INFLUENCE OF THE CANTILEVER TYPE ON OBSERVATION OF MAGNETIC DOMAINS USING THE MAGNETIC FORCE MICROSCOPY IN EXTERNAL MAGNETIC FIELDS

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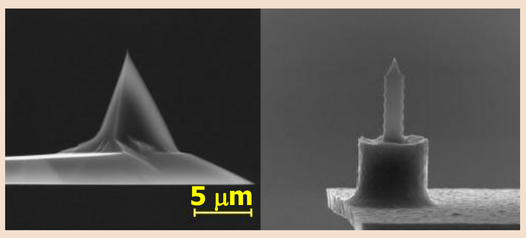
AIM: Analysis of the magnetic force microscopy (MFM) contrast on the surface of garnet magnetic film in dependence on the used probe.

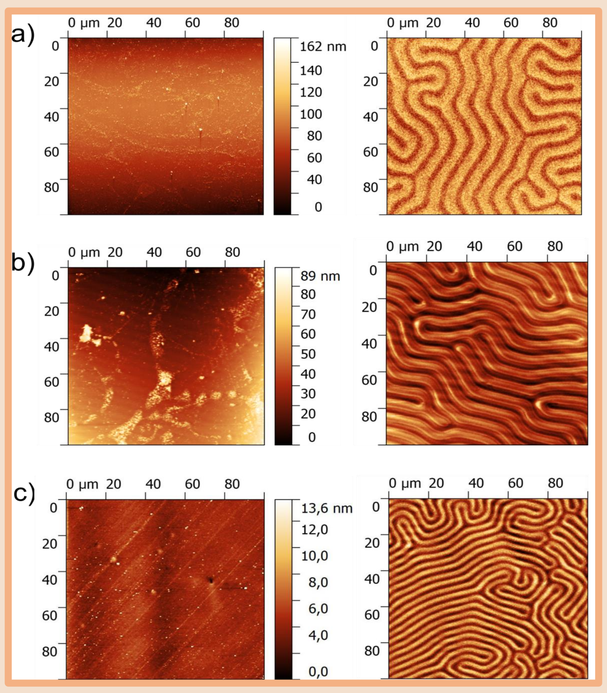
EXPERIMENTAL

- **Equipment**
  - The AFM/MFM measurements were performed at modular system NTEGRA Prima (NT-MDT).
  - Scanning by the probe.
  - Maximum size of the analyzed area 100 × 100 μm^2.
  - Resolution up to 20 nm.
  - The system is equipped with coils generating the in-plane and out-of-plane magnetic fields up to 1000 G and 500 G, respectively.
- **Sample**
  - 5 μm thick film of $(YSmLuCa)_3(FeGe)_5O_{12}$ prepared on the GGG substrate by isothermal liquid phase epitaxy (LPE).
  - Smooth surface, optimal material for magnetic bubble memories due to strong induced perpendicular magnetic anisotropy.
- **Measuring probes**
  - MFM 10 with CoCr coating (left subplot)
  - HA_FM and HA_FM/HC with CoFe and CoCr coating (right subplot)

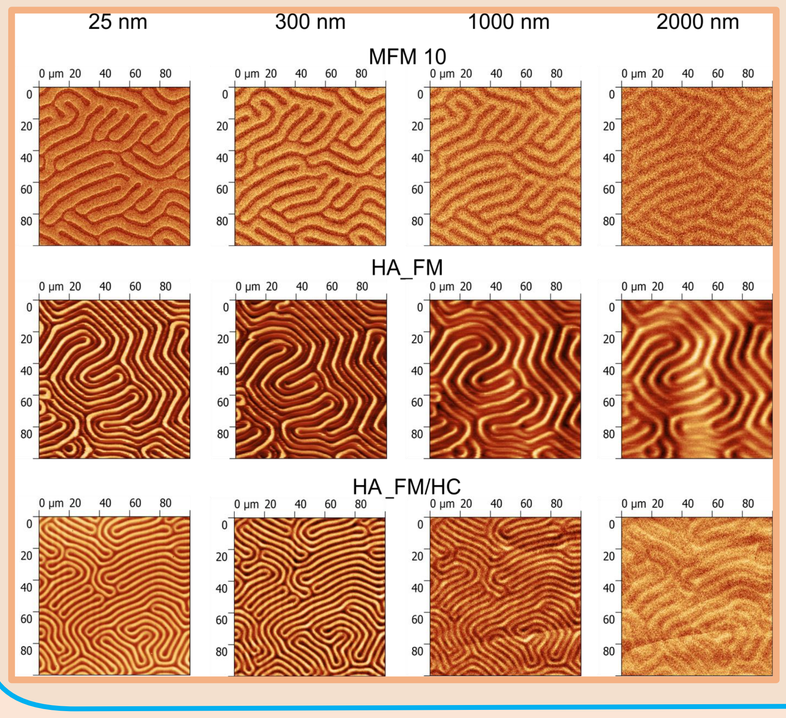


Cantilever type	Producer	Cantilever length, l ± 5μm	Cantilever width, w ± 5μm	Cantilever thickness, μm	Resonant frequency , ± 10% kHz	Force constant, ± 20%N/m	Tip coating	Tip curvature radius nm
MFM 10	NT-MDT	125	30	1.5 - 2.5	87 - 230	1.45-15.1	CoCr	40
HA_FM	NT-MDT	223	34	2.85 - 3.15	77	3.5	CoFe	65
HA_FM/HC	ScanSens	223	34	3	77	3.5	CoCr	<10

WITHOUT MAGNETIC FIELD

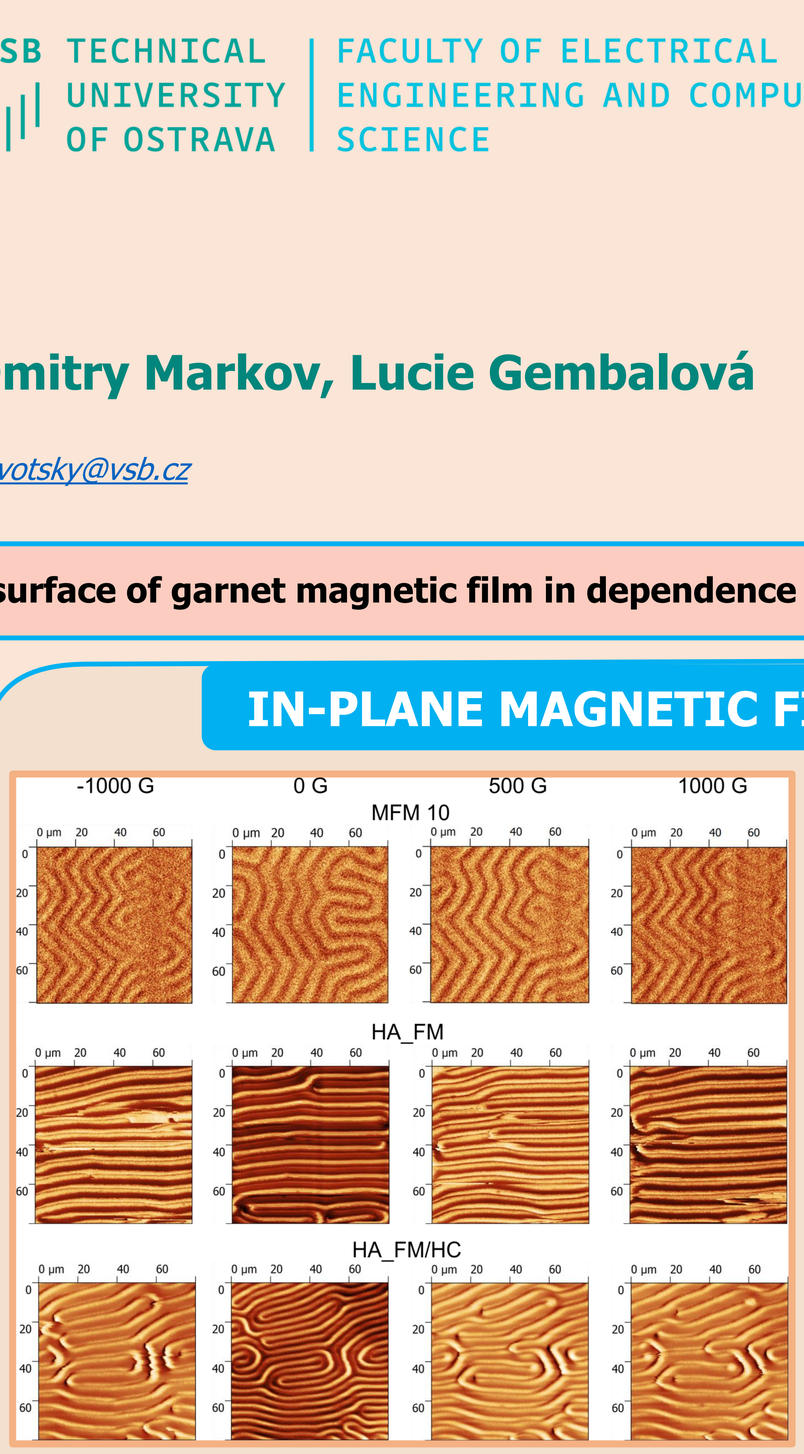


- The surface topographies (AFM, left column) and their corresponding magnetic images (phase shift, MFM, right column) observed on the surface of garnet film using the (a) MFM 10, (b) HA_FM, and (c) HA_FM/HC cantilevers. The lift of the tip in the MFM second pass is 300 nm and the scan speed is 0.5 Hz.
- Using all probes we obtained crossed stripe magnetic domain patterns indicating local perpendicular anisotropy of studied sample.
- By comparing MFM images, better and detailed magnetic contrast is measured in the case of HA_FM probe. We expect that it is connected with different geometries (see Table above) and coercive fields of used tips.

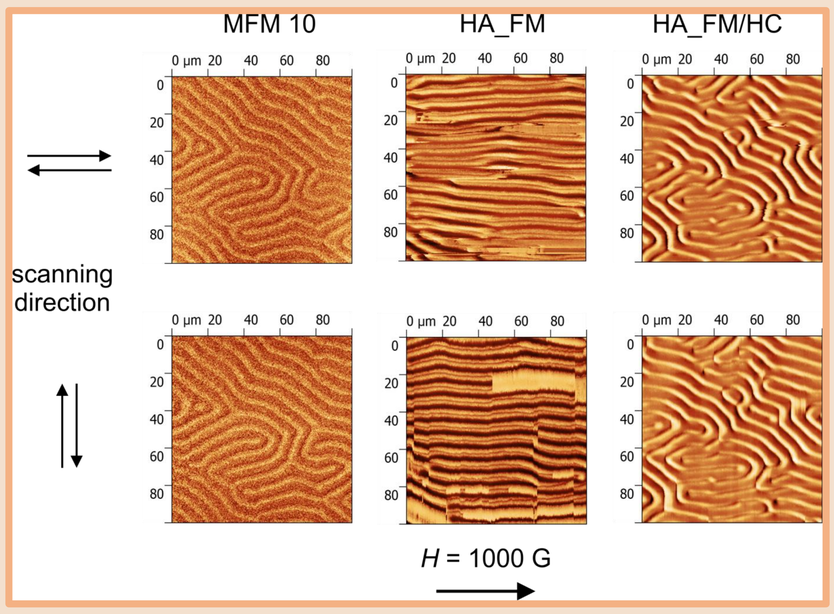


- The experiments when the scan speed is 0.5 Hz and the distance d_z between the probe and sample surface is 25 nm, 300 nm, 1000 nm, and 2000 nm.
- Optimal distance d_z for garnet film lies within the range 300 – 500 nm.
- HA_FM cantilever shows good results also for extreme heights 2000 nm and 25 nm when the domains are still readable.
- MFM 10 probe exhibits much worse MFM contrast that is significantly deteriorated with increasing / decreasing distance above 500 nm / under 300 nm.

IN-PLANE MAGNETIC FIELD

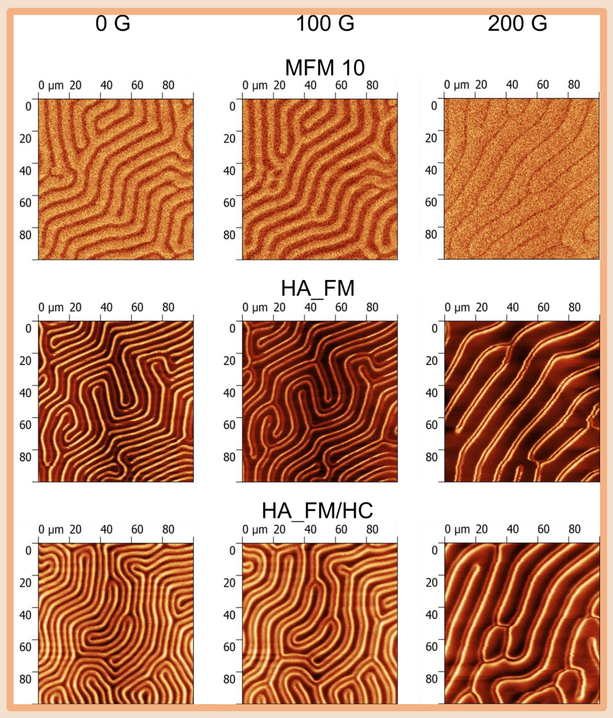


- The scanning is performed along the in-plane magnetic field changing its magnitude from -1000 G to 1000 G.
- MFM 10 shows clear contrast without signal loss and artifacts. Domain patterns do not change much, a certain decrease in contrast is detected with increasing magnetic field.
- HA_FM exhibits yellow areas corresponding to the signal loss. These areas originate at lower in-plane fields and spread with its increasing. This cantilever is inappropriate for such kind of measurements.

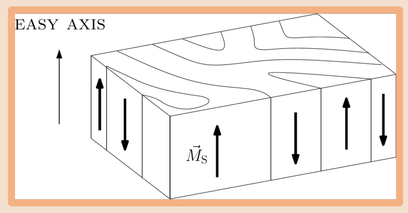


- Detection ability of probes during applying constant magnetic field 1000 G and scanning in directions parallel and perpendicular to it.
- Contrast of MFM 10 probe is not dependent on the scanning direction.
- Large yellow areas with signal loss are detected for HA_FM probe, when scanning direction is perpendicular to applied magnetic field.

OUT-OF-PLANE MAGNETIC FIELD



- Magnetic domain patterns measured without and in the presence of out-of-plane external magnetic field of 100 G and 200 G.
- Domains wall shifts are observed, domains in the direction of magnetic field are expanding at the expense of those in the opposite direction that are narrowing.
- For MFM 10 probe the magnetic contrast decreases due to the interaction of a tip with applied magnetic field.
- Sufficient contrast even at higher magnetic fields is observed for HA_FM and HA_FM/HC tips.



CONCLUSIONS

Results of the work confirm that MFM contrast observed on the surface of garnet magnetic film strongly depends on the used probe:

- Thin **HA_FM probe** with high saturation magnetization and lower coercive field is suitable for MFM experiments without and with out-of-plane magnetic fields.
- Thicker **MFM 10** probe exhibits lower saturation magnetization and higher coercive field. It gives sufficient MFM contrast even at higher in-plane magnetic fields.
- Universal **HA_FM/HC probe** shows sufficient resolution nearly for all kinds of experiments.

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