Noise Characteristics
in Magnetic Tunnel Junctions

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Superparamagnetic tunnel junctions

Tunnel-magnetoresistance specifications

- sensitivity
- absolute resistance
- hysteresis $H_c$
- signal noise

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Superparamagnetic tunnel junctions
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Superparamagnetic tunnel junctions
Thermally unstable magnetization

Arrhenius equation:

\[ \frac{1}{\tau} = f_0 e^{-\Delta E/kT} \]

\[ \Delta E = K_{\text{anisotropy}} \times \text{Volume} \]
Superparamagnetic tunnel junctions

Magnetization of superparamagnetic particles

\[ L(a) = \coth(a) - \frac{1}{a} \]

\[ a = M_s \times \text{Vol} \times H / kT \]

volume

magnetic field

temperature

NiFeCo 1 \( \mu_B \)/300K

\[ \frac{M}{M_s} \text{ vs. } H \text{ (Oe)} \]
Cu / 0.8 nm NiFeCo / Cu

(400)_{FM}  
(400)_{Cu}

(222)  
(220)  
(200)  
(111)
Superparamagnetic tunnel junctions

Cu / 0.8 nm NiFeCo / Cu

The graph shows the magnetic field (Oe) on the x-axis and the magnetic moment (mu) on the y-axis. The graph includes data for three temperatures: 170 K, 270 K, and 310 K, indicated by the different lines and symbols.
Superparamagnetic tunnel junctions

Cu / NiFeCo / Cu

0.8 nm

0.6 nm

\( H_c \) (Oe)

slope (memu/Oe)

\( M_s \) (emu/cc)

\( M_s \) (emu/cc)

temperature (K)

temperature (K)
Superparamagnetic tunnel junctions

hysteresis-free magnetic field sensor

- Voltage (V) vs. Field (Oe)

- Materials:
  - CrMnPt
  - FeCo
  - Al₂O₃
  - NiFeCo
  - Ru

- Resistance: $R = 20 \, \text{k}\Omega$
Superparamagnetic tunnel junctions

Tunnel-magneto-resistance specifications

- sensitivity
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Thermal Fluctuations and Noise in Superparamagnetic Nanoparticles
Asymmetric RTS (Random Telegraph Signal) Noise

\[ S(\omega) \sim \left\{ (\tau_1 + \tau_2) \left[ \left( \frac{1}{\tau_1} + \frac{1}{\tau_2} \right)^2 + \omega^2 \right] \right\}^{-1} \]

\[ \tau_1 = \tau_0 \exp(-\Delta E_1 / kT), \quad \tau_2 = \tau_0 \exp(-\Delta E_2 / kT) \]

\[ \Delta E_{1,2} = \frac{K_u V}{kT} (1 \mp h)^2, \quad h = \frac{H}{H_k} \]


Temperature and Frequency Dependence of Noise at $H = 0$

\[ \omega = 1 \]

\[ \omega = 10 \]
Field Dependence of Noise

\[ KV/ kT = 18 \]

\[ \omega = 1 \]

\( (h = H / H_k) \)
Superparamagnetic tunnel junctions

The SDT sensor
Noise measurements in superparamagnetic tunnel junctions

Setup

- Batteries
- Low noise preamplifier
- Control System Analyzer
- DAC Card
- Coolers
- Thermocouple
- Shields

Operating conditions:

- ± 50 Oe
- 250K - 320K
- 60 µHz - 100 kHz
- (planned: -20 GHz)

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Noise measurements in SPM tunnel junctions
preliminary results

Low frequency peak in noise spectrum @ switching point
Noise measurements in superparamagnetic tunnel junctions

**Planned Work**

- Extension of experimental capabilities up to 30 GHz
- Noise measurement as a function of: frequency, field, temperature and voltage
- Transport and Magnetization measurements of superparamagnetic layers