Imaging Nanoscale Magnetization Using Scanning-Probe Magneto-Thermal Microscopy

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Primary CNF Tools Used: JEOL 9500, GCA 5x stepper

Abstract:

High resolution, time-resolved magnetic microscopy is crucial for understanding novel magnetic phenomenon such as skyrmions, spinwaves, and domain walls. Currently, achieving 10-100 nanometer spatial resolution with 10-100 picosecond temporal resolution is beyond the reach of table-top techniques. We have developed a time-resolved near field magnetic microscope based on magneto-thermal interactions, which achieved spatial resolution of sub-100 nm. Our results suggest a new approach to nanoscale spatiotemporal magnetic microscopy in an accessible, table-top form to aid in the development of high-speed magnetic devices.

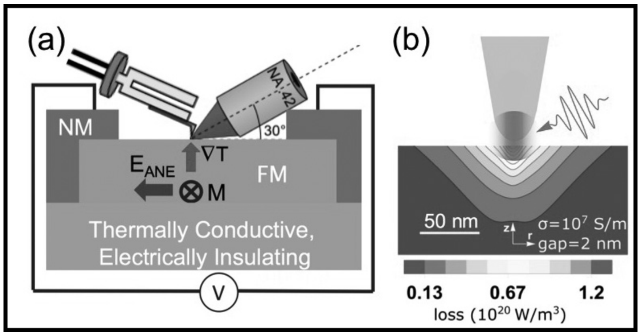

Figure 1: Schematics of (a) our scanning near field magneto-thermal microscopy setup, illustrating laser, sample and scan probe, and (b) near-field interaction. The sample figure in (b) is from Ref. [5].

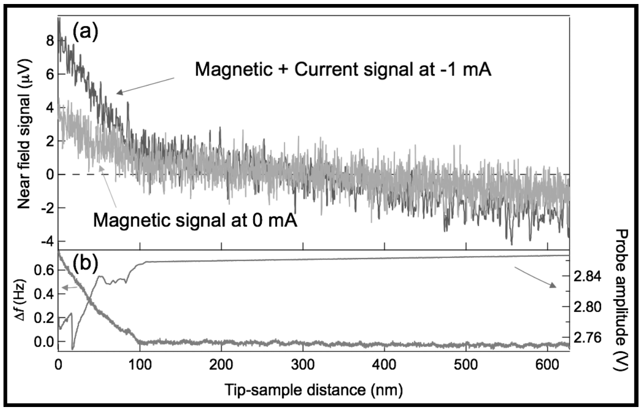

Figure 2: Near-field characteristic. Tip-sample distance dependence of (a) near-field signals and (b) probe parameters.

Summary of Research:

Our group has previously developed a time-resolved magneto-thermal microscopy [1-3]. We apply a pulsed laser to create thermal gradient ∇T. The local magnetization M subjected to ∇T generates an electric field E_{ANE} through anomalous Nernst effect [Figure 1(a)]. This enables us to do magnetic imaging, with a spatial resolution of 650 nm and a temporal resolution of 10 ps. This technique can be used to image both local static and dynamic magnetization, as well as an applied current density [4]. In this work, we extend the magneto-thermal microscopy to nanoscale resolution with near-field light. We use a gold-coated cantilever glued on tuning fork as our probe, controlled by atomic force microscopy.

We shine a laser on the tip apex, and the near field enhancement of the electric field at the tip [5-6] heats the sample as a nanoscale heat source [Figure 1(b)]. The heating length scale is comparable to the tip radius; below 100 nm.

We first study a 5 µm × 15 µm CoFeB/Hf/Pt sample fabricated using photolithography with the GCA 5x stepper. We confirm the near-field characteristic of the signal by measuring as a function of tip-sample distance. We record the near-field signal as well as other probe parameters as the tapping probe approaches the sample [Figure 2]. The near-field signal increases when the tip

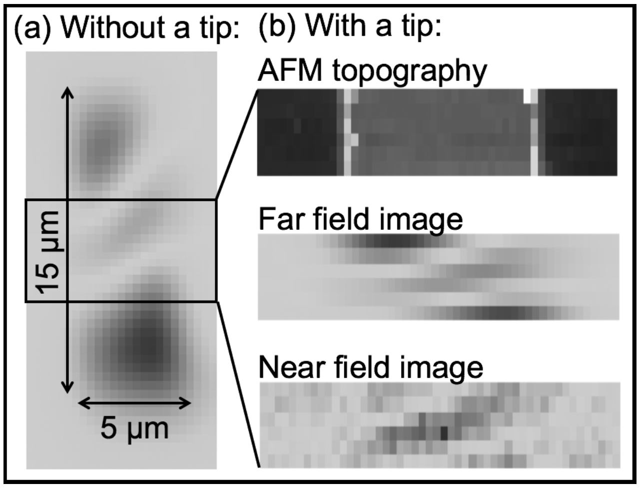

Figure 3: Magnetic multi-domain imaging. (a) Magnetic far-field images of a multi-domain state. (b) With a scanning probe tip, topography, far-field and near-field images acquired simultaneously.

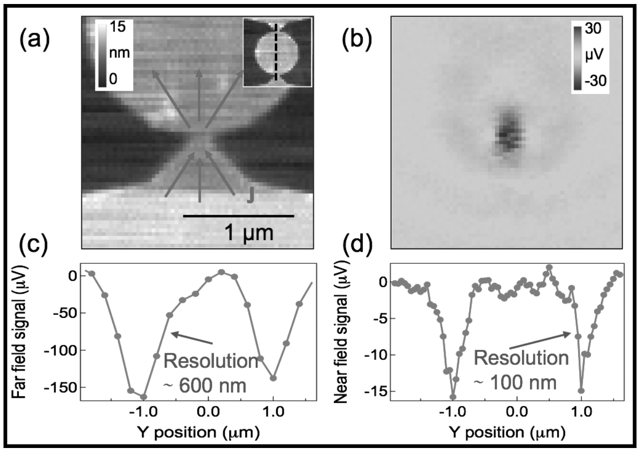

Figure 4: Current imaging and spatial resolution. (a) Topography and (b) current density images acquired by a near field tip. Line cuts through two necks (as illustrated in the inset of (a)) of (c) far field and (d) near field signals for resolution comparison.

is in first contact with the sample, indicated by an initial increase of the frequency and decrease of the amplitude. The short-range nature of the signal is consistent with a near-field interaction.

We next demonstrate magnetic imaging of near field scanning probe with a multi-domain state. Figure 3(a) shows a far-field image taken by a focused light to confirm the magnetic state. Figure 3(b) shows topography, far-field and near-field images, acquired simultaneously with the scanning probe. The near-field image resembles the far-field image, but with higher resolution. We note that the near-field image has a smallest feature of ~ 300 nm in this sample, which is below the optical diffraction limit of the set-up. That feature is likely the actual domain wall width rather than being limited by the instrument resolution.

To probe instrument resolution further, we measure in current imaging mode and use a new sample designed with a sharp current density feature. The sample is a thin-film heterostructure composed of 5 nm $Ni_{81}Fe_{19}$/2 nm Ru, then patterned into a 2-μm-diameter disk with two 130 nm necks using JEOL 9500 e-beam lithography. Figure 4 shows topography and near-field current density images taken with the near-field scanning probe. By taking linecuts through two necks, as shown in Figure4(a) inset, we compare signals between focused light far field and scanning probe near field. The scanning near-field image has higher resolution than far field image, and based on sharp features, demonstrates an upper bound of spatial resolution of 100 nm.

Conclusions and Future Steps:

We have developed a time-resolved scanning near field magneto-thermal microscopy for magnetic and current imaging. We confirmed near field nature of the signal, and characterized the spatial resolution to be sub-100 nm. In the future, we will apply this instrument to study the dynamics of nanoscale spin textures.

References:

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