

Processing of needles-like images of magnetic domain structures in ultrathin cobalt wedge

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Abstract: This document presents the required layout of papers to be submitted for publication in the proceedings of the 8th International Conference on Pattern Recognition and Information Processing (PRIP'2005). The abstract may not be longer than 150 words.

Keywords: Leave one blank line after the Abstract and write your Key-Words (3 - 5 words).

1. INTRODUCTION

Study of magnetic domain structure images is an important topic for high density data storage task. The review of methods for magnetic domains imaging analysis can be found in the monograph [1]. Domains imaging analysis was performed in the book by using Kerr effect in optical microscope. The studied cobalt wedge (with thickness $0 < d < 2$ nm) was grown on (110) Mo buffer layer. Similar samples were intensively investigated at room temperature using different techniques [2, 3].

Digital image processing is a powerful tool for investigation of magnetic images. Processing of magnetic domain structure image is usually limited to the simplest mathematical methods only (averaging and subtraction of images). Modern technology includes many tools for image processing and allow to detect pattern with different shape by methods of mathematical morphology [4].

Digital processing of magnetic domain structure image is usually limited to the simplest mathematical methods only (averaging and subtraction of images). More advanced methods were developed in our papers.

The review of different methods of magnetic domains imaging one can find in the monograph

In this paper, we propose an approach to detect needle like structure in images of magnetic domain structures in ultrathin cobalt wedge. The algorithm is based on transformation of needles-like images into binary patterns of particles and then calculate their geometrical parameters. Such procedure is useful for determination of different factors inducing preferention of domain wall orientation connected with e.g. vicinal substrate, crystalline magnetic anisotropy, stresses, in-plane applied magnetic field.

2. IMAGES INPUT AND PREPROCESSING

Visualization of domain structure is induced by polar Kerr effect. The Carl Zeiss Jenapol optical polarizing microscope with halogen lamp illumination was equipped with a high sensitivity camera having 1300x1030 pixels cooled CCD element and a computer controlled frame

grabber. The video signal was electronically processed, subsequently digitized and then improved by standard image processing techniques (including subtracting of reference image). Digitalization of magnetic domain structure image and its numerical processing can be performed for some purposes:

- enhancement of domain structure image contrast
- determination of different parameters describing domain structure geometry (shape domain period, a bubble domain diameter, volume difference between domains with different magnetization vector orientation)
- determination of magnetization vector orientation in DS
- finding correlation between different domain structure patterns.

The sample was investigated using microscope magnifications corresponding to $(0,4 \times 0,36)$ mm² areas. A computer controlled set-up enabled changes of: (i) sample image $I(i,j)$ registration time, (ii) perpendicular to the film plane magnetic field pulse characterized by amplitude H_j and its duration time Δ ($\Delta = 1,5$ s was in experiments described below).

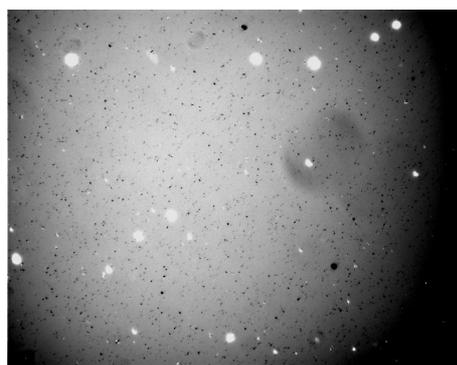


Fig. 1. Reference image of domain structure in cobalt wedge $I(i,j)$

The domain images $I_{DS}(i,j)$ were taken in zero magnetic field. The (i,j) denotes a pixel position in an image $I(i,j)$. Image of the sample after well defined magnetic history were used for calculation of pixels $P_{DS}(i,j)$. The following procedure was used for domain structure study: the reference image $I(i,j)$ (fig.1) was registered after sample saturation using $H_1 < 0$ magnetic field and then a domain structure image $I_{DS}(i,j)$ (fig.2) was recorded in zero magnetic field after application of a pulse magnetic field $H_1 > 0$.

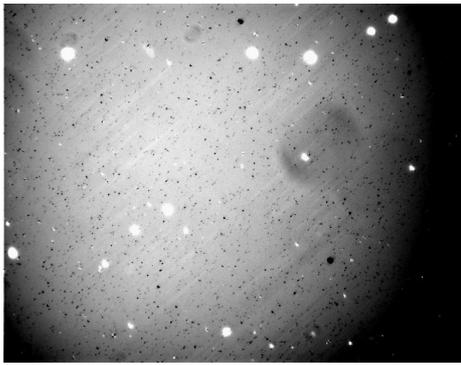


Fig. 2. Domain structure image of domain structure in cobalt wedge $I_{Ds}(i,j)$

Each resulting images was calculated, using the formula:

$$P_{Ds}(i,j) = I_{Ds}(i,j) - I(i,j).$$

Procedure of the image subtraction for different power is shown in fig.3.

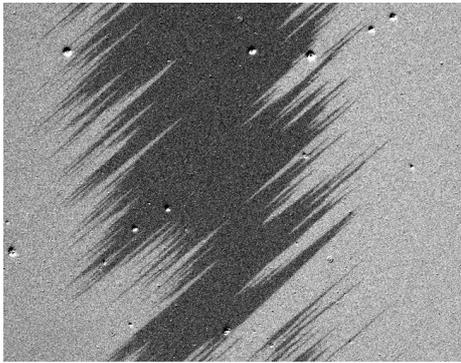


Fig. 3. Differential image of domain structure in cobalt wedge $I_{Ds}(i,j) - I(i,j)$

Fig.3. illustrates a domain structure image, in which the preferential orientation of magnetic domain walls with characteristic needles-shaped domain structure was found. This preferred direction is connected with magnetic anisotropy induced in Co by the Mo (110) buffer [2,3].

3. Analysis needles-like objects on image of domain structure

The algorithm for detection needle-like structure on magnetic image consists of four phase: improvement of gray-scale image quality, thresholding, morphological processing, separating of needle-like elements.

Gray-scale image has an impulse noise and physical faults are ususally obtained (fig. 3). It is necessary to improve quality of this image for correcting brightness histogram. This procedure accomplishes by less-noise filtration:

- salt&pepper,
- median.

Brightness uniform enhances correct gray histogram for stabilization threshold detection (fig. 4).

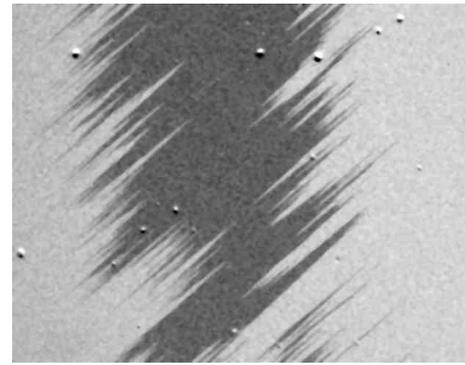


Fig. 4. Improved magnetically image of molibden wedge

The auto thresholding techniques are used to determine the threshold pixel value such that all gray level values less than or equal to threshold belong to one class 0 and the other gray level values belong to another class 1 in binary image. This procedure decrease count of image characteristic.

The source and improved images consist of two basic phase: domain structure and background. Therefore optimal method for automatic thresholding is metric. The threshold value is the pixel value k at which the following expression is minimized:

$$\sum_{i=0}^{i=k} h(i) |i - \mu_1| = \sum_{i=k+1}^{i=N-1} h(i) |i - \mu_2|,$$

where, μ_1 is the mean of all pixel values in the image that lie between 0 and threshold (k), and μ_2 is the mean of all the pixel values in the image that lie between $k+1$ and maximal pixel value on image.

Thresholding of improved gray-scale image results to a binary image with pattern of changing of magnetic field and some noise objects (fig. 5). For realization of this operation an optimal method is [5].



Fig. 5. Binary image of molibden wedge after thresholding

Morphological phase of algorithm is used to correct edges of needle-like structure and remove geometrical noise. Generally, noise at binary image is explained by physical faults of wedge surface. It is characterized as separate objects with small area. The physical faults can present on image background and foreground. First they are removed on background by measuring and comparing geometrical characteristics (Fig. 6).



Fig. 6. Binary image of molibden wedge after removing physical faults on background

Then, closing operation restores broken distinct elements of needle-like structure. For analysis physical faults on foreground, it is necessary to invert binary image and repeat removing operation (Fig. 7).



Fig. 7. Results of morphology phase of removing restoring physical faults

Inverting of resulting image and opening operation completely restore form of needle-like structure (Fig. 8).

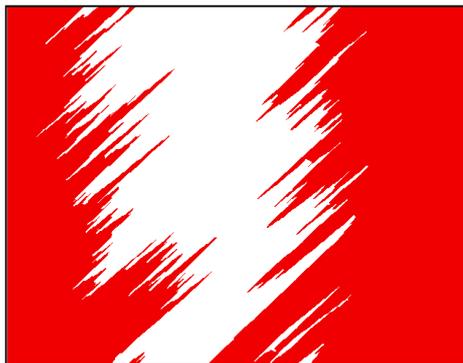


Fig. 8. Results of phase of restoring forms of acicular structure.

Next phase is separating of needle-like elements. A convex hull can be envisioned as an imaginary elastic string stretched around the object. This operate is based on detecting of convex patterns. Pattern with convex border for foreground and background enclose all elements of needle-like structure (Fig. 9).

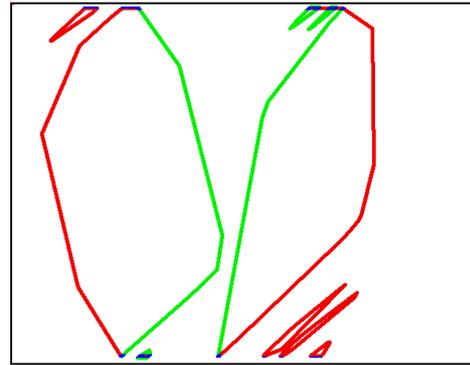


Fig. 9. Results of phase of separating element: a) convex borders, b) regions of interest for needles-like structure..

That borders allow choosing regions of interest (Fig. 10). Using of this regions decrease count pixels for analysis and remove border noise.

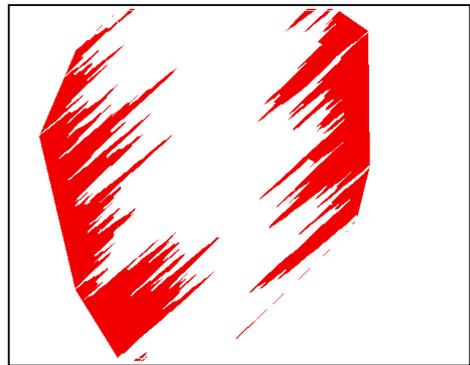


Fig. 10. Results of phase of separating element: a) convex borders, b) regions of interest for needles-like structure..

Opening operation removes needle-like elements form region of interest. Subtracting two previous results gives needle-like elements (Fig. 11).

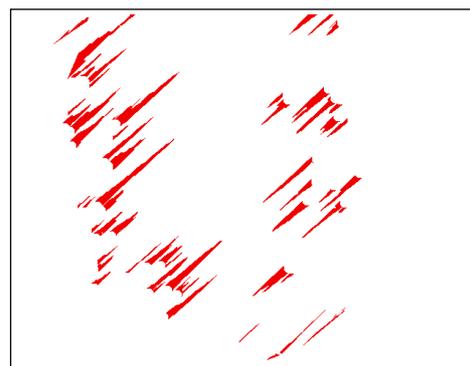
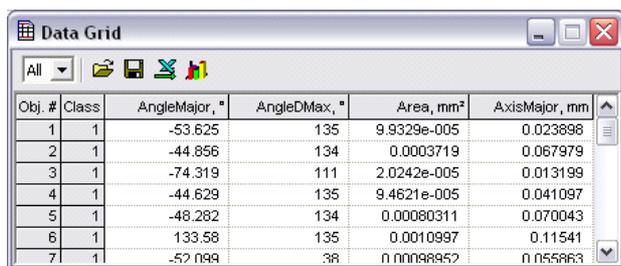


Fig. 11. Binary patterns of needles-like elements of magnetic domain structure image

The elements of neddle-like structure can play important role for description properties of magnetic field. The sensibility of characteristics of field depends on size of elements. Therefore counting iterations for opening operation influence to size of separable elements and sensibility of measuring (Fig. 7).



Obj. #	Class	AngleMajor, °	AngleDMax, °	Area, mm ²	AxisMajor, mm
1	1	-53.625	135	9.9329e-005	0.023898
2	1	-44.856	134	0.0003719	0.067979
3	1	-74.319	111	2.0242e-005	0.013199
4	1	-44.629	135	9.4621e-005	0.041097
5	1	-48.282	134	0.00080311	0.070043
6	1	133.58	135	0.0010997	0.11541
7	1	-52.099	38	0.00098952	0.055863

Fig. 6. Table with result of measuring of acicular elements

This algorithm allows to measure some important characteristics of these elements:

- needles preferention angle,
- distribution of the angle,
- needles length,
- length distribution
- area of needle.

For cobalt wedge (with thickness $0 < d < 2 \text{ nm}$), mean angle of orientation is equal to 34° , mean needle length is equal to 0.054 mm

4. CONCLUSION

The algorithm of digital processing of needles-like image of magnetic domain in ultrathin cobalt was proposed. The algorithm is based on transformation of needles-like images into binary patterns of particles and then calculate their geometrical parameters. Such procedure is useful for determination of different factors inducing preferention of domain wall orientation connected with e.g. vicinal substrate, crystalline magnetic anisotropy, stresses, in-plane applied magnetic field.

5. ACKNOWLEDGEMENT

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