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Capacitive distance control for measuring particulate magnetic media with Magnetic Force Microscopy.

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It is challenging to precisely image magnetic structures in a context of pronounced topography. Tapping mode techniques have been developed to provide a practical solution to the need for magnetic characterization in these situations. By successively scanning the topography of the sample and its magnetic signal on a line-by-line basis, the sample's inherent topography and most dust contamination can be dealt with, constituting a convenient method for the study of e.g. patterned media, or other small structures. But as research and development push the relevant dimensions downward, higher sensitivity and spatial resolution are required of the measurement. It thus becomes necessary to move to vacuum, whereby the cantilever sensitivity is increased and adhered water layers can be removed. Vacuum operation also facilitates low temperature measurements, which generally present stability advantages apart from the possibility of applying large magnetic fields. The quantitative evaluation of measurement data introduces a further constraint on the measurement, that the tip must not be modified between measurements.

Because tapping mode is not practical in vacuum on account of the large cantilever quality factor, and is inconvenient when seeking quantitative evaluation results, we need to develop appropriate non-contact vacuum operation methods. In the following we describe a non-contact method that is well suited to measuring patterned media, or other samples with substantial topography. It provides high sensitivities and thus lateral magnetic resolution.

In past work we have investigated a bimodal measurement technique in which the different effects of the tip-sample interaction on different cantilever oscillation modes was exploited[1]. A different degree of freedom is used for distance control here – specifically, that the capacity between tip and sample depends on the tip-sample distance. By looking at the cantilever response to an applied oscillating bias, we obtain a measure of this capacitance and thus a proxy for the tip sample distance.

Figure 1 shows a series of measurements performed on a Co/Pt bit pattern media using the tip-sample capacitance as a control parameter. The method can be used to follow the topography locally as shown in panels 1a and 1b in Figure 1. This results in a direct measurement of the topography of the sample which is shown in panel 1b of Figure 1. By construction, however, this results in a tip trajectory surface that makes a quantitative analysis of the sample magnetization exceedingly difficult. Panels 2a and 2b in Figure 1 show the results of a measurement taken at an average tip sample distance. The tip-sample capacitance, which is shown in panel 2b, accordingly resembles the sample topography in this case. A difficulty in the interpretation of the raw frequency shift data shown in the panels 1a and 2a is due to the fact that the tip can only measure the magnetic force gradients in superposition with other tip sample interactions such as van-Der-Waals or electrostatic interactions. Nevertheless, the knowledge of the topography gives us the possibility to subtract these background interactions from the frequency shift data at constant average height. Thus we could obtain an image of the magnetic tip sample interaction.

A series of such images which reveal the magnetization of the sample clearly is shown in panels 3a to 3f in Figure 1. The data was taken in subsequent scans at an average tip-sample distance at different magnetic fields between 0 mT and 355 mT in order to investigate the switching behavior of the media[2].

1. Schwenk, J., Marioni, M., Romer, S., Joshi, N. R. & Hug, H. J. Non-contact bimodal magnetic force microscopy. *Applied Physics Letters* **104,** 112412 (2014).

2. Hauet, T. *et al.* Reversal mechanism, switching field distribution, and dipolar frustrations in Co/Pt bit pattern media based on auto-assembled anodic alumina hexagonal nanobump arrays. *Phys. Rev. B* **89,** 174421 (2014).

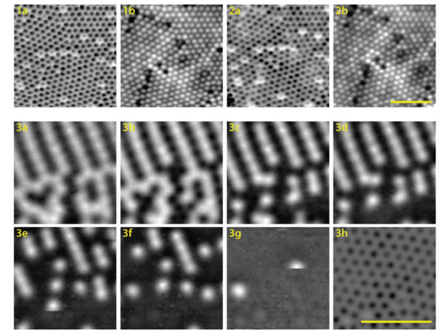

Figure 1: The images show measurements on particulate media. Panels 1a/b show a measurement taken at constant local tip sample distance, 1a: frequency shift, 1b: topography image. Panels 2a/b show a measurement taken at constant average tip sample distance, 2a: frequenca shift, 2b: capacity signal resembling the topography. Panels 3a-h show the switching of the magnetisation of the sample at magnetic fields of 0mT (a), 81mT (b), 162mT (c), 183mT (d), 207mT (e), 230mT (f), 311mT (g) and 355mT (h). Both scalebars indicate 500nm.