UC San Diego

UNIVERSITÉ DE LORRAINE

Manipulation of the magnetization of Perpendicular magnetized Rare-earth-transition metal alloys using polarized light

S. Mangin

CMRR Center for Magnetic Recording Research

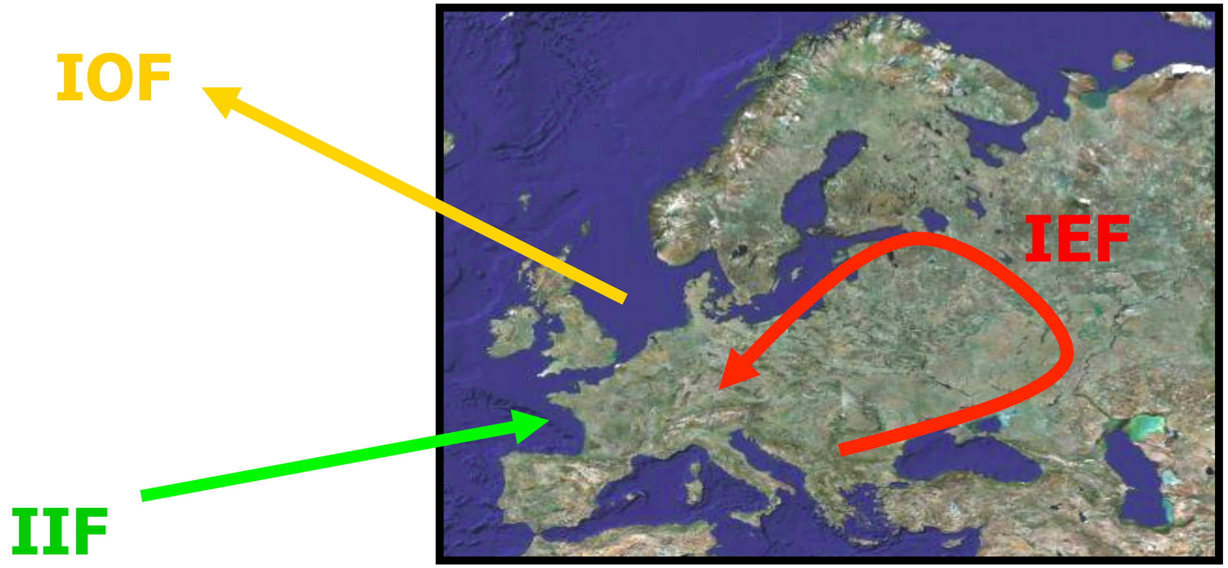
Jan 31st 2013 IEEE – Magnetic Society

7th Framework Program for Research

IEF : Intra-European Fellowships

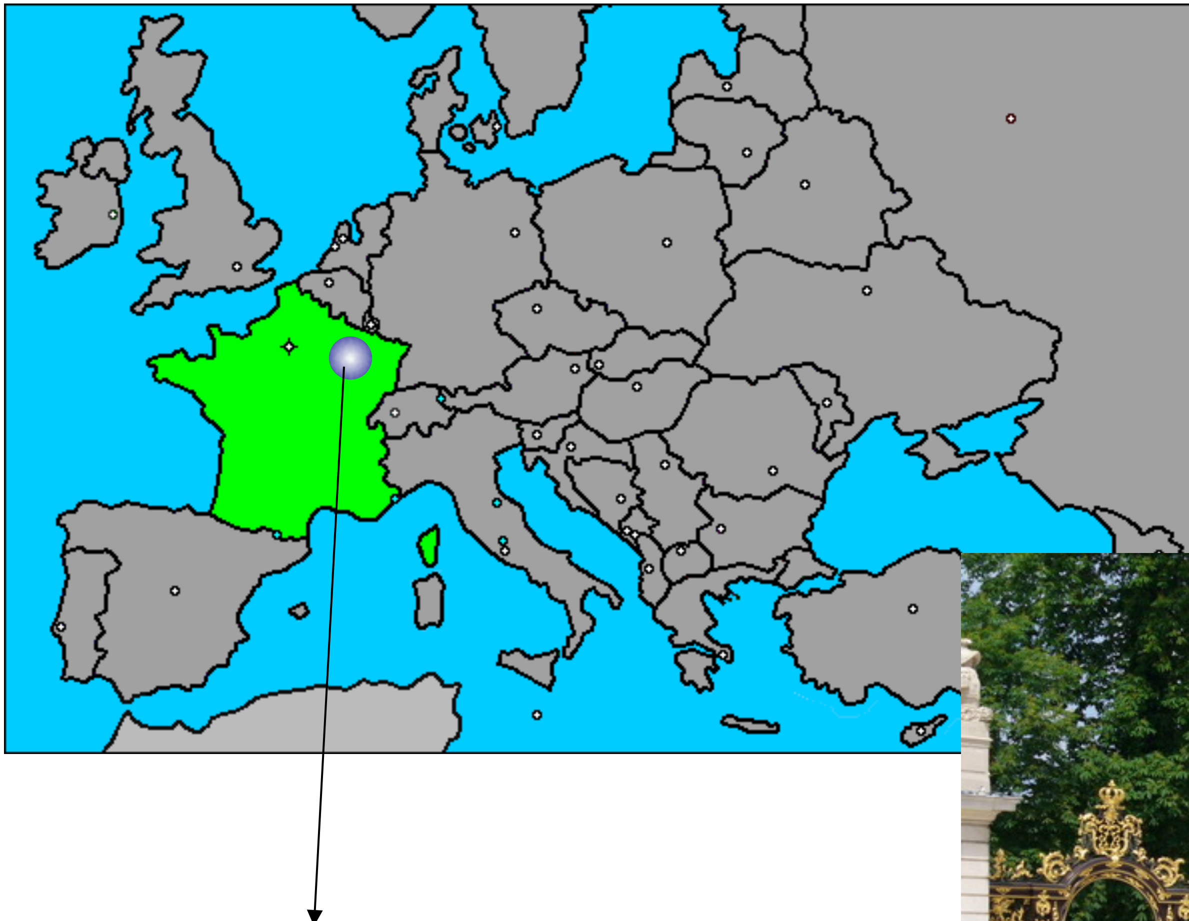
IOF : International Outgoing Fellowships

IIF : International Incoming Fellowships



Optical Probe and Manipulation of Magnetization at the nanometer scale

Nancy (France)



Nancy

Institut Jean Lamour

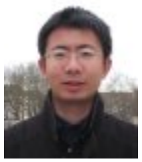
- Born from 5 laboratories merging : 400 peoples

Nano-science **Surface science**

Nuclear Fusion **Metallurgy**

Jan 2015 : New common building

Nanomagnetism /Spintronic









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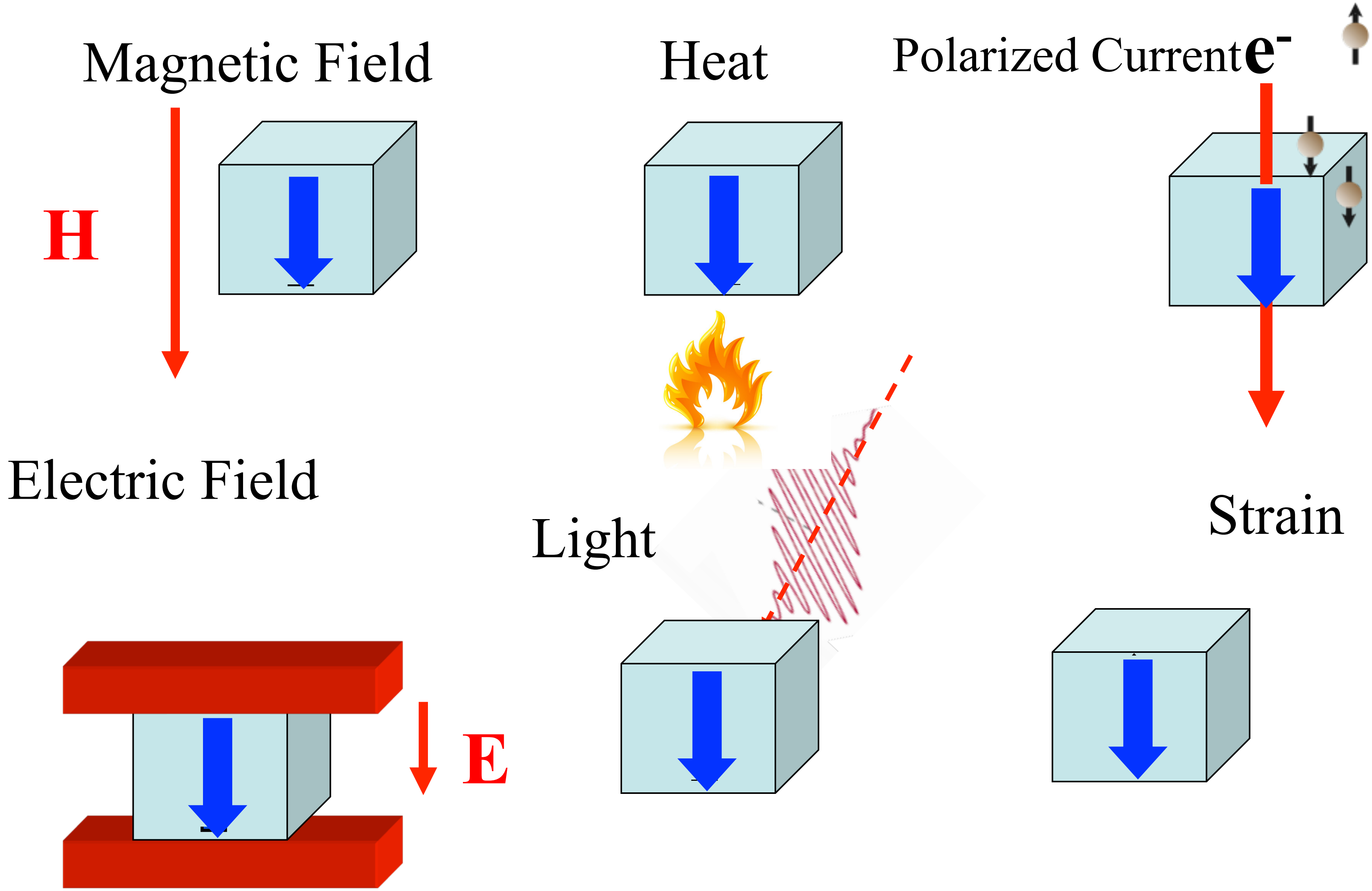
2 technicians, 2 CNRS researcher, 7 faculty members, 6 Ph.D & Post-Doc

http://www.lpm.u-nancy.fr/nanomag/

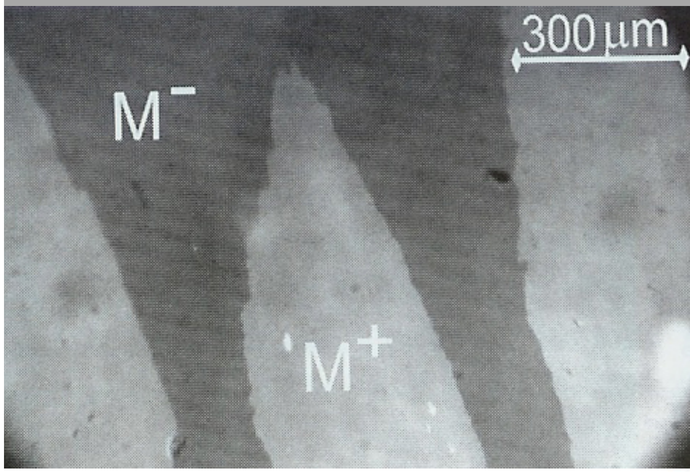
Magnetization & Spin manipulation



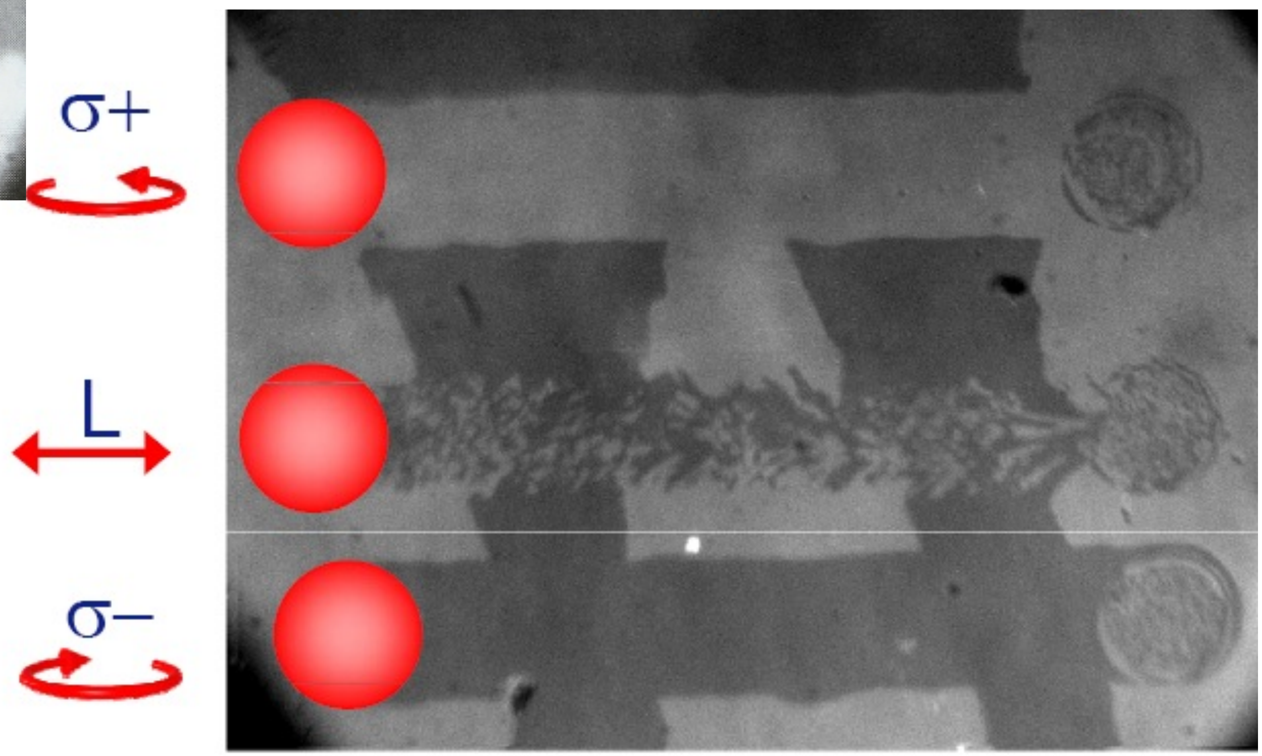
Outlines

- Introduction
  - All optical switching
  - Our goals
- All optical switching for TbCo
  - Influence of composition
  - Influence of thickness
- Devices
  - How to record magnetization switching in TbCo

All optical switching



40 fs pulses, 1 kHz repetition

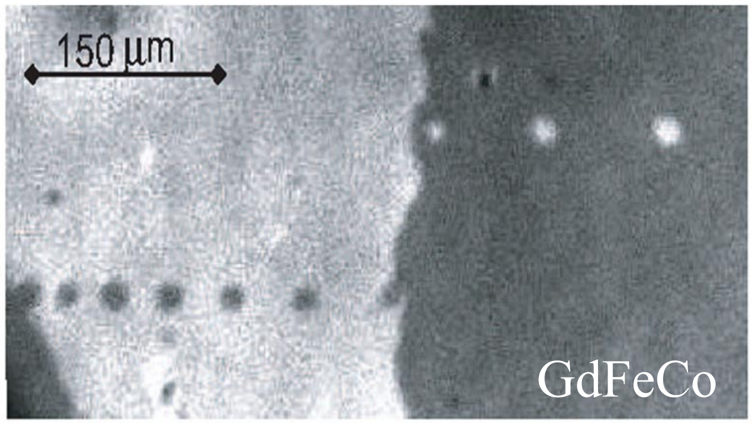


20 nm thick $Gd_{22}Fe_{74.6}Co_{3.4}$

C.D. Stanciu *et al*, Phys. Rev. Lett. 99, 047601 (2007)

Light induced magnetization reversal

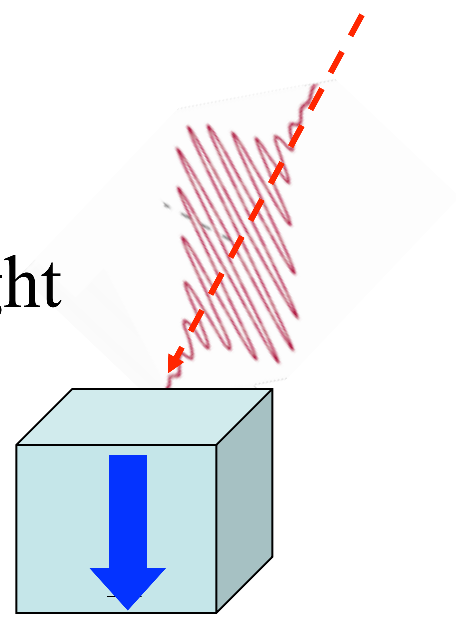
All-optical switching with circularly polarized light



Stanciu et al., PRL **99**, 047601 (2007)

- All-optical writing works without any applied external magnetic field
- All-optical writing event depends on combination magnetization and laser helicity
- All-optical switching only works above a certain fluence threshold

What is (are) the mechanism(s) ?



- **Magnetic field** created by a laser beam

Inverse Faraday effect

$$\vec{H}_{eff} = \frac{\varepsilon_0}{\mu_0} \alpha \underbrace{\left[\vec{E}(\omega) \times \vec{E}^*(\omega)\right]}_{circular\ polarization}$$

- **Heat** transfer by the laser

- **Angular momentum** transfer by the laser

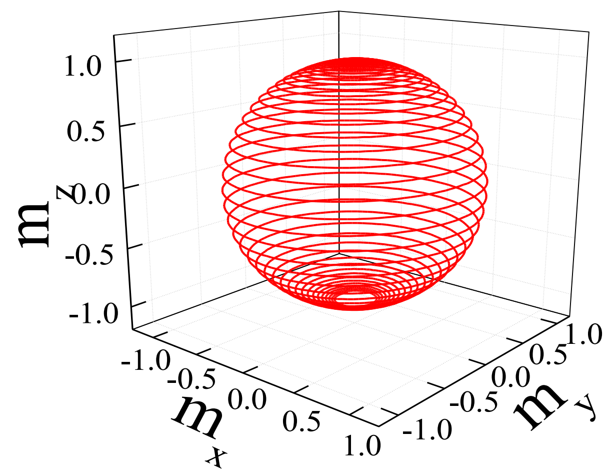
Still under discussion

Magnetic field

Inverse Faraday effect

$$\vec{H}_{eff} = \frac{\varepsilon_0}{\mu_0}\alpha\underbrace{\left[\vec{E}(\omega)\times\vec{E}^*(\omega)\right]}_{circular\ polarization}$$

- Could reach several Tesla ?
- Sign depends on polarization
- Short field pulse

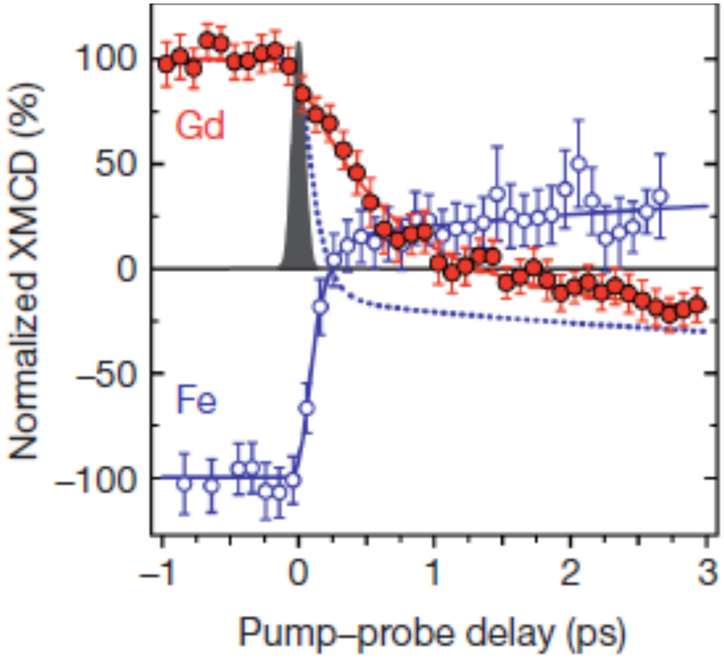


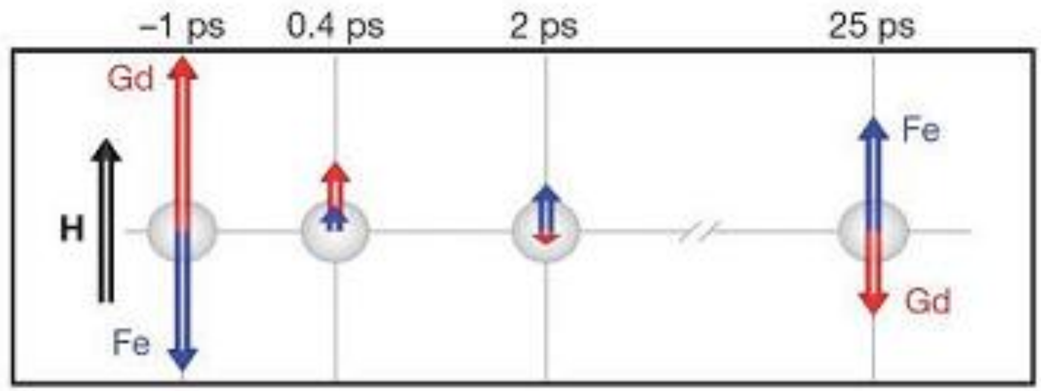
From LLG equation 100 ps field pulse is needed
LLB ?

$H_{IFE} \sim 0.52kOe$

J.M. Li et al J. Appl.Phys. **111**, 07D506 (2012)

Heat

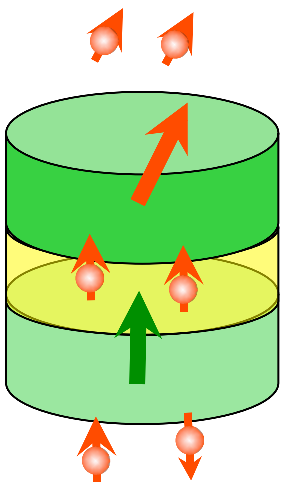


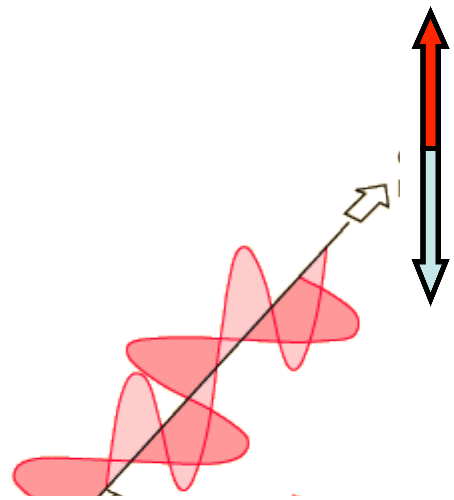


- Ferrimagnetic material is needed
- Doesn’t depends on polarization
- Will depend on pulse length

Radu *et al.*, Nature **472**, 205 (2011)

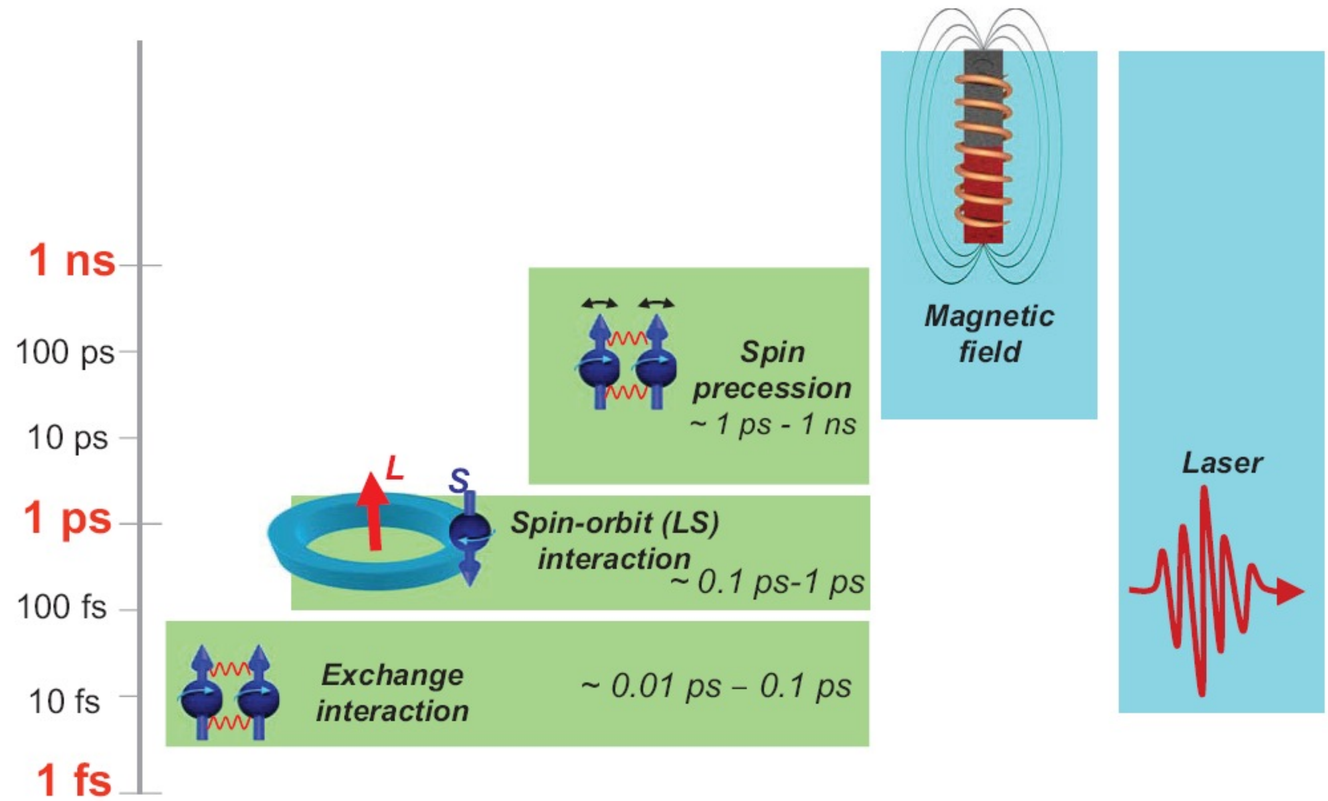
Angular Momentum transfer





- Sign depends on polarization
- Light transfers little angular momentum
-

What are the Interactions / Time scales

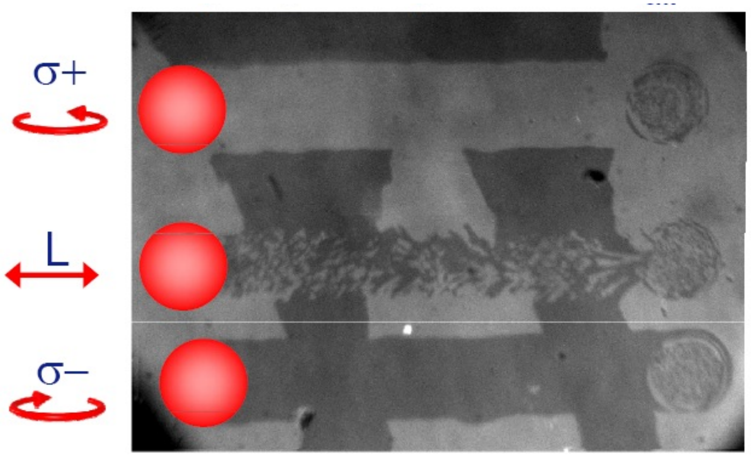


- Field switching — Slow
- Spin Transfer — Fast

What are the important parameters ?

20 nm thick $Gd_{22}Fe_{74.6}Co_{3.4}$

40 fs pulse 1 kHz repetition



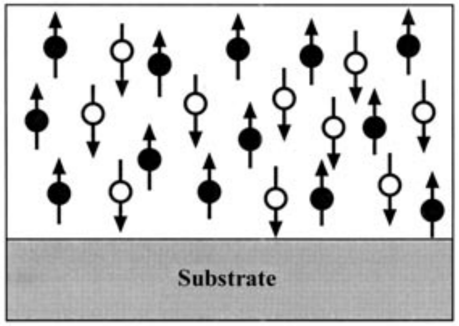
- Polarization ?
- Pulse length ?
- Fluence ?
- Repetiton ?

Laser

- Thickness ?
- Rare earth – Transition metal ?
- Ferrimagnetic ?
- Composition ?

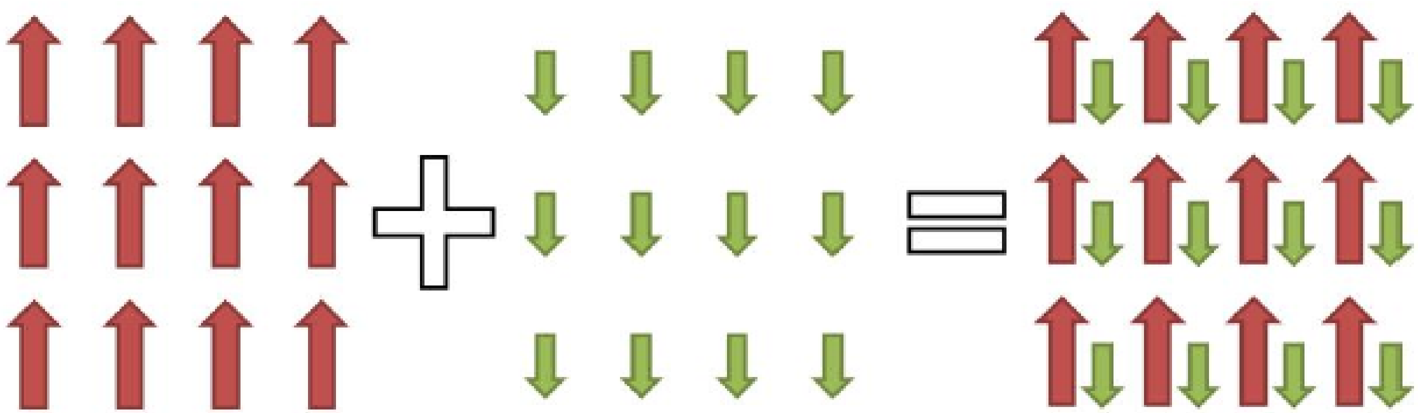
Material

Why RE-TM alloys ?



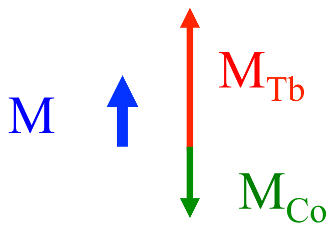
ferrimagnetic RE-TM alloy

rare earth (Gd, Tb)	transition metal (Fe, Co ,Ni)	alloy (GdFeCo)



The materials : Ferrimagnetic alloys

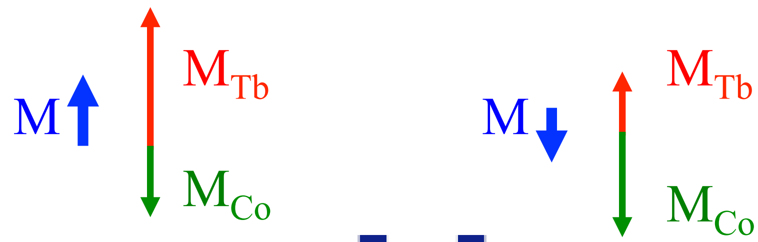
Tb_XCo_{1-X}

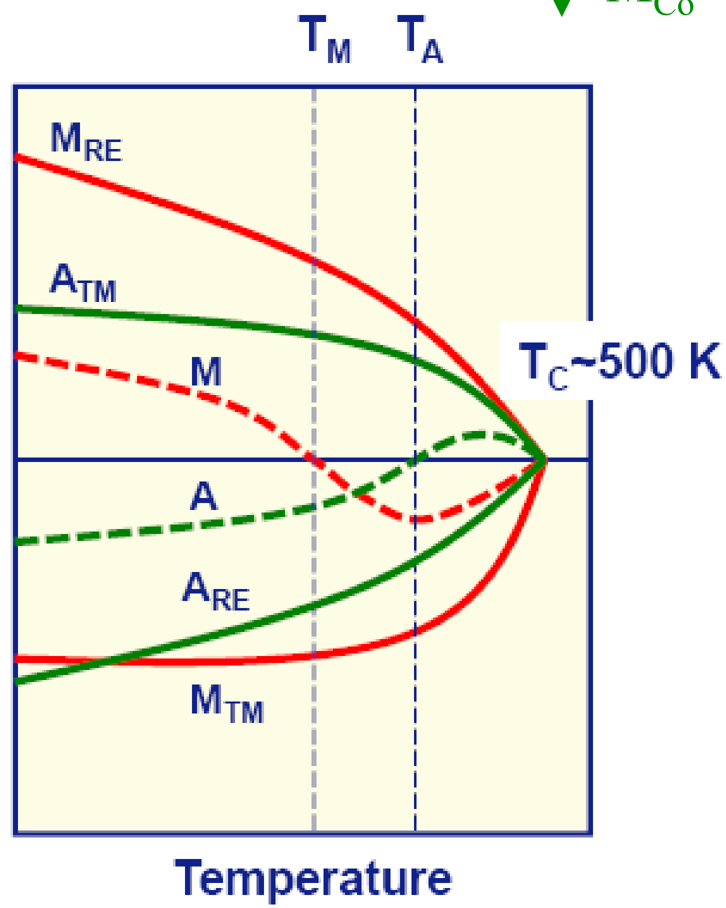


$$M_{RE} = g_{RE}\,(\gamma)\,A_{RE}$$

$$M_{TM} = g_{TM}\,(\gamma)\,A_{TM}$$

$$g_{RE} \neq g_{TM}$$

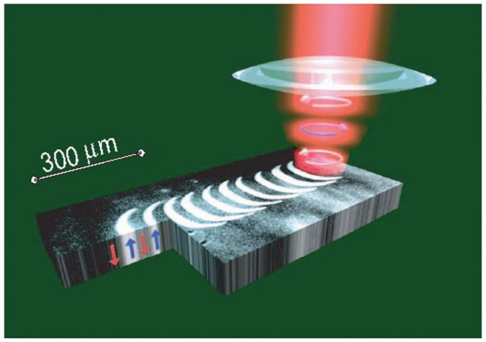




Angular Momentum Compensation at T_A

Magnetization Compensation at T_M

Can we use it ?



Magnetic data storage, Magnetic Memories , Magnetic Logic ?

Low energy 10 fj to switch 20 nm x 20 nm

Fast Magnetizations reversal in 100 fs

*Phys Rev B **86**, 140404(R) (2012)*

High density ?

High Perpendicular Magnetic anisotropy

Detectable ?

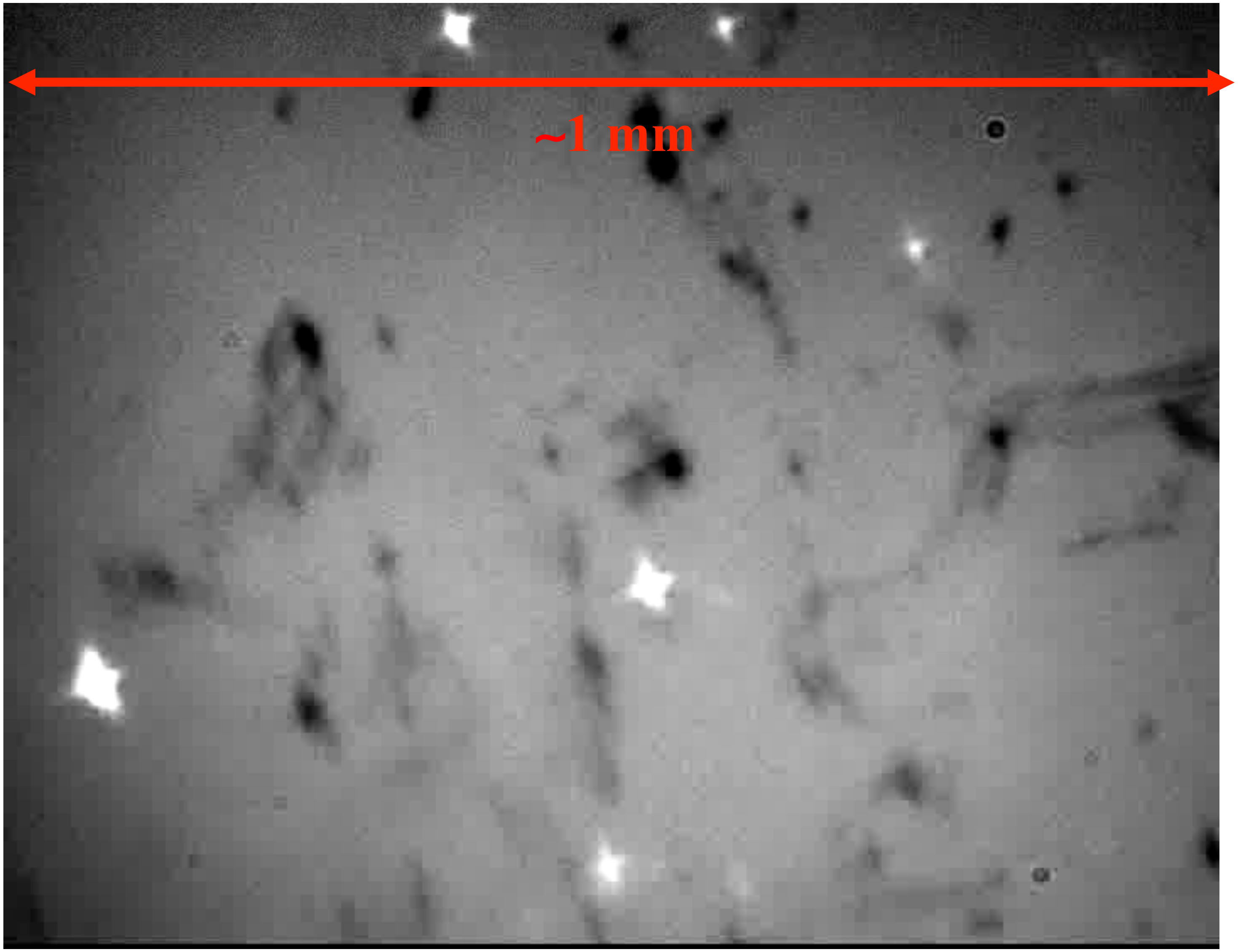
Can a current "read" Magnetization orientation

Our Goal

- **Demonstrate AOS for other materials**
  - Better understanding
  - Find material compatible with application requirement
- **Tune parameters**
  - Magnetization
  - Thickness
- **Build devices**

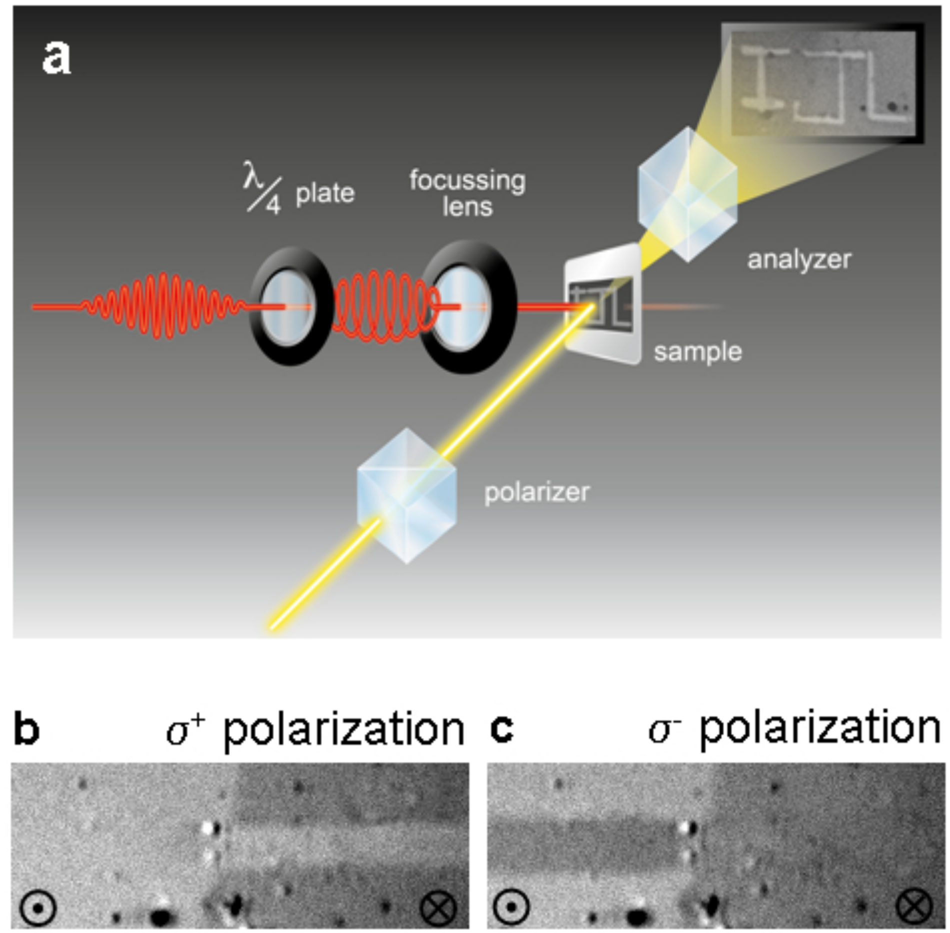
All-optical switching in TbCo

AG Aeschlimann: circular polarized LASER beam, spot size: 20 μm



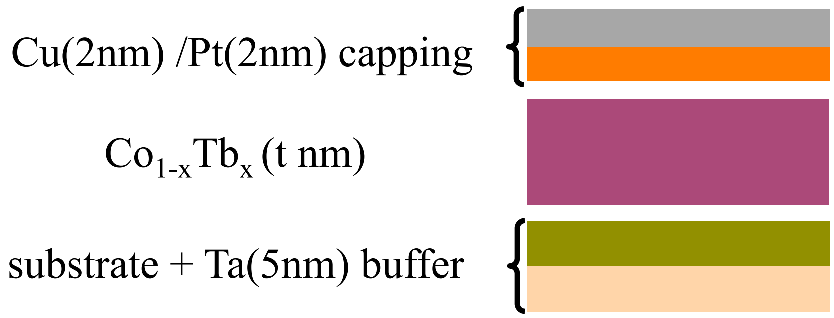
AOS – TbCo vs GdCo

$Tb_{0.26}Co_{0.74}$	≠	$Gd_{22}Fe_{74.6}Co_{3.4}$
Ferrimagnetic	=	Ferrimagnetic
H_C = 6 000 Oe	≠	H_C = 400 Oe
H_K = 6 T	≠	Low H_K
Close to compensation	=	Close to compensation
t= 20 nm	=	t= 20 nm
400 fs and 10ps	≠	50 fs

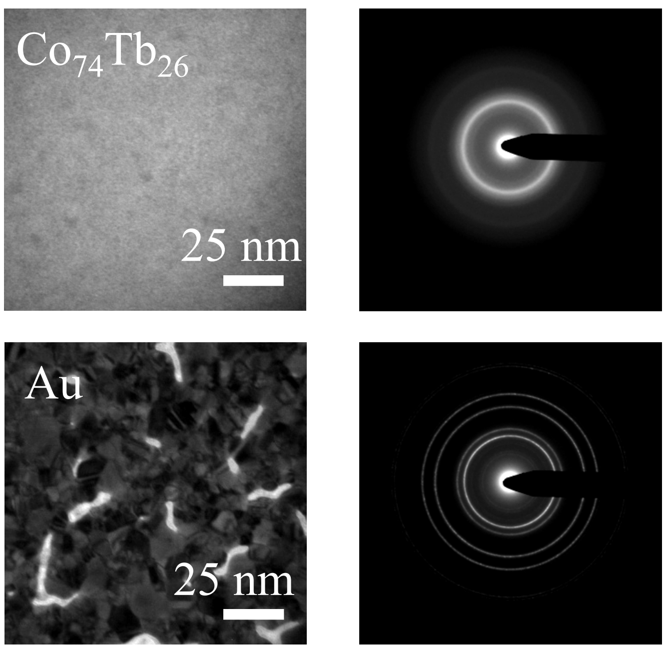


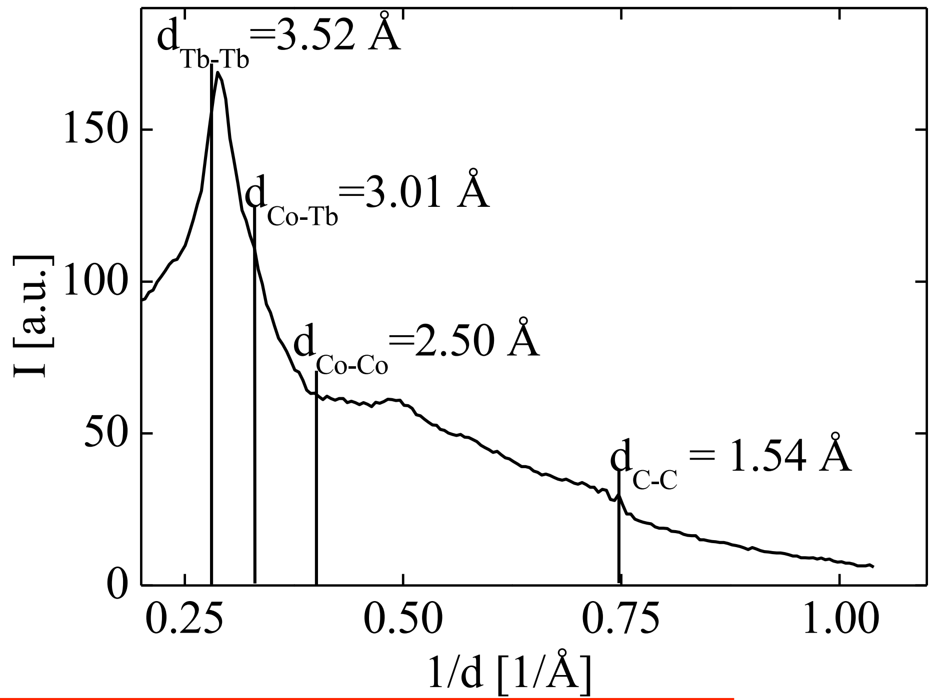
All-optical switching for a high anisotropy material (~ $4x10^6$ ergs/cm^3)

Amorphous structure of $Co_{1-x}Tb_x$ alloys



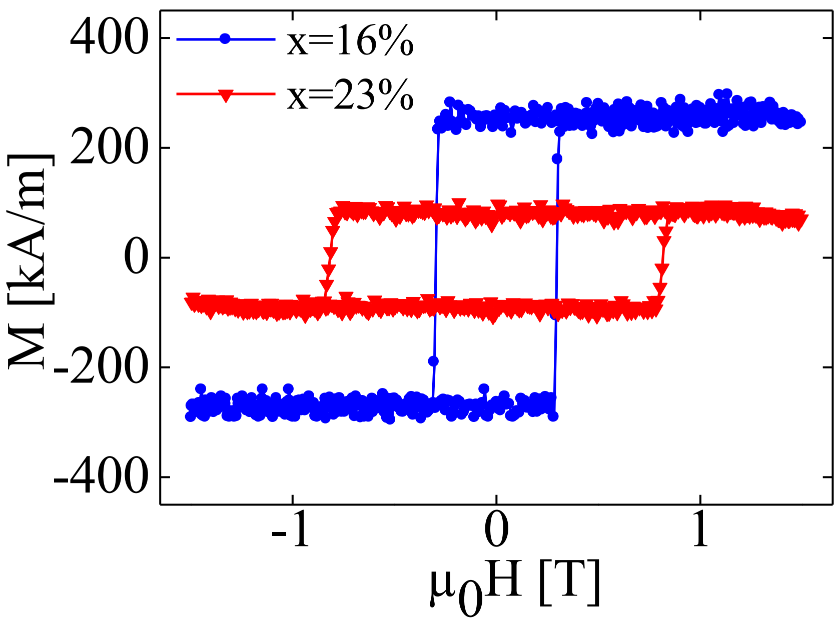
Transmission electron microscopy:

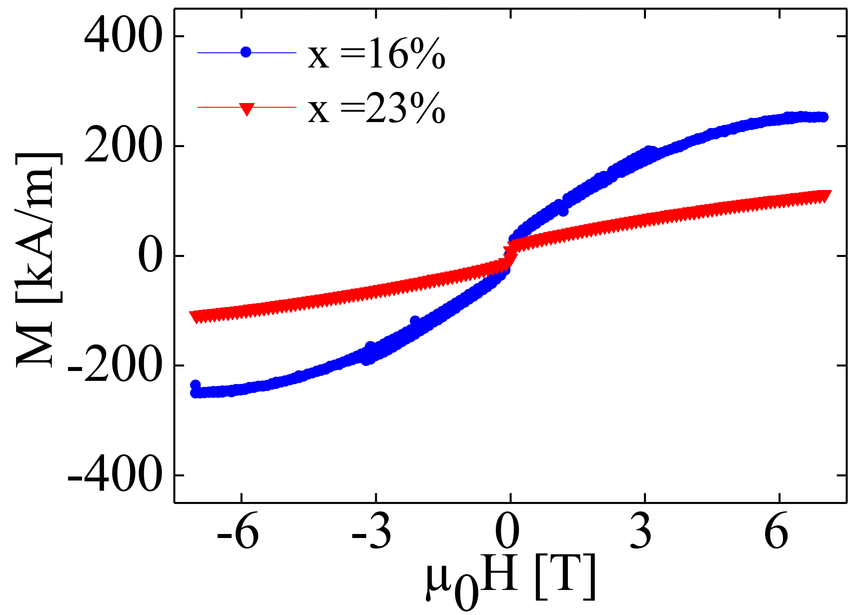


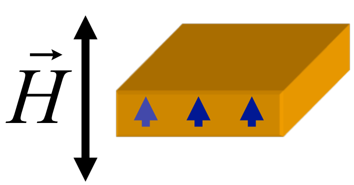


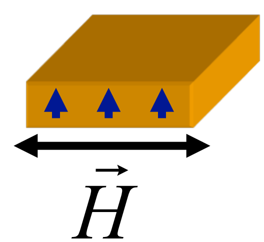
➔ $Co_{1-x}Tb_x$ amorphous for $12\% \leq x \leq 26\%$

Perpendicular anisotropy



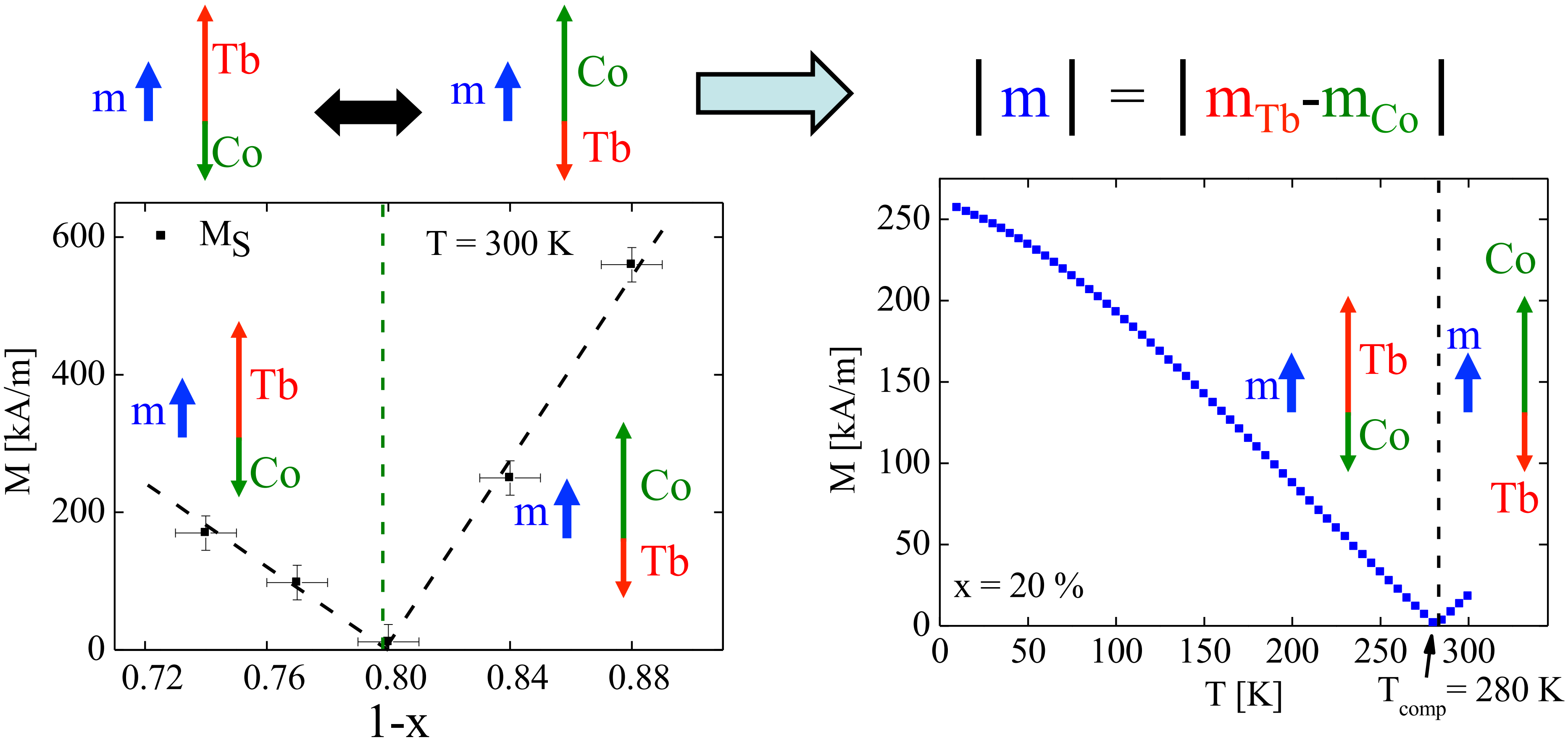






➔ $Co_{1-x}Tb_x$ has PMA for $8\% \leq x \leq 34\%$

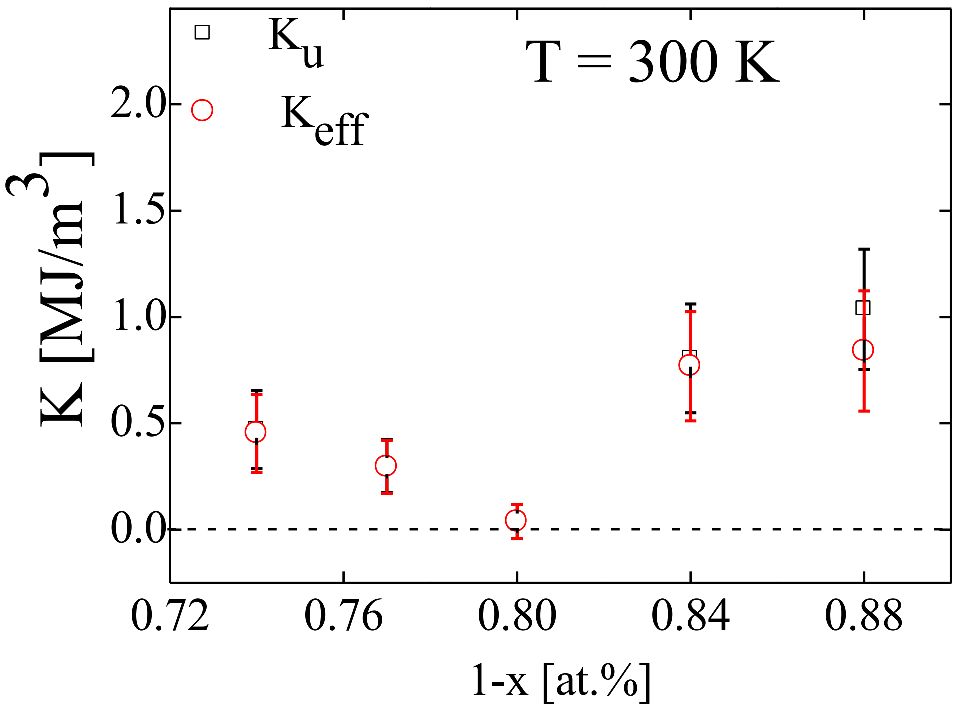
Tunable magnetization

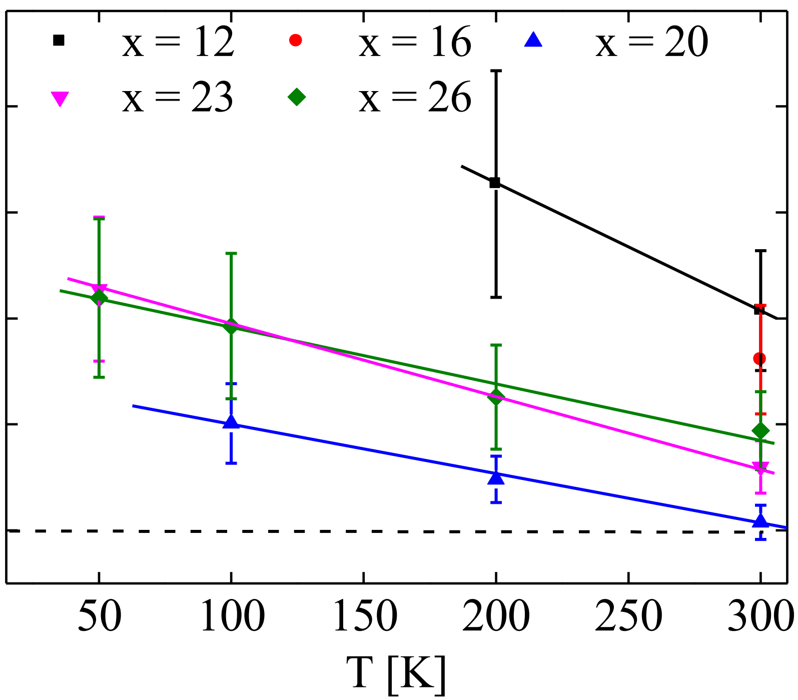


➔ $0 \leq M\,(x,T) \leq 600$ kA/m

M. Gottwald, et al J. Appl. Phys 111 083904 (2012)

Tunable Perpendicular Magnetic Anisotropy

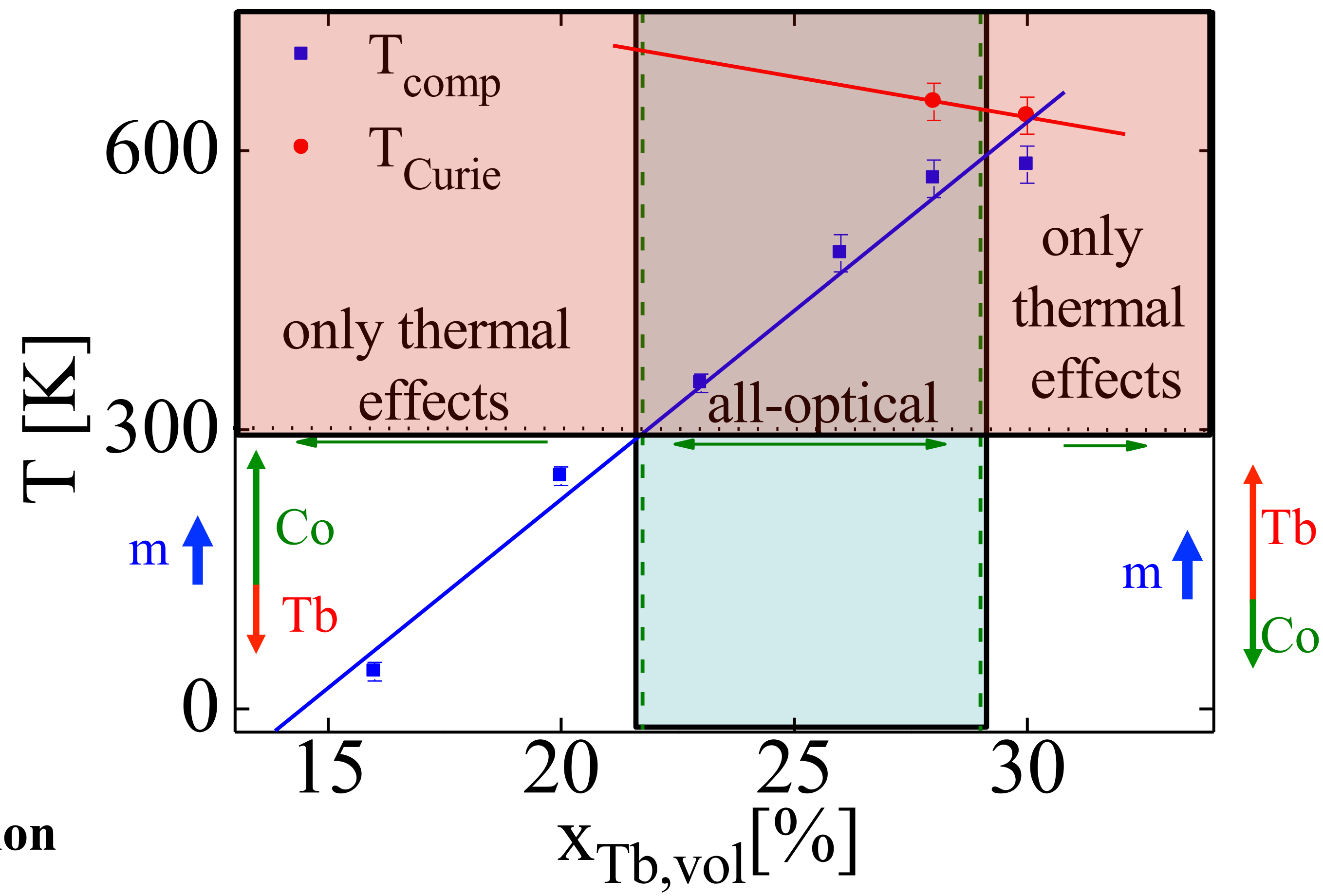




→ Origin of PMA unclear

→ 50 kJ/m^3 ≤ K (x,T) ≤ 1600 kJ/m^3

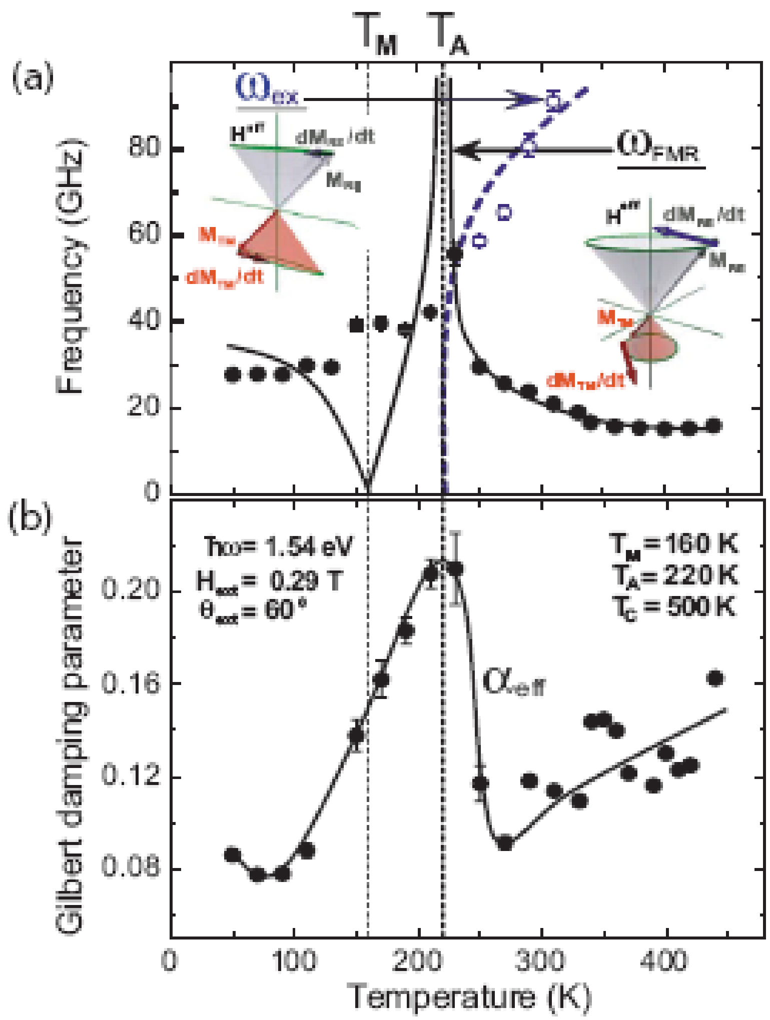
Composition influence on AOS



Conclusion

- AOS observed close to compensation
- AOS observed above compensation

Understanding



At T_A any torque is very efficient

- **Magnetic field** created by a laser beam

  Not efficient

- **Heat** transfer by the laser

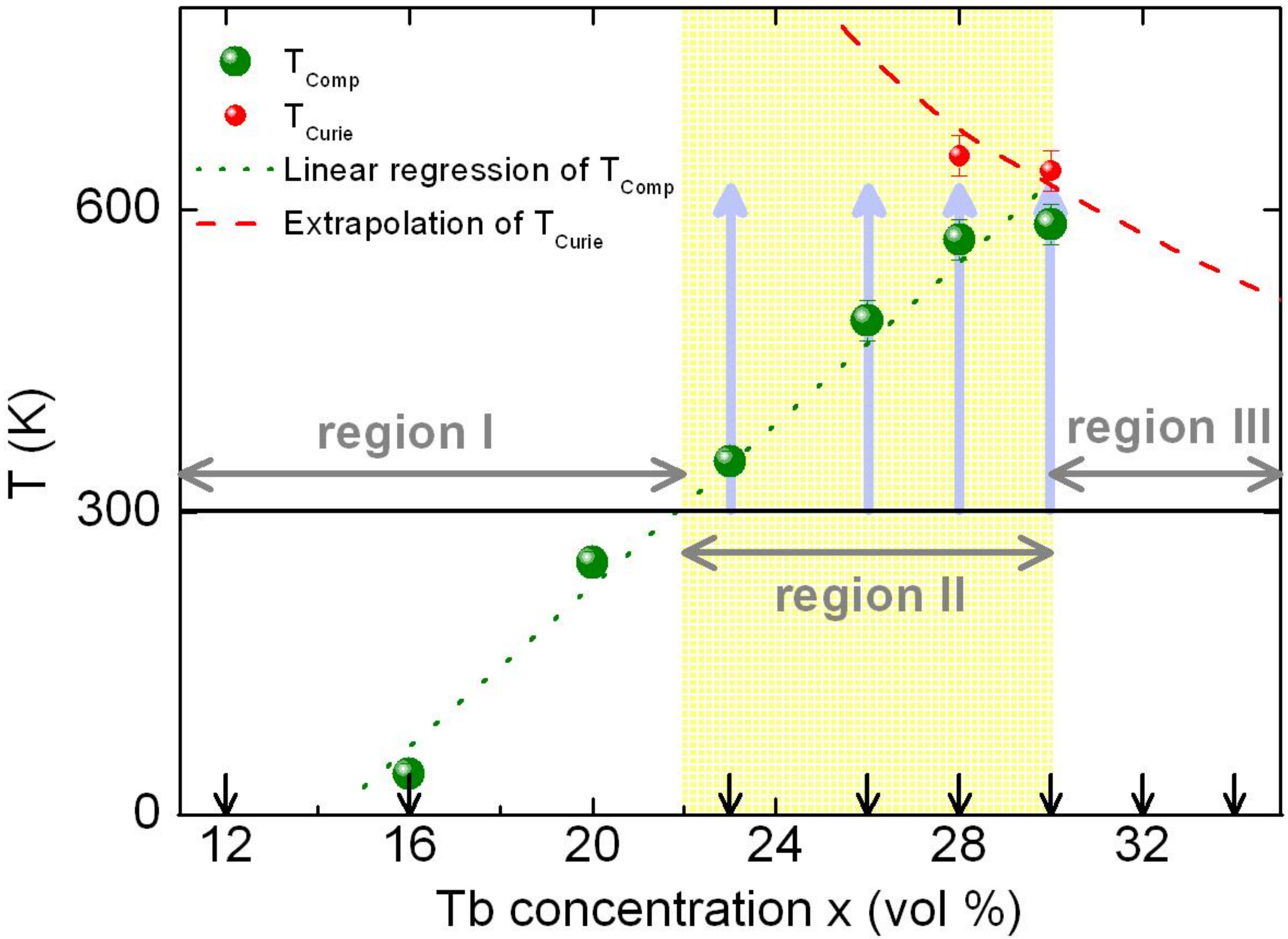
  Bring the sample to T_A

- **Angular momentum** transfer by the laser

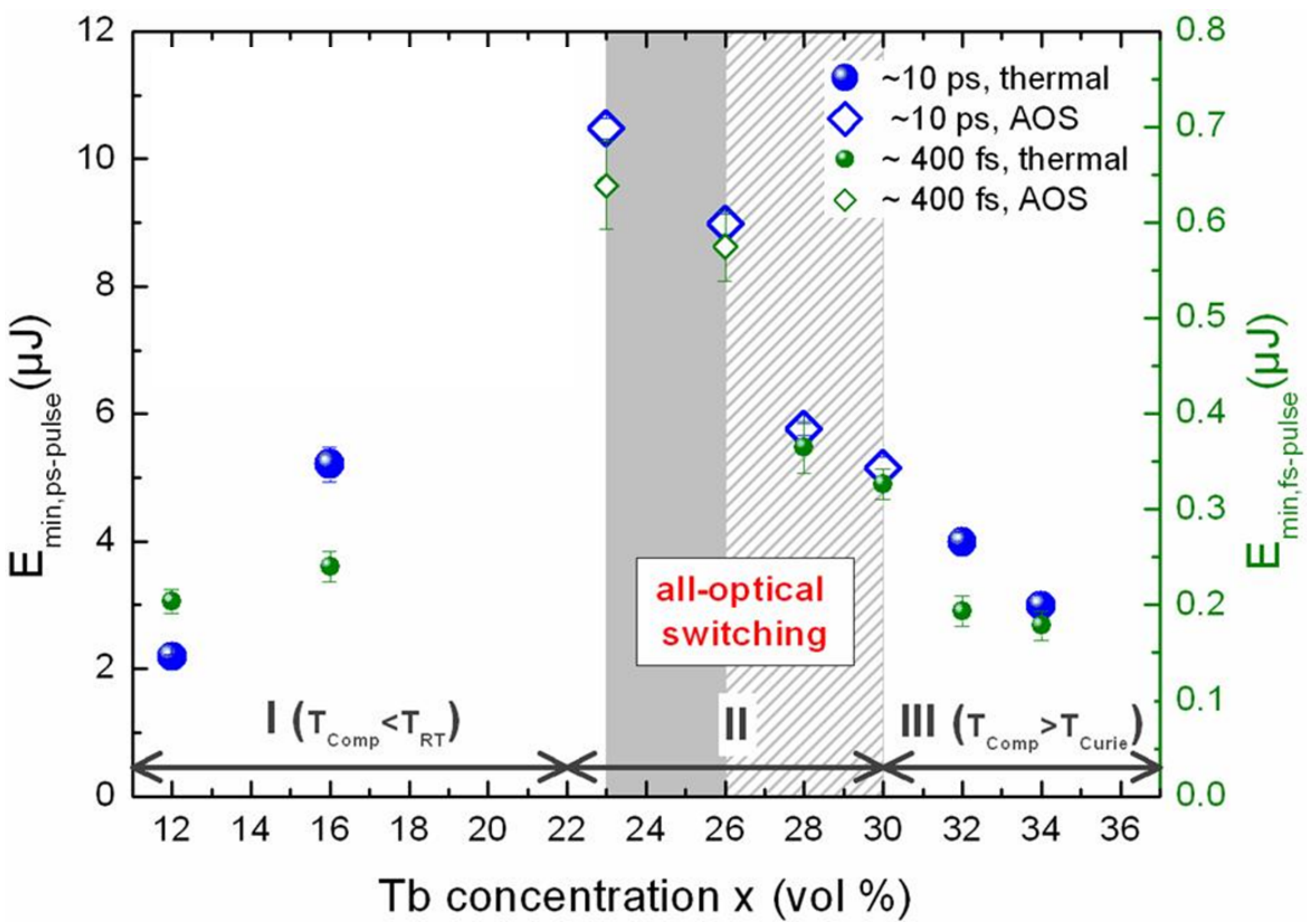
  Switching at T_A

Stanciu et al, Phys. Rev. B **73**, 220402 (2006)

Influence of the composition

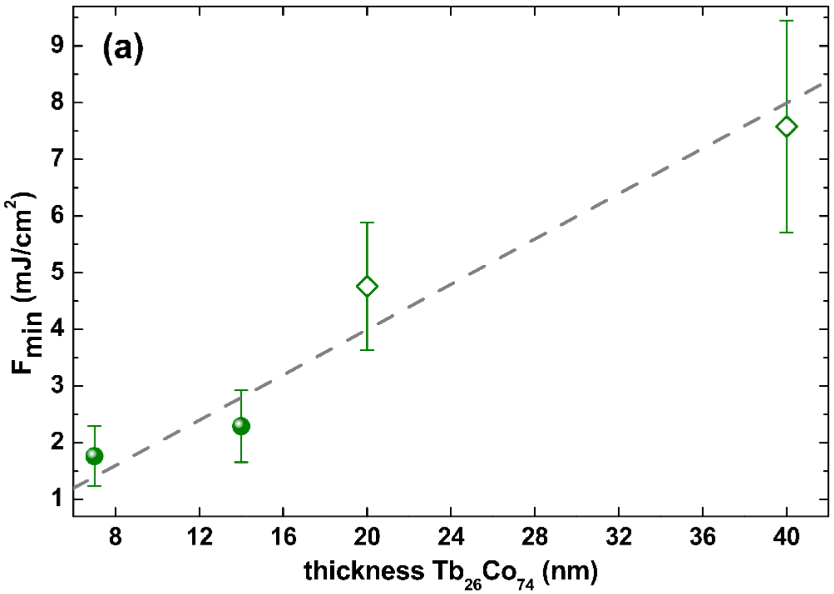


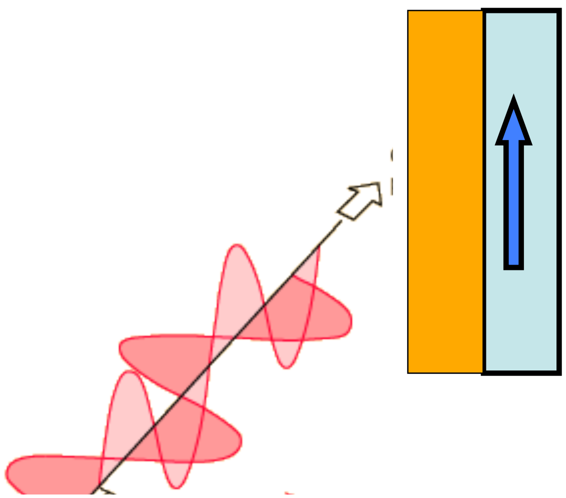
Influence of concentration and pulse duration

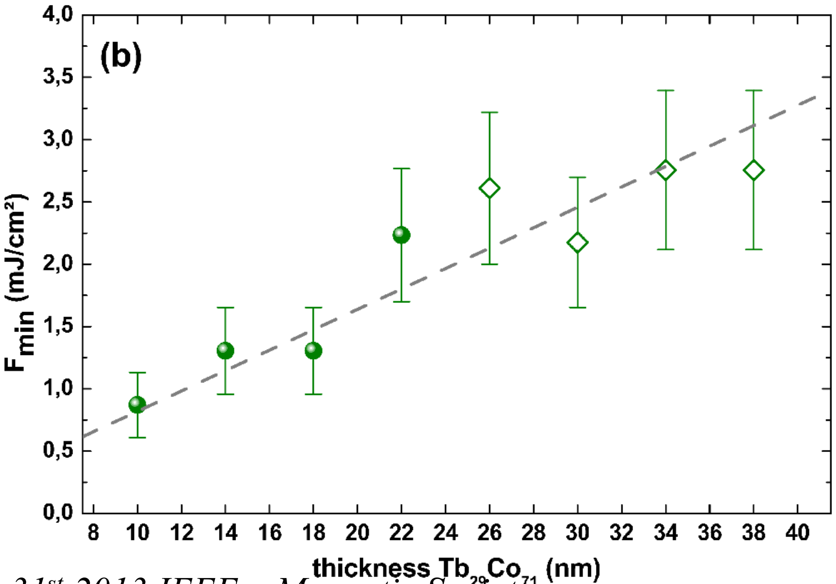


S. Alebrand et al., Appl. Phys. Lett. ***101****, 162408 (2012)*

Thickness dependence







Competition between:

- Heat transfer
- Angular momentum transfer

Model

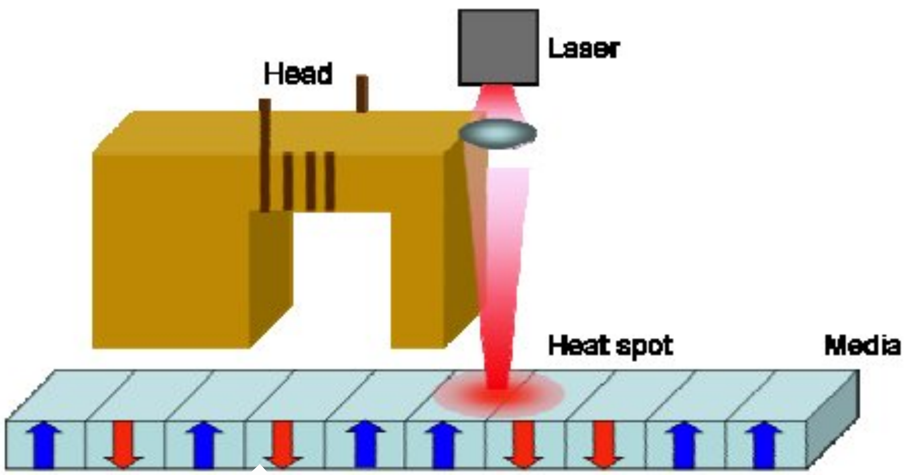
- **Magnetic field** created by a laser beam

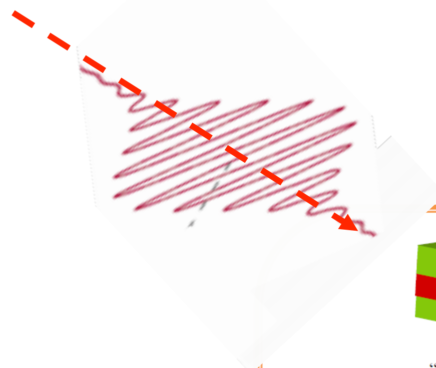
- **Heat** transfer by the laser

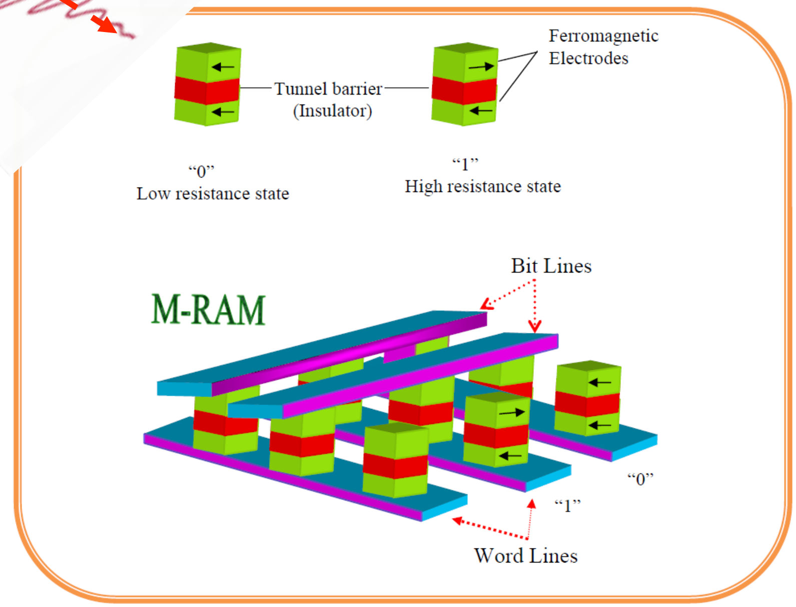
+

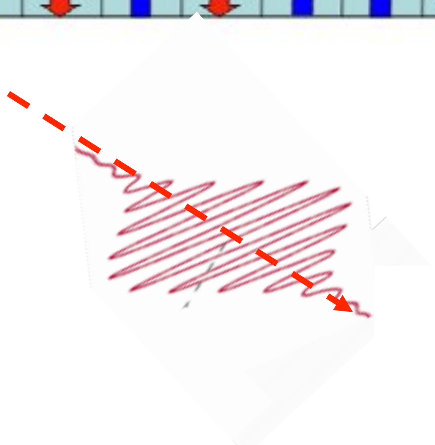
- **Angular momentum** transfer by the laser

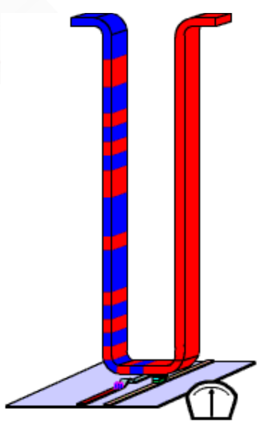
Applications









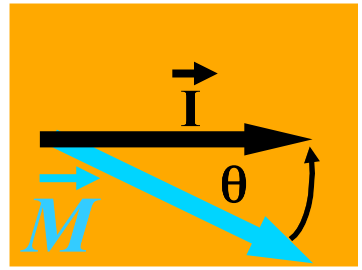


Data Storage

Memories
Logic } Read Data

Transport measurements to Read

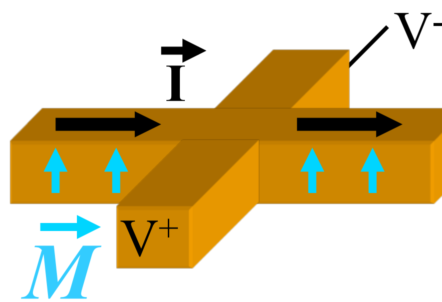
Anisotropic Magnetoresistance (AMR)



$$\Delta R(M) = (R_{\parallel} - R_{\perp})\cos^2(\theta)$$

➔ M ∥ I

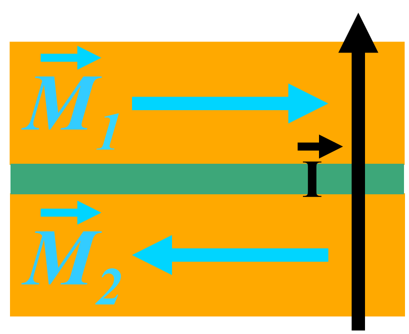
Extraordinary Hall Effect (EHE)



$$\Delta R(M) = R_{EHE} \cdot \frac{(\vec{I} \times \vec{M}) \cdot \hat{e}_z}{|\vec{M}| \cdot |\vec{I}|}$$

➔ M ⊥ plane

Giant Magnetoresistance (GMR)

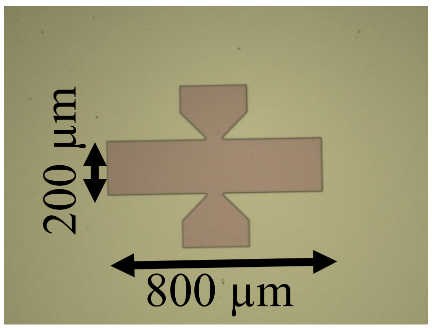


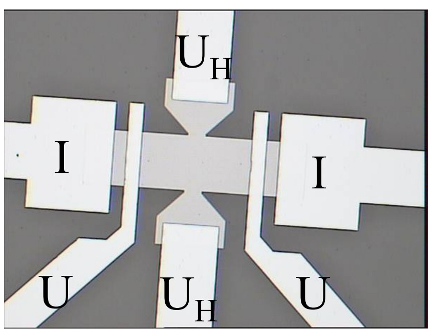
$$\Delta R(M) = GMR \cdot \left(\frac{\vec{M}_1 \cdot \vec{M}_2}{|\vec{M}_1| \cdot |\vec{M}_2|} \right)^2$$

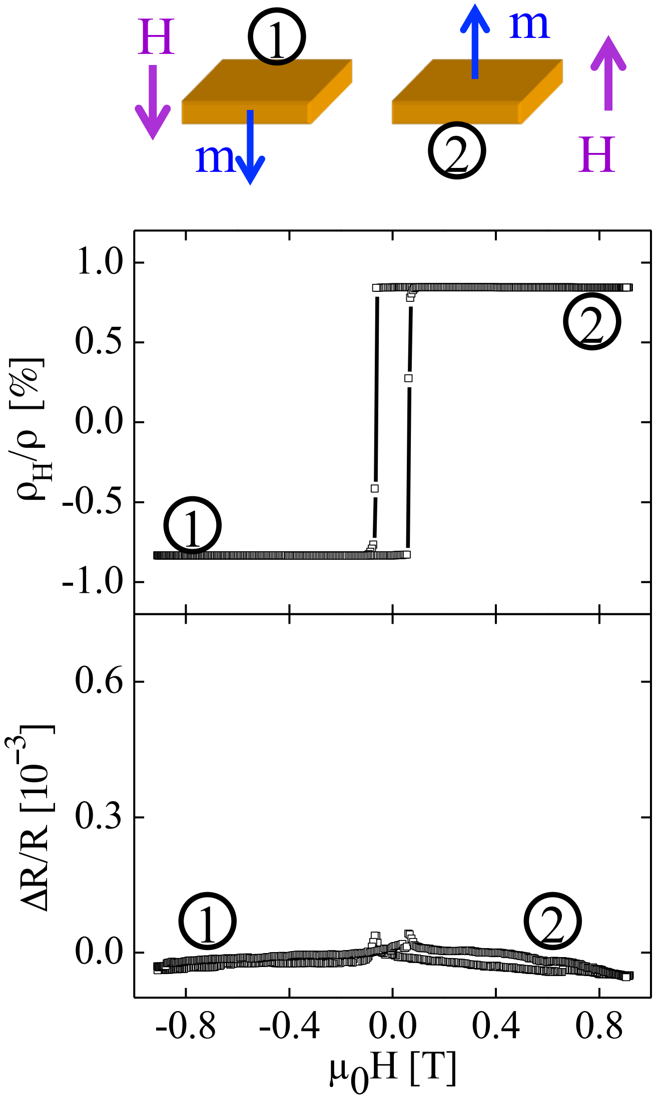
➔ $\theta(M_1, M_2)$

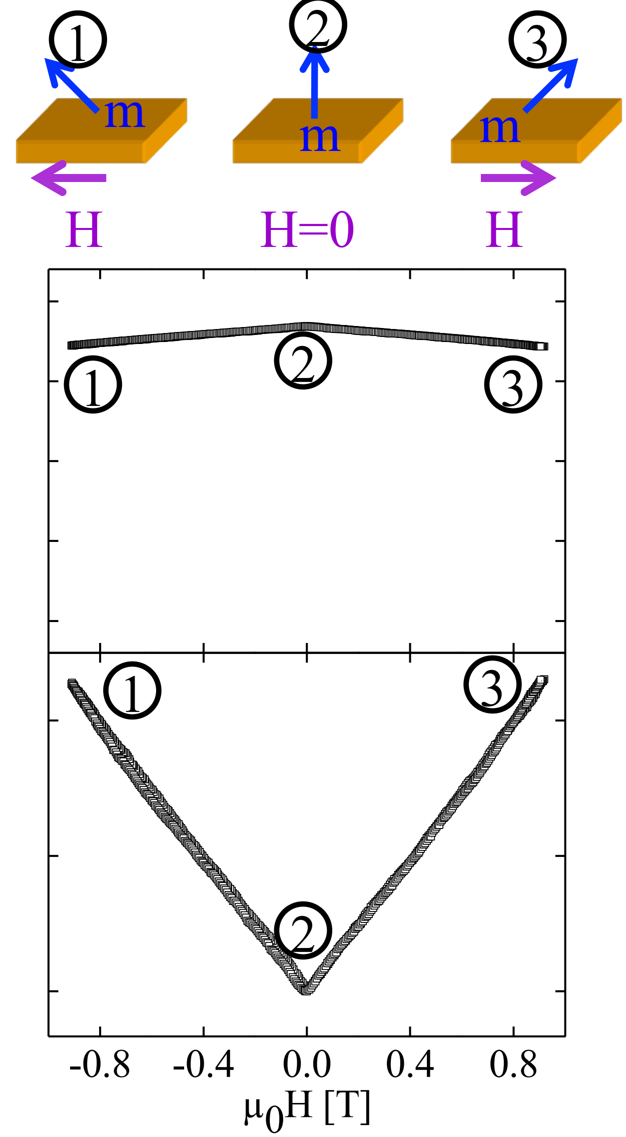
Transport properties of CoTb alloys

MgO/$Co_{88}Tb_{12}$/MgO







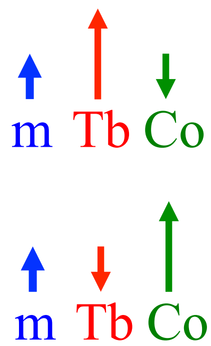


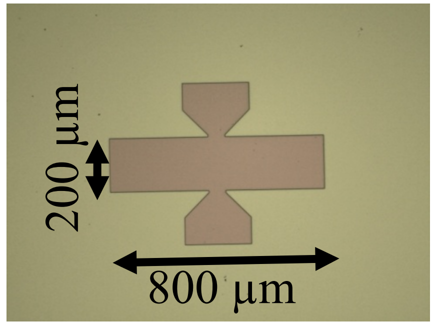
➔Complementary tools to observe magnetization reversal

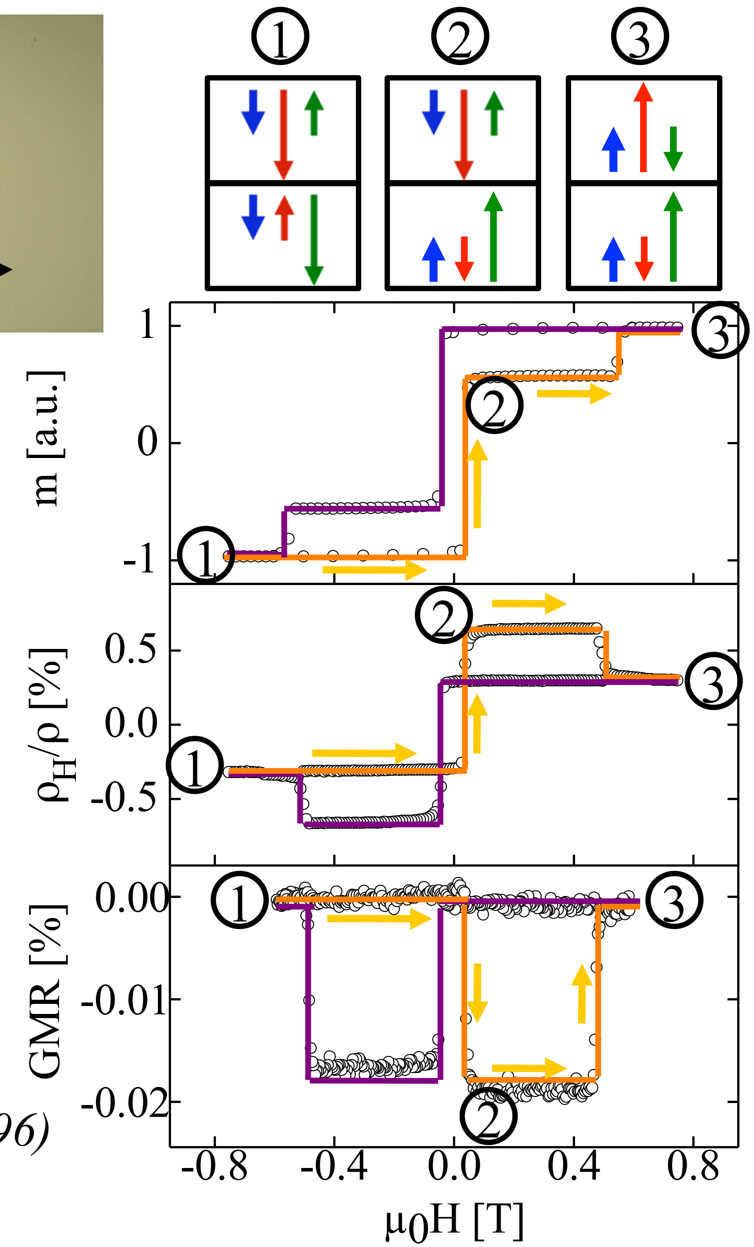
Spin valves

$Co_{74}Tb_{26}$

$Co_{88}Tb_{12}$







- ➔Decoupled soft & hard layer
- ➔EHE Sign positive for Co sublattices
- ➔GMR sign : Co sublattices
- ➔Small GMR (low polarization, short electron mean-free path?)

C. Bellouard et al Phys. Rev. B ***53****, 5082-5085 (1996)*

M. Gottwald et al Phys. Rev. B 85, 064403 (2012)

Conclusion

- Demonstration of AOS for TbCo
- Composition and thickness dependence
- Model based on Heat + Angular momentum transfer
- TbCo reversal may be probed using transport measurements

S. Alebrand et al., Appl. Phys. Lett. ***101****, 162408 (2012)*

M. Gottwald et al Phys. Rev. B 85, 064403 (2012)
M. Gottwald, et al J. Appl. Phys 111 083904 (2012)

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International French-USA Workshop

Toward Low Power Spintronic Devices

July 8th - 12th , 2013 La Jolla, California

http://nanomag.ucsd.edu/iwst/

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D.L STEIN: New York University (USA)*

S.S.P. PARKIN : Stanford / IBM –Almaden (USA)*
B. DIENY: Spintec (France) *
J. A. KATINE: HGST-WD- San Jose (USA)*
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D. RALPH: Cornell University (USA) *
Y. SUZUKI: Ozaka University (Japan)
V. LOMAKIN: UC San Diego (USA)*
L. PREJBEANU : Crocus (France)
D. APALKOV: Samsung Electronics - **Grandis (USA) ***
J.ÅKERMAN: University of Gothenburg (Sweden)*

*confirmed speakers

Abstracts (see template online) must be submitted before March 1, 2013. Posters and oral presentations will be selected by the scientific committee and authors will be informed of the selection by April 1st.

Registration will be accepted until June 1st