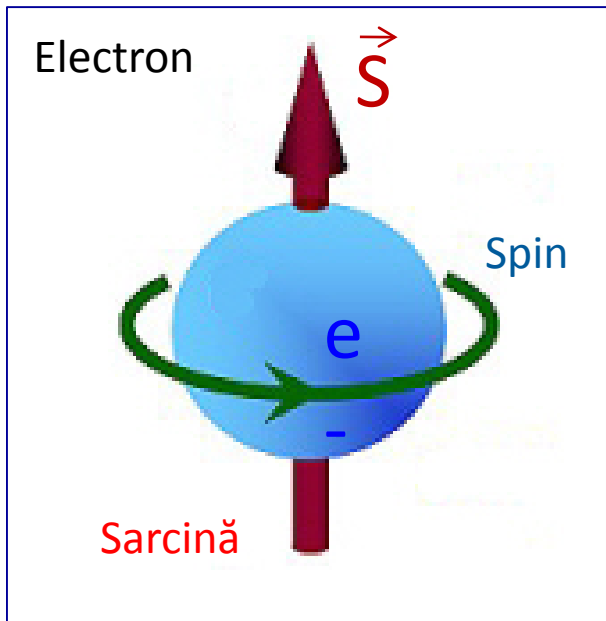
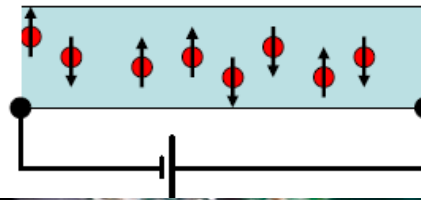

Materiale avansate cu aplicatii în domeniul dispozitivelor spintronice folosite în tehnologia stocării informației <MADSPIN>

Dr. Mihai GABOR



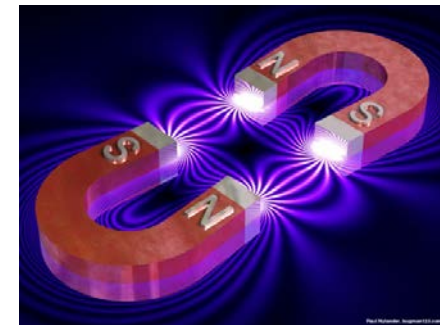
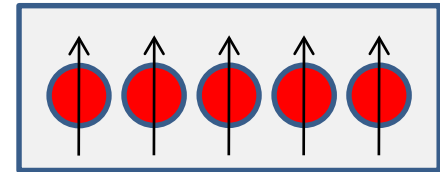
Electron = sarcină +

↓
electronică



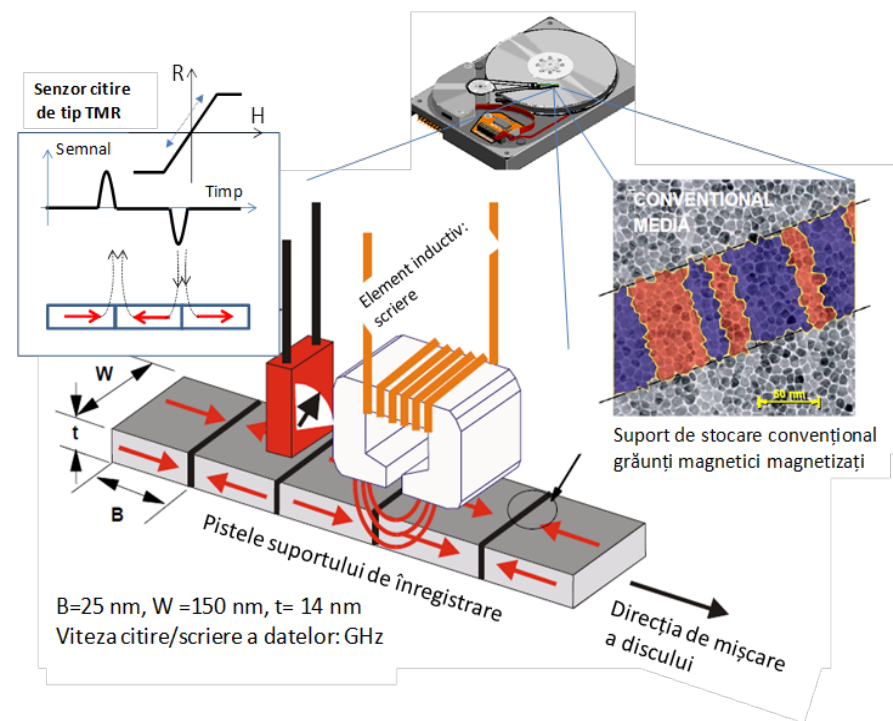
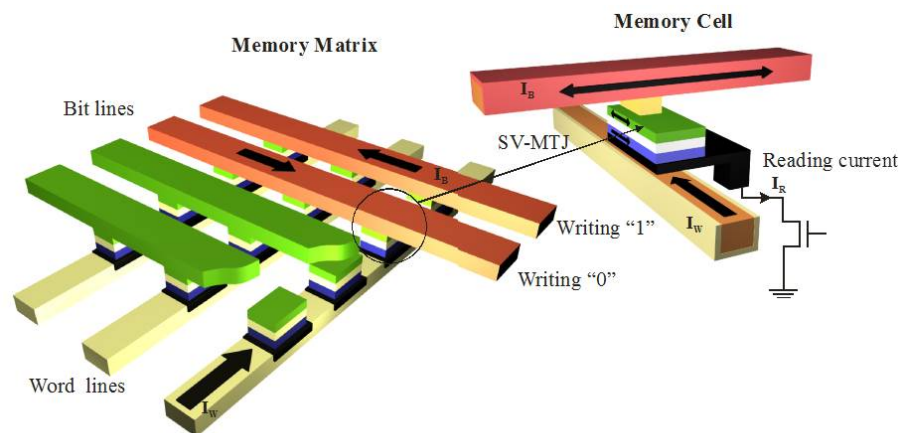
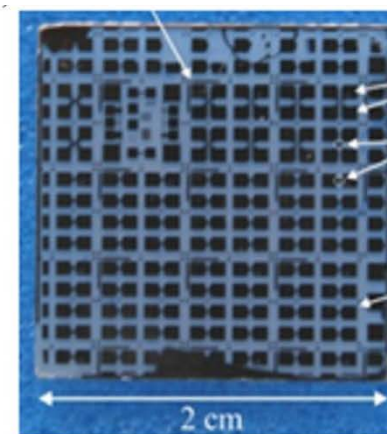
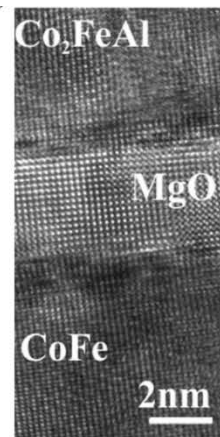
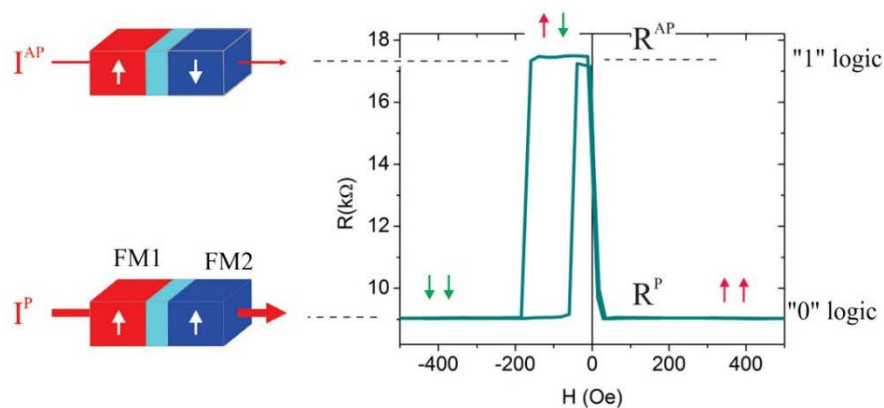
spin

↓
magnetism

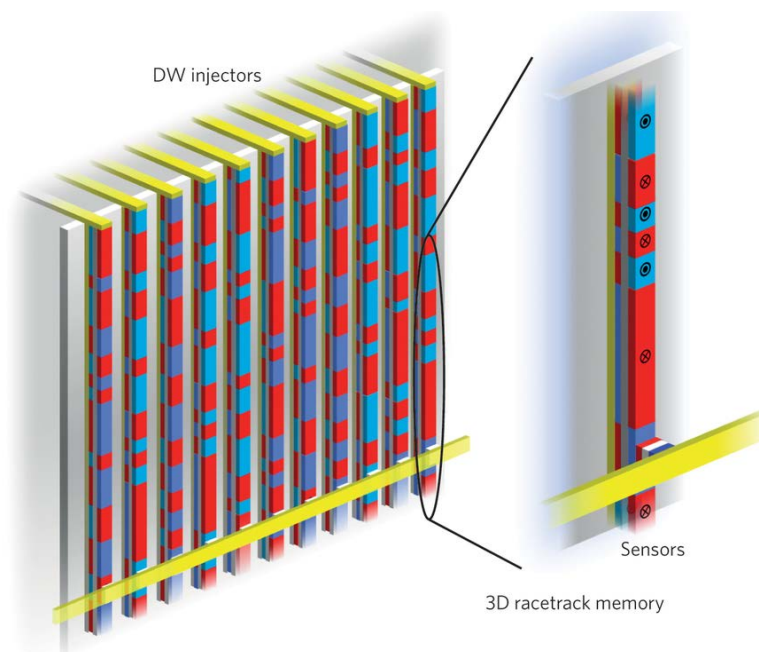
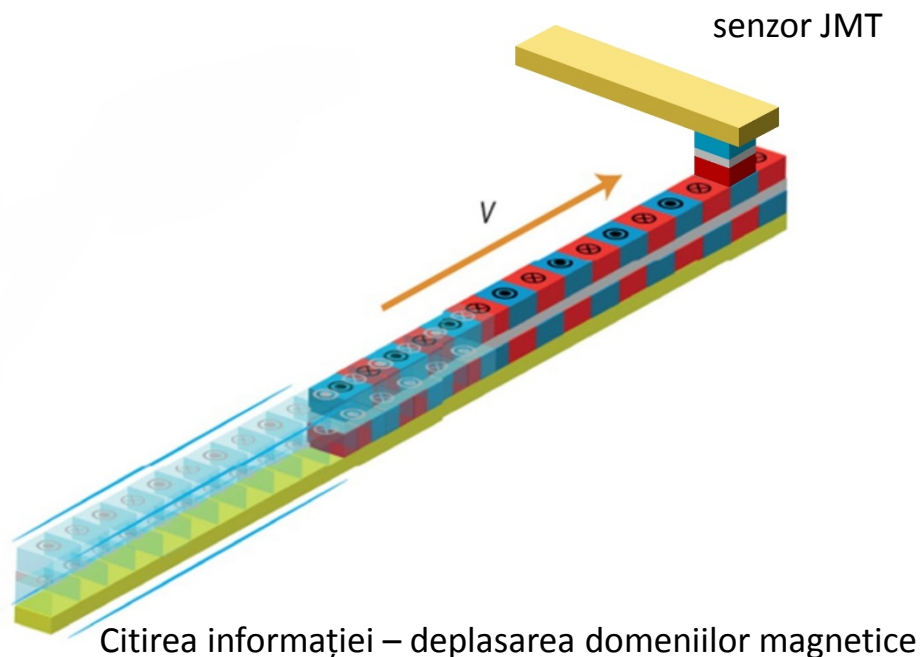


Scopul **spin-electronicii** este de a combina **electronica** și **magnetismul** pentru dezvoltarea de dispozitive în care atât **sarcina** cât și **spinul** să joace un rol activ.

Joncțiunea magnetică tunel (JTM) – aplicații



Memoria magnetică de tip „race-track”



Stuart Parkin and See-Hun Yang, Nature Nanotechnology, 2015

Materiale feromagnetice

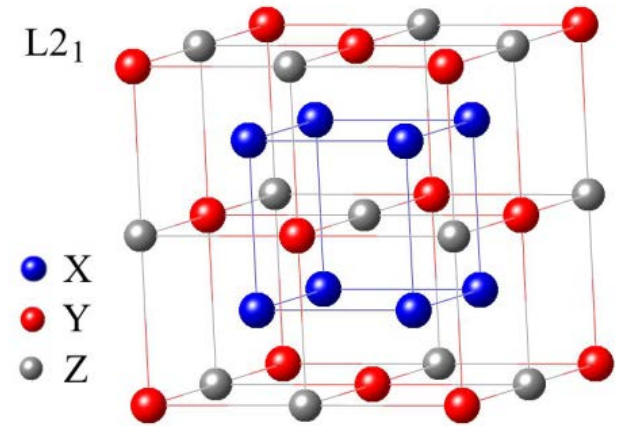
- anizotropie magnetică perpendiculară
- polarizare de spin ridicată
- amortizarea Gilbert redusă

Control local al orientării magnetizării

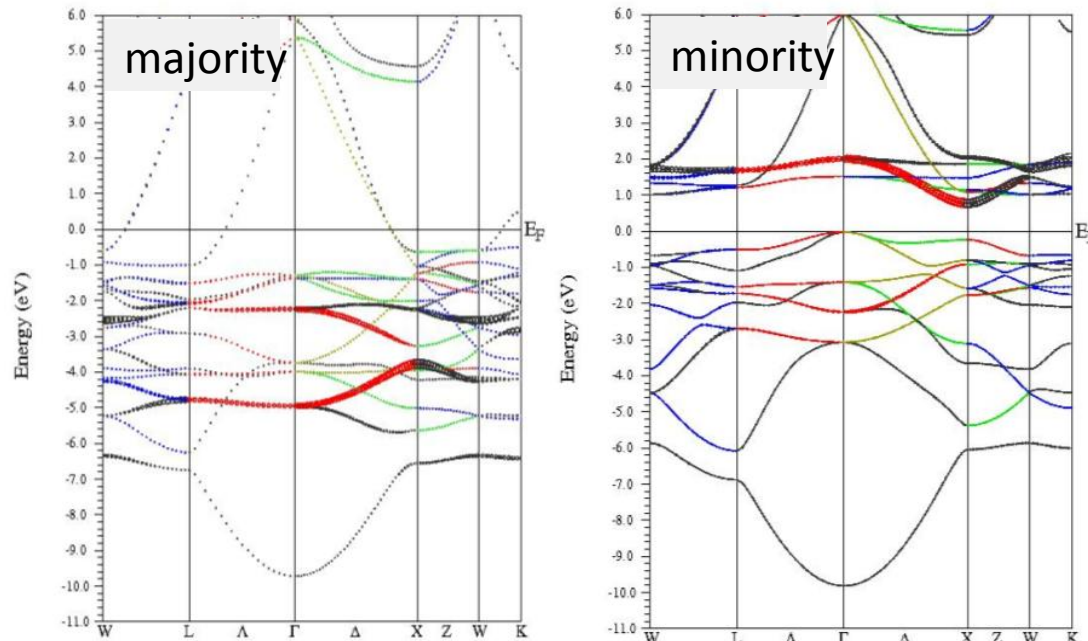
Aliajul Heusler semimetalic $\text{Co}_2\text{FeAl}_x\text{Si}_{1-x}$ (CFAS)

- Aliajul full Heusler $\text{Co}_2\text{FeAl}_x\text{Si}_{1-x}$ (CFAS)

- structură $L2_1$ aparținând grupului spațial (Fm-3m)
- temperatură Curie ridicată > 700 K
- caracter feromagnetic localizat ($4.96\mu_B/\text{f.u.}$)



- Calcul de structuri de benzi rezolvat în spin folosind codul *ab-initio* Wien2K în formalismul LSDA+U

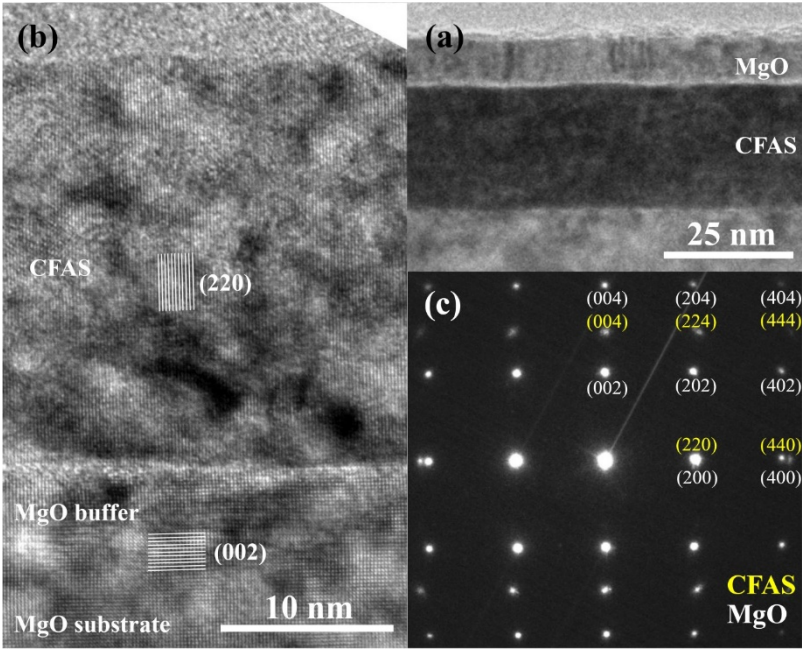
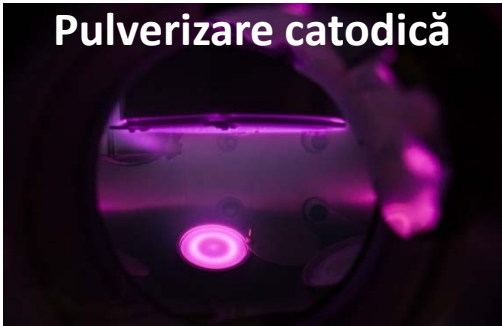


Teoretic CFAS prezintă:

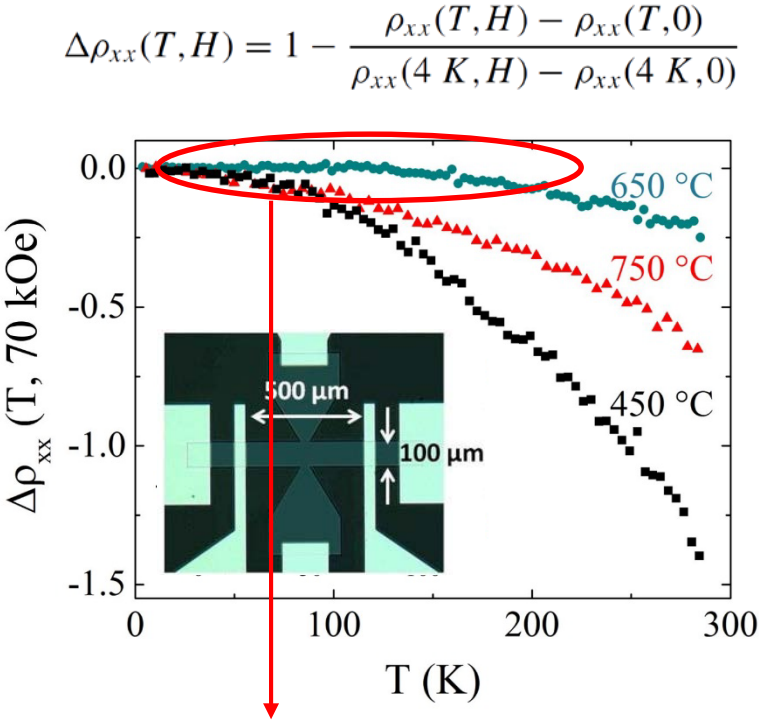
- polarizare de spin 100%
- amortizarea Gilbert redusă

Practic ???

- $\text{MgO}(001)//\text{Co}_2\text{FeAl}_{0.5}\text{Si}_{0.5}$ (25 nm)/ $\text{MgO}(5\text{ nm})$

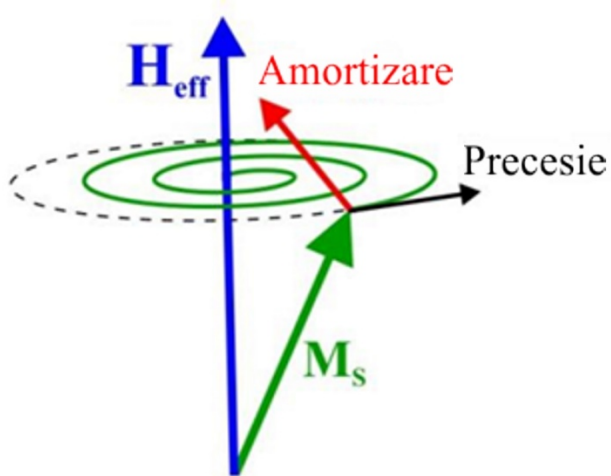


Creștere epitaxială confirmată de MET.

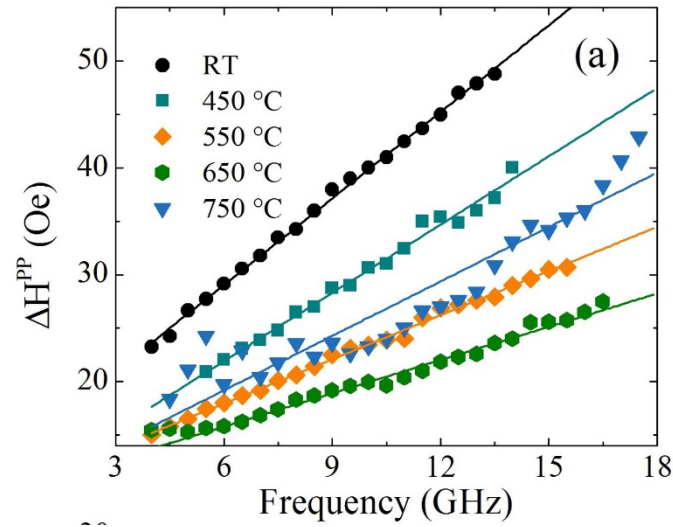
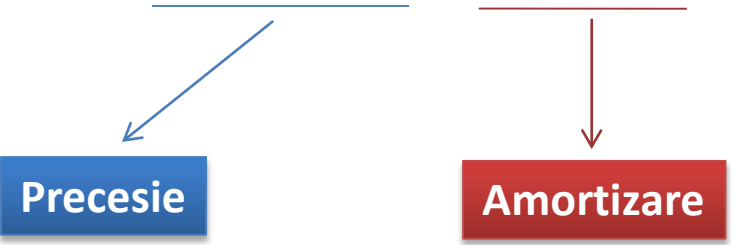


- Caracter semimetalic

Proprietăți magnetice la frecvențe înalte



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



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

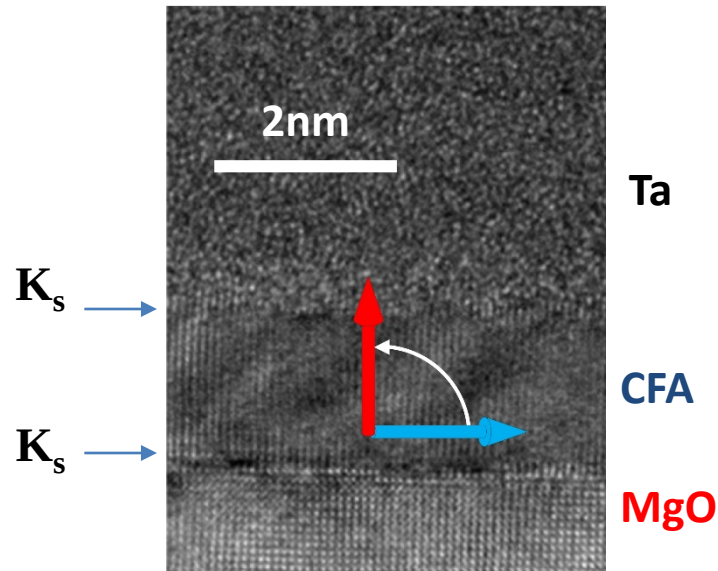
Lărgimea linei de rezonanță vs. frecvență permite determinarea constantei de amortizare Gilbert:

- CFAS films:
 $\alpha = 1.9 \times 10^{-3}$ (pt. Permalloy : $\alpha \approx 10^{-2}$).

• Amortizare Gilbert redusă

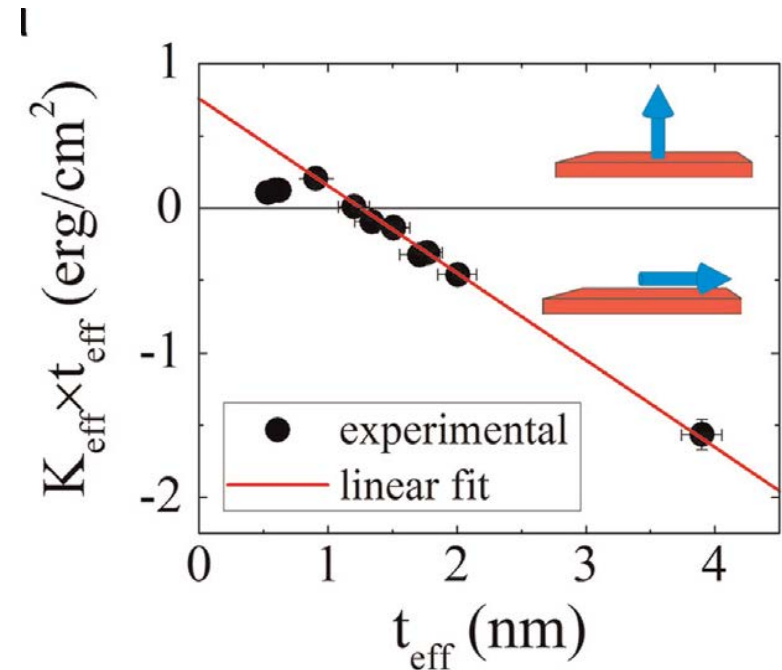
Rezultate – filme de CFA cu anizotropie magnetică perpendiculară

MgO(001)/CFA (grosime var.)/ Ta (5 nm)



$$K_{\perp} = K_{\perp v} + 2K_{\perp s}/d$$

Anizotropia magnetică este datorată hibridizării orbitalilor O 2p cu orbitalii (Co,Fe) 3d + ridicarea degenerării datorită CSO puternic.



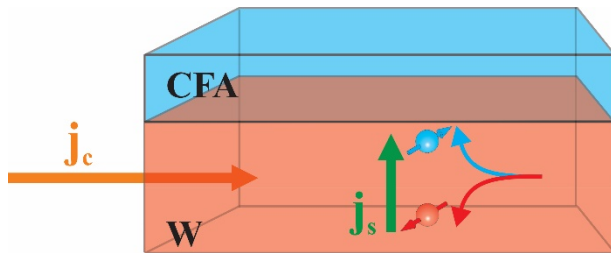
Pentru filme cu **grosimi inferioare la 1 nm** magnetizarea se orientează spontan perpendicular la planul filmului.

• **Anizotropie magnetică perpendiculară**

CFAS candidat ideal pentru memorii „race-track”

Controlul local al magnetizării prin intermediul curenților de spin

Efectul Hall de spin



$$\mathbf{J}_s^{\text{SH}} = \alpha_{\text{SH}} \left(-\frac{\hbar}{2e} \right) J_c [\hat{\mathbf{z}} \times \hat{\mathbf{s}}] \quad \text{E. Hirsch Phys. Rev. Lett. 83, 1834 (1999)}$$

Dinamica magnetizării

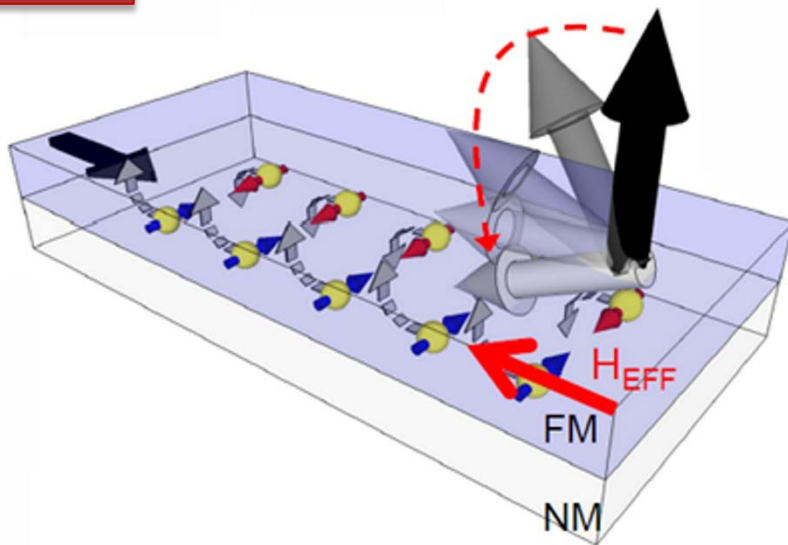
$$\frac{\partial \mathbf{m}}{\partial t} = -\gamma \mathbf{m} \times \mathbf{H}_{\text{eff}} + \alpha \mathbf{m} \times \frac{\partial \mathbf{m}}{\partial t} - \underbrace{b \mathbf{m} \times (\mathbf{m} \times \boldsymbol{\sigma})}_{\mathbf{H}_{\text{EFF}}^{\text{long}}} - \underbrace{a (\mathbf{m} \times \boldsymbol{\sigma})}_{\mathbf{H}_{\text{EFF}}^{\text{trans}}}$$

$\mathbf{H}_{\text{EFF}}^{\text{long}}$

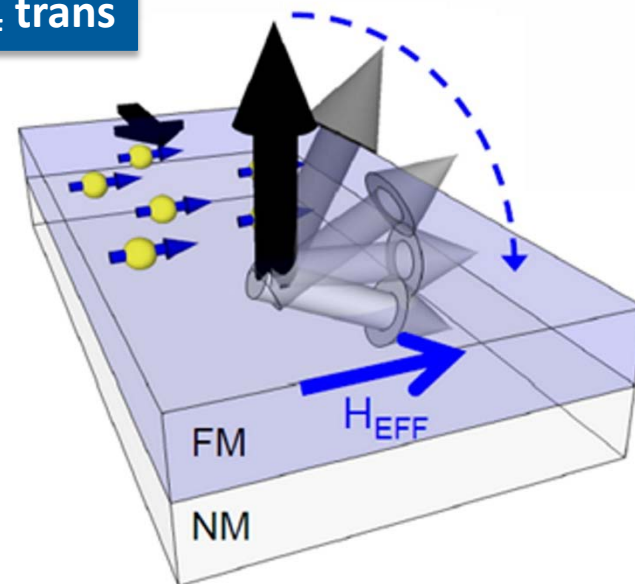
$\mathbf{H}_{\text{EFF}}^{\text{trans}}$

Zhang et al., PRL, 88, 236601, (2002)

$\mathbf{H}_{\text{EFF}}^{\text{long}}$



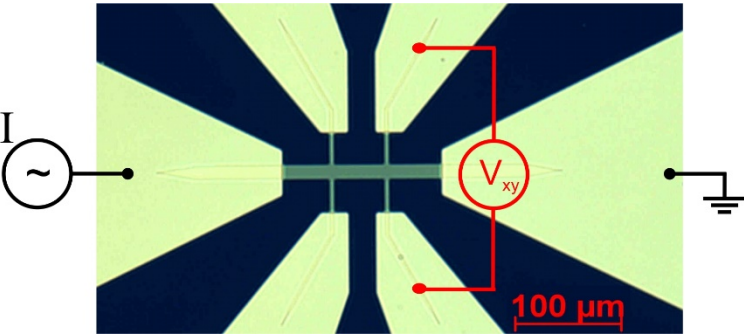
$\mathbf{H}_{\text{EFF}}^{\text{trans}}$



Caracterizarea câmpurilor magnetice efective în W/CFA/MgO

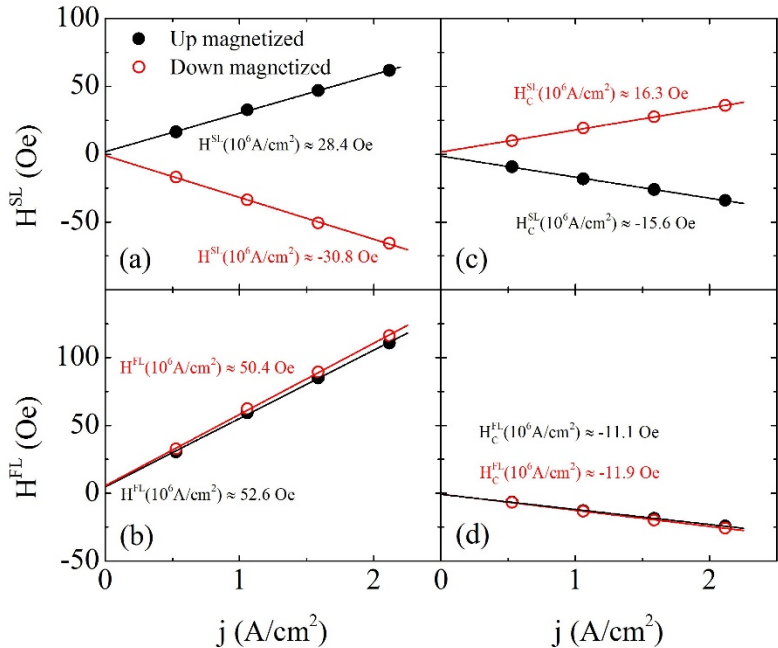
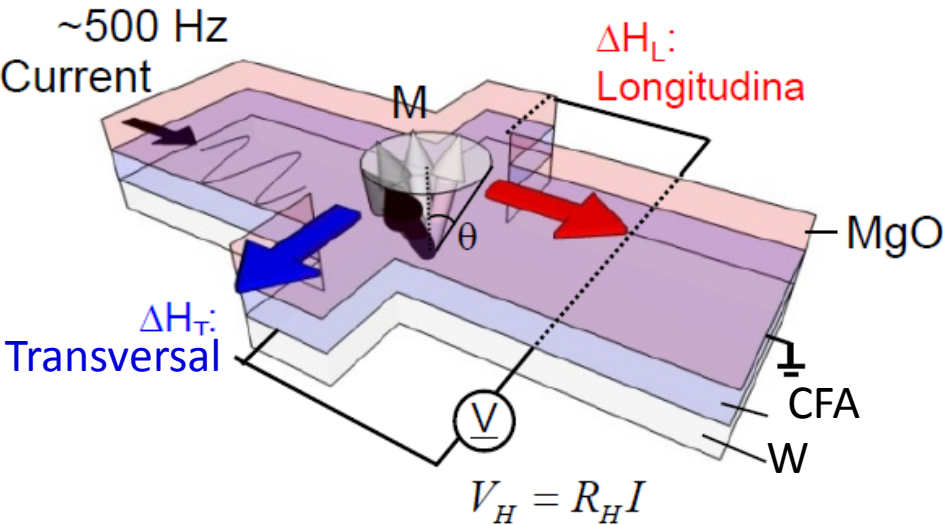
Si//W(5.5 nm)/CFA(0.8 nm)/MgO(1.0 nm)/Ta(2.0 nm)

Dispozitivul experimental



$$H_{L,T} = -2 \frac{\partial V^{2\omega}}{\partial H_{L,T}} \bigg/ \frac{\partial^2 V^\omega}{\partial H_{L,T}^2}.$$

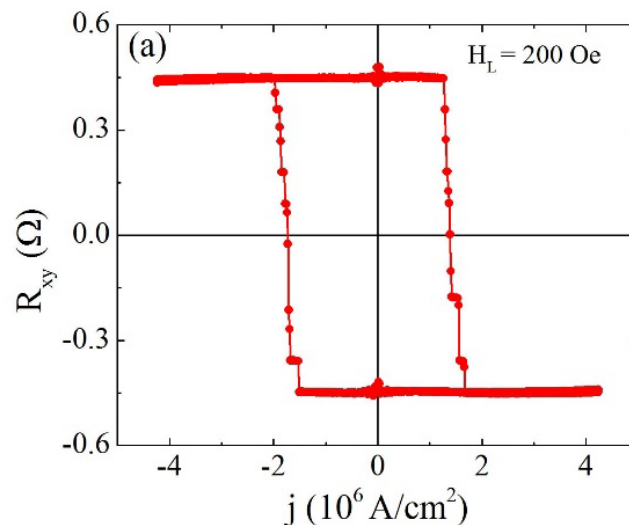
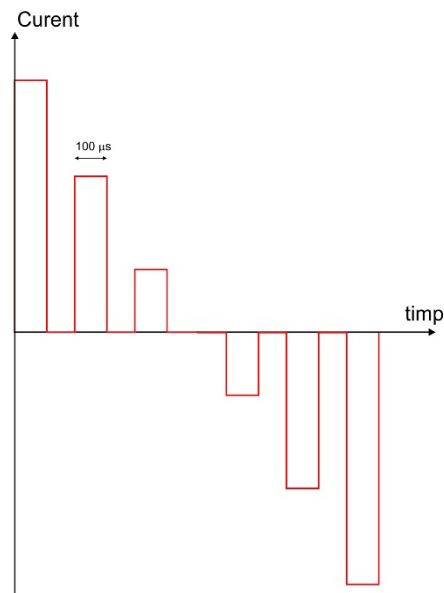
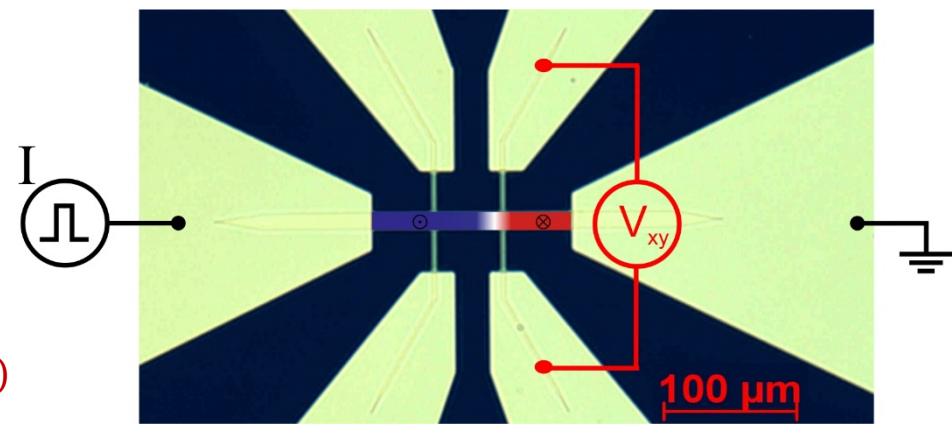
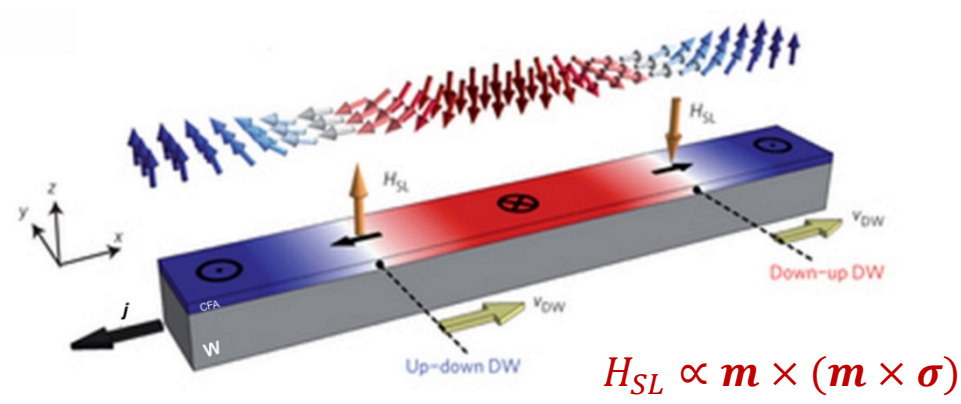
Junyeon Kim et al. Nat Mater **12** (3), 240 (2013).



Cele mai mari valori raportate până acum in literatură

Ex: H_{EFF} aprox. 100 de ori mai mare decât câmpul Oe produs de aceeași densitate de curent

Comutarea magnetizării – deplasarea pereților de domeniu



$$j_c \cong 2 \times 10^6 \text{ A/cm}^2$$

Valoarea acceptabilă
pentru aplicații
 $\leq 10^7 \text{ A/cm}^2$

1. Aliajul Heusler $\text{Co}_2\text{FeAl}_x\text{Si}_{1-x}$ candidat ideal pentru realizare de memorii „race-track”.
 2. Structurile de tip W/CFA(S)/MgO permit comutarea magnetizării la densități de curent de ordinul $1\text{MA}/\text{cm}^2$.
-
1. Determinarea vitezei de deplasarea a domeniilor magnetice.
 2. Realizarea de structuri de tip „race-track”.

Publicații în reviste cotate ISI:

- 1) *Correlations between structural, electronic transport, and magnetic properties of $\text{Co}_2\text{FeAl}_{0.5}\text{Si}_{0.5}$ Heusler alloy epitaxial thin films*, **MS Gabor**, M Belmeguenai, T Petrisor Jr, C Ulhaq-Bouillet, S Colis, C Tiusan, **Phys. Rev. B**, 054433, (2015) (**FI = 3.73**).
- 2) *Temperature dependence of the perpendicular magnetic anisotropy in Ta/Co₂FeAl/MgO structures probed by Anomalous Hall Effect*, **MS Gabor**, T Petrisor, O Pop, S Colis, C Tiusan, **Journal of Magnetism and Magnetic Materials**, 392, (2015)(**FI = 2.00**).
- 3) *Effective 90-degree magnetization rotation in Co_2FeAl thin film/piezoelectric system probed by microstripline ferromagnetic resonance* M Gueye, F Zighem, M Belmeguenai, **MS Gabor**, C Tiusan, D Faurie **Applied Physics Letters** 107 (3), 032908, (2015), (**FI=3.57**).
- 4) *Experimental study of spin-wave dispersion in Py/Pt film structures in the presence of an interface Dzyaloshinskii-Moriya interaction* AA Stashkevich, M Belmeguenai, Y Roussigné, SM Cherif, M Kostylev, **M Gabor**, D Lacour, C Tiusan, M Hehn, **Physical Review B** 91 (21), 214409, (2015) (**FI = 3.73**).
- 5) *Capping layer-tailored interface magnetic anisotropy in ultrathin Co_2FeAl films* M Belmeguenai, **MS Gabor**, T Petrisor Jr, F Zighem, SM Chérif, C Tiusan **Journal of Applied Physics** 117 (2), 023906 (2015) (**FI = 2.71**).

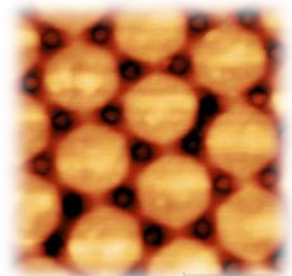
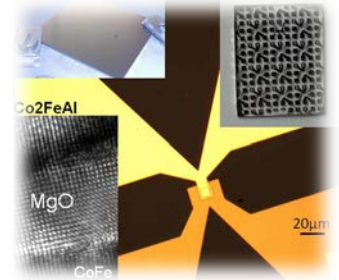
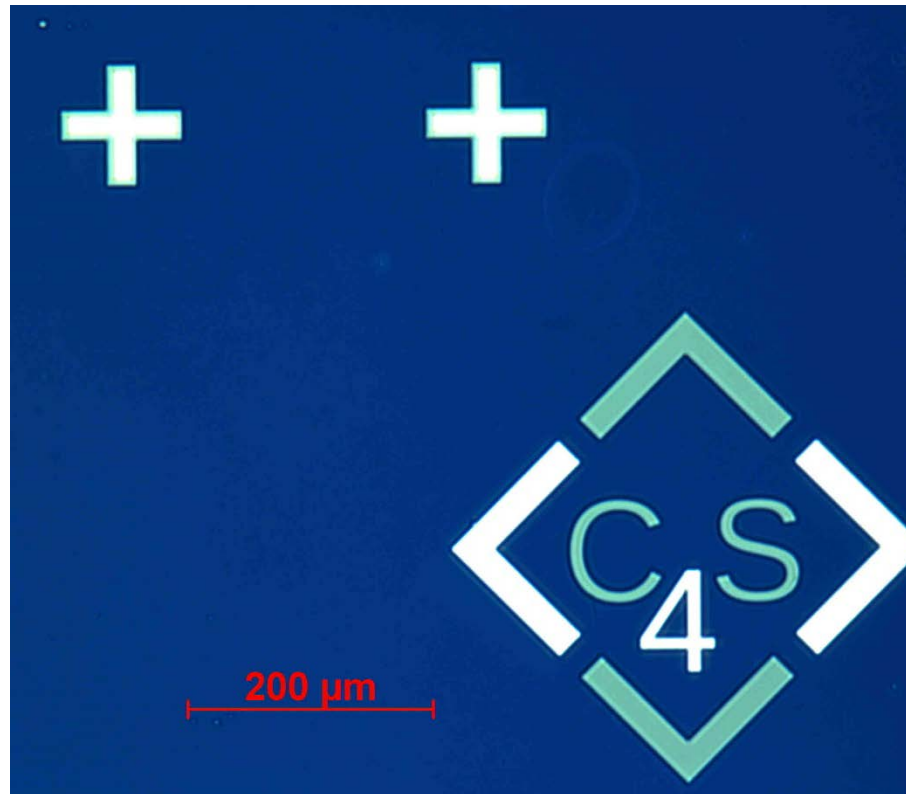
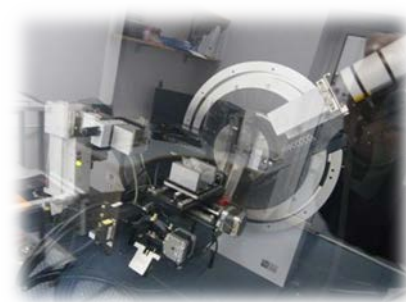
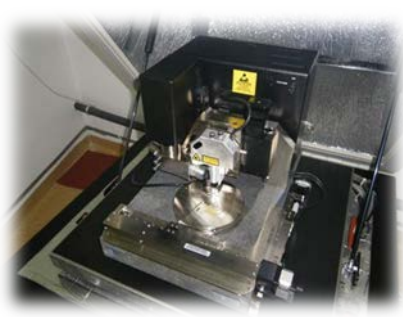
Prezentări orale la conferințe internaționale:

- 1) *Magnetization manipulation by spin orbitronic effects in permalloy/heavy metal doped copper bilayers*, **M.S. Gabor** , T. Petrisor jr., C. Tiusan, M. Belmeguenai, F. Zighem, S. Colis, D. Lacour, M. Hehn, 20th International Conference on Magnetism, 5-10 July, Barcelona, Spain

Proiect național de cercetare finanțat:

- **PN-II-RU-TE-2014-4-1820, Dispozitive spintronice avansate cu aplicații în tehnologia comunicațiilor și stocării informației pe bază de compuși Heusler.**

Muțumiri !



**T. Petrisor Jr, C. Tiusan, T. Petrisor
A. Mesaros, R. Mos, M. Nasui, L. Ciontea**

