“PRO INVENT” RESEARCH CONFERENCE–24.03.2016

Advanced spintronic devices for communication and data storage technologies based on Heusler compounds <SPINCOD>

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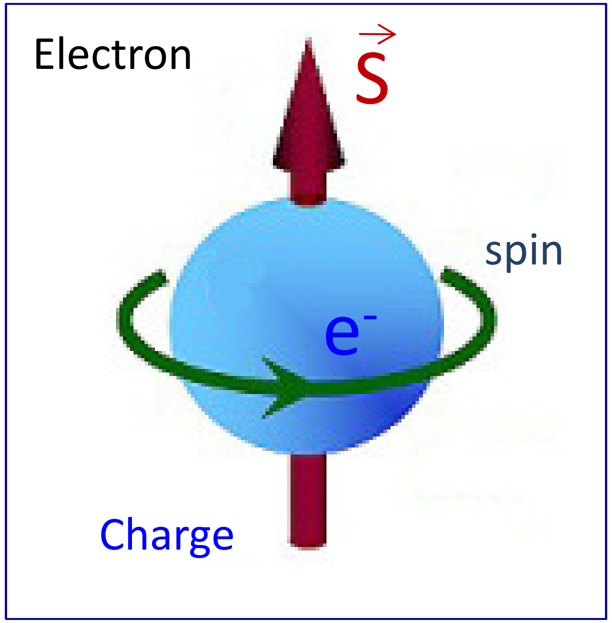
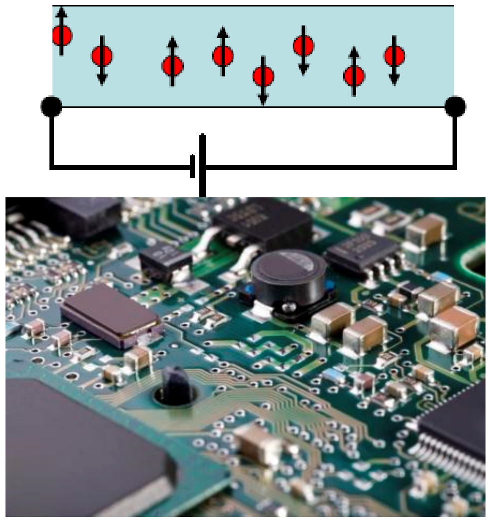
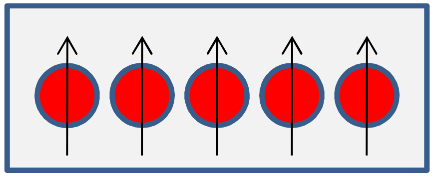
Spintronics

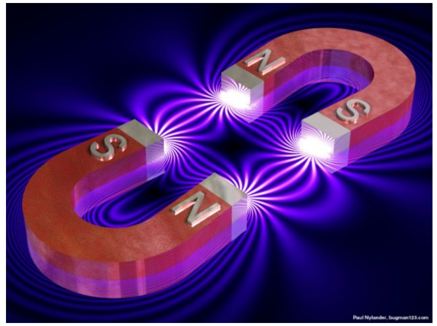


Electron = charge + spin

electronics **magnetism**







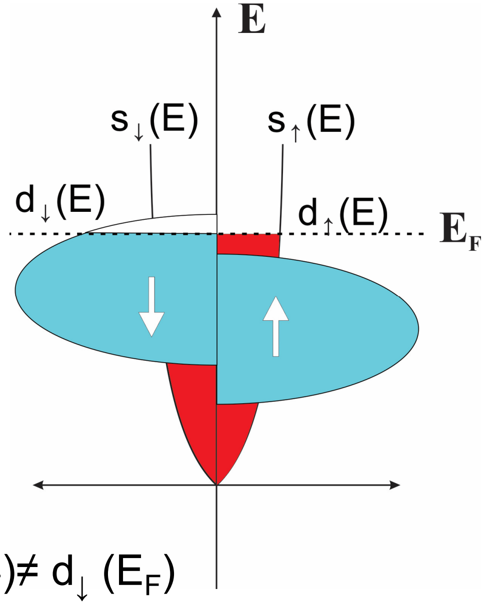
Purpose of spin-electronics: *``Teaching electrons new tricks´´*
by manipulating the electron spin in solid state electronic devices

combine electronics and magnetism in order to make new devices
in which both the charge and the spin of the electron play an active role

Spin dependent transport

Spintronic devices are based on the spin dependent electronic transport

Electronic structure of a
3d ferromagnetic material



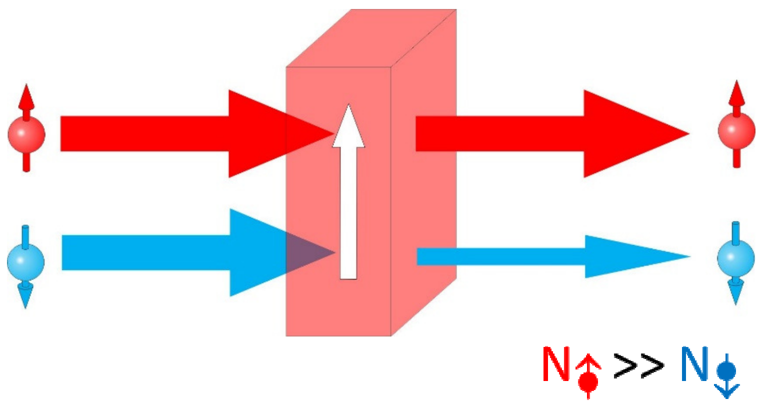
$d_{\uparrow}(E_F) \neq d_{\downarrow}(E_F)$

Fermi Golden rule:

$$P_{s-d}^{\sigma} \propto |M_{s-d}|^2 d_{\sigma}(E_F)$$

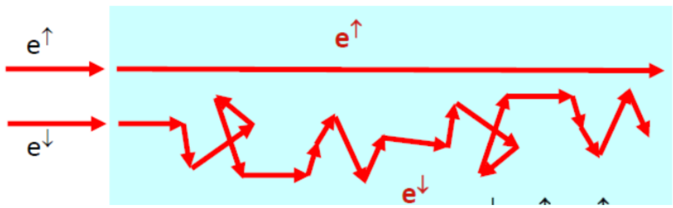
Current carried in two independent "spin-up" and "spin-down" channels

Ferromagnetic film – spin filter



$$P = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}}$$

Different s-d scattering rates for spin up and down electrons

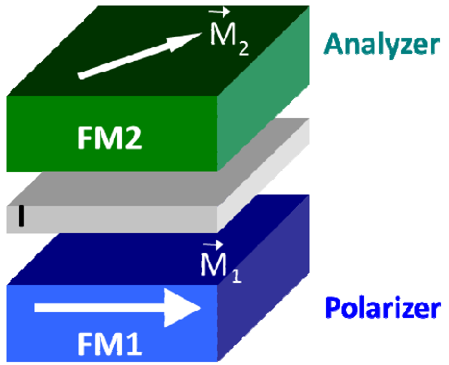


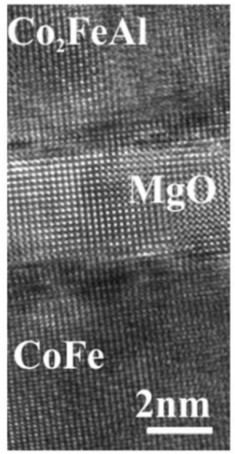
$$\lambda_{\uparrow Co} = 10nm; \lambda_{\downarrow Co} = 1nm$$

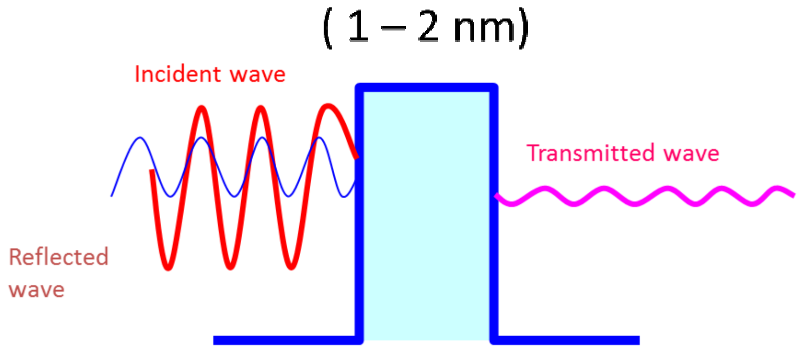
$$\rho^{\uparrow} \ll \rho^{\downarrow}$$

Magnetic tunnel junction (MTJ)

Two ferromagnetic electrodes separated by an insulating tunnel barrier

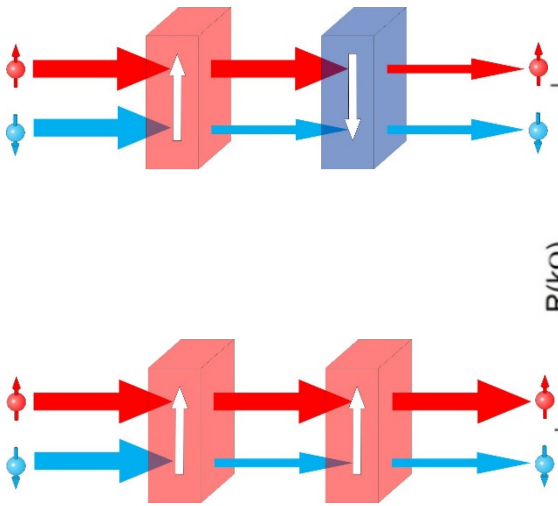


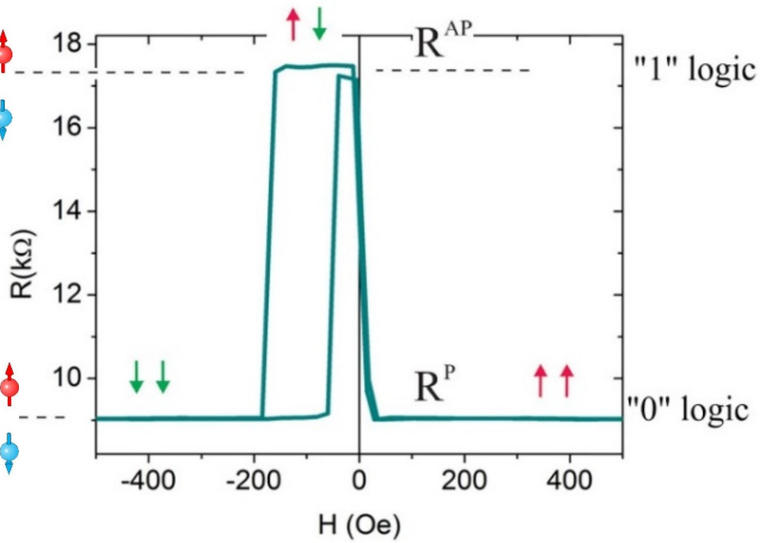




The *wave nature of the electron* determines the tunnel effect

➔ Pure **QM approach**
➔ No Classical explanation

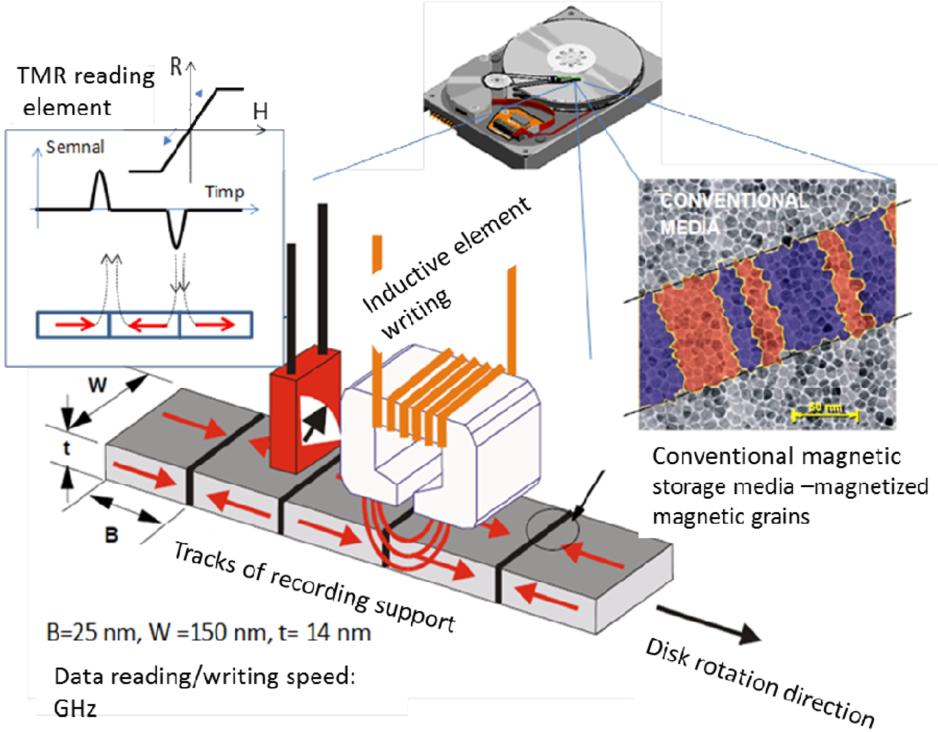


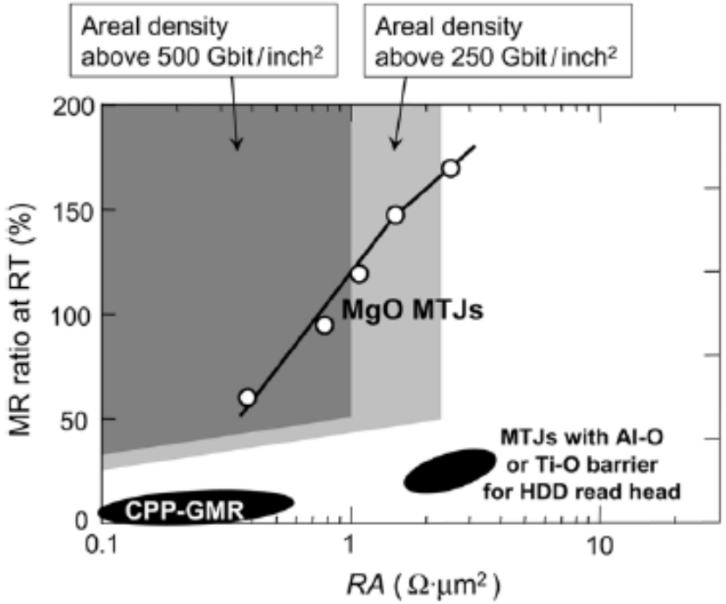


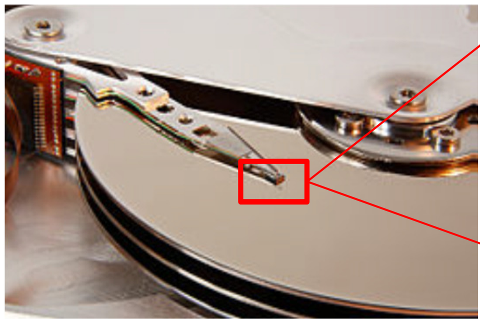
$$\frac{\Delta R}{R} = \frac{R_{AP} - R_P}{R_P} = \frac{2P_P P_A}{1 - P_P P_A}$$

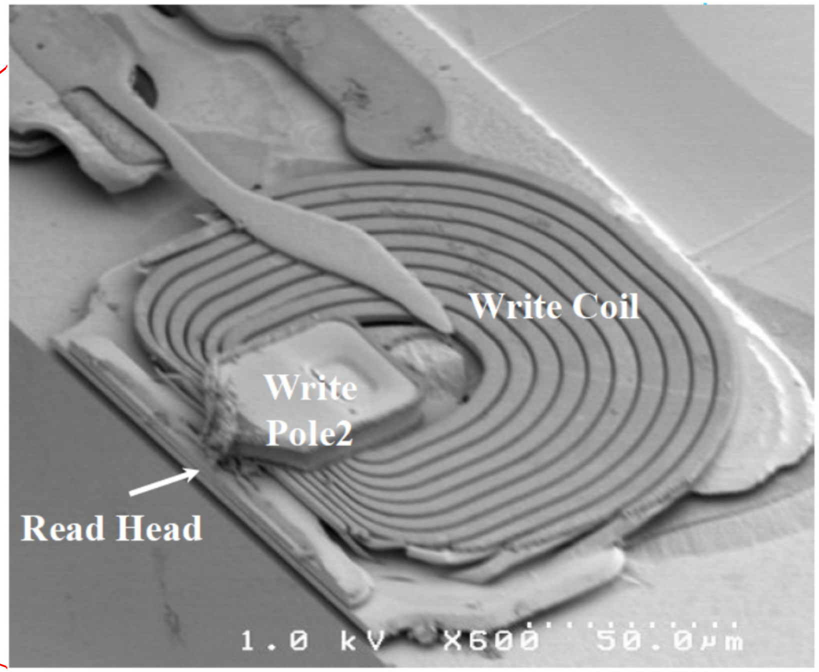
TMR amplitude ~ P amplitude

Magnetic tunnel junction (MTJ) - read head in HDD

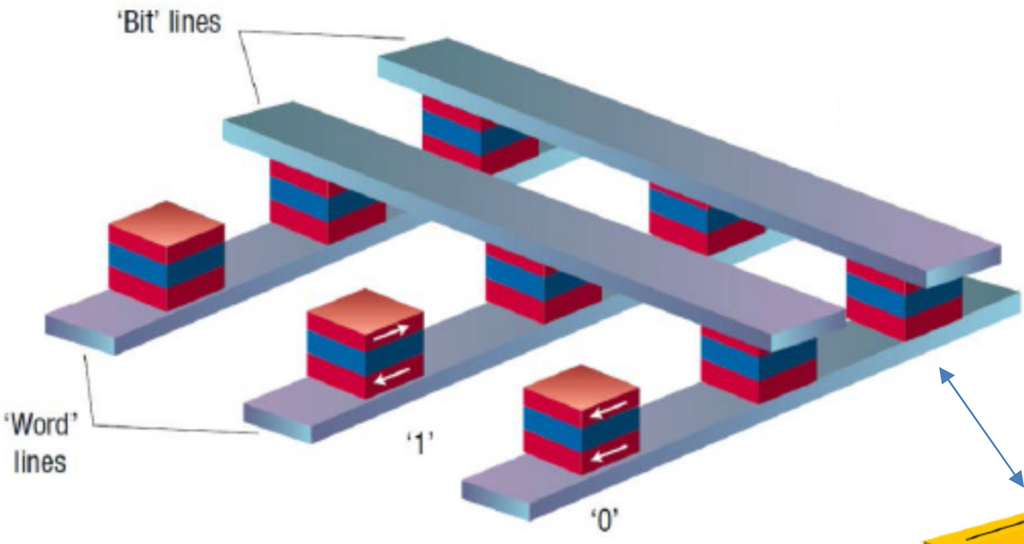






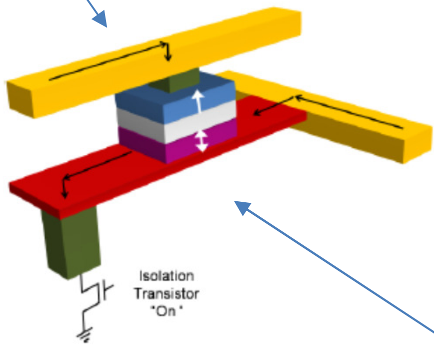


Magnetic tunnel junction (MTJ)– elementary cell of magnetic random access memories (MRAM)



Writing - rotation of the free layer

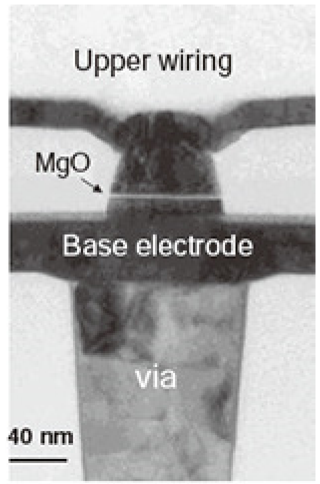
Reading - detection of the resistance of the junction



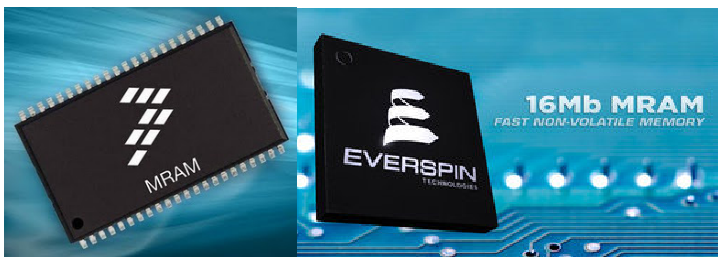
MTJ as MRAM component must fulfill requirements

- **Thermal stability**
- **Magnetic stability**
- **Single domain like switching behaviour**

+ high endurance
+ high scalability



S. Miura et al., SSDM 2014



S.Tehrani et al. PROCEEDINGS OF THE IEEE, VOL. 91, NO. 5

Next generation of magnetic tunnel junctions – Material challenges

Performance of MTJs dependent on the TMR amplitude, the switching speed and mag-noise ratio:

Increased TMR -> MTJ with electrodes having P=100% - half metal

Increased switching speed -> MTJ with electrodes having low damping

Optimize mag-noise -> optimally controlled high frequency damping

SPINCOD – Objectives

Elaboration and characterization of highly spin polarized Heusler alloys thin films with extrinsically controlled Gilbert damping and their integration in spintronic devices.

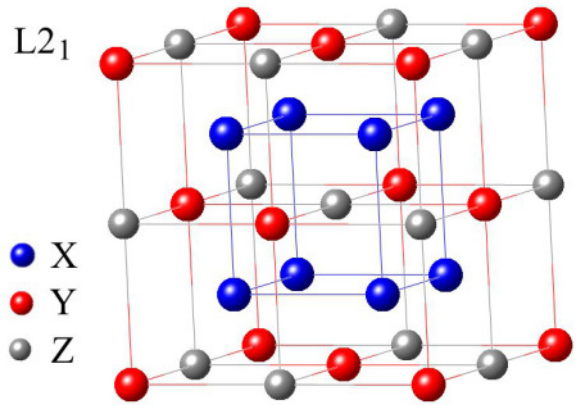
O1: Deposition and characterization of highly spin polarized Heusler alloys thin films as electrodes for MTJs

O2: Deposition and characterization of Heusler based MTJs with extrinsically controlled high frequency damping

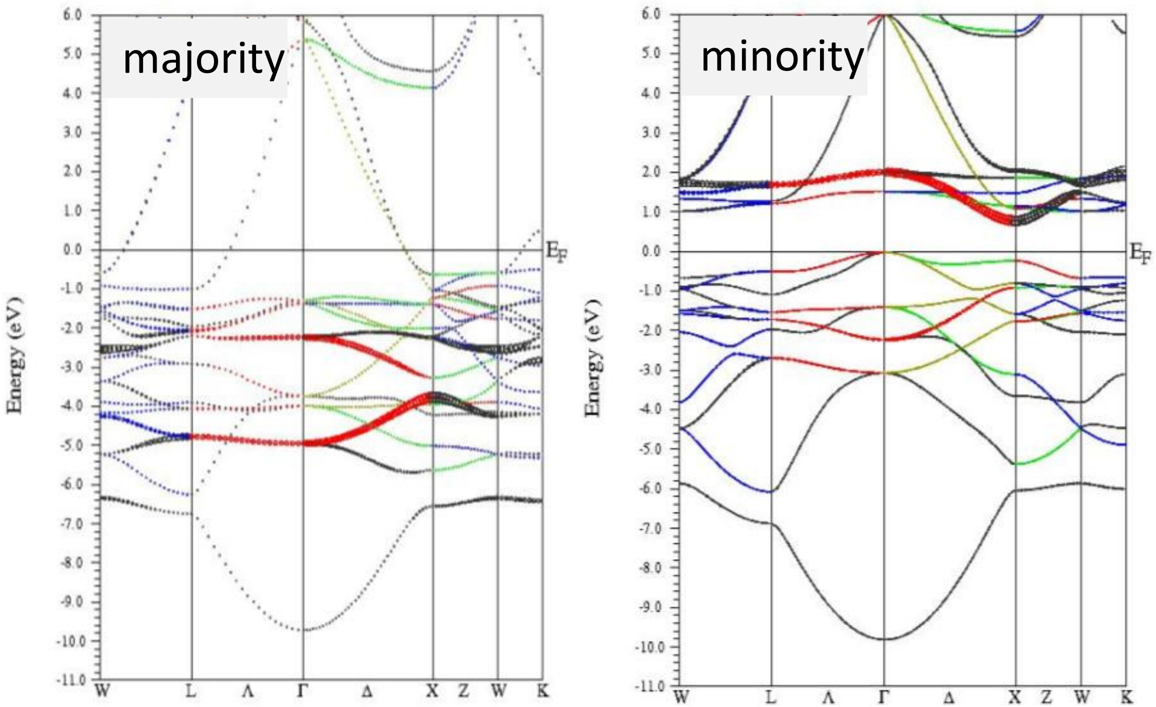
Why Heusler ???

SPINCOD – RESULTS - Half metallic $Co_2FeAl_xSi_{1-x}$ Heusler alloys

- **$Co_2FeAl_xSi_{1-x}$ full Heusler**
  - alloys $L2_1$ structure belonging to the 225 (Fm-3m) space group:
  - high Curie temperature > 700 K
  - localized magnetic character ($4.96\mu_B$/f.u.)



- spin resolved band structure calculations
  Wien 2k *ab-initio* code LSDA+U formalism

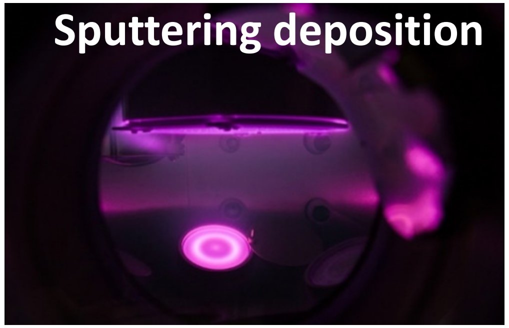


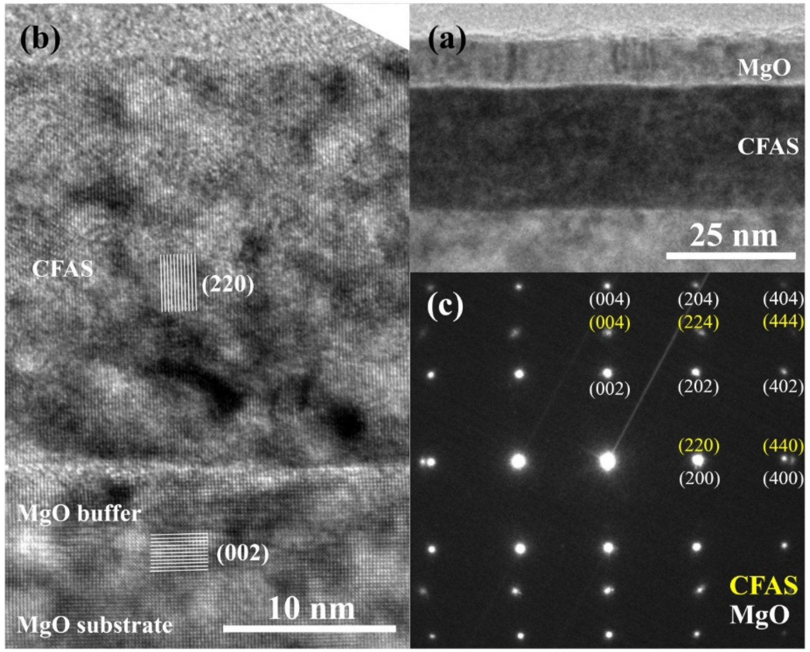
Theoretically CFAS shows:
- 100% spin polarization
- Low *high frequency damping*

Practically ???

SPINCOD – RESULTS - Half metallic CFAS Heusler alloys thin films

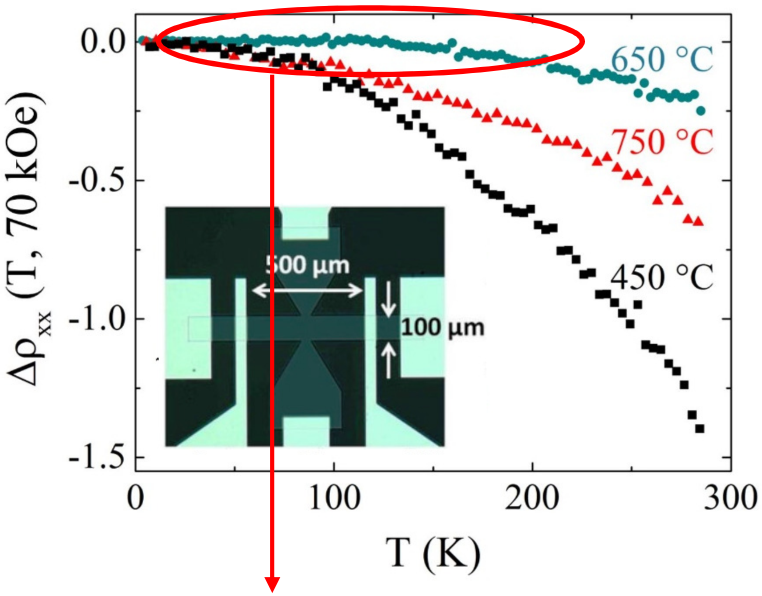
- **MgO(001)//$Co_2FeAl_{0.5}Si_{0.5}$ (25 nm)/ MgO(5 nm)**





Epitaxial growth confirmed by TEM

$$\Delta\rho_{xx}(T,H) = 1 - \frac{\rho_{xx}(T,H) - \rho_{xx}(T,0)}{\rho_{xx}(4\ K,H) - \rho_{xx}(4\ K,0)}$$

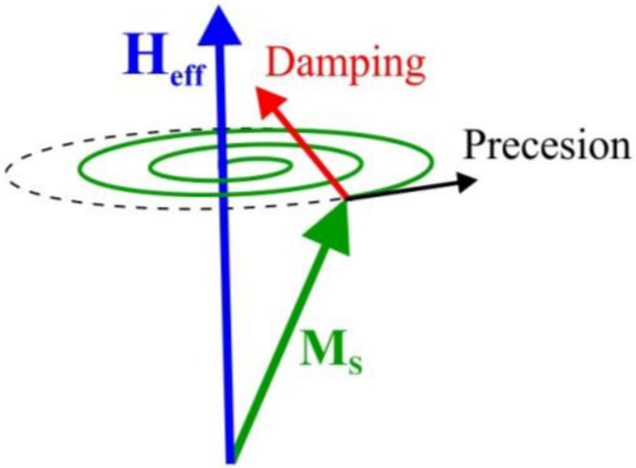


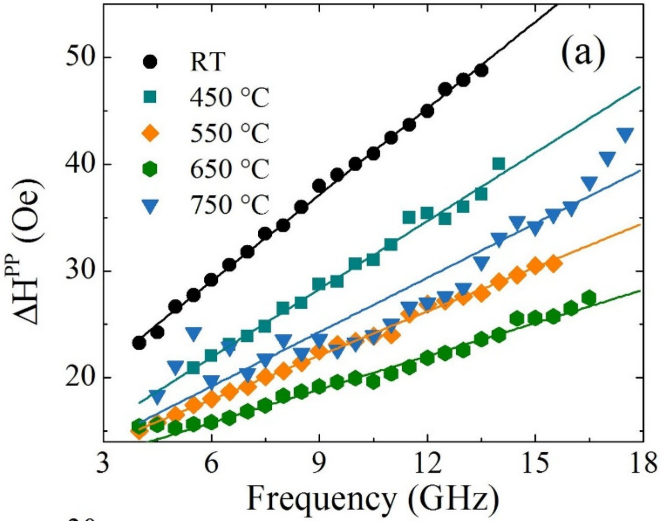
- **Half metallic character (100 % SP)**

M.S. Gabor et al., PHYSICAL REVIEW B 92, 054433 (2015)

SPINCOD – RESULTS – High frequency dynamics

High frequency dynamics





LLG equation:

$$\frac{\partial \hat{m}}{\partial t} = -\gamma \hat{m} \times \left(\vec{H}_E \right) + \alpha \hat{m} \times \frac{\partial \hat{m}}{\partial t}$$

Precession **Damping**

$$\Delta H^{PP} = \frac{2}{\sqrt{3}} \frac{2\pi}{\gamma} \times \alpha_{\mathrm{eff}} f + \Delta H_0$$

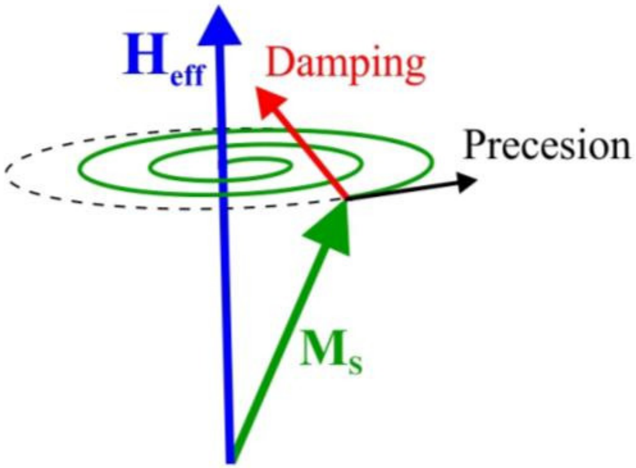
Linewidth vs. frequency gives the effective damping constant:

- CFAS films:
  - **$\alpha = 1.9\text{x}10^{-3}$ (for Permalloy : $\alpha \approx 10^{-2}$).**

M.S. Gabor et al., PHYSICAL REVIEW B 92, 054433 (2015)

SPINCOD – RESULTS – Controlling damping through spin pumping

High frequency dynamics



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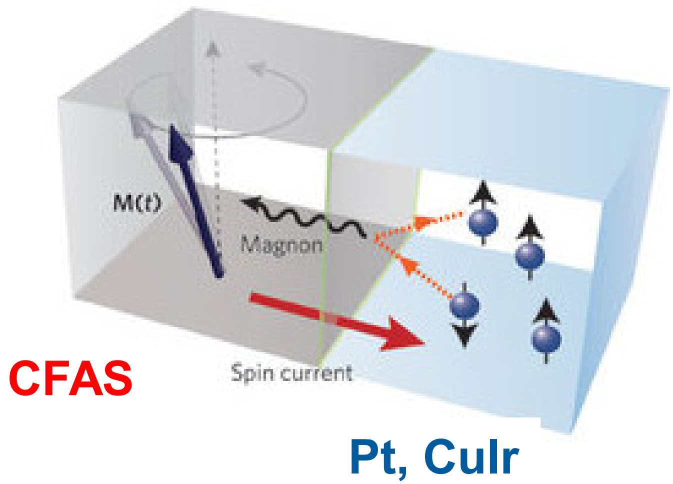
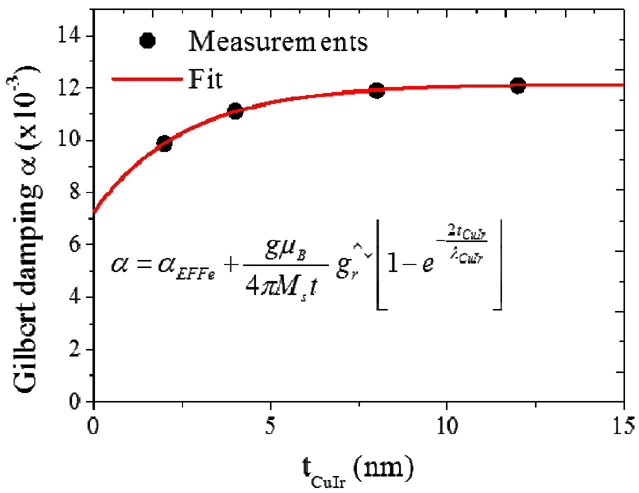
Precession

Damping

M.S. Gabor et al., PHYSICAL REVIEW B 92, 054433 (2015)



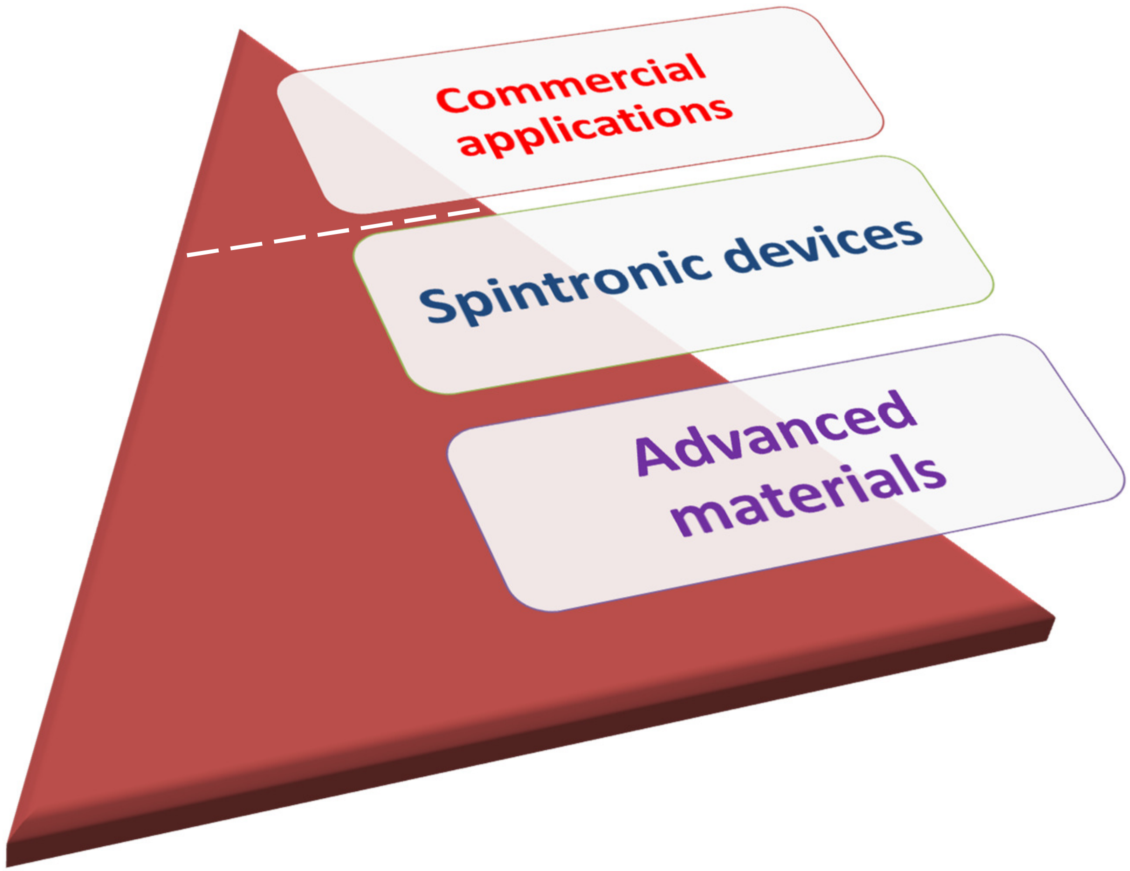
Si/SiO2/CFAS (10 nm)/ $Cu_{0.94}Ir_{0.06}$(t nm)/Al(1.3 nm)

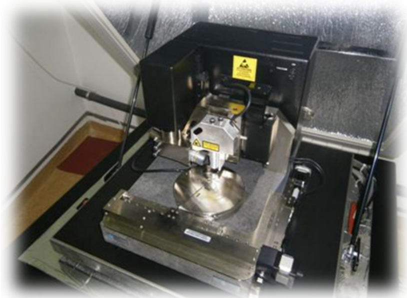


CFAS ideal electrode for MTJs

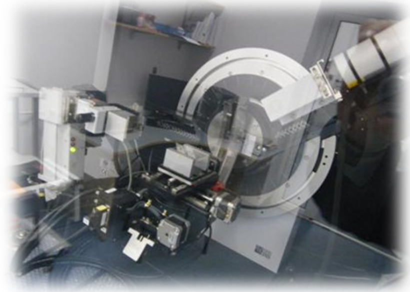
Research strategy - SPINCOD

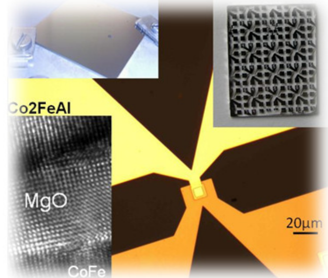
PN-II-RU-TE nr. 255/01.10.2015 Advanced spintronic devices for communication and data storage technologies based on Heusler compounds. SPINCOD

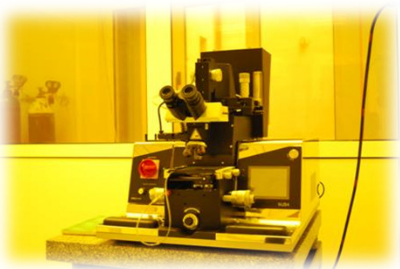


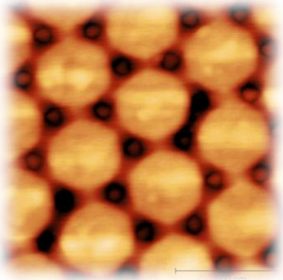


Acknowledgements









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