DOMAIN STRUCTURE IN THIN NICKEL FILM OBSERVED BY LOW- AND HIGH-COERCIVITY MAGNETIC FORCE MICROSCOPY PROBE

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1. Introduction

The magnetic properties of solid matters are given by magnetic dipoles, which are usually not equally oriented throughout the volume, but they keep their direction only within small regions called magnetic domains [1]. Magnetic domains present an interesting subject to study, because they have a close connection with processes that take place while magnetizing and demagnetizing a ferromagnetic material [2].

Various methods have been proposed to visualize magnetic domain structure [2], such as the Magnetic Force Microscopy (MFM) [3,4]. Nowadays, this method becomes popular for two main reasons. The first one is its ability to scan an image of the domain structure and the topography simultaneously. Thus, it provides a possibility to find a correlation between magnetism and any morphological changes on the surface. The second reason is a high lateral resolution of the method, which is approximately at the level of several tens of nanometres. Although this imaging technique has already been successfully applied to various types of magnetic materials, a measurement methodology is still not perfectly mastered and need to be developed. For instance, there is a wide selection of magnetic tips that differ either in the value of coercivity or in the value of magnetic moment. Unfortunately, when selecting a tip, one always have to choose a compromise between high lateral resolution at low sensitivity or a high signal-to-noise ratio linked with a concern that the tip's field will affect the domain structure in interest. This, of course, markedly complicates the selection of appropriate tip for a specific type of sample that results in ambiguities regarding the tip selection.

The aim of this paper is to demonstrate, on a thin ferromagnetic layer of Ni, how the coercivity of the tip affects the MFM image of domain structure. The domain images are recorded by atomic force microscope operated in the MFM mode.

2. Experimental details

A Ni layer with thickness of 60 nm was prepared by thermal evaporation (vacuum better than 10^{-3} Pa)on the Si substrate through shadow masks in order to determine an area of 2×1 cm^2. Surface properties of the ferromagnetic layer have been studied by an atomic force microscope from the Veeco Instruments Inc., the model Dimension Edge™. Image of the film's domain structure was scanned under the same conditions by two different probes, both from the Bruker. The first has a magnetic coercivity of H_c< 10 Oe (the model MESP-LC), the second one has a coercivity of H_c = 400 Oe (the model MESP). Scanning parameters and the quality of the probes was verified by measuring the XYZ calibration grating and the magnetic recording tape. All measurements were carried out in air.

3. Results and discussion

The surface of the deposited nickel film [Fig. 1(a)] was very smooth (RMS roughness of w = 0.7 nm), covered with only tiny protrusions with average height of 2.3 nm. The highest protrusions in Fig. 1(a) are around 6 nm high. In order to increase the contrast in the MFM images, the phase shift was scanned at the smaller distance (namely, 20 nm) from the surface. None of the protrusions in Fig. 1(a), however, is high enough to disturb the process of scanning magnetic interactions. In terms of surface quality, the film appears to be ideal for the MFM measurements. Nevertheless, the image of domain structure recorded by the high coercivity probe is significantly disturbed [Fig. 1(b)]. The domains (light and dark stripes)in the image are misaligned. A strong interaction of the probe with the film surface was projected also into the phase shift, which the microscope measured while scanning the topography. In this phase image (not shown here), the pattern of domain structure could be distinguished that is identical with the one depicted in detail in Fig. 1(b).

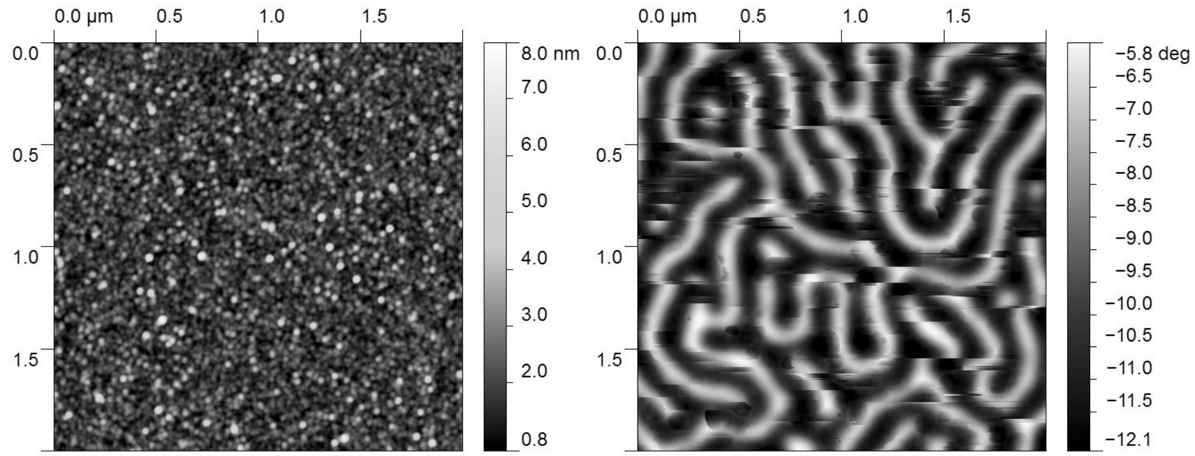

Fig. 1: *Topography (a) and domain structure (b) of a thin planar Ni film recorded by the MFM probe with high coercivity. Domain structure (more particularly the phase shift) was scanned at a distance of 20 nm from the surface of the sample. The size of the scanned area is 2 × 2 μm^2. There are clearly visible artefacts in the phase shift image.*

Changing most of the scanning parameters such as Scan speed, PID gains, Setpoint, or Lift height (i.e., tip-surface separation) had no effect on the observed image artefacts. It turned out, however, that by decreasing the amplitude of the free cantilever oscillations to one-third of the original value (from 6 V to 2 V), the number of image artefacts decreased. We have not found, however, any combination of scanning parameters that would result in an error-free image of the domain structure recorded by the high coercivity probe.

In view of the fact that most of the scanning parameters including the Lift height had no influence on the image artefacts, we come to conclusion that the high coercivity tip probably changed the magnetic domains configuration because of its stray field. The strongest interaction of the tip with the film surface takes a place in the first step of the MFM measurement cycle, during which the microscope records the topography.

With the MFM probe of low coercivity, we managed to obtain the perfect image of a domain structure of the sample [Fig. 2(a)]. The maze-like domain pattern formed without the action of an external magnetic field. A similar configuration of domains was also observed by other researchers on thin Ni films[5,6] or single-crystal Co dots [7]. Owing to a small thickness, ferromagnetic films have only one layer of domains.

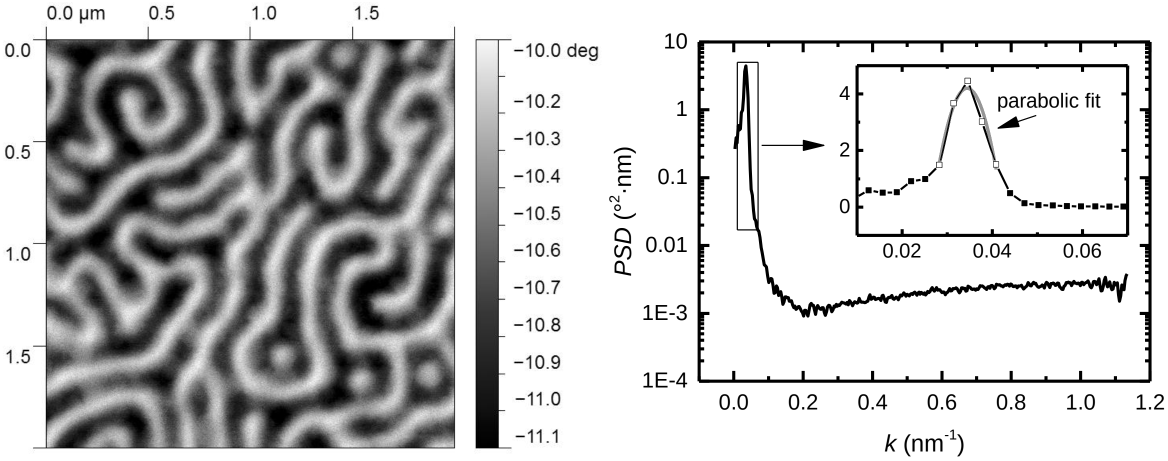

Fig. 2: *Domain structure of the same sample but recorded by the MFM probe with low coercivity (a). Dependence of the radial Power Spectral Density, PSD on wavenumber, k (b), determined from analysis of the phase image (a). Inset: Detail on the area in which the PSD function reaches the maximum values.*

One parameter which can be quite accurately determined from the Fig. 2(a) is the periodicity of the stripes. To determine its value we used the radial Power Spectral Density (PSD) analysis. The dependence of the *PSD* on wave number *k* is shown in Fig. 2(b) in logarithmic scale. Only one pronounced peak is visible in the dependence, which corresponds to the spacing of domains. In order to determine as accurately as possible the peak maximum, we applied parabolic approximation[Fig. 2(b), the inset]. Assuming lamellar structure, the periodicity of the stripes is directly proportional to the wavelength $\lambda = 2\cdot\pi/k$. Since the peak position lies at $k = 0.03442$ nm, the repetition period of magnetic domain stripes is 183 nm. This value is in accordance with the period (181 nm), reported by Snowden [8] in her thesis, for a 60 nm thick Ni film evaporated onto a glass substrate.

A similar analysis can also be done for the image that was measured by the high coercivity probe [Fig. 1(b)].The peak position corresponds to the period of 181 nm, which is in relation to the analysis of the image measured by the low coercivity probe. It seems, therefore, that if one needs only to determine the value of period, it does not matter whether he will use the probe with high or low coercivity. The resulting analysis of the phase image gives the same result.

On the other hand, application of probes with low coercivity has one drawback, the lower sensitivity to magnetic forces. As a result, the signal-to-noise level significantly decreases as it is obvious from the phase shift image [Fig. 2(a)]. When using the probe with high coercivity, the total range of the phase shift was 7.4°, while using the probe with low coercivity it was 1.4° only. Thus, the amount of data contained in the phase shift record dropped more than five times, whereas the noise level was conserved.

4. Conclusions

On the 60 nm Ni film, we have demonstrated, how the coercivity of the MFM probe affects the image of domain structure. In the phase image recorded by the high coercivity probe were numerous artefacts, which could not be removed by varying the scanning parameters. With the low coercivity probe, we acquired an error-free image of a domain structure. At the same time, however, we saw a significant drop in the signal-to-noise ratio. The domains in 60 nm Ni film were organized into a maze-like structure, without action of an external magnetic field. The period between domains of the same orientation was 183 nm. In addition, we found that the correct value of period can also be determined by analysing the distorted image, recorded by the high coercivity probe.

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