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MODELING OF MAGNETOELECTRIC EFFECTS IN MAGNETOSTRICTIVE / PIEZOELECTRIC MULTILAYERS USING A MULTIPHYSICS SIMULATOR.

F. Rasoanoavy[1] , V. Laur[1], R. Smaali[2] , P. Queffelec[1]

[1]University of Brest – CNRS, UMR 3192 Lab-STICC, ISSTB, 6 av. Le Gorgeu, CS 93837, 29238 Brest Cedex 3, France.

[2]Clermont Université, Univesité Blaise Pascal, Lasmea, BP 10448, F-63000 Clermont-Ferrand 2- CNRS, UMR 6602, LASMEA, F63177

Lab-STICC

Outline

- Context
- Magnetoelectric effect
- Theoritical aspects
- Static modeling of magnetoelectric structures
- RF simulations of magnetoelectric structures
- Conclusion and prospects

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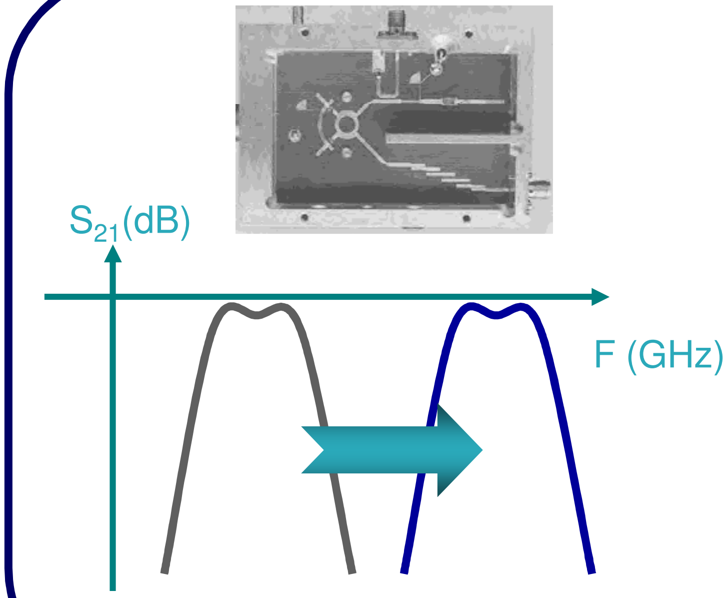
Context

Wireless technology development / emerging services

➥ Compact and low cost tunable systems



Transmission parameters of a tunable filter

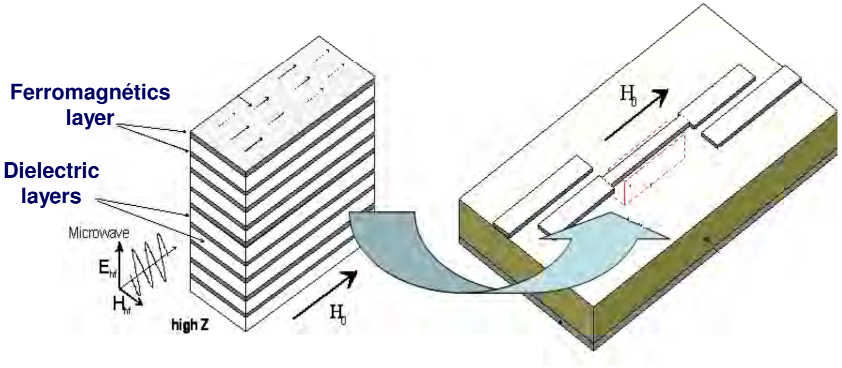
Substrates with tunable ε and/or μ:

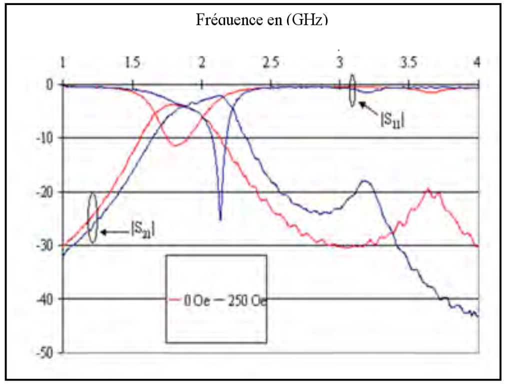
- ✓ Ferroelectrics
- ✓ Ferromagnetics
- ✓ Liquid Crystals
- ✓….

$$fr = \frac{c}{2l_{eff}\sqrt{\varepsilon_{eff} \times \mu_{eff}}}$$

Context

- ➢ Use of ferroelectric layers :
  - ☺ Electrical biasing
  - ☹ Impedance mismatch (high ε) & Loss Tanδ>10^{-2}
- ➢ Use of ferromagnetic layers :
  - ☺ Significant variations of μ under a weak bias field (max 250 Oe)
  - ☹ Application of an external DC magnetic field (coils integration)





Δ H_0 = 250Oe Fr:1,8→2,1GHz

→ Δ F/F = 19 %

➡ Association of piezoelectric and magnetostrictive materials

- ☺ high tunability of ferromagnetic materials
- ☺ enable an electrical biasing
- ☺ low losses compared with ferroelectrics

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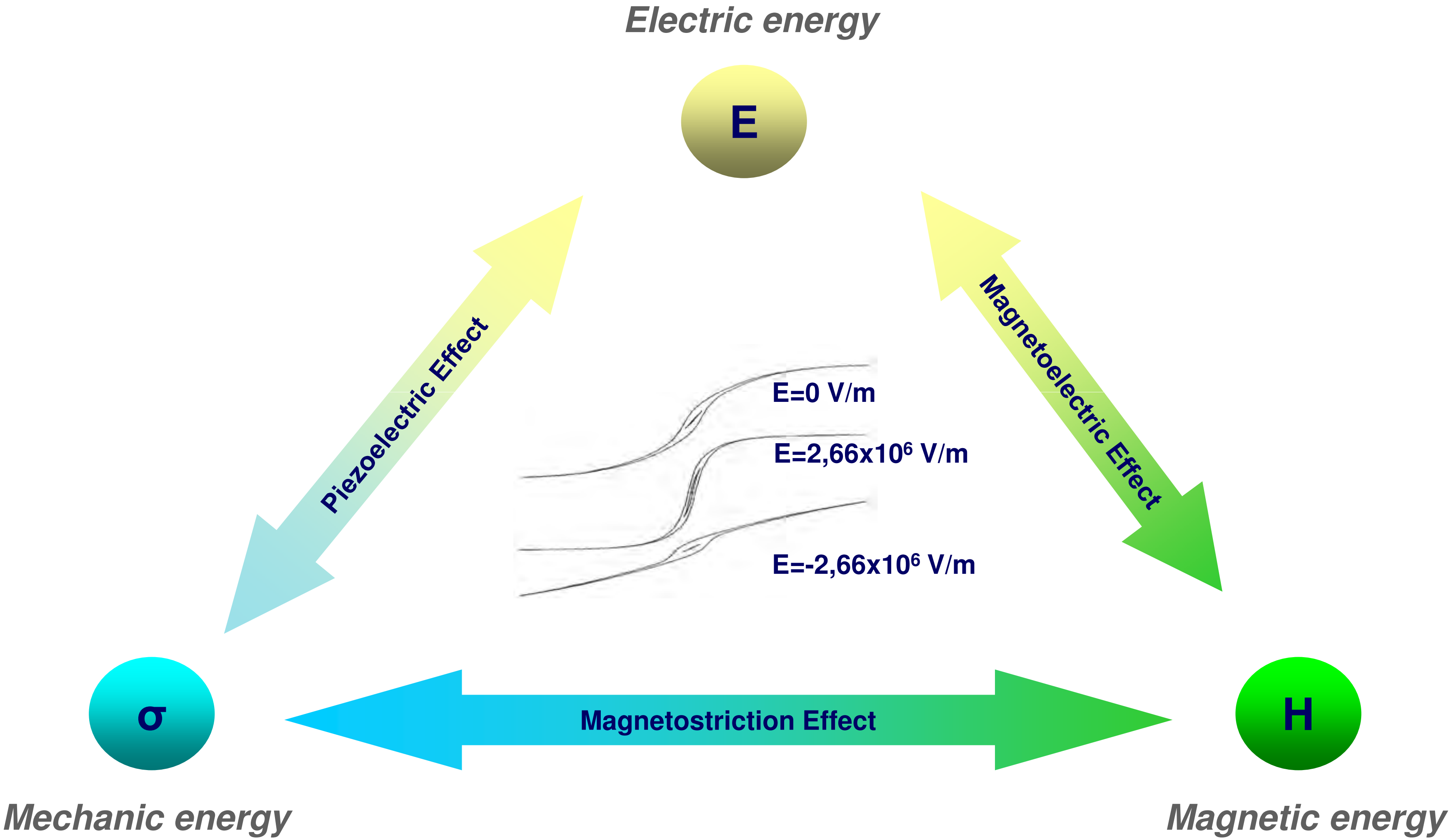
Magnetoelectric effects



Electric energy

E

Piezoelectric Effect

Magnetoelectric Effect

E=0 V/m

E=2,66x10^6 V/m

E=-2,66x10^6 V/m

σ

Magnetostriction Effect

H

Mechanic energy

Magnetic energy

November 17-19, 2010 Comsol Conference

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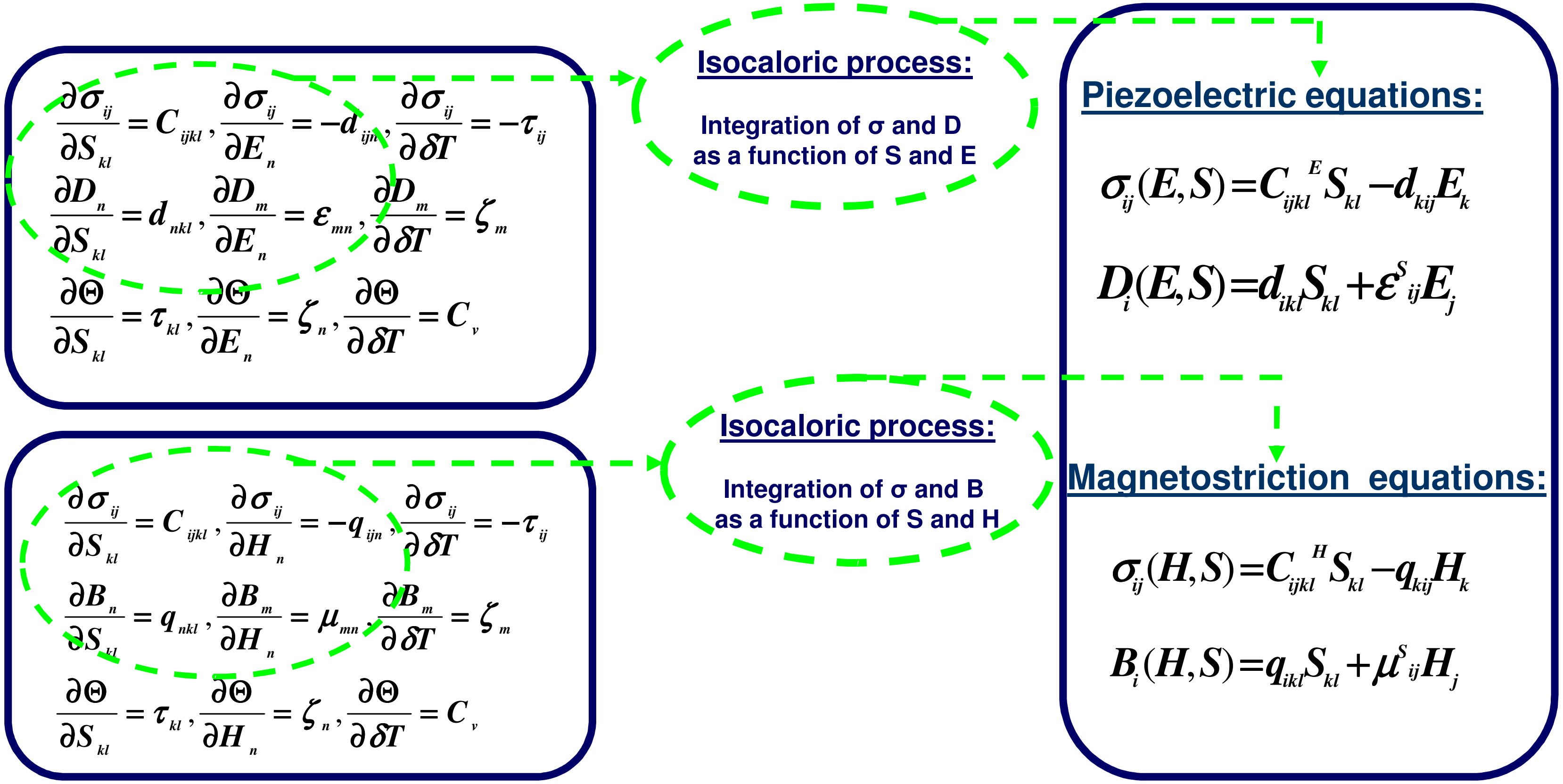
Theoritical aspects

Maxwell and Callen’s relationships for an « electro-magneto-mechanics » system give us:



$$\frac{\partial \sigma_{ij}}{\partial S_{kl}} = C_{ijkl},\ \frac{\partial \sigma_{ij}}{\partial E_{n}} = -d_{ijn},\ \frac{\partial \sigma_{ij}}{\partial \delta T} = -\tau_{ij}$$

$$\frac{\partial D_{n}}{\partial S_{kl}} = d_{nkl},\ \frac{\partial D_{m}}{\partial E_{n}} = \varepsilon_{mn},\ \frac{\partial D_{m}}{\partial \delta T} = \zeta_{m}$$

$$\frac{\partial \Theta}{\partial S_{kl}} = \tau_{kl},\ \frac{\partial \Theta}{\partial E_{n}} = \zeta_{n},\ \frac{\partial \Theta}{\partial \delta T} = C_{v}$$

Isocaloric process:

Integration of σ and D as a function of S and E

Piezoelectric equations:

$$\sigma_{ij}(E,S) = C_{ijkl}{}^{E} S_{kl} - d_{kij} E_{k}$$

$$D_{i}(E,S) = d_{ikl} S_{kl} + \varepsilon^{S}{}_{ij} E_{j}$$

$$\frac{\partial \sigma_{ij}}{\partial S_{kl}} = C_{ijkl},\ \frac{\partial \sigma_{ij}}{\partial H_{n}} = -q_{ijn},\ \frac{\partial \sigma_{ij}}{\partial \delta T} = -\tau_{ij}$$

$$\frac{\partial B_{n}}{\partial S_{kl}} = q_{nkl},\ \frac{\partial B_{m}}{\partial H_{n}} = \mu_{mn},\ \frac{\partial B_{m}}{\partial \delta T} = \zeta_{m}$$

$$\frac{\partial \Theta}{\partial S_{kl}} = \tau_{kl},\ \frac{\partial \Theta}{\partial H_{n}} = \zeta_{n},\ \frac{\partial \Theta}{\partial \delta T} = C_{v}$$

Isocaloric process:

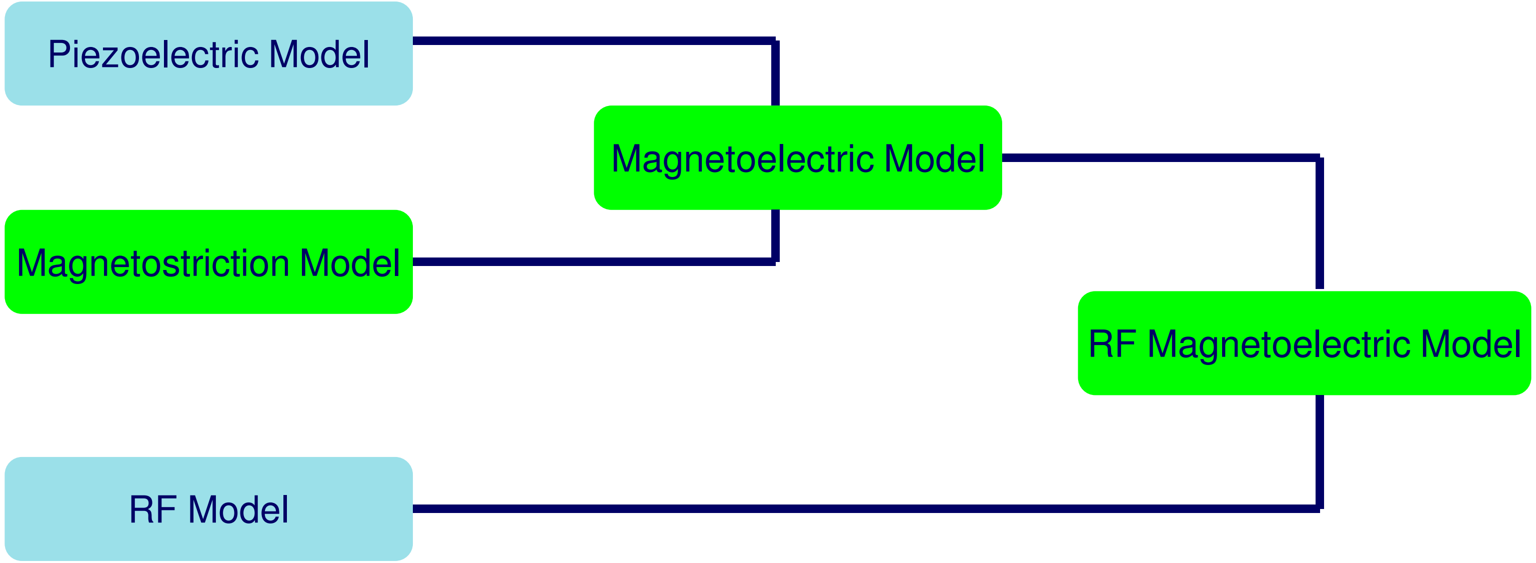
Integration of σ and B as a function of S and H

Magnetostriction equations:

$$\sigma_{ij}(H,S) = C_{ijkl}{}^{H} S_{kl} - q_{kij} H_{k}$$

$$B_{i}(H,S) = q_{ikl} S_{kl} + \mu^{S}{}_{ij} H_{j}$$

Theoritical aspects



« X » Model Already integrated in Comsol Multiphysics

« X » Model Developed and Implemented in Comsol Multiphysics (at the Lab-STICC)

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Modeling of magnetoelectric structures

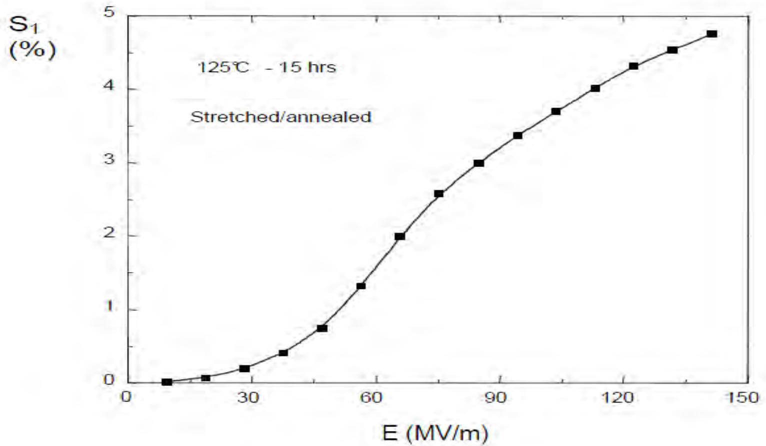
Validation of piezoelectric model : Comparison between experimental and Comsol-based deflections of a PVDF cantilever

Sample holder

Metalic Electrode

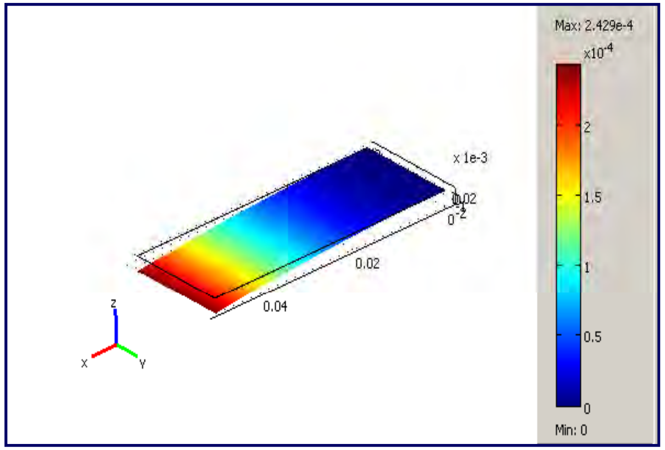
PVDF thick film

Metalic Electrode



PVDF longitudinal strain as a function of stregnth electric field

*Q. M. Zhang and col. « Recent advences in highly Electrostrictive P(VDF-TrFE-CFE »

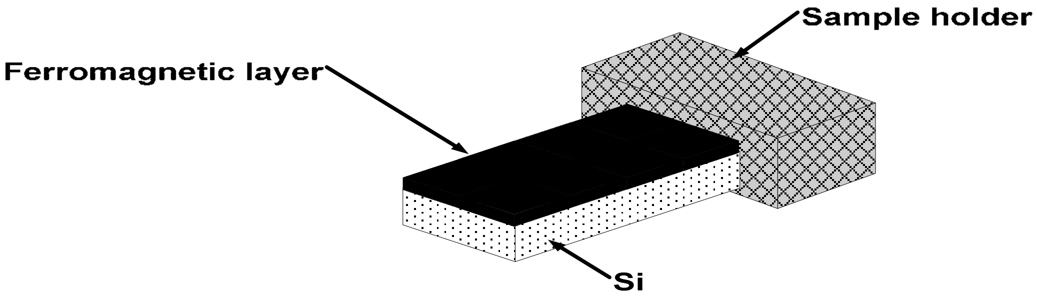


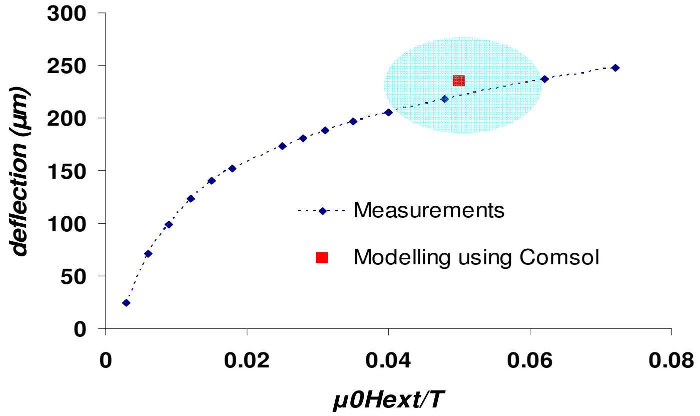
Comsol-based simulation of a PVDF cantilever

➡ Good agreement between experimental and Comsol-based deflections

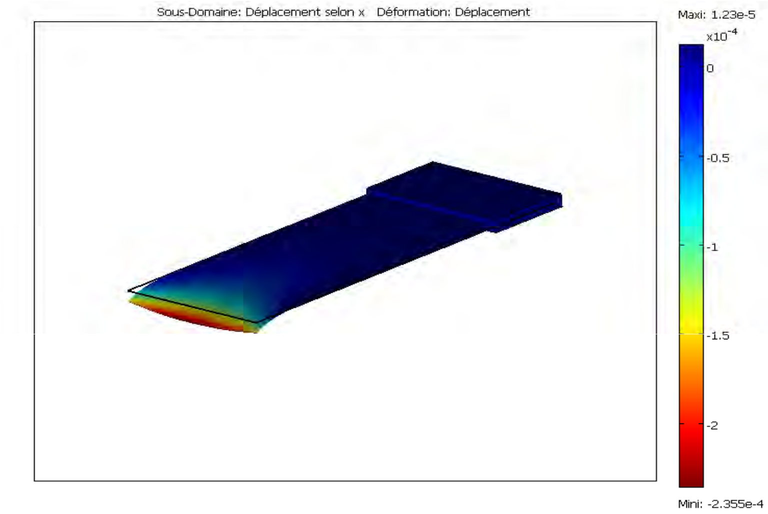
Modeling of magnetoelectric structures

Validation of the developed magnetostrictive model





Comparison between Comsol-based calculated deflection and experimental results for a TbDyFe / Si cantilever.



Finite-element calculated deflection of a TbDyFe / Si cantilever under a DC magnetic field

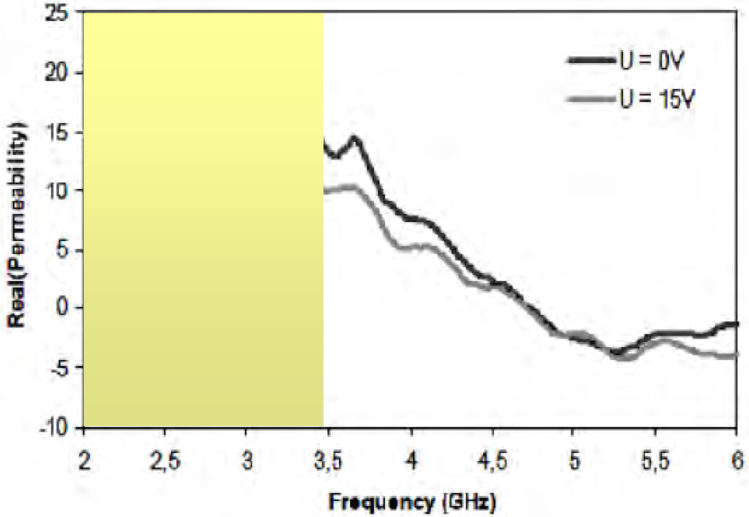
➡ Good agreement between experimental and Comsol-based deflections

Modeling of magnetoelectric structures

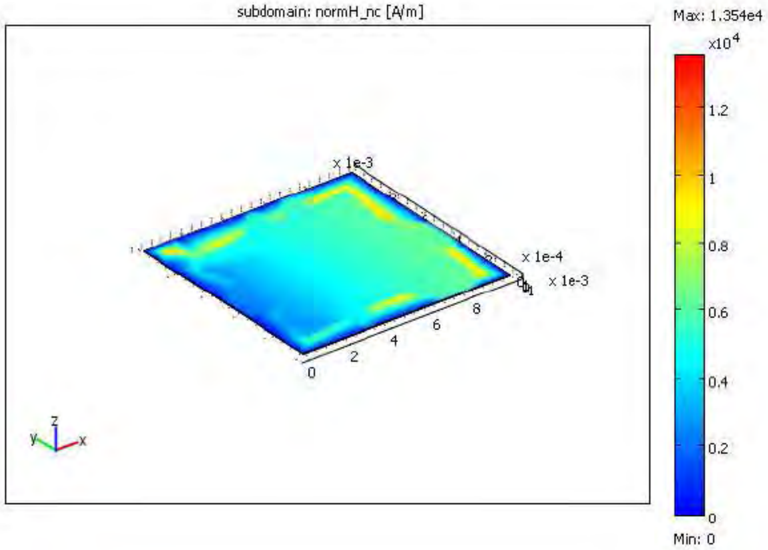
Modeling of a trilayer magnetoelectric structure

PVDF
e = 10µm, ε = 11 , d_{33} = –33 pC/N, d_{31} = 23 pC/N

FeCoB Magnetostrictive layers
e = 140 nm, H_K = 20 Oe, $4\pi M_s$ = 19000 G, λ_s = 50.10^{-6}



Permeability spectrum measured in a tri-layered (FeCoB / PVDF / FeCoB) structure under an electrical voltage U=15V.

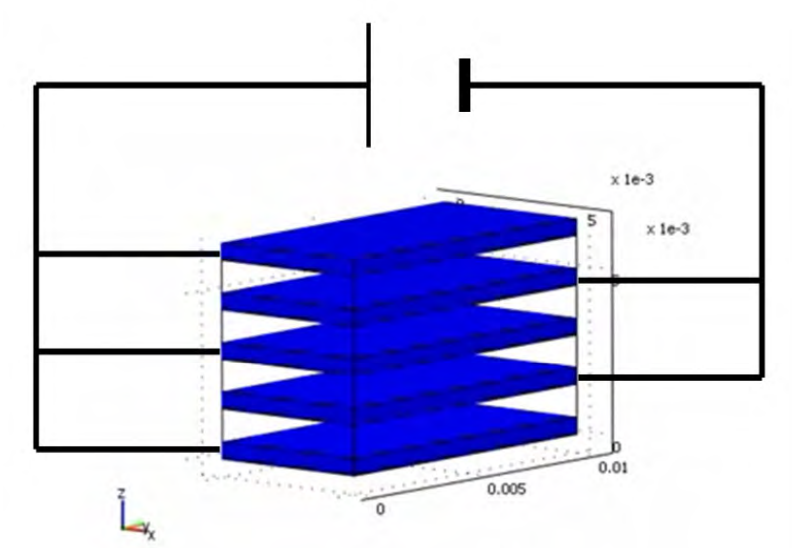


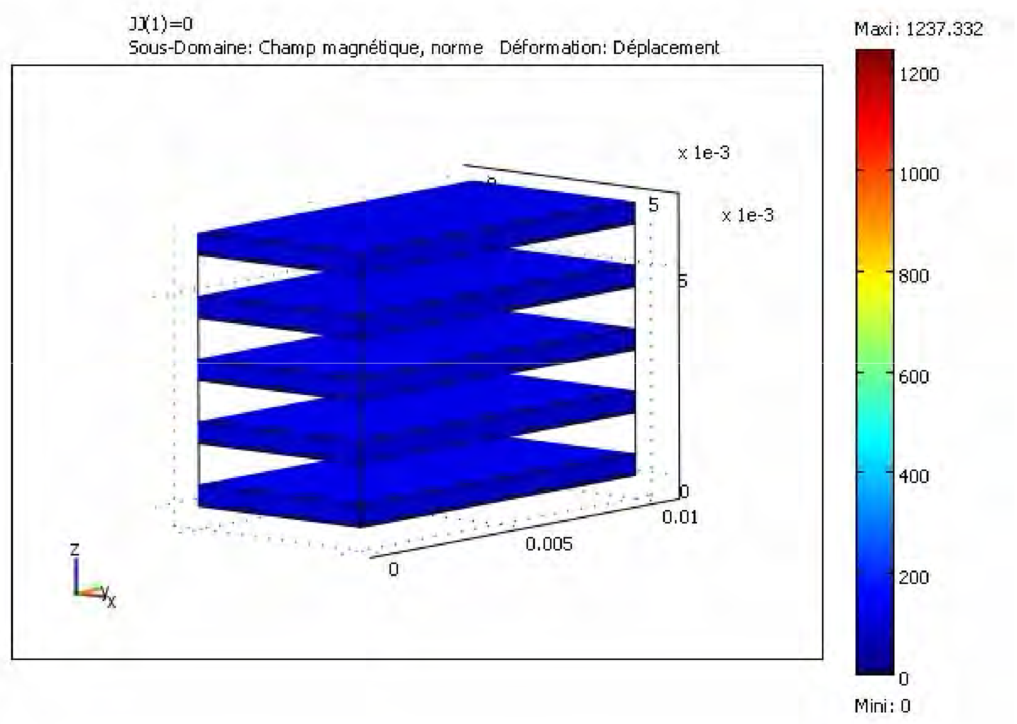
Induced magnetic field about of 60Oe in the FeCoB layer under a static electric field.

Decrease of the permeability (~30%) under an electric field of 1,5MV/m, corresponding with the calculated of the magnitude field induced using static magnetoelectric model

Modeling of magnetoelectric structures

Modeling of a multilayer {piezoelectric/magnetostrictive}x5 structure





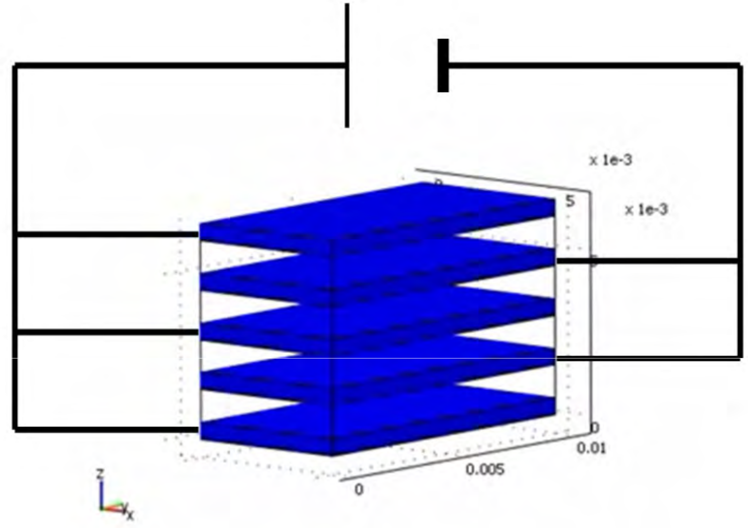
☺ Stronger interaction with RF field (c

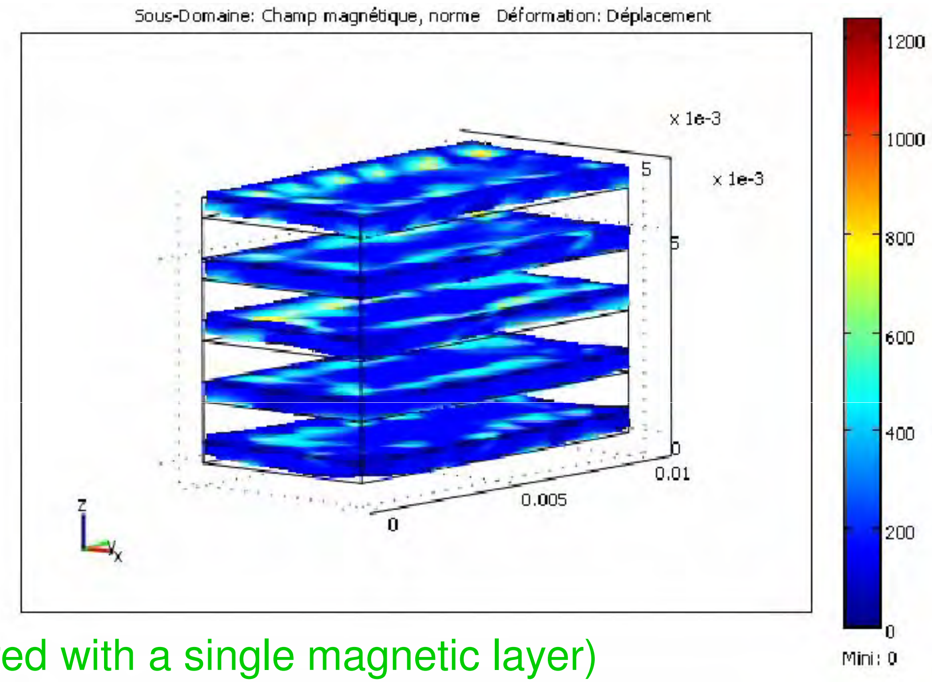
☹ Technologically complicated

➡ Mulitlayer composite driven by a piezoelectric actuator (electric field bias)

Modeling of magnetoelectric structures

Modeling of a multilayer {piezoelectric/magnetostrictive}x5 structure





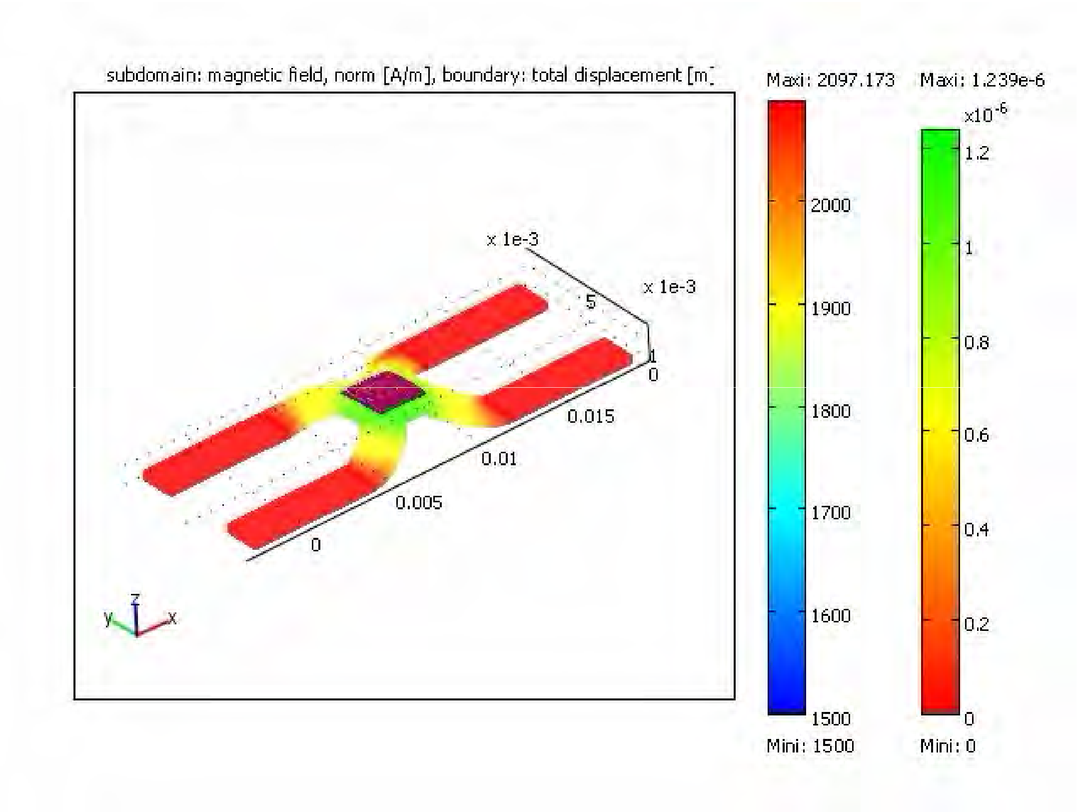
☺ Stronger interaction with RF field (compared with a single magnetic layer)

☹ Technologically complicated

➡ Mulitlayer composite driven by a piezoelectric actuator (electric field bias)

Modeling of magnetoelectric structures

Uniaxial piezoelectric actuators for microwave tunable applications



☺ The stress induced by the application of electric field leads to an induced magnetic field about of 25Oe in the multilayer

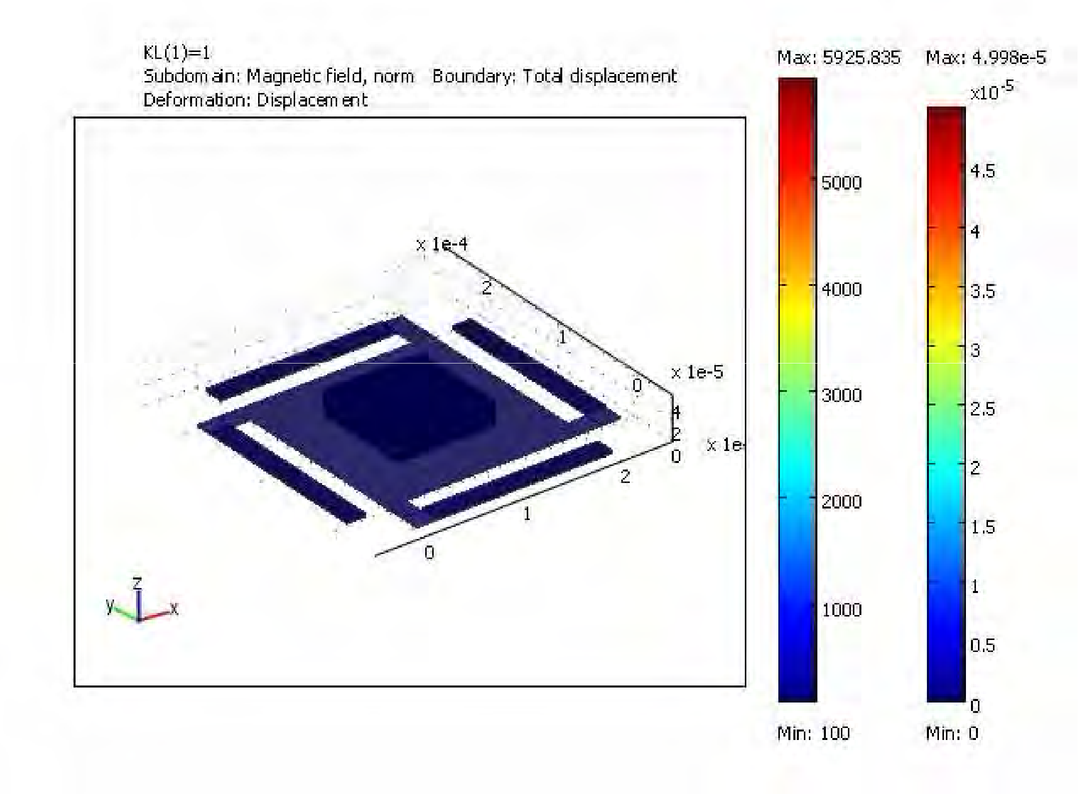
☺ Low DC bias Voltage

☺ Easy integration in RF circuit

☹ Weak strain induced at interface { Multilayer / piezoelectric actuator } (compared with biaxial structure)

Modeling of magnetoelectric structures

Biaxial piezoelectric actuators for microwave tunable applications



☺ Stronger strain induced in the Multilayer.

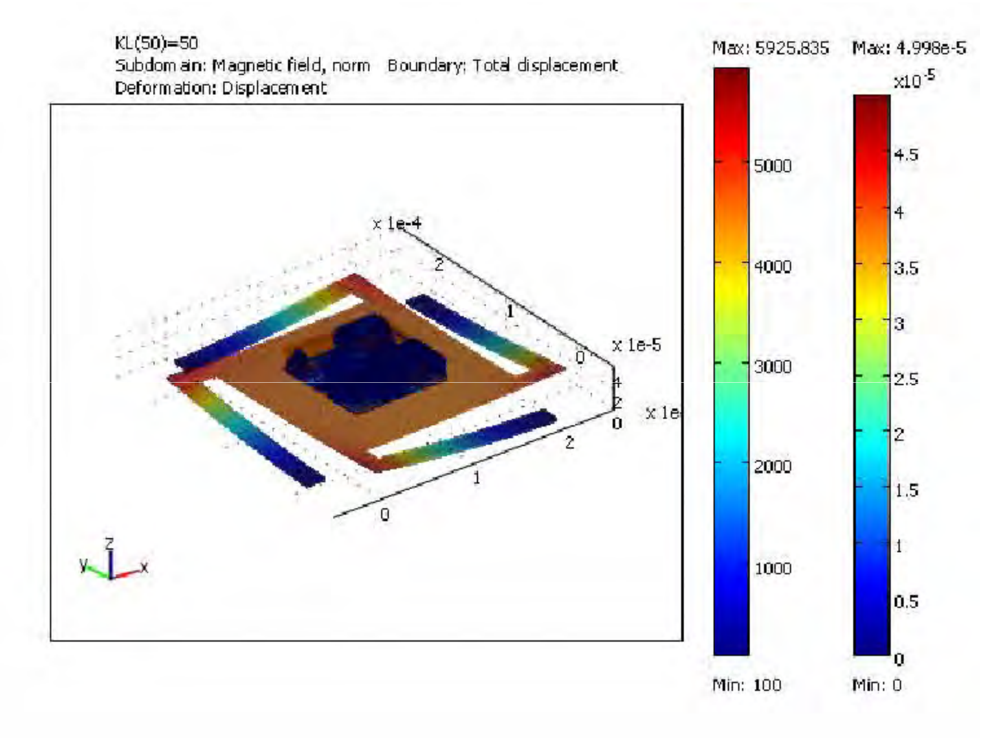
☺ Easy integration in RF circuit

☺ Low DC bias Voltage

☹ Complicated fabrication

Modeling of magnetoelectric structures

Biaxial piezoelectric actuators for microwave tunable applications



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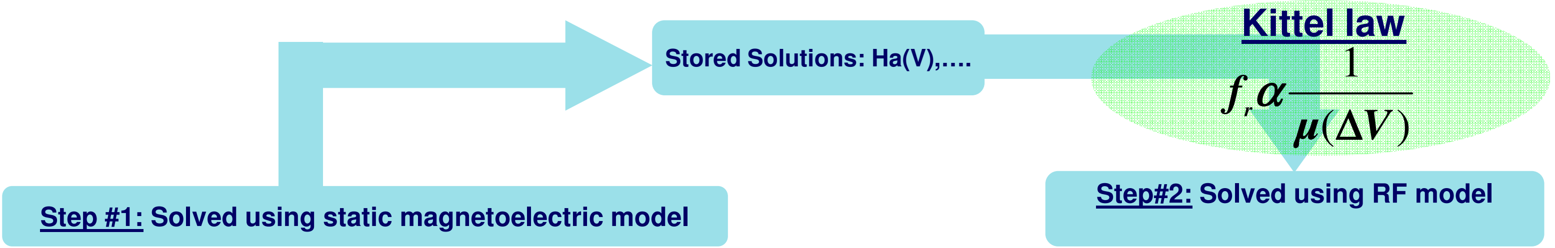
RF simulations of magnetoelectric structures

Magnetoelectric tunable microstrip line



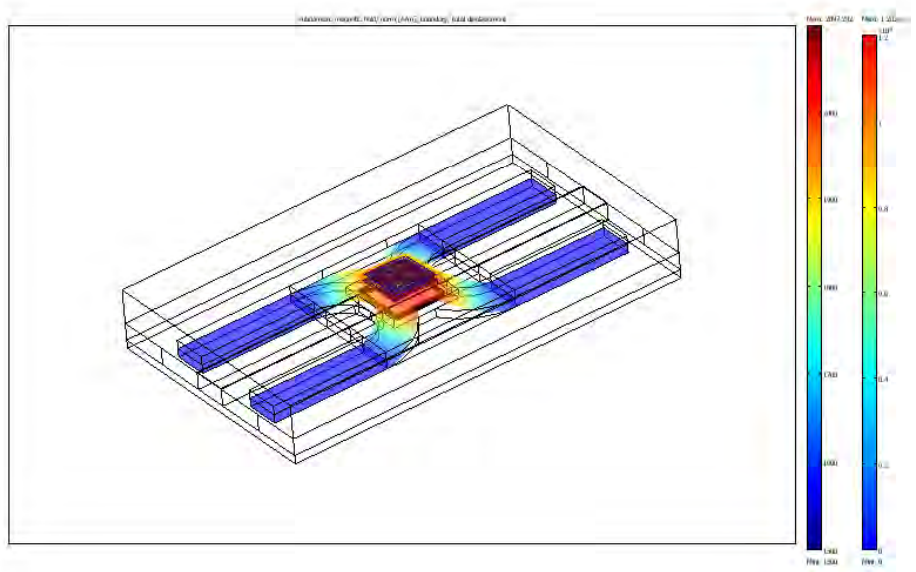
Stored Solutions: Ha(V),....

Kittel law

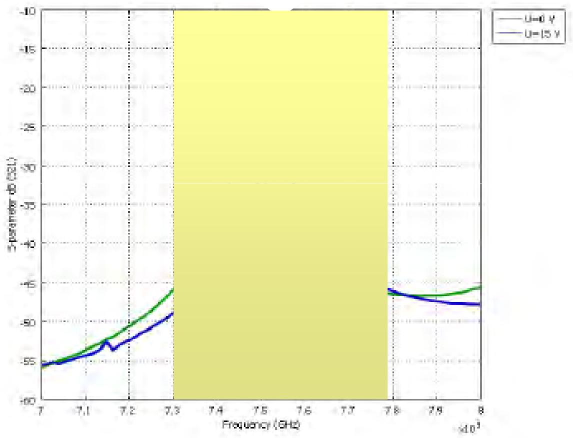
$$f_r \alpha \frac{1}{\mu(\Delta V)}$$

Step #1: Solved using static magnetoelectric model

Step#2: Solved using RF model



Induced magnetic field distribution , actuated by a piezoelectric actuator (uniaxial), under an electrical voltage U=15V



Magnitude of the transmission parameter of a microstrip line loaded by a magnetodielectric actuator for 0V and 15V.

☺ Tuning of the resonance peak about of 50MHz under an external electric field (U=15V)

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Conclusion

- ➢ Development of a magnetostriction, and magnetoelectric specific models using Comsol Multiphysics

- ➢ Capacity to determine:

  - the total displacement of the actuator
  - the stress induced in the ferromagnetic layer
  - the voltage induced magnetic field in the ferromagnetic layers

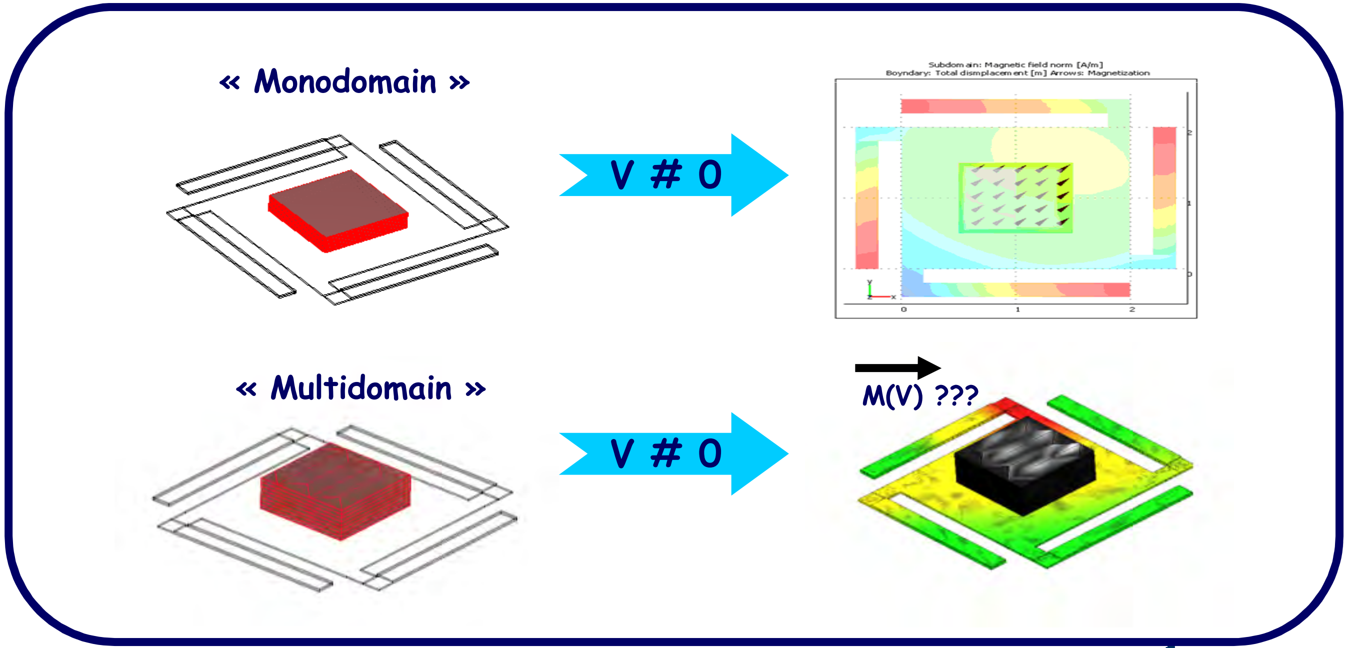
- ➢ Developement of a RF tunable magnetoelectric model:

  - simulation of a tunable microstrip line based on {ferromagnetic/PVDF} multilayers driven by an electric field

Prospects

➢ Future use of Comsol:

- design of new magnetoelectric tunable RF functions
- implementation of the free energy model (rotation of the magnetization)
- implementation micromagnetic simulations (domains wall movements)



Thank You for Your Attention