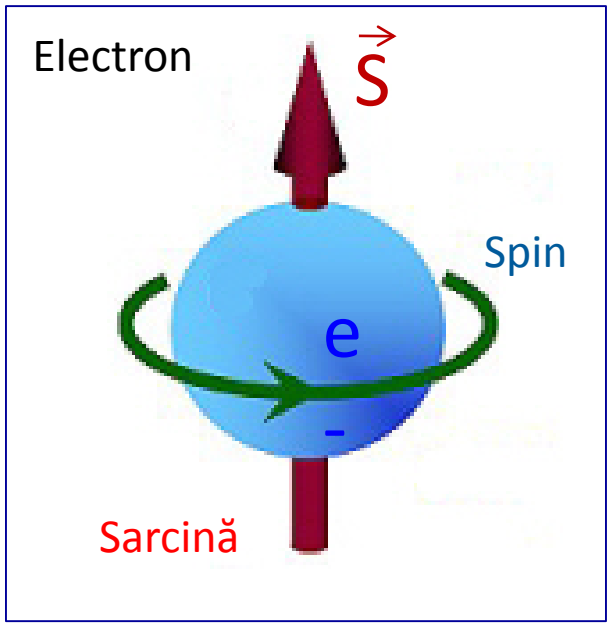
TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

Centrul de Supraconductibilitate Spintronica si Stiinta Suprafetelor

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

Dr. Mihai GABOR

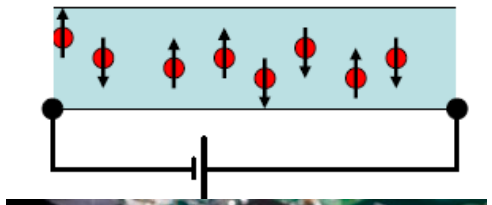
Spintronica

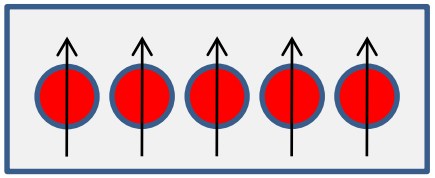


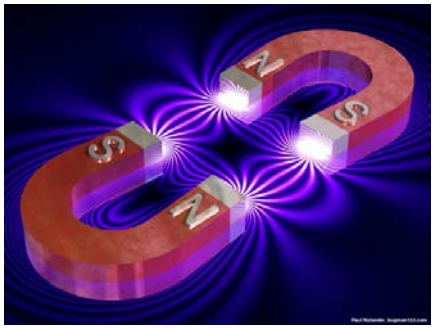
Electron = sarcină + spin

electronică

magnetism

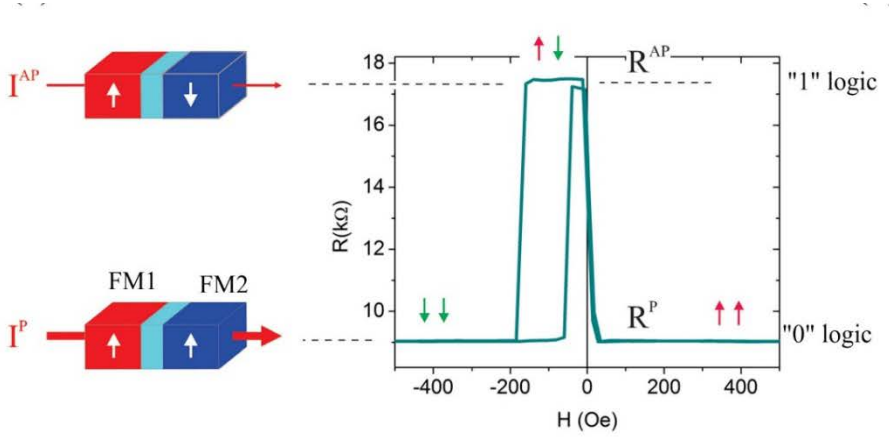


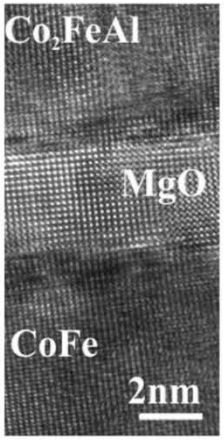


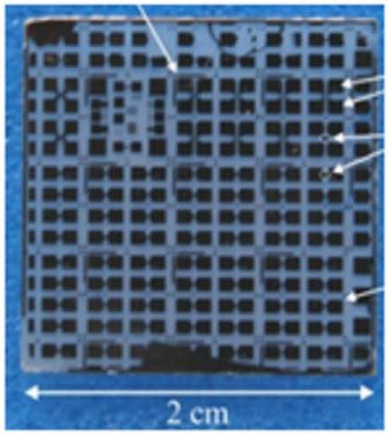


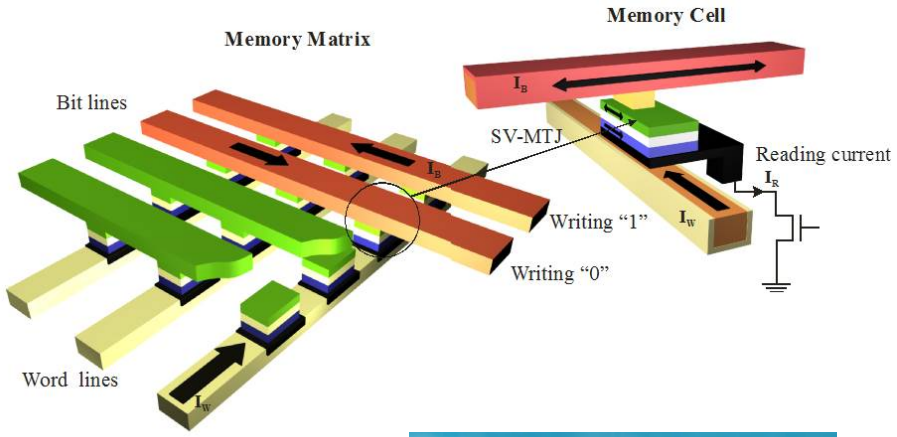
Scopul spin-electronicii este de a combina electronica și magnetismul pentru dezvoltarea de dispozitive în care atât sarcina cât și spinul să joace un rol activ.

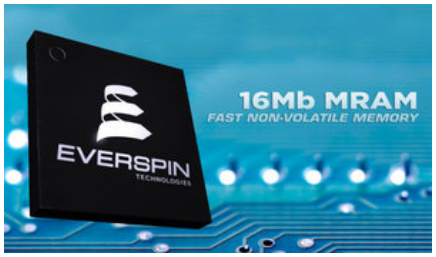
Joncțiunea magnetică tunel (JTM) – aplicații

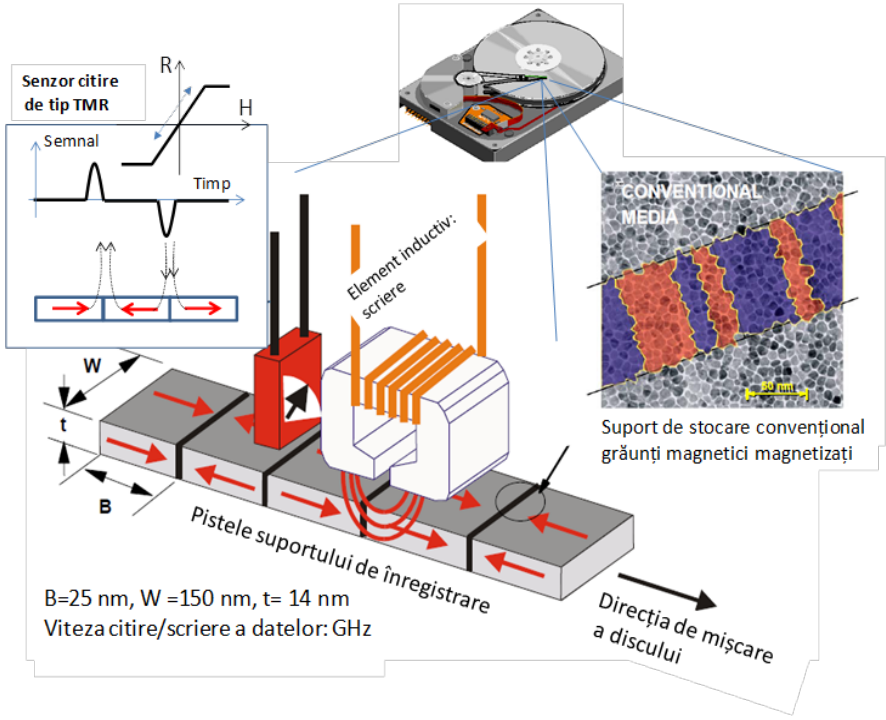








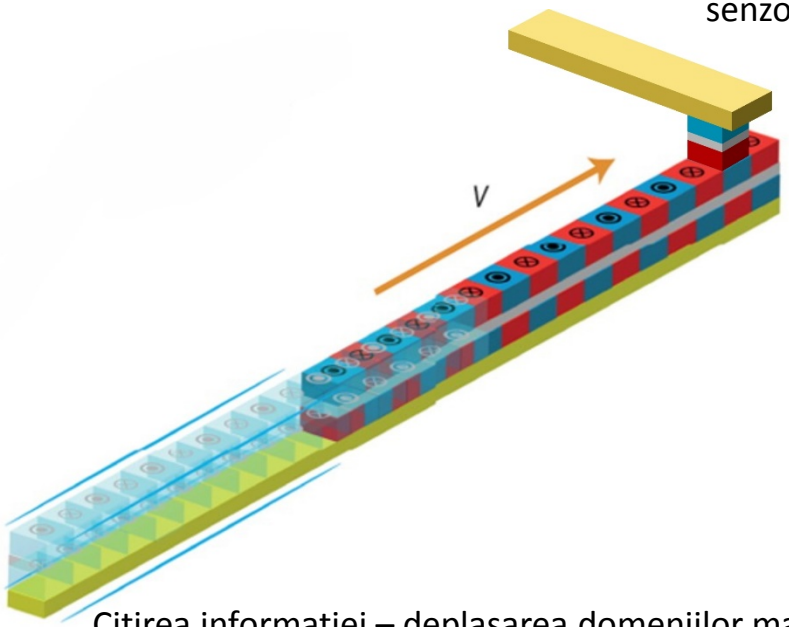




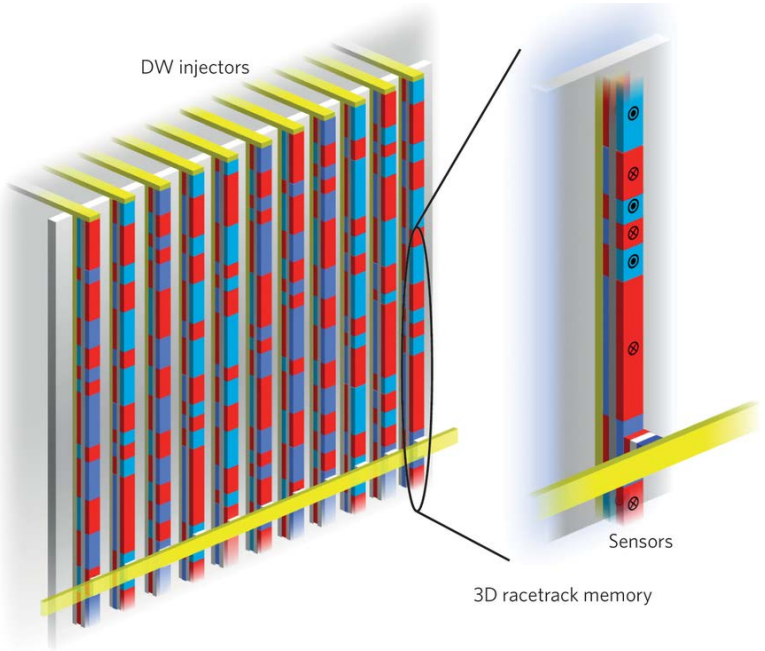
S.Tehrani et al. PROCEEDINGS OF THE IEEE, VOL. 91, NO. 5 2014

Dispozitive spintronice de generație viitoare

Memoria magnetică de tip „race-track”



Citirea informației – deplasarea domeniilor magnetice



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

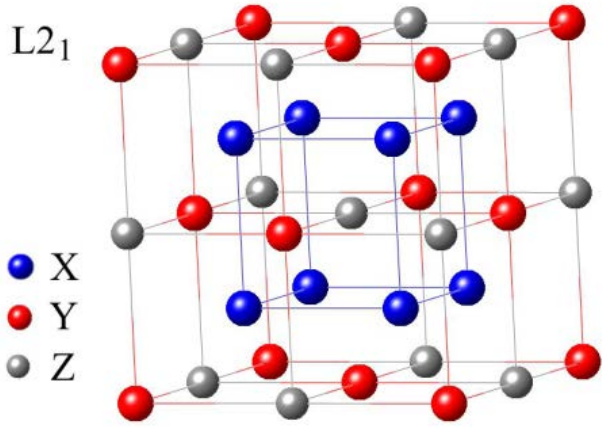
Materiale feromagnetice

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

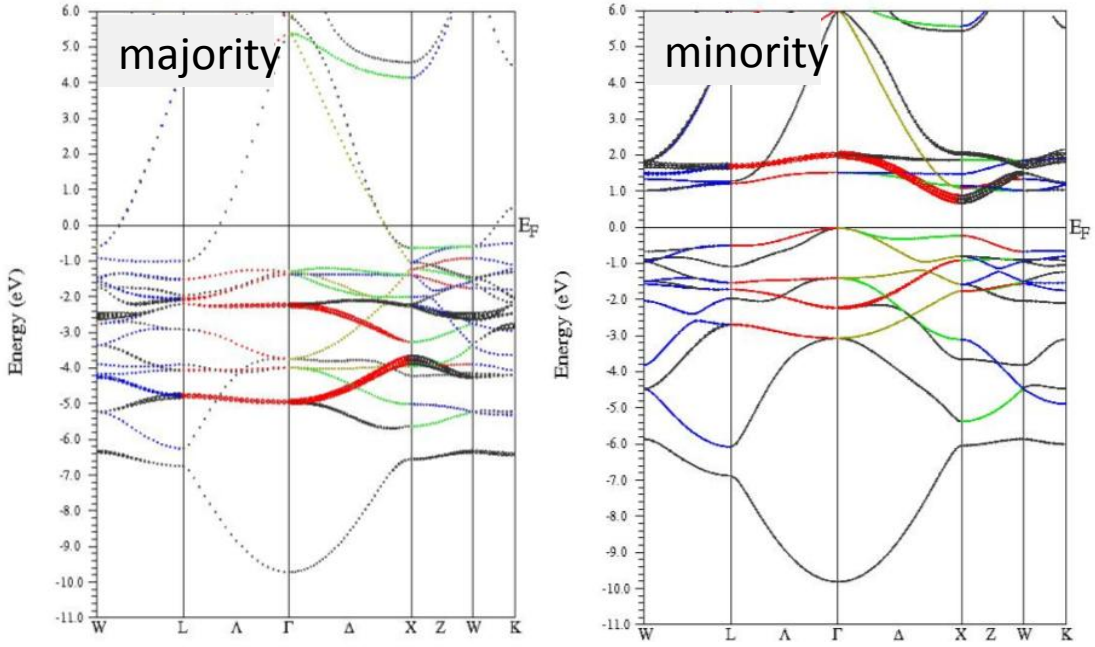
Control local al orientării magnetizării

Aliajul Heusler semimetalic $Co_2FeAl_xSi_{1-x}$ (CFAS)

- **Aliajul full Heusler $Co_2FeAl_xSi_{1-x}$ (CFAS)**
  - structură $L2_1$ aparținând grupului spațial (Fm-3m)
  - temperatură Curie ridicată > 700 K
  - caracter feromagnetic localizat ($4.96\mu_B$/f.u.)



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

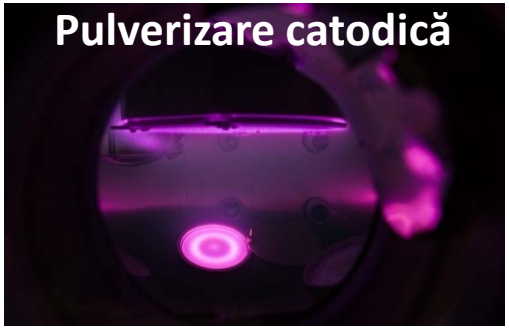


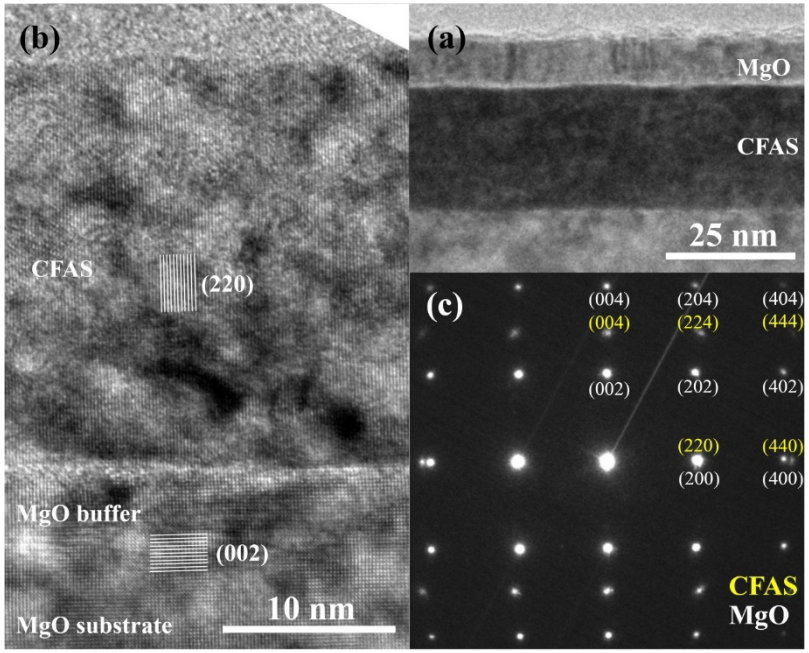
Teoretic CFAS prezintă:
- **polarizare de spin 100%**
- **amortizarea Gilbert redusă**

Practic ???

Rezultate – filme de CFAS epitaxiale

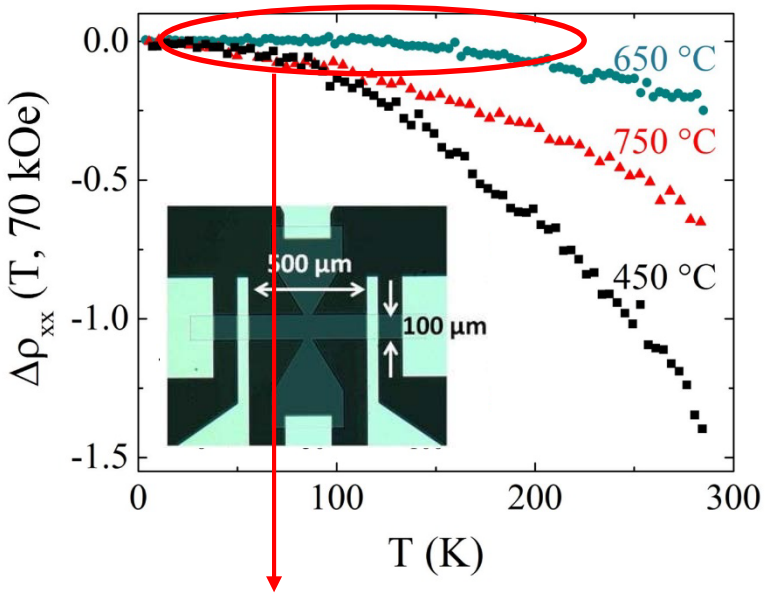
- MgO(001)//$Co_2FeAl_{0.5}Si_{0.5}$ (25 nm)/ MgO(5 nm)





Creștere epitaxială confirmată de MET.

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

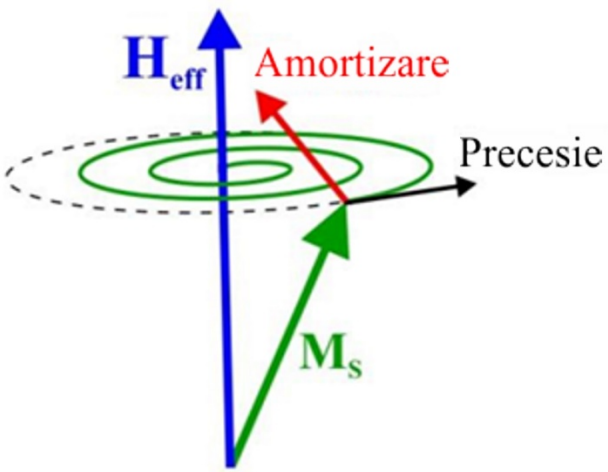


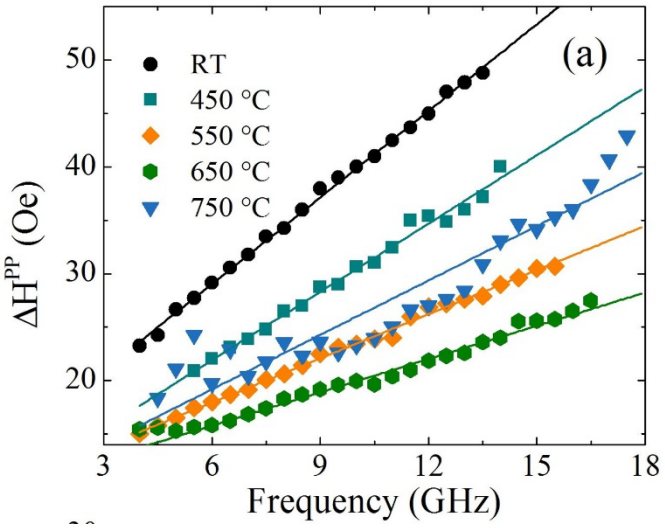
- **Caracter semimetalic**

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

Rezultate – filme de CFAS epitaxiale

Proprietăți magnetice la frecvențe înalte





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

Precesie — **Amortizare**

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

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

- CFAS films:

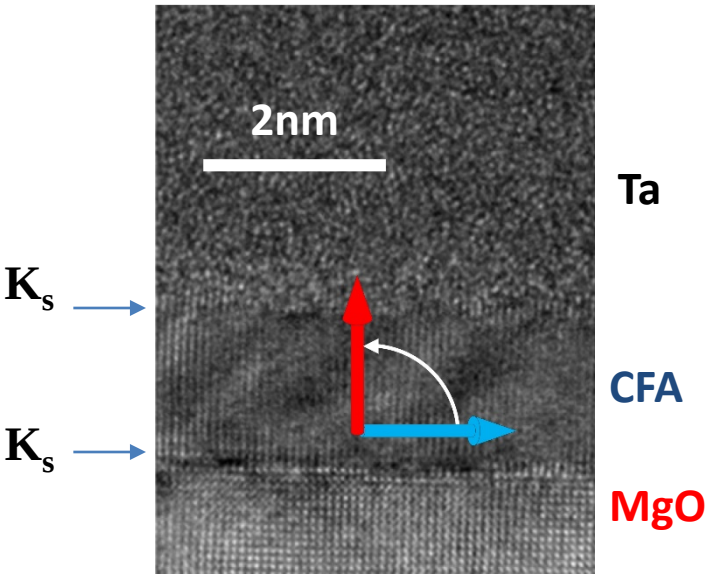
  $\alpha = 1.9 \times 10^{-3}$ (pt. Permalloy : $\alpha \approx 10^{-2}$).

- **Amortizare Gilbert redusă**

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

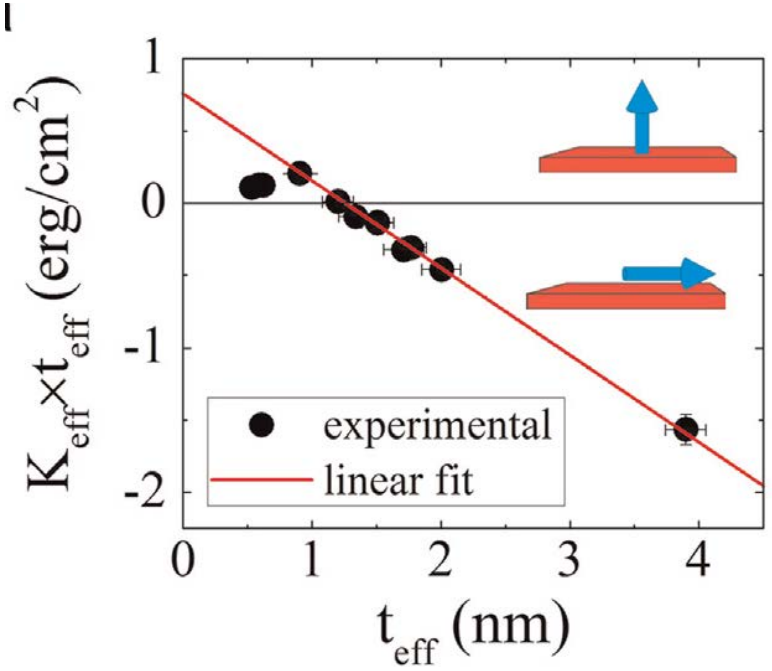
Rezultate – filme de CFA cu anizotropie magnetică perpendiculară

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.

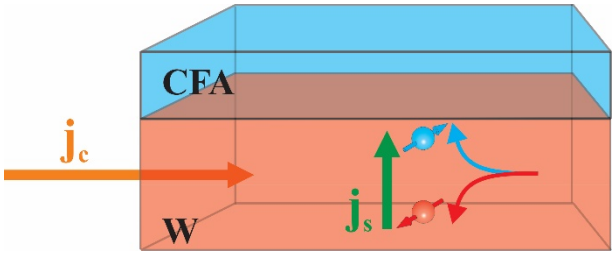
- **Anizotropie magnetică perpendiculară**

CFAS candidat ideal pentru memorii „race-track”

MS Gabor, et al. JMMM, 79, 392, (2015)
M Belmeguenai, et al.JAP 117 (2), 023906 (2015)

Controlul local al magnetizării prin intermediul curenților de spin

Efectul Hall de spin



$$\mathbf{J}_s^{SH} = \alpha_{SH}\left(-\frac{\hbar}{2e}\right) J_c\,[\hat{\mathbf{z}} \times \hat{\mathbf{s}}]$$

E. Hirsch Phys. Rev. Lett. 83, 1834 (1999)

Dinamica magnetizării

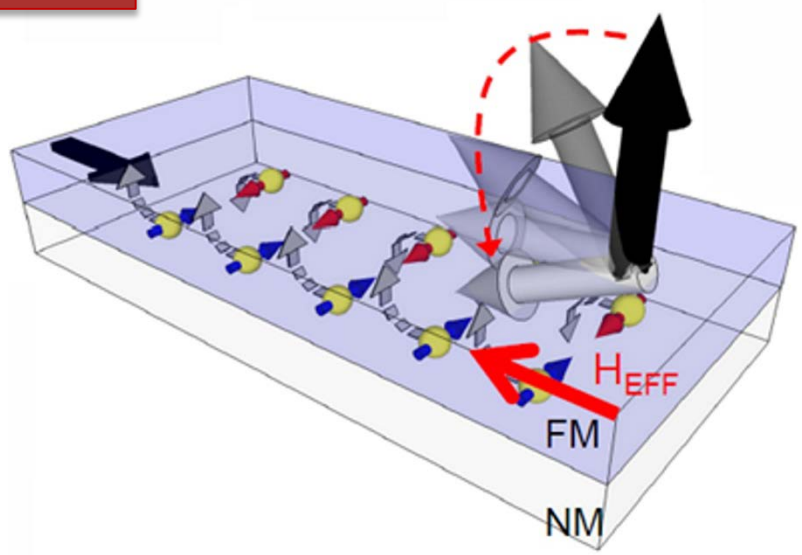
$$\frac{\partial \boldsymbol{m}}{\partial t} = -\gamma \boldsymbol{m} \times \boldsymbol{H}_{eff} + \alpha \boldsymbol{m} \times \frac{\partial \boldsymbol{m}}{\partial t} - b\boldsymbol{m} \times (\boldsymbol{m} \times \boldsymbol{\sigma}) - a(\boldsymbol{m} \times \boldsymbol{\sigma})$$

H_{EFF} long

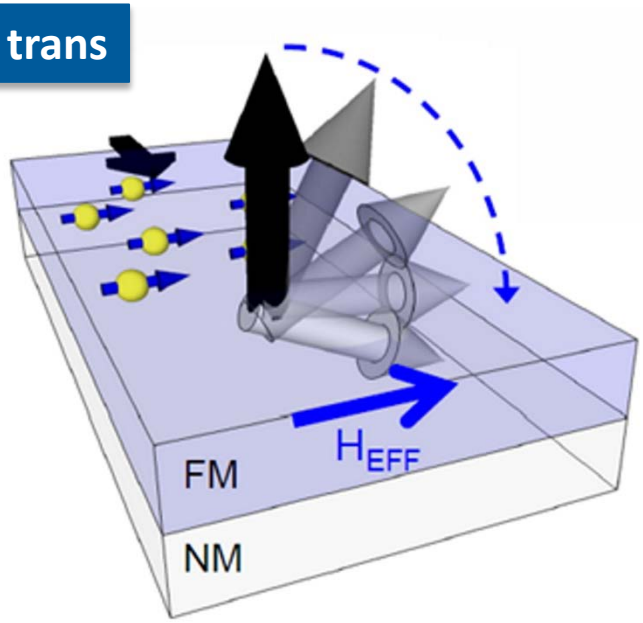
H_{EFF} trans

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

H_{EFF} long



H_{EFF} trans



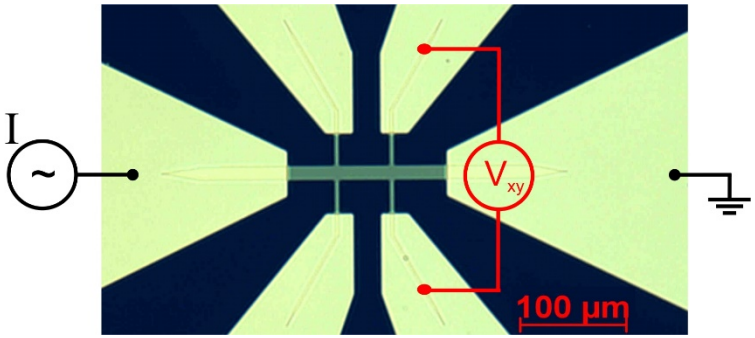
Caracterizarea câmpurilor magnetice efective în W/CFA/MgO

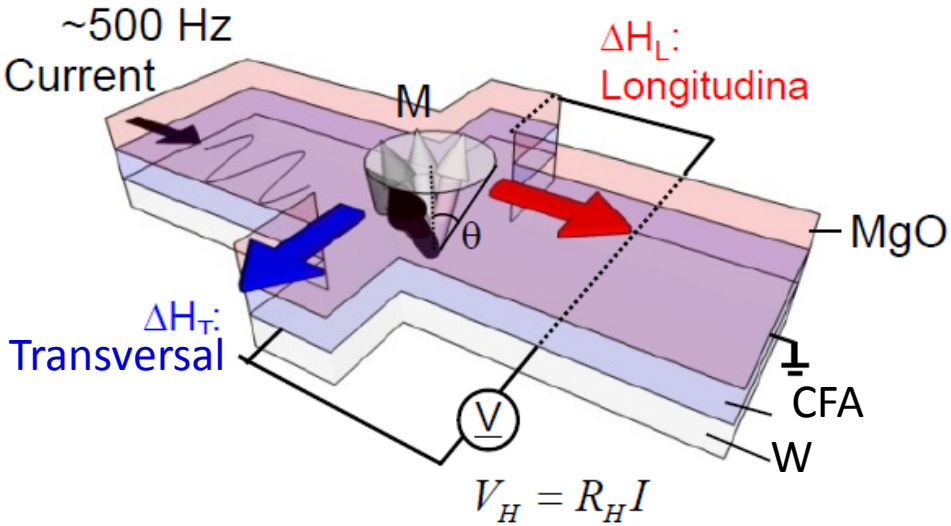
Si//**W(5.5 nm)/CFA(0.8 nm)/MgO(1.0 nm)**/Ta(2.0 nm)

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

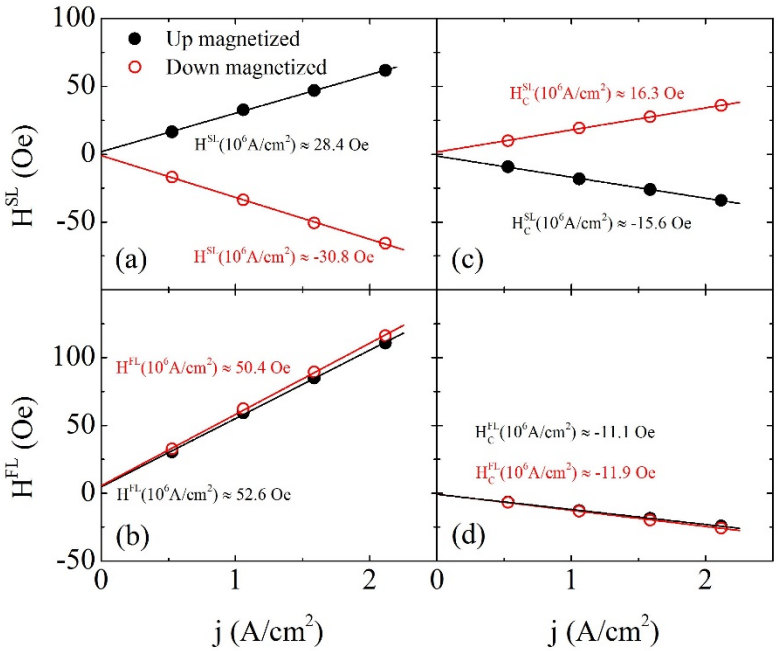
Junyeon Kim et al. Nat Mater **12** (3), 240 (2013).

Dispozitivul experimental





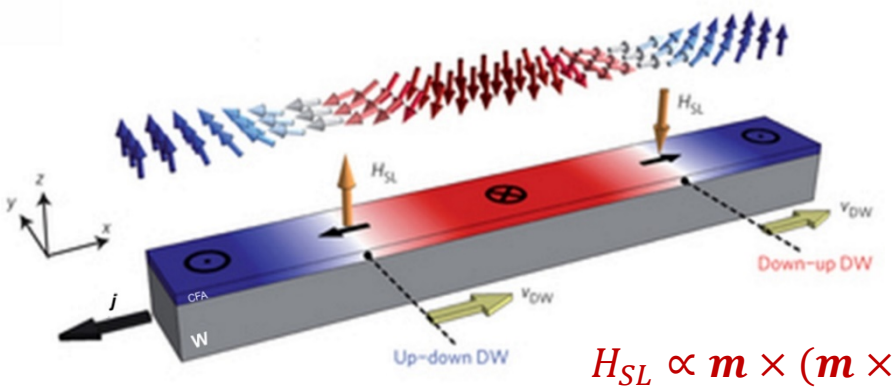
$$V_H = R_H I$$



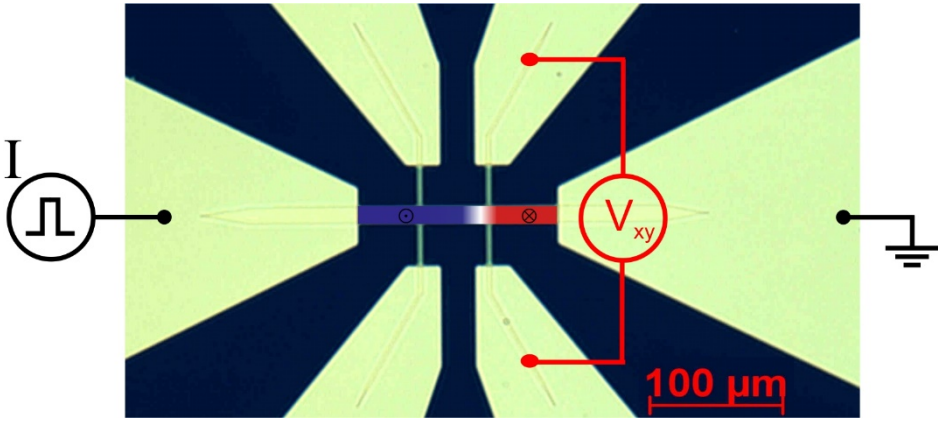
Cele mai mari valori raportate până acum in literatură

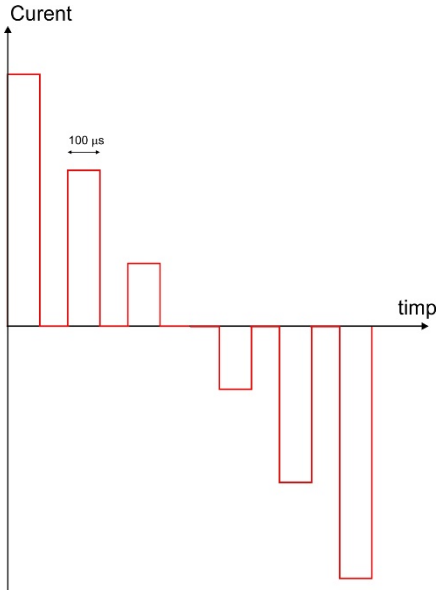
Ex: H_{EFF} aprox. 100 de ori mai mare decât câmpul Oe produs de aceeași densitate de curent

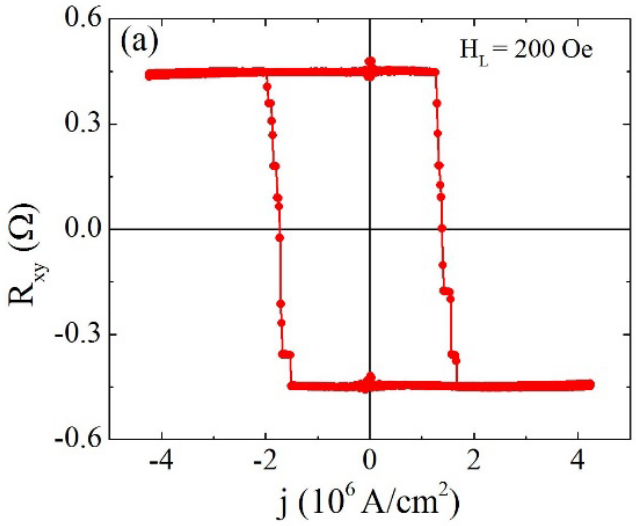
Comutarea magnetizării – deplasarea pereților de domeniu



$$H_{SL} \propto \boldsymbol{m} \times (\boldsymbol{m} \times \boldsymbol{\sigma})$$







$$j_c \cong 2 \times 10^6 \, A/cm^2$$

Valoarea acceptabilă pentru aplicații <= 10^7 A/cm²

M.S. Gabor et al., trimis APL

Concluzii și perspective

1. Aliajul Heusler $Co_2FeAl_xSi_{1-x}$ 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 $1MA/cm^2$.

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 Co_2 FeAl $_{0.5}Si_{0.5}$ 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/Co 2 FeAl/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 Co2FeAl 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**).

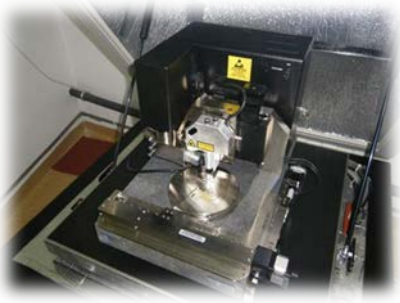
5) *Capping layer-tailored interface magnetic anisotropy in ultrathin Co2FeAl films M Belmeguenai****, MS Gabor,*** *T Petrisor Jr, F Zighem, SM Chérif, C Tiusan* ***Journal of Applied Physics*** *117 (2), 023906 (2015)* (**FI = 2.71**).

Prezentări orale la conferințe internaționale:

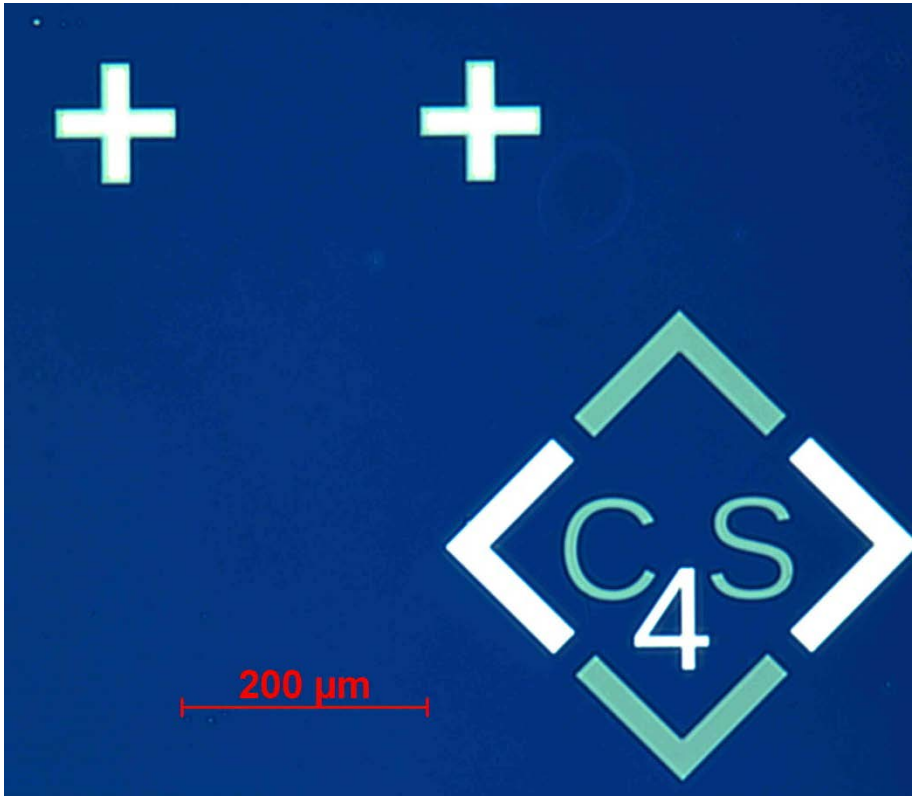
1) *Magnetization manipulation by spin oribitronic effects in permalloy/heavy metal doped copper bilayers,* ***M.S. Gabor*** *, T. Petrisor jr., C. Tiusan, M. Belmeguenai, F. Zighem, S. Colis, D. Lacour, M. Hehn,* 20th International Conference on Magnetism, 5-10 July, Barcelona, Spain

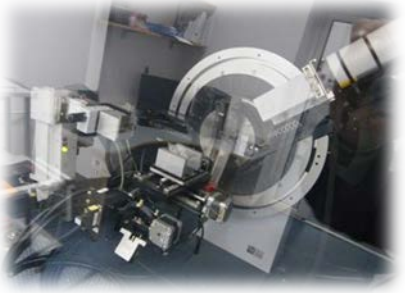
Proiect național de cercetare finanțat:

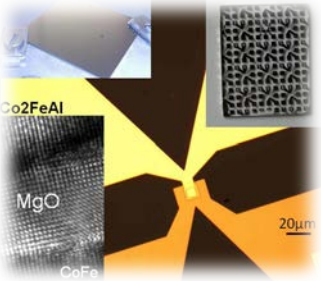
- ***PN-II-RU-TE-2014-4-1820, Dispozitive spintronice avansate cu aplicații în tehnologia comunicaților și stocării informației pe bază de compuși Heusler.***

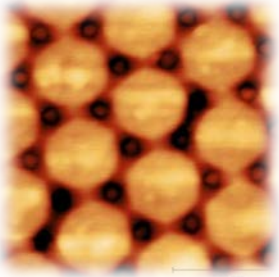


Mulțumiri !









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