

## SLS Symposium on Magnetism

Tuesday, February 12, 2013

10:00 to 12:15, WBGB/019

### 10:00 Luminescence-based scanning transmission x-ray microscopy

*C. A. F. Vaz, C. Moutafis, M. Buzzi, C. Quitmann, and J. Raabe*

### 10:30 XMCD/XLD study of the magnetoelectric coupling mechanism in the multiferroic composite Co/PMN-PT(011)

*J. Heidler, C. Piamonteze, R. Chopdekar, J. Dreiser, C. Jenkins, E. Arenholz, L.J. Heyderman, F. Nolting*

### 11:00 Coffee

### 11:15 Time-resolved Dynamics of Topological Solitons in Perpendicular Magnetic Anisotropy Nanostructures

*C. Moutafis, F. Büttner, A. Bisig, M. Foerster, M.A. Mawass, M. Schneider, C.M. Günther, J. Mohanty, J. Geilhufe, C.V. Korff Schmising, T. Schulz, R. Lavrijsen, J. Franken, H.J.M. Swagten, M. Weigand, S. Eisebitt, M. Kläui, J. Raabe*

### 11:45 Electric Field Induced Magnetization Reorientation in Strain Coupled Artificial Multiferroic Nanostructures

*M. Buzzia, R. V. Chopdekar, J. L. Hockel, A. Bur, G. Carman, L. J. Heyderman, F. Nolting*

# Luminescence-based scanning transmission x-ray microscopy

C. A. F. Vaz,<sup>1, a)</sup> C. Moutafis,<sup>2</sup> M. Buzzi,<sup>2</sup> C. Quitmann,<sup>2</sup> and J. Raabe<sup>2</sup>

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We show a new development in scanning transmission x-ray microscopy whereby the x-ray transmission of thin films is measured by using the x-ray induced optical luminescence radiated from the substrate.<sup>1,2</sup> As a proof of principle, we demonstrate the imaging of the magnetic domain configuration of cobalt structures fabricated on MgO(001) using x-ray induced optical luminescence in a scanning transmission microscope (Fig. 1). This method enables the measurement of the electronic and magnetic spectroscopic properties of single crystalline layers and buried heterostructures with nanometer lateral resolution and elemental sensitivity and opens scanning transmission x-ray microscopy to materials which cannot be grown on membranes or as freestanding thin films.

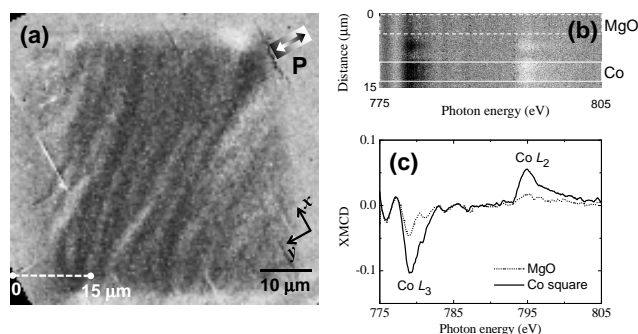


FIG. 1. Scanning x-ray magnetic dichroism images of a 50  $\mu\text{m}$  Co square defined on a 0.5 mm thick MgO(001) substrate. (b) X-ray magnetic circular dichroism energy scan for the Co  $L$  edge across the dashed line shown in (a); the signal integrated across the full and dashed box is shown in (c) for the MgO and Co regions of the sample.

<sup>1</sup>C. A. F. Vaz, C. Moutafis, C. Quitmann, and J. Raabe, Appl. Phys. Lett. **101**, 083114 (2012).

<sup>2</sup>C. A. F. Vaz, C. Moutafis, M. Buzzi, and J. Raabe, “X-ray excited optical luminescence of metal oxide single crystals,” (2013), unpublished.

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# XMCD/XLD study of the magnetoelectric coupling mechanism in the multiferroic composite Co/PMN-PT(011)

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Since the turn of the century multiferroics i.e. materials with more than one ferroic order, have seen a tremendous revival of activity, because the electric-field control of magnetism could enable new device paradigms [1]. The progress has been fueled by the growth of multiferroic composites, which show simultaneous ferromagnetic and ferroelectric (FE) ordering across different layers and have the potential for significantly enhanced magnetoelectric responses at room temperature. One of the envisaged strategies to achieve magnetoelectric coupling in composite multiferroics relies on strain to couple between the FE phase via the piezoelectric effect and the magnetic phase via magnetostriction.

$[\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3]_{(1-x)}\text{-}[\text{PbTiO}_3]_x$  (PMN-PT) is an relaxor ferroelectric with strong piezoelectric properties near the morphotropic phase boundary  $x=0.3$  [2] - Wu et al. reported on the piezoelectric properties for PMN-PT(011) (see Fig. 1), which exhibits a remanent in-plane FE polarization in addition to the two out-of-plane polarizations [3]. To shed light on the impact of the FE order of PMN-PT(011) on the electronic and atomic structure of a Co top layer we employed X-ray magnetic circular dichroism (XMCD) and X-ray linear dichroism (XLD) measurements for Co and Ti respectively. In Fig. 2 the development of an magnetic easy axis upon rotation of the FE polarization in-plane is shown. Besides strain-mediated coupling, we will present data indicating an additional charge driven magnetoelectric coupling due to accumulation/depletion of electrons at the Co/PMN-PT interface.

[1] J. M. Rondinelli, M. Stengel and N. Spaldin, *Nature Nanotechnology* **3**, 46 (2008).

[2] M. Ghasemifard and Gh. H. Khorrami, *Modern Physics Letters B* **26**, No18, 1250118 (2012).

[3] T. Wu et al., *Appl. Phys. Lett.* **98**, 012504 (2011).

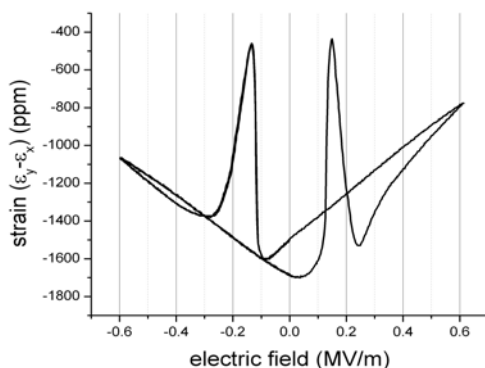


Figure 1: in-plane piezoelectric strain response upon switching the ferroelectric substrate PMN-PT (011) measured with a biaxial strain gauge [1]. At +/- 0.14 MV/m the FE polarization rotates in-plane.

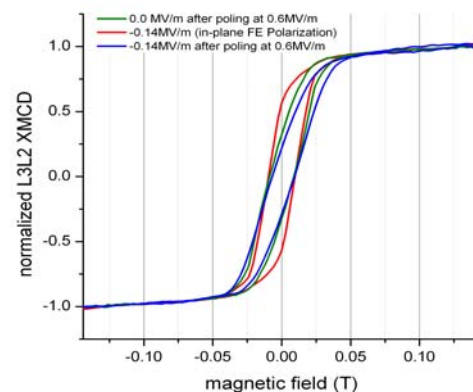


Figure 2: XMCD hysteresis loops measured in grazing incidence along the [01-1] direction as a function of applied electric field. Green /blue spectra correspond to an oop FE polarization of PMN-PT, the red hysteresis loop depicts the development of an magnetic easy axis when the FE polarization is switched in-plane.

# Time-resolved Dynamics of Topological Solitons in Perpendicular Magnetic Anisotropy Nanostructures

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Magnetic bubbles are topological solitons in perpendicular magnetic anisotropy (PMA) materials [1]. It has been predicted that confined PMA solitons exhibit intriguing dynamical behaviour such as a gyrotropic motion, ultra-fast switching and breathing-like expansion and shrinking of the magnetic bubble's size [1-2]. Their rich excitation spectrum is directly linked to their topological properties, as described by their Skymion number [1,2]. However, dynamical imaging of such behaviour has been missing until now. We provide here a first experimental demonstration of the previously predicted rich dynamics of magnetic topological solitons confined in perpendicular anisotropy nanostructures: specifically, we present time-resolved direct imaging data of i) the gyrotropic motion of such solitons, as well as ii) their expansion and shrinking dynamics. We image these dynamics with a pump-and-probe scheme and picosecond time-scale resolution using Scanning Transmission X-ray Microscopy and X-ray holography. We use a tailored magnetic superlattice configuration ([Ta(2)/Pt(2)/[CoB(0.35)/Pt(0.7)]x39/CoB(0.35)/Pt(2)] and [Pt(2)/[CoB(0.4)/Pt(0.7)]x29/CoB(0.4)/Pt(2)]), microfabricated in disc-shaped dots, that enabled the pump-and-probe PMA dynamics [3].

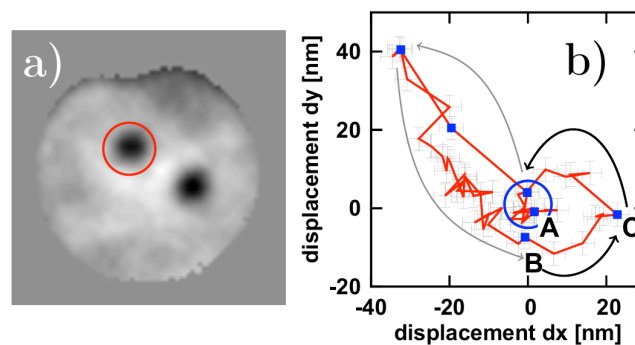


Figure 1. a) A 600 nm diameter CoB/Pt dot in the multi-bubble state. b) The gyrotropic trajectory of the bubble under investigation (outlined by a red circle in a)).

These results show that we can now readily access and manipulate the excitation spectrum of confined PMA solitons, outline its link to their underlying topological properties and provide a much wider scope for dynamical experiments in magnetic elements beyond vortex dynamics.

[1] C. Moutafis et al., *Phys. Rev. B* **76**, 104426, 2007.

[2] C. Moutafis et al., *Phys. Rev. B* **79**, 224429, 2009.

[3] R. Lavrijsen et al., *Appl. Phys. Lett.* **98**, 132502, 2011.

# Electric Field Induced Magnetization Reorientation in Strain Coupled Artificial Multiferroic Nanostructures

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The continuously increasing demand of data storage systems that exhibit both high-speed and low energy consumption has encouraged researchers to look for novel ways of manipulating and recording information. In respect to this, one promising and viable solution is to couple a magnetostrictive ferromagnet to a ferroelectric piezoelectric creating an artificial multiferroic, a material in which is possible to manipulate the magnetization configuration by applying an electric field.

In this work we demonstrate an electric field induced 90-degrees magnetization reorientation in  $200 \times 100 \text{ nm}^2$  Ni nanopillars deposited on a PMN–PT ferroelectric piezoelectric substrate. Imaging of the magnetic domain configuration was obtained using X-ray magnetic circular dichroism effect at the Ni  $L_3$  edge with the photoemission electron microscope at the Surface/Interface: Microscopy beamline of the Swiss Light Source. Applying an electric field which drives the polarization reversal of the ferroelectric, the magnetization in the nanopillar rotates coherently from the easy axis defined by the magnetostatic anisotropy, to the 90 degrees off temporary easy-axis, defined by the converse magnetoelectric interaction generated by the piezoelectric strain. The initial and final magnetization configurations are single domain as shown both by PEEM microscopy and by micromagnetic simulations rendering the observed phenomenon interesting for application in magnetoelectric MRAMs.

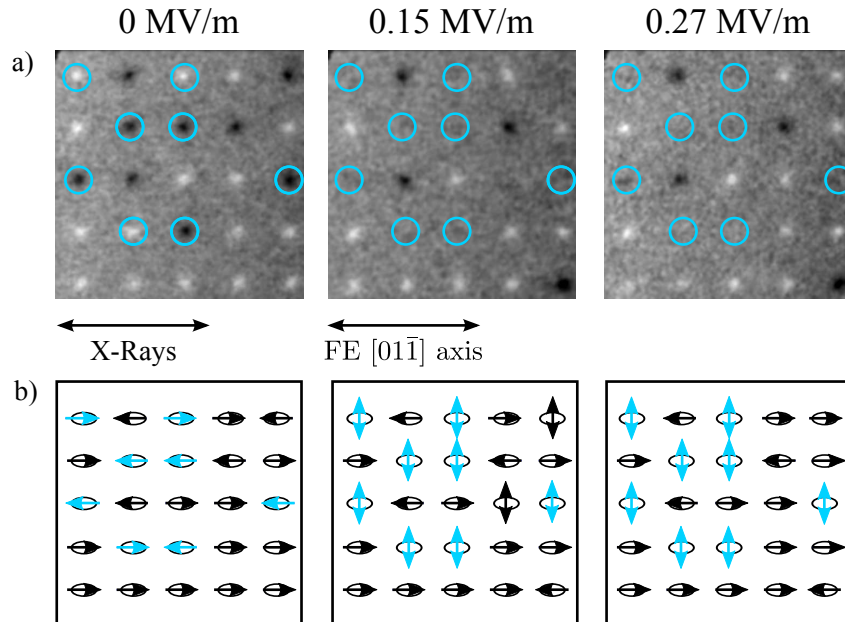


Figure 1: (a) Sequence of successive XMCD images of  $200 \times 100 \text{ nm}^2$  dot recorded at the Ni- $L_3$  edge from the same region at different applied electric fields. (b) Sketch of the magnetic configuration of the dots obtained by the XMCD contrast. The polarization reversal happening at 0.15MV/m causes the dots circled in cyan to rotate their magnetization perpendicularly to the shape anisotropy easy axis.