Investigation of yttrium iron garnet films with optical and magnetic force microscopy

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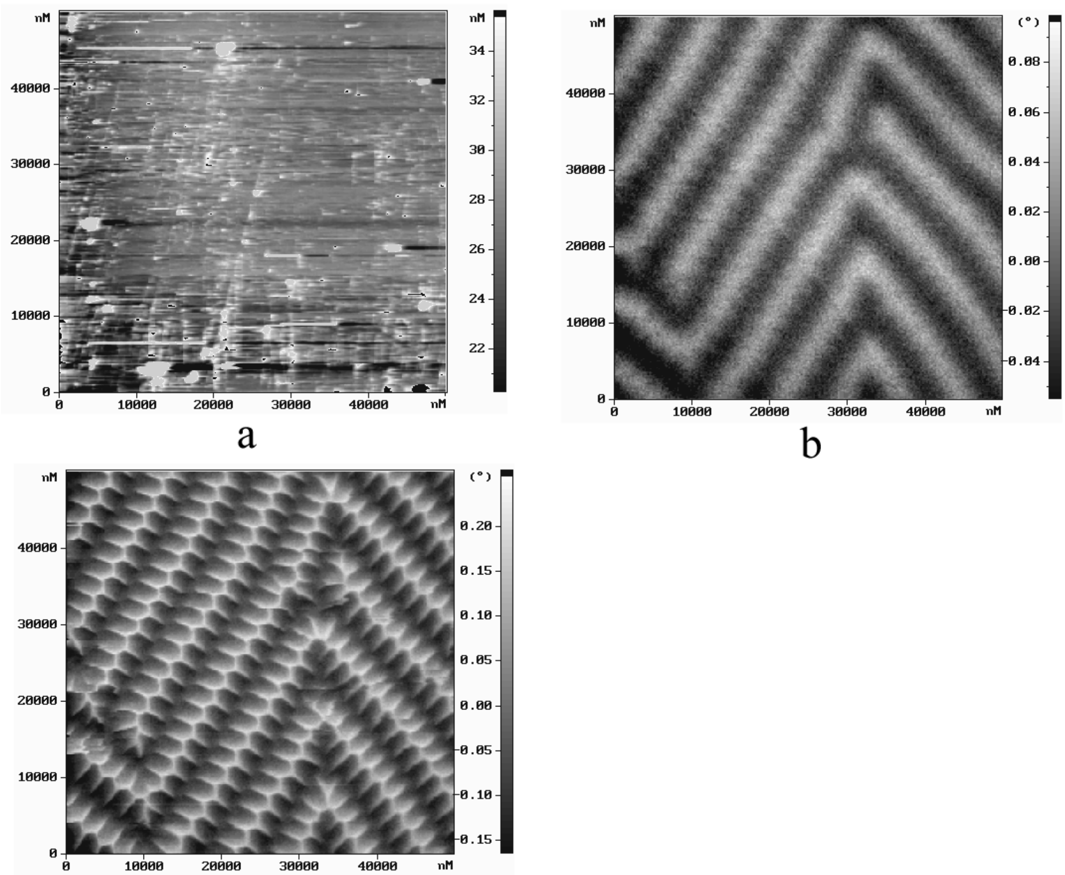
Inhomogeneous films of yttrium iron garnet (YIG) with substantial variation of anisotropy field across the film thickness have been studied using both the magnetic force microscopy (MFM) and the optical microscopy. The YIG films of thickness $d = 5 \div 30$ μm were grown epitaxially on gadolinium gallium garnet (GGG) substrates at temperature monotonically varying in time. The change ΔH in the anisotropy field across the film thickness was measured [1] with the ferromagnetic resonance (FMR) methods and appeared to be as high as 100-500 Oe.



a b c

The MFM study was performed using scanning probe microscope Solver P47H produced by NT-MDT (Russia). The device was operating in the resonant mode. Two-pass technique

[2] was used to obtain separate topographic and MFM images of the same area. The topographic line scan is first taken, and then this information is used to make the second pass at a constant user-defined flying height *h*. The shift in the cantilever phase, recorded at the second pass, is caused by the sensitivity of the cantilever coated with a ferromagnetic material to the second derivative of the sample's stray field. Two types of coating were used: Co and FeCoNi films

The magneto-optical study was carried out with a polarization microscope. The Faradey effect was used to observe domain structures in the films. Note that just stripe domain patterns were observed optically, whereas the MFM images demonstrated much moor complicated structures. Fig. 1(a) shows a topographic image (a) for the YIG film with $d = 18.7$ μm and $\Delta H = 400$ Oe. Fig. 1(b,c) are the MFM images taken at the different scan heights *h*. Fig. 1(b) broadly resembles structures seen using the optic microscope, although we have not observed optically any modulation along the stripe domain direction. In Fig. 1(c) one can see a fine structure in form of the needle-shaped pattern. This structure is typical for inhomogeneous YIG films while it has not been seen in uniform ($\Delta H < 50$ Oe) films. We believe that the fine structures observed in MFM studies are associated with the distortions of the domains in a narrow near-surface layer. Because of the small thickness, this layer is unable to make a substantial contribution to the Faraday rotation, thus we fail to observe optically these peculiarities, while the MFM allows to discover them. Note that the YIG has a smaller constant of Faradey rotation than Bi-doped garnets have. An existence of the modulation along the stripe domain direction (biperiodic stripe domain structures) can be observed in Bi-garnets by means of optics [3], but we do not know about such experiments carried out with YIG films.

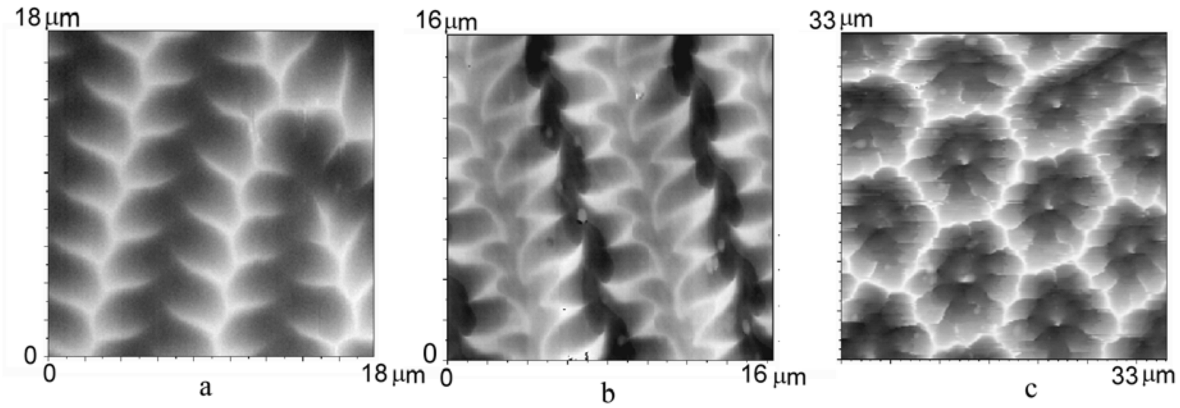


Fig. 2

Some more examples of MFM images are represented in Fig. 2, where scans (a) and (b) were made on the same film as in Fig. 1 and scan (c) shows the domain structure in the YIG film with $d = 23$ μm and $\Delta H = 370$ Oe.

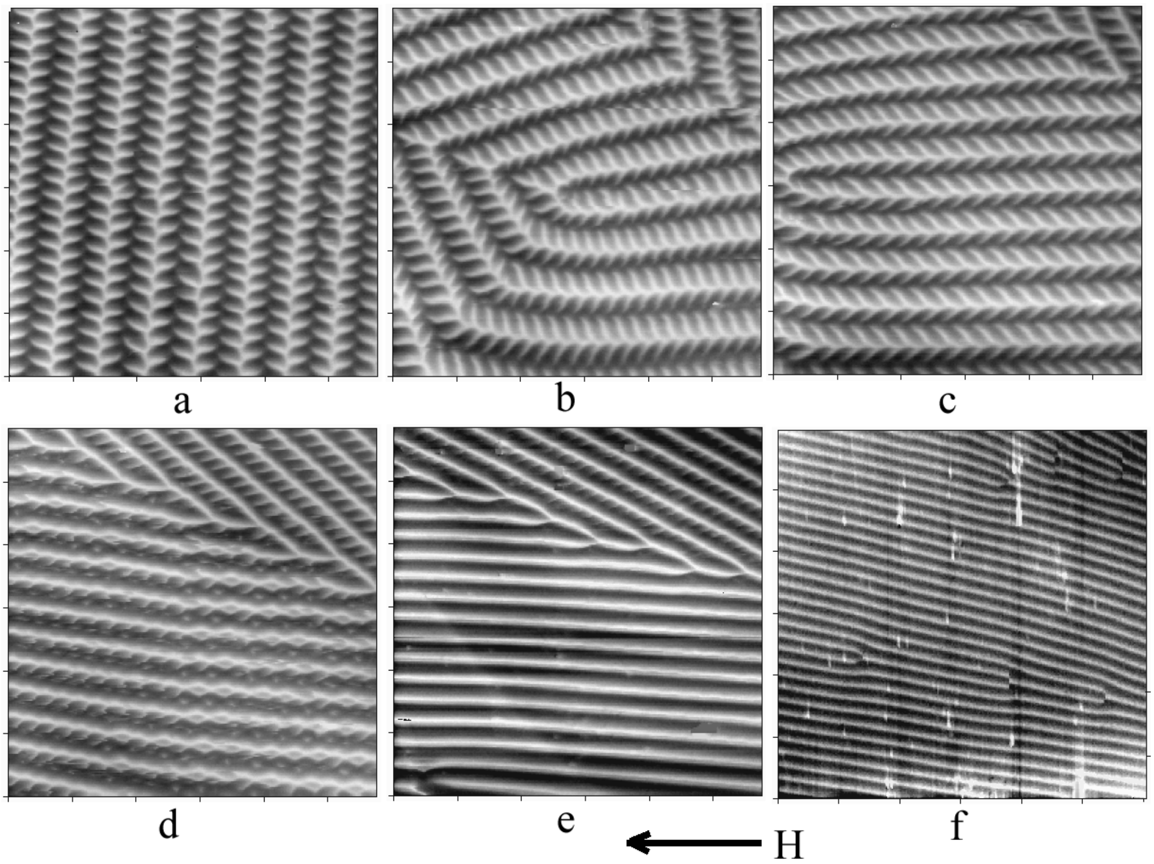


Fig. 3. MFM images made in the applied external magnetic field: a) $H = 0$; b) H=30 Oe; c) H=80 Oe; d) H= 150 Oe; e) H=205 Oe; f) H=350 Oe.

A series of domain structure transformations has been observed when we applied an external magnetic field **H** lying in plane of the YIG film. Fig. 3 gives an example of the images taken at successive increasing in the magnetic field strength. The scan area is 50×50 μm, the sample is the same as in Fig. 1.

We conclude that the distribution of the second derivative of the stray field from the inhomogeneous YIG films has the specific needle-shaped pattern. The applied magnetic field affects both the stripe domains and the needle form.

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