Status and trends in high performance magnetic imaging using Scanning Probe Microscopy(SPM)

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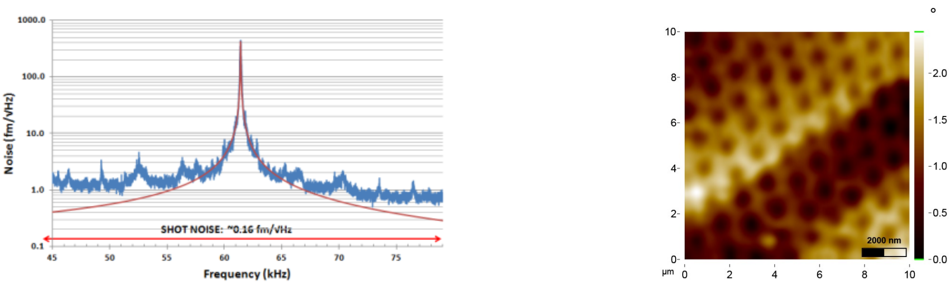
We will give an overview of the state of the art Scanning Probe Microscopes (SPM) for magnetic imaging in the 20mK to 300K temperature range. Recent developments in cryofree cryostats and dilution refrigerators (DR) have opened a new avenue for scientists suffering from heavy Helium costs.

We shall first describe the design of High Resolution MFM which can achieve 10nm magnetic resolution. Such high resolution is possible with unprecedented ~12fm/√Hz noise floor of the cantilever deflection electronics.

We shall also describe a mK-Scanning Probe Microscopes (mK-SPM) operating in Scanning Tunnelling Microscope (STM), Scanning Hall Probe Microscope (SHPM) and Atomic/Magnetic Force Microscope (AFM/MFM) mode in a wide temperature range of 20mK-300K. SHPM images of magnetic materials at 20mK will be presented.

An Oxford Instrument cryogen-free DR (Triton DR400) with 400uW cooling power and 7mK base temperature is used for the experiments. A 1W Pulse Tube cryo-cooler is integrated into the DR. After wiring and attaching the microscope we achieved 20mK base temperature. Piezo driven Stick slip coarse approach mechanism is used to bring the sample in to close proximity of the sample.

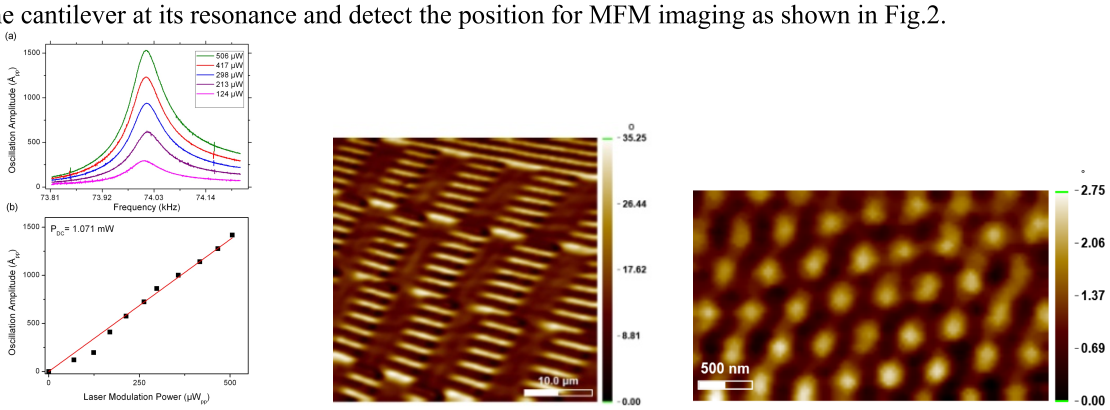
We have also designed a Fabry-Perot interferometer for our mK-AFM which has a measured ~1fm/√Hz noise level @ 4K as shown in Fig.1.(a), while the shot noise limit was ~0.2fm/√Hz. The system uses a dielectric multilayer coating at the end of the fiber to achieve this unprecedented noise level. We tested the microscope in MFM mode with a harddisk sample and imaging Abrikosov vortices in BSCCO as shown in Fig.1.(b)-(c). We hope to improve the noise levels further and achieve better than 5-6nm resolution for mK-MFM.



(a)　　　　　　　　　　　　　　　　　　(b)

Fig1.(a) Noise floor of our interferometer (b) MFM image of Abrikosov Vortex Lattice in BSCCO at 4K.

A novel method for excitation of Atomic Force Microscope(AFM) cantilevers by means of radiation pressure for imaging has been developed for the first time. Piezo excitation is the most common method for cantilever excitation. However, it has quite a few drawbacks like causing spurious resonance peaks and non-ideal Lorentzian curves. The force exerted by the radiation pressure is quite weak but sufficient to excite the cantilever to tens of nanometers for imaging in vacuum, as the Q increases to few thousands.　An amplitude modulated fiber coupled 1.31μm laser is used to excite the cantilever at its resonance and detect the position for MFM imaging as shown in Fig.2.



(a)　　　　　　　(b)　　　　　　　(c)

Fig.2.(a) Calibration of AFM cantilevers using radiation pressure (b) MFM image of Hard disk at 4K (c) MFM image of Abrikosov Vortex Lattice in BSCCO at 4K.