Electron Vortex Beam Characterization of L1₀ FePt Nanograins

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Due to the increasing demand of data storage capacity, hard disk drives are still important for long term, large volume data storage. Heat assisted magnetic recording (HAMR) is currently the most promising technology for advancing disk drive areal density well beyond 1 Tb/in² [1]. HAMR uses very high anisotropy materials such as L1₀ ordered FePt to maintain data thermal stability and store information. It is critical to understand the structure and magnetic properties of FePt nanograins at grain or atomic level because the variations in microstructure and properties cause severe recording performance degradation. Electron magnetic circular dichroism (EMCD) coupled TEM, is likely to be the only way to investigate their magnetic properties along with their microstructure. Classic EMCD methodology with a parallel beam has been reported to detect dichroism signal at nm level [2, 3], but is challenging to reach atomic resolution. The quantitative analysis is also very complicated because of the poor signal-to-noise (S/N) ratio in spectra. An alternative way to perform EMCD is to use electron vortex beam (eVB) which carries orbital angular momenta and is adjustable in size [4]. Up to now, the detection of dichroism method by eVB is still at its very early stage. Production of eVBs using a diffraction hologram produces multiple probe beams at the specimen, which can create overlapping images. For HAMR FePt nanograins, overlap effects from neighbor grains are also needed to be considered.

Here we report several collection methods to perform eVB-EMCD on L1₀ ordered FePt nanograins using TEAM I microscope with a Gatan Tridiem GIF (NCEM, Molecular Foundry). The new available vortex beam grating (from University of Oregon) installed on February 2017 shows side beam is improved to approx. 30% of the total intensity [5]. Plan view samples of FePt with grain size of 8 nm were prepared by mechanical polishing, dimpling and ion mill until almost perforated. Nanomill (Fischione) is applied to clean the sample surface.

For the first collection setup, a normal STEM/EELS was used. As shown in Figure 1a and b (same image in different intensity limits), there are two ghost images in a line at the sides of the 0 beam image. The two ghost images are from the +1 and -1 beam, respectively. Figure 1a inset shows a typical vortex beam from the first eVB grating on TEAM I. Three Fe L₂,₃ edge spectra were collected from the +1, 0 and -1 beam images. Clearly, there is no overlap from beams or other grains as the +1 and -1 images are in the vacuum and well separated. Three Fe L₂,₃ EELS spectra normalized by L₁ from the +1, 0 and -1 beams are shown in Figure 1c. The difference in Fe L₃/L₂ ratio could be related to dichroism, while asymmetry in the intensity and shape of the +1, -1 probes, position-dependent background signal produced by the other diffracted orders, etc, could also change the L₃/L₂ ratio.

It is clear that the first method is only applicable to grains at the edge of the specimen which had issues of bending, stabilities, and tilting, etc. In order to study grains within the sample (away from the edge), we studied a second setup, in which confocal STEM mode (or image mode, diffraction off) was used.
Similar to TEM mode, the vortex beams can be seen directly by the CCD/GIF. GIF entrance aperture can be used to select the desired post-specimen beam.

In both above two experiments, we used atomic size eVB and wanted to see how the EELS spectra look like using eVB. One consequence for the atomic size eVB is that the probe current is limited and the EELS spectra are noisy. Even with a special high-brightness FEG on TEAM I, the EELS spectra collected for 30s in 2nd setup have a poor S/N in raw data (Figure 2). Increased stability is necessary for a longer exposure. We will discuss further about the data collection and propose the condition that could get dichroism. At the same time, new strategy (i.e. eVB with aberration, eVB holography) is ongoing.

References
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Figure 1. STEM images (a) and (b) of L10 FePt using eVB (inset) in different intensity limits. (c) Fe L_{2,3} edge spectra (smoothed) from the +1, 0 and -1 beam.

Figure 2. (a) STEM image of L10 FePt using eVB and (b) Fe L_{2,3} edge spectra (smoothed) from the +1, 0 and -1 beam by 2nd method from the center grain in (a).