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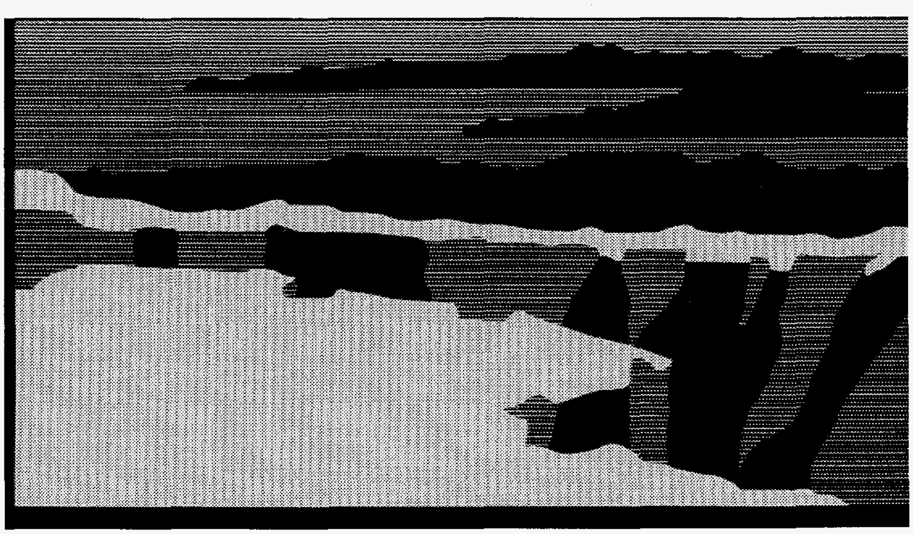

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MAGNETIC RESONANCE FORCE MICROSCOPY WITH A PERMANENT MAGNET ON THE CANTILEVER

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The magnetic resonance force microscope (MRFM) is a microscopic 3-D imaging instrument based on a recent proposal[1] to detect magnetic resonance signals mechanically using a micro-mechanical resonator. MRFM has been successfully demonstrated in various magnetic resonance experiments including electron spin resonance,[2] ferromagnetic resonance[3] and nuclear magnetic resonance.[4] In order to apply this ultra-high, 3-D spatial resolution technique to samples of arbitrary size and shape, the magnetic particle which generates the field gradient $\nabla \mathbf{B}$, (and, therefore, the force $\mathbf{F} = (\mathbf{m} \bullet \nabla \mathbf{B})$ between itself and the spin magnetization $\mathbf{m}$ of the sample) will need to be mounted on the mechanical resonator. Up to the present, all experiments have been performed with the *sample* mounted on the resonator. This is done, in part, to avoid the spurious response of the mechanical resonator which is generated by the variation of the magnetization of the magnetic particle as the external field is varied.[3]

We have explored the possibility of using several fine particles of unmagnetized $Nd_2Fe_{14}B$ glued on an atomic force microscope cantilever as the permanent magnet. The $Nd_2Fe_{14}B$ particles were chosen in hope that their large magnetic anisotropy will prevent their magnetization from changing with the change of the external field (in the range of several hundred gauss) and thus reduce the spurious noise in the MRFM system. The particles were placed on a cantilever in an epoxy which sets in several hours. The cantilever was then placed in a persistent current superconducting magnet with the 4.2 T field parallel to the cantilever while the epoxy was setting. The resonance frequency f_c of the loaded cantilever is reduced from about 15 kHz without the $Nd_2Fe_{14}B$ particles to 5.62 kHz with the $Nd_2Fe_{14}B$ particles. Using a value of the spring constant k of the cantilever of about 0.08 N/m, we estimate that the total mass of the $Nd_2Fe_{14}B$ and epoxy is about 55 ng. As there is no data for the magnitude of the magnetic field of the $Nd_2Fe_{14}B$ micro-particles, we measure this magnetic field generated by the $Nd_2Fe_{14}B$ particles ${}_M\mathbf{H}$ by performing an MRFM experiment[3] on a DPPH particle using the setup shown in Fig. 1. At a given rf frequency f_{rf}, the magnetic field $\mathbf{H}_0+\mathbf{H}_M$ at the site of the DPPH particle is constant at $2\pi f_{rf}/\gamma$ at resonance, where $\gamma=1.76\times10^7$ /(Gs) is the gyromagnetic ratio and $\mathbf{H}_0$ is the magnetic field generated by the electromagnet. The variation of $\mathbf{H}_M$ with distance z between the DPPH and $Nd_2Fe_{14}B$ particles is shown in Fig. 2 for $\mathbf{H}_0$ both parallel and anti-parallel to the initial polarization direction of the $Nd_2Fe_{14}B$ particles. It was found that the polarized

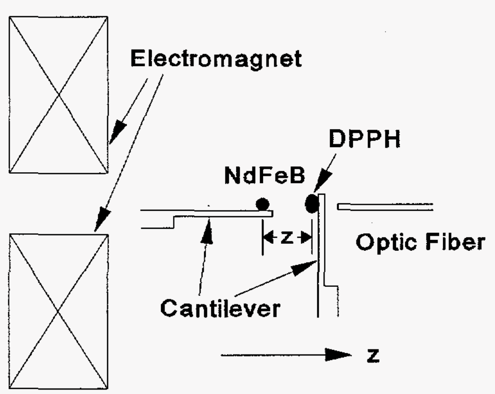

Fig.1. A schematic diagram of the MRFM setup.

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magnetization M_H of the $Nd_2Fe_{14}B$ particles does not change with the applied field, suggesting that the $Nd_2Fe_{14}B$ particles will produce a smaller spurious cantilever response in the MRFM experiment than other soft thin film magnets. Assuming that the $Nd_2Fe_{14}B$ particles form a spherical shape and the DPPH is placed on its polarization axis, the variation of $\mathbf{H}_M$ with z can be fit by the theoretical prediction (shown in Fig. 2) with the radius R of the $Nd_2Fe_{14}B$ sphere at 12 μm. This value is in good agreement with the value of R~13 μm which we estimate from our knowledge of the mass of the particles.

Although M_H is independent of the applied field, the resonance frequency f_c of the cantilever (with the $Nd_2Fe_{14}B$ particles on it) varies with $\mathbf{H}_0$ as shown in Fig. 3, as a result of the interaction between the $Nd_2Fe_{14}B$ particles and the electromagnet. In our setup shown in Fig. 1, the force between the field gradient $\partial H_0/\partial z$ of the electromagnet along its axis z (which varies with $\mathbf{H}_0$) and the $Nd_2Fe_{14}B$ particles alters the restoring force when the cantilever flexes and therefore the effective spring constant of the cantilever. Thus f_c varies with $\mathbf{H}_0$ which makes it difficult to modulate the spin magnetization of the sample at f_c in the MRFM experiment. This behavior suggests that an extremely uniform external field is required to conduct the MRFM experiment when the magnetic particle is mounted on the cantilever.

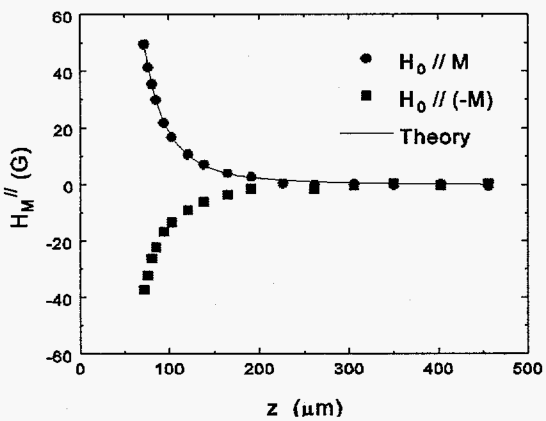

Fig. 2. The sign and magnitude of the field $H_M^{//}$ of the $Nd_2Fe_{14}B$ particles parallel to the applied field H_0. We show the value of the field at the center of the DPPH particle as a function of distance z between these two particles. The solid line is the theoretical fit assuming that the $Nd_2Fe_{14}B$ is a sphere with the radius of 12 μm.

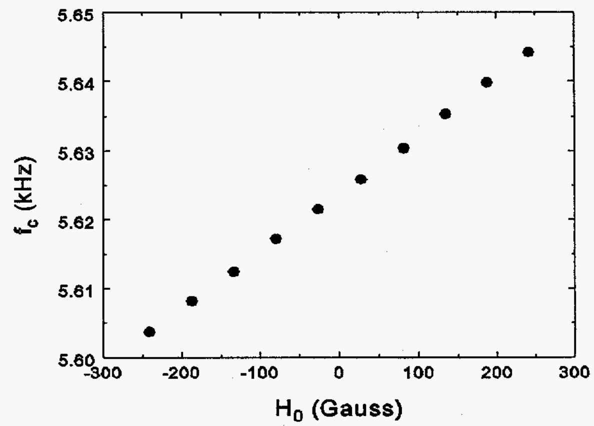

Fig. 3. Variation of the cantilever resonance frequency f_c with the bias field H_0.

[1] J.A. Sidles, Appl. Phys. Lett. **58**, 2854 (1991).
[2] D. Rugar, C.S. Yannoni, and J.A. Sidles, Nature **360**, 563 (1992).
[3] Z. Zhang, P.C. Hammel, and P.E. Wigen, Appl. Phys. Lett. **68**, 2005 (1996).
[4] D. Rugar, O. Zügar, S. Hoen, C.S. Yannoni, H.-M. Vieth, and R.D. Kendrick, Science **264**, 1560 (1994).