

## Imaging Perpendicular Magnetic Domains in Plan-view Using Lorentz Transmission Electron Microscopy

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The study of magnetic materials requires an understanding of not only their magnetic properties, but also their microstructure. Transmission electron microscopy (TEM) is a powerful characterization instrument because of its ability to provide both microstructural and magnetic information. In TEM, electrons can be deflected by a Lorentz force created by a magnetic field from a magnetic material. This deflection can then be detected by electron holography [1] or the Fresnel Lorentz imaging technique [2]. In this report, we present the results of applying the latter technique with a novel use of the plan-view orientation to observe perpendicularly magnetized domains in thin film media used in hard disk drives. The results show that in this orientation, for which the electron beam is parallel to the dominant magnetic fields in the sample, the TEM can be effectively used to obtain information about the magnetic domains (i.e. the recording bits).

For this study, we used perpendicular magnetic recording (PMR) media [3] from a commercial hard disk drive. Multiple sets of four tracks each, in which each track has a different recording density, were written circumferentially on the media. Each recorded bit in the thin film is a single magnetic domain with magnetization either up or down. It contains hundreds of CoCrPt alloy grains, which have diameters of about 7nm and are separated by a thin oxide intergranular phase and a coercivity of about 5000 Oe. To identify the recorded bits, we used magnetic force microscopy (MFM) to obtain an image of the recorded tracks (Figure 1) clearly shows the multiple four-track sets.

In the study itself, conventional TEM sample preparation was used to make a plan-view PMR media specimen: grinding, polishing, dimpling, and ion milling. The specimen was imaged using a FEI Titan 80-300 Environmental TEM at an operation voltage of 300kV. A Lorentz lens was used instead of the objective lens to avoid demagnetizing the specimen. At a large defocus of about 1 cm, MFM-like bit pattern images became visible with some image enhancement and processing. As can be seen in Figure 2, the defocused Lorentz TEM image shows dark and bright contrast (indicated by arrows) that resembles that of the MFM image (Figure 1). The dimension of the contrast pattern was then measured by line scans were found to match the MFM measurements. The recorded tracks are clearly being imaged in the Lorentz image.

A tilting experiment was also done to find the relationship between the specimen orientation and the image contrast. A double tilt holder tilting up to  $\pm 20$  degrees both along the holder axis and the perpendicular axis was used. At some tilt positions, the highest frequency tracks show up and disappear, but in the greater part of the image, the MFM-like contrast from the tracks remains the same.

It is not yet clear how the Lorentz image contrast is being obtained in the PMR media but the magnetic fields outside the specimen certainly have a horizontal component. However, what is significant here is that, with the use of the plan-view orientation, the large defocus Lorentz TEM technique can be applied

to studying various magnetic materials with magnetic fields that are only weakly interacting with the TEM electron beam.

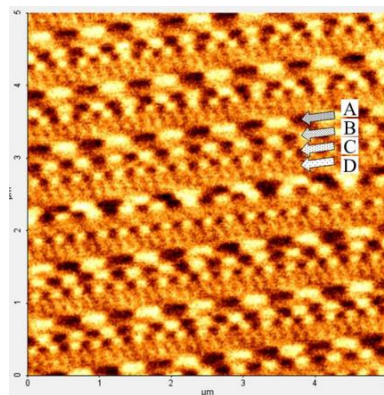
#### References:

[1] R. E. Dunin-Borkowski *et al*, Science 282.5395 (1998) p. 1868-1870.

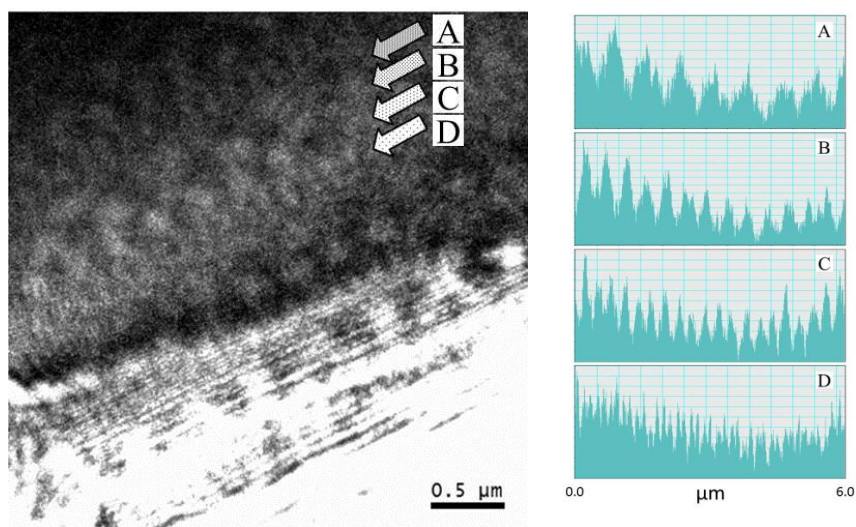
[2] K. Tang *et al*, IEEE Trans. Magn. 32.5 (1996) p. 4130-4132. [3] G.

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**Figure 1.** MFM image ( $5\ \mu\text{m} \times 5\ \mu\text{m}$ ) of the PMR media showing multiple sets of tracks; the four tracks (indicated by arrows) within each set have different recording densities. The recorded bits have density ratios of 4:8:12:20, corresponding to around 70 / 120 / 170 / 350 kfc/i (kilo flux change per inch) (i.e. A, B, C, D in bits, respectively). Park Systems XE-70 was used with MikroMasch NSC18/Co-Cr tip in non-contact mode to obtain the image.



**Figure 2.** Left: Lorentz image after image processing to enhance the contrast. Equivalent tracks to the MFM image are indicated by arrows. Right: Intensity profile of line scans of the tracks clearly show that the bit patterns match those expected and are consistent with the MFM image.