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The Structure Analysis of Ultrathin Magnetics Films

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Abstract

Algorithm of magnetic structures extraction and analysis is proposed here. This algorithm allows to gain successful results and calculates a large number of characteristics of structures on magneto-optical images. The algorithm consists of three parts: background correction, structure extraction and calculation of dendrite characteristics. For correction of magnetic image we use methods for magneto-optic contrast. One of the basic features of structure extraction part is a preservation of border properties. Therefore the basic processing of extraction is applied for binary image. Proposed characteristics allow to describe and to classify dendrites. For analysis of complex magnetics structures topological properties are calculated for three basic objects types: body, holes and gulf. Arithmetical combination of such properties describes and characterizes . It is used as well as for single dendrite both for dendrites of magneto-optical and medical images.

1. Introduction

The magnetic ordering in ultrathin films is one of the intensively studied phenomena at present time. Digital image processing is a powerful tool for investigation of magnetic data. Processing of magnetic domain structure image is usually narrowed by the simplest mathematical methods (just an averaging and subtraction of images). From the other hand, modern technology includes splendid tools for image processing and allows to detect patterns with different shape by methods of mathematical morphology. Magnetic reorientation phase transition (RPT) in "sandwich" structures containing ultrathin films between vertical and in-plane magnetization states attracts a particular attention of scientists all over the World.

The RPT can be induced by changing of: (i) thickness d of magnetic layer or (ii) overlayer and/or underlayer structures [1]. To investigate such a problem an optical microscopy is used as one of the basic methods for domain structure description. One of the most interesting domain pattern is a dendrite. Shape of dendrite has very complex branchy structure with plenty of characterising parameters.

All measurements were performed at room temperature using a classical optical polarizing microscope with CCD camera based on the polar Kerr effect. Perpendicular to sample plane magnetic field H pulses or alternating field HAC with decreasing amplitude were applied after saturation to induce the domain structure. A sample image was recorded after different magnetic history. To improve the image

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contrast the following normalization numerical procedure was performed:

$$P(i,j) = \frac{(I(i,j) - I_{-}(i,j))}{(I(i,j) + I_{-}(i,j))},$$

where I_- denotes level in gray level of individual image pixel which is positioned at (i,j) of the reference image recorded in remnant state after sample saturation at HS < 0 and I_+ describes pixel value after application the pulse of magnetic static field with amplitude H_+ or HDS in the opposite direction (I_+ or I_D) or AC field with decreasing amplitude [2]. The gray level of pixels is proportional to local values for both normalized remnant magnetization mR and maximal Kerr rotation φ_{max}.

2. Magnetic structures

There are many different types of magnetic structures [3]. We observe four basic configurations of magnetic structures in ultrathin magnetic films in the frame of two types of magnetization reversal.

1. Magnetization reversal process is characterized by many nucleation centers in observation area

a. Blobs (fig. 1a): they are solid objects, without internal structure; blobs growing is isotropic.

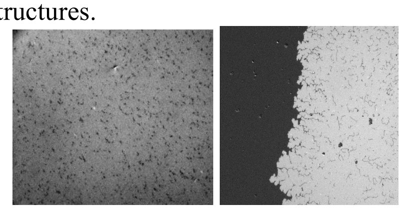
2. Magnetization reversal proces is characterized by limited number of nucleation centers in observation area.

b. Front (fig. 1b): this is a big object that is characterized by flat growing in one direction.

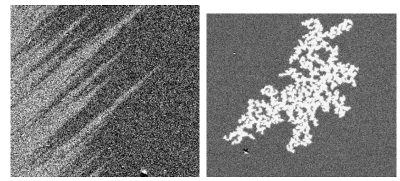
c. Needles (fig. 1c): they are very elongated in one direction objects. Usually they have sharp terminations.

d. Dendrites (fig 1d): they are very complex objects. Dendrites represent connected structure of branch.

Other objects usually constructed by these four types of structures.



a) b)



c) d)

Fig 1. Four types of magnetic structures: a) blobs, b) fronts, c) needles, d) dendrites.

3. Algorithm of magnetics structure analysis

The algorithm of calculation of dendrite image properties consists of three parts (fig. 2). The first part6.Hubert R., Schдfer R., Magnetic Domains., Springer, Berlin 1998. is for background correction of obtained image. The second one is for extraction a pattern of dendrite structure. The third one calculates different characteristics of structures.

Usually an impulse noise and physical faults appear in halftone magnetic image (fig. 1). First of all it is necessary to take a binary image.

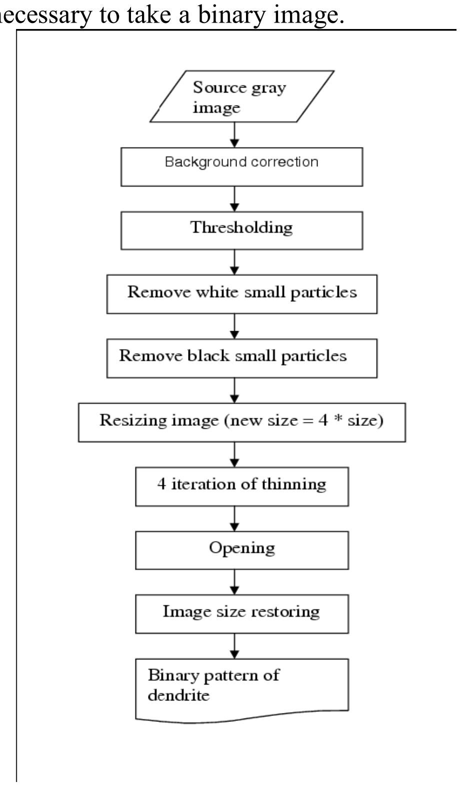


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Fig. 2. Gray images of dendrites structure – source

Image binarization is executed by thresholding. A preprocessing operation of a image allows to gain a better result if it is performed before thresholding. It is necessary to improve quality of image by correcting a Brightness histogram. Preprocessing operation includes two stages correction of background and reduction of short noise. Image consists of two components: a constant and magnetooptic components. If we consider
a constant component of the magnetic image as a background we can use traditional operation of background correction to improve magnetooptic contrast of it [3,4]:

$$C_{x,y} = \frac{(I_{x,y} - B_{x,y}) \cdot (W_{max} - B_{x,y})}{(W_{x,y} - B_{x,y})}$$

where $I_{x;y}$ is a value of pixel's brightness of the image with magnetooptic component, $B_{x;y}$ is a value of pixel's brightness for the image from a constant component, $W_{x;y}$ is value of pixel's brightness for the image at full saturation D of the chamber (light overflow), W_{max} is a maximal value of brightness of the image at saturation of chamber $C_{x;y}$ is a new value of pixel's brightness in the corrected image.
Magnetooptic image is notable with its strong short noise. Removing it by median or lowpass filter usually changes borders of dendrites. Therefore for halftone image we can use only background correction and thresholding.
The autothresholding techniques are used to determine the threshold pixel value. All gray level values which are less or equal to threshold belong to the class 0 while other gray level values belong to class 1 in binary image. This procedure decreases a number of image characteristic. Automatic thresholding is executed by Otsu method.
Result of thresholding is an image with "salt-and-pepper" noise. Therefore it is necessary to remove all separated black or white regions with size less than 5 pixels. False tails and bridge are presented in image after this operation.

It is not allowed to use simple morphology processing, due to necessity to preserve a border. To perform this operation an image is resized in 400 percents, and four iterations of thinning are carried out to correct tails and bridge. In this case the best thinning method is Zhang-Suen [5].
Morphological "open"- operation removes false bridge and tails. Then we can restore size of image and take binary pattern of structure.
Geometrical characteristics of objects are the basis for any research. The high resolution of optical microscopes brings high accuracy in calculation of geometrical characteristics of objects. Most frequently measured parameters of magnetic structures are:
area, perimeter, linear sizes, factor of elongation (the relation of two main moments),
and form factor.

4. Calculation of characteristics

There are many kinds of characteristics for structures description: geometrical, optical, topological.

Topological characteristics are more complex and include more interesting information about shape magnetic structure.

There are several ways to describe an object's form. The most interesting characteristics is compactness. Compactness factor is a ratio of a particle area to the area of the smallest rectangle contained all points of objects. It is defined as

$$compactness = \frac{K \cdot AREA}{perimeter^2},$$

were AREA - is an area of dendrite, perimeter - is a perimeter of dendrite, K - is a calibration coefficient. The compactness factor belongs to the interval [0, 1]. The closer a shape of a particle to the rectangle, the nearer the compactness factor to 1. To define a topological features of the image a binarization of the images is carried out (as it is in the previous case).

Topological features of complex structures (bodes, gulfs, holes) are detected by operations of boolean logic and mathematical morphology smoothing. We defined three topological regions on dendrite images: body of dendrites, gulf and holes (fig. 3).

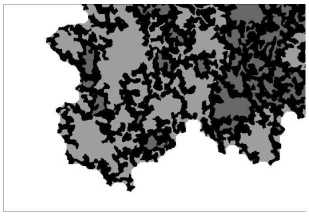

Fig. 3. Hierarchical image after binarisation with topological features: black - body of dendrites, light gray - gulf, dark gray - holes

Gulf and holes are regions between dendrites. Gulf has connection with free space.

This regions are extracted by specific algorithm (fig.4).

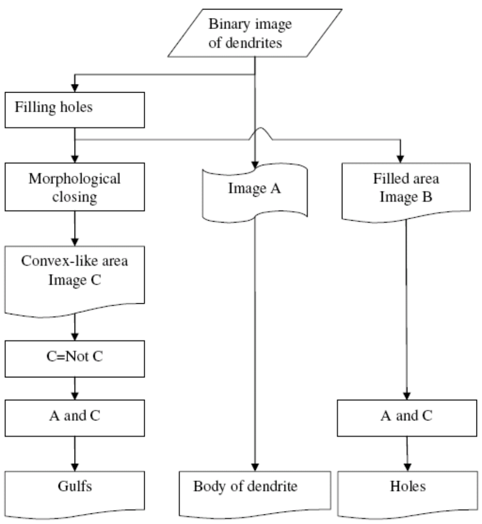

Fig. 4. Algorithm extraction body of dendrite,gulfs and holes

The dendrites body encircled with holes. We propose next characteristic to describe these topological features: total area, gulf ratio, hole ratio, dendrite ratio. Total area is defined as a sum of all topological regions:

$$TotalArea = Area(gulf) + Area(holes) + Area(dendrites),$$

were Area(gulf) - area of gulf regions, Area(holes) - area of holes regions, Area(dendrites) - area of regions of dendrite body. Others characteristics correspond to space filling and are defined as:

$$gulfratio = \frac{Area(gulf)}{TotalArea};$$
$$holeratio = \frac{Area(holes)}{TotalArea};$$

This characteristics describe rate of each type of region topology. For description of topological properties of dendrites it is necessary to extract a structures skeleton from a binary image.

This operation is realized by binary thinning operation (Zhang-Suen algorithm [5]). The basic definition for calculation are characteristics of body, skeleton, nodes and tails (fig. 5). A body corresponds to region of structures body. A skeleton is a centerline of geometrical object. Nodes are branchpoints of structure. Tails are last fingers of branch.

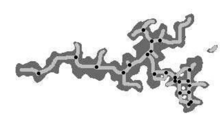

Fig. 5. Topological features of dendrites: gray - dendrites body, light gray - skeleton, black – nodes

For description of topology features of dendrite we define following characteristics:

branchiness, curliness, length, mean width of dendrite, tailness, tails curliness, tails ratio. Branchiness and curliness describe complexity of dendrite. They are defined by ratio of number of nodes to length of skeleton and number of skeletons segment correspondingly. The skeletons segment is a fragment of skeleton between nodepoints or endpoints.

$$Branchiness = \frac{count(nodes)}{length(skeleton)};$$
$$Curliness = \frac{count(nodes)}{count(segments)}.$$

Full length of structure corresponds to length of skeletons. Definition of tails allows to produce characteristics for description correlation termination properties with complexity of dendrites. They are tailness, tails curliness and tails ratio.

The most complex characteristic is structures width. It changes from point to point. We can't define the width of skeleton in nodepoints and dendrites crossing. It is very complicated to distinguish skeleton's endpoints from noise. For solution of this problem we proposed next approximation of mean dendrite's width:

meanwidth=Area/length

This characteristic is just an approximation of real structures width. Construction of structures width distribution is very complex task, and small mistake appears when it performed. For magnetic complex structure this approximation is comparable with accuracies to real value.

5. Conclusion

This characteristics is just an approximation of real structures description. Construction of width distribution is very complex task, and small mistake appears when it performed. For magnetic structure this approximation is comparable with accuracies to real value. This algorithms are realized in a software package "Zubr" for magnetic structures image investigation. The analysis divided to four basic groups: blobs, fronts, needles, dendrites. This groups are basis for analysis many other more complex structures. The software package "Zubr" allows to study static structures and it evolution and allow to take quality results.

Acknowledgement

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