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Micromechanical Instruments for Ferromagnetic Measurements

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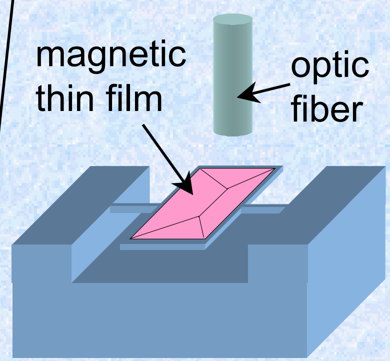
MEMS Integration of Electromagnetic Systems: Impact on the Next Generation of Magnetometers.

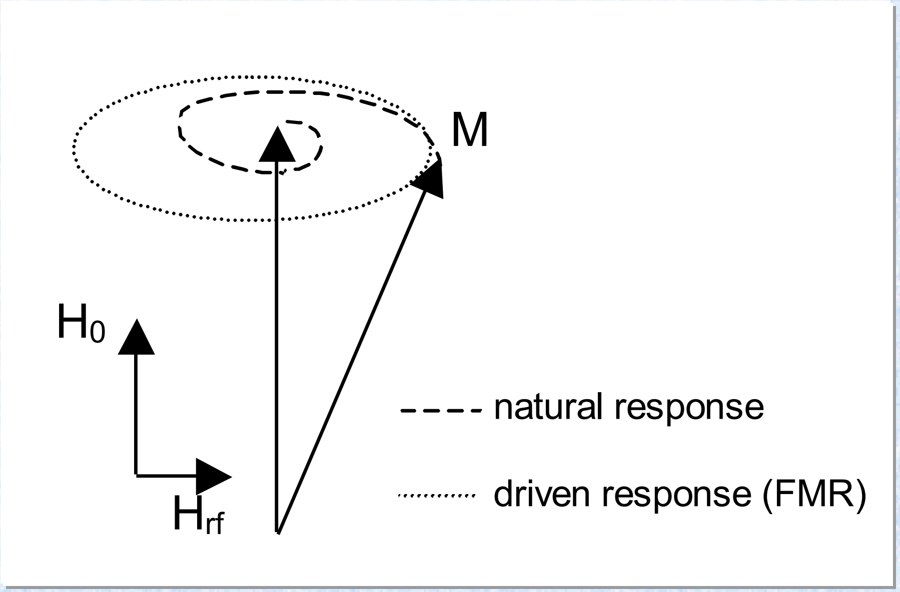
Magnetometer Sub-Systems ➤ MEMS Integration ➤ Industrial Impact

Magnetometer Sub-Systems	MEMS Integration	Industrial Impact
optical	**magnetism laboratory on a chip**	*near term*
microwave		smart substrates
mechanical		new probe microscopes
magnetic		*long term*
		nanometer scale MRI
		spin quantum mechanics



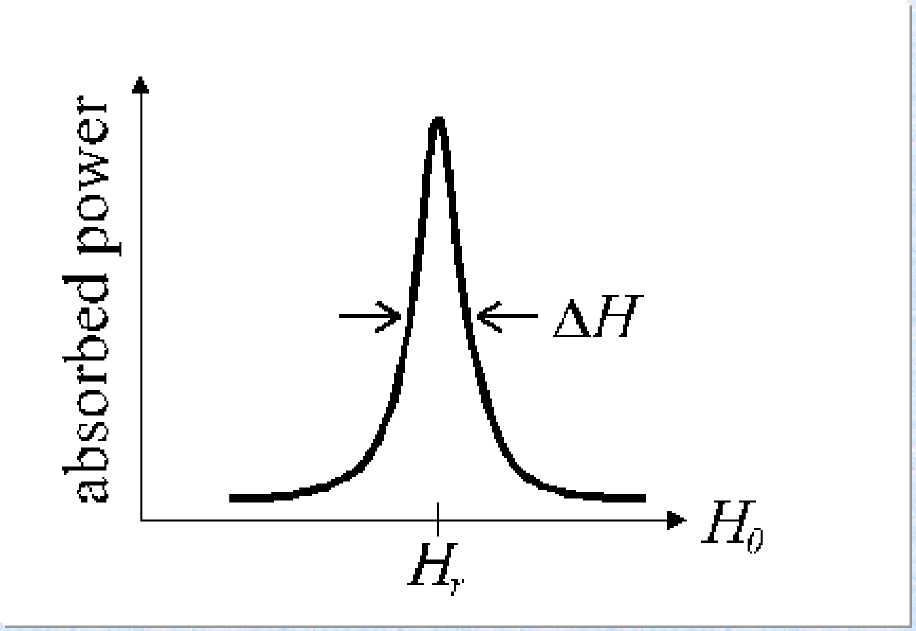
MEMS torque resonator

Ferromagnetic resonance (FMR).

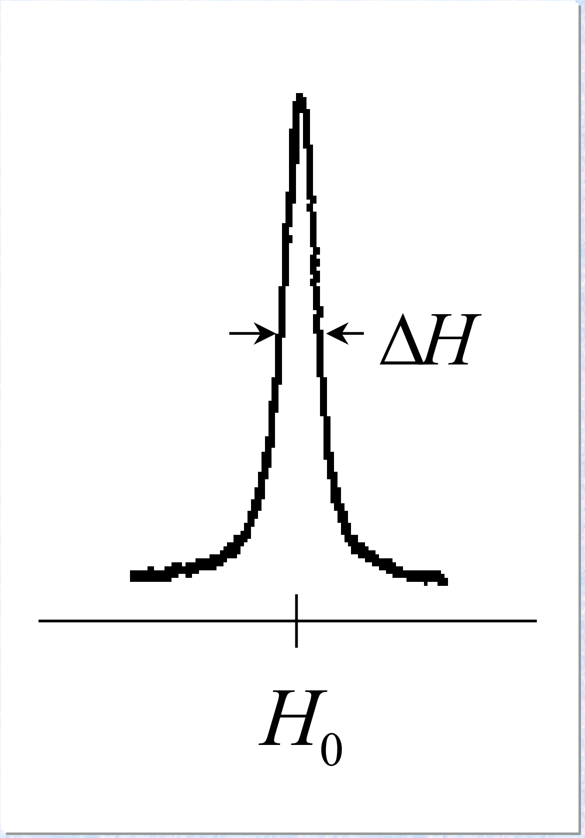


Precession and relaxation of **M** in response to an applied field **H**.

Lorentzian absorption line typical of FMR showing microwave power absorption as a function of swept bias field.



Quick review of FMR parameters.

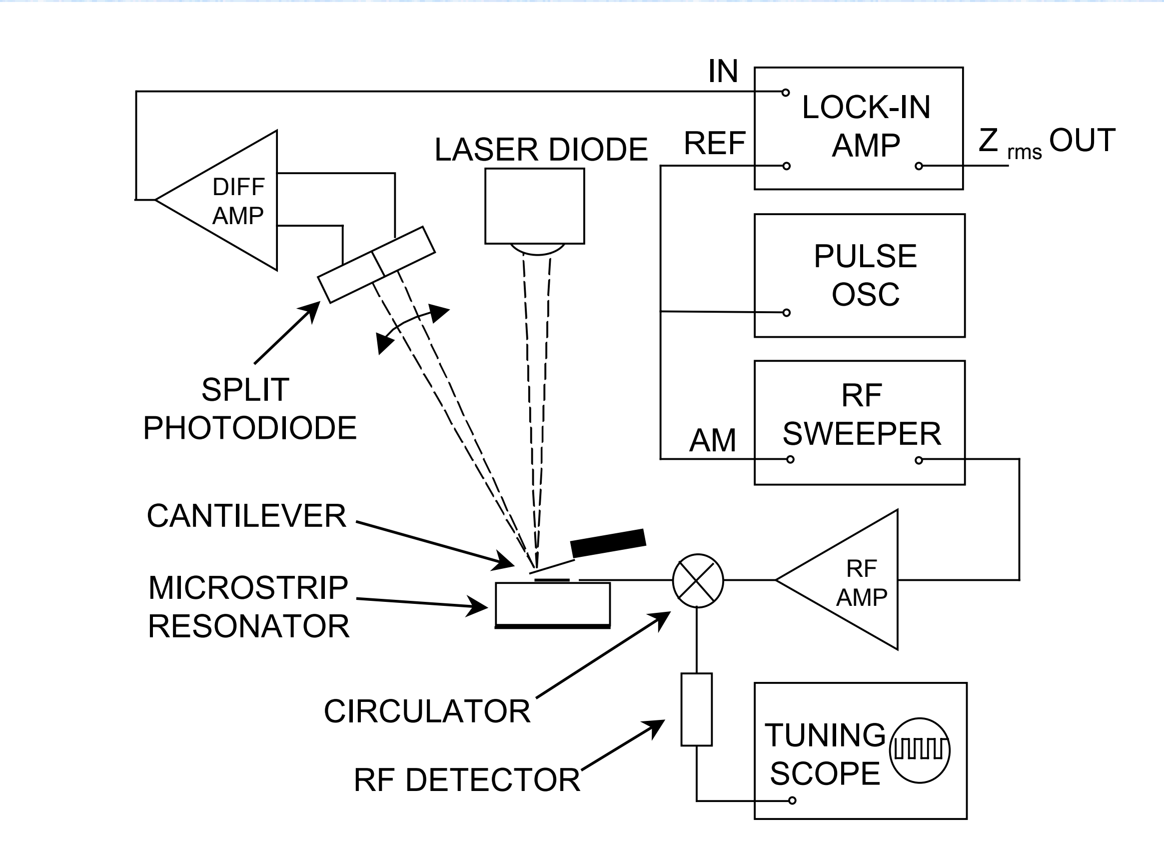


$$M_s = \frac{1}{H_0}\left(\frac{\omega^2}{\gamma^2} - H_0^2\right)$$

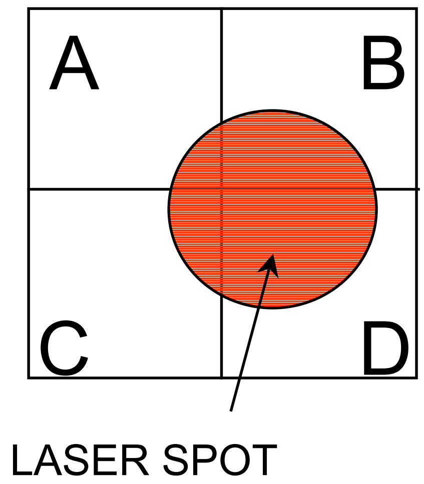
$$\alpha = \frac{\gamma}{2\omega}\Delta H$$

$$\chi'' = \frac{M_s}{\alpha}\frac{\gamma}{\omega}\left(\frac{M_s + H_0}{M_s + 2H_0}\right)$$

Instrumentation.

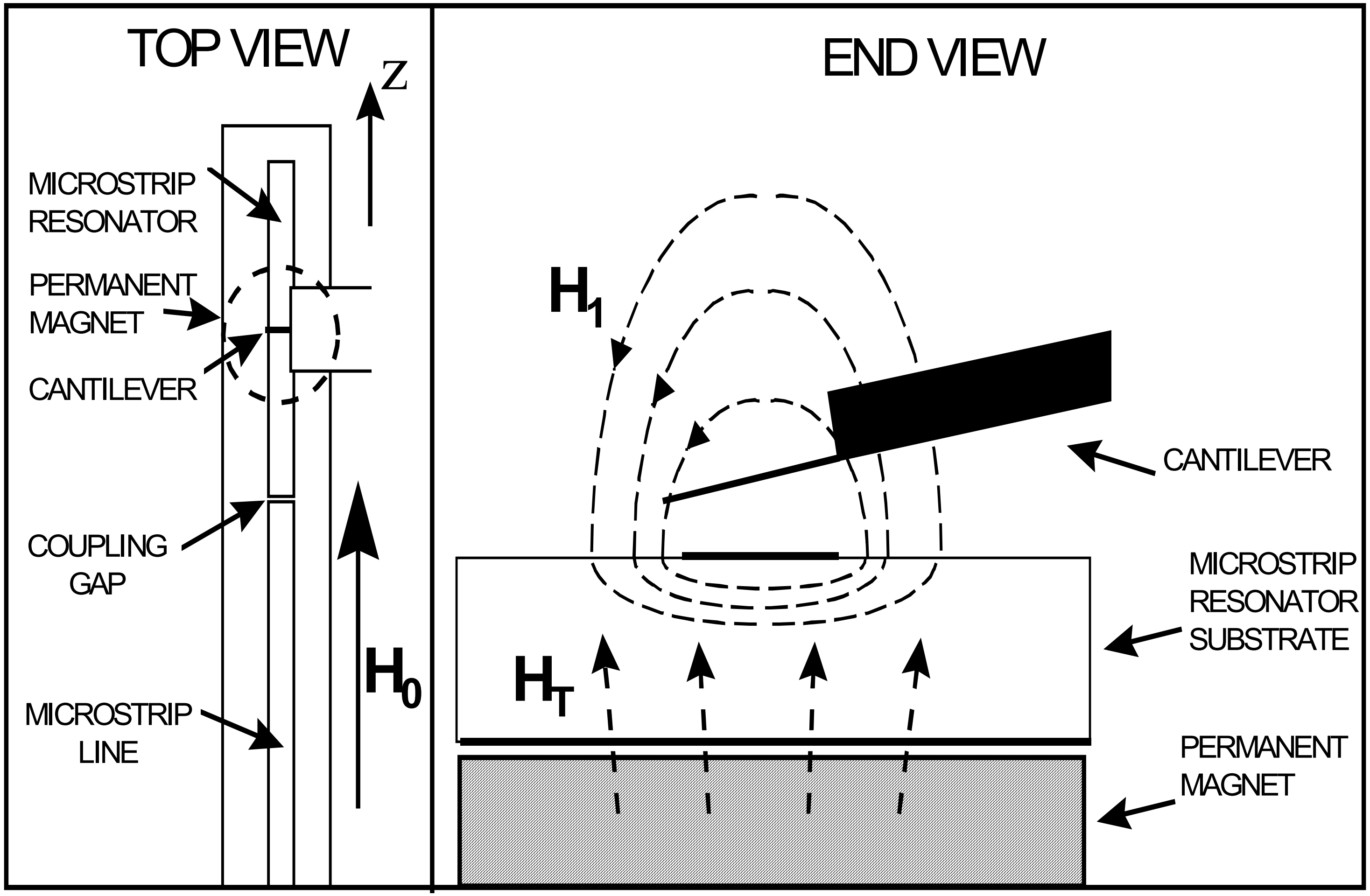


FOUR QUADRANT PHOTODIODE



Torsion mode $\frac{(A+C)-(B+D)}{A+B+C+D}$

Deflection mode $\frac{(A+B)-(C+D)}{A+B+C+D}$


TOP VIEW
Z
MICROSTRIP RESONATOR
PERMANENT MAGNET
CANTILEVER
COUPLING GAP
MICROSTRIP LINE
H_0
END VIEW
H_1
CANTILEVER
MICROSTRIP RESONATOR SUBSTRATE
H_T
PERMANENT MAGNET

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Cantilever characteristics

Deflection

$$K_s = Ewt^3/4l^3$$

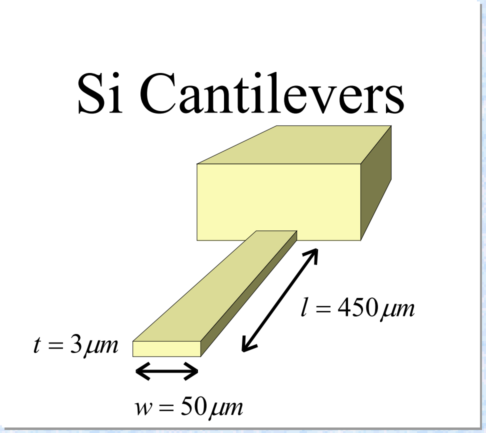
$$F_{noise}\Big/\sqrt{Hz} = \sqrt{\frac{2K_s k_b T}{Q\,f_o}}$$

$$K_s = 0.2\ N/m$$

$$f_o = 15\ kHz$$

$$Q = 200$$

$$F_{noise} \approx 10^{-14}\ N/\sqrt{Hz}$$



Torsion

$$K_s = \frac{E(wt^3)}{6(1+m)l}$$

$$T_{noise}\Big/\sqrt{Hz} = \sqrt{\frac{2K_s k_b T}{Q\,f_o}}$$

$$K_s = 3\cdot 10^{-8}\ N\cdot m/rad$$

$$f_o = 250\ kHz$$

$$Q = 250$$

$$T_{noise} \approx 10^{-17}\ N\cdot m/\sqrt{Hz}$$

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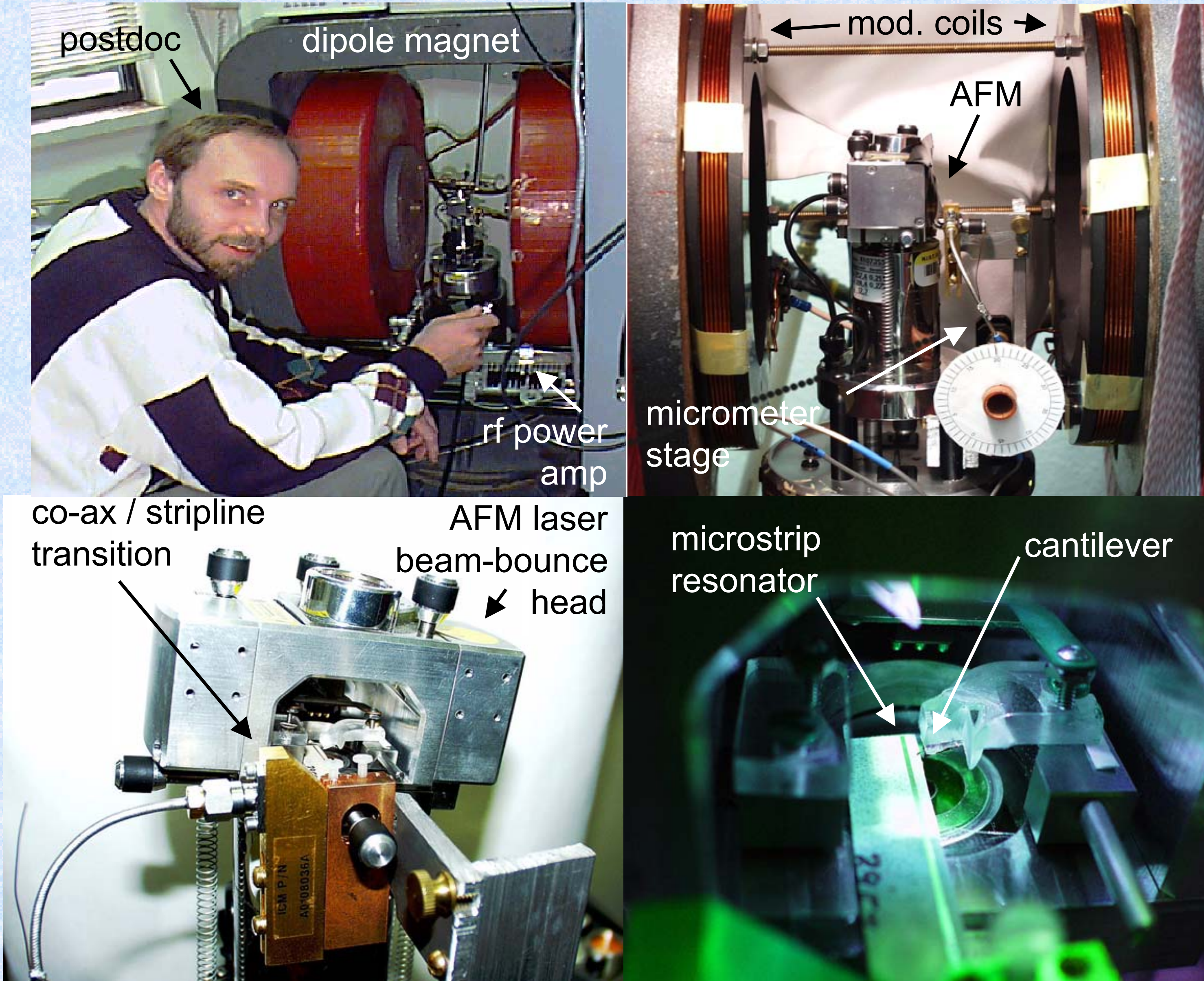
Apparatus for micromechanical detection of FMR



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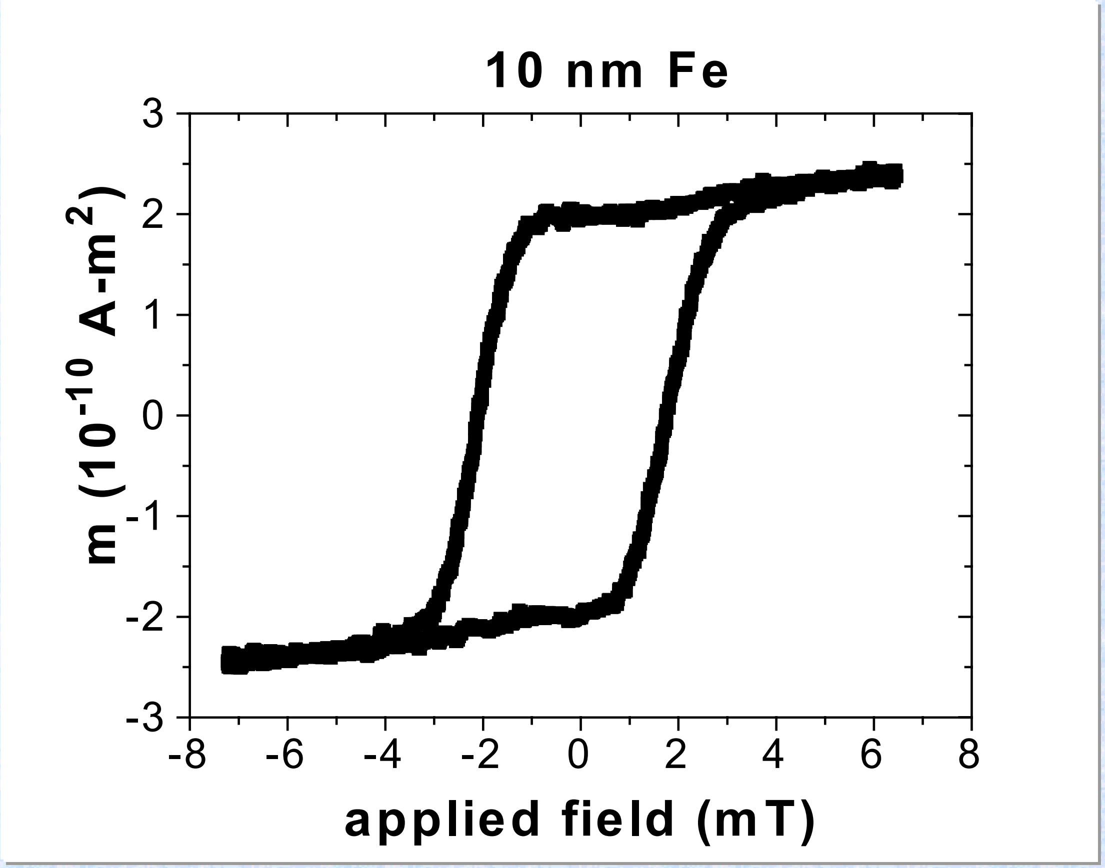
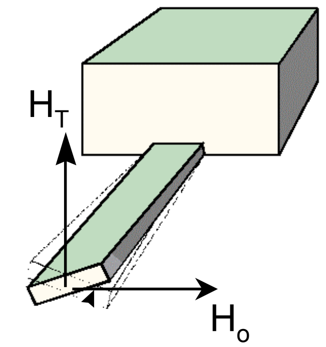
Micro torque magnetometer.



$$T = \mu_o M H_T V$$



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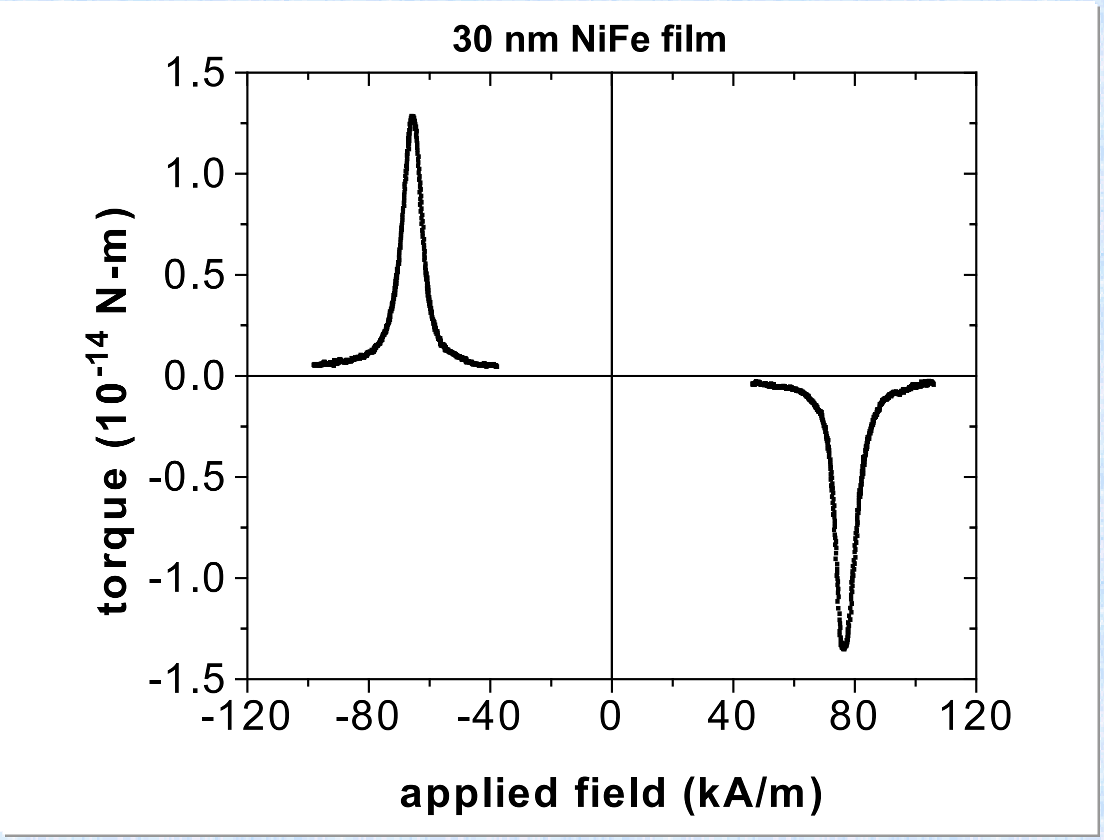
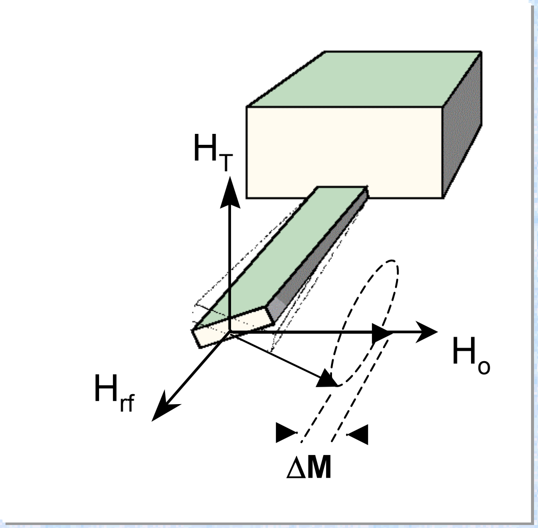
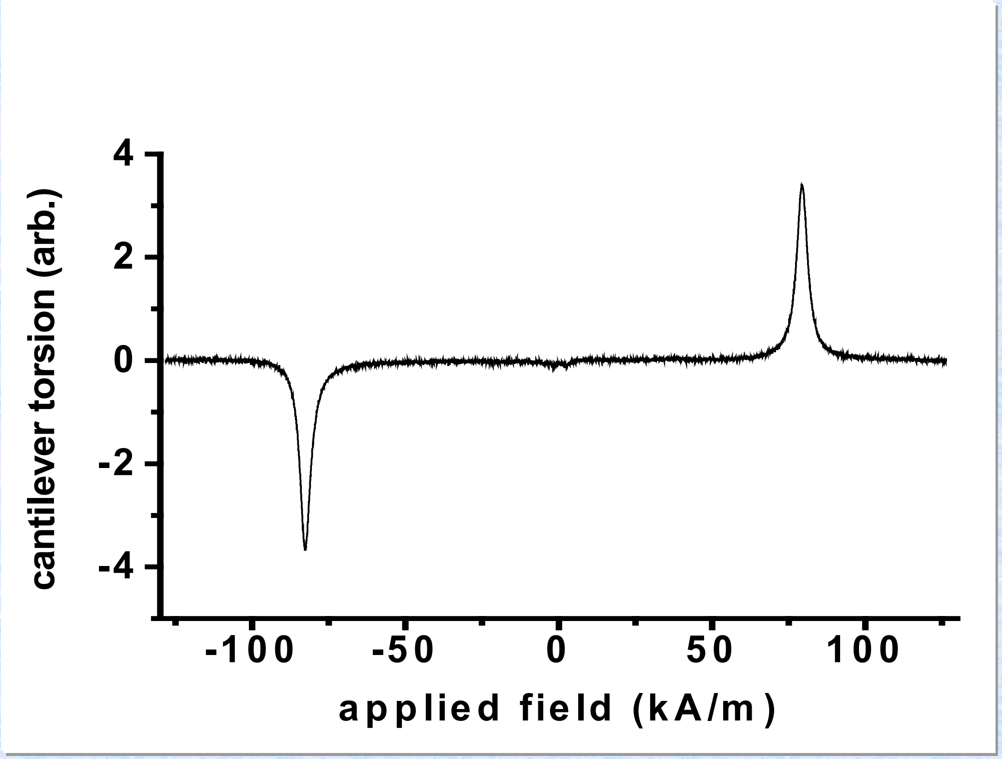
FMR with a micro resonating torque magnetometer: magnetic moment modulation.



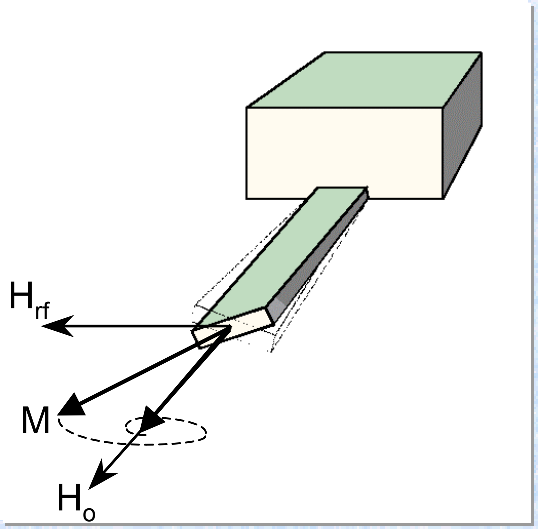
$$\Delta T_{quasi-static} = \mu_o \Delta M H_T V$$



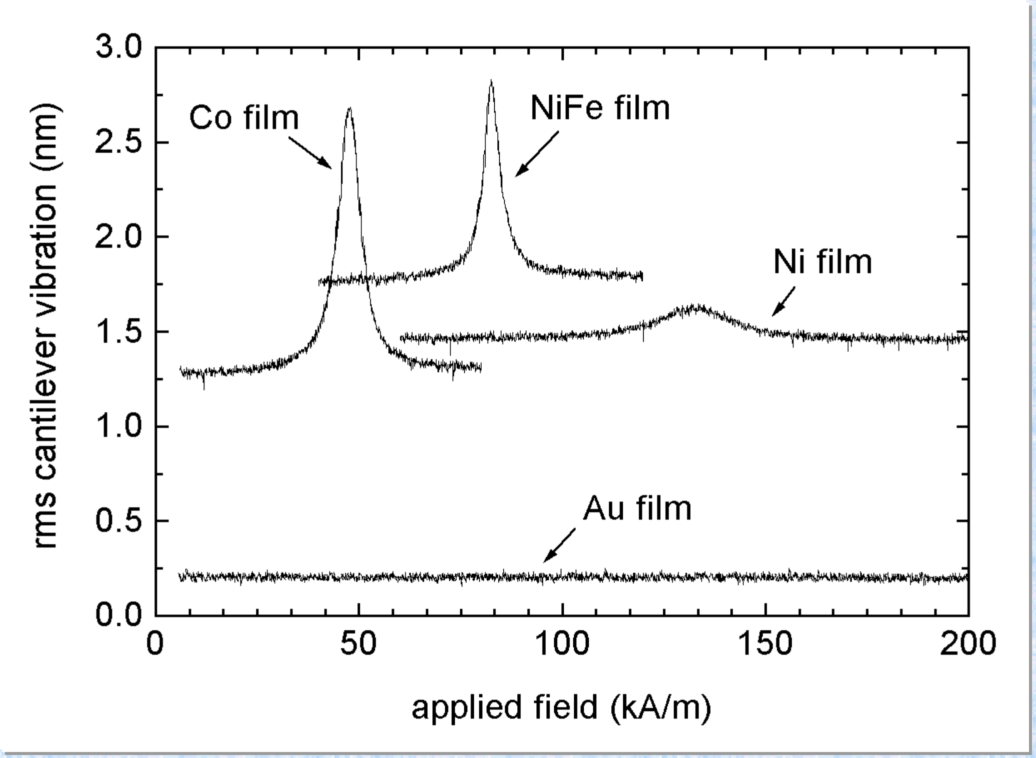
FMR with a micro resonating torque magnetometer: spin angular momentum damping.



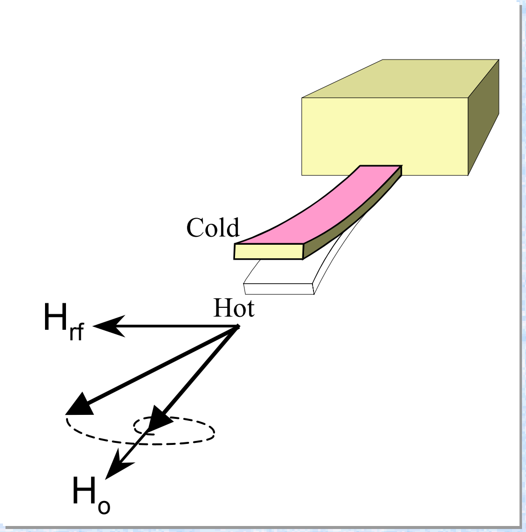
$$T_{dynamic} = \frac{\mu_0 M_s}{2\alpha(2H_r + M_s)} H_{rf}^2 V$$



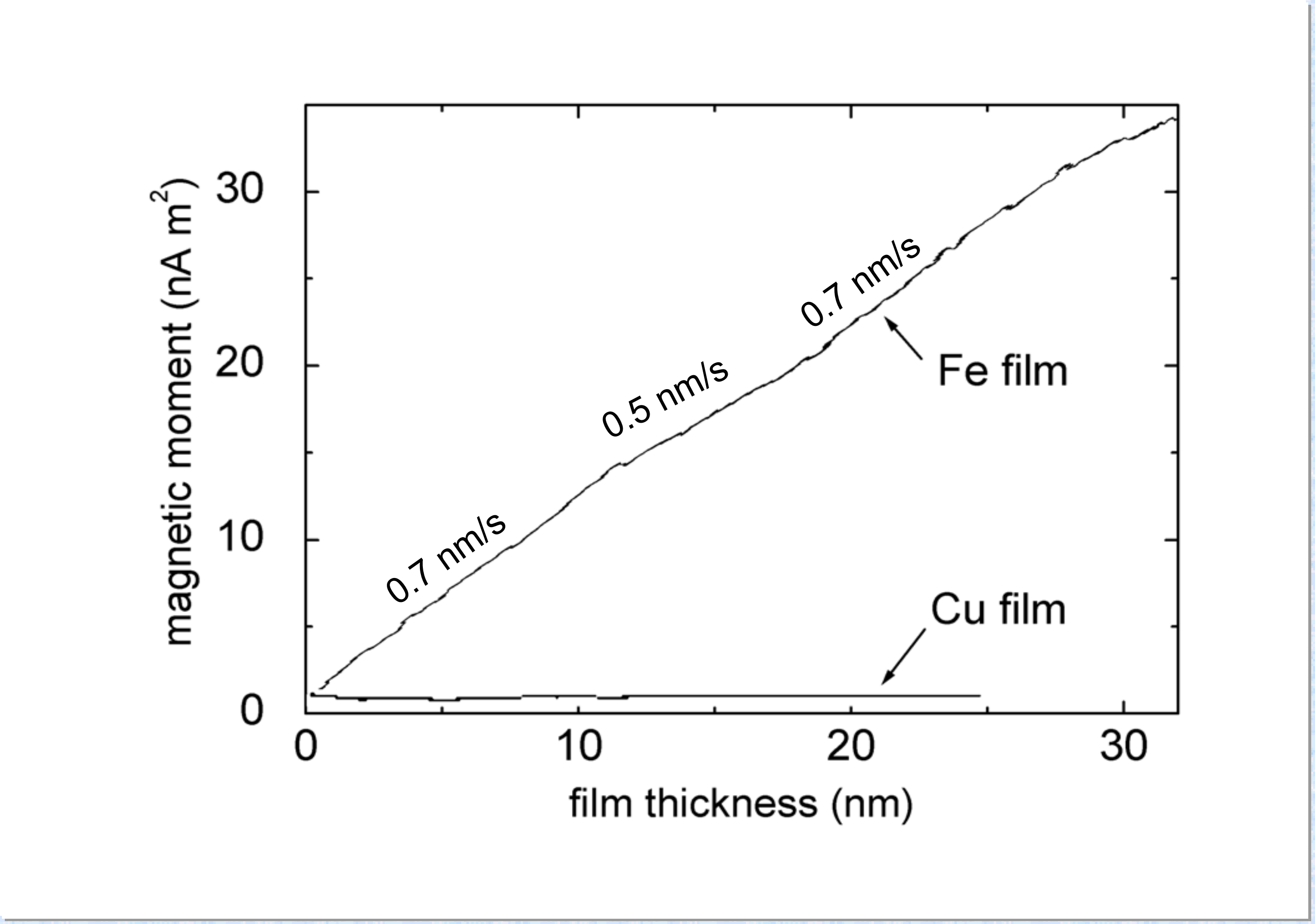
FMR with a micromechanical calorimeter sensor.



$$P = \frac{\mu_0 M_s \gamma (H_r + M_s)}{2\alpha (2H_r + M_s)} H_{rf}^2 V$$

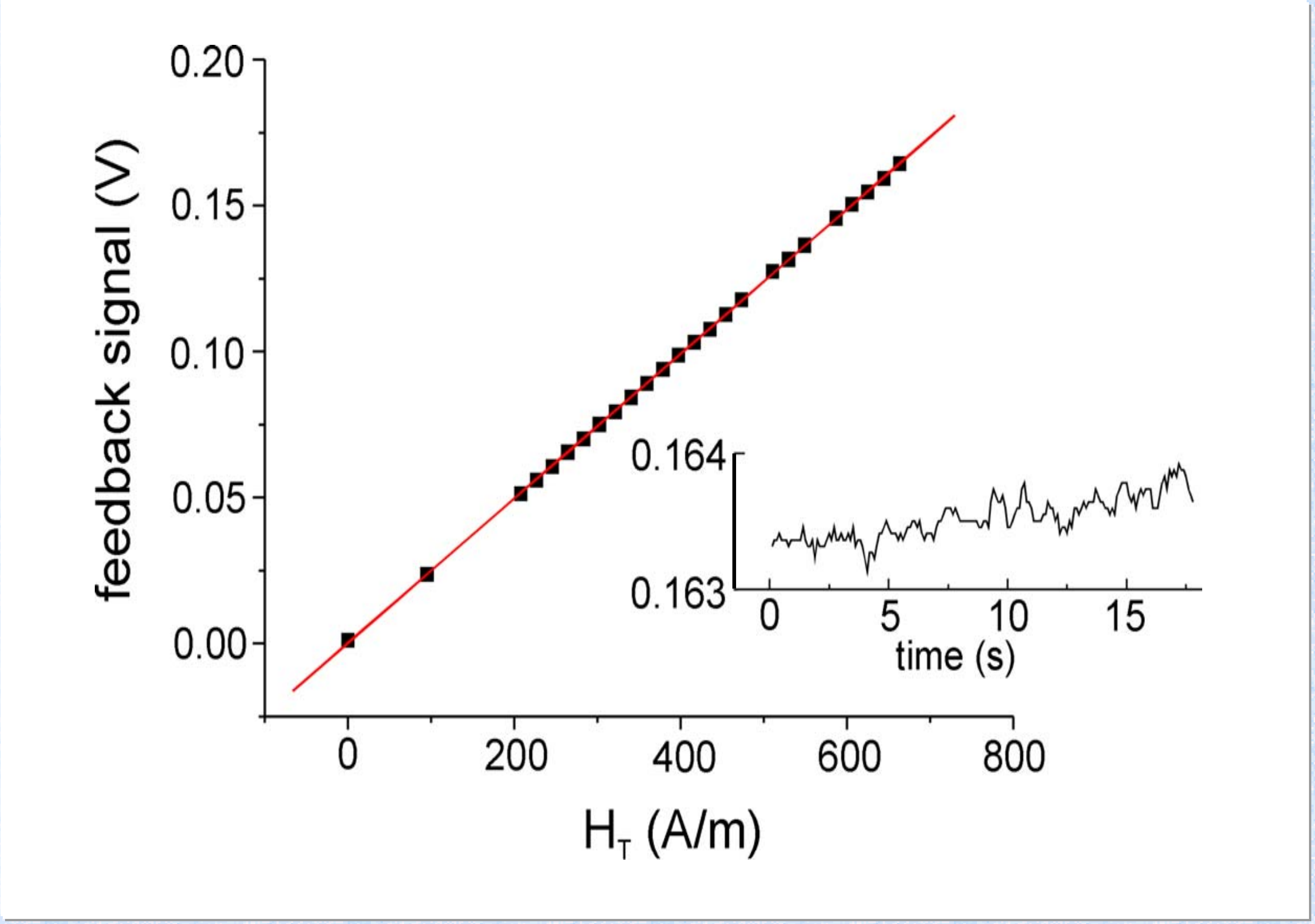


in situ monitoring during thin-film deposition.



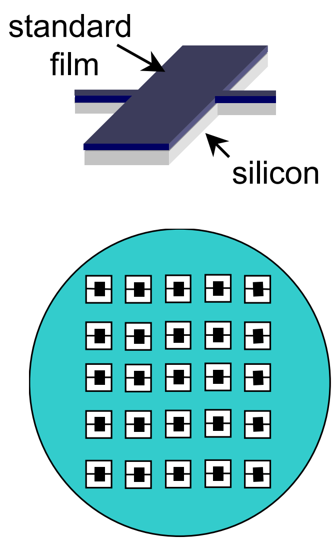
Magnetic moment measured with a resonating torque microbalance versus film thickness measured with a quartz crystal microbalance.

in situ monitoring during thin-film deposition.

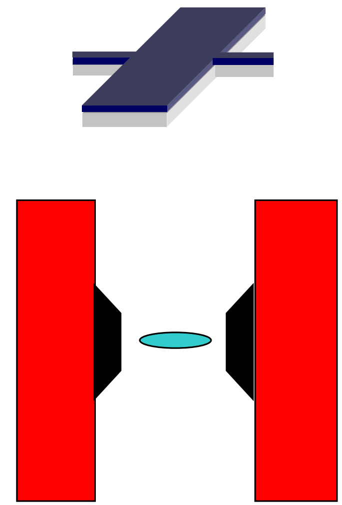


Active damping feedback signal versus torque field for a 30 nm thick permalloy film.

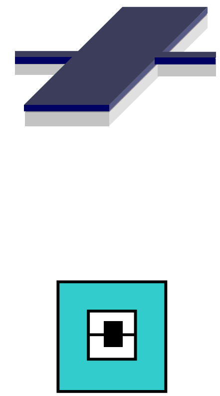
Smart Substrates for Calibrated Magnetometry of Ultra Thin Magnetic Films



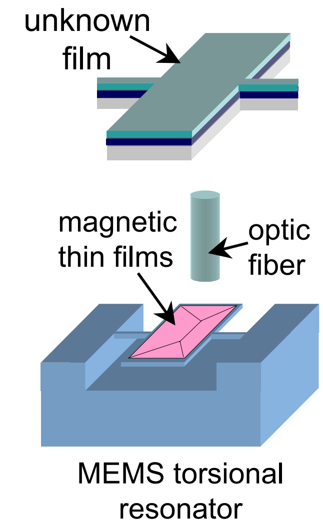
Batch fabricate MEMS torsional oscillators are coated with "standard" magnetic film at the wafer level.



$M_r t$ of the "standard" film is measured at the wafer level in the calibration lab.

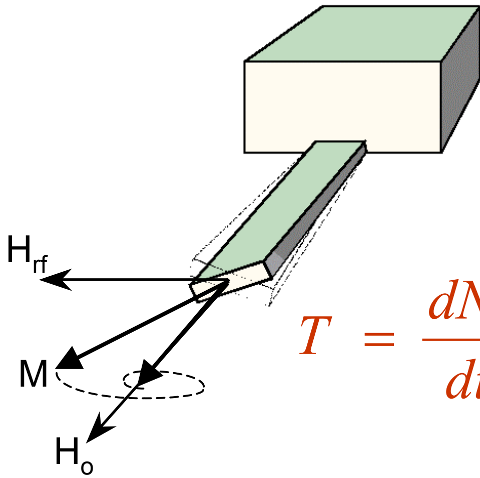


The wafer is diced up into coupons for MEMS test fixtures.

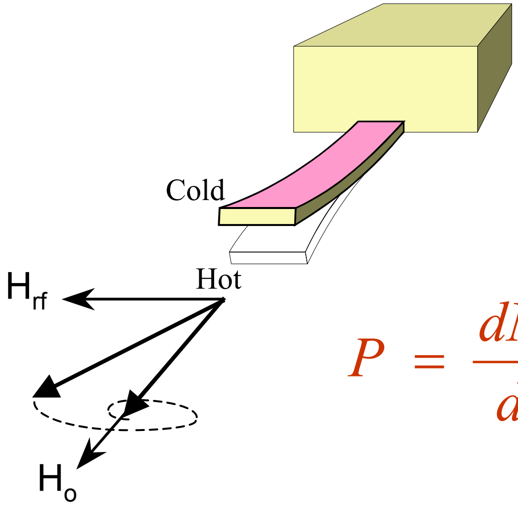


A direct comparison of the unknown film and the "standard" film is made during the deposition and subsequent processing steps on the factory floor.

FMR absorption of photon energy and angular momentum.



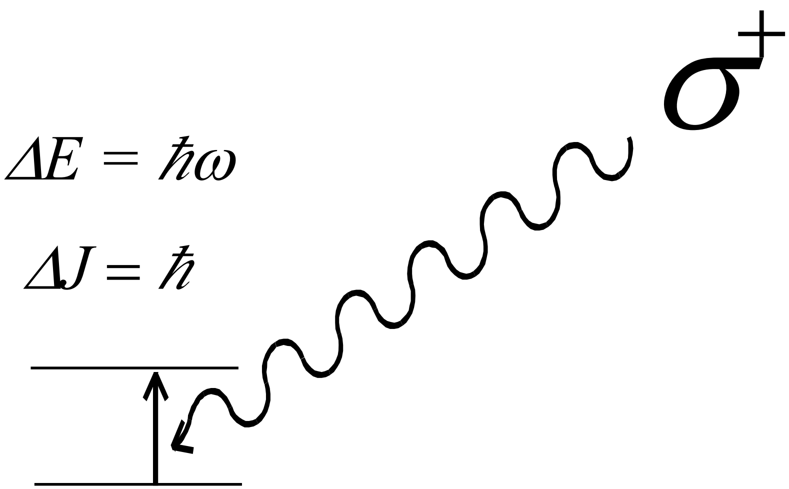
$$T = \frac{dN}{dt}\hbar$$



$$P = \frac{dN}{dt}\hbar\,\omega$$

$$\Delta E = \hbar\omega$$

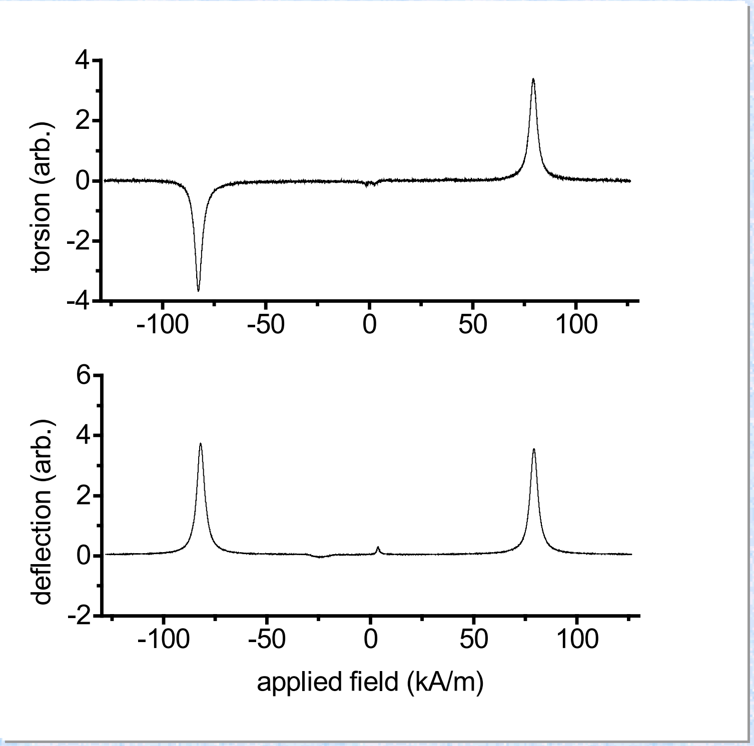
$$\Delta J = \hbar$$

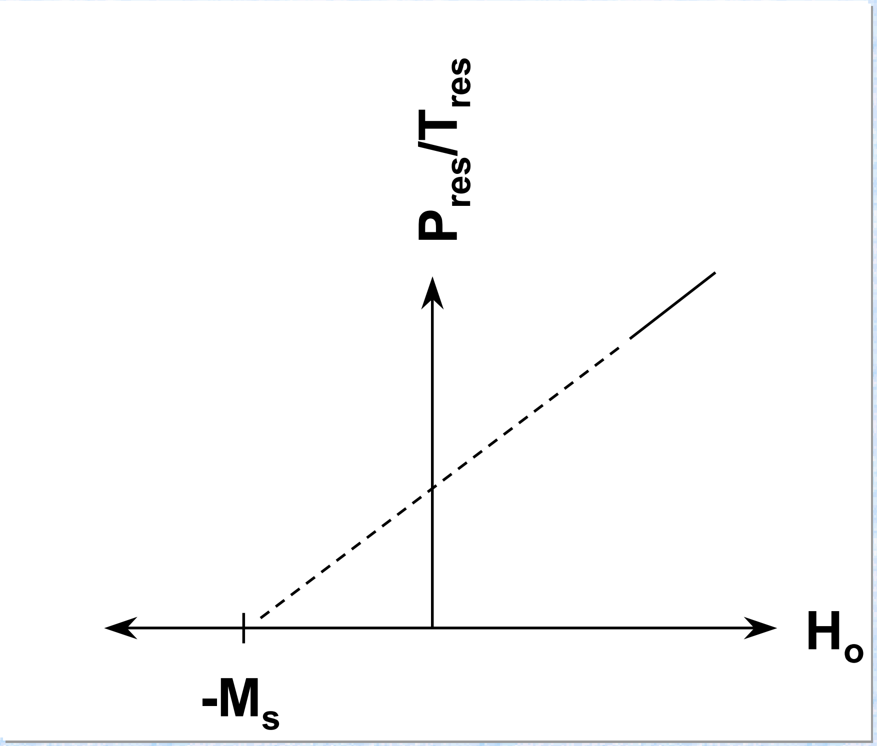


$$P/T = \omega$$

Combining cantilever torque and deflection (power) measurements of the same sample:

$$P_{res} = \gamma(H_0 + M_s)T_{res}$$





Deflection and torque measurements taken with the same experimental configuration.

New way to measure M_s or, alternatively, the ratio of γ's of different spin systems.

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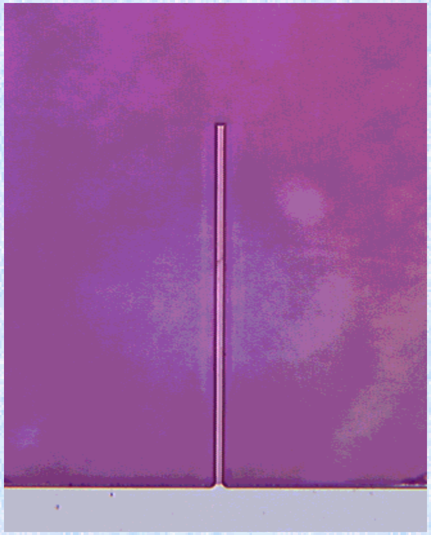
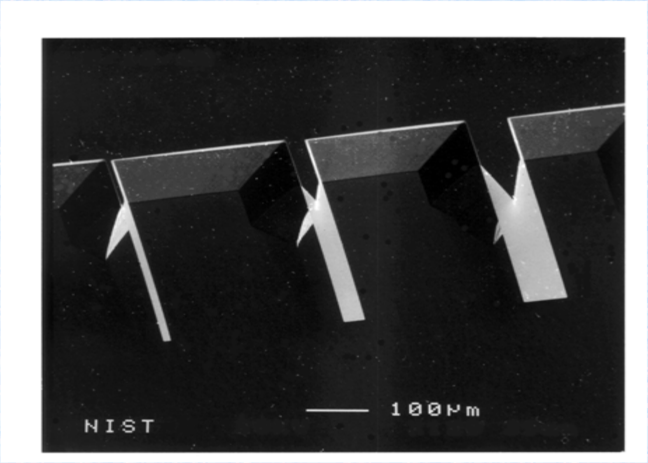
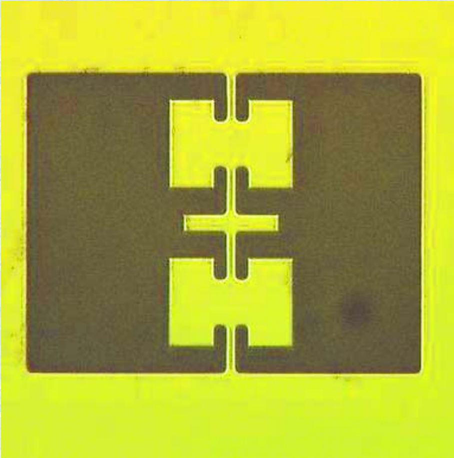
MEMS Magnetometer Projects at NIST-Boulder.



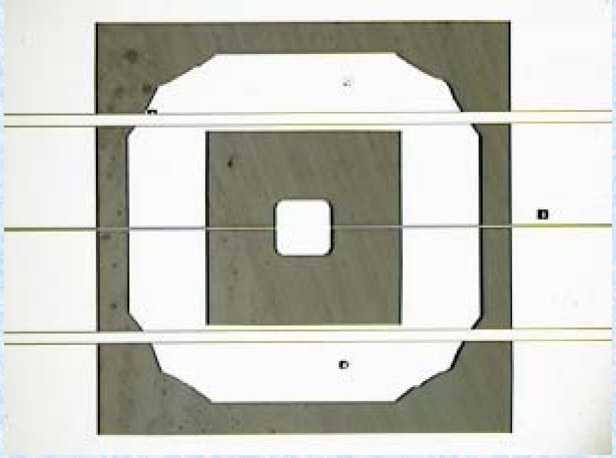
Dielectric bimaterial cantilever



Ultra thin cantilevers



Triple torsional oscillator



High Q torsional oscillators

Magnetic moment sensitivity comparisons ($A \cdot m^2$)