and S. Cramm Appl. Phys. Lett. **88**, 072506 (2006).
[11] Wilhelm F., Poulopoulos P., Shrivastava P., Wende H., Farle M., Baberschke K., Angelakeris M., Flevaris N. K., Grange W., Kappler J. P., Ghiringhelli G., and Brookes N. B. Phys. Rev. B **61**, 8647 (2000).
[12] Henke B. L., Gullikson E. M. and Davis J. C., The webpage of *Center of X-ray Optics LBNL* (2002).