



# **Co<sub>2</sub> Mn-based Heusler compounds for spintronics: Chemical order and interplay between the magnetic damping and the underlying electronic structure**

C. Guillemard, A. M. Bataille, S. Petit-Watelot, J.-C. Rojas-Sánchez, F. Bertran, S.  
Andrieu

## **► To cite this version:**

C. Guillemard, A. M. Bataille, S. Petit-Watelot, J.-C. Rojas-Sánchez, F. Bertran, et al.. Co<sub>2</sub> Mn-based Heusler compounds for spintronics: Chemical order and interplay between the magnetic damping and the underlying electronic structure. Colloque Louis Néel XIX, May 2019, Toulouse, France. <hal-04066240>

**HAL Id: hal-04066240**

**<https://hal.science/hal-04066240v1>**

Submitted on 12 Apr 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

# $\text{Co}_2\text{Mn}$ - based Heusler compounds for spintronics

Chemical order and interplay between the magnetic  
damping and the underlying electronic structure



Colloque Louis Néel XIX



C. Guillemard, S. Petit-watelot, F. Bertran, A. M. Bataille,  
J.-C. Rojas-Sanchez, S. Andrieu

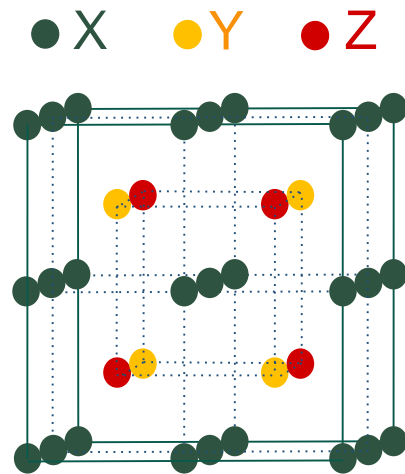
# Outline

1. Heusler compounds & spintronics
2. Crystal growth and structure
3. Testing the Half Metal Magnet behavior by SR-PES
4. Ultra-low damping materials

# Heusler compounds

## Half-Metal Magnets (HMM)

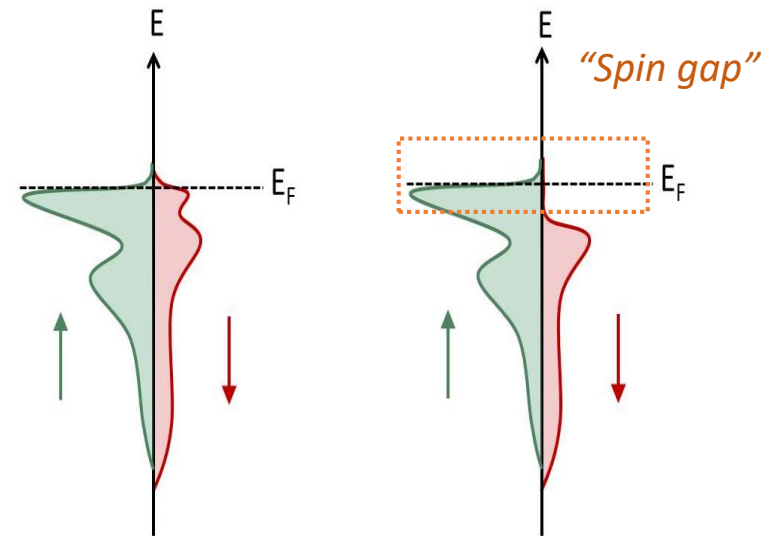
F. Heusler, *DPG* 5, p 219 (1903).



$Cu_2MnSn$ ,  $W_2PdSb$ ,  
 $Zr_2TiGe$  ...

Some of them are  
predicted HMM

R. A. De Groot *et al.*, *PRL* 50, 2024 (1983).



Standard FM

Half Metal  
Magnet

$$\frac{D_{\uparrow}(E_F) - D_{\downarrow}(E_F)}{D_{\uparrow}(E_F) + D_{\downarrow}(E_F)} = 1$$

# Half Metal Magnet

## Interest for spintronics

- Magneto-resistive devices :

Ex: Spin valves, MTJ, STT-MRAM...

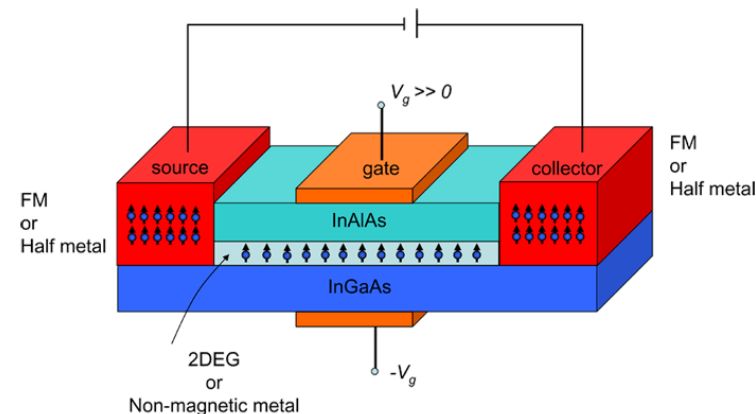
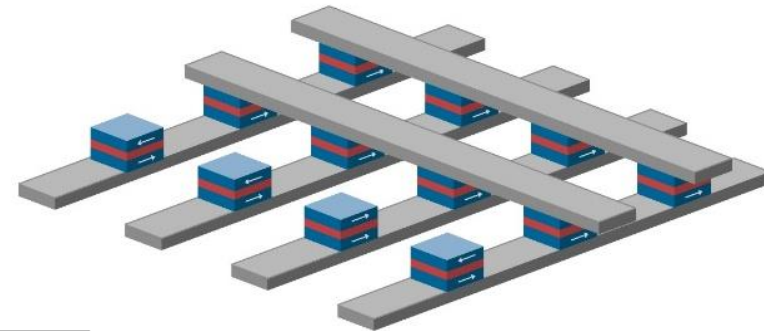
- Nano-oscillators

- Spin injection:

ISHE, Spin transistor

- Magnonics:

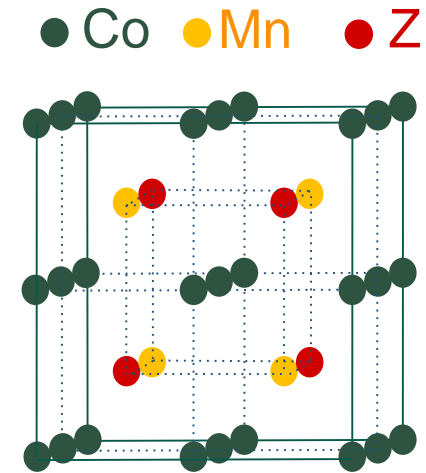
Logic gates & processing



# Motivations

## Why Co<sub>2</sub>Mn- based Heusler compounds?

- High Curie temperature
- Convenient lattice parameters
- Predicted HMM (*ab initio* calc.)
- Ultra low damping
- Spin gap confirmed in Co<sub>2</sub>MnSi S. Andrieu *et al.*, Phys. Rev. B **93**, 094417 (2016)



$$5,6 < a_{\text{Co}_2\text{MnZ}} < 6 \text{ \AA}$$

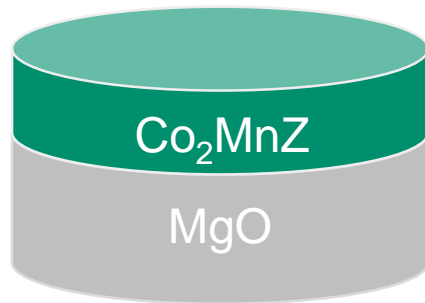
$$T_{\text{C}} > 800 \text{ K}$$

# Outline

1. Heusler alloys & spintronics
2. Crystal growth and structure
3. Testing the Half Metal Magnet behavior by SR-PES
4. Ultra-low damping materials

# Elaboration

## Molecular Beam Epitaxy features

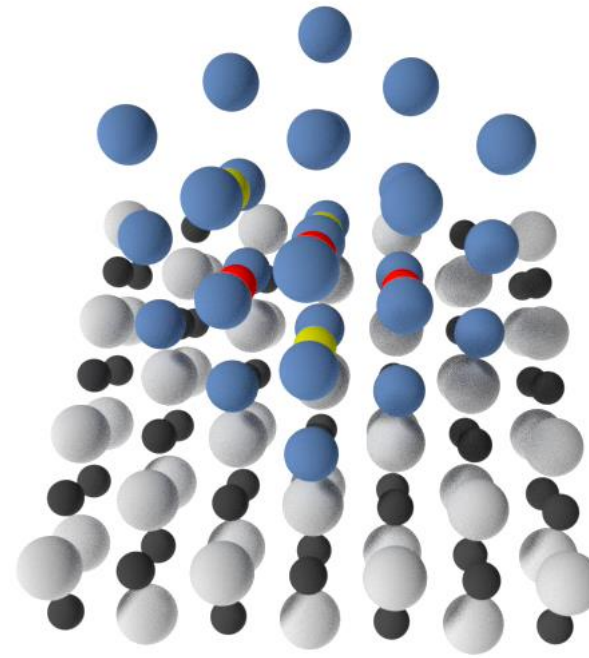


Co-evap of each element

Co: e-gun

Mn: K-cell

X: it depends



Growth temperature:  $\approx 450^{\circ}\text{C}$

Annealing  $\approx 800^{\circ}\text{C}$

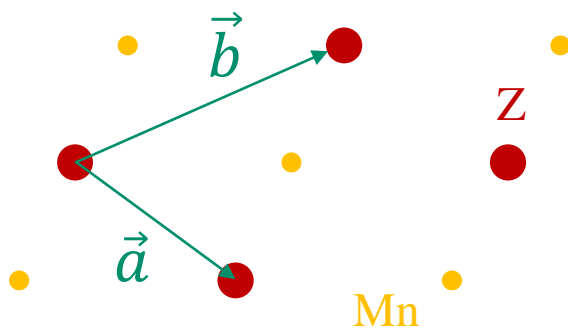
$\text{Co}_2\text{MnZ}$  [100] (001) //  $\text{MgO}$  [110] (001)



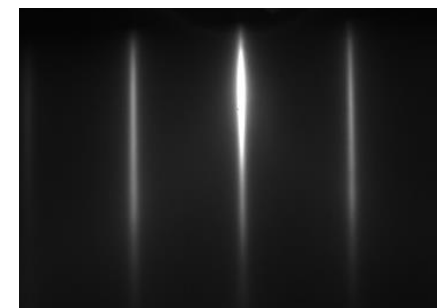
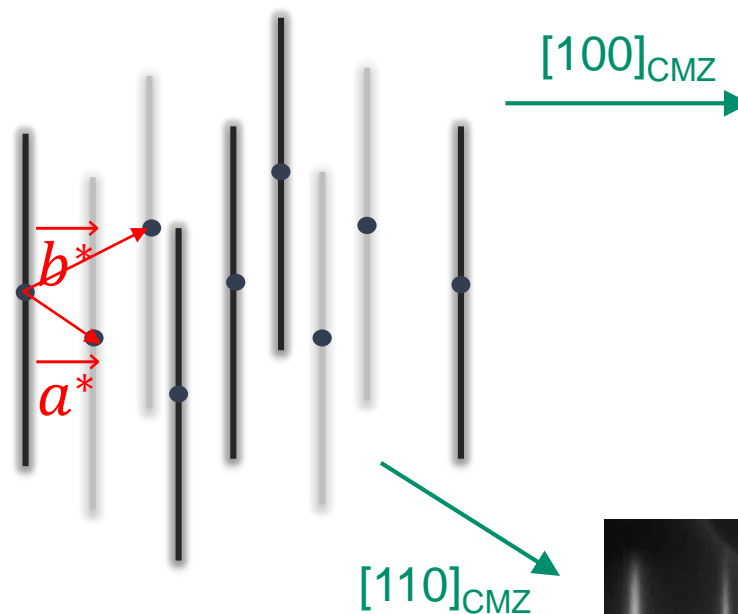
# Surface structure

## L2<sub>1</sub> RHEED patterns

2D real lattice:



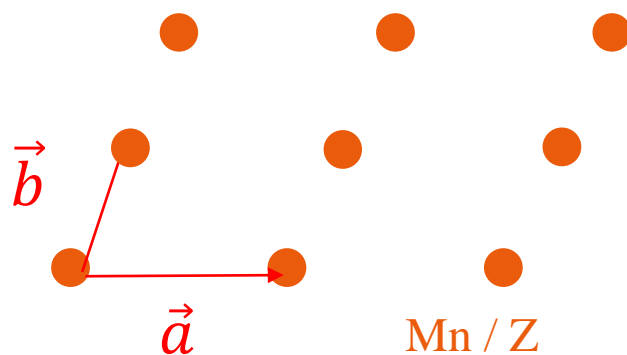
2D reciprocal lattice:



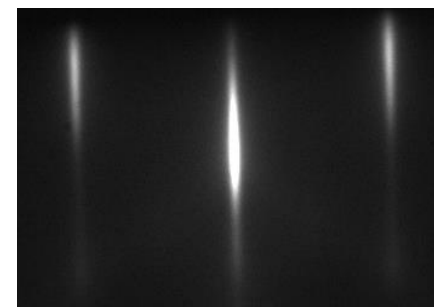
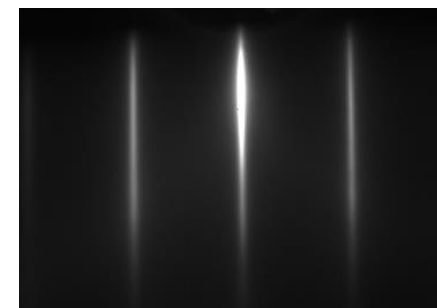
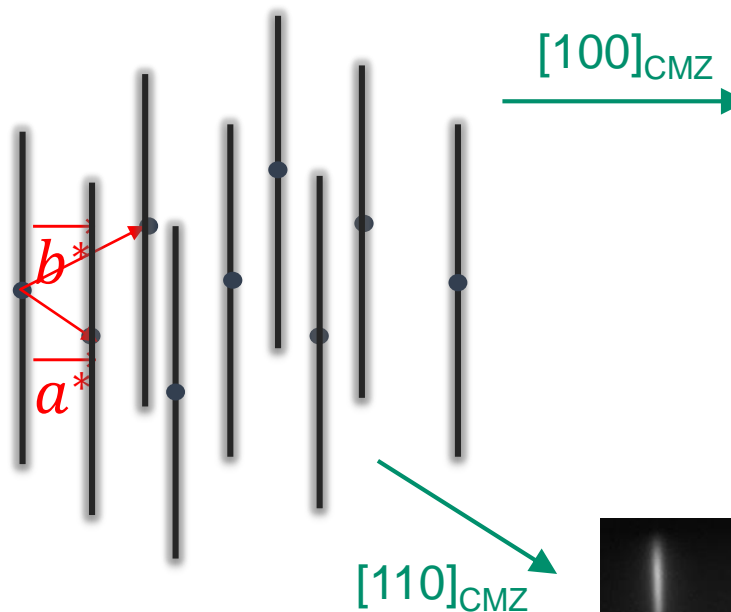
# Surface structure

## B2 RHEED patterns

2D real lattice:

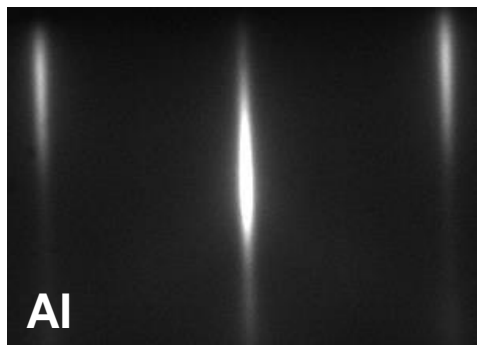


2D reciprocal lattice:

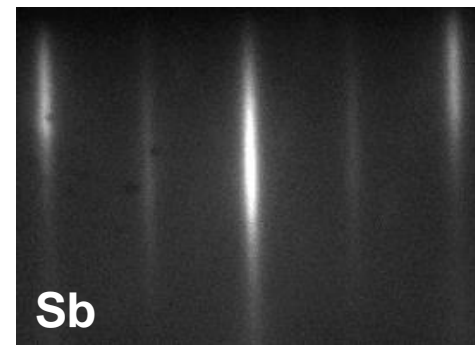
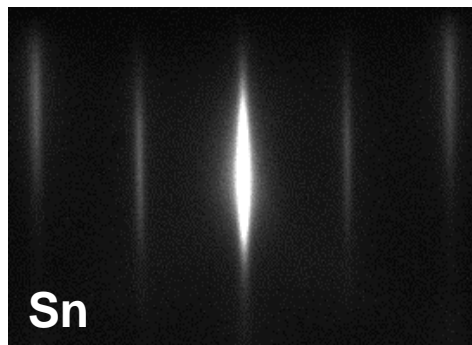
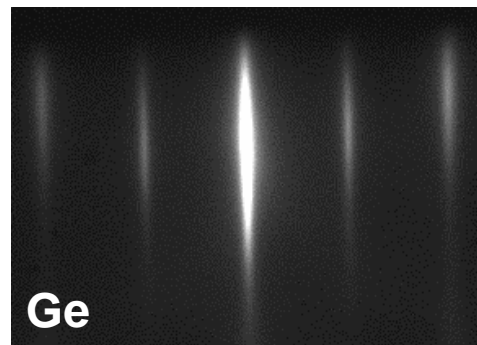
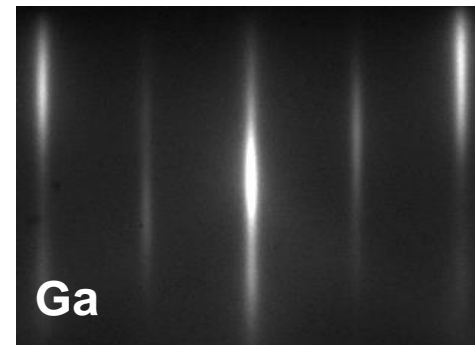
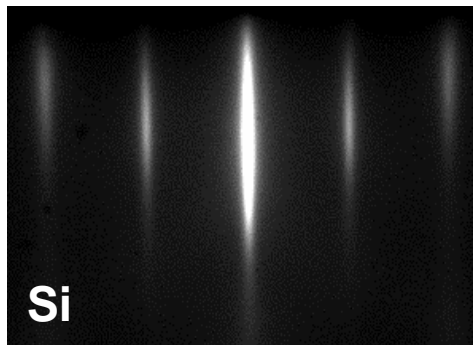


# [110] RHEED patterns

$\text{Co}_2\text{MnZ}$  with  $Z = \text{Al, Si, Ga, Ge, Sn, Sb}$

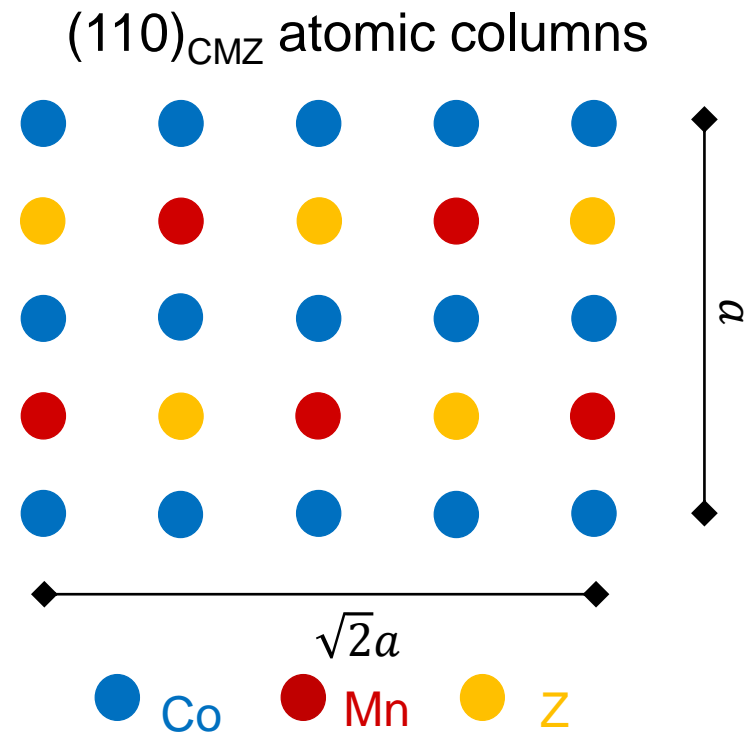
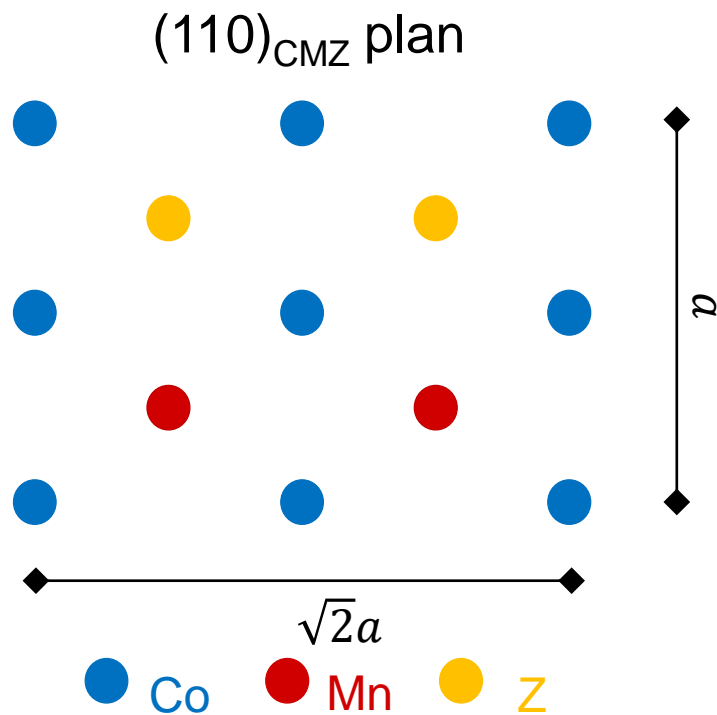


No half streaks = B2



# HR-TEM

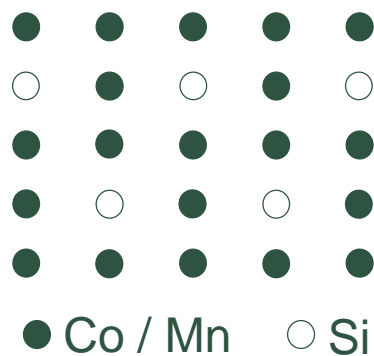
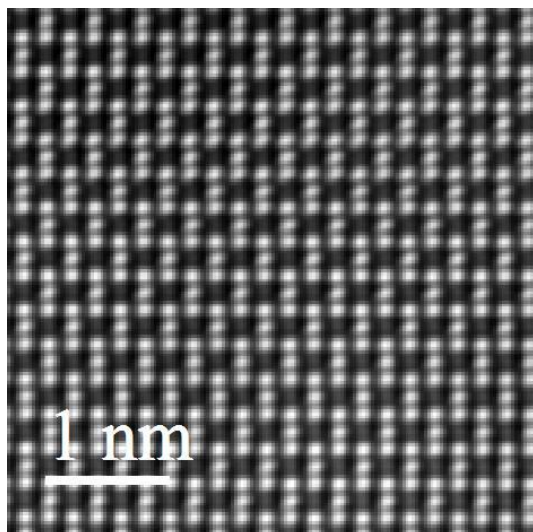
## Cross sections



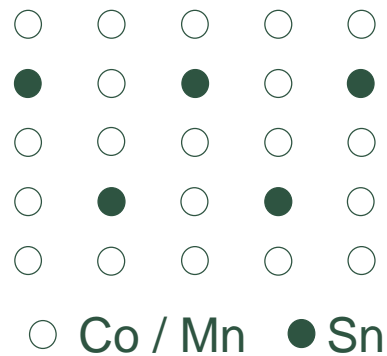
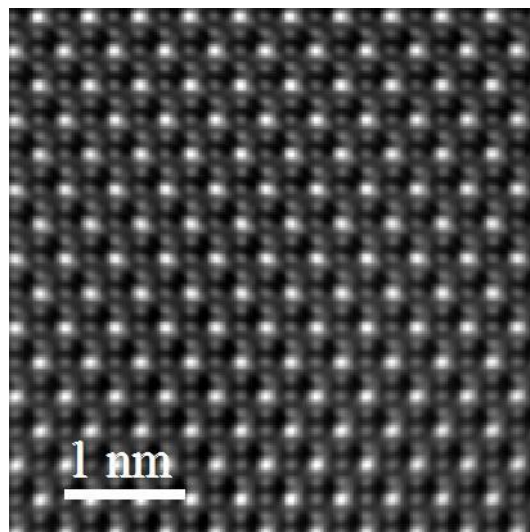
# HR-TEM

## HAADF

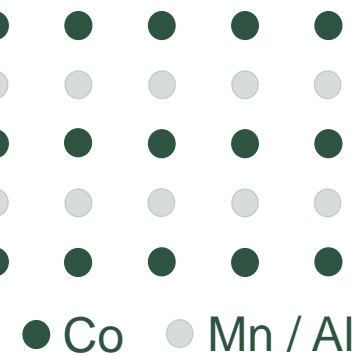
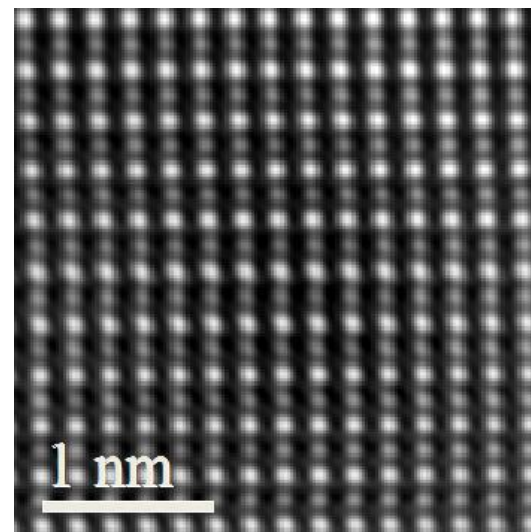
Co<sub>2</sub>MnSi



Co<sub>2</sub>MnSn



Co<sub>2</sub>MnAl



# Outline

1. Heusler alloys & spintronics
2. Crystal growth and structure
3. Testing the Half Metal Magnet behavior by SR-PES
4. Ultra-low damping materials



# Spin-Resolved PES

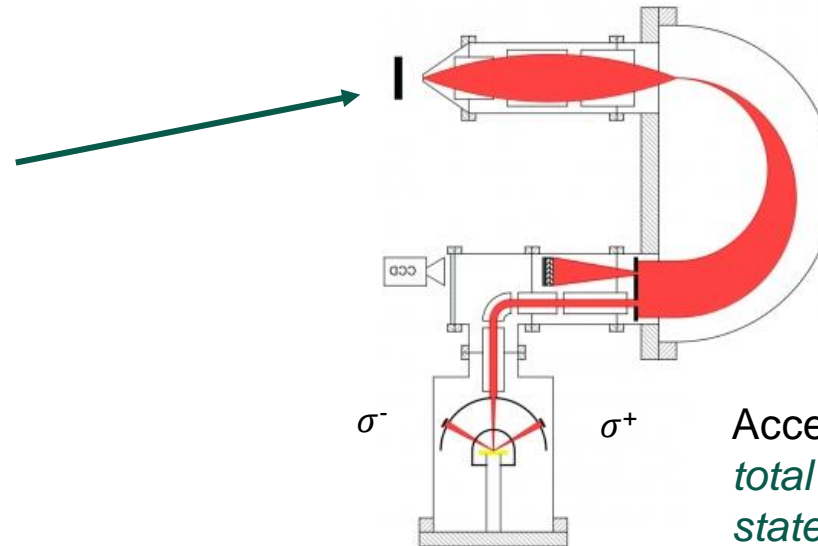
## The Cassiopée Beamline



SOLEIL : 2,75 GeV storage ring, Saint Aubin, Fr.

Mott detection SR-PES

Angular aperture of  $\pm 8^\circ$

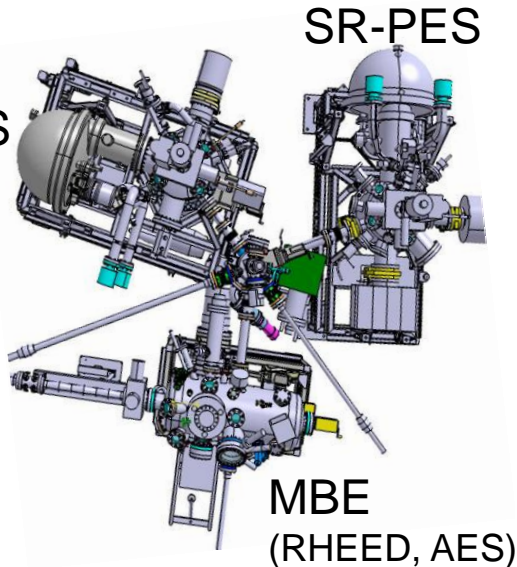


Access to the  
*total density of  
states resolved  
in spin*

AR-PES

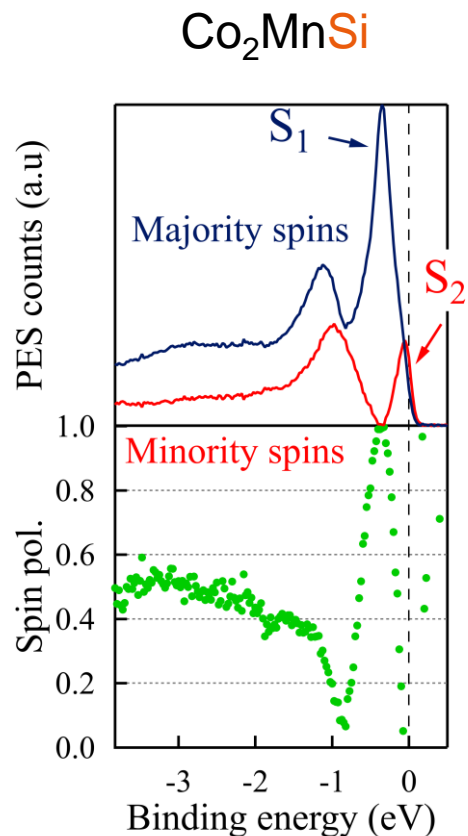
2 e-guns (5  
pockets)  
4 effusion  
cells  
=

14 materials  
in the MBE

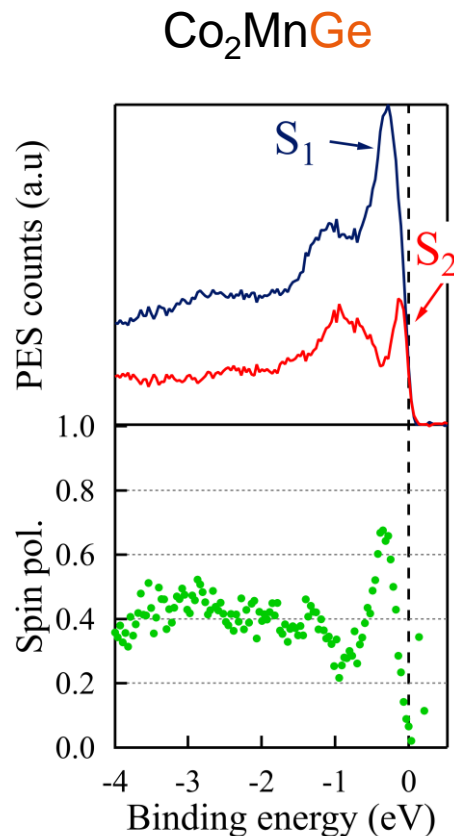


# Spin-Resolved PES

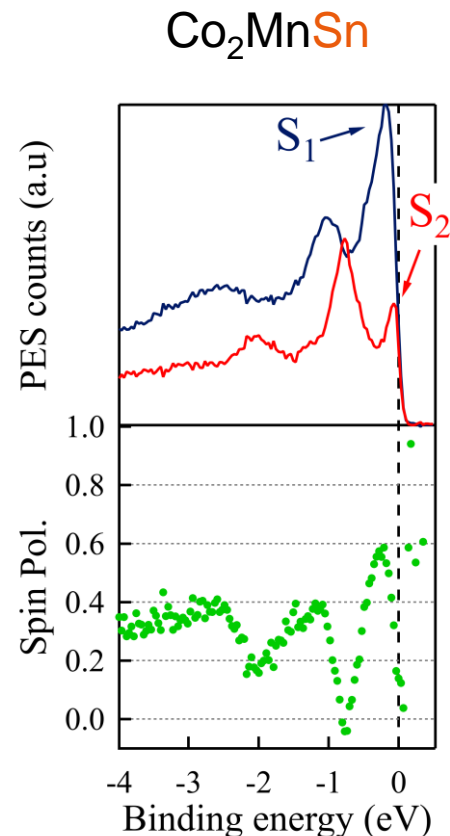
$\text{Co}_2\text{MnZ}_{\text{IV}}$  with  $\text{Z}_{\text{IV}}=\text{Si, Ge, Sn}$



$h\nu=37\text{ eV}$   
 $P$  polarization



$h\nu=30\text{ eV}$   
 $P$  polarization



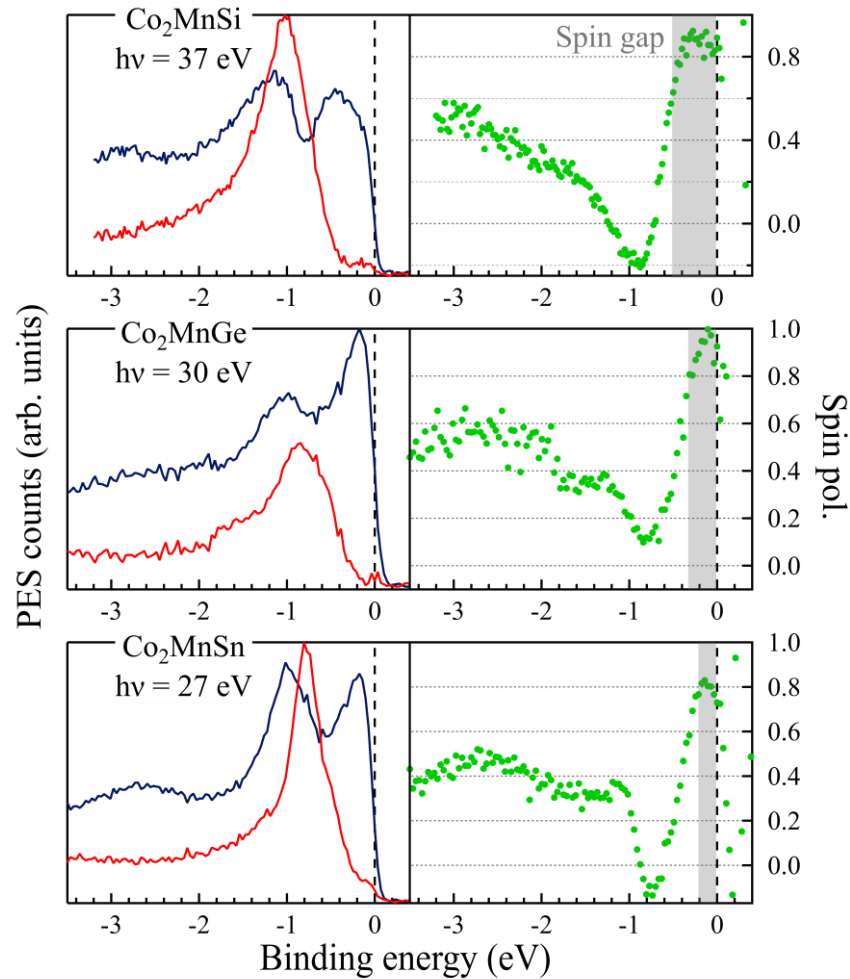
$h\nu=27\text{ eV}$   
 $P$  polarization

- Same shape
- Surface resonant state. [S. Andrieu *et al.*, Phys. Rev. B **93**, 094417 (2016)]
- Loss of polarization at  $E_F$



# Symmetry & Spin-Resolved PES

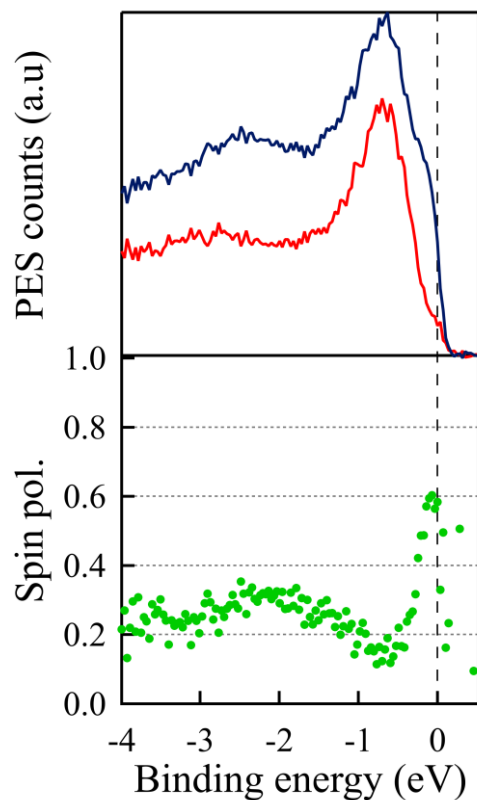
## $\text{Co}_2\text{MnZ}_{\text{IV}}$ with $\text{Z}_{\text{IV}}=\text{Si, Ge, Sn}$



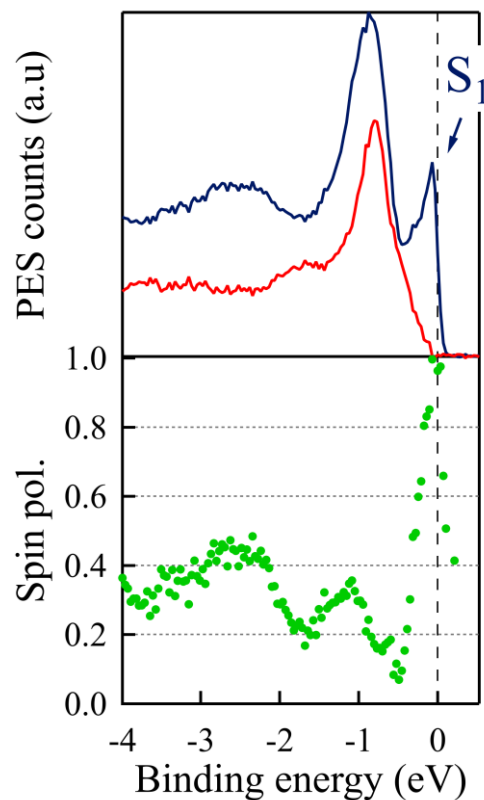
- ✓ With S polarization,  $S_1$  and  $S_2$  are no longer excited
- ✓ Max of SP at  $E_F$
- ✓ Spin gaps !

# Spin-Resolved PES

$\text{Co}_2\text{MnZ}_{\text{III}}$  with  $\text{Z}_{\text{III}}=\text{Al, Ga}$



$\text{Co}_2\text{MnAl}$   
 $h\nu=37\text{ eV}$   
 $P$  polarization

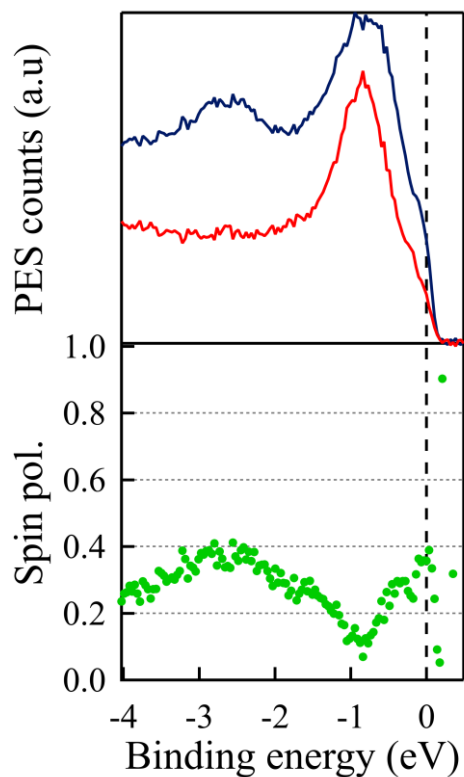


$\text{Co}_2\text{MnGa}$   
 $h\nu=37\text{ eV}$   
 $P$  polarization

- ✓ 1 less  $e^-$  = Surface states above  $E_F$
- ✓ Max of SP at  $E_F$
- ✓ Spin gap for  $\text{Co}_2\text{MnGa}$

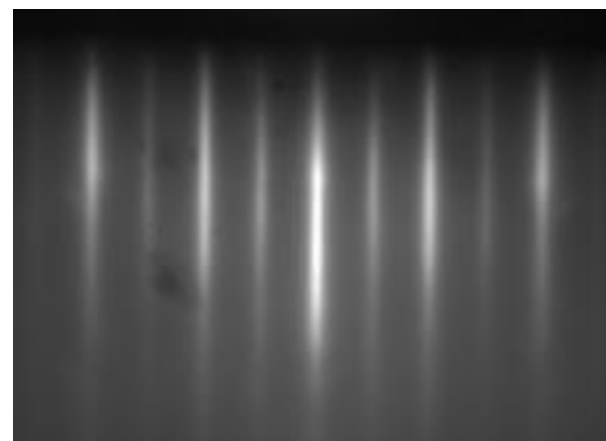
# Spin-Resolved PES

$\text{Co}_2\text{MnZ}_V$  with  $Z_V=\text{Sb}$



$\text{Co}_2\text{MnSb}$   
 $h\nu=37\text{ eV}$   
 $P$  polarization

- ✓ Weakly polarized
- ✓ Certainly due to Sb segregation and/or reconstruction at the surface

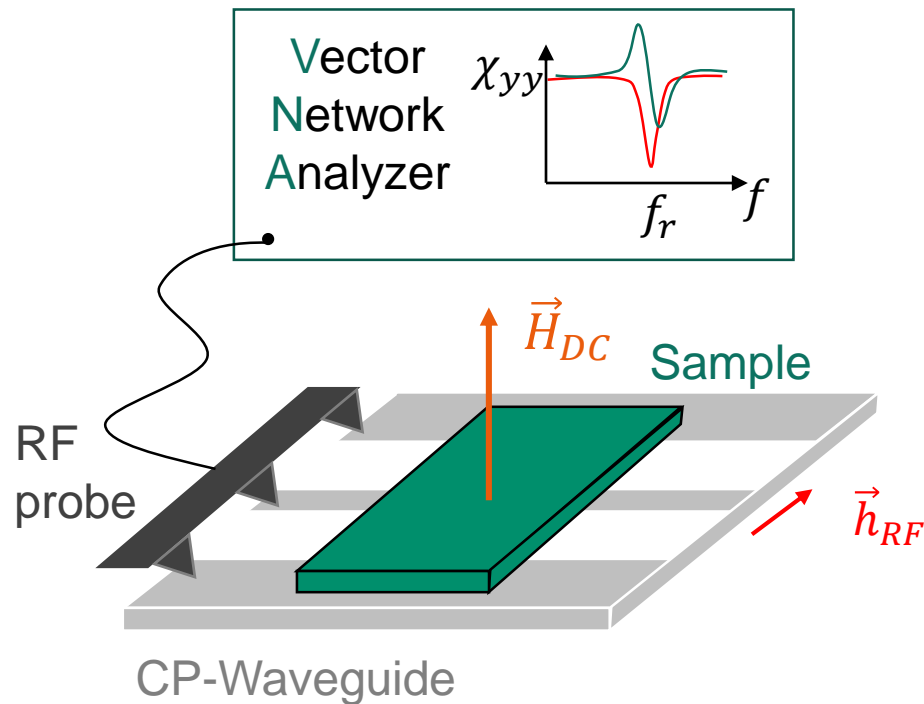


# Outline

1. Heusler alloys & spintronics
2. Crystal growth and structure
3. Testing the Half Metal Magnet behavior by SR-PES
4. Ultra-low damping materials

# $\perp$ VNA-FMR

## Set-up



$\vec{H}_{DC}$  : out-of-plane static magnetic field

$\vec{h}_{RF}$  : in-plane RF magnetic field

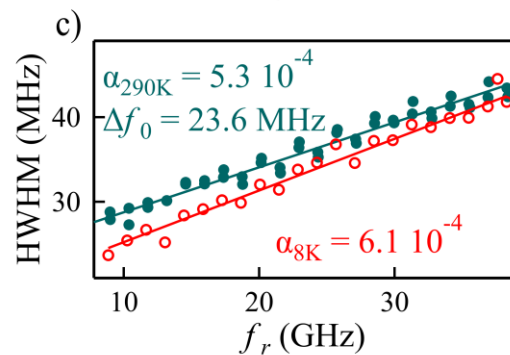
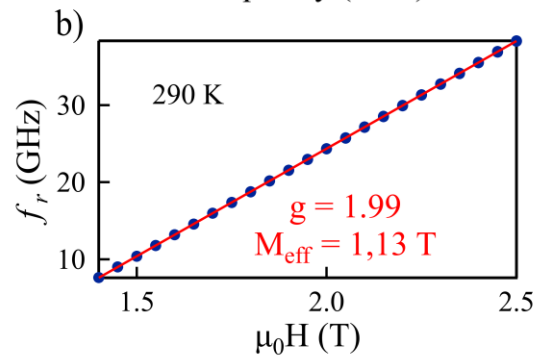
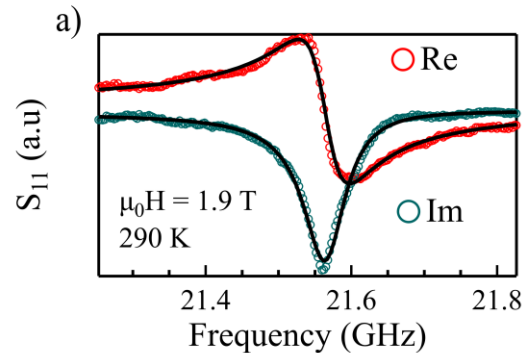
- $H_{DC}$  up to 2.5 T
- Kittel law :
$$f_r = \gamma_0 (H_0 - M_{eff})$$
- Gilbert damping given by HWHM
$$\Delta f = 2\alpha f_r + 2\Delta f_0$$
- 2-magnons scattering avoided
- No corrections (raw effective values)

# ⊥VNA-FMR

## Ultra-low magnetic damping

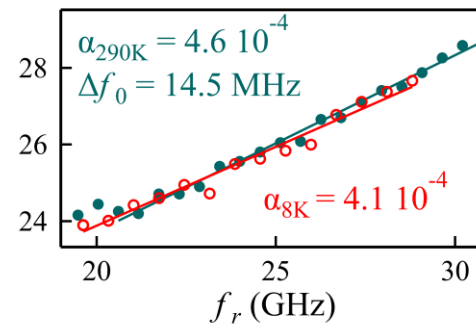
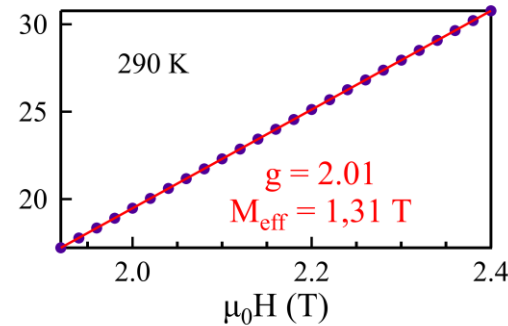
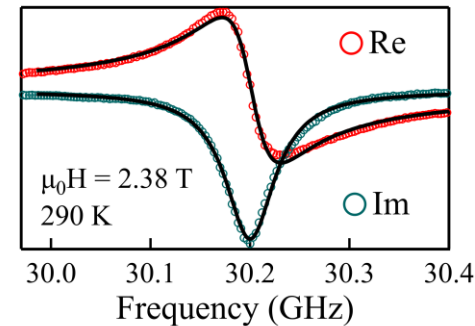
Co<sub>2</sub>MnGe

- $\alpha = 5,3 \cdot 10^{-4}$
- $g = 1,99$
- $\Delta f_0 = 23,6 \text{ MHz}$



Co<sub>2</sub>MnSi

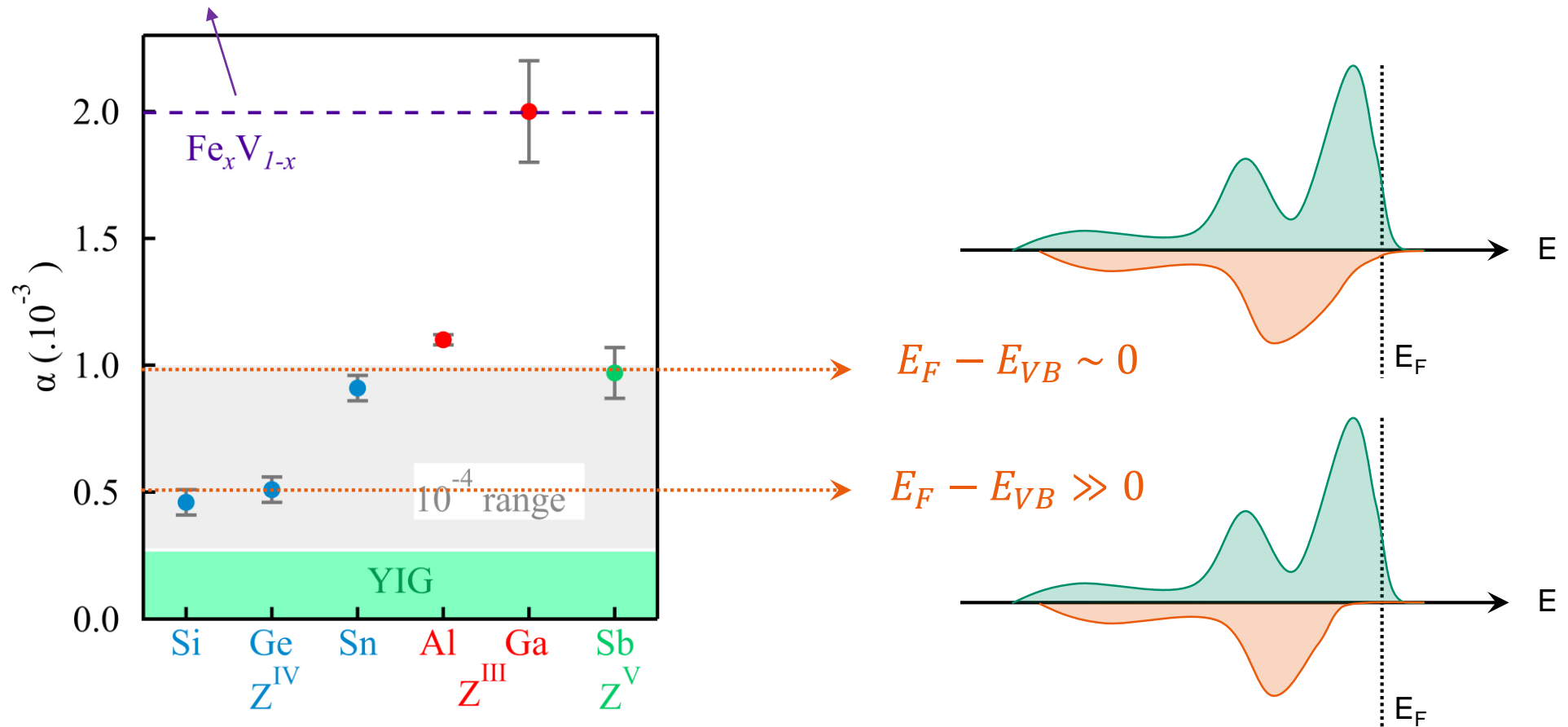
- $\alpha = 4,6 \cdot 10^{-4}$
- $g = 2,01$
- $\Delta f_0 = 14,5 \text{ MHz}$



# ⊥VNA-FMR

## Co<sub>2</sub>MnZ damping results

T. Devodler *et al.*, *Appl. Phys. Lett.* **103**, 242410 (2013)



# Summary

- Elaboration of epitaxial films precisely controlled & chemical order resolved
  - Trouble with Sb !
- $\text{Co}_2\text{MnZ}$  are high spin polarized materials with very small damping
- Reduction of the damping when  $E_F$  far from any minority DOS
- Next step is to get PMA



# Thank you