Magnetic Domain Imaging Of Perpendicular Exchange-Coupled Ferromagnetic/Antiferromagnetic Systems By Soft X-Ray Holography

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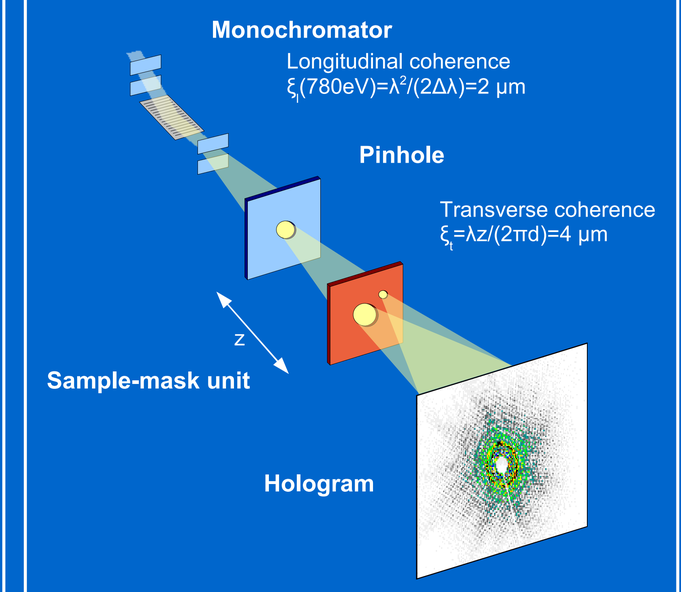
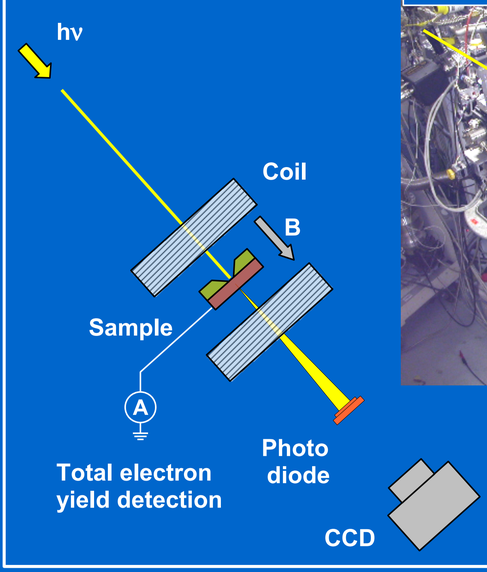
Introduction

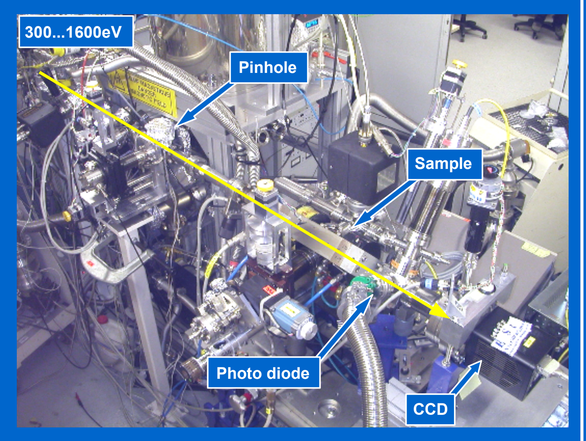
Magnetic domain imaging by soft x-ray holography [1] was employed to investigate the exchange coupling phenomenon in layered systems composed of ferromagnetic $[Co/Pt]_n$ multilayers with perpendicular anisotropy exchange-coupled to antiferromagnetic IrMn and FeMn films. We have exploited both element selectivity and the ability to image in applied magnetic fields to follow the magnetization reversal along the hysteresis loop with sub-micrometer resolution. Multiple reference holes were used for better image quality [2]. Our setup allows holographic imaging as well as absorption measurements by recording the transmitted intensity or the total electron yield signal. The sensitivity limits of this technique were explored by imaging the uncompensated moments in the antiferromagnetic layer, which correspond to an equivalent thickness of about one monolayer only [3]. Our domain images show that the uncompensated antiferromagnetic moments are aligned parallel to the magnetization of the ferromagnetic layer.

Principal setup



Setup for imaging and spectroscopy





Sample-Mask Structure

Focus Ion Beam milled Mask | **Cross-section of mask and magnetic multilayer** | **Magnetic Domain structure**

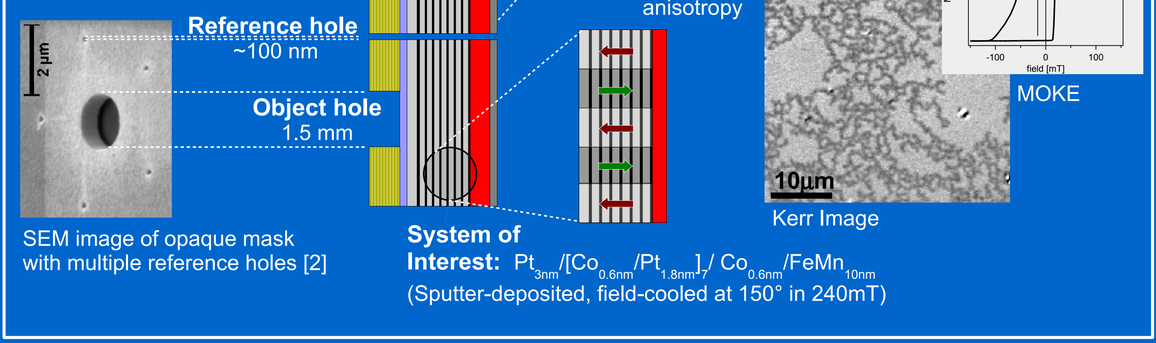
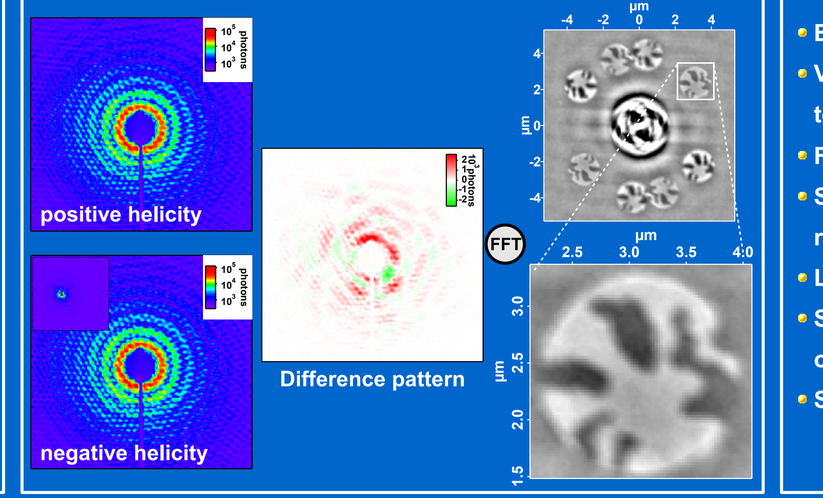


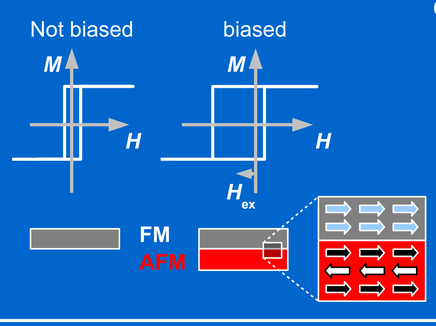
Image reconstruction



Characteristics

- Element selective imaging technique (XMCD)
- Versatile sample environment (magnetic field, temperature)
- Fast image acquisition (~10^1..10^2s)
- Straightforward and fast image reconstruction
- Large information depth (~20nm [4])
- Suited for buried and layered systems with out-of-plane magnetisation
- Sub-micrometer resolution

Role of uncompensated moments in exchange bias systems



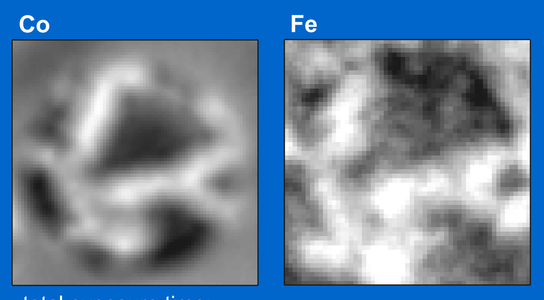
Origin of exchange bias:

Exchange coupling of FM moments to *un*compensated AFM moments

***Un*pinned moments:**
- **rotate with the FM**
- **Coercivity enhancement**

Pinned moments: <<1ML
- **anchored to the AFM**
- **Loop shift (H_{ex})**

Direct observation of uncompensated AFM moments

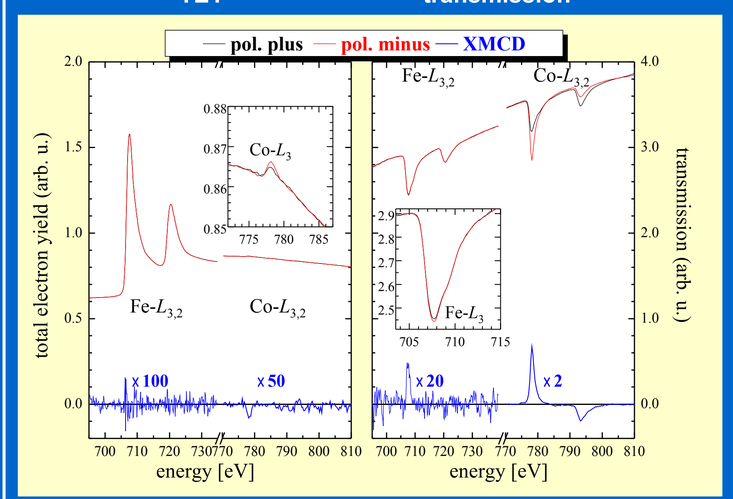


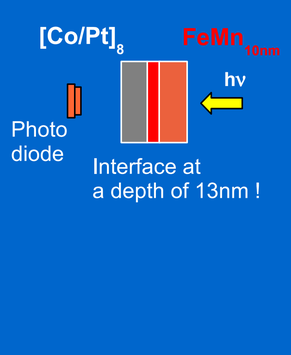
$[Co_{0.6\ nm}/Pt_{1.8\ nm}]_8 / FeMn_{1nm}$

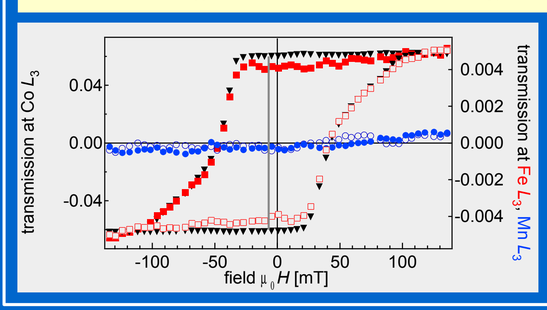
- **Moments responsible for the exchange bias effect**
- ~ 1 effective monolayer contributes to the Fe contrast [3]
  - Sufficient for imaging
- Resolution is limited by 290nm (Ø) reference hole

Spectroscopic detection of deeply buried uncompensated AFM moments

TEY | transmission







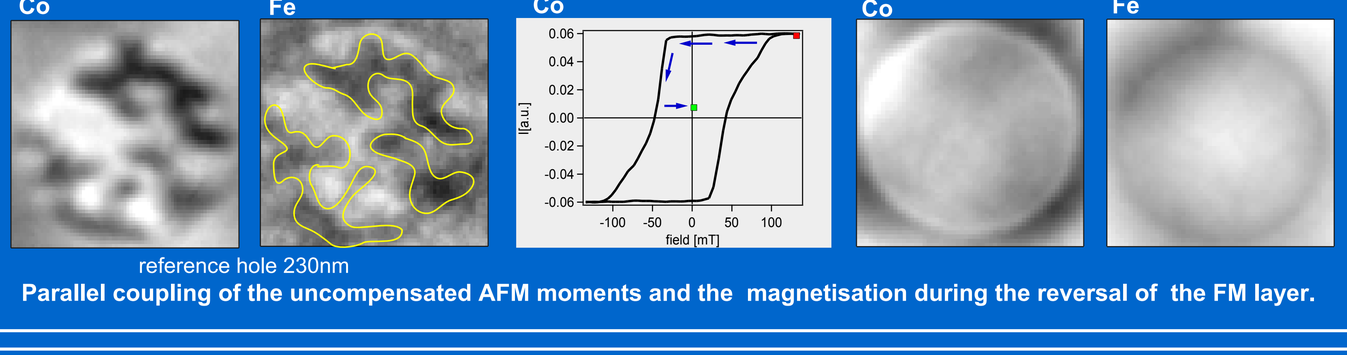
- Weak Fe signal in transmission from buried AFM moments (~1 out of 55 ML)
- Large background in transmission owing to the non-pertubated beam passing the reference holes
- TEY detection is not possible due to the limited depth sensitivity

Imaging the reversal of uncompensated AFM moments

Remanent domain structure after sweeping the field through the nucleation point

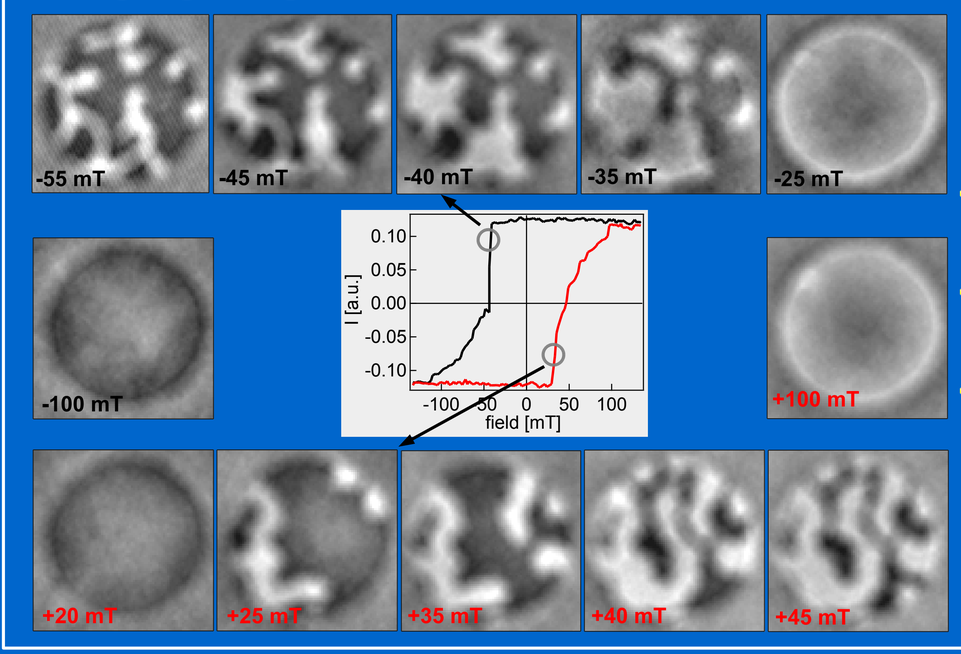
$[Co_{0.6\ nm}/Pt_{1.8\ nm}]_8 / FeMn_{10nm}$

Saturation state



Parallel coupling of the uncompensated AFM moments and the magnetisation during the reversal of the FM layer.

Imaging magnetisation reversal



- **Reversal character: Domain nucleation, domain wall propagation, annihilation**
- **Reversal along the ascending branch occurs at smaller fields and at different places**
- **Is there an asymmetric nucleation density and reversal process in both branches?**
  - **Need for a larger field of view and higher resolution (<250nm)**

References:

[1] S. Eisebitt et al., Nature **432**, 885 (2004) [2] W. F. Schlotter et al., Appl. Phys. Lett. **89**, 163112 (2006)
[3] J. Camarero et al., Appl. Phys. Lett. **89**, 232507 (2006) [4] R. Nakajima et al., PRB, 59, 6421 (1999)

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