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Influential factors affecting the quantification accuracy of magnetic moments with electron magnetic chiral dichroism technique

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Background:
Electron magnetic chiral dichroism (EMCD), a transmission electron microscopy (TEM) technique based on electron energy-loss spectroscopy (EELS), allows quantitative measurements of element-selective spin and orbital moments at a high spatial resolution [1-2]. Since EMCD was first demonstrated in 2006 [1], the investigation of the influencing factors of quantitative determination has always been fundamentally important. The influencing factors of asymmetrical diffraction condition, plural scattering effect and signal-to-noise ratio (SNR) have been mostly discussed in the literature, and some data treatment methods have been correspondingly proposed. However, more questions are open. First, deconvolution has been routinely applied to EMCD spectrum to remove the plural scattering, but how effective the deconvolution of momentum-resolved spectra can be? Second, how the universal problem of electron damage can affect the EMCD quantification? Third, what is relationship between SNR and quantification accuracy? We explored our answers to these questions.

Method:
For the first question, TEM experiments were performed on a wedge-shaped area in a plane-view TEM specimen of Fe/MgO(001) thin film. A series of low-loss EELS, conventional in-axis core-loss EELS with Fe-L2,3, and pairs of q-resolved core-loss EELS with Fe-L2,3 edges at two chiral positions were acquired from areas of different thicknesses, using spectrum imaging in the scanning TEM mode (STEM-SI), as in Figure (a). The in-axis EELS and q-EELS before and after deconvolution with changing thickness were then compared.

For the second question, TEM experiments were performed on a cross-sectional TEM specimen of Co/MgO(001) thin film. The surface oxidation layer and amorphous layer were damaged under continuous electron irradiation, as in Figure (a). The changes in shape and intensity of EELS spectrum Co-L2,3 edges under continuous electron irradiation were followed and its influence on the shape of EMCD spectrum was discussed.

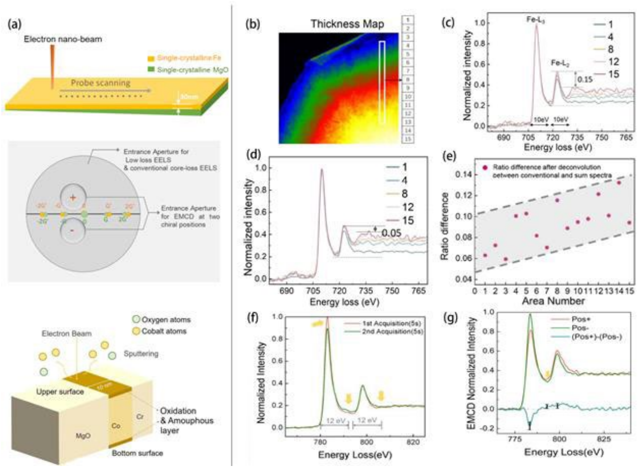
For the third question, a pair of EELS spectra at Co-L2,3 edges were mathematically constructed. The background, L3 edge, L2 edge and continuum background of each spectrum were respectively described by one inverse power exponent function, two gaussian functions and one double arctan step function. Various degrees of white gaussian noise were added to the EELS spectra. EMCD spectra with different SNR were thus obtained, and quantification results were compared.

Results and Conclusions:
(1)The q-resolved spectra after deconvolution still contain residual plural scattering, which is more significant in thicker areas than thinner ones, as shown in Figure (c-d). It is then derived that the existence of such residual plural scattering would bring artifacts to ml/ms value. The thicker the detected area is, the higher the ml/ms value would be obtained even after deconvolution. We suggest that even deconvolution would be performed, EMCD spectra should be acquired from sufficiently thin samples for minimizing the plural scattering effect in originally detected spectra before any deconvolution [3-4].

(2) Under sustained electron irradiation during spectra acquisition, a gradual removal of the thin surface oxidation layer, rather than a simple continuous thickness reduction that changes the diffraction and plural scattering conditions, can lead to notable residual nonmagnetic components in EMCD spectra and may make the quantified result of the orbital-to-spin moment ratio remarkably higher than the actual value, as in Figure (f-g). It was thus proposed to pay great attentions to the surface oxidation and to minimize the effect of oxidation layer by performing electron irradiation on the target area prior to EMCD experiments, for improving the quantification accuracy [5].

(3) For quantitative measurement of orbital-to-spin moment ratio of Fe, Co, Ni with an error range within about 50% of actual value, the minimum noise degree should be smaller than 0.01.

Graphic:



Keywords:

TEM, EMCD, quantification, magnetic moment

Reference:

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