Novel Magnetic Force Microscopy Operation Employing Torsional Resonance Mode

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Abstract

The constant miniaturization of magnetic bits in hard-disk drives creates the need for a convenient and versatile high resolution magnetic imaging method. Magnetic Force Microscopy (MFM), a scanning probe technique, has been widely used for this purpose for more than two decades [1,2]. However, the current MFM lateral resolution in ambient conditions is roughly equal to the magnetic bit size of commercial hard-disks (≈40 nm), making imperative the improvement of MFM performance. In this work, we present the advantages of performing MFM imaging employing the Torsional Resonance (TR) mode of cantilever oscillation [3].

Traditional vibrating tip modes of MFM operation, e.g. Tapping Mode MFM (TM-MFM), employ the flexural ("diving board") cantilever deflection signal for feedback control, while the detection scheme is principally sensitive to forces perpendicular to the sample. However, TR-MFM takes advantage of the torsional (twisting) cantilever deflection. In this case, lateral forces that act on the tip can cause a change in the torsional resonance frequency of the cantilever, allowing the local characterization of sample properties and the detection of in-plane components of force-fields.

The utilization of TR mode for imaging in-plane components of magnetic fields has been demonstrated [4,5], but not extensively studied. In this work, TR-MFM is examined in detail [6]. Measurements have been performed using a commercial scanning probe microscope (Dimension Icon, Bruker). Home-coated magnetic probes have been used: hard magnetic CoCr layers have been deposited on commercial Atomic Force Microscopy (AFM) probes (Nanosensors), using ultrahigh vacuum magnetron sputtering. A double-pass method is used for performing MFM measurements: a TM-AFM main scan yields the surface topography, while the long-range magnetic forces are detected using a lifted TR-MFM scan (or a TM-MFM scan, for comparison).

TR-MFM provides two main advantages over conventional TM-MFM measurements. The first is related to the insensitivity of TR mode to out-of-plane forces and most notably, the Van der Waals forces. Thus, the only long-range forces contributing to the signal detection scheme are magnetic forces, allowing the magnetic imaging of a surface with total absence of topography-related signal (see figure 1). The second advantage originates from the minimal flexural oscillation amplitude. As the flexural cantilever oscillation is only excited thermally, the corresponding oscillation amplitude is around 1 nm, more than one order of magnitude lower than in the case of TM-MFM. This provides the ability of performing dynamic MFM measurements with significantly reduced tip sample distance (the tip can even be lowered during the “lifted” scan). As a result, improved spatial resolution can be achieved (see figure 2), while preserving a high signal-to-noise ratio.

Taking into account the above-mentioned advantages, it is argued that TR-MFM provides a significant improvement to a prolific magnetic imaging method widely used in Academia and in Industry.

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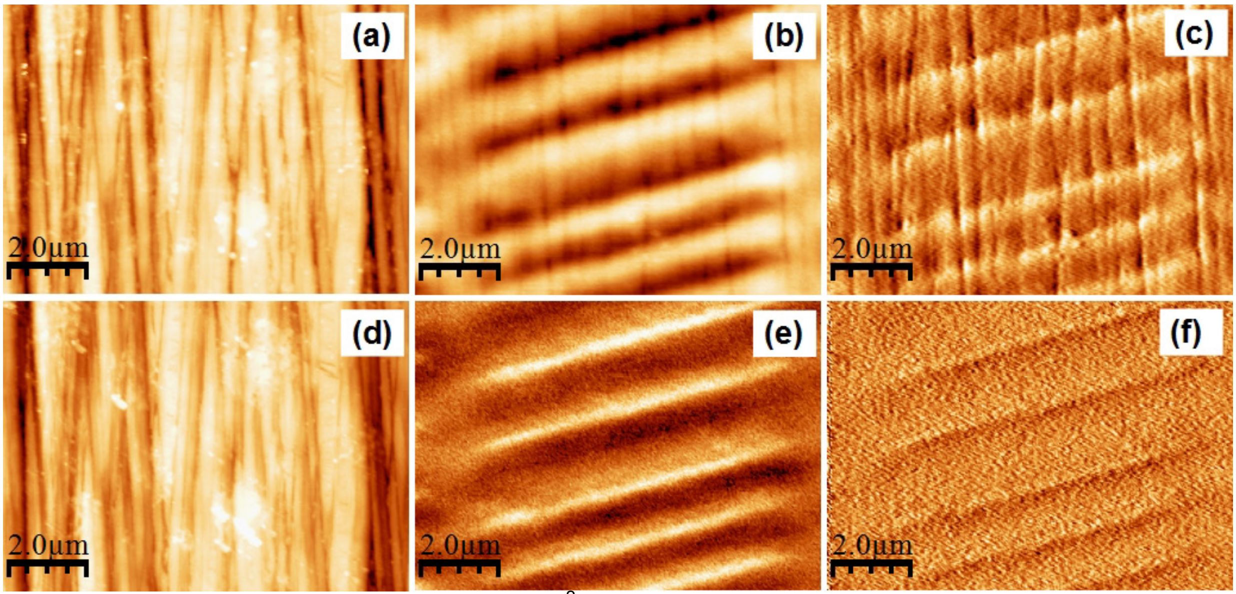

Figure 1: MFM phase imaging of a 0.1 Gb/inch^2 longitudinal magnetization hard-disk. The images have been obtained at the same position. (a-c) TM-MFM, lift height: 20 nm, (a) topography (0 – 68.4 nm), (b) phase image (0 – 4.3 deg.), signal/noise ratio: 13, (c) derivative of phase image (0 – 10.6 deg/μm). (d-f) TR-MFM, same area as in (a-c), lift height: -5 nm, (a) topography (0 – 60.0 nm), (b) phase image (0 – 0.5 deg.), signal/noise ratio: 25 (c) derivative of phase image (0 – 2.4 deg/μm). As TR mode is sensitive to lateral force gradients, the TR-MFM contrast is reversed with respect to TM-MFM.

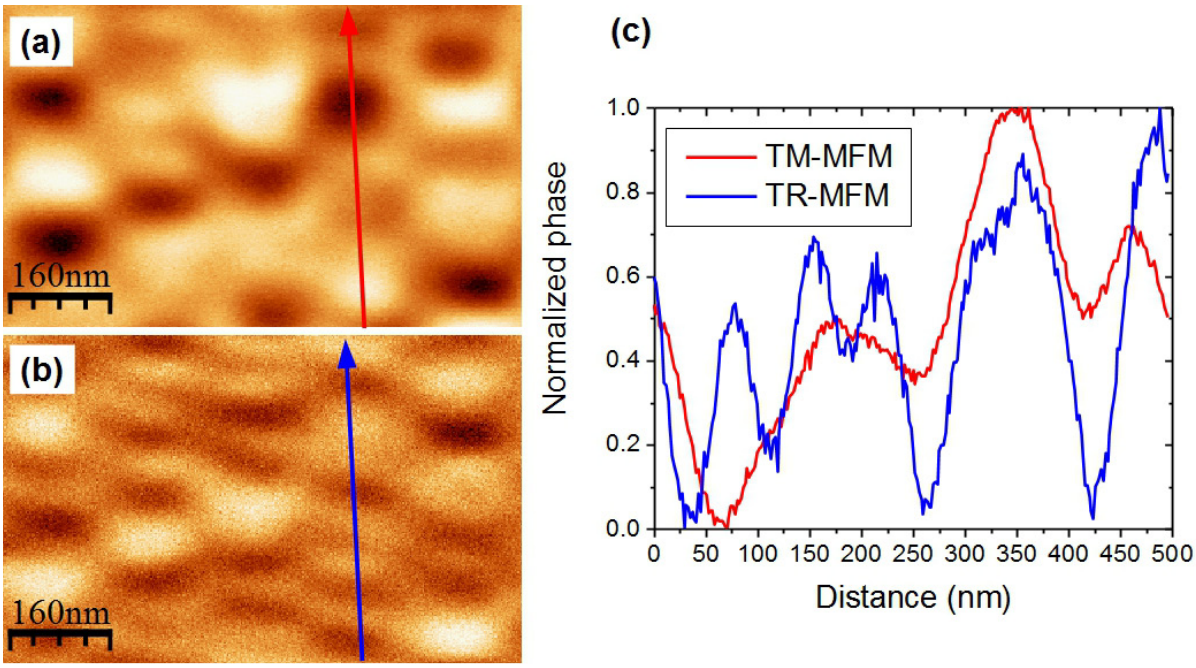

Figure 2: MFM phase imaging of a 100 Gb/inch2 perpendicular magnetization hard-disk. The images have been obtained at the same position. (a) TM-MFM phase image, lift height: 15 nm, color scale: 0 – 2.4 deg., S/N ratio: 17. (b) TR-MFM phase image, same area as in (a), lift height: -29 nm, color scale: 0 – 1.0 deg., S/N ratio: 4. (c) Line profiles averaged along the indicated directions in (a) and (b). The TM-MFM line profile has been inverted.