Magnetic resonance force microscopy investigations of spintronic devices

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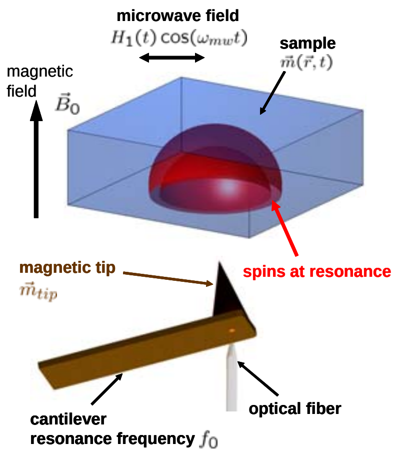
MRFM principle:



$$\vec{B}_{total}(\vec{r}) = \vec{B}_0 + \vec{B}_{tip}(\vec{r})$$

The tip field defines sample volume in which spins are at resonance

The gradient of the tip field and the sample magnetization cause force acting on the cantilever:

$$\vec{F}(\vec{r},t) = -[\vec{m}(\vec{r},t)\cdot\nabla]\vec{B}_{tip}(\vec{r})$$

Very small forces detectable by modulation of the microwave field at the resonance frequency f_0 of the cantilever – mechanical resonator with high Q factor (~100000).

MRFM is a new **three dimensional** magnetic imaging technique for the **dynamic** magnetic properties of spintronic devices with extremely **high sensitivity**

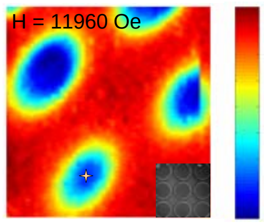
Predecessor built at OSU: sensitivity ~ 2000 electron spins
Possible: single electron sensitivity [1] and beyond...

References:

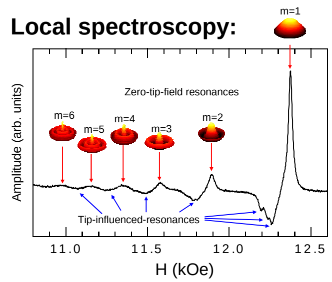
[1]: D. Rugar, R. Budakian, H.J. Mamin & B.W. Chui, Nature **430**, 329 (2004).
[2]: T. Mewes, J. Kim, D.V. Pelekhov, G.N. Kakazei, P.E. Wigen, S. Batra, P.C. Hammel, PRB, in press.
[3]: T.Q. Deng et al., Microwaves & RF **36**, 84 (1997).
[4]: J.A. Marohn et al., IEEE Trans. Magn. **42**, 378 (2006).

Information obtained by MRFM [2]:

Spatially resolved images:

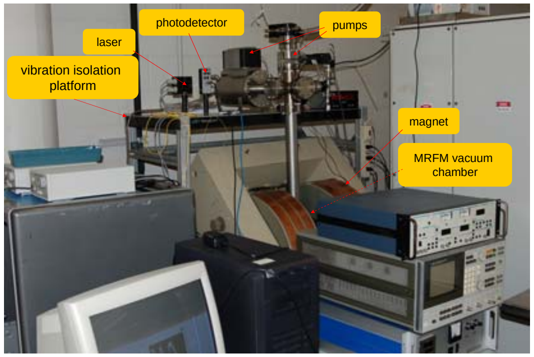


Local spectroscopy:



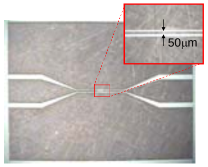
- MRFM spectra contain information about the local and global dynamic magnetic properties
- MRFM gives spatially resolved images of the dynamic properties

MRFM setup @ MINT:



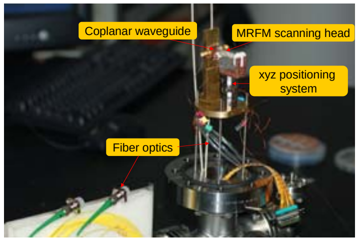
Broadband microwave excitation using CPWs:

So far MRFM experiments have used microwave coils, striplines and resonators – this limits the usable frequency range.

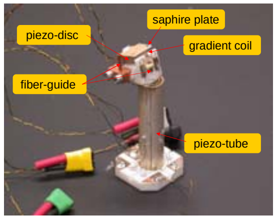


- Coplanar waveguides (CPWs) allow broadband excitation over a wide frequency range – up to 20GHz [3].
- Tapering the central conductor, while adjusting the gap to maintain the impedance, allows to achieve higher current densities and thus higher microwave fields.

Improved MRFM scanning head



- Modular structure, samples easily mounted and tested on CPW
- Precise „coarse" positioning (500 nm) in all three dimensions over wide travel range (2mm)



- Piezo-tube for scanning and fine positioning
- Piezo-disc to mechanically drive cantilever @ f_0
- Optical-fiber for cantilever position detection
- Additional fiber to measure sample-cantilever distance

- Saphire plate electrically isolates cantilever from piezo-disc
- New gradient coil to generate field gradient at the end of the cantilever
  - ⇒ Determination of magnetic moment of the tip
  - ⇒ Sample-on-cantilever magnetometry [4]

Conclusion & Outlook:

- MRFM is a new characterization tool for spintronics
  - locally measures dynamic magnetic properties (ESR/FMR)
  - provides spatially resolved information
  - extremely high sensitivity
- Coplanar waveguide structures allow microwave excitation of the sample over wide frequency range
- New MRFM head design allows easy sample exchange
- In-built fiber-optic measurement of the sample-cantilever distance
- New gradient coil integrated in MRFM head
- Sample-on-cantilever magnetometry is also possible

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