Investigation of magnetic domains in $(YSmLuCa)_3(FeGe)_5O_{12}$ films using MFM and other techniques

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JEMS 2019 Joint European Magnetic Symposia

AIM: Detailed analysis of the behavior of magnetic domains by magnetic force microscopy (MFM) technique in transparent ferrite–garnet films

Sample

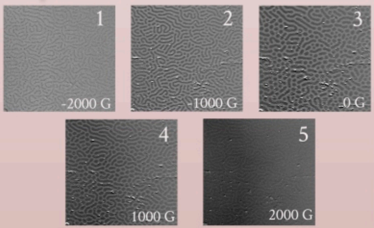
- To test the influence of various parameters of MFM measurement (the distance in the lift mode, rate of scanning, different probes, the effect of the external magnetic field etc.) we needed the sample which:
  1) is homogeneous, so that the measurements in different points are comparable,
  2) has quite smooth surface, so that it does not complicate the measurements,
  3) has clear and stable domain structure even without any external field.
- 5 µm thick magneto-optical film of $(YSmLuCa)_3(FeGe)_5O_{12}$ formed on the substrate of gadolinium gallium garnet (GGG) – $Gd_3Ga_5O_{12}$. The layer was produced by isothermal LPE method.
- The GGG is very stable at 200 –500 ~K. It used to be considered for magnetic bubble memories and still has optical applications.

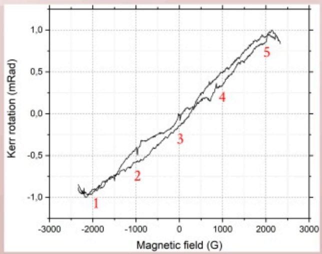
Techniques

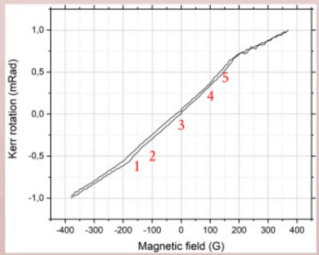
- **SEM (Scanning Electron Microscopy)** – Scanning Electron Microscope FEI Quanta 650 FEG equiped with EDX
- **MOKE (Magneto-optic Kerr effect)** – Differential magnetooptic intensity method with red laser diod (670 nm).
- **MOKM (Magneto-optical Kerr Microscopy)** – Zeiss Axio Imager D1m microscope. The microscope equipped with white xenon lamp XBO 75 W, Orca-Spark CCD camera and "Kerrlab" imaging software
- **AFM/MFM** – Ntegra Prima microscope (NT-MDT, Russia). The microscope is further extended by external magnets applying magnetic fields up to ±500 Gauss out-of-plane and ±1000 Gauss in-plane.

Magneto-optical Kerr Microscopy

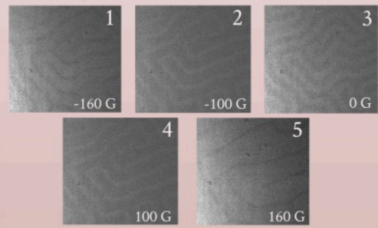
In-plane field







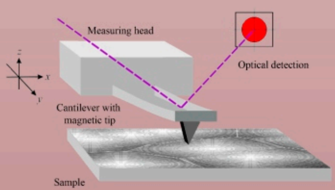
Out-of-plane field



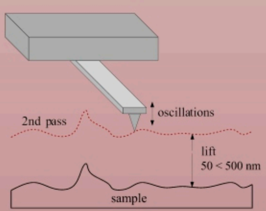
AFM - MFM: Principle of operation and results

- AFM = Atomic Force Microscopy (a) is based on the interaction between a tip and a sample via atomic forces.
- MFM = Magnetic Force Microscopy(b) - a tip covered with magnetic layer interacts with the long-range magnetic field above a sample.

a)



b)



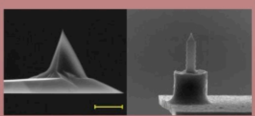
- Two pass technique AFM-MFM: the first pass reads the topography (contact or semi-contact/tapping mode), the second pass is done in the lift mode - the tip oscillates around the constant distance above the sample and acquires the information about the magnetic field. The change of the phase shift is proportional to the gradient of the magnetic force

$$\Delta\varphi \approx \frac{QF_z'}{k}$$

where Q is the quality factor of the cantilever, k its spring constant and

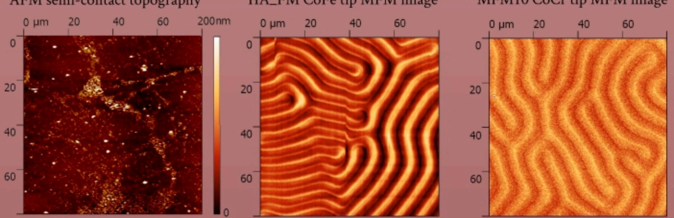
$$F_z' = \mu_0 \int \mathbf{M}_T \frac{\partial^2 \mathbf{H}_S}{\partial z^2} dV_T$$

depends on the magnetization of the tip $\mathbf{M}_T$ and the field around the sample $\mathbf{H}_S$



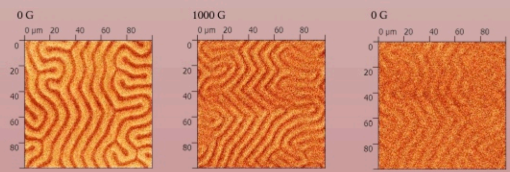
The tips are magnetized perpendiculaly to the sample surface and their coercivity is up to 16 kA/m.

MFM01 and MFM10 with CoCr coating (on the left, the the yellow line has a length of 5 µm)
HA_FM with CoFe coating (on the right, in scale)



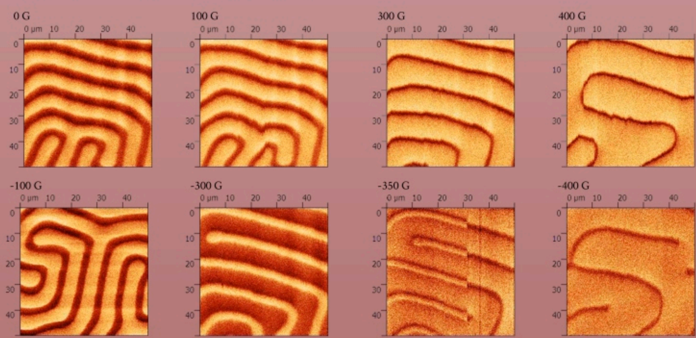
In-plane field

Magnetic field parallel to the surface in the directions → and ← was applied, with several magnitudes up to 1000 Gauss. MFM10 probe, lift height 300 nm. Only minor changes in domain shapes can be recognized, the magnetic contrast gradually decreased due to the demagnetization of a tip.



Out-of-plane field

Magnetic field perpendicular to the surface in the directions up and down was applied, with several gradually increasing magnitudes up to 500 Gauss. MFM10 probe, lift height 300 nm.
Major changes in domain structure were observed. The magnetic contrast decreased and even inverted due to the interaction of a tip with external field.



- In out-of-plane external field domain walls shift, the brightly depicted domains are expanding, the dark ones shrinking.
- After the change of the orientation of the field to the opposite direction, the dark domains become wider and the bright ones narrow down.
- At 350 Gauss the magnetic contrast fades considerably and at 32µm column there is an image inversion as a result of the switch of the tip magnetization. The dark and the bright spots in the last two images would otherwise be opposite.

This work was supported by the projects SP 2019/26 and LQ 1602, both funded by Ministry of Education, Youth and Sports of the Czech Republic.