Searching and Testing New Materials for Cantilevers

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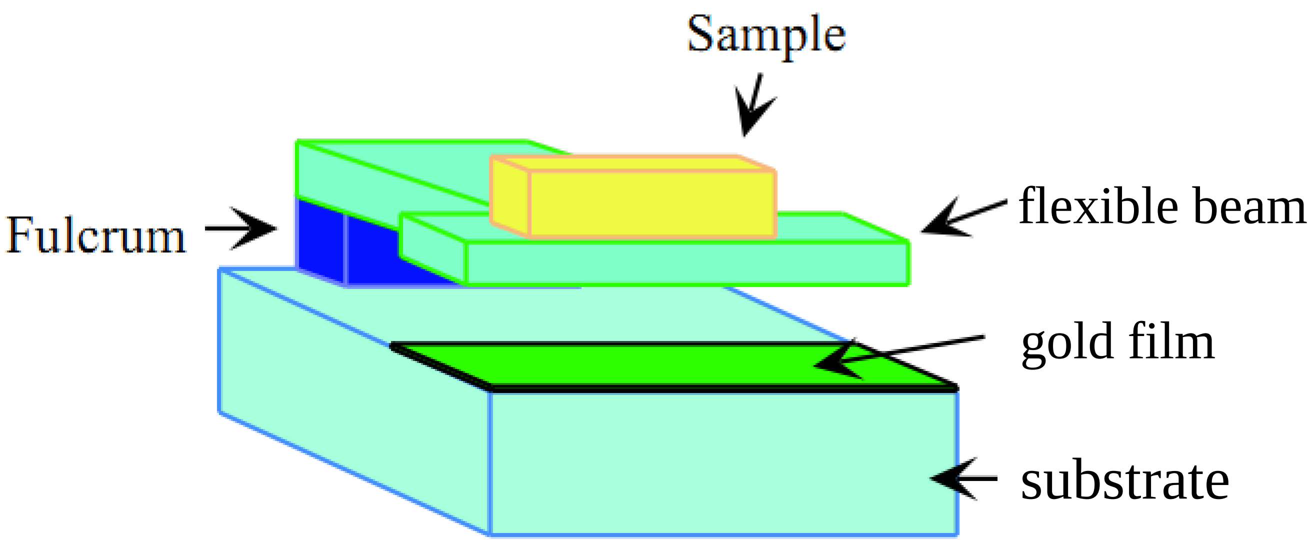
What is a cantilever

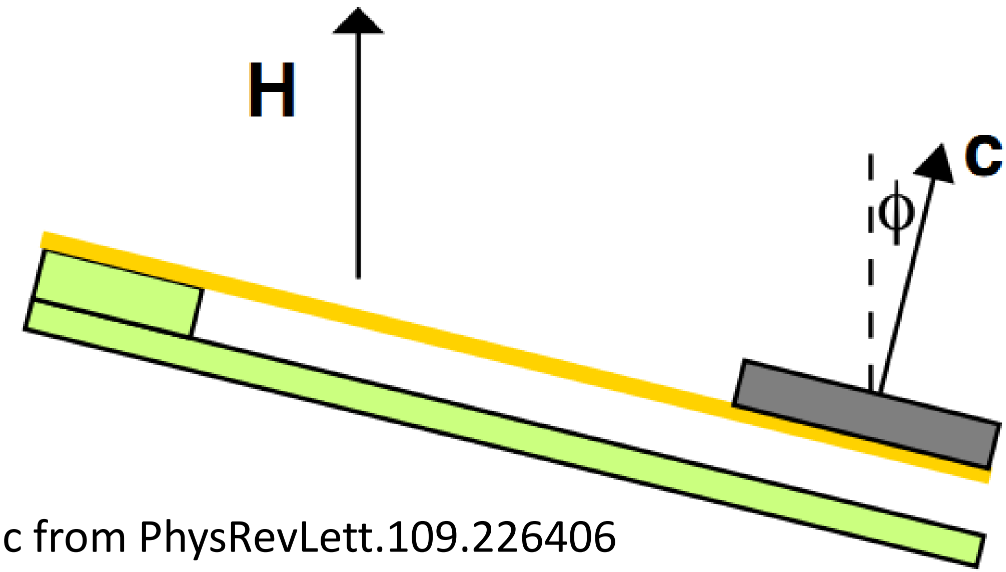
- We are focusing on cantilevers for measuring the magnetic torque.



Pic from NHMFL cantilever handbook

What counts most is the flexible beam

Principle



Pic from PhysRevLett.109.226406

$$Force: \; F = M \cdot \frac{dB}{dz}$$

$$Torque: \quad \tau = M \times B$$

M is magnetization

Magnetic field is applied in the xz-plane. The torque is in y-direction

$$\vec{\tau} = \mu_0 \vec{M} \times \vec{H} = \mu_0 (M_z H_x - M_x H_z)\hat{y}$$

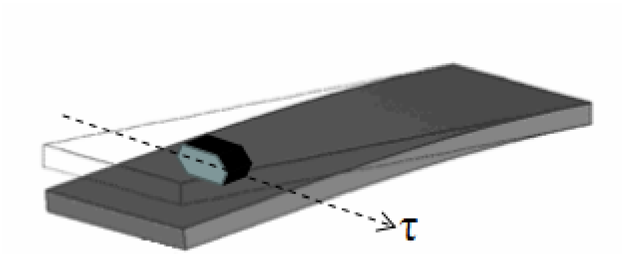
$$= \mu_0 (\chi_z H_z H_x - \chi_x H_x H_z) = \Delta\chi \mu_0 H^2 \sin\phi \cos\phi$$

$\Delta\chi$ is the magnetic susceptibility anisotropy

Torque magnetometry measures the magnetic susceptibility anisotropy of samples.

Principle(continue)

The torque is measured capacitively



The magnetic torque leads to the deflection of the beam
Resulting in change of capacitance

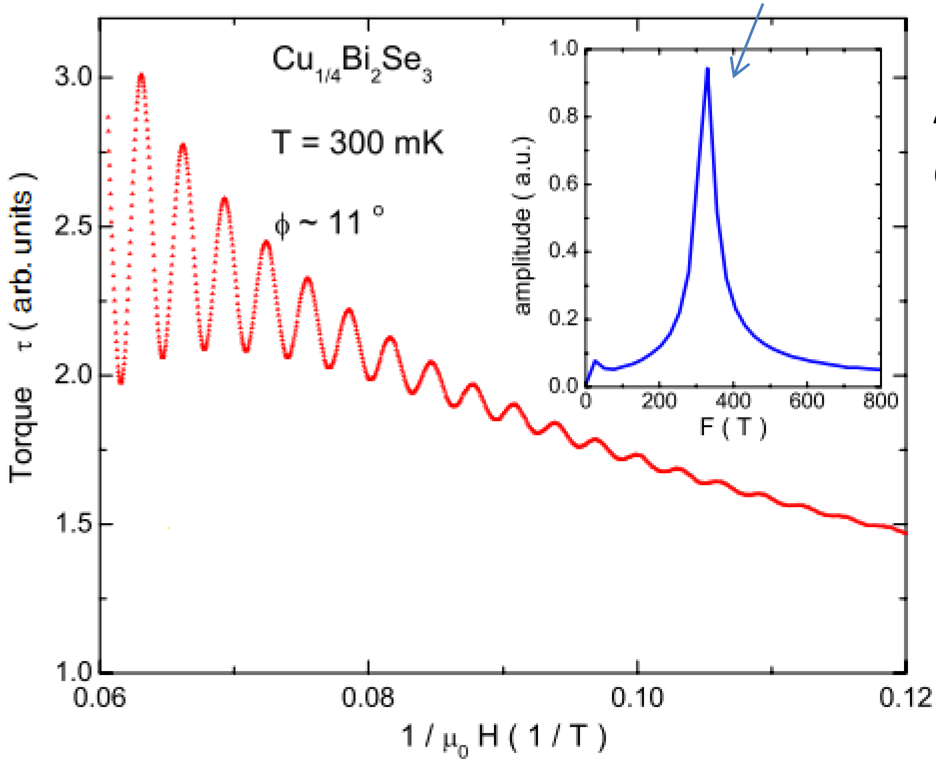
High sensitivity: $10^{-9} EMU$ to $10^{-11} EMU$ (for capacitance based)

No limitation of magnetic field and magnetic sample

The use of a cantilever

- Taking observing quantum oscillation as an example.

Fast Fourier Transformation



According to Landau quantization and de Haas-van Alphen effect, for metals,

$$F_s = \frac{\hbar}{2\pi e} A$$

A is the cross section of Fermi surface

Oscillation Frequency =325T

Pic from PhysRevLett.109.226406

Why need new materials for cantilevers?

- We need a cantilever that can be used in a pulsed field.

Why we need a pulsed field?

NHMFL-PFF Capabilities

Pulsed magnets

- Cell 1 (65 T short pulse, 15 mm, 25 msec)
- Cell 2 (65 T short pulse, 15mm, 25 msec)
- Cell 3 (65 T short pulse, 15 mm, 25 msec)
- Cell 4 (65 T short pulse, 15 mm, 25 msec)
- Cell 5 (35T Midpulse 25mm, 100 msec)
- 60T Long Pulse, 2500 ms, 32 mm,100 msec flattop
- 100T Multi Shot, 2500 ms,15mm, 20 msec above 40T
- 240T Single Turn, 10 mm, 0.006 ms

Superconducting magnets

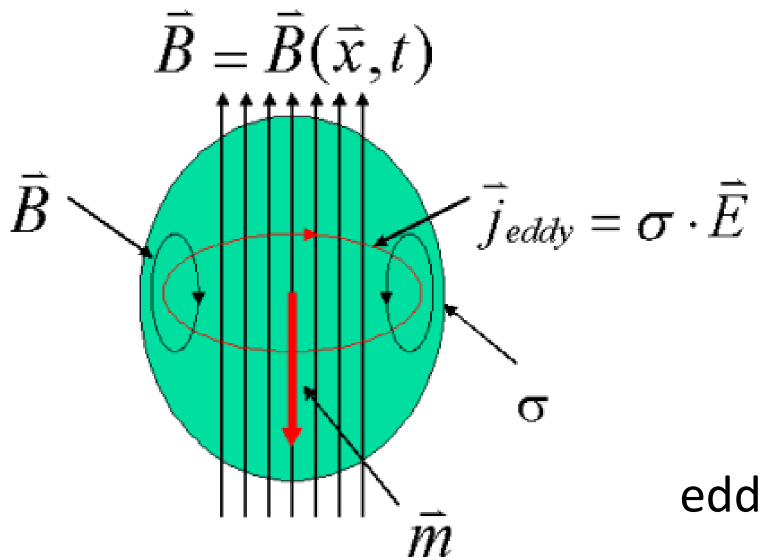
•18/20 52mm bore 10mK – 300K
•15/17T 40mm bore 100mK – 300K
•15/17T 250mK – 300K
•14T PPMS 50mK – 300K
•7T Split Coil Optical Access 1.5K – 300K

Pic from NHMFL 2013 summer school

Requirements for materials(1)

- Why new materials? Why conductors fail to?

$$\varepsilon = -\frac{d\Phi}{dt} = -\frac{d}{dt}\int B\cdot dl = -\int \frac{dB}{dt}\cdot dl$$



eddy current produced, resulting in a torque

Pic from Institut für Festkörperphysik

Requirements for materials(2)

- A possible material should be stiff.

Kapton(polyimide)3.2GPa

Brass 100-125GPa

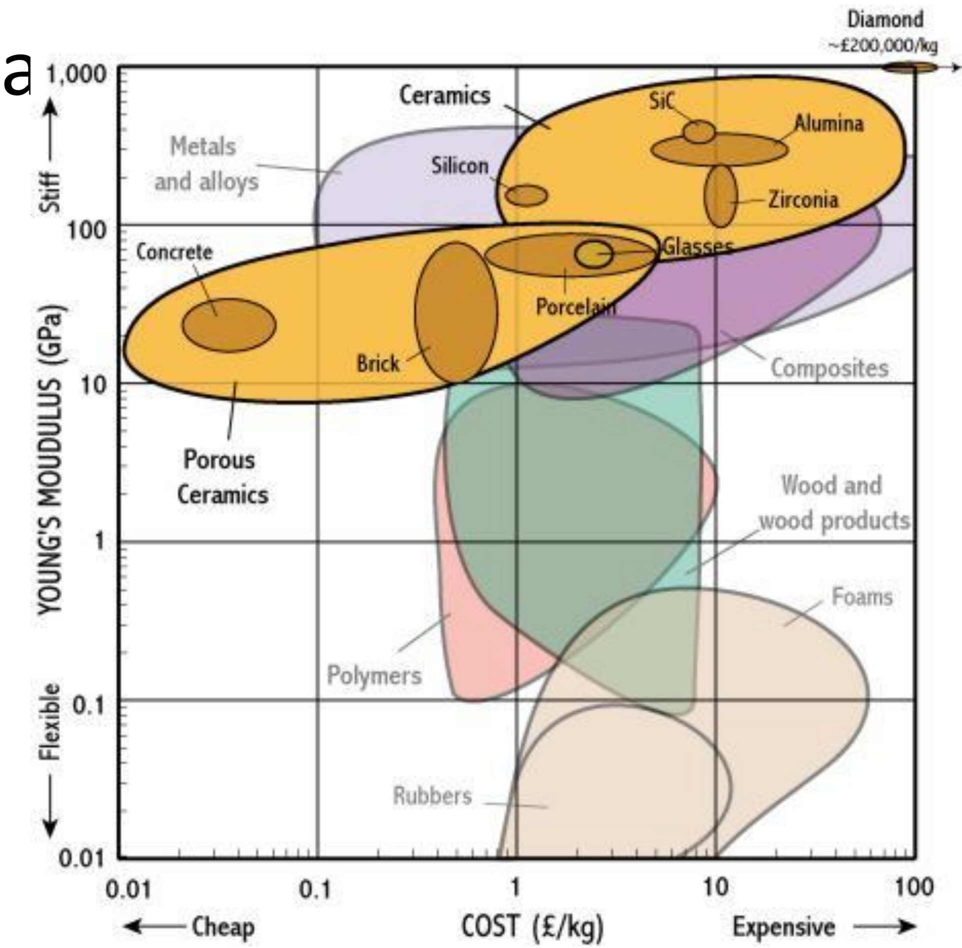
diamond 1220GPa

quartz 97.2GPa (para)

76.5GPa (per)

Ceramic varies

Metallic oxide



Pic from materials group of Cambridge

The procedure of testing

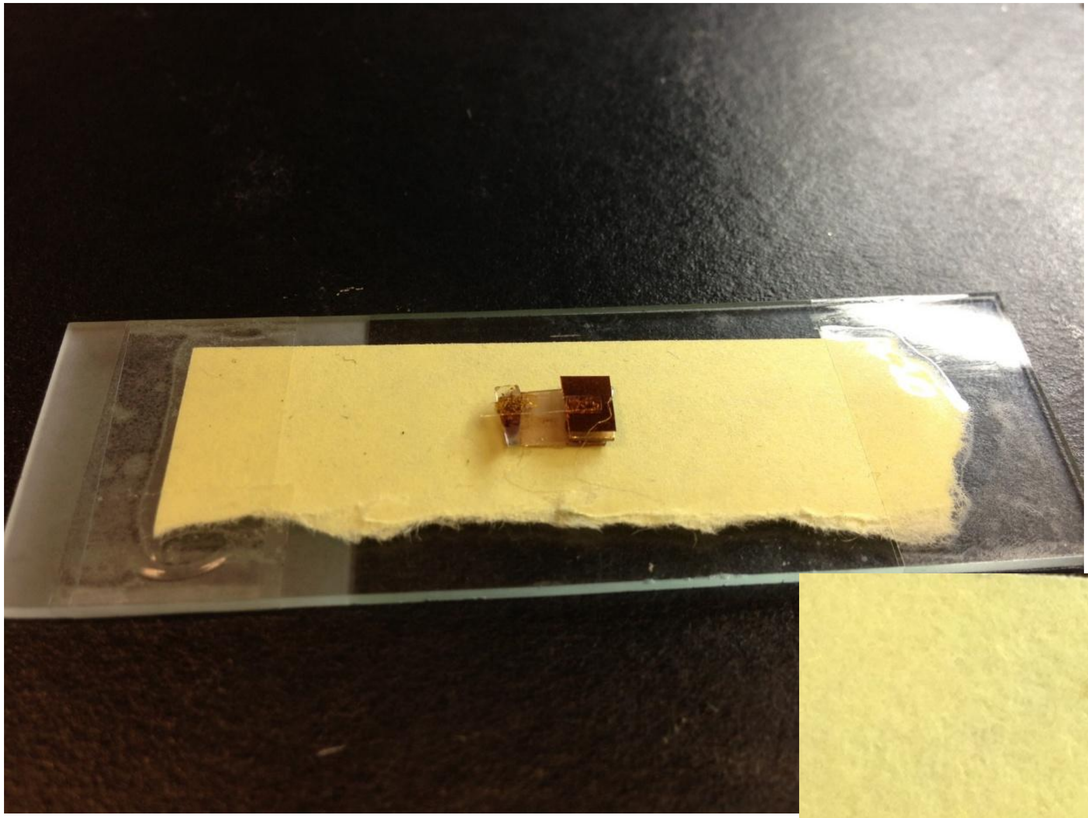
- Before testing, find a kind of possible material and make a cantilever, measure capacitance.
- Measuring capacity signal with a static field and without control of temperature and low temperature
- If fitting well, applying a pulsed field and obtaining data.
- Analyze data. Compare different materials

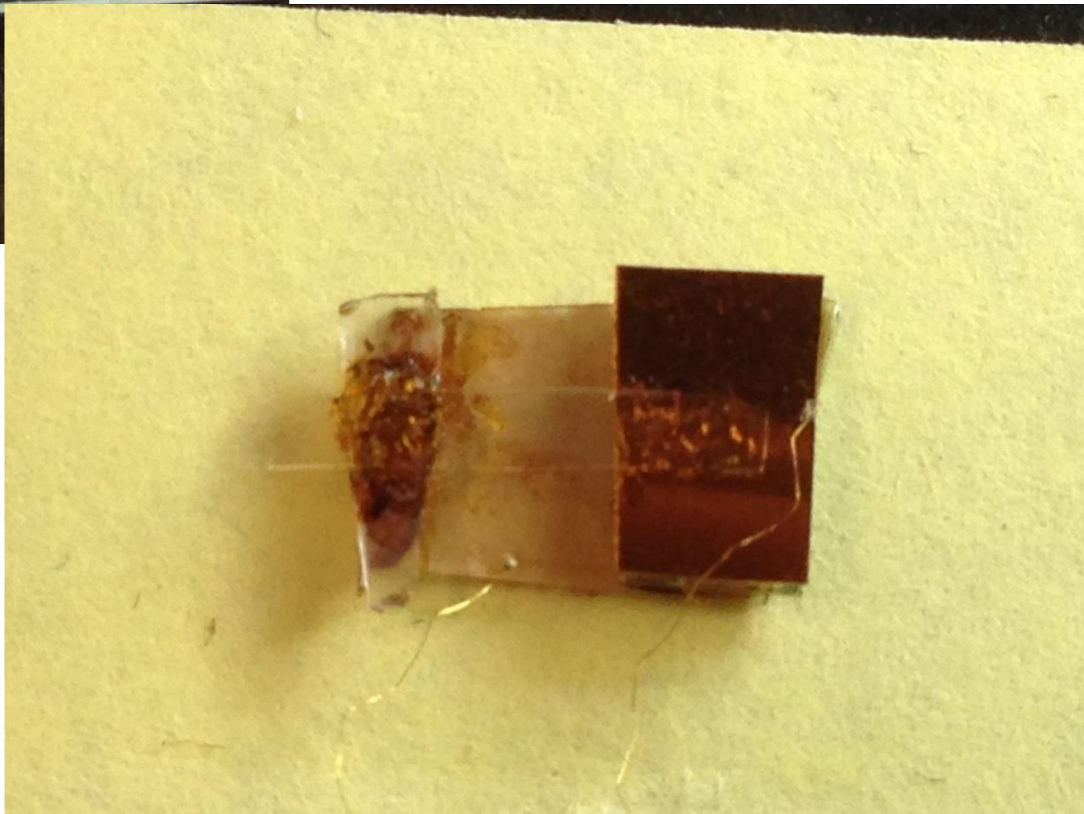
Parameters

- Different kinds of materials
- The parameters of the flexible beams.
  - Length, width, thickness, shape etc

$$K = \frac{Ywt^4}{l}$$

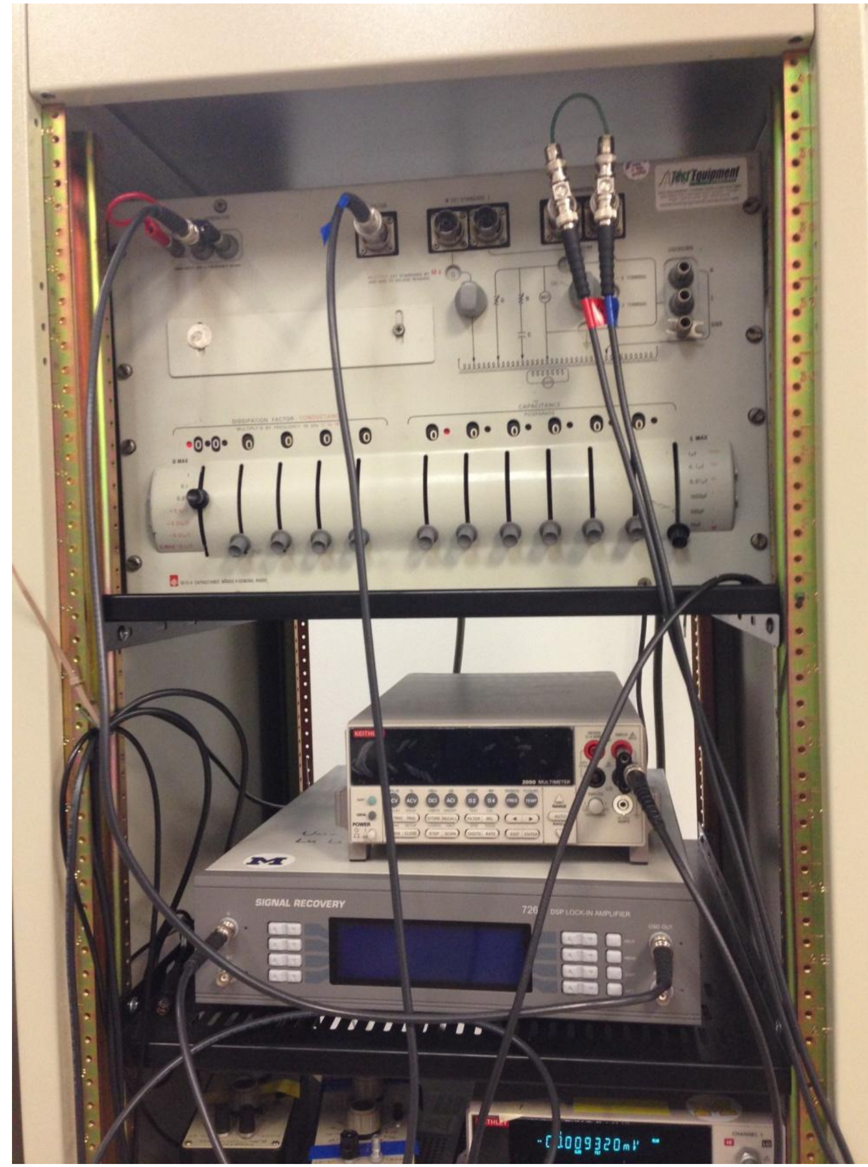
K represents spring constant
Y represents Young's modulus
l,w,t represent length, width, thickness





An example:
made of quartz
length:5mm;width:1.2mm;
thickness 100um

Cryogenic equipment



Capacitance bridge and lock-in amplifier

Thank you!