Magnetoelectric coupling mechanisms in the multiferroic composite Co/PMN-PT(011) - a search using X-ray magnetic circular dichroism

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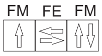
Introduction - multiferroic composites and their spintronics potential

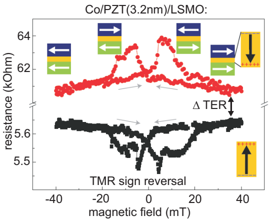
Artificial Multiferroics, such as ferromagnetic–ferroelectric heterostructures, are a route to obtain strong magnetoelectric (ME) coupling at room temperature.
The interactions between the magnetic and electric orders are not only of scientific but also of technological interest, as they could allow the electric control of magnetic properties and lead to new device concepts, e.g. multiferroic tunnel junctions (MTJ) [1].



Tunnel electroresistance (TER)
Tunnel magnetoresistance (TMR)

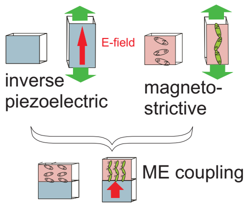
Pantel et al.: Ability to control the amount and sign of the interface spin polarization in MTJ's, [2].

The origin of theTMR sign change is yet under debate and could be assigned to hybridization or charge screening as relevant coupling mechanisms.

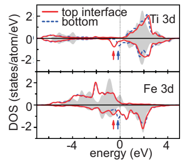


Proposed coupling mechanisms between a ferromagnet and a ferroelectric

Strain
Elastic coupling at the ferromagnet-ferroelectric interface.

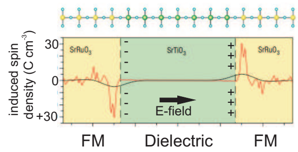


Hybridization
Change in interface bonding upon reversing the polarization e.g. Fe/BaTiO$_3$ [3],[4] .



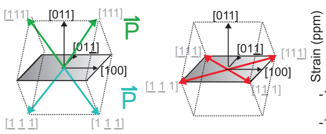
Orbital-resolved DOS for interfacial atoms in a Fe/BaTiO3 multilayer [3]

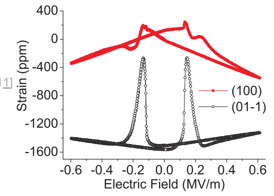
Charge screening
Carrier mediated accumulation of spin-polarized carriers is a general characteristic of all ferromagnetic electrodes in contact with insulators, regardless of the details of bonding [5],[6].



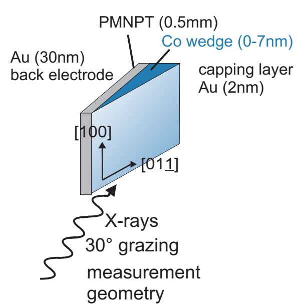
Co on [Pb(Mg$_{1/3}$Nb$_{2/3}$)O$_3$]$_{0.68}$-[PbTiO$_3$]$_{0.32}$ (011) - a multiferroic composite

Relaxor ferroelectric close to the morphotrophic phase boundary
Rhombohedral crystal structure [7], 60μC/cm^2
Possible polarization states:





ref.[7]



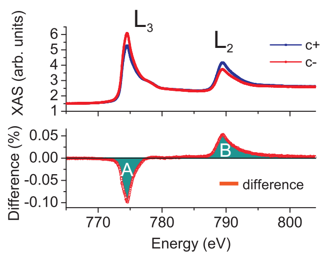
Technique: X-ray magnetic circular dichroism

- Element selective
- Surface sensitive
- XMCD sign determines the spin orientation
- Sum rules give quantitative information on spin and orbital angular momenta [8]:

$$\mu_{s,eff} = \frac{-(A-2B)\mu_B * n_h}{I(L_3)+I(L_2)}$$

n_h No of 3d holes

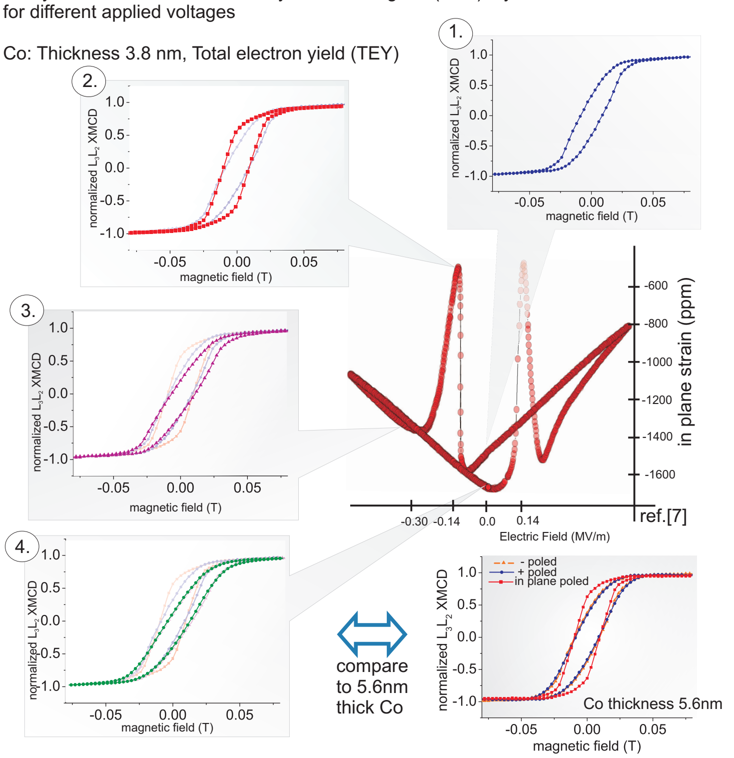
Co XMCD arising from the directional spin alignment.



Strain mediated magnetoelectric coupling

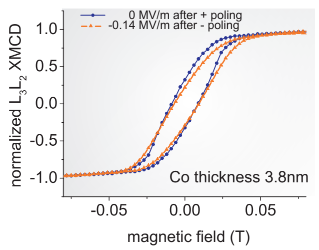
Co hysteresis curves measured by XMCD along the (01-1) crystal direction for different applied voltages

Co: Thickness 3.8 nm, Total electron yield (TEY)

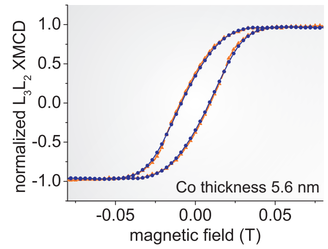


Charge driven magnetoelectric coupling

Dependence on the substrate polarity

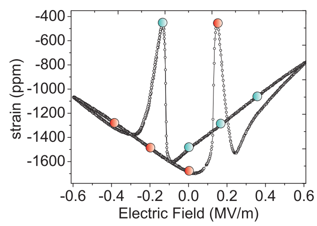


magnetic anisotropy influenced by the spin accumulation /depletion (same in plane strain !)

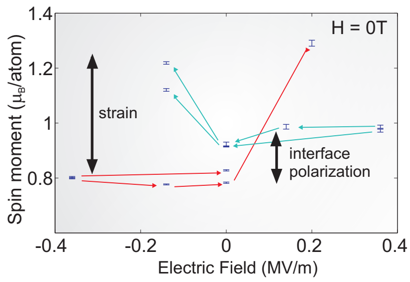


The thickness is larger then probing depth (TEY). As expected it is an interface effect.

XMCD sum rule analysis



For perpendicular to the plane poled PMN-PT the strain curve inhibits a slope depending on the applied voltage.



This slope dependence (see left figure) is not found in the spin moment obtained from sum rules analysis [8].
Here, it is only relevant, whether the polarization is pointing towards the interface or away from it.

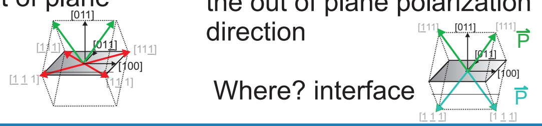
Summary: We observe 2 different coupling mechanisms

Strain
Development of an easy axis (in plane vs out of plane polarization)

Where? bulk

Charge screening
Co spin moment depends on the out of plane polarization direction

Where? interface



References

[1] Y. Wang et al., NPG Asia Mater. 2(2), 61 (2010).
[2] D. Pantel et al., Nature materials Vol 11, 289 (2012).
[3] C. G. Duan et al. , PRL 97, 047201 (2006).
[4] S. Valencia et al. , Nature materials Vol 10, 753 (2011).
[5] M. Ye. Zhuravlev et al. PRB 81, 104419 (2010).
[6] J. M. Rondinelli et al., Nature nanotechnology Vol 3, 46 (2008).
[7] T. Wu et al., J. Appl. Phys. 109, 124101 (2011).
[8] J. Stöhr, JMMM 200, 470 (1999).