Spin dynamics in point contacts to single ferromagnetic films

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Literature discussion

2 December 2009

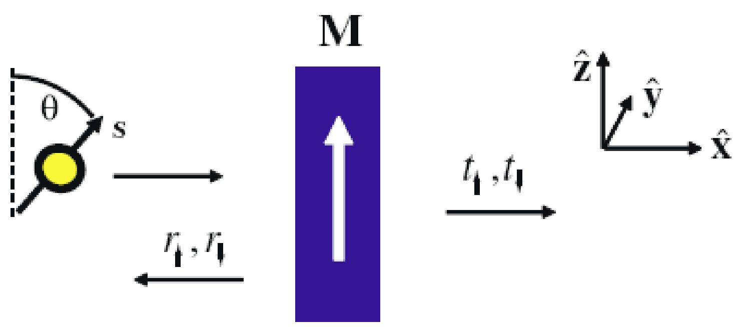
Tim Verhagen

Spin Transfer Torque; Toy model 1

- Need change flow spin current

- $$\begin{aligned} \text{torque} &\propto \int dA \text{ spin current} \\ &\propto \int dA \text{ electron velocity} \times \text{spin density} \\ &\propto A(\text{ spin current}_{\text{in}} + \text{ spin current}_{\text{trans}} - \text{ spin current}_{\text{refl}}) \end{aligned}$$

- $$\text{torque} = \begin{cases} \neq 0 & \text{if } t_\uparrow \neq t_\downarrow, r_\uparrow \neq r_\downarrow \\ 0 & \text{if } t_\uparrow = t_\downarrow, r_\uparrow = r_\downarrow \text{ or spin collinear with M} \end{cases}$$



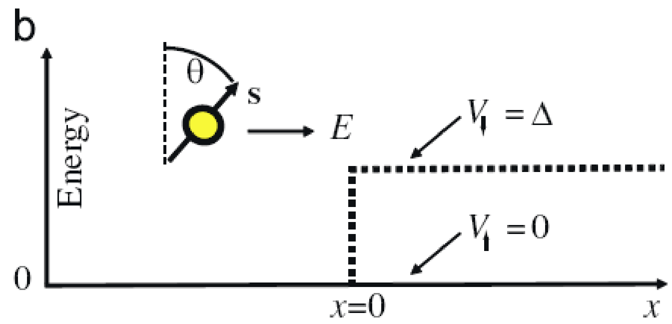
Review: Journal of Magnetism and Magnetic Materials 320 issue 7 (2008)

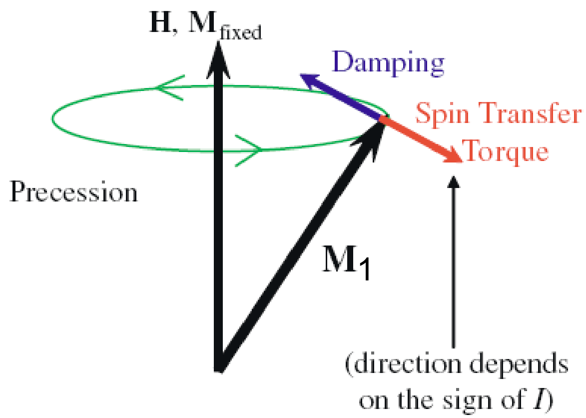
STT Toy model 2

- Apply stoner model to toy model 1
- Spin current density is discontinuous at interface -> torque in x-direction
- Spin precession around z-axis, but dephasing due to different path lengths
- $(d\mathbf{m}_1/dt) \propto I\eta(\Theta)\underbrace{\mathbf{m}_1 \times}[\underbrace{\mathbf{m}_1 \times \mathbf{m}_2}].$

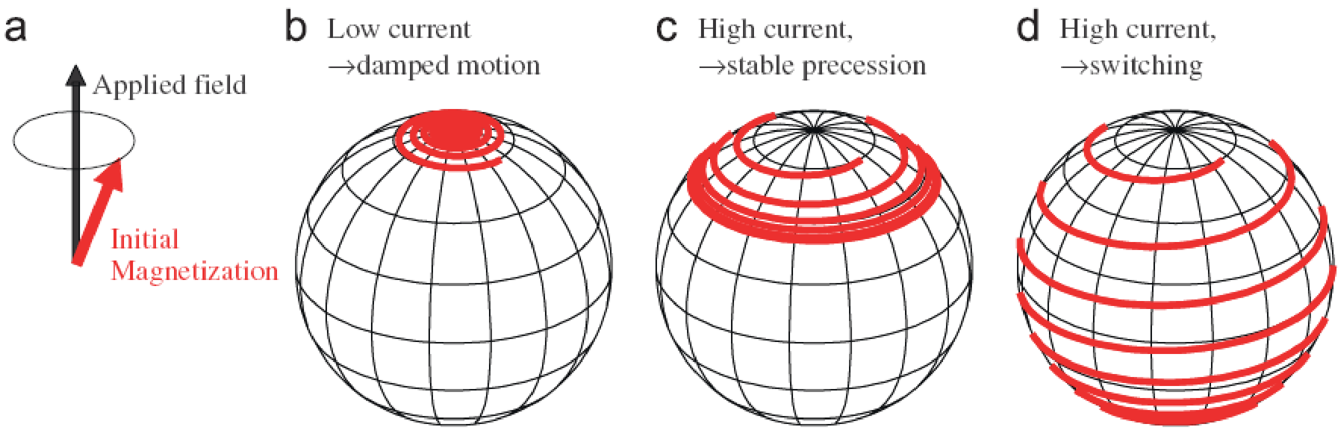
Generated torque

dissipation

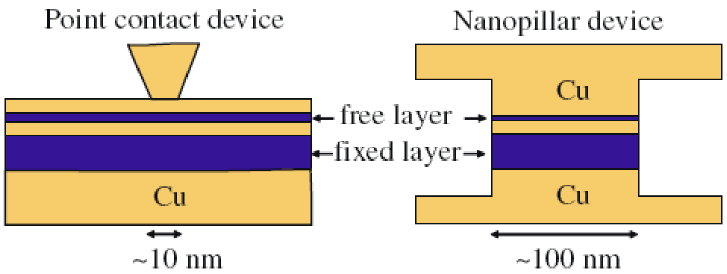




Spin transfer torques



Experimental point contacts



- Small point contact, so current and not magnetic (Oersted) driven
- Size point contact $R_{\text{Sharvin}} = \frac{16\rho l}{3\pi d^2}$

Current voltage characteristics

- Obtain from Green's functions I(t), consisting of

$$I(t) = I^0(t) + I^1(t) + I^2(t) + I^3(t)$$

$I^0(t)$: Total current trough orifice

$I^1(t)$: Inductive correction without electron-phonon interaction

$I^2(t)$: Inductive correction with electron-phonon interaction

$I^3(t)$: Inelastic interactions

- In classical low frequency limit, $\omega \ll \omega_D$

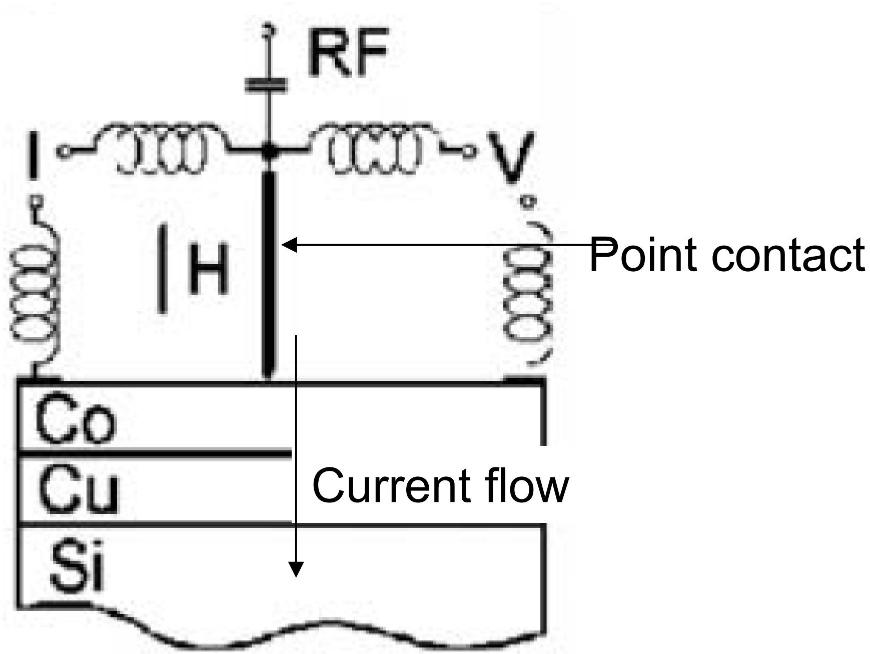
$$\bar{I}(\bar{V}) = (\Omega/\pi)\int_0^{\pi/\Omega} I_0(V_0 + V_1 \cos \Omega t)dt,$$

- And if $V_1 \ll V_0$

$$\delta I(V) = \frac{V_1^2}{4}\left(\frac{d^2 I}{dV^2}\right)_{I=I_0}$$

Omel'yanchuk, Fiz nizk Temp 9, 284

Setup



- Ag or Cu point contact up to 20 nm diameter
- 5, 10 or 100 nm thick Co film
- Measure differential resistance (lock-in technique modulating current 10-50 μA @ 443Hz)
- Field up to 5 T
- ? How do they make the contact? STM, micrometer screws?
- ? RF source? Network analyzer?

IV without radiation

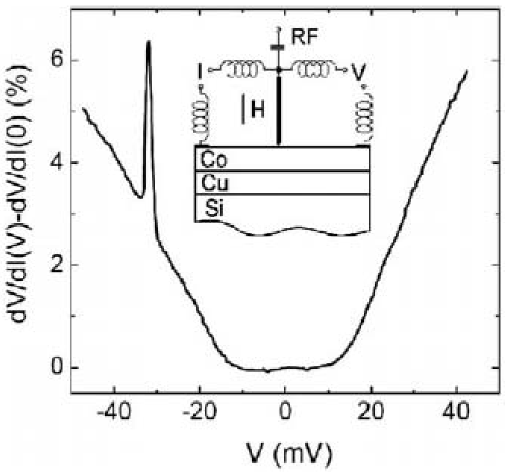
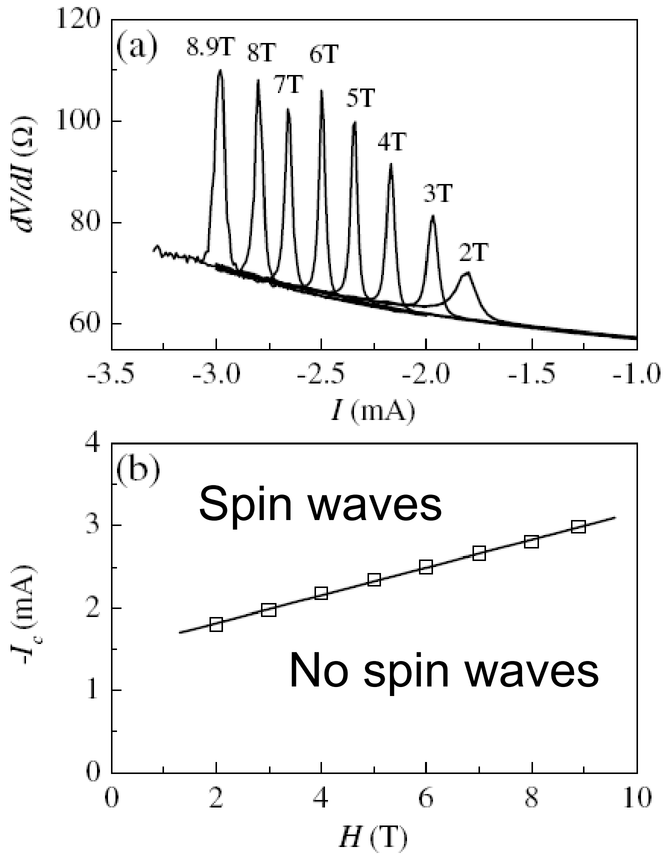


FIG. 1. Relative differential resistance for point contacts of a Cu needle and a 100 nm thick Co film, R_0=7.2 Ω, $H_\perp$=4 T. The inset shows the schematic of the experiment.

Excitations magnetic layer



Co|Ag

H > Hsaturation

↓

Excite spin waves

↓

Magnetisation changes

↙ ↘

Increase R

$\mu_{\downarrow} > \mu_{\uparrow}$

↓

$$\Delta\mu = \mu_{\uparrow} - \mu_{\downarrow} < 0$$

Ji, Chien and Stiles, prl 90, 106601 (2003)

Observe 2 features

- rectification behaviour

- stimulation

rectification behaviour

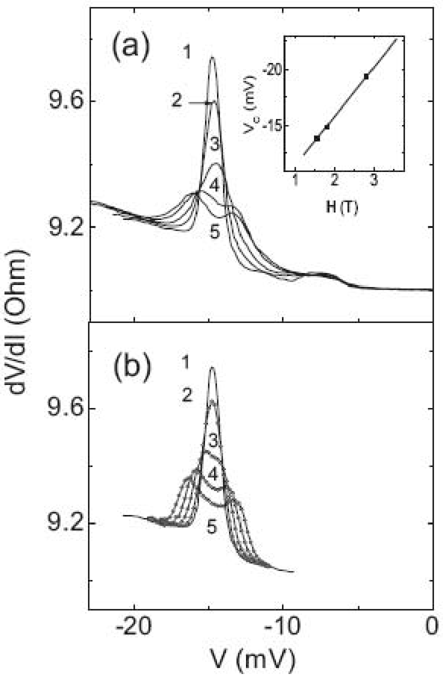


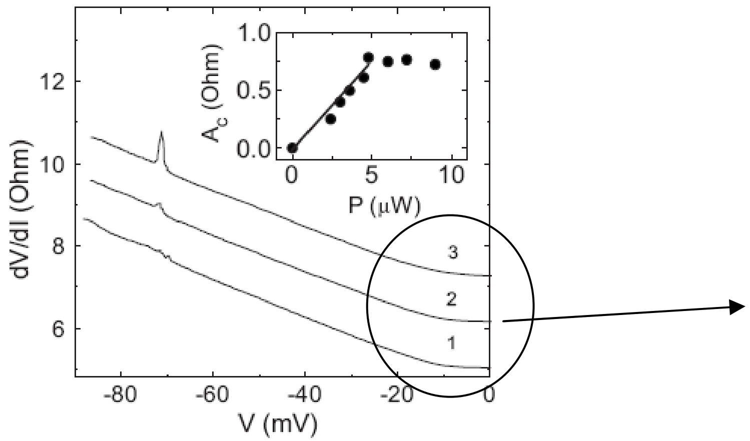
FIG. 2. (a) dV/dI as a function of bias for a point contact of a Cu needle and a 100 nm thick Co film under irradiation with frequency of 2 GHz and powers $P = 0$, 12, 24, 36, and 48 μW (curves 1, 2, 3, 4, and 5, respectively). (b) Calculated dependence according to Eq. (2) for $V_1 = 0.5$, 1, 1.5, and 2 μV (curves 2, 3, 4, and 5, respectively). Curves 1 in (a) and (b) are identical. Inset: critical voltage (STT peak position) as a function of the external field.

Ac radiation is rectified in PC

$$\delta I(V) = \frac{V_1^2}{4}\left(\frac{d^2 I}{dV^2}\right)_{I=I_0}$$

V1 ~7mV

stimulation



No rectification!

FIG. 3. Spin-wave peak in dV/dI stimulated by increasing the power of irradiation at 2 GHz for rf powers $P=0$, 2.4, and 3.6 μW (curves 1, 2, and 3, respectively). The curves are shifted vertically by 1 Ω for clarity. The contact is Cu-Co(100 nm), $R_0=5.04\ \Omega$, and $H_\perp=2.47$ T. The inset shows the amplitude of the induced peak as a function of rf power.

Resonant absorption

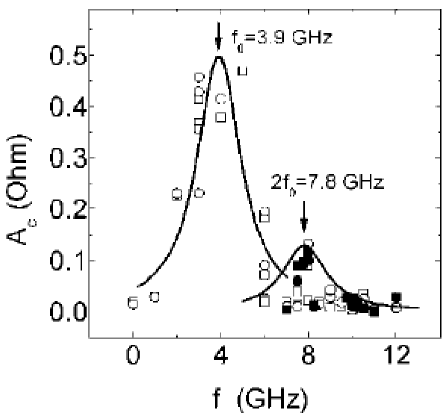


FIG. 4. Amplitude of a spin-wave peak for a Cu-Co(10 nm) contact with R_0=6.7 Ω as a function of the rf for P_{rf}=4 and 10 dB m, open and solid symbols, respectively. Circles and squares correspond to the positive and negative bias sweep directions. $H_{\parallel}$ =1 T. Lines are Lorenzian peaks approximating the data, with characteristic frequencies f_0 and $2f_0$.

Other samples are 100nm thick!

Why parallel and not perpendicular?

- Only affected around PC
- Different features than for bulk
- Induced mechanical stress, anisotropy, magneto constriction in pc core

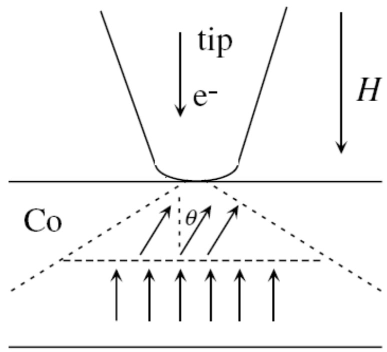


FIG. 4. A microscopic picture of a point contact between an Ag tip and a Co film with an external magnetic field applied perpendicular to the Co layer. On entering the Co film, electrons first pass through a localized "free region" right underneath the tip and before entering the "static region" as the current spreads out. The horizontal dashed line marks the boundary between the free and static regions.

Conclusion

- Shown resonant and non-resonant behaviour
- PC can have a wide spread in characteristics
- Measured ‘hundreds of pc’, can show some statistics on behaviour
- Ballistic of diffusive?
- Influence of thickness?