Searching and Testing New Materials for Cantilevers

REU Program  Dou Liu
Advisor: Lu Li
What is a cantilever

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

What counts most is the flexible beam

Pic from NHMFL cantilever handbook
**Principle**

**Force**: \( F = M \cdot \frac{dB}{dz} \)

**Torque**: \( \tau = M \times B \)

\( M \) is magnetization

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

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

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

\( \Delta \chi \) is the magnetic susceptibility anisotropy

Torque magnetometry measures the magnetic susceptibility anisotropy of samples.

Pic from PhysRevLett.109.226406
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.

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
Why need new materials for cantilevers?

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

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) 3.2 GPa
  - Brass 100-125 GPa
  - Diamond 1220 GPa
  - Quartz 97.2 GPa (para)
    - 76.5 GPa (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!