Mariusz OZIMEK[1], Andrzej SIKORA[1], Wiesław WILCZYŃSKI[2]

Electrotechnical Institute, Division of Electrotechnology and Materials Science (1), Electrotechnical Institute (2)

The study of magnetic domain development in shielding films using MFM technique

Abstract. *In the article we've described results of the research aimed on recognition magnetic domain structures of thin magnetic film that can be used as a shield. By correlating magnetic domain structures with macroscopic properties of the film, we can implement a new approach, where the large group of small samples is used to select limited group of large samples in order to perform final tests and select the solution suitable for mass production.*

Streszczenie. *W artykule zostały opisane wyniki badań mających na celu wskazanie możliwości zastosowania mikroskopii sił magnetycznych w opisywaniu cienkich warstw magnetycznych, stosowanych w ekranowaniu pola elektromagnetycznego. (**Badania magnetycznych właściwości powierzchni cienkich warstw ekranujących za pomocą techniki MFM**).*

Keywords: magnetron sputtering, magnetic domain, magnetic force microscopy, shielding thin films.
Słowa kluczowe: rozpylanie magnetronowe, domeny magnetyczne, mikroskop sił magnetycznych, warstwa ekranująca.

Introduction

Due to increasing popularity of various electronic devices in the market, with particular growth of wireless data and energy transfer solutions, one must be aware of presence of the electromagnetic noise in the environment. The issue of electromagnetic immunity and compatibility must be considered very carefully during designing of new devices, but is also should be taken into account in terms of influence of all those devices on living organisms.

Lately, the problem of electromagnetic immunity is discussed even more widely due to the very high activity of the sun expected within next decade, which can cause serious damages to power systems.

One of the methods of providing a high quality shielding is production of conductive and magnetic thin films deposited on specific substrates by plasma techniques. By creating complex multilayers structure, one can obtain very efficient shielding coverings [1-10].

Obtaining the information about the shielding attenuation efficiency, requires relatively large sample (the surface should be not smaller than 132 cm^2) [11]. It leads to extremely large costs of the tests. Therefore the macro-micro-macro approach can be applied (Fig.1).

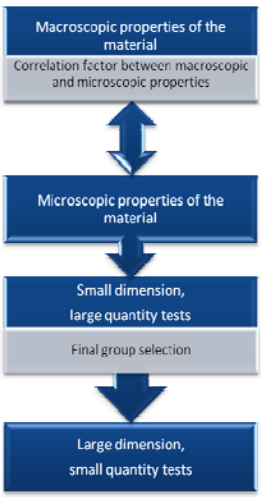

Fig.1. Macro-micro-macro approach diagram

The macroscopic properties are related to micro- and nanoscopic ones. In case of magnetic thin shields, the origin of this relation is related to size, shape and homogeneity of magnetic domains structure [12-14]. Therefore one can conclude the macroscopic properties of the material by testing its properties on the level of a few microns of dimension. This allows to reduce the costs of sample production. In case of magnetic thin films, when the best magnetic domain structure is developed, the macroscopic test can be performed on a limited number of samples. The advantages of such an approach are the reduced time and costs of the shielding development process.

In order to obtain the information about the magnetic domains structure, one can use Near Field Microscopy technique: MFM – Magnetic Force Microscopy, where the interactions between the magnetic sample and the microscope tip are recorded [15-17].

Experimental work

Magnetic thin films were prepared by impulse sputtering in vacuum chamber 0.2 m^3 of volume, equipped with magnetron gun of the WMK-100 type. $Ni_{85}Fe_{15}$ target, was sputtered onto Si substrate at room temperature and in pure argon atmosphere. Obtained ferromagnetic layers thicknesses were in the range from 80 to 150 nm.

The measurements of the domain structure of the films were performed in MFM mode using Innova instrument (Veeco Co.). Obtained results allowed to evaluate both: topography (roughness, grain size), and magnetic (domains size and shape) properties. The examples of the results are shown on figure 3.

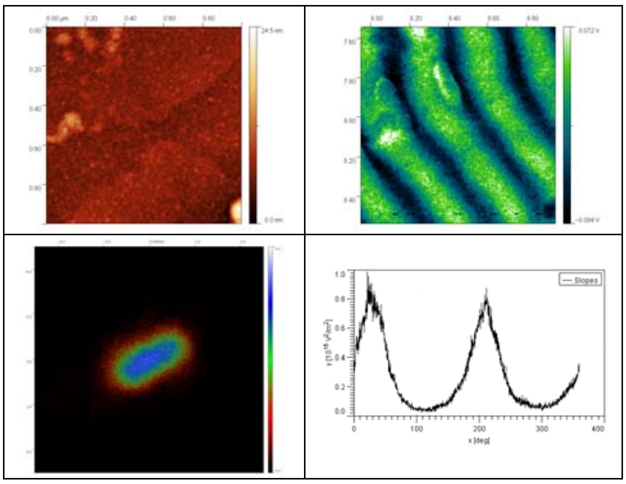

Fig.3. Examples of the MFM measurement and analysis results: topography (left top), magnetic domain map (right top), slopes analysis of the magnetic domains two-dimensional and linear graphs (left and right low)

One can see relatively flat surface with homogenous, grainy structure and few defects (larger grains). The map of magnetic domains reveals linear structures with minor defects caused by the presence of the features visible on the topography map. The brighter and darker lines represent up and down magnetic momentum orientation. When large number of the samples is analyzed, one needs to use values representing the properties of the surface so as to be able to compare them.

The surface can be characterized by roughness parameters and grain size (grain analysis procedure). Also the thickness of the film can be easily measured in order to correlate it with sputtering parameters. The magnetic structures however need to be also described with specific algorithm. According to tests we've performed, it can be convenient to characterize them with tools designed for topography analysis. The slope distribution analysis tool delivers the information in two formats: two-dimensional map showing the colour-related density of direction and steepness of the slopes. The second format is the graph showing this same information as graph in theta angle function.

This feature allows to obtain quantitative information about the way the magnetic domain create specific shapes. Examples of the results are presented in figure 4.

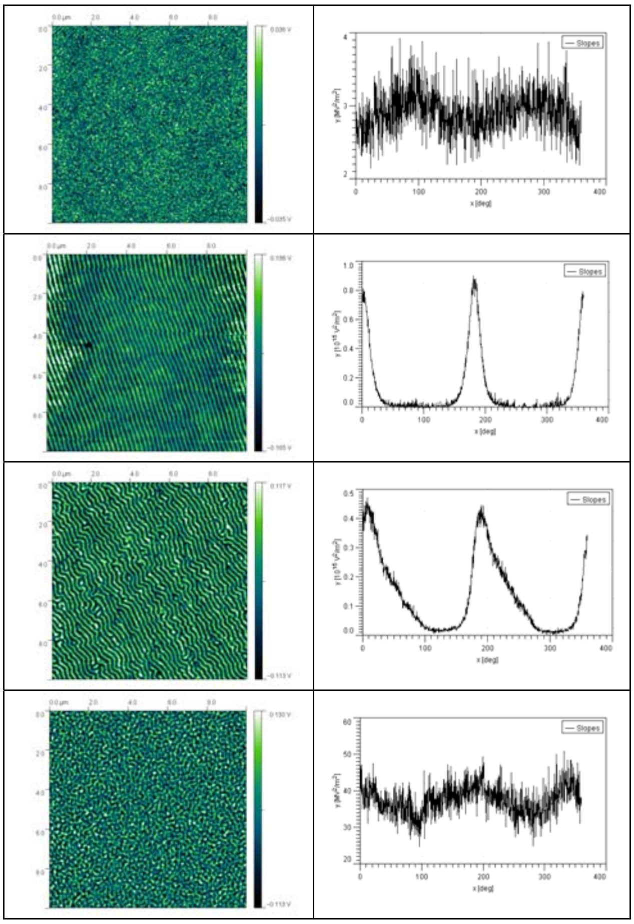

Fig.4. Example visualizations of some magnetic domains (left side) measured with MFM. Slope distribution analysis graphs (right side)

One can see the relation between the graphs and the complexity of the shapes. It is easy to see if the magnetic structures developed in any privileged direction. By determining Full Width at Half Maximum factor, we could compare several samples and see clear relation to the sputtering parameters (Fig.5).

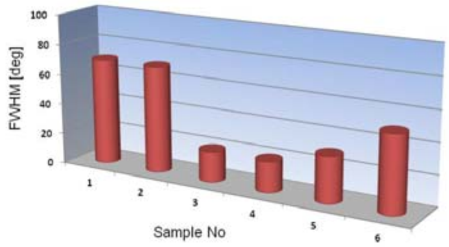

Fig.5. Full Width at Half Maximum (FWHM) of the slope distribution graphs calculated for different samples

Small values for samples 3-5 correlate with straight, long structures like presented as second from the top in figure 4.

Another feature designed for topography evaluation is the grain analysis tool. In this case it was used to calculate the mean size of magnetic domain structures (the algorithm can identify certain areas of MFM map as grains). Figure 6 shows the graph comparing values calculated for example set of samples. One can see that samples 3-5 have large magnetic structures.

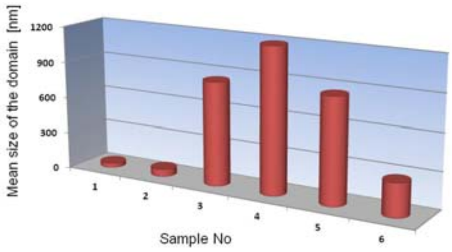

Fig.6. Mean size of the domain structures calculated for different samples

The complexity of the shape of the structures should be taken into account as well. Although FWHM factor shows whether the edges of the structures have some particular properties, but a quite different structure can produce the same values (first and last example shown in figure 4). Therefore another tool should be used to evaluate the results. The fractal dimension is a statistical quantity that gives an indication of how completely a fractal appears to fill space, as one zooms down to finer and finer scales. If we expect that the domain structure will have very complex shape, it can be useful to describe it by that way [18]. The graph showing values of example set of samples is shown in figure 7.

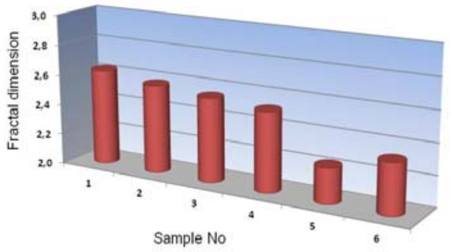

Fig.7. Fractal dimension of the domain structures calculated for different samples

By analyzing few sets of parameters describing the magnetic structures, one needs to correlate them to each other in order to obtain one value corresponding to the macroscopic model of the material. Further works are in progress.

Economical potential

One can expect, that due to the increase in annual production of electronic devices, especially containing sophisticated digital circuits and using wireless data transmission and energy transfer, as well as the growing demand for enhancement of the safety of fragile data storage and transmission, the electromagnetic shielding will play significant role in development of new constructions. Wide bandwidth of data transmission enables solutions covering all spectra of electromagnetic radiation, therefore new solutions will be desired on the market. Taking into account the amount of annual production of most popular devices: cell phones, PDA's, laptops and others, the economic impact of introducing new product cannot be underestimated. Considering information as the most valuable property, one can expect, that solutions improving data safety will strengthen their position on the market.

Future aspects

Development of diagnostic methods allowing to use presented macro-micro-macro approach should have impact on the market within few years. As a matter of fact, one can already purchase products which were designed with supportive role of diagnostic tools used in nanotechnology. Possibility of reducing new product's development costs as well as time necessary to introduce this product to the market, will make presented approach very attractive. The main challenge now is to gather knowledge and to develop physical models which will be used to determine macroscopic properties of the object basing on the results of the micro- or nanoscopic measurements. One can expect a significant progress in this field within next decade.

LITERATURA

[1] Choi Y.S., Yoo Y.H., Kim J.G. Kim S.H., A comparison of the corrosion resistance of Cu-Ni stainless steel multilayers used for EMI shielding, *Surface & Coatings Technology*, 201 (2006), 3775-3782

[2] Jaroszewski M., Dielectric characterization of EM composite barrier materials with plasma layers on nonwoven fabrics. *Composite Interfaces*, 19 (2012), n.3–4, 171–178

[3] Huang J.L., Yau B.S., Chen C.Y., Lo W.T., Lii D.F., The electromagnetic shielding effectiveness of indium tin oxide films, *Ceramics International*, 27 (2001), 363-365

[4] Pospieszna J., Jaroszewski M., Ziaja J., Szafran G., Koprowska J., Włókniny polipropylenowe z węglowym pokryciem plazmowym w technice ekranowania pola EM, *Przegląd Elektrotechniczny*, 84 (2008), nr.10, 270-271

[5] Kim S.W., Yoon C.S., High-frequency electromagnetic properties of soft magnetic metal-polyimide hybrid thin films, *Journal of Magnetism and Magnetic Materials*, 316 (2007), e893-e895.

[6] Jaroszewski M, Pospieszna J, Ziaja J; Dielectric properties of polypropylene fabrics with carbon plasma coatings for applications in the technique of electromagnetic field shielding, *Journal of Non-Crystalline Solids*, 356 (2010), n11-17, 625-628

[7] Ziaja J., Jaroszewski M.: EMI shielding using composite materials with plasma layers. *Electromagnetic waves*, (2011), 425-448, InTech.

[8] Kim W.M., Ku D.Y., Lee I., Seo Y.W., Cheong B., Lee T.S., Kim I., Lee K.S. The electromagnetic interference shielding effect of indium-zinc oxide/silver alloy multilayered thin films, *Thin Solid Films*, 473 (2005), 315-320.

[9] Ziaja J., Ozimek M., Janukiewicz J. Cienkowarstwowe ekrany pola elektromagnetycznego otrzymywane metodą impulsowego rozpylania magnetronowego*, Przegląd Elektrotechniczny*, 5 (2010), 222-224.

[10] Ziaja J., Koprowska J., Janukiewicz J. Using Plasma Metallisation for Manufacture of Textile Screens Against Electromagnetic Fields, *FIBRES & TEXTILES in Eastern Europe*, 16 (2008), n.5, 64-66.

[11] Więckowski T.J., Janukiewicz J.M., Method for Evaluating the Shielding Effectiveness of Textiles, *FIBERS & TEXTILES in Estern Europe*, 14 (2006), 18-22.

[12] McCord J., Westwood. J., Domain Optimization of Sputtered Permalloy Shields for Recording Heads, *IEEE Transaction on Magnetics*, 37 (2001), n.4, 1755-1757.

[13] Ozimek M., Sikora A., Gaworska-Koniarek D., Wilczyński W. Nanoskopowa analiza orientacji domen magnetycznych z wykorzystaniem technik bliskiego pola, *Przegląd Elektrotechniczny*, 4 (2010), 72-74.

[14] Hsieh C.T., Liu J.Q., Lue J.T., Magnetic force microscopy studies of domain walls in nickel and cobalt films, *Applied Surface Science*, 252 (2005), 1899-1909.

[15] Liebmann M., Schwarz A., Kaise U., Wiesendanger R. Magnetization reversal of structurally disordered manganite thin film with perpendicular anisotropy, *Physical Review B*, 71 (2005), 104431-1 - 104431-1.

[16] Koblischka M.R., Hartmann U. Recent advances in magnetic force microscopy, *Ultramicroscopy*, 97 (2003), 103-112.

[17] Koblischka M.R., Hewener B., Hartmann U., Wienss A., Cristoffer B., Persch-Schuy G. Magnetic force microscopy applied in magnetic data storage technology, *Applied Physics A*, 76 (2003), 879-884.

[18] Kalinin S., Gruverman A. (Eds.), Scanning Probe Microscopy Electrical and Electromechanical Phenomena at the Nanoscale 2, (2007), Springer.

***Authors**:*

MSc Eng. Mariusz Ozimek, Electrotechnical Institute Division of Electrotechnology and Materials Science, M. Sklodowskiej-Curie 55/61, 50-369 Wroclaw, E-mail: m.ozimek@iel.wroc.pl;

PhD Eng. Andrzej Sikora, Electrotechnical Institute Division of Electrotechnology and Materials Science, M. Sklodowskiej-Curie 55/61, 50-369 Wroclaw, E-mail: a.sikora@iel.wroc.pl;

PhD DSc Wiesław Wilczyński, Electrotechnical Institute, Pozaryskiego 28, 04-703 Warsaw, E-mail: w.wilczynski@iel.waw.pl.