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DYNAMIC OF MAGNETIC DOMAINS IN AMORPHOUS Fe-Sm THIN FILMS

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Fe-Sm composite thin films were prepared using co-sputtering method by using a DC planar magnetron arrangement. Pure iron disk and samarium 1×1 cm^2 chips were used as composite target. The structure of samples for different composition was studied by small-angle X-ray diffraction. Magnetic domain structure of thin film was revealed through Bitter-Elmore technique. Sequential images of magnetic domain structure and their modification as a consequence of magnetic field direction change were observed using a high resolution reflected-light microscope and digital camera. The obtained images have revealed the existence of two main types of magnetic domain structure: wide-stripes (type I stripe domains) for in-plane magnetic field direction and labyrinth and/or maze structure (type II stripe domains) for perpendicular to film plane magnetic field direction. Different types of structures from stripe to maze were evidenced while the magnetic field direction is changed from parallel to normal to the film plane. Models of observed magnetic structures in Fe-Sm films were proposed and discussed in connection with the direction of applied magnetic field.

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1. Introduction

In the last decade, a lot of studies were reported on amorphous magnetic thin films in a wide range of compositions. Missing of crystalline arrangement of atoms simplified the number of terms involved in magnetic equations, especially relating to magnetic parameters dependent on direction, such as magnetic anisotropy and magnetostriction. In order to obtain new disordered materials, one way is to add metalloid elements (B, P, S etc) and/or to modify deposition parameters how should be the substrate cooling. In some cases, amorphous and nanocrystalline thin films were obtained only as "broken" of one of Hume-Rothery rules: the high difference of atomic radius between alloying elements. Ideal alloying elements to obtain 3d based amorphous thin films are rare-earth metals (RE) of lanthanide group. In first instance, attention was focused on gadolinium, terbium, dysprosium, holmium and europium. Studies of 3d (Fe, Co, Ni)-rare earth amorphous alloys are interesting from two points of view: technological and fundamental research. Among the first studied alloys of this type were there with Gd because of its ferromagnetic properties and potentials use in magnetic recording [1, 2]. The development of thin films media for data storage recommend also other RE alloying elements, such are Tb and Dy. From the fundamental research viewpoint, various compositions were studied in order to evaluate the degree of atomic and magnetic order [3, 4, 5]. Experimental results have been clearly indicated that in the case of composition closed to Laves phase ($REFe_2$ equilibrium crystalline phase) atoms and spin sites have an amorphous spatial distribution and exhibited a long-range magnetic order. On the other hand, it was demonstrated that thermally evaporated RE-TM (TM-transition metals) thin films are amorphous and some compositions have perpendicular anisotropy suitable for perpendicular magnetic recording. An extensive study of RE-TM alloys was performed in [6], concerning compositional and structural

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characterization, magnetic properties (Curie temperature, uniaxial magnetic anisotropy constant K_u, exchange constant, hysteresys loop and magnetic domains parameters).

Fe-Sm alloy thin films were relatively poor studied and most of them are related to atomic arrangement, histeresys loop and magnetic anisotropy [7-10]. Investigations on Fe-Sm magnetic domain structures are also relatively few. Development of samarium- and cobalt-based super-magnets and undertaken studies upon large magnetostriction of samarium-based alloys gave the possibility to use these alloys as actuators in MEMS devices.

This paper is focused on magnetic domain structures of amorphous Fe-Sm alloy thin films and on induced changes by magnetic field direction change. Models for observed magnetic domains and correlation with anisotropy measurement are discussed.

2. Experimental

Fe-Sm amorphous thin films were obtained using multifunctional sputtering installation described in [10]. The installation allows three types of sputtering arrangements: diode, planar magnetron and opposite-target magnetron. For opposite target arrangement, two modalities are possible: with permanent magnets inside and without permanent magnets inside. Cathodes with permanent magnets inside were used in our work. In this case, the magnetic field intensity on substrate surface was 45 kA/m and magnetic lines direction was parallel to substrate surface. The DC power used was 350 W. The films were deposited on glass substrates from composite target of 12 cm diameter and consisting in a 0.3 cm thick disk of pure iron partially inserted with small 1x1 cm^2 samarium rectangles. Argon was used as sputtering gas. The base pressure of argon was 2×10^{-6} Torr and sputtering pressure was 3×10^{-3} Torr. The film thickness was measured using interferential method. The composition of amorphous thin films was determined using electron probe microanalysis (EPMA). The film structure was investigated by small-angle X-ray diffraction technique (XRD). After deposition, surface of thin films was covered with a thin aluminium layer, in order to increase their reflectance. In this manner, the samples had a mirror-like surface permitting the domain structure study (absence of strained surface layer).

For magnetic domains observation was used the wet colloid technique, also named Bitter-Elmore technique. Technique details and magnetic colloid preparation are described elsewhere [11]. The used colloid contains aggregates of magnetite with 100 nm mean diameter and individual particles with 10 nm mean diameters. The small diameter of aggregates ensures that observed structures are not distorted by colloid-constituents physical dimensions and the full resolution of optical microscope can be used. After positioning in centre of microscope stage, few drops of magnetic colloid were placed on film surface. In order to ensure a uniform distribution of colloid in a thin sheet a 0.5 mm in thick microscope glass slide was placed over.

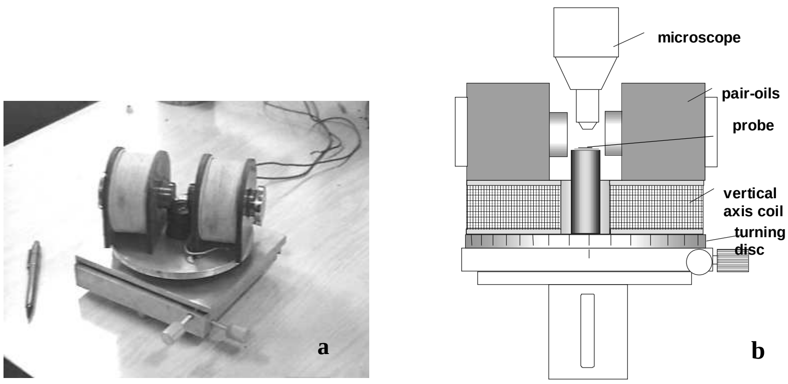

Fig. 1. New microscope stage equipped only with horizontal coils (a) and full schematic arrangement for domain observation (b).

For domain observation, a highly resolution reflected-light microscope (Epival Interphako-Karl Zeiss-Jena™) was used. The microscope was equipped with a new stage shown in Fig. 1a. The stage is equipped with a coils arrangement consisting in a vertical axe single-coil and horizontal axis pair-coils. The role of coils arrangement is to produce magnetic field with various intensities and directions. The new stage permits x-y fine displacement (in order to specify location of observed area on film surface) and 360 degrees of free rotation (for direction of magnetic field lines changing in film plane). The new stage was manufactured from aluminium in order to avoid magnetic field lines distortion. Changing the direction of field lines from normal-to-film plane is performed by adequate balancing of supply current of horizontal and vertical coils. The rate of simultaneous current decreasing in horizontal coil and current increasing in vertical coils was initially calibrated in order to avoid significant variations in absolute field intensity. Observed images were picked up with an Olympus digital camera (1260x980 pixel resolutions).

3. Results

Using various composition of target, different film compositions were obtained: $Fe_{71}Sm_{29}$, Fe_{52} Sm_{38} and $Fe_{43}Sm_{57}$. The films with composition of $Fe_{71}Sm_{29}$ and 900 nm in thick were chosen for magnetic domains investigation. For this composition, Fe-Sm films are X-ray amorphous.

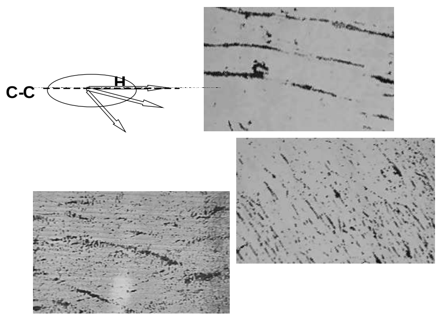

Fig. 2. Domain patterns and induced changes function of magnetic field direction rotation in-plane of Fe-Sm film.

The first step in our experiment was to study domain structures and their changes for in-plane applied magnetic field. In this case, only horizontal pair-coils were supplied. The turning disk of stage was rotated and dynamics of domains in horizontal plane was observed. Images picked up for 0, 45 and 90 degrees respect to C-C axis (cathode axis-direction of magnetic field during obtaining) are presented in Fig. 2. For applied field parallel to C-C axis direction, stripes magnetic domains appear (first picture in Fig. 2). Slow rotation of turning disk revealed that direction of stripes follows the direction of magnetic field. A change in domain width and distortion of domain walls accompany this phenomenon. The structure of domains after a 90 degrees rotation shows that in third picture of Fig. 2. The structure is one of largest stripes, with high instability and having wide and weak definite domain walls.

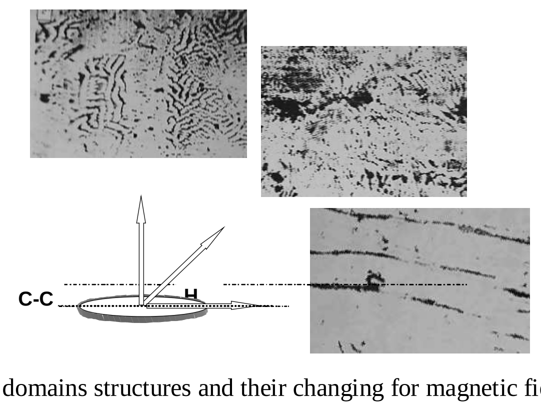

Fig. 3. Magnetic domains structures and their changing for magnetic field rotation in vertical plane to Fe-Sm film surface.

In the second step of experiment, horizontal axis coils was first supplied. This means that applied magnetic field is parallel to the film plane. The expected structure of stripes from first experiment was obtained (third picture of Fig.3). In order to obtain different direction of applied field in a normal plane to film surface, the supply current of horizontal coils was slow decreased and simultaneously was increased in vertical axis coil. In this manner, the magnetic field vector direction on film surface is changed from horizontal direction to vertical one. The observed structure changes from parallel stripes (third picture of Fig. 3) to maze type (middle picture of Fig. 3) and then to "fingerprint" structure, distributed in large regions (first picture of Fig. 3).

4. Discussion

The presence of stripe domain structure in amorphous materials was reported by the other authors. A comprehensive discussion concerning various stripe structures is presented in ref. [12]. The simplest model of structure consists in alternate magnetization stripes (Fig. 4a). The structure appears to be one of high instability. After Malozemoff et al. [12] six alternatives are possible to "stabilize" this structure and one among these is to take in consideration a small tilt for magnetization in respect of stripe axis. For a tilted magnetization the stripes domains should be accompanied by the surface closure domains. In this manner, free energy of magnetic system is substantially minimized.

The tilted magnetization in film plane is characterized by two vector components: one major component parallel with stripe axis and the second, minor component, normal to this axis. The magnitude of magnetization components depends on tilted angle of magnetization and this is in closed correlation with magnetic anisotropy. Function of tilted angle different domain structures can be appeared. For example, in the proposed model, type I stripe domains, shown in Fig. 4b the magnetization direction alternates in film plane and its normal component is in film plane for each domain. This type of stripe domain structure is properly for magnetic field lines directed parallel to initial direction of field lines from sputtering process.

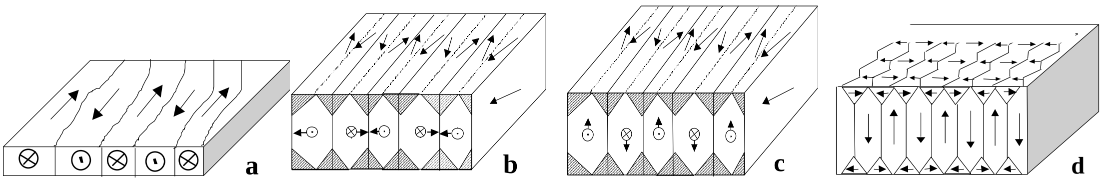

Fig. 4. Models for magnetic domain structure in Fe-Sm film: a) stripe domains, highly instable; b) stripe domains, improved stability, type I; c) stripe domains, improved stability, type II; d) so-called bubble magnetic domain structure for normal-to-plane applied field.

In the hypothesis that magnetization is tilted out-of-film plane, the oblique magnetization makes a small angle with film plane Thus there is a small magnetization component (minor component) normal to the film plane and a big one (major component) in film plane. The presence of normal component for magnetization permits a new arrangement of domains. As a matter of fact in the second experiment a fingerprint type structure with zigzag domain walls was found out. The proposed model for this type of domain structure is shown in Fig. 4c. The fingerprint structure (type II stripe structure) is properly for magnetic field lines directed perpendicular to film plane. This kind of stripe domain structure is a precursor for magnetic bubble structure, which appears as a result of collapse effect of fingerprint domains at critical value of normal to film plane applied field. Figure 4d shows the model for so-called bubble domain structure. Previous investigations concerning magnetic anisotropy of Fe-Sm films have been confirmed the presence of a tilted direction of easy axis of magnetization with a small tilted angle out of film plane.

5. Conclusion

Iron-samarium amorphous thin films, with the composition $Fe_{71}Sm_{29}$ obtained by sputtering in presence of weak magnetic field were investigated. Investigations are related to magnetic domain structures. Observed structures are parallel stripes for magnetic field lines directed parallel to initial direction of field lines from sputtering process (type I stripe domains) and fingerprint structures (type II stripe domains) for magnetic field lines directed perpendicular to film plane. The evidenced structures are in close correlation to magnetic anisotropy direction of Fe-Sm films. Iron-samarium films exhibit a tilted easy anisotropy axis such as that shown in a previous work. The tilted anisotropy can be explained by the existence of two components for magnetization vector in Fe-Sm films. One of component, called major component, is directed parallel to the domain axis and is a consequence of internal structure of ferromagnetic clusters. This component is responsible for stripe structure formation. The second component, called minor component, is directed normal to film plane. This component ensures the structures in case of perpendicular magnetic fields. Models for each structure were proposed. The validity of the models was verified by observing the domain structure changinh during modification of magnetic field direction.

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