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Lock-in transitions in magnetic stripe systems with imposed nucleation center arrays

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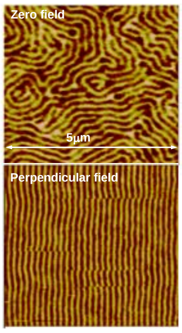
Motivation

Magnetic domains in thin films have a variety of patterns and sizes, depending on the magnetic anisotropies, magnetic history and film thickness. Thin magnetic films with *perpendicular* anisotropy can form *magnetic stripe phases* in which the domain structure self-organizes in regular patterns of up- and down magnetization resembling finger prints.



These Magnetic Force Microscopy images show 180 nm wide magnetic domains in 40 nm $GdFe_5$ thin films. After applying an in-plane magnetic field, the fingerprint pattern of the domains changes to a stripe structure.

Pinning of domain walls normally occurs on defects in the sample. We have created artificial nucleation centers in order to obtain stripe domains without an applied field. In this way pinning of domain walls can be studied statically with AFM/MFM and dynamically with time-resolved resonant x-ray scattering.

Specifically, we have used a 30 kV / 30 nm diameter Focused gallium Ion Beam probe to locally destroy the perpendicular anisotropy in such films, with ion doses ranging from 1 to 50 gallium atoms/nm². We have produced rectangular arrays of such dots with array spacing close to the domain periods of two different samples, 200 and 400 nm respectively.

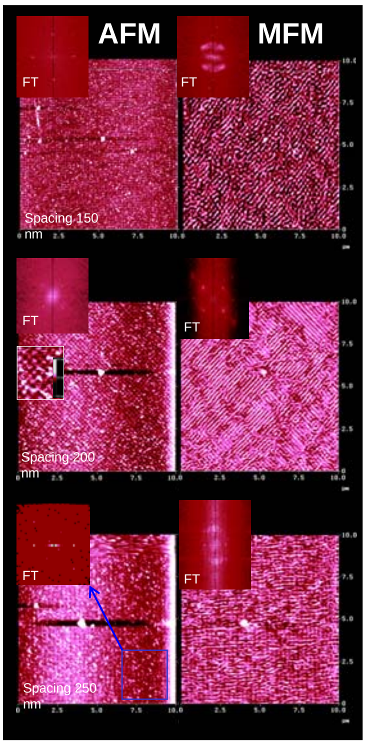
AFM / MFM $GdFe_5$ (zero applied field)

Despite the minute ion doses, AFM reveals the damage arrays as a lattice of 0.3-0.5 nm indentations, clearly visible in the Fourier transform.

MFM shows different types of lock-in transitions of the intrinsic domain pattern to the imposed damage patterns depending on their dose and spacing:

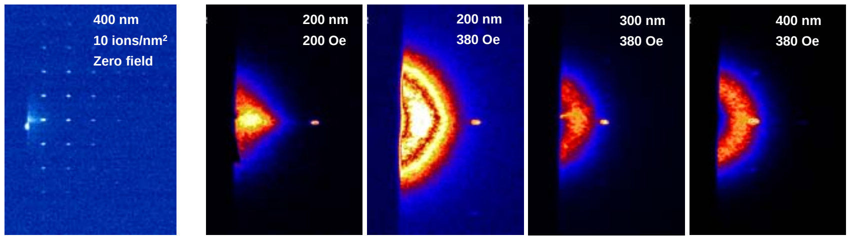
- 150 nm: ordered along diagonal of array domain width = ~ √2 x dot spacing
- 200 nm: ordered parallel to array domain width = ~ dot spacing (scan direction rotated by 45⁰)
- 250 nm: ordered parallel to array broadened domains domain width < dot spacing

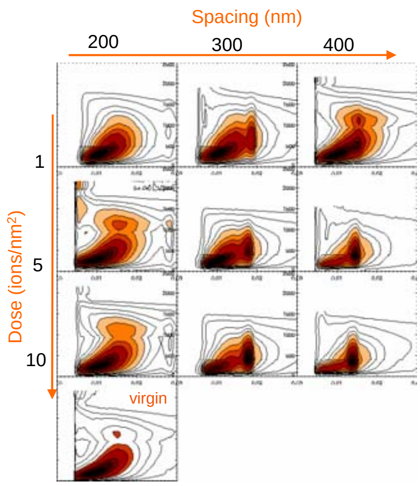
The best lock-in occurs in the 200 nm array where the domains have a correlation length of ~2-4 µm.

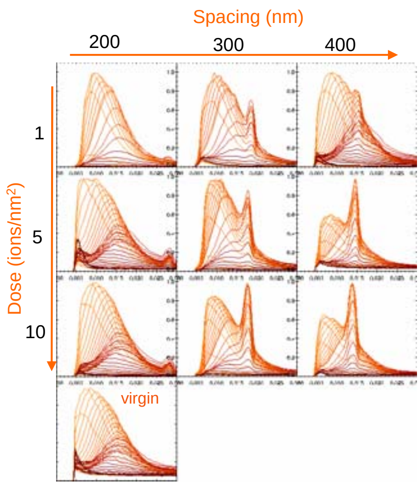


Resonant magnetic x-ray scattering ($Gd_{11.25}Tb_{3.75}Fe_{85}$)

The field dependence of these lock-in transitions has been followed with resonant x-ray scattering on another sample with higher anisotropy and 400 nm average domain size. The magnetic scattering of the dots is clearly observed and display a well-defined spacing. The stripe domains show a superposed ring of magnetic scattered intensity which locks in to the dot pattern in a manner depending on dot spacing and dose.



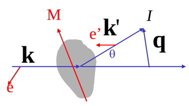




Theory

$$I \propto \left|\sum_n e^{i\mathbf{q}\cdot\mathbf{r}_n} F_n\right|^2$$

F_n Scattering amplitude



$$\mathbf{q}=\mathbf{k}'-\mathbf{k}$$

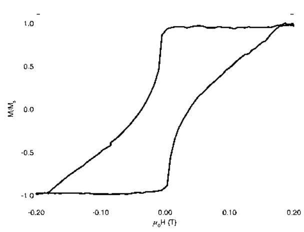
$$q=\frac{4\pi}{\lambda}\sin\theta$$

$$I \propto \left|\sum_n e^{i\mathbf{q}\cdot\mathbf{r}_n}\left[\hat{\mathbf{e}}'\cdot\hat{\mathbf{e}}F_n^{(0)} - i(\hat{\mathbf{e}}'\times\hat{\mathbf{e}})\cdot\hat{\mathbf{M}}_n F_n^{(1)} + (\hat{\mathbf{e}}'\cdot\hat{\mathbf{M}}_n)(\hat{\mathbf{e}}\cdot\hat{\mathbf{M}}_n)F_n^{(2)}\right]\right|^2$$

Charge scattering Circular dichroism Linear dichroism

The magnetic scattering cross-section depends on the polarization of the light and the direction of the magnetization.

MOKE



Hysteresis loop in perpendicular applied field.

Conclusions

- Dots produced by Focused gallium Ion Beam can serve as artificial nucleation centers.
- Pinning of domain walls produce a preferential ordering of the domains.
- The domain walls rotate and expand depending on the spacing of the array.
- Best stripe domain patterns are obtained when the lattice spacing matches the domain width.
- Magnetic domain walls are positioned on the dots of the nucleation array.

Acknowledgement

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