Thermal Transfer Torque

Jean-Philippe Ansermet
Ecole Polytechnique Fédérale de Lausanne

Group

Post-docs

• S. Bréchet,	*theory*
• M. Abid,	*nanostructures of many kinds*
• Simon Granville,	*transport measurements*
• M. Belesi,	*NMR of solids, multiferroics*

Grad students

• Haiming Yu,	*thermal spin torque*
• E. Papa,	*FMR and heat current*
• F. Comandè	*OMAR and ESR of Organic LED*

Funding

Swiss NSF,
Swiss-India joint research,
Swiss-China joint research
SCOPES – Moldova- Romania

Charge – Heat – Spin transport in ferromagnetic nanostructures

Initial motivation :

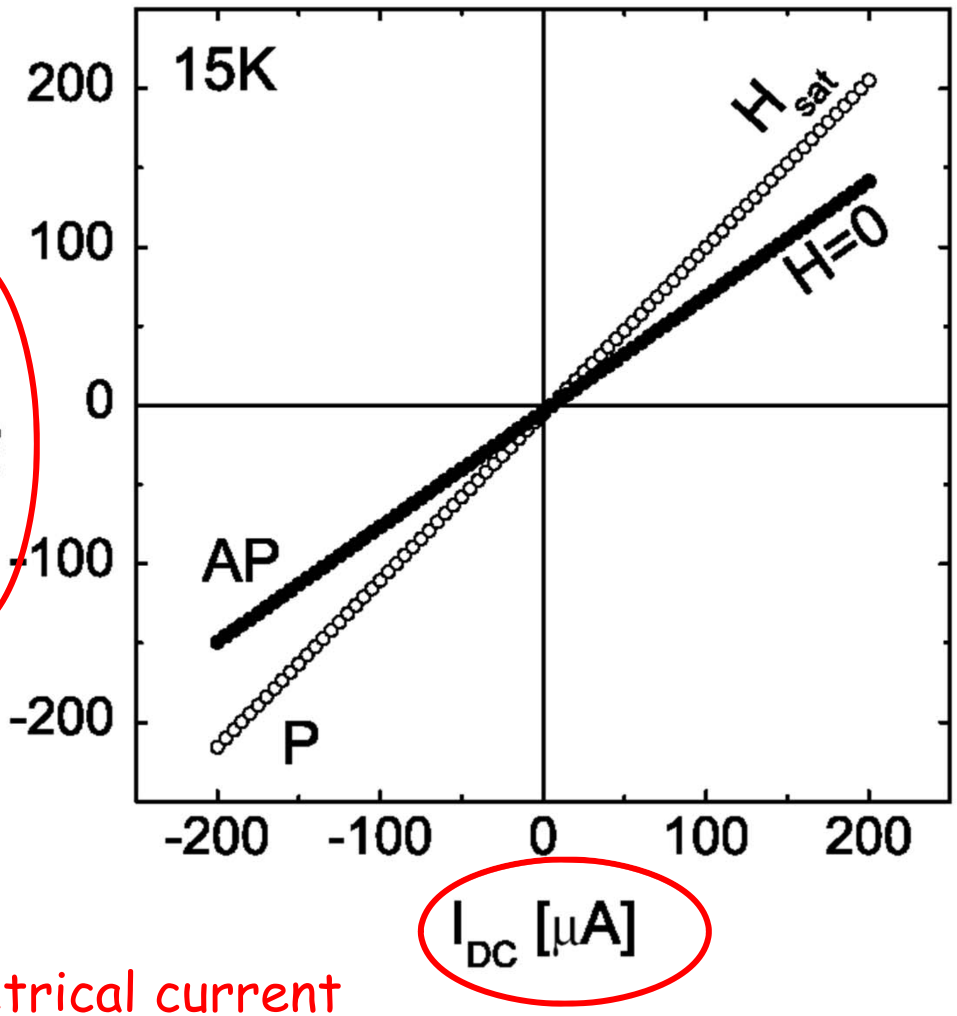
Spin transfer torque effect

- Due to spin relaxation
- Dissipation to be found in transport

-> Magneto-Thermo-Galvanic Voltage (MTGV)

Probing spin-charge-heat transport : Thermo Galvanic Voltage (TGV)

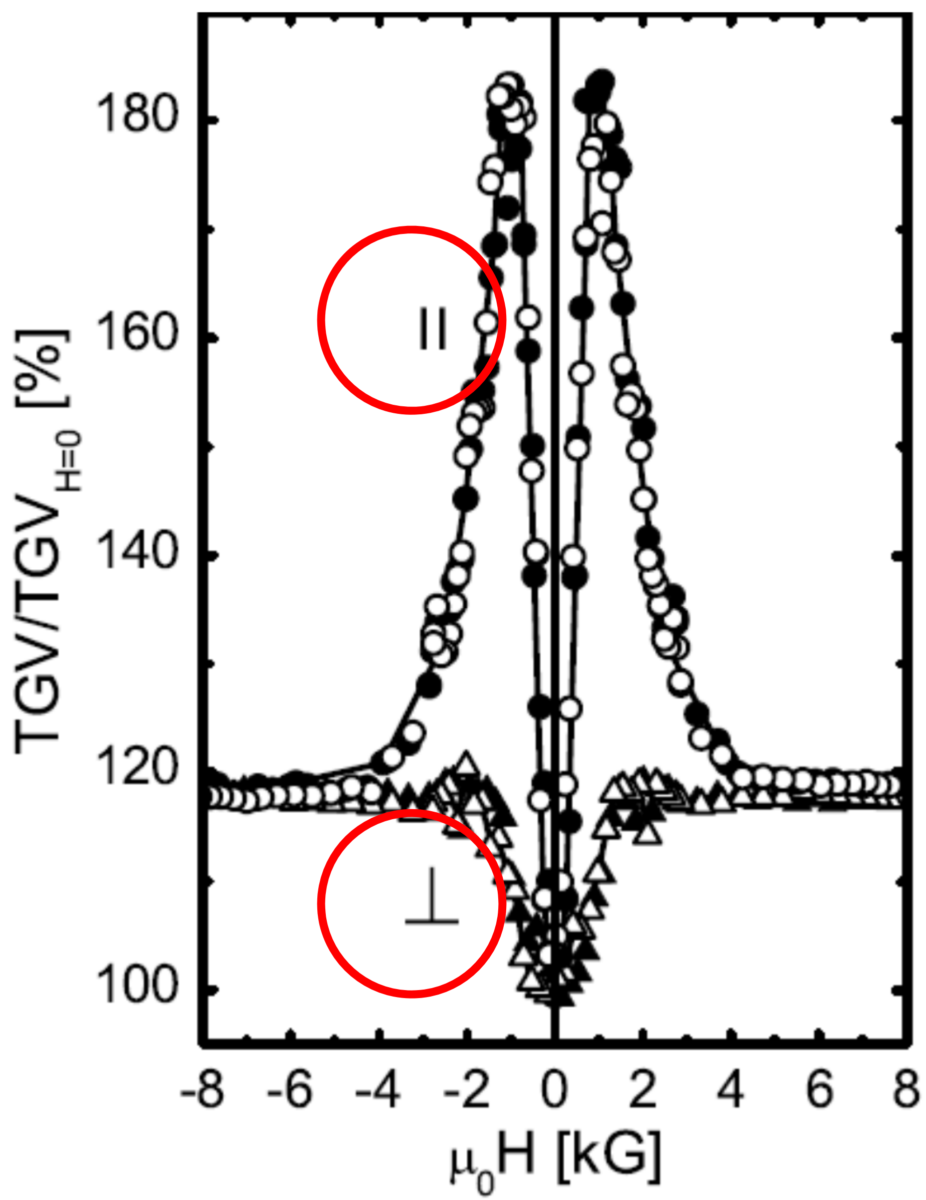
Response to a température oscillation

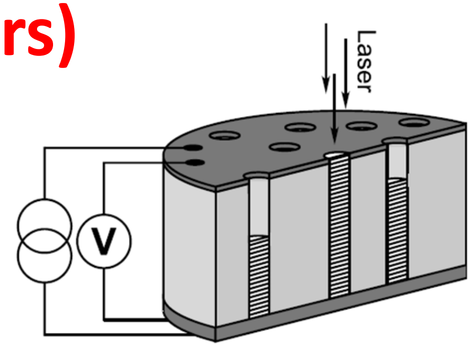


DC electrical current

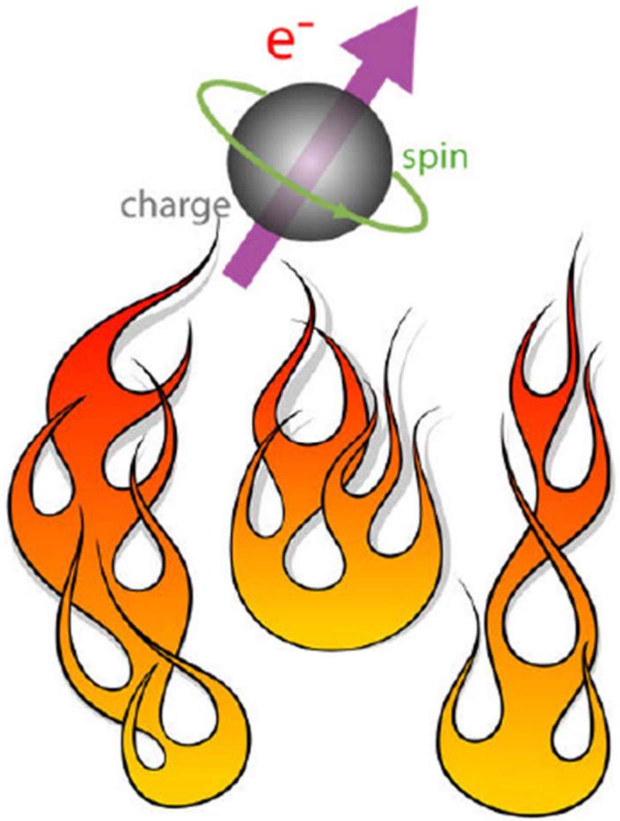
Gravier 2004

Co-Cu multilayered nanowires (300 bi-layers)





Proposal for a Priority Programme



Spin Caloric Transport (SpinCaT)

Deutsche Forschungsgemeinschaft DFG

MTGV modelled with a «three-current» model

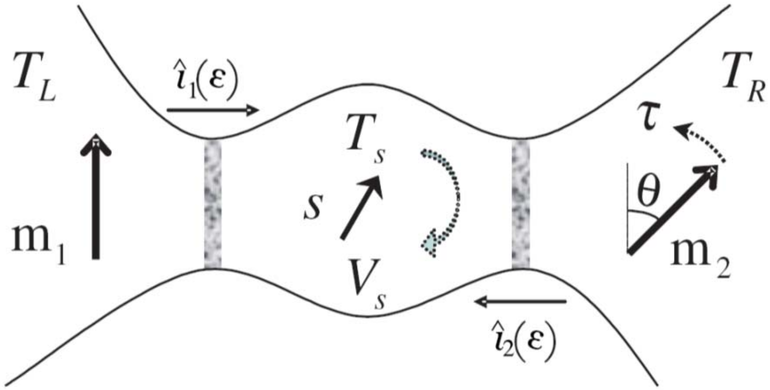
$$\begin{pmatrix} \mathbf{j}_s \\ \mathbf{j}_+ \\ \mathbf{j}_- \end{pmatrix} = - \begin{pmatrix} L_{ss} & L_{s+} & L_{s-} \\ L_{+s} & L_{++} & L_{+-} \\ L_{-s} & L_{-+} & L_{--} \end{pmatrix} \begin{pmatrix} \nabla T \\ \nabla \mu_+ - q_+ \mathbf{E} \\ \nabla \mu_- - q_- \mathbf{E} \end{pmatrix}$$

… suggests coupling of heat and spin current

… but we did not consider it !

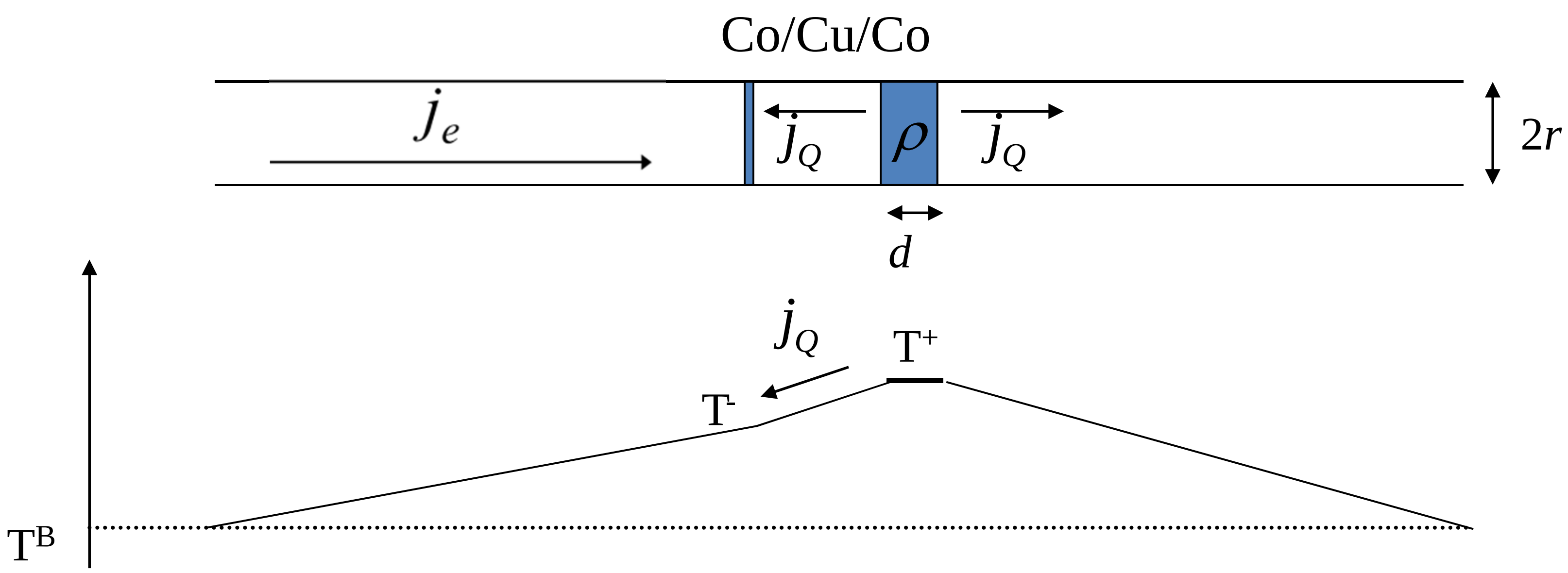
Thermal spin torque predicted in 2007

M. Hatami, G.E.W. Bauer, Q. Zhang, P.J. Kelly,
Phys. Rev. Lett. 99, 066603 (2007)



$$\tau \sim P\Delta V + P'S\Delta T$$

Joule heating of a spin valve in a nanowire

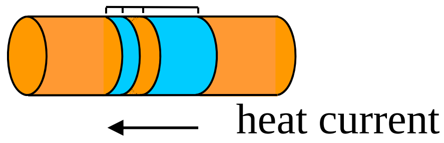


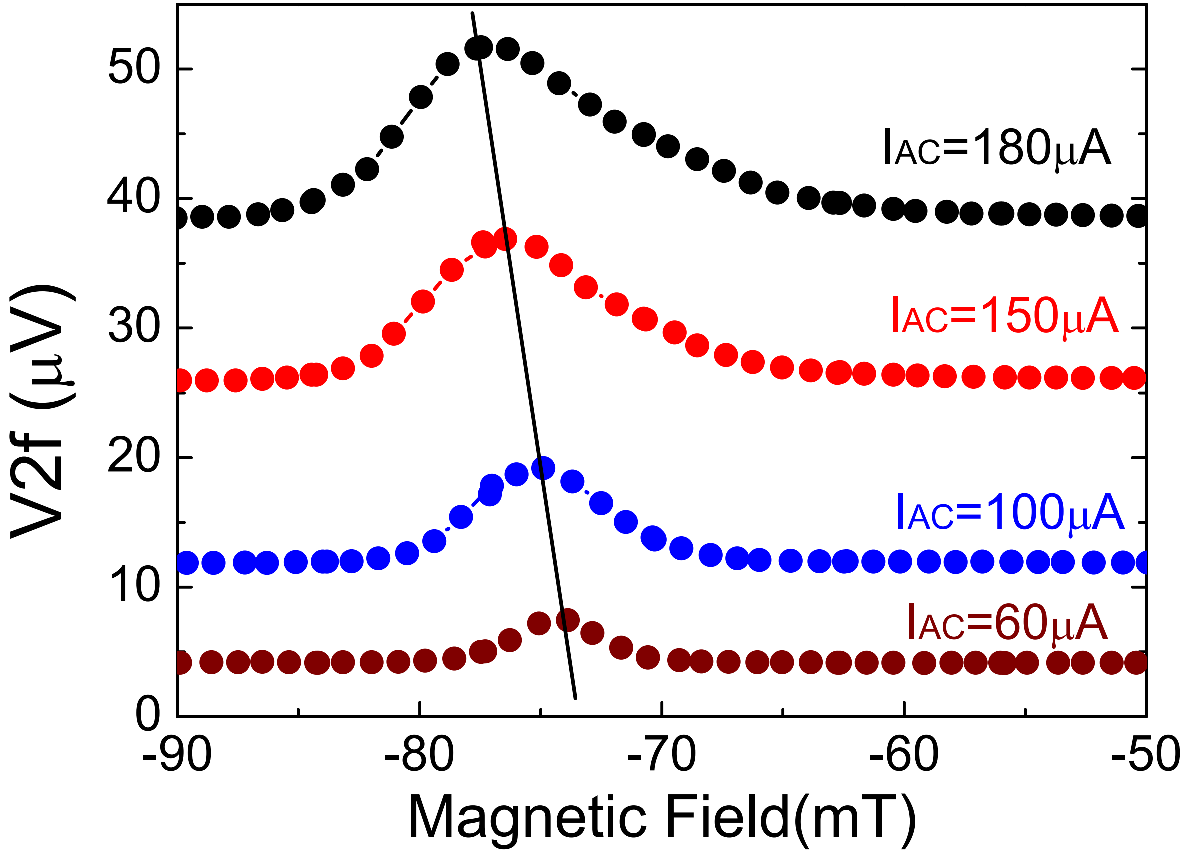
$$\nabla T \approx 10'000 K / cm!!$$

$$\frac{1}{2}\rho\frac{d}{\pi r^2}I^2 = j_Q \pi r^2 \quad \Rightarrow \quad \boxed{j_Q \propto \frac{1}{r^4}}$$

Nanowires **ideal** for large j_Q

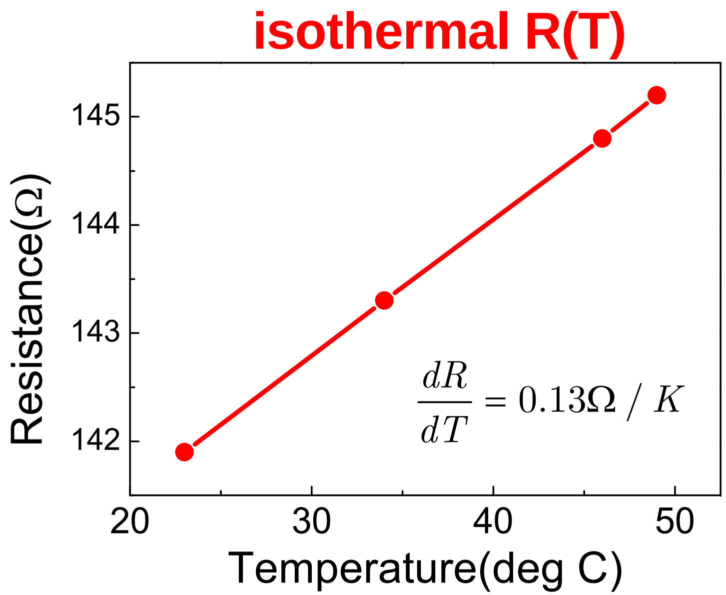
Heat current (not temperature) changes the switching field

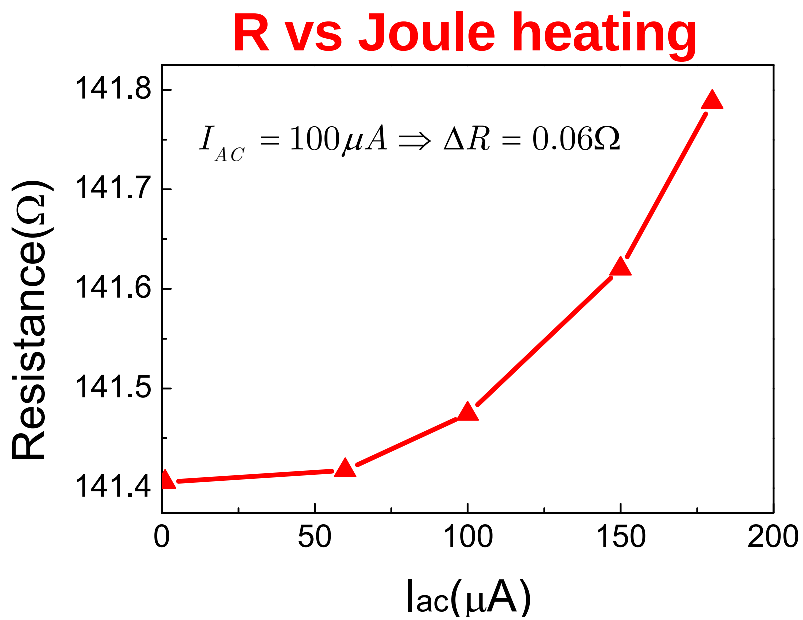




Haiming Yu, et al., Phys. Rev. Lett. **104**, 146601 (2010)

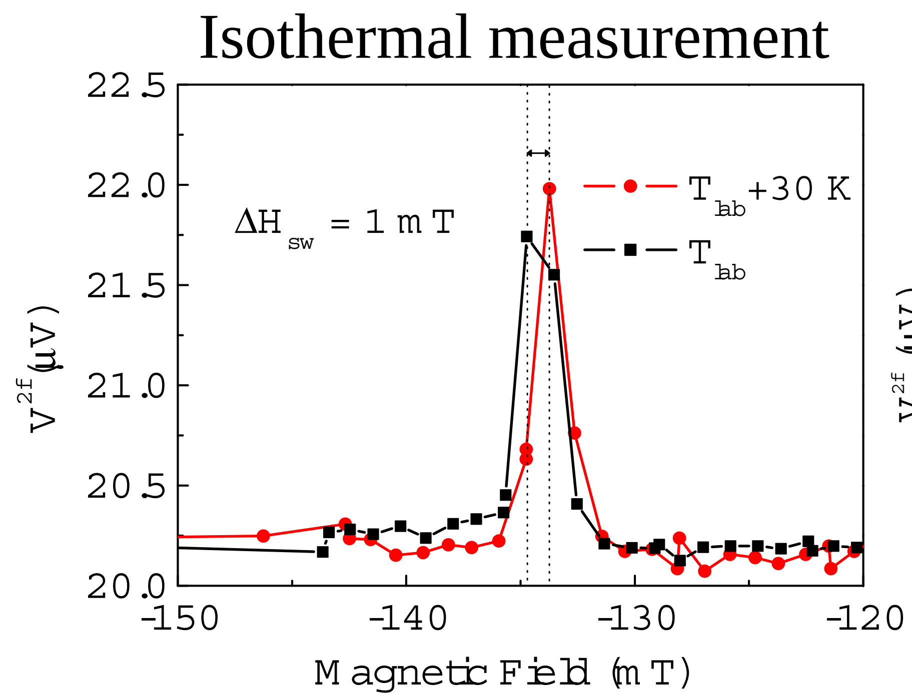
Checking temperature rise

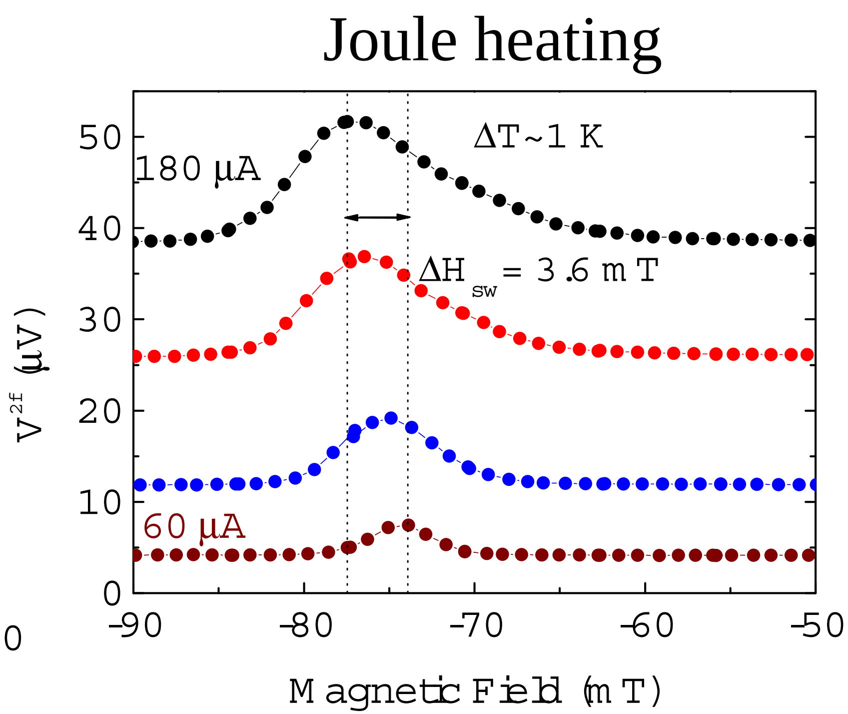




$$I_{AC} = 100\mu A \Rightarrow \boxed{\Delta T \approx 0.5K}$$

change of switching field NOT due to ΔT

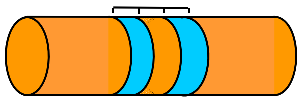




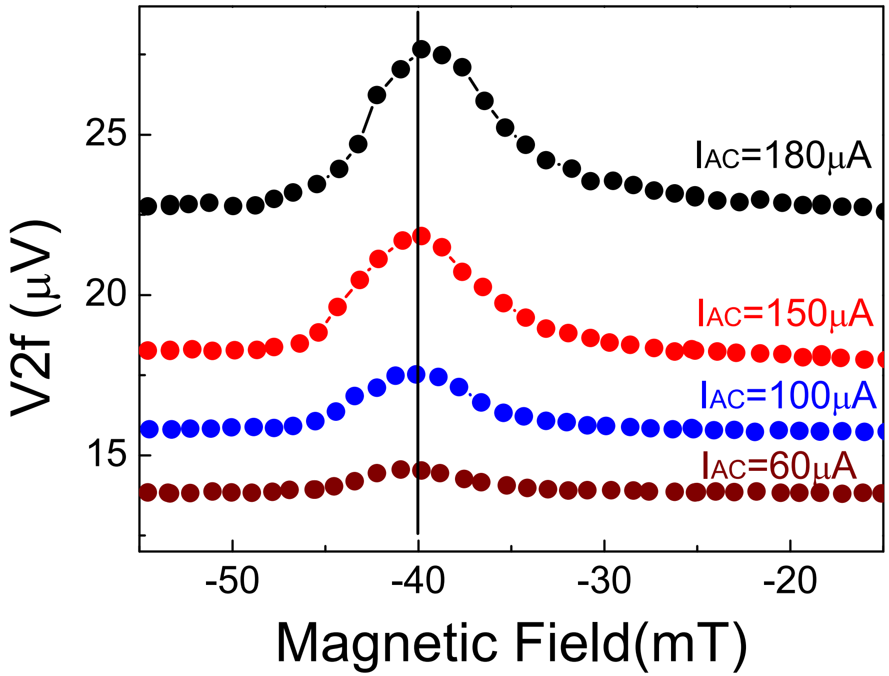
$$1\ \text{K} \rightarrow \Delta\text{H}_{SW} = 0.03\ \text{mT}$$

$$\Delta\text{H}_{SW} = 100 \times \Delta T\ \text{effect}$$

Other check experiment : symmetric spin-valve



Without heat current



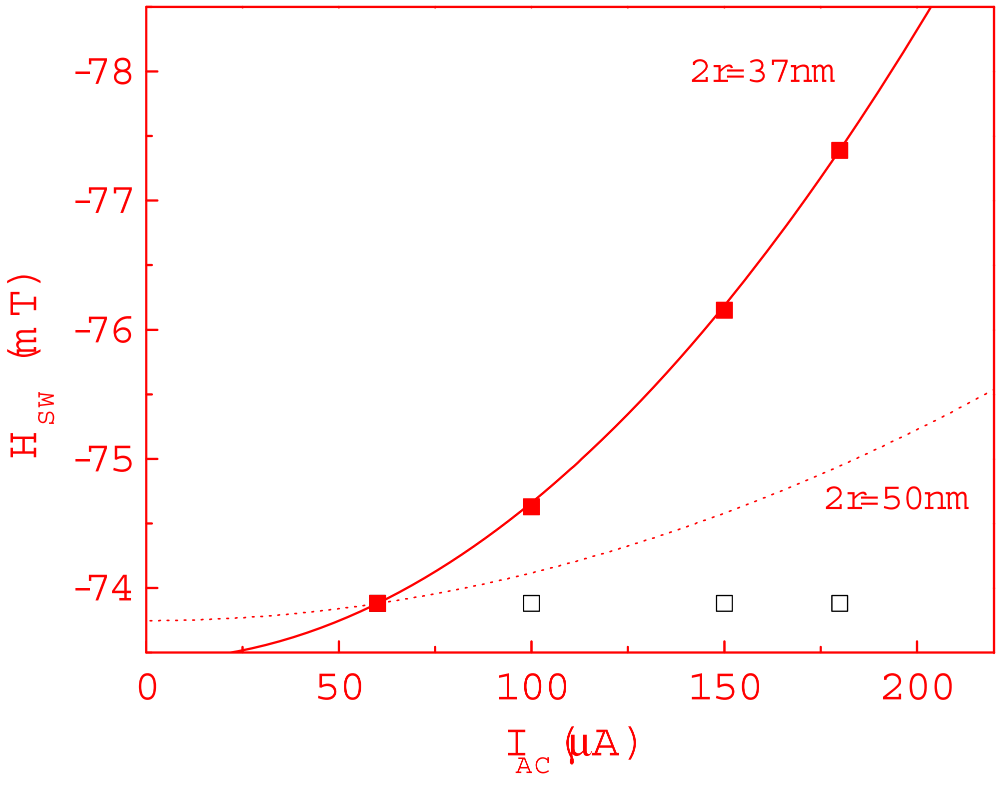
Haiming Yu, Phys. Rev. Lett. **104**, 146601 (2010)

Analyzing the data

We have

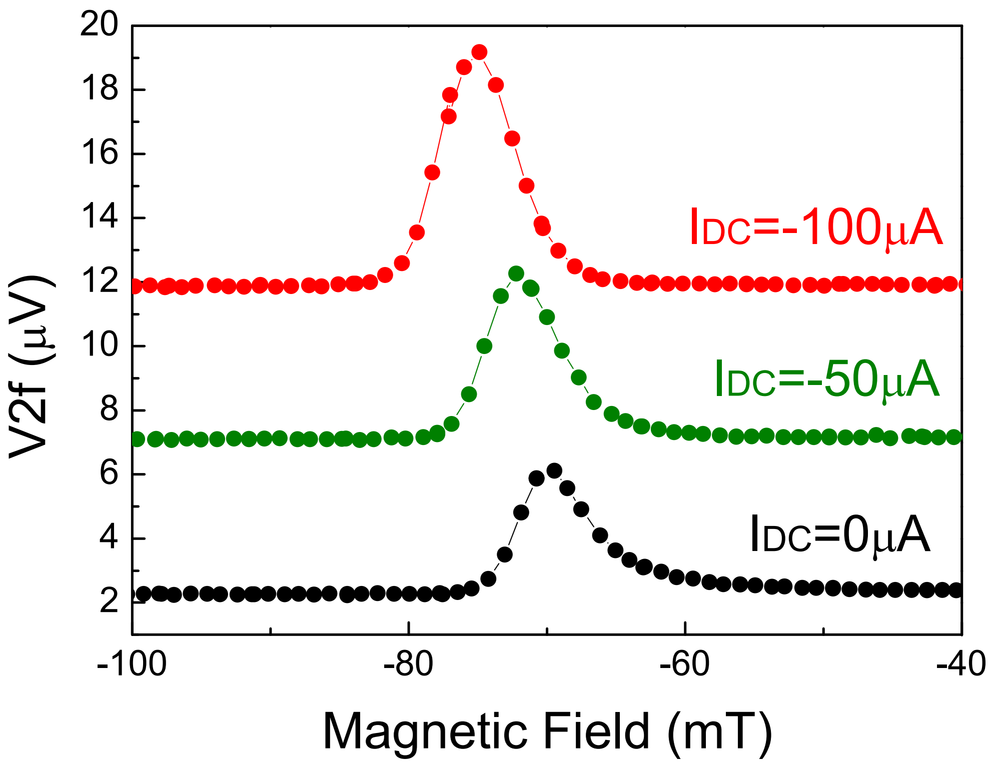
2 independent sets of data

Switching field vs heat current



V2f peak height

$$V = R(\tau, T)I \qquad V^{2f} = \frac{\partial R}{\partial \tau}\left(\tau^{f}_{STT} I_{AC} + \tau^{2f}_{TST} I_{DC}\right) + \frac{\partial R}{\partial T}\Delta T_{2f} I_{DC}$$



Hump amplitude increases

Generalized three-current model

Onsager phenomenological relations + Pauli matrices

$$\begin{pmatrix} j_q \\ j_e \\ j_m \end{pmatrix} = 2 \begin{pmatrix} -l_0 & Tk_0 & T\frac{k}{e}M \\ -k_0 & c_0 & \frac{c}{e}M \\ -kM & cM & \frac{c_0}{e} \end{pmatrix} \begin{pmatrix} \nabla T \\ \nabla V \\ \frac{dm}{dx} \end{pmatrix}$$

Bulk spin current :

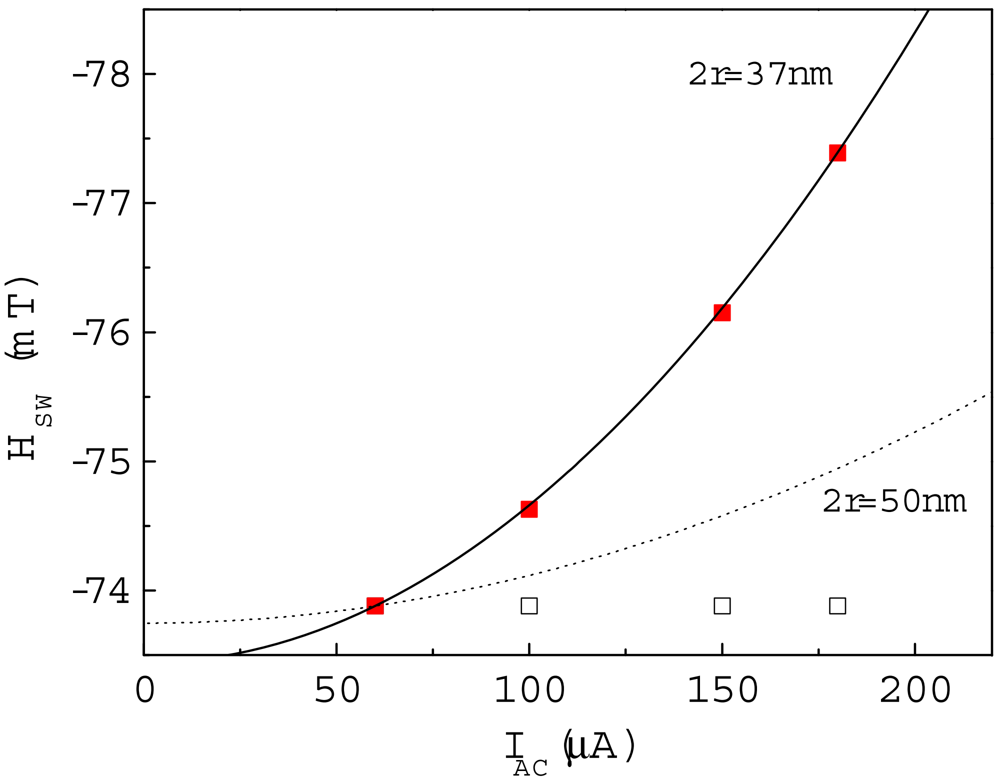
$$j_m = 2c\left(\nabla V - S_{eff} \nabla T\right)$$

J. Dubois and J.-Ph. Ansermet, Phys. Rev. B 78, 184430 (2008).

Simulation of Switching field

$$j_m = 2c\left(\nabla V - S_{eff}\nabla T\right)$$

$$\frac{\Delta H_{sw}^{TST}}{\Delta H_{sw}^{STT}} = \frac{\tau_{TST}}{\tau_{STT}} = \frac{j_{m,TST}}{j_{m,STT}} = \frac{S_{eff}\nabla T}{\nabla V}$$



V2f peak height
(just a 2nd order development, sorry)

$$V = R(\tau, T) I \qquad \Delta V = I\left[\left(\frac{\partial R}{\partial \tau}\frac{\partial \tau}{\partial j_m} j_m\right) + \frac{\partial R}{\partial T}\Delta T^{2f}\right]$$

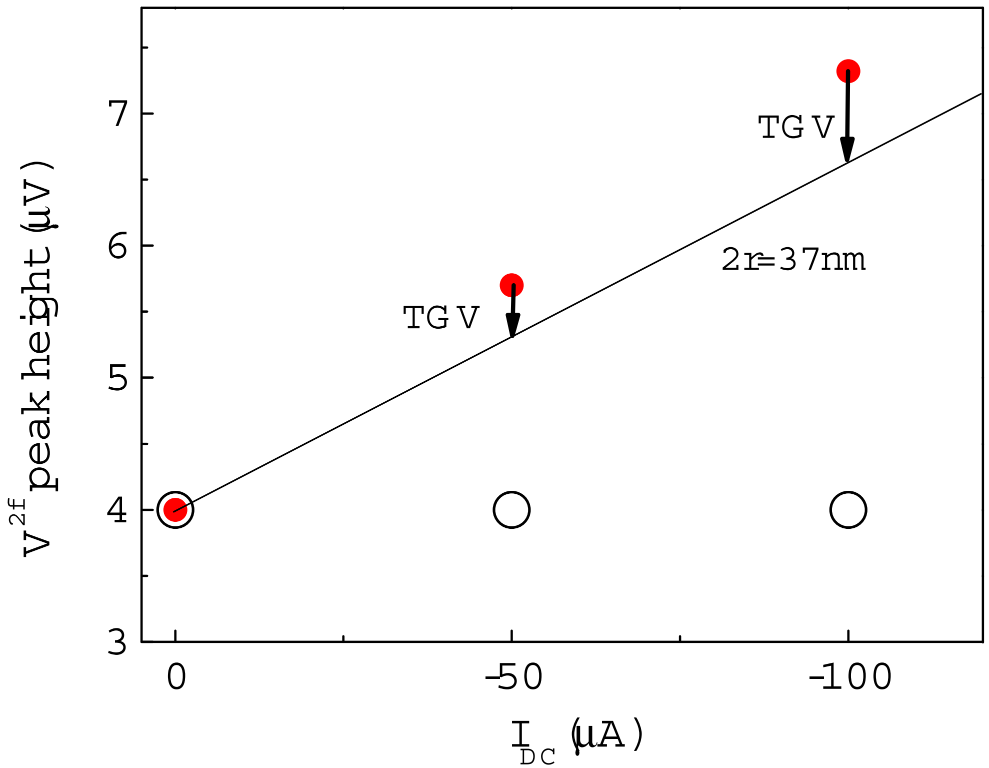
$$j_m = 2c\left(\nabla V - S_{eff}\nabla T\right) \qquad \nabla T = A_1 I^2$$

$$I = I_{AC} + I_{DC}$$

$$\Delta V = \left(I_{AC} + I_{DC}\right)\left[-\frac{\partial R}{\partial \tau}\frac{\partial \tau}{\partial j_m} 2c\left(\rho\frac{\left(I_{AC} + I_{DC}\right)}{\pi r^2} + S_{eff} A_1 \left(I_{AC} + I_{DC}\right)^2\right) + \frac{\partial R}{\partial T}\Delta T^{2f}\right]$$

$$V^{2f}{}_{peak} = \left(\left(-\frac{\partial R}{\partial \tau}\frac{\partial \tau}{\partial j_m} 2c\left(\rho\frac{I_{AC}{}^2}{\pi r^2} + 3S_{eff} A_1 I_{DC} I^2{}_{AC}\right)\right)\right) + \frac{\partial R}{\partial T}\Delta T^{2f} I_{DC}$$

Simulation of V2f peak height



$$\nabla T = A_1 I^2$$

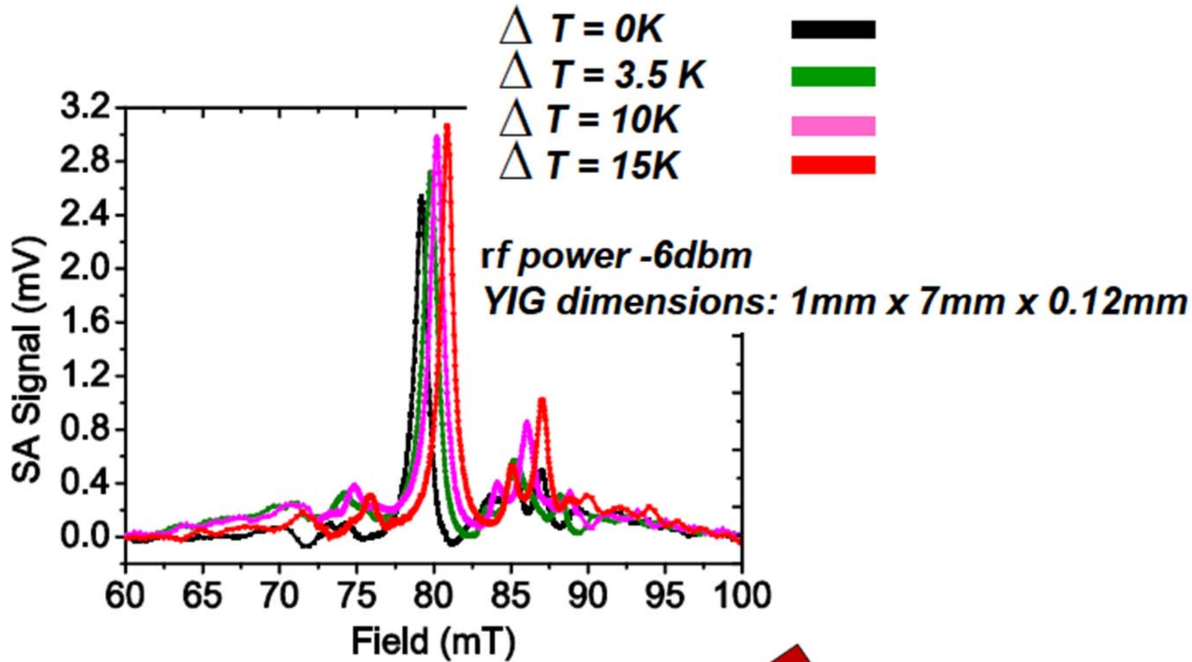
$$V^{2f}{}_{peak} = \left(\frac{\partial R}{\partial \tau} \frac{\partial \tau}{\partial j_m} 2c \left(\rho \frac{I_{AC}{}^2}{\pi r^2} + 3 S_{eff} A_1 I_{DC} I^2_{AC} \right) \right) + \frac{\partial R}{\partial T} \Delta T^{2f} I_{DC}$$

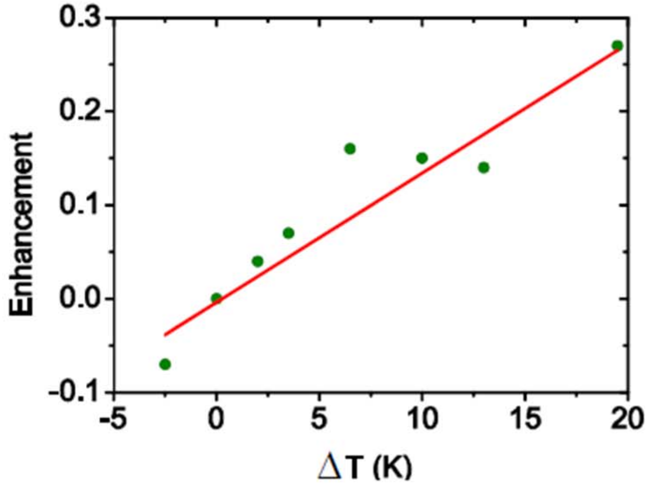
Recent work

Magnetization Dynamics

in the presence of a heat current

Effect of a thermal gradient on YIG FMR

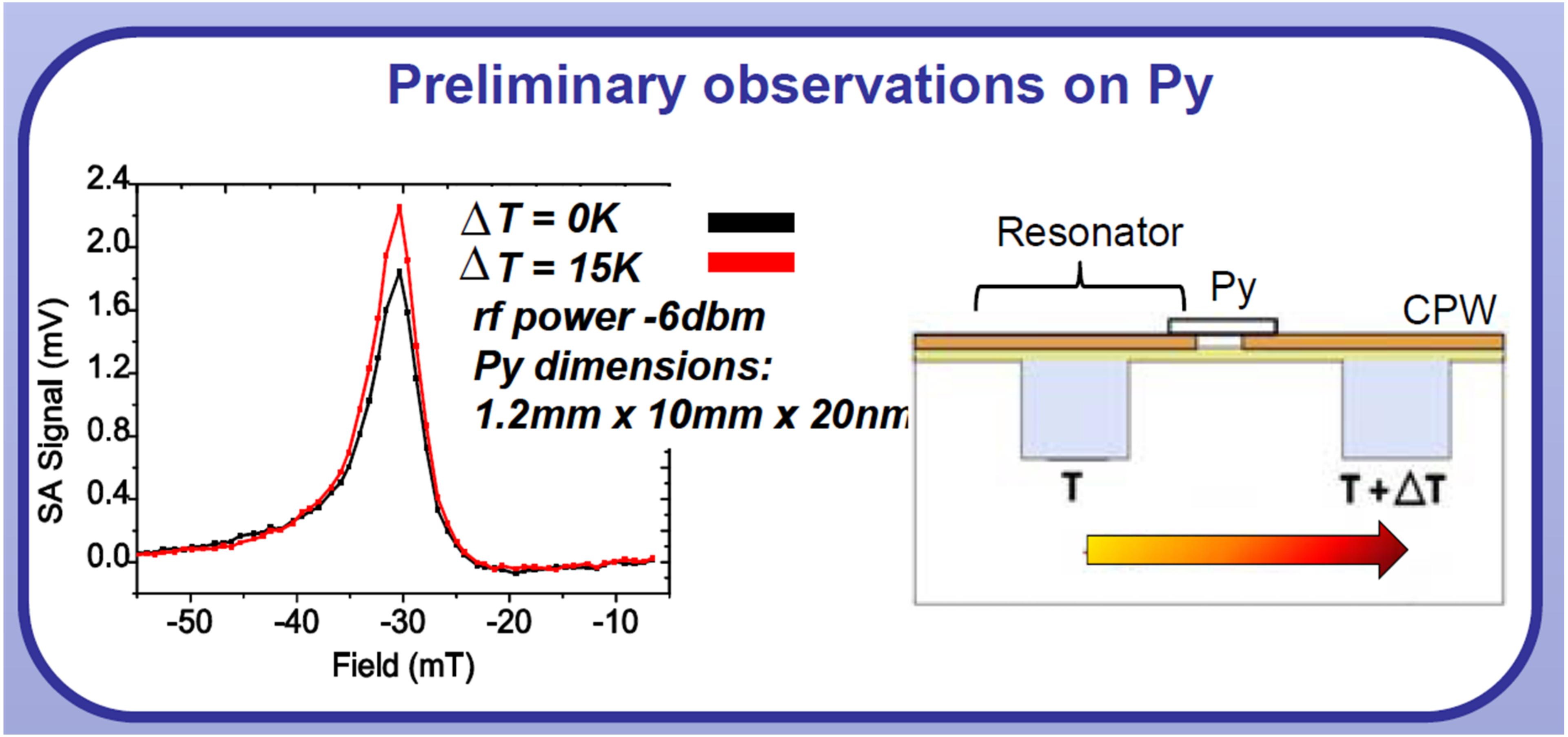




Enhanced FMR peak amplitude upon the application of a temperature gradient

Elisa Papa, poster at this conference

FMR under heat current : permalloy



Elisa Papa, poster at this conference

$$\begin{pmatrix} \mathbf{J}_\uparrow \\ \mathbf{J}_\downarrow \\ \mathbf{Q} \end{pmatrix} = -\begin{pmatrix} \sigma_\uparrow & 0 & \sigma_\uparrow S_\uparrow \\ 0 & \sigma_\downarrow & \sigma_\downarrow S_\downarrow \\ \sigma_\uparrow \Pi_\uparrow & \sigma_\downarrow \Pi_\downarrow & k \end{pmatrix} \cdot \begin{pmatrix} \nabla \mu_\uparrow / e \\ \nabla \mu_\downarrow / e \\ \nabla T \end{pmatrix}$$

Gravier et al. Phys. Rev. B 2006

Sachter et al. Nat. Phys. 2010

1. The three-current model
2. At large scales, $\mu_\uparrow = \mu_\downarrow$
3. Spin-dependent transport, $\sigma_\pm = \sigma_0(1 \pm \beta)$ $\varepsilon_\pm = \varepsilon_0(1 \pm \eta)$

bulk spin current $$j_p = -\sigma(\eta - \beta)\varepsilon \nabla T$$

Summary

Heat-driven spin currents

- magnetization switching in nanostructures
- spurious temperature rise avoided in nanowires
- Modelling with a generalized 3-current model

Ferromagnetic resonance

- Effect of heat current on the amplitude of FMR (narrowing or Overhauser ?)