Magnetic Force Microscopy with a diCP-II Atomic Force Microscope

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ABSTRACT

Magnetic force microscopy is an expansion upon the nano-scale analysis enabled by the principles of atomic force microscopy. This mode of microscopy images surface magnetic characteristics of a sample with vertical resolution of 20-30 nanometers and lateral resolution of 50-100 nanometers. Images of a sample's magnetic domain are found by recording the interactions between a magnetic probe and stray magnetic fields from the sample. In this study, magnetic (MESP-CMT) probes with a radius of 20 nanometers and a sputtered CoCr coating were mounted within the diCP-II Veeco Instruments atomic force microscope, substituting standard contact (CONT20A) mode probes that were previously used to conduct tip-to-sample interactions. Given the conductive properties of the magnetic coating, the MESP probes allow the possibility of future experiments involving electrical and capacitance microscopy.

Introduction

The ability to image a large variety of magnetic samples throughout a range of conditions, along with the capacity to measure nano-scale magnetic domains with an applied force as low as 10^{-14}N, showcase the versatility of magnetic force microscopy in the field of surface material analysis. The compatibility of magnetic force microscopy in conjunction with other forms of microscopy such as scanning tunneling microscopy allows analysis of several distinct surface characteristics of a single sample. Magnetic force microscopy is particularly applicable to magnetic data storage media, as the need to increase data density requires ever finer analytical tools.

The successful implementation of magnetic force microscopy is dependent upon the mechanical oscillation of a scanning probe and the measurement of different force regimes up to 200 nanometers above the surface of the sample.

One of the main drawbacks of magnetic force microscopy is its inability to provide rigorous, quantitative analysis of surface features. While the imaging is very responsive to changes in magnetic domains, because of the small net force, it is difficult to plot the magnetic moment of the sample relative to the deflection of the probe at each point being scanned.

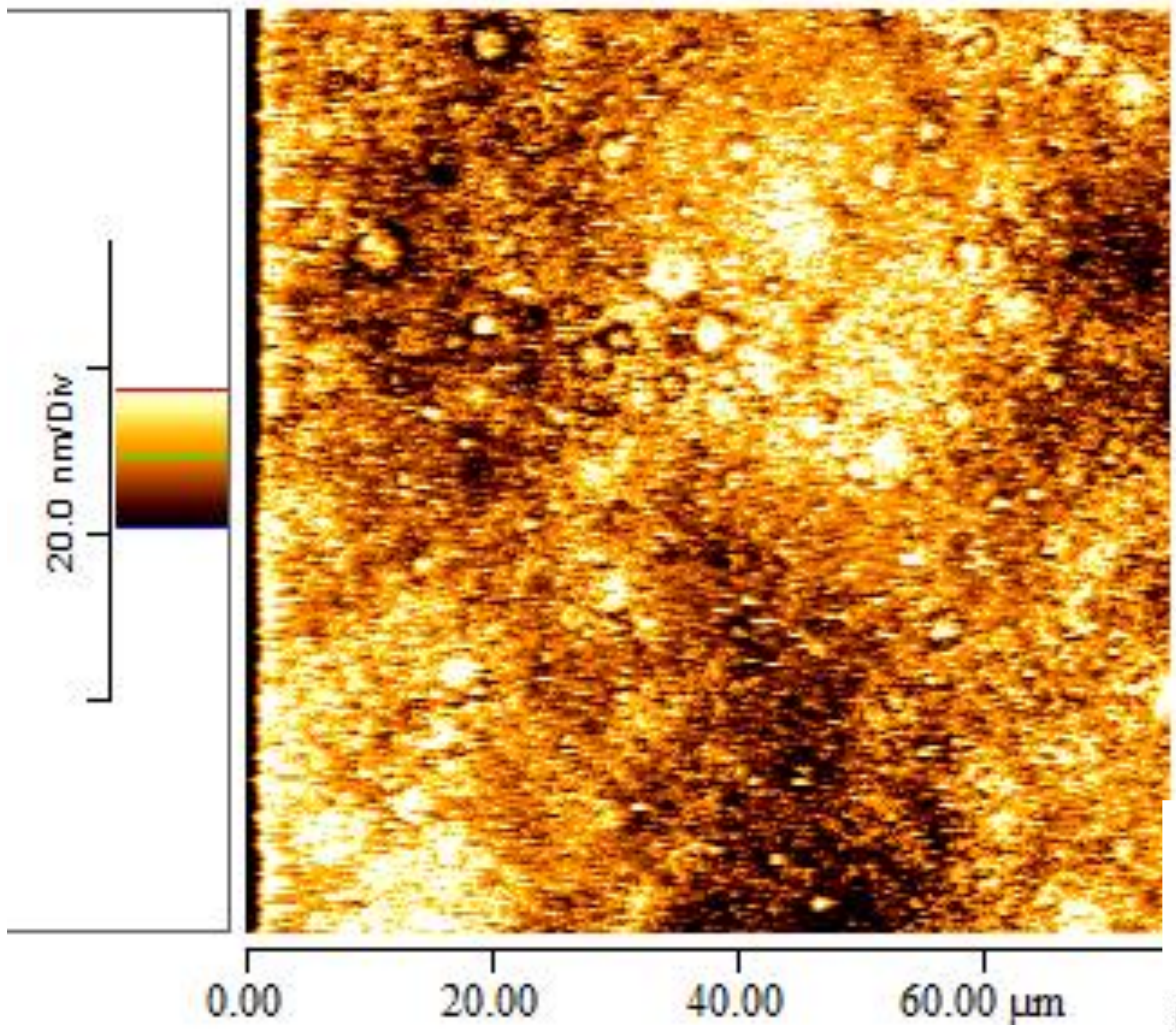


Figure 2: Image of YIG substrate with image size 80 µm x 80 µm

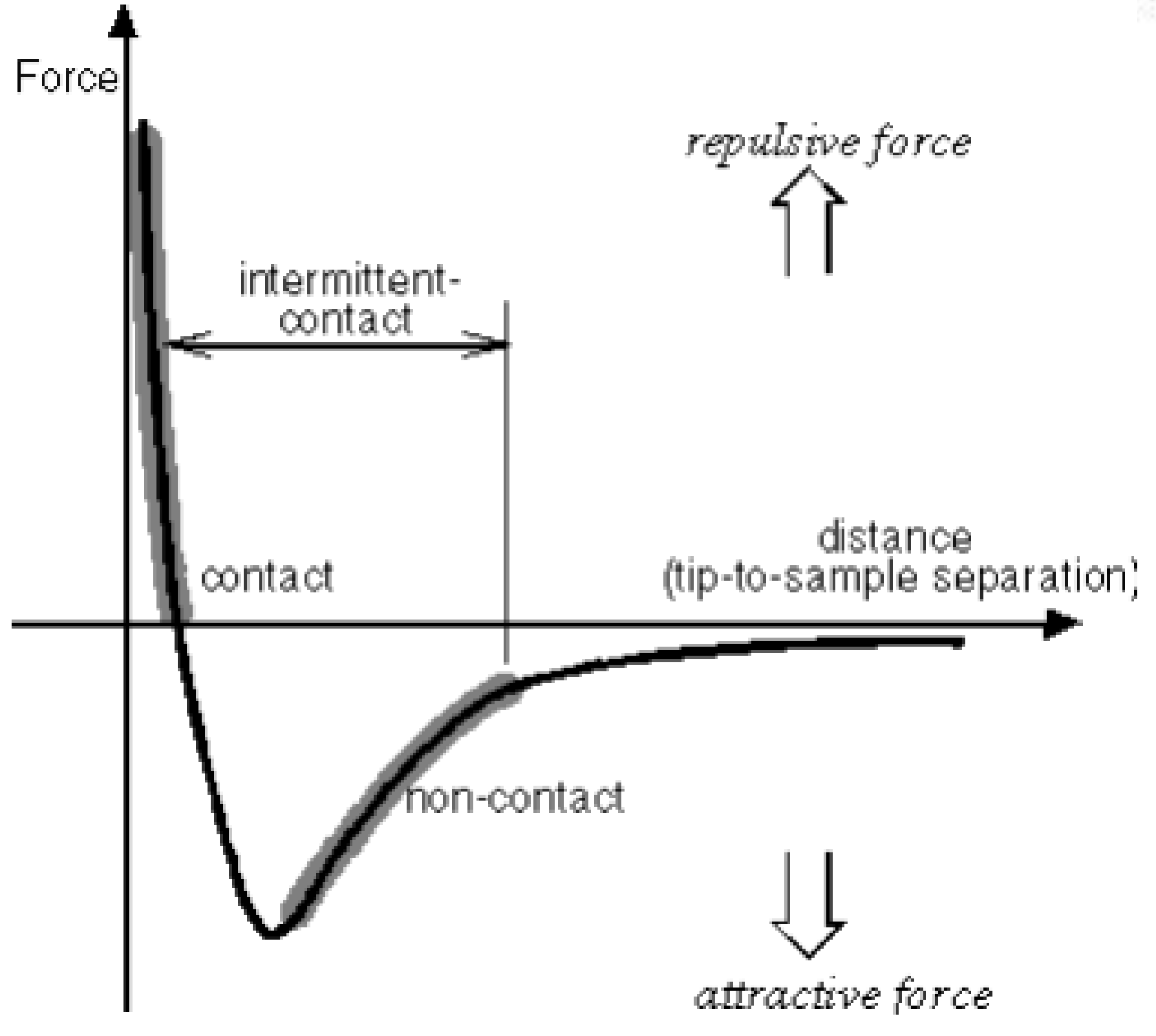


Figure 3: Interatomic Force vs. Distance Curve [1]

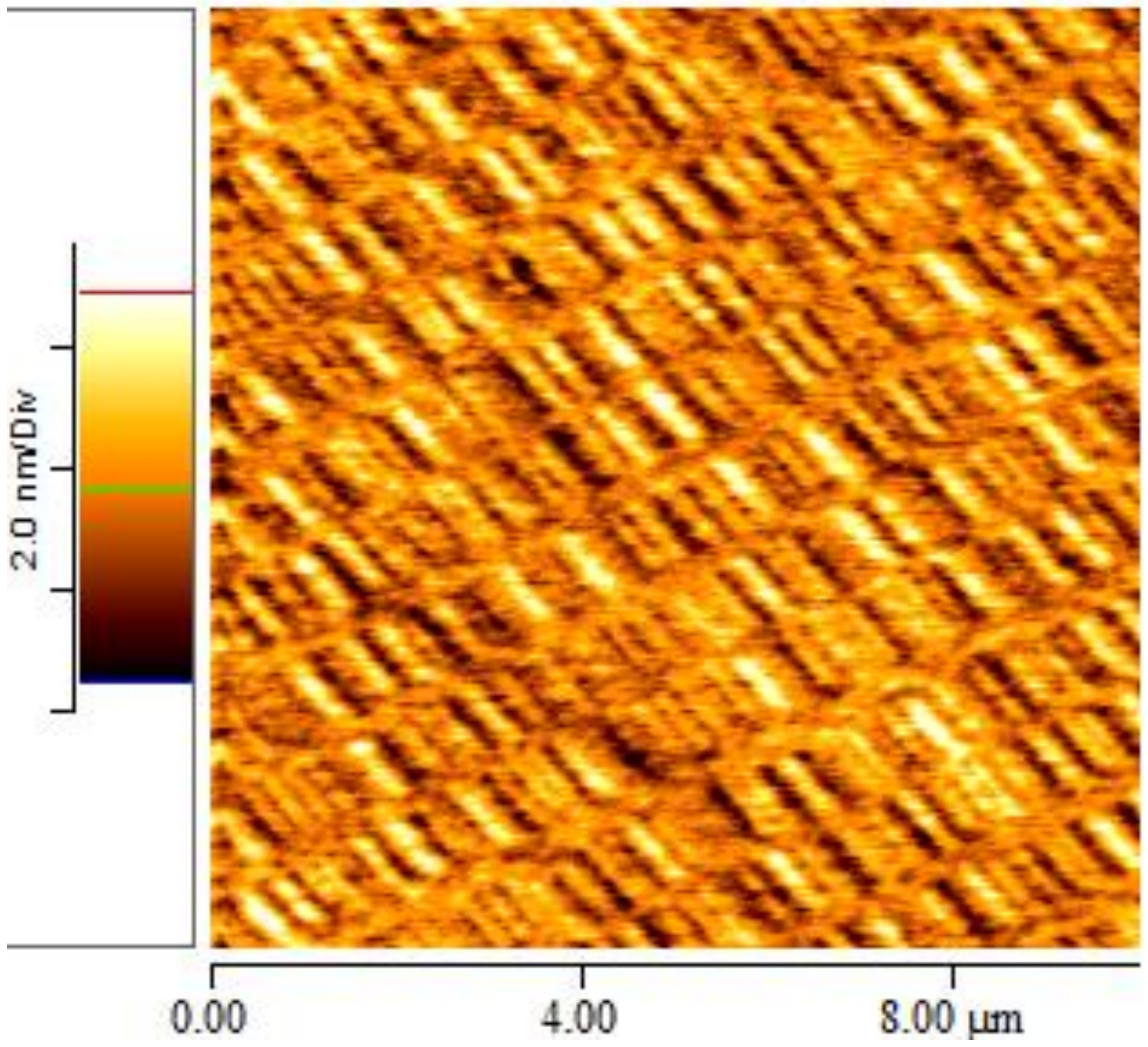


Figure 1: Magnetic domain of a hard disc, with an image size of 10 µm x10 µm

Materials and Methods

When a magnetic tip is brought close enough to the sample to experience near-field attractive forces due to van der Waals force, the high spring constant cantilever acts like a non-magnetic probe, mapping the topography of the sample surface. At this force regime approximately 1-15 nanometers away from the sample, the stray magnetic fields acting upon the tip are overwhelmed by the van der Waals force gradient. However, by bringing the magnetic tip up from the sample by approximately 50-200 nanometers, the far-field force gradient of magnetic fields dominate, and can provide a proper image of the sample's magnetic force domains. By combining the data collected from two scans of topographical and magnetic images, a procedure called Lift Mode™ can be used to filter topography effects from the magnetic images.

The high spring constant of magnetic cantilevers prohibits magnetic probes from being rastered across the contact regime of a sample without damage to either the probes or the sample. Instead, the cantilevers used in this experiment were oscillated at a high frequency near their resonance point, at about 540 kHz, in both the near-field and far-field regimes. This oscillation brings a cantilever into the contact regime intermittently, essentially 'tapping' the sample. As the cantilever approaches the sample, the forces acting on the cantilever change the effective spring constant, dramatically changing the amplitude of oscillation. This change in amplitude triggers the feedback mechanism in the piezoelectric scanner below the sample, thus creating topographical images of the sample.

The magnetic probes used in this study were MESP-CPMT probes from Bruker Corporation. They were coated in a Cobalt-Chromium alloy, with a magnetic coercivity of 500 Oe. A tip magnetizer with coercivity of 2000 Oe was used to align the magnetic domains of the cantilever.

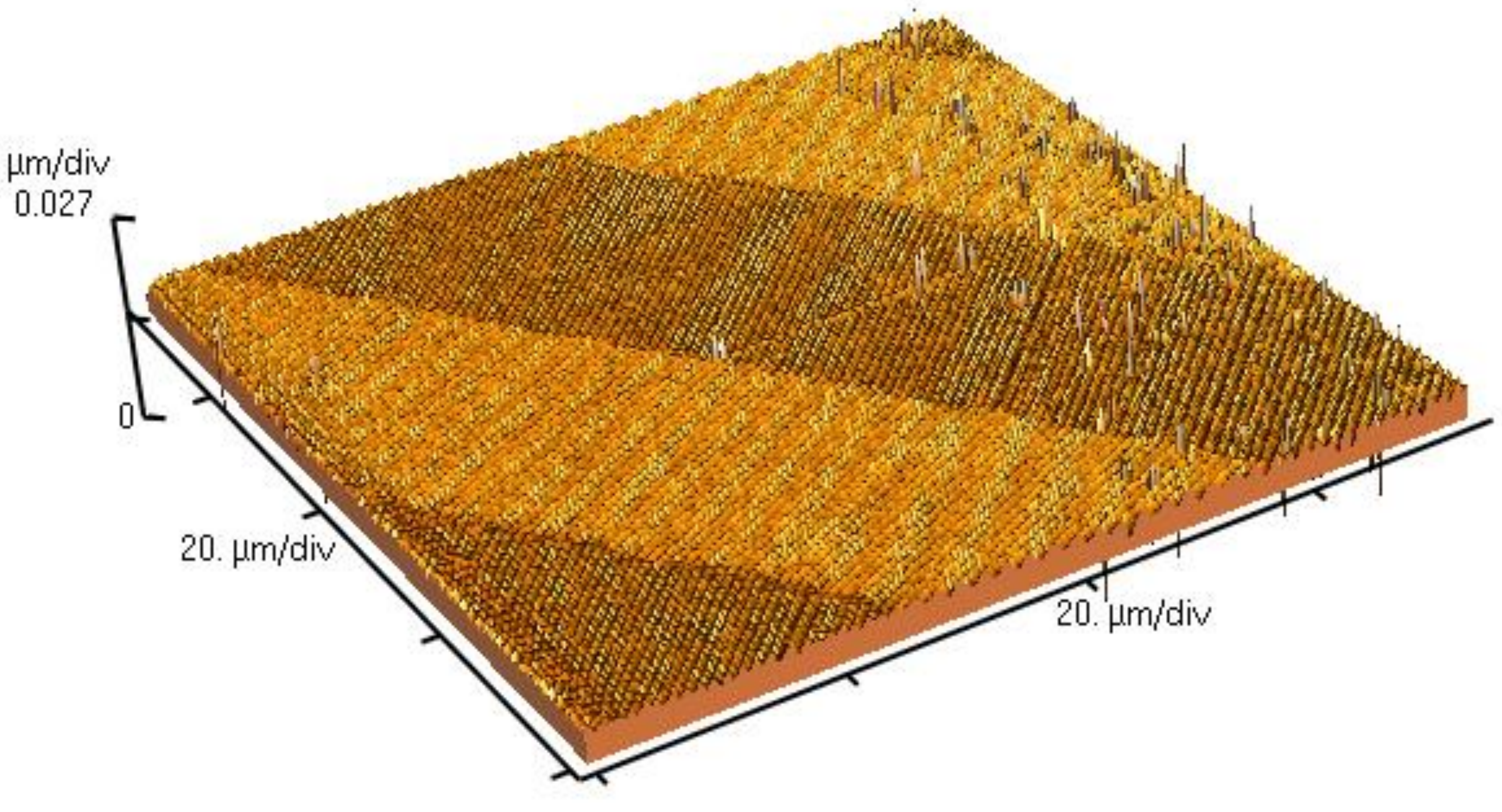
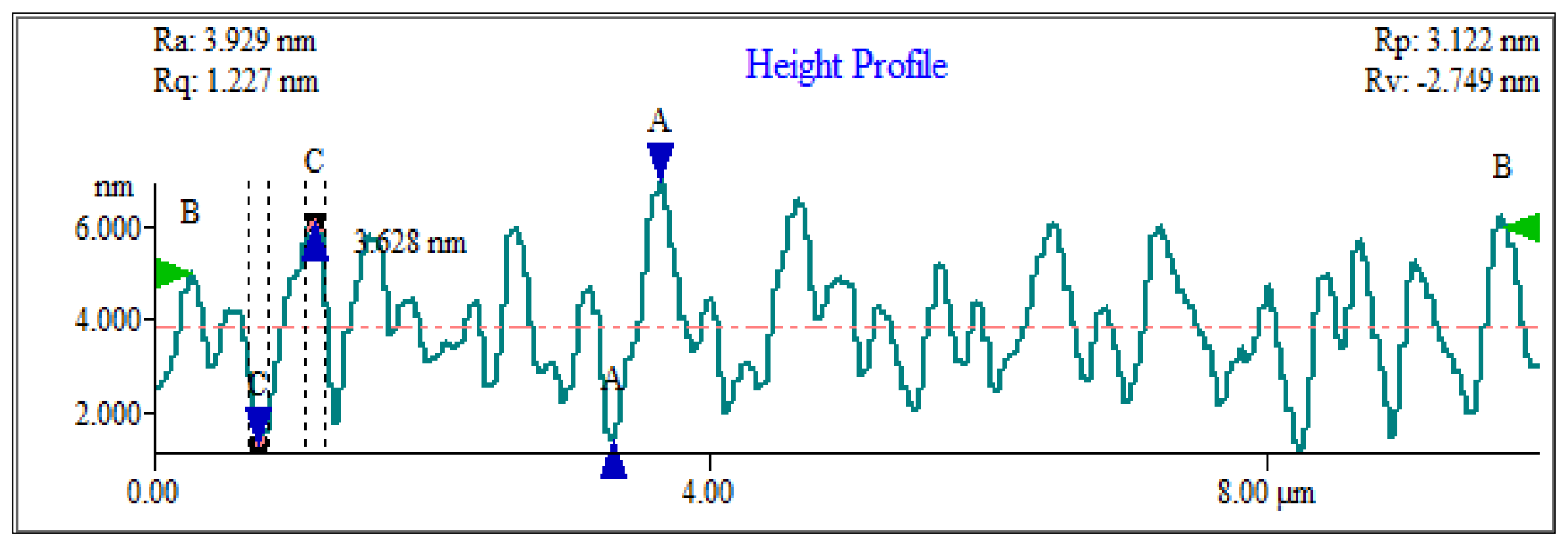


Figure 4: 3-dimensional representation of magnetic domain of a strip of magnetic tape with image size 80 µm x 80 µm

Results

We succeeded in obtaining clear magnetic images of various kinds of magnetic storage tape and hard discs. Average change in domains in the hard disc samples were represented by a cantilever deflection of 4.411 nm and a periodicity of 4.86 encoded bytes per µm, but the average magnetic moment of a byte embedded within a hard disc was unable to be calculated. Attempts to find distinct magnetic domains in yttrium iron garnet substrates were unsuccessful.



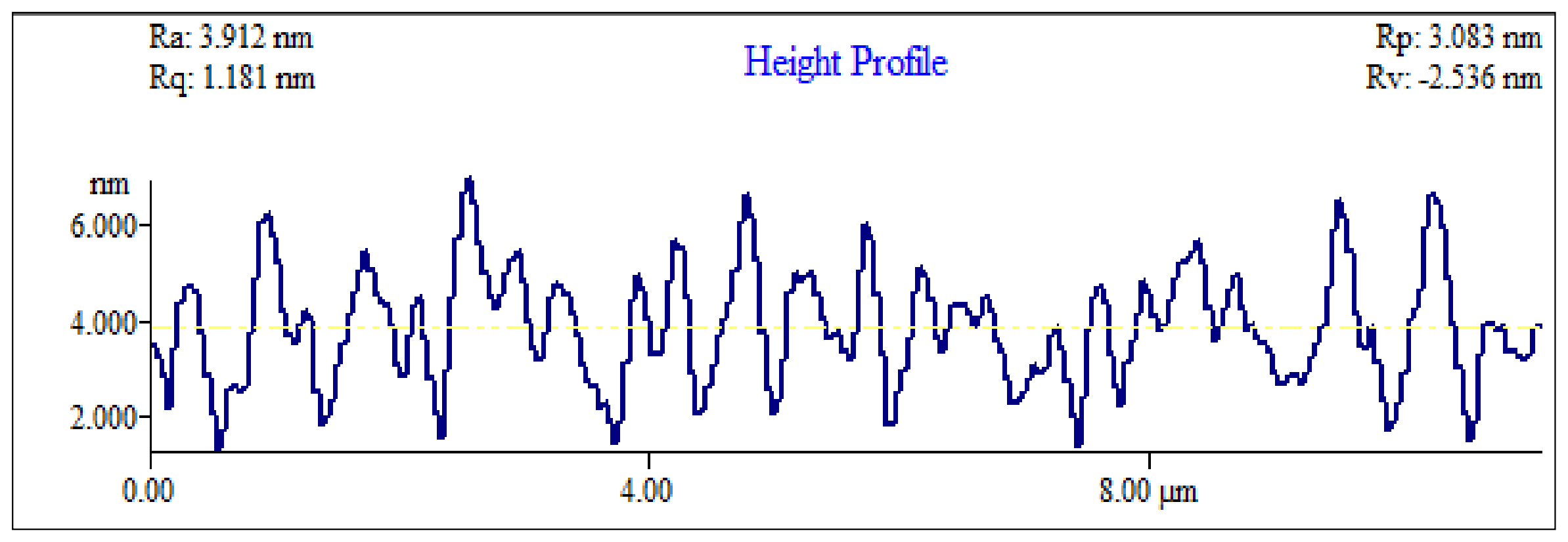


Figure 5 & 6: Topographical profile of hard disc along perpendicular lines of magnetic features.

Future Steps

By establishing magnetic force microscopy as a valid material surface analysis technique at Kenyon College, more complex applications of the fine control provided by the diCP-II microscope can be pursued. Reexamining magnetic tapes with known magnetic domains will enable a greater understanding of the magnetic moments of Co-Cr coated cantilevers, thus allowing a more quantitative exploration of other magnetic samples. Application of an electrostatic bias and/or external magnetic field could lead to experiments that generate our own high-density data fields.

Acknowledgements

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