Application Note CI03

Magnetic Resonance Imaging of Nanoscale Tobacco MosaicVirus at 300 mK using ANPx51 positioners

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Introduction

Magnetic Resonance Force Microscopy (MRFM) is a three-dimensional imaging technique derived from classical magnetic resonance imaging (MRI). In an effort to increase the resolution of MRI from the millimeter to the sub-micrometer range, MRFM uses a cantilever for signal detection instead of a coil as used in classical MRI apparatus. A recent experiment by C. L. Degen, now at ETH Zürich, and his colleagues at IBM Almaden demonstrates improvement of MRFM imaging resolution to length scales of a few nanometers, representing a 100-million fold increase in volume resolution over conventional MRI [1]. In the setup used for these groundbreaking experiments, two attocube ANPx51 positioners played the crucial role of coarse positioning the sample over the nanoscale magnetic tip, see Figure 1. The experiment was conducted inside a dilution refrigerator at a temperature of 300 mK.

For their nanoscale imaging experiment, Degen and coworkers attached Tobacco Mosaic Virus particles to the tip of an ultra-soft cantilever in vertical orientation (Figures 1, 2). The cantilever end was then positioned in close proximity to a tiny magnetic tip providing a strong and inhomogeneous magnetic field. With a typical separation of only several tens of nanometers, a highly accurate and robust positioning process was crucial. In Degen's experiment, two attocube ANPx51 nanopositioners carried out this positioning process with highest precision and reliability.

Underneath the magnetic tip, a copper nanowire was used to generate an rf-magnetic field with a center frequency of 114.8 MHz. At this frequency, the Larmor resonance condition is satisfied at a magnetic field of approximately 2.7 T. Due to the strong position dependence of the magnetic field created by the conical magnetic tip, resonance only occurs in a spherically shaped "resonant" slice (see Figure 1). With magnetic field gradients exceeding 106 T/ m, the resonant slice can be as thin as a few nanometers, defining the imaging resolution of the MRFM apparatus. A magnetic resonance signal is generated by periodically inverting the nuclear spins in the slice at the mechanical frequency of the cantilever. These nuclear spin inversions present an oscillating force to the cantilever, typically of order attoNewton rms, resulting in a small mechanical oscillation of the cantilever that is proportional to the number of nuclear spins in the resonant slice. By scanning two-dimensional slices at different tip-sample separation while simultaneously recording the amplitude of the cantilever motion, information on the 1 H spin distribution of the sample was obtained. The recorded data were subsequently transformed into a real-space 3D image by means of a sophisticated software algorithm, see Figure 3.

In summary, attocube's ANPx51 positioners were used in an MRFM setup with the task to precisely and reliably position a magnetic tip and a copper nanowire to close proximity of an ultra-sensitive cantilever. The MRFM setup was used to investigate and reconstruct the 1H spin distribution of Tobacco Mosaic Virus particles, representing a 100-million fold improvement in volume resolution over conventional MRI.

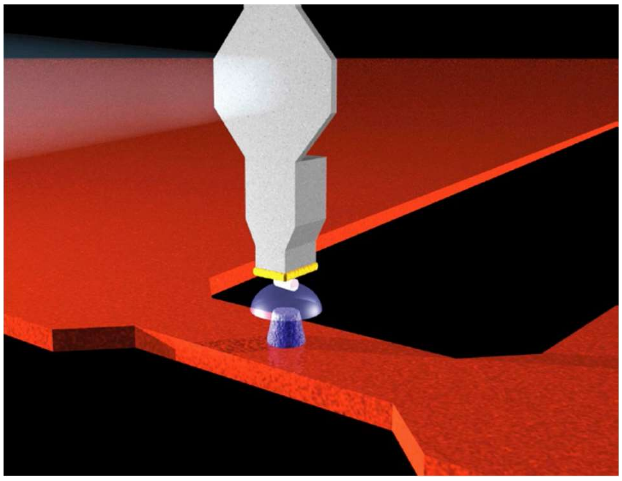

Figure 1: *Schematic drawing of the MRFM setup showing the ultra-sensitive cantilver (grey), tobacco virus (white), and magnetic tip (blue). Magnetic resonance is achieved within the resonant slice (faint blue), where the gradient magnetic field of the tip and the rf magnetic field created by the microwire (red) satisfy the Larmor condition. The microwire and magnetic tip are brought to close proximity with the cantilever by taking advantage of two attocube ANPx51 nanopositioners.*

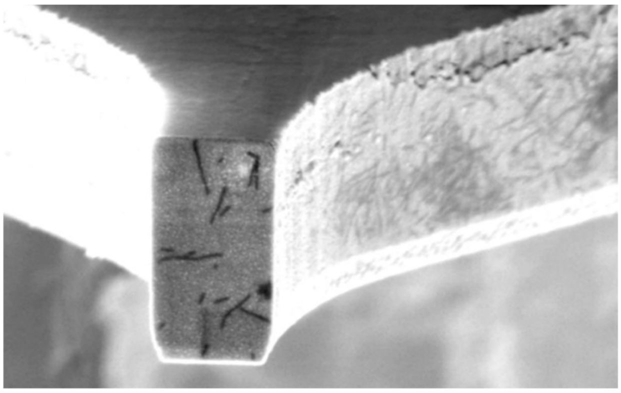

Figure 2: *SEM image of the tip of the ultra-sensitive silicon cantilever used for the MRFM experiment, clearly showing several Tobacco Mosaic virus particles.*

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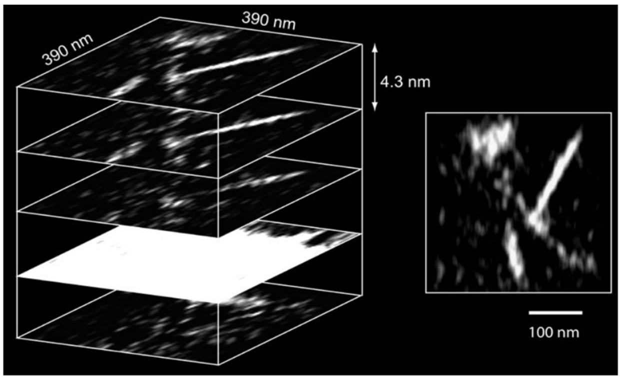

***Figure 3:** Three dimensional reconstruction of the [1]H-spin distribution of a virus particle sitting on an adsorbed hydrocarbon layer. The insert shows a representative horizontal slice located 13 nm above the hydrocarbon layer.*

References

[1] C. L. Degen, M. Poggio, H. J. Mamin, C. T. Rettner, and D. Rugar, PNAS 106, 1313 (2009). doi:10.1073/pnas.0812068106