

Films minces, matériaux fonctionnels et nanostructures FINANO

**Laboratoire des Sciences des Procédés et des Matériaux
CNRS (UPR 3407)
Université Paris 13, Sorbonne Paris Cité**



FINANO Films minces, matériaux fonctionnels et nanostructures
Responsable: Damien Faurie

3 groupes de recherche (Opérations de recherche)

Magnétisme et nanostructures

M. BELMEGUENAI

S.M. CHERIF

Y. ROUSSIGNE

A. SACHKEVITCH

O. ROUSSEAU PostDoc

Propriétés mécaniques de films minces

P. DJEMIA

D. FAURIE

F. CHALLALI

F. TETARD

S. MERABTINE PhD

C.H. CHEN PhD

Couplage magnétoélastique et multiferroïques

F. ZIGHEM

S. MERCONE

M. GUEYE PhD

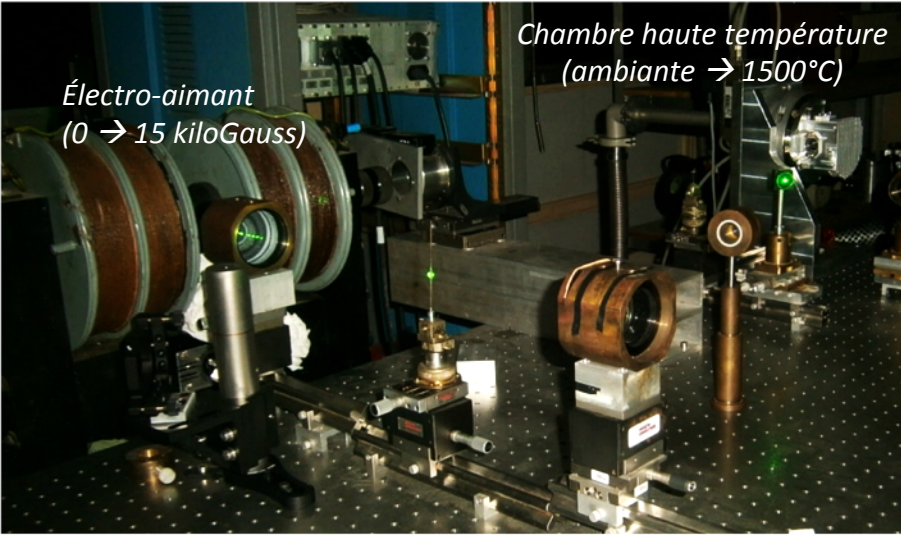
TTH. NONG PhD

A. BOROWIAK PostDoc

Ingénieur d'étude : A. GARCIA-SANCHEZ (AFM, Spectroscopies)

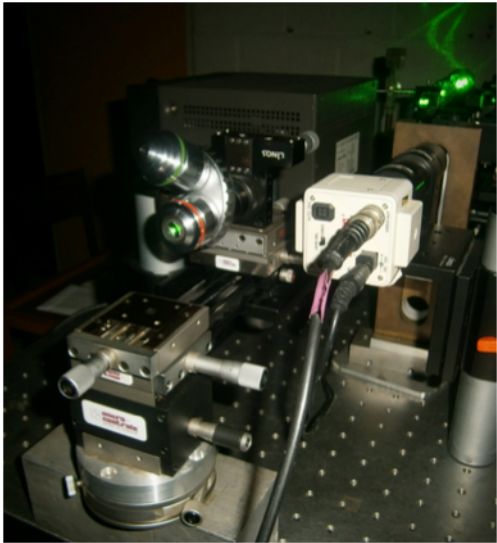
Equipements communs : Spectroscopie Brillouin

Spectroscopie optique (Brillouin) + environnements échantillons

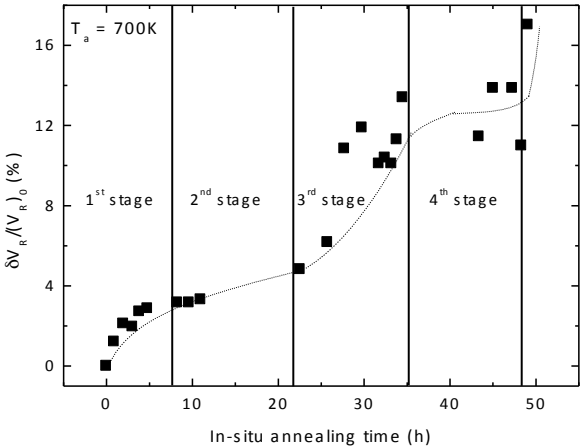


Cnano « Imadyn 1&2 » (Y. Roussigné)
ANR « Spinstress » (D. Faurie)

Micro-Brillouin

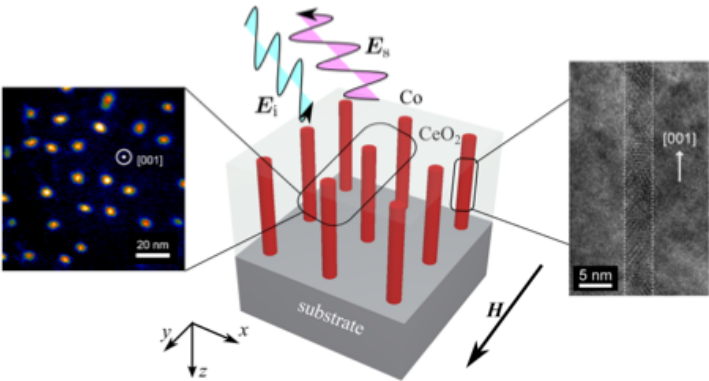


Ondes acoustiques de surface

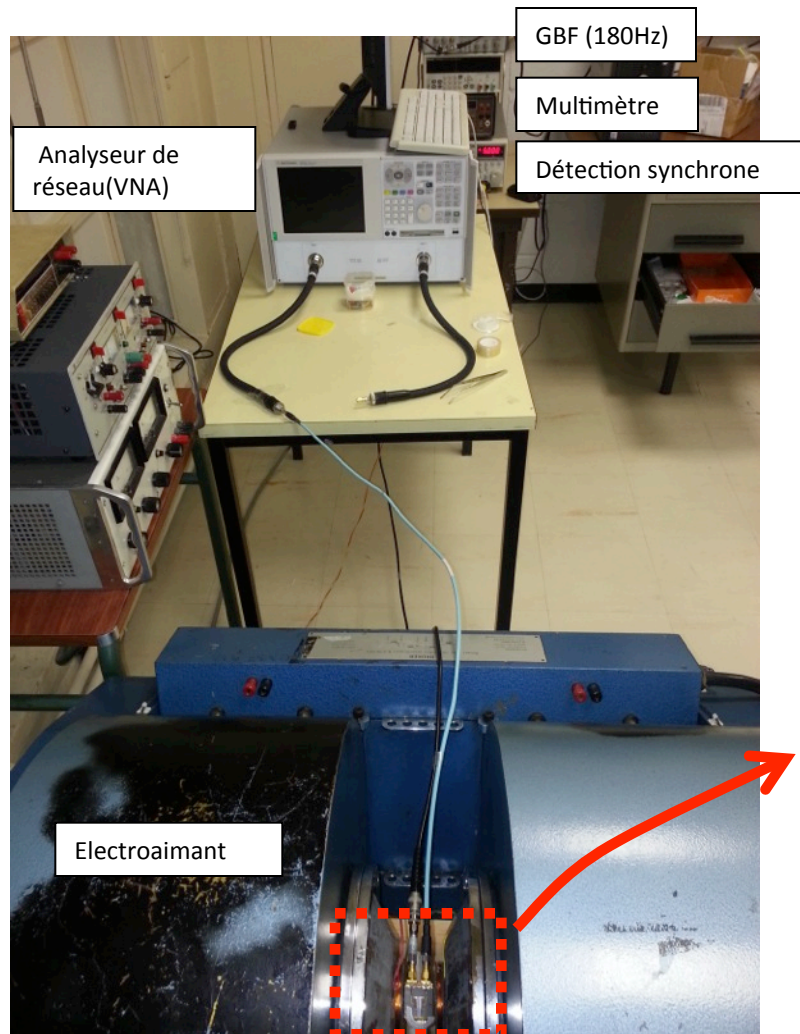


Domaine du
GigaHertz

Ondes de spin dans les nanostructures

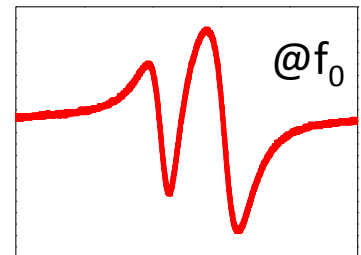
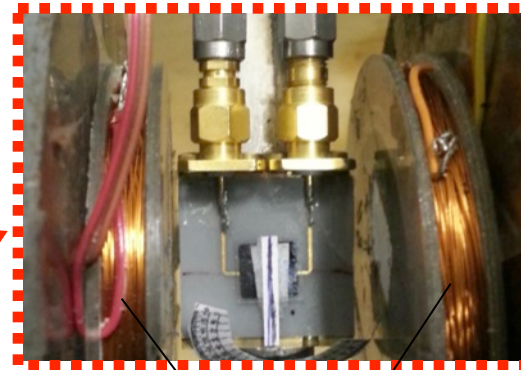


Equipements communs : Résonance ferromagnétique

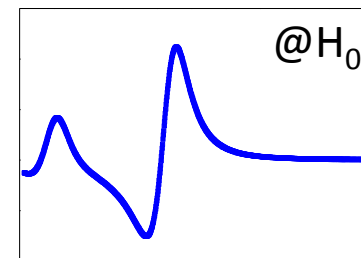


- Champ magnétique: 0 - 20 kG
- Frequence: 10 MHz – 40 GHz
- Balayage en champ (H) ou en fréquence (f)

Ligne micro-ruban permettant l'excitation de l'aimantation de films minces et nanostructures



H (kG)



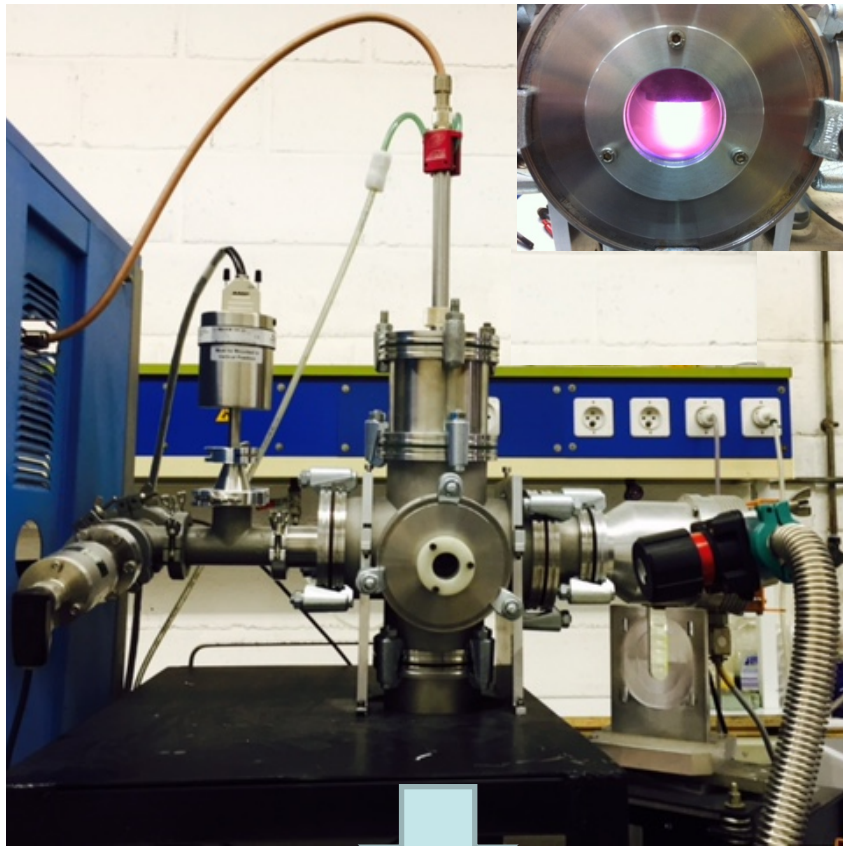
f (GHz)

Equipements communs : Elaboration

Petit bâti PVD mono-source

Installé au LSPM (Bat.L2)

Fait maison (~30 k€ HT)

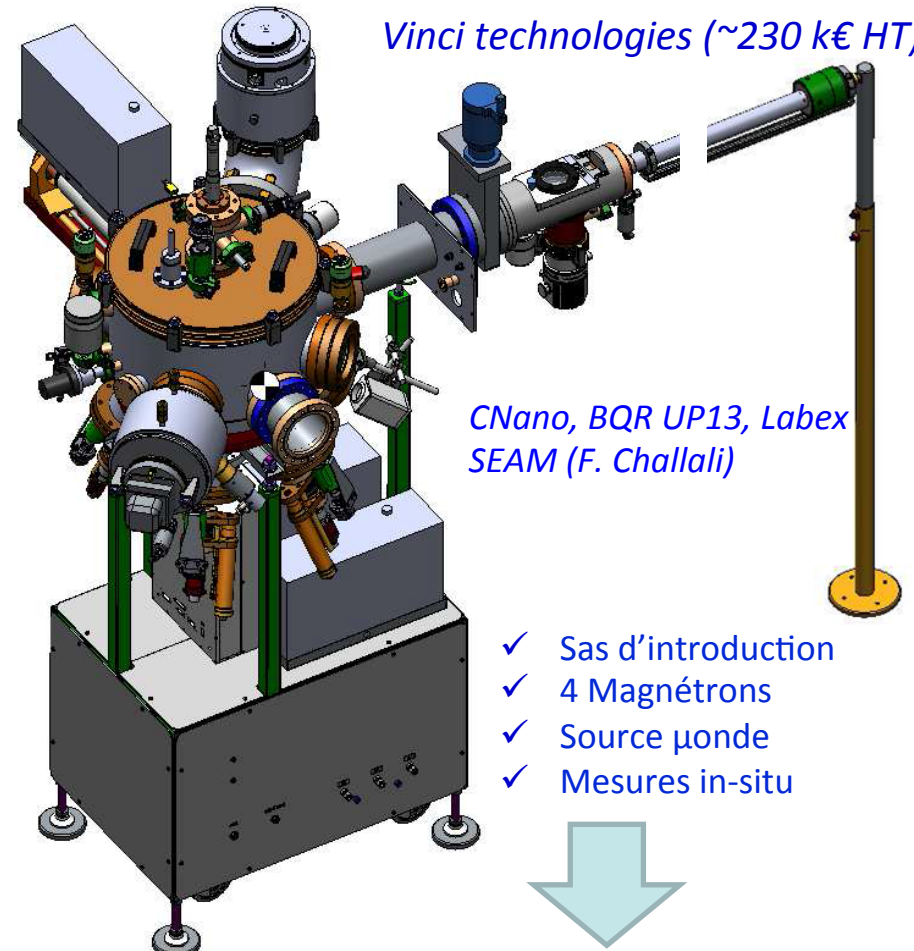


- Dépôts non réactifs en Ar et réactifs avec O_2 et/ou N_2
- Monocouches,
- Dépôt à partir d'une seule cible

Grand bâti PVD multi-source

Installation en salle blanche UP13 en 2016

Vinci technologies (~230 k€ HT)



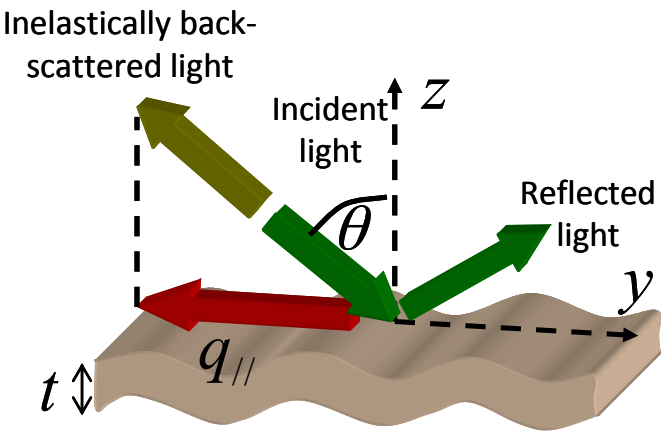
CNano, BQR UP13, Labex SEAM (F. Challali)

- ✓ Sas d'introduction
- ✓ 4 Magnétrons
- ✓ Source μ onde
- ✓ Mesures in-situ

- Dépôts non réactifs en Ar et réactifs avec O_2 et/ou N_2
- Monocouches, **Multicouches**,
- **Co-pulvérisation (binaires, ternaires, quaternaires)**
- **Contrôle in-situ de l'épaisseur**

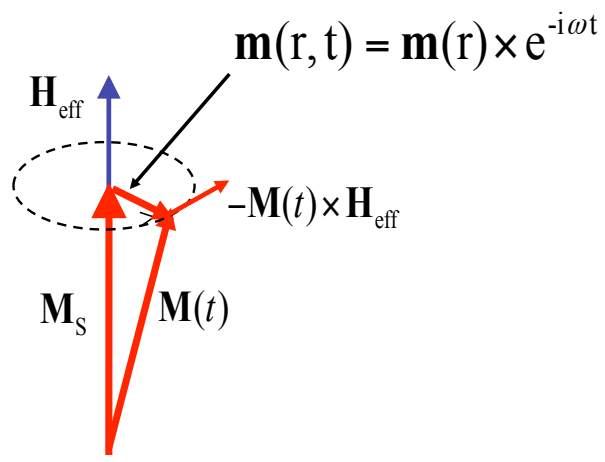
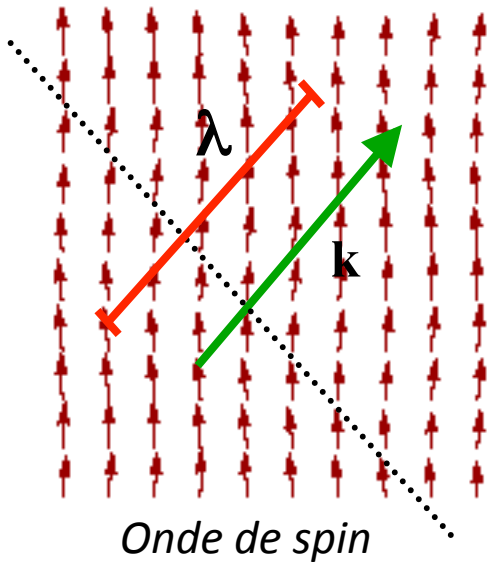
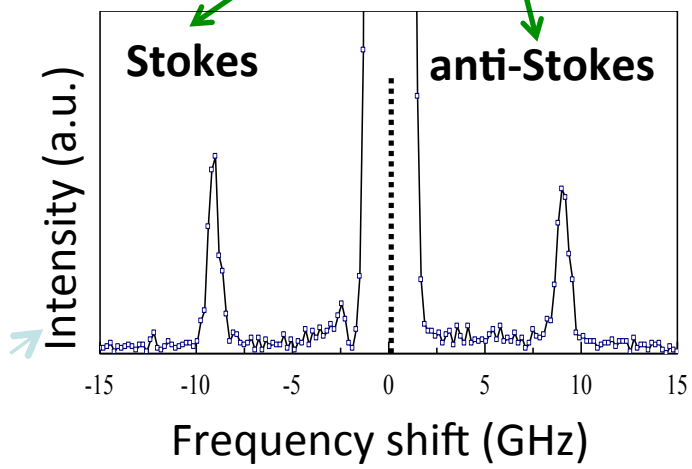
Groupe 1 : Spectroscopie Brillouin et dynamique de l'aimantation

(M. Belmeguenai, S.M. Chérif, Y. Roussigné, A. Stashkevitch)



Diffusion inélastique de la lumière par une onde de spin
→ Décalage en fréquence

$$f_{\text{diffusée}} = f_{\text{incident}} \pm f_{\text{onde de spin}}$$



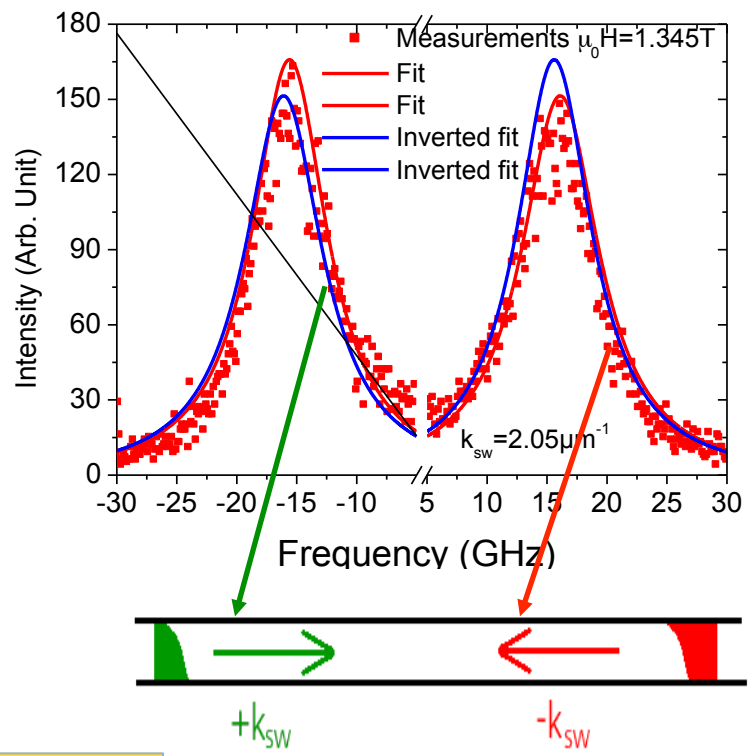
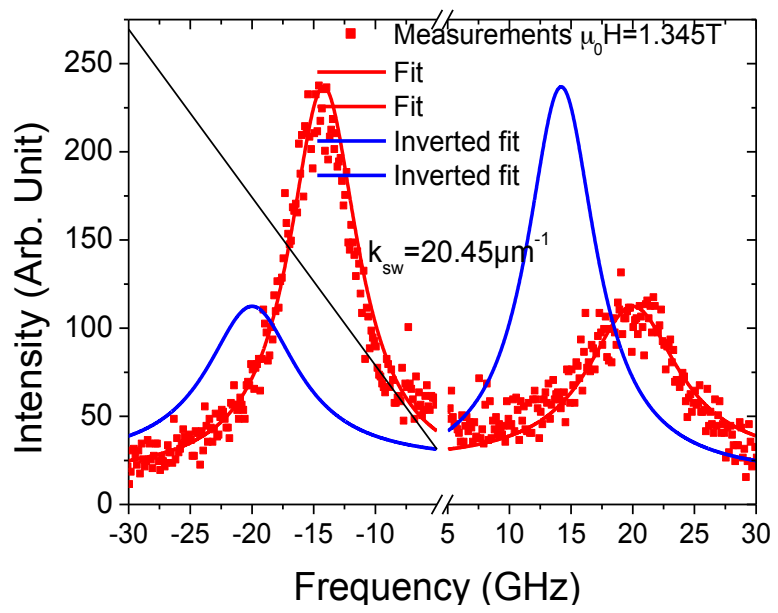
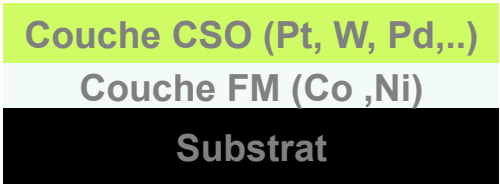
$$2\text{GHz} < f_{\text{onde de spin}} < 300\text{GHz}$$

Groupe 1 : Spectroscopie Brillouin et dynamique de l'aimantation

(M. Belmeguenai, S.M. Chérif, Y. Roussigné, A. Stashkevitch)

Etude de l'interaction Dzyaloshinskii-Moriya (DMI) dans des couches ultra-minces

- DMI:
- Modification du Couplage Spin-Orbite stabilisant les skyrmions
 - Vitesse de propagation de paroi de domaine
 - Spectroscopie Brillouin (BLS) → méthode simple et directe



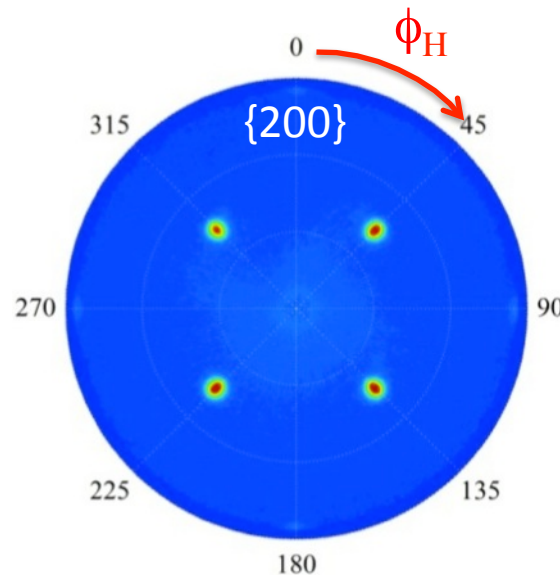
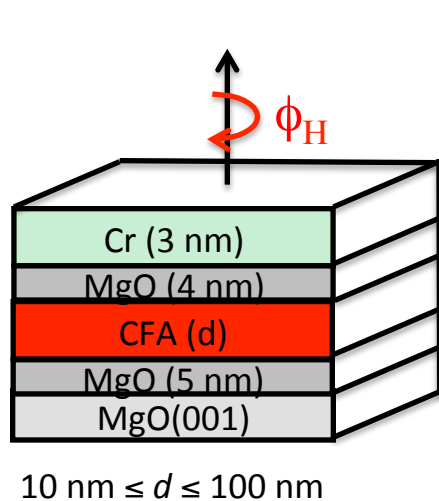
Phys. Rev. B: Rapid Com; 91, 180405(R) (2015)
Phys. Rev. B 91, 214409 (2015)
Nature Nanotechnology, à paraître

$$\Delta f = \frac{2\gamma}{\pi M_S} D_{eff} k_{sw}$$

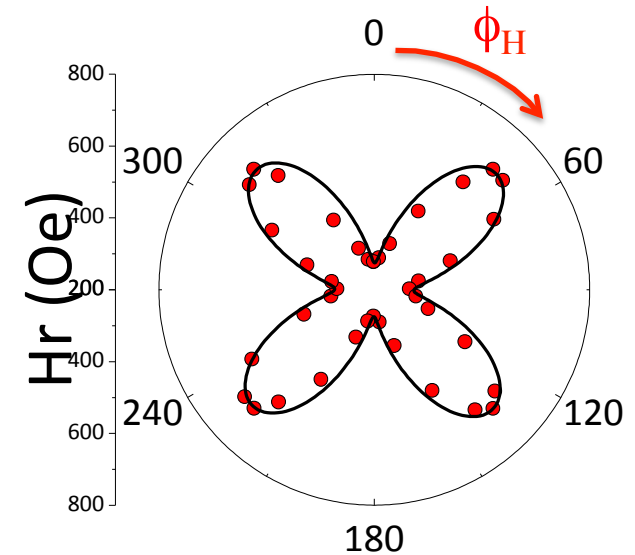
Groupe 1 : Spectroscopie Brillouin et dynamique de l'aimantation

(M. Belmeguenai, S.M. Chérif, Y. Roussigné, A. Stashkevitch)

Corrélation entre relations d'épitaxie et anisotropie magnétique



Epitaxial growth shown
by x-ray diffraction



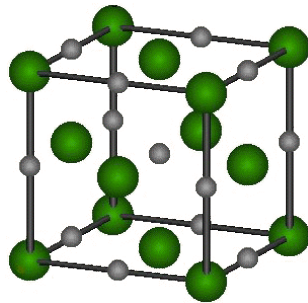
Fourfold magnetic anisotropy
probed by FMR

Belmeguenai *et al.* Physical Review B **87** (18), 184431 (2013)

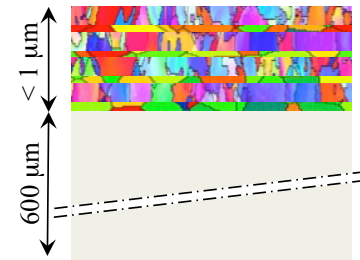
Groupe 2 – Mécanique des films minces

(F. Challali, P. Djemia, D. Faurie, F. Tetard)

Single-crystal (ab-initio)



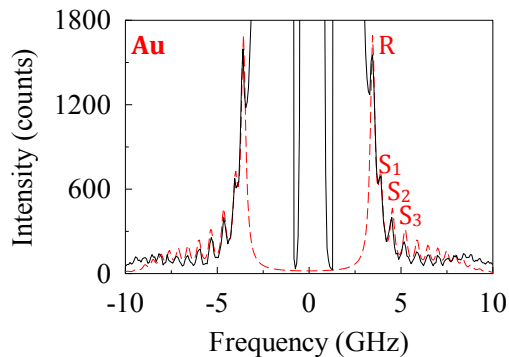
Multilayers and polycrystalline thin films



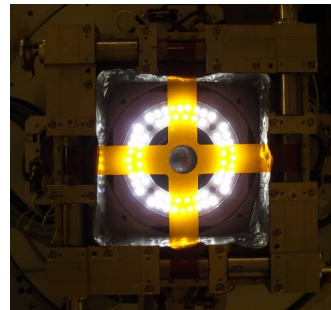
Homogenization

Comparison to experimental data

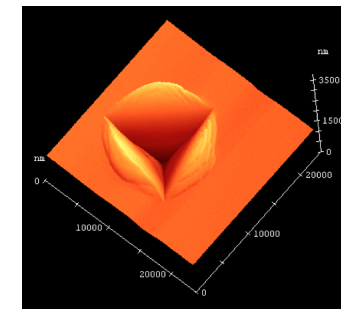
Acoustic measurements and quasi-static tests



Brillouin light scattering



*Mechanical tests
+ x-ray Diffraction in situ*

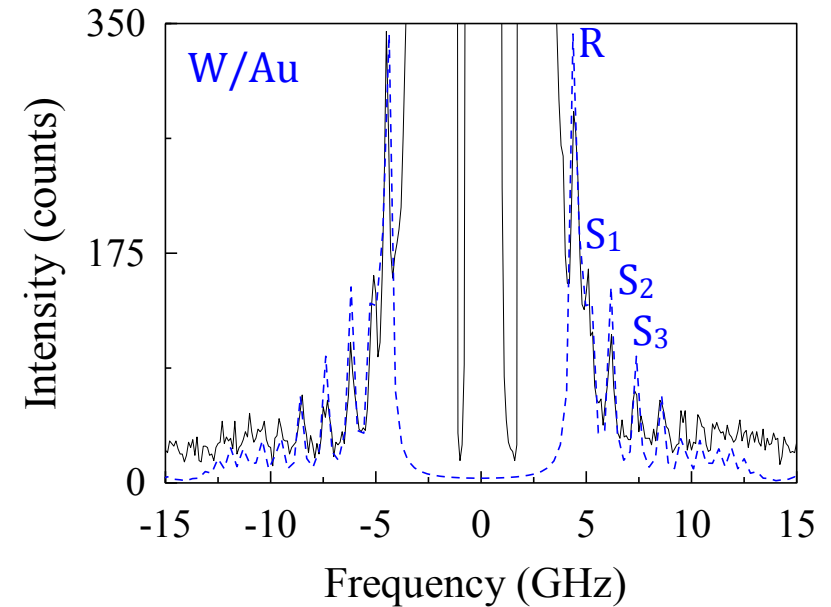
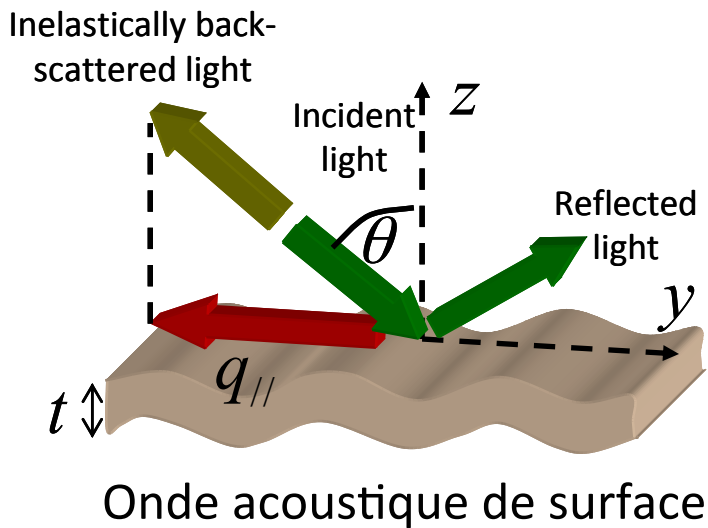


Nanoindentation

Groupe 2 – Mécanique des films minces

(F. Challali, P. Djemia, D. Faurie, F. Tetard)

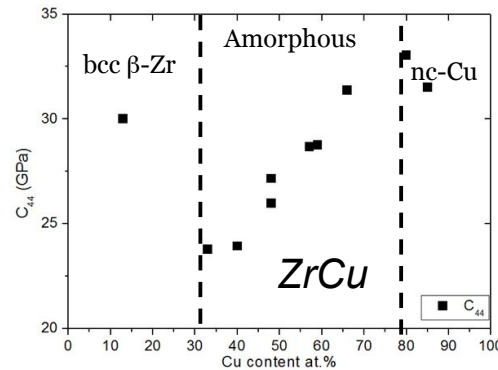
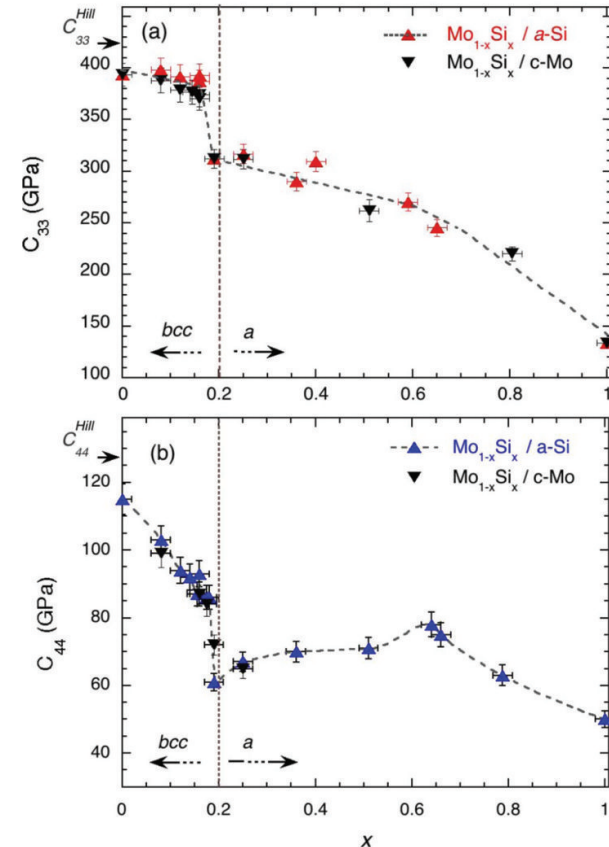
$$\text{frequency}_{\text{acoustic-wave}} = f(C_{ij}, \rho)$$



- BLS : Détermination des vitesses acoustiques et constantes élastiques

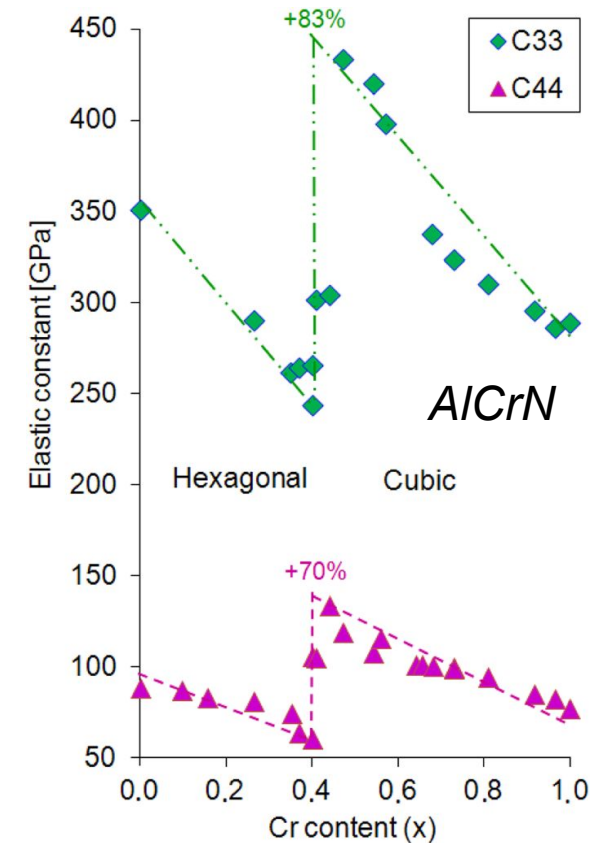
Groupe 2 – Mécanique des films minces (F. Challali, P. Djemia, D. Faurie, F. Tetard)

« Amorphous → Crystal » transition



→ Strong effect of phase transition on the elastic constants, probed by acoustic measurements

« Hexagonal → Cubic » transition

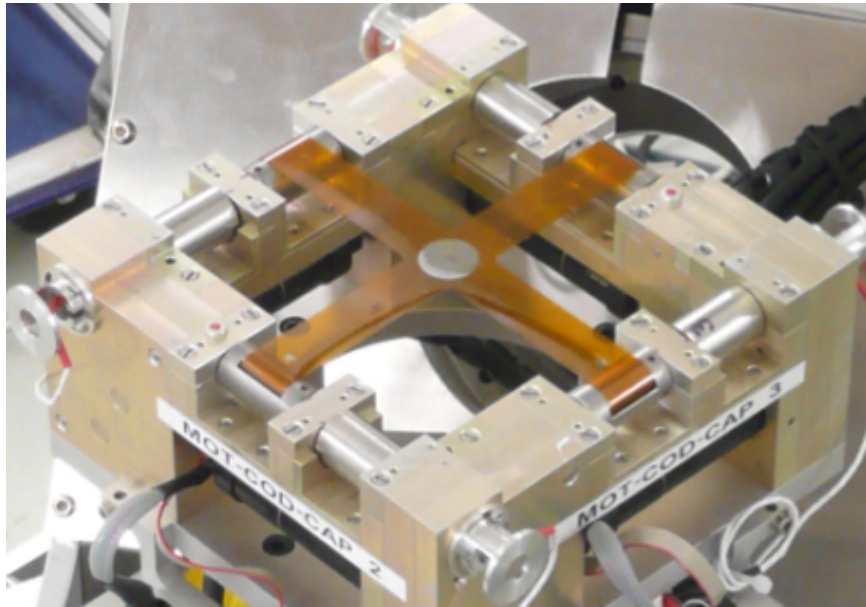


Appl. Phys. Lett. **106**, 041601 (2013)
Phys. Rev. B **88**, 174104 (2013)

M-Eranet « MC2 » (P. Djemia), Contrat de collaboration avec Saint Gobain Recherche depuis 2011 et ESSILOR depuis 2016 (P. Djemia)

Groupe 2 – Mécanique des films minces

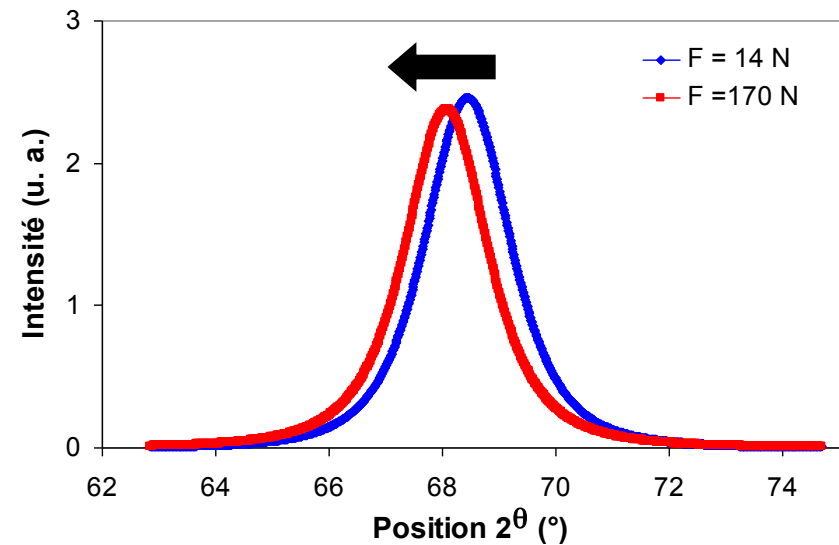
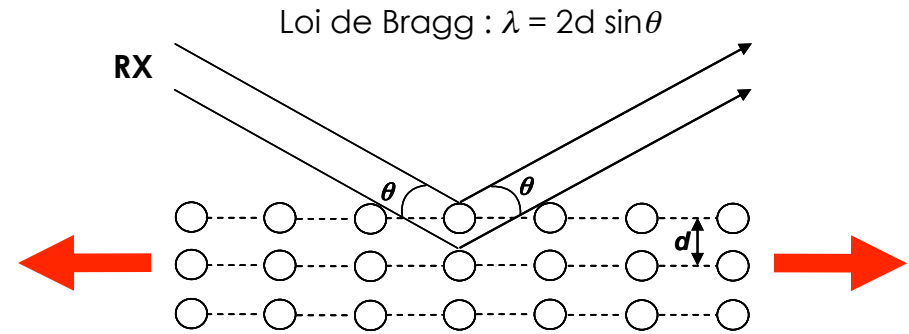
(F. Challali, P. Djemia, D. Faurie, F. Tetard)



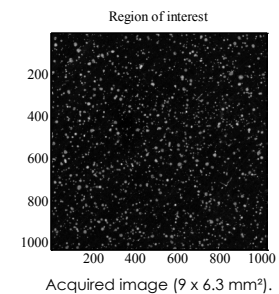
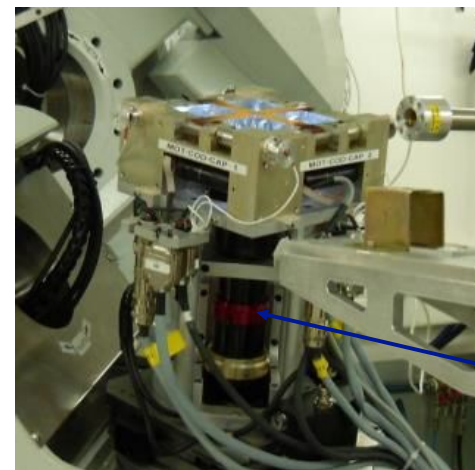
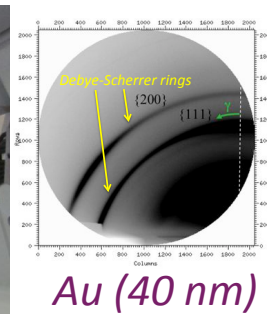
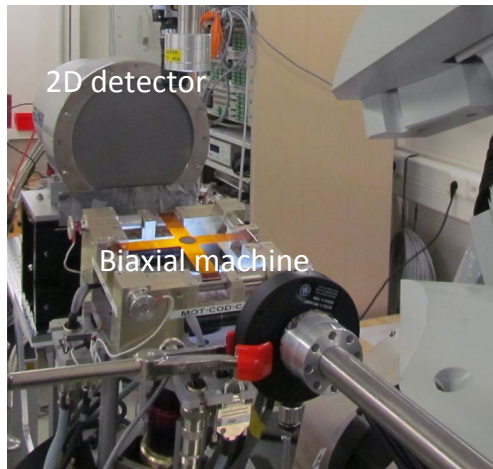
Films minces sur substrats polymères

LATTICE STRAINS

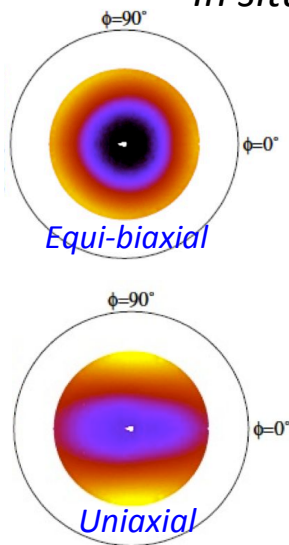
$$\{\varepsilon\}_{\Phi\Psi}^{hkl} = \ln\left(\frac{d_{\Phi\Psi}}{d_{\Phi\Psi}^{(0)}}\right) = \ln\left(\frac{\sin\theta_{\Phi\Psi}^{(0)}}{\sin\theta_{\Phi\Psi}}\right) \approx \frac{d_{\Phi\Psi} - d_{\Phi\Psi}^{(0)}}{d_{\Phi\Psi}^{(0)}}$$



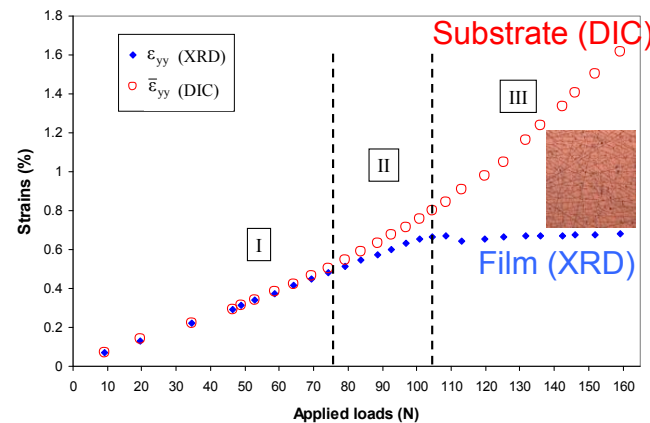
Groupe 2 – Mécanique des films minces (F. Challali, P. Djemia, D. Faurie, F. Tetard)



In situ XRD



in situ DIC



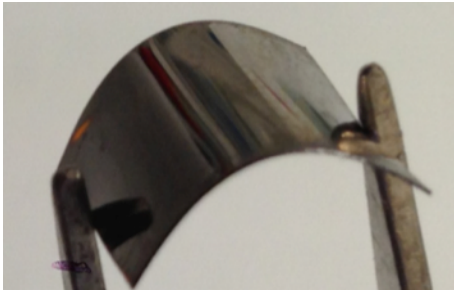
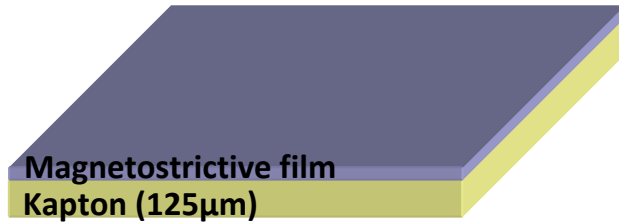
Mechanical behavior of thin film on flexible substrate

Acta Materialia **61**, 5067-5077 (2013)

Journal of Applied Crystallography **47**, 181-187 (2014)

Groupe 3 – Magnétoélasticité de systèmes flexibles

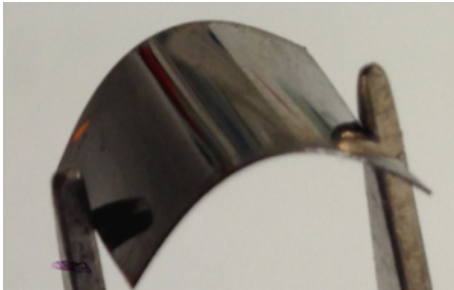
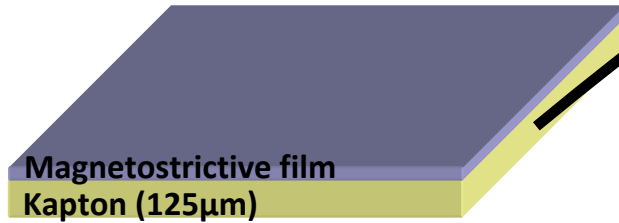
(S. Merccone, F. Zighem)



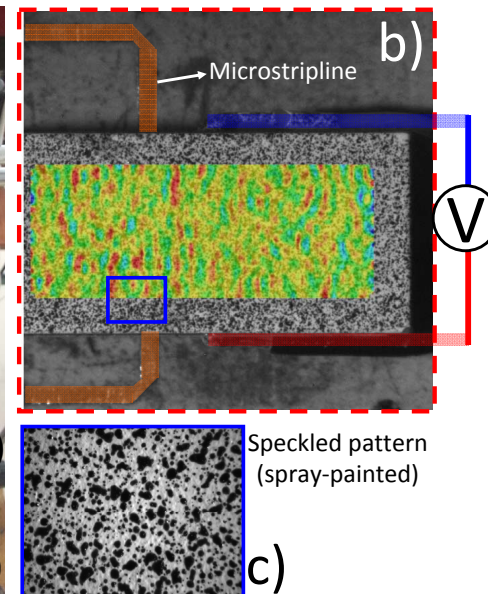
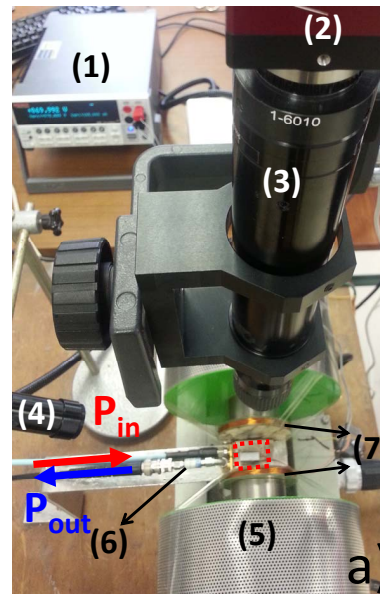
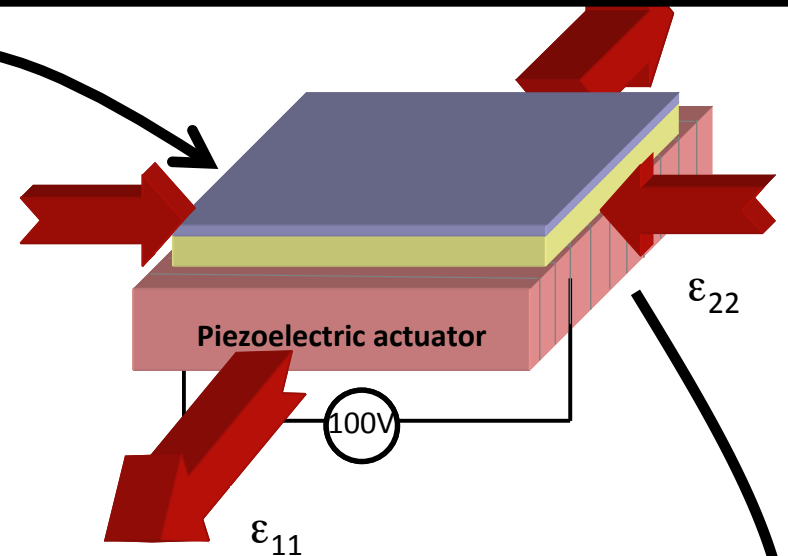
Films minces magnétiques sur
substrats polymères

Groupe 3 – Magnétoélasticité de systèmes flexibles

(S. Mercone, F. Zighem)



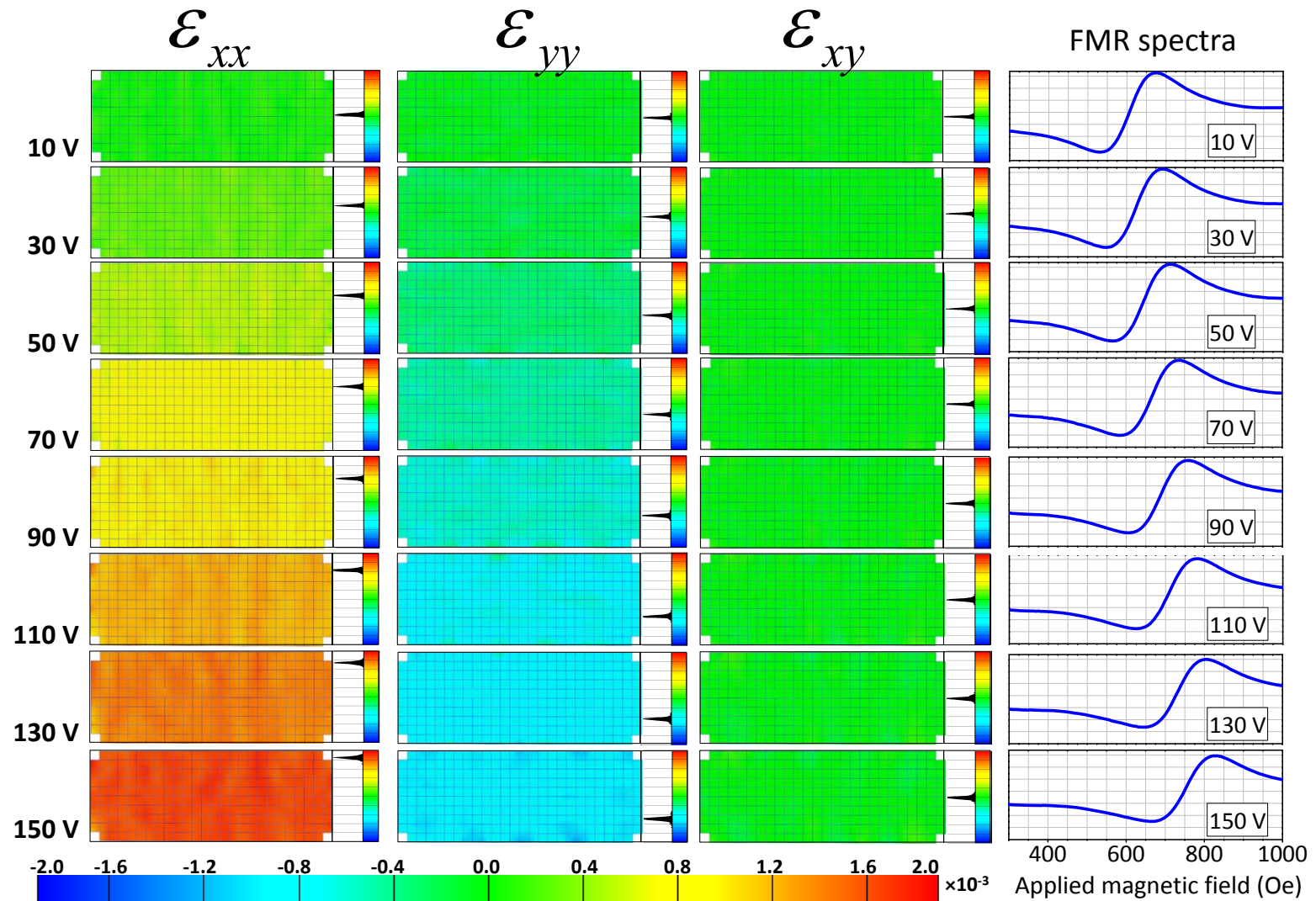
Films minces magnétiques sur substrats polymères



Groupe 3 – Magnétoélasticité de systèmes flexibles

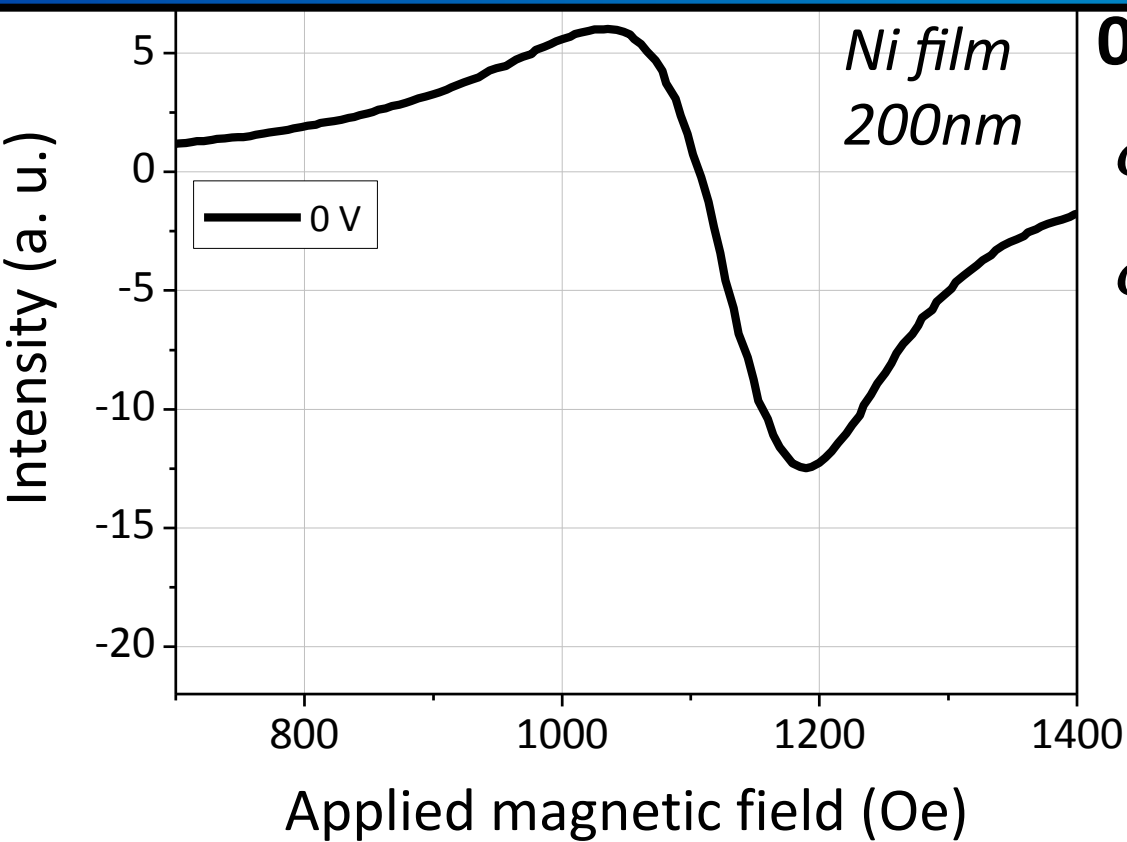
(S. Mercone, F. Zighem)

Coupling Strain measurements (DIC) and Ferromagnetic Resonance



Groupe 3 – Magnétoélasticité de systèmes flexibles

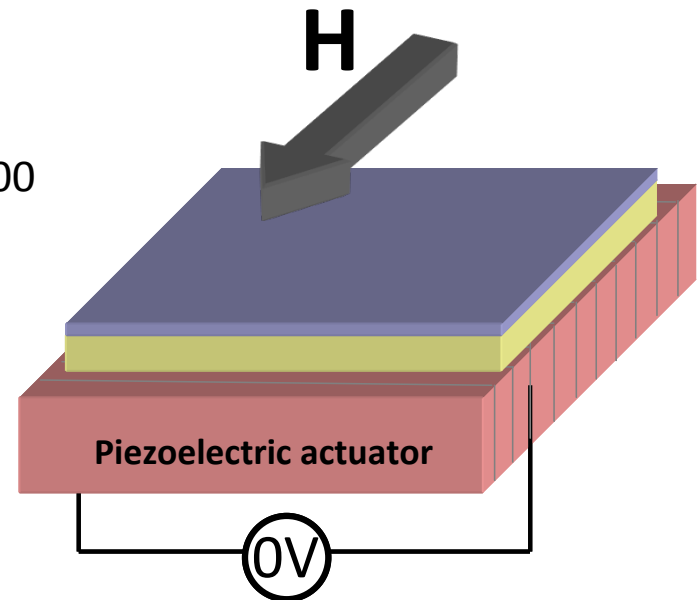
(S. Mercone, F. Zighem)



0 V:

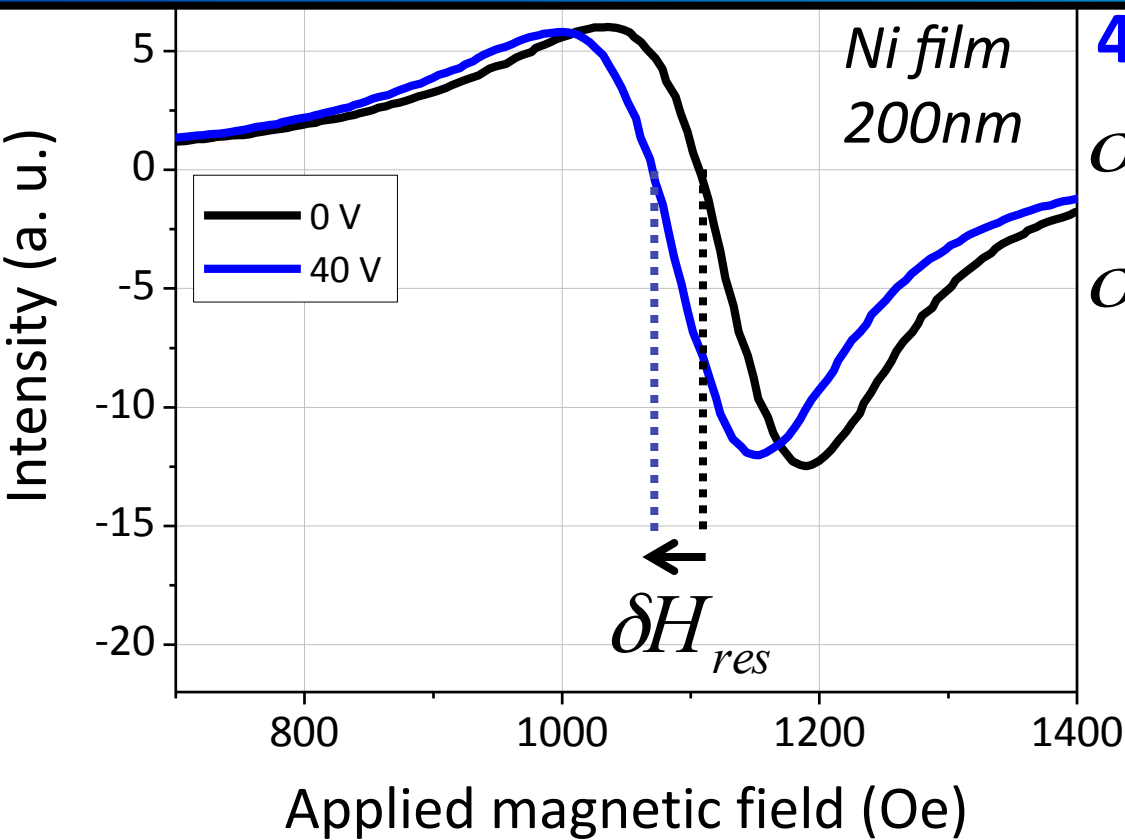
$$\sigma_{xx}^{\text{applied}} = 0 \text{ MPa}$$

$$\sigma_{yy}^{\text{applied}} = 0 \text{ MPa}$$



Groupe 3 – Magnétoélasticité de systèmes flexibles

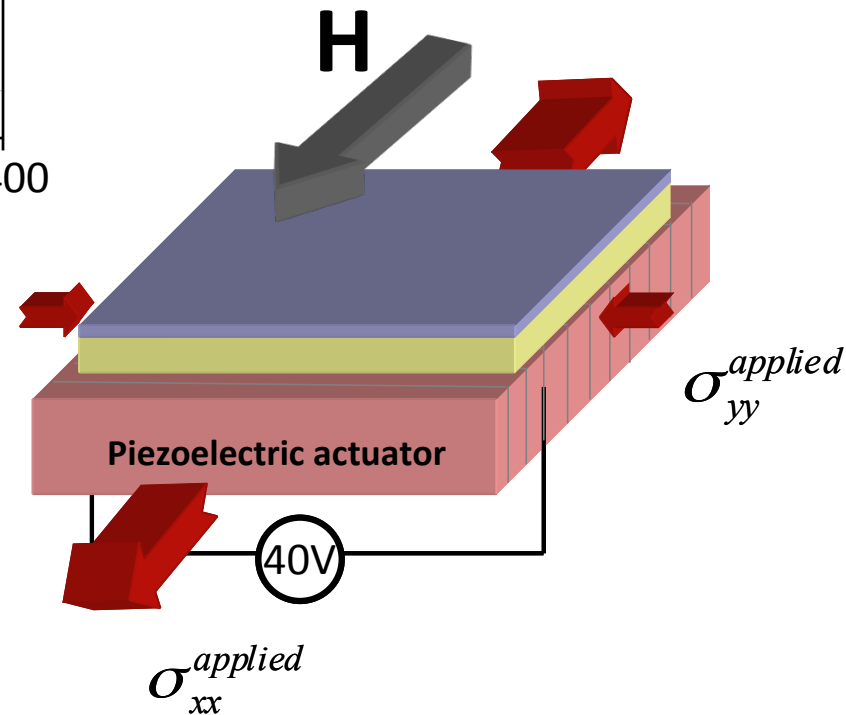
(S. Merccone, F. Zighem)



40 V:

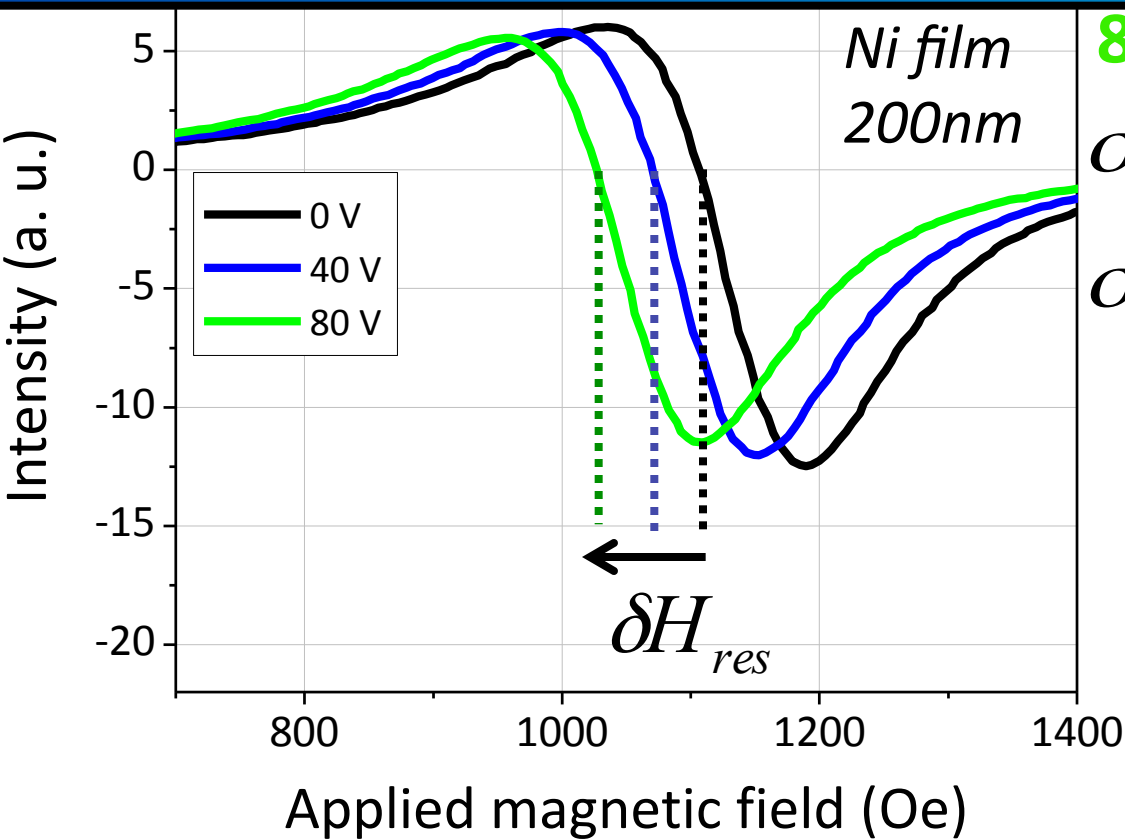
$$\sigma_{xx}^{applied} = 45 \text{ MPa}$$

$$\sigma_{yy}^{applied} = -15 \text{ MPa}$$



Groupe 3 – Magnétoélasticité de systèmes flexibles

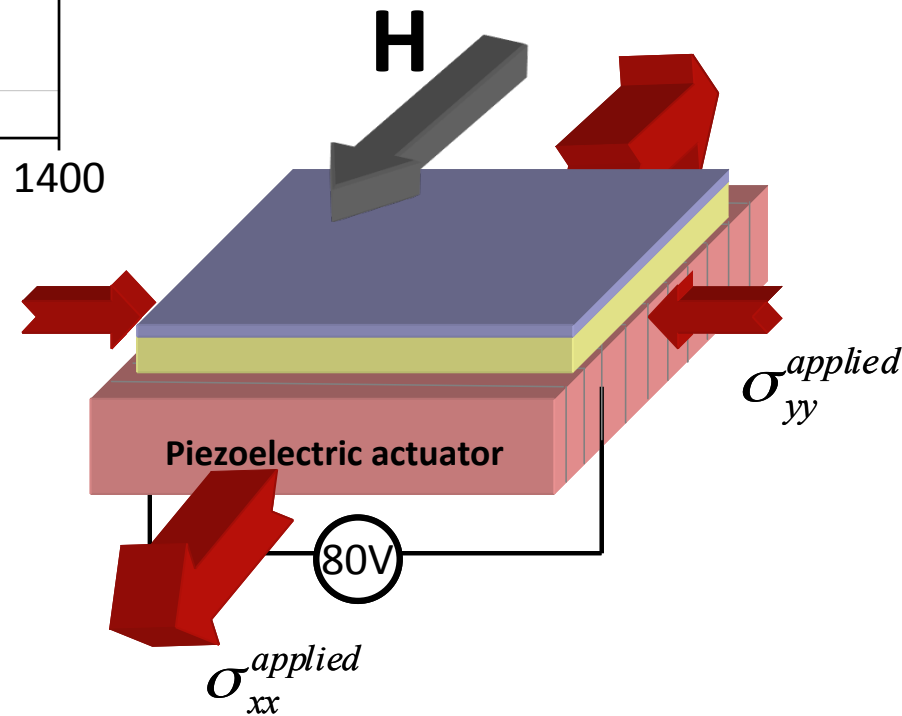
(S. Merccone, F. Zighem)



80 V:

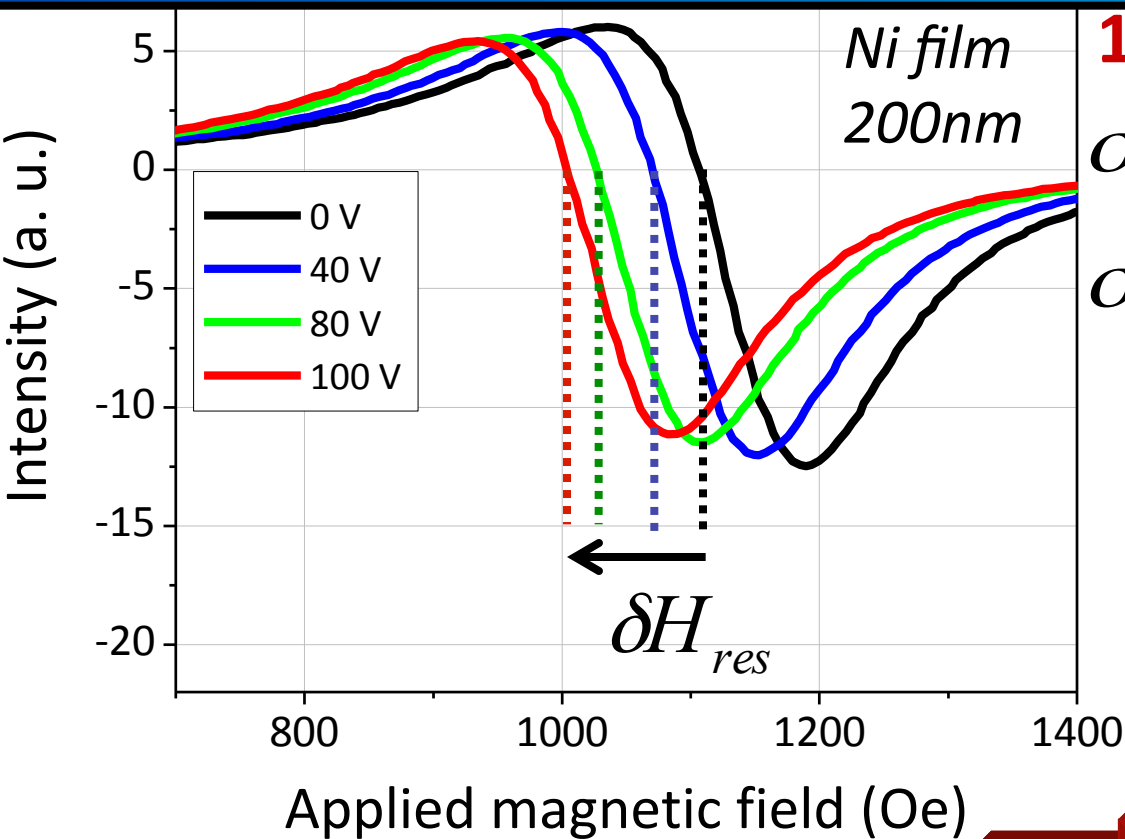
$$\sigma_{xx}^{applied} = 102 \text{ MPa}$$

$$\sigma_{yy}^{applied} = -35 \text{ MPa}$$



Groupe 3 – Magnétoélasticité de systèmes flexibles

(S. Merccone, F. Zighem)

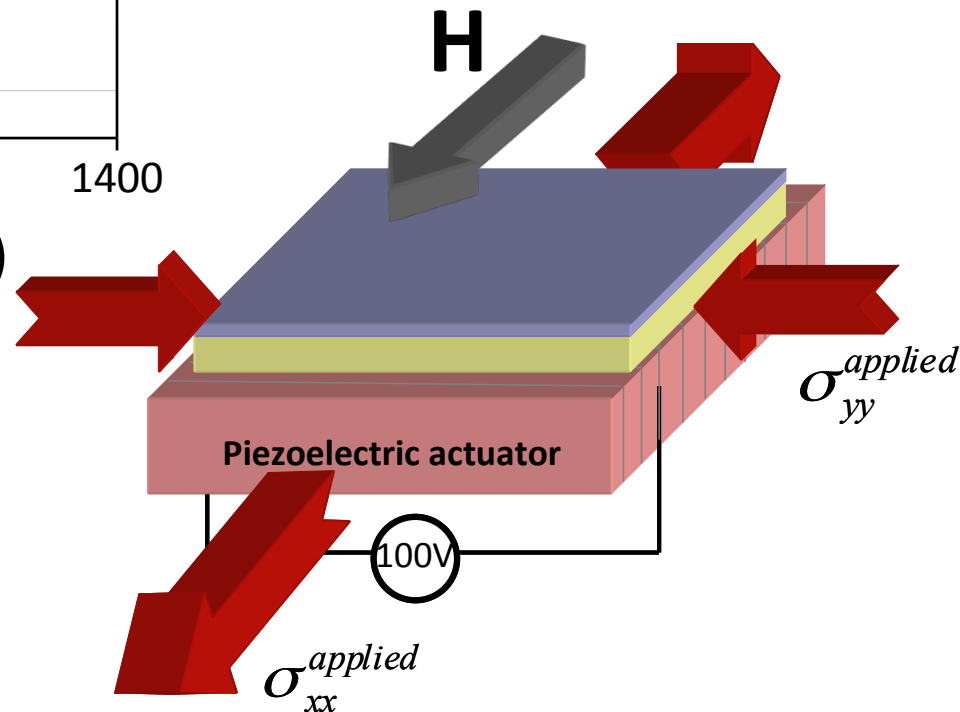


100 V:

$$\sigma_{xx}^{applied} = 127 \text{ MPa}$$

$$\sigma_{yy}^{applied} = -52 \text{ MPa}$$

Determination of magnetostriction coefficient $\lambda = -35.10^{-6}$



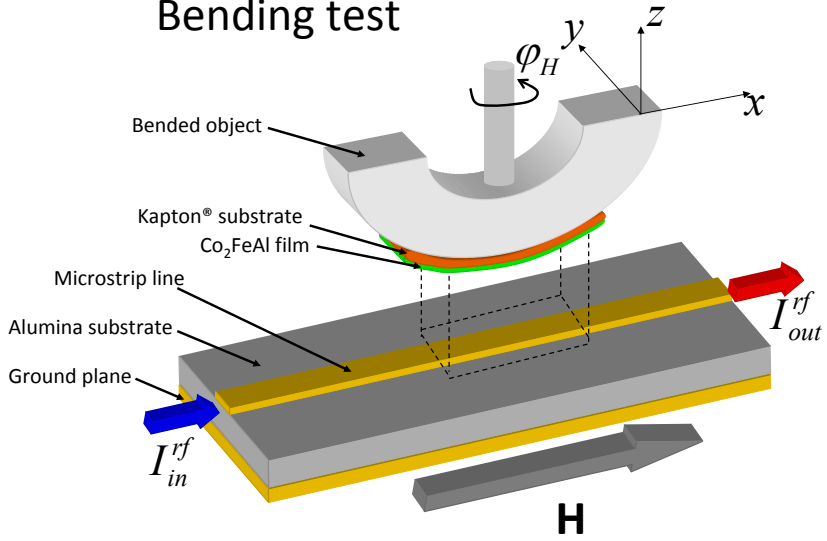
Applied Physics Letters 105 (5), 052411 (2014)

Applied Physics Letters 107 (3), 032908 (2015)

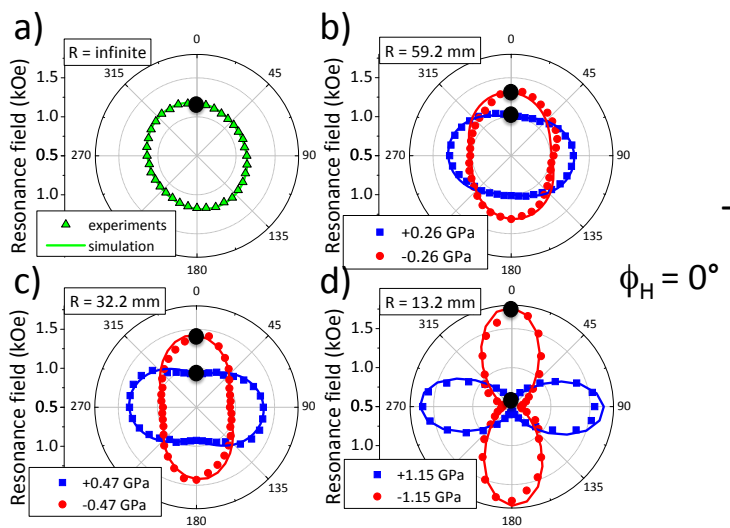
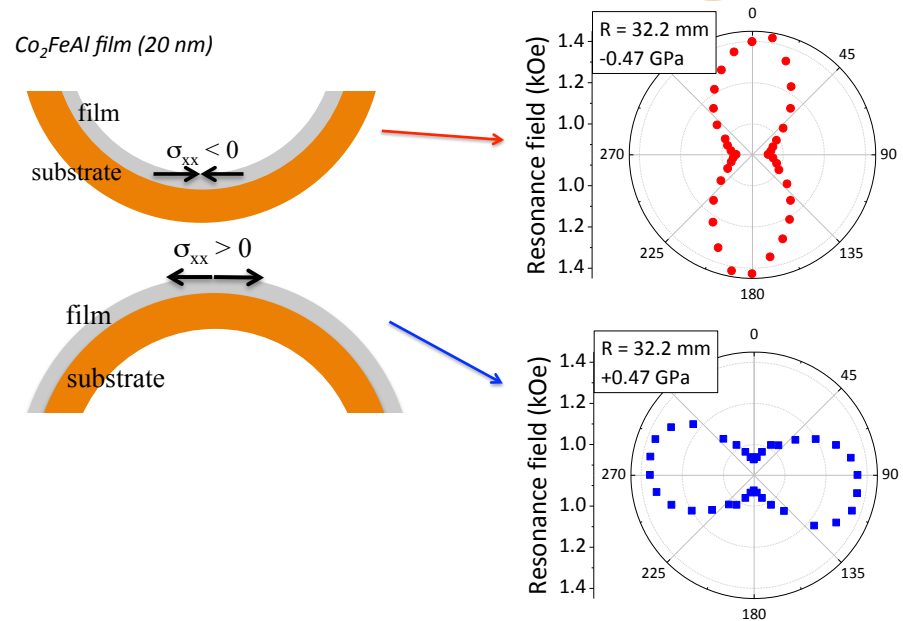
Groupe 3 – Magnétoélasticité de systèmes flexibles

(S. Mercone, F. Zighem)

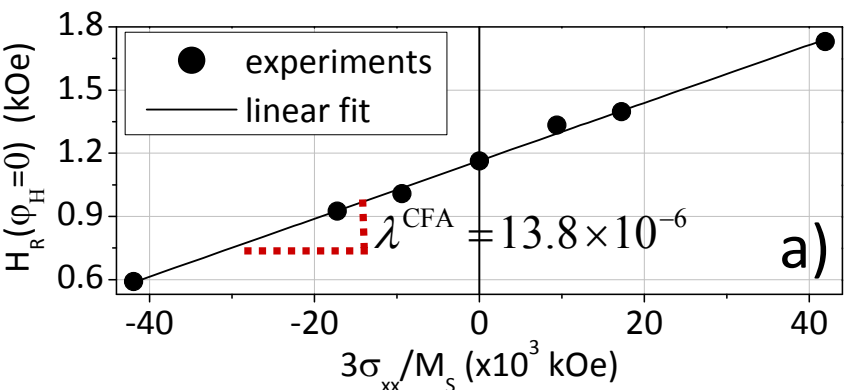
Ferromagnetic Resonance + Bending test



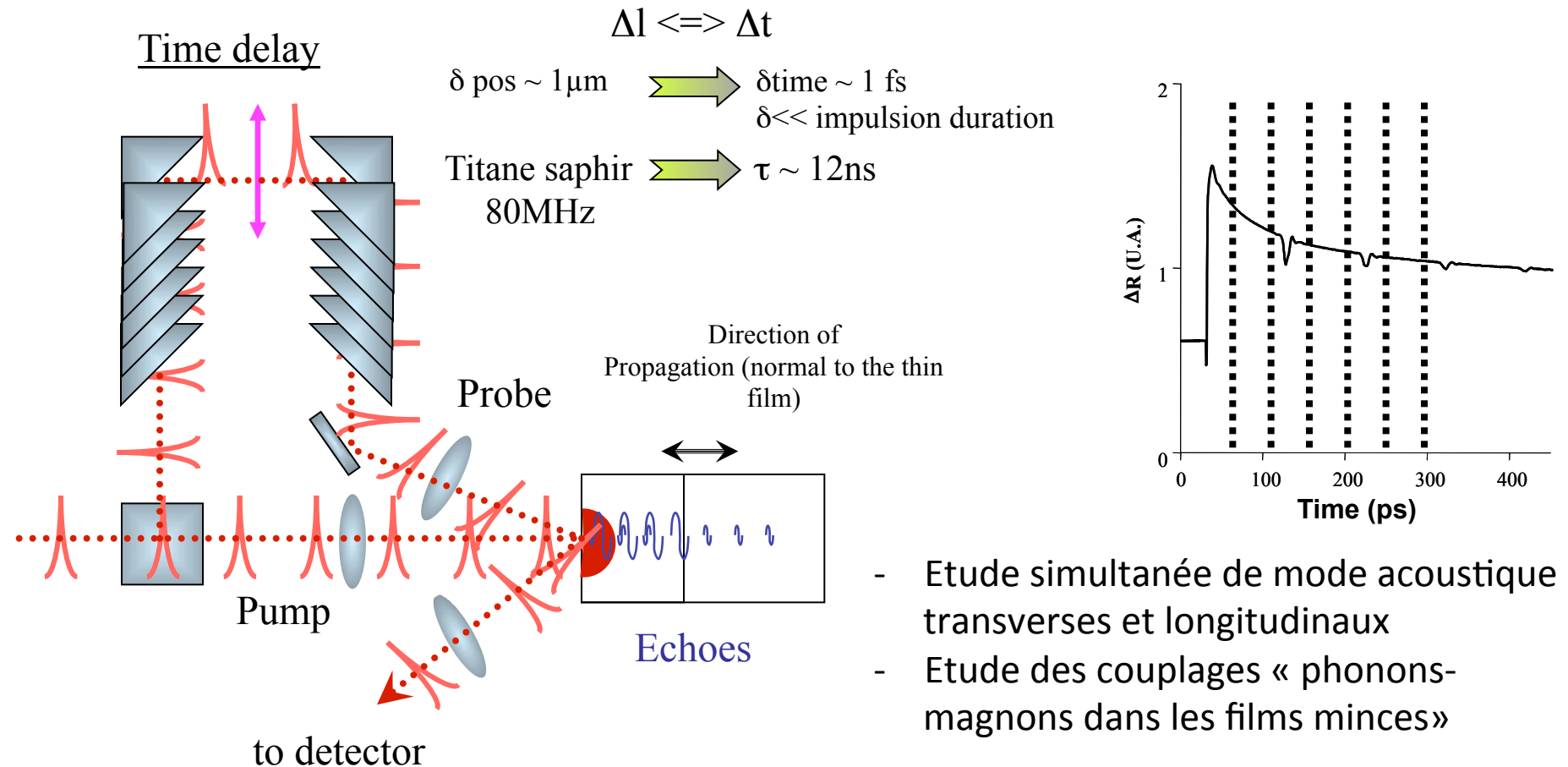
Effect on magnetic anisotropy



Determination of magnetoelastic coefficient



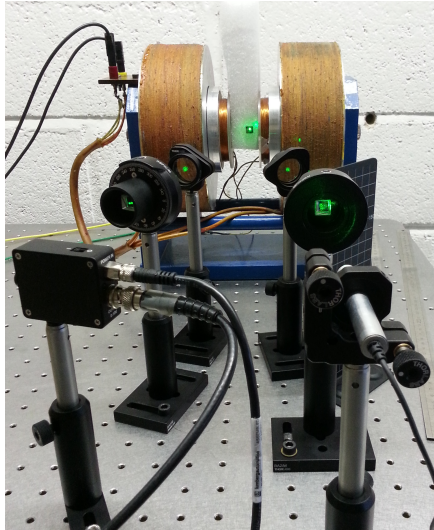
Acoustique picoseconde (à coupler avec la spectroscopie Brillouin)



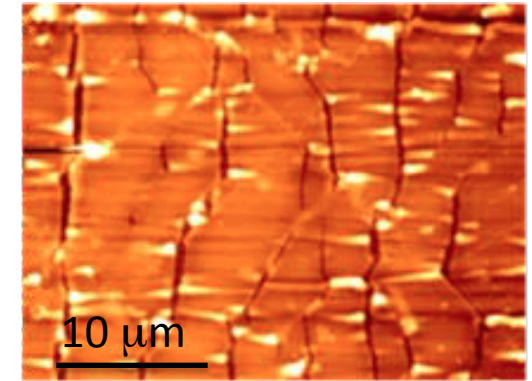
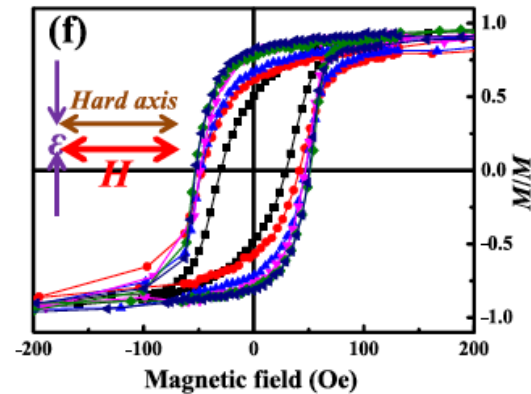
- Etude simultanée de mode acoustique transverses et longitudinaux
- Etude des couplages « phonons-magnons dans les films minces »

Développements instrumentaux en cours

Développement d'un magnétomètre à effet Kerr avec essais de traction uniaxiaux *in situ*

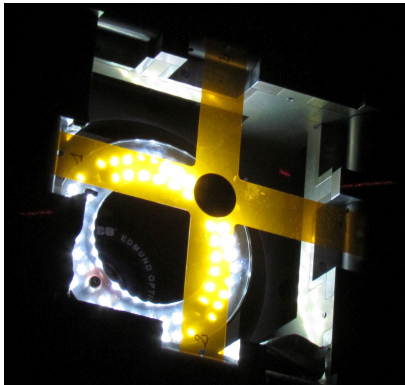


Projet USPC-NUS « MagnoFlex » (F. Zighem)



Effet des micro-fissures sur la réponse magnétique

« Exportation » de ce dispositif à Soleil



- (i) Machine de traction biaxiale dédiée aux matériaux souples
- (ii) Diffraction des rayons X (DRX)
- (iii) Microscope magnéto-optique à effet Kerr (MOKE)

Temps de faisceau en Juillet 2016

Merci de votre attention

LSPM-CNRS
Université Paris 13
99 Av J. B Clément
93430 Villetaneuse, France

www.lspm.cnrs.fr

Fax: +33 1 49 40 34 14
+33 1 49 40 39 38