Vol. **115** (2009) *ACTA PHYSICA POLONICA A* No. 1

Proceedings of the European Conference “Physics of Magnetism” (PM’08), Poznań 2008

Magnetic Tailoring of Domains in NiFe/Au/Co/Au Multilayers by He Ion Bombardment through Nanospheres

W. Glapka[a,b], P. Kuświk[a], I. Sveklo[c], M. Urbaniak[a], K. Jóźwiak[d], T. Weis[e],
D. Engel[e], A. Ehresmann[e], M. Błaszyk[a], B. Szymański[a], A. Maziewski[c]
and F. Stobiecki[a]

[a]Institute of Molecular Physics, Polish Academy of Sciences
M. Smoluchowskiego 17, 60-179 Poznań, Poland
[b]Faculty of Physics, A. Mickiewicz University, Poznań, Poland
[c]Faculty of Physics, University of Białystok, Poland
[d]Poznań University of Technology, Institute of Materials Science, Poznań, Poland
[e]Institute of Physics (EP IV) and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT)
University of Kassel, Kassel, Germany

Sputter deposited $(\mathrm{Ni_{80}Fe_{20}/Au/Co/Au})_{10}$ multilayers, characterized by alternating in-plane and perpendicular anisotropies of the NiFe and Co layers, respectively, and out-of-plane stripe (labyrinth) domain structure in the Co layers, were bombarded by He^+-ions (10 keV) through a mask consisting of polystyrene nanospheres with a diameter of 470 nm. The changes of multilayers magnetic properties after ion bombardment are correlated with the used mask structure.

PACS numbers: 75.70.−i, 75.60.−d

1. Introduction

Magnetic patterning, i.e., local changes of magnetic properties without topographical changes is of particular interest due to possible applications in a new generation of magnetic storage media. This effect, originating from the local atomic structure modification, can be induced by ion bombardment [1–3]. Because of special requirements for magnetic hard disc technology the attention is focused on magnetic layered films with perpendicular anisotropy (e.g., Co/Pt, Co/Au) [4, 5]. As a result of intermixing at the interfaces the perpendicular anisotropy decreases with increasing ion dose and for large fluence transforms to easy-plane anisotropy [4, 6]. Magnetic patterning in nanoscale can be realized by focused ion beam [7], or by bombardment through stencil [8] or lithographic masks [4]. In this contribution we demonstrate that large area magnetic patterning in the nanoscale can be realized by 10 keV He ion bombardment of NiFe/Au/Co/Au multilayers through a single layer of polystyrene (latex) nanospheres arranged in a regular lattice. Nanosphere lithography is a well known method applied for fabrication of ordered arrays of nanodots. Such structures were prepared by material deposition or removing (by ion etching) [9] through the mask consisting of nanospheres. According to our best knowledge up to now the nanosphere lithography was not used to realize magnetic patterning via ion bombardment.

2. Experimental

The $(\mathrm{Ni_{80}Fe_{20}}\text{-2 nm/Au-2 nm/Co-0.6 nm/Au-2 nm})_{10}$ multilayer (ML) was deposited on a naturally oxidized Si(100) wafer [10] and cut into two samples. One of the samples was the reference sample and was not treated with ions. Hexagonally arranged, close-packed arrays of polystyrene nanospheres (diameter 470 nm) were deposited on the multilayer surfaces via a self-assembly process realized by dip coating. Subsequently, a thin 3 nm Au film was deposited above the nanospheres in order to provide the charge transfer during scanning electron microscopy (SEM) imaging and ion bombardment. The perfect nanospheres lattice is confirmed by SEM images (Fig. 1).

The ion bombardment through the mask consisting of nanospheres was performed using 10 keV He^+-ions and with a dose $D = 10^{15}$ $\mathrm{He^+/cm^2}$. Before the magnetic characterization the nanospheres were washed out in tetrahydrofuran (THF) using ultrasonic cleaner. The magnetic force microscopy (MFM) measurements were performed in ambient conditions with an Ntegra Prima scanning probe microscopes (NT-MDT) using the “tapping mode” for topography imaging and the “lift mode”

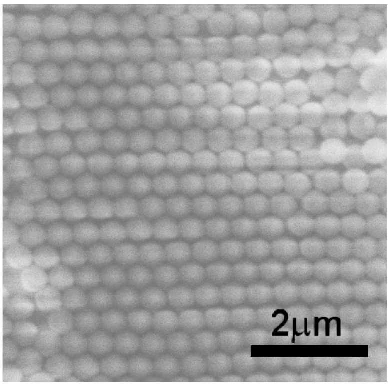

Fig. 1. The grid structure of polystyrene nanospheres on the sample surface observed with SEM.

(height 70 nm) for magnetic imaging. The MFM setup allows investigations of the magnetic structure in a permanent external magnetic field (out-of-plane in our investigations). The magnetization process, as a function of the magnetic field H applied perpendicularly to the sample plane was investigated using the equipment for polar magnetooptical Kerr effect (MOKE) measurements described in Ref. [11].

3. Results and discussion

Figure 2 displays the hysteresis loops of the uniform $(\mathrm{Ni_{80}Fe_{20}}$-2 nm/Au-2 nm/Co-0.6 nm/Au-2 nm$)_{10}$ ML which was not subjected to the ion bombardment, and the hysteresis loops of the ML after the ion bombardment with $D = 10^{15}$ $\mathrm{He^+/cm^2}$.

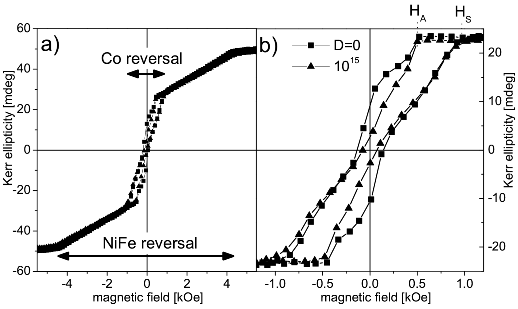

Fig. 2. (a) Polar magnetooptical Kerr effect hysteresis loops of $(\mathrm{Ni_{80}Fe_{20}}$-2 nm/Au-2 nm/Co-0.6 nm/Au-2 nm$)_{10}$ multilayer before (■) and after (▲) ion bombardment. Part (b) is hysteresis loops for the magnetization reversal of Co layers separated from part (a).

The shapes of the presented loops are typical of MLs consisting of ferromagnetic layers with alternating anisotropies: easy axis anisotropy perpendicular to the MLs plane (Co), and easy plane anisotropy (NiFe) [10]. Because of the weak interaction between the layers (outside the H range corresponding to the domain structure, that is for $|H| \geq H_N$, H_S, where H_N and H_S denote the fields in which the domains are nucleated and annihilated, respectively [10, 12]), it is possible to separate the magnetization reversal processes of the layers with perpendicular anisotropy and in-plane anisotropy. Figure 2b displays the hysteresis loops corresponding to the magnetization reversal of the Co layers. The loops are typical of the stripe domain pattern of the ML with perpendicular anisotropy. The influence of the ion bombardment on the hysteresis loop shape is evidenced by the decrease in coercivity field and the remanence magnetization. This tendency is in agreement with our earlier investigations [6], however, changes are significantly smaller here. It may result from two facts. First of them concerns different sample structure. In the work of Kuświk et al. [6] the influence of the $\mathrm{He^+}$-ion bombardment (10 keV) on the sandwich-type $(\mathrm{Ni_{80}Fe_{20}/Au/Co/Au})_1$ film was investigated and not on an ML. The second, more important fact is that in measurements of the MLs for which the ion bombardment was performed through the nanosphere mask, the lateral ion dose distribution is not constant within the laser spot of the MOKE setup, thus averaging lateral areas penetrated by different ion doses (Fig. 3).

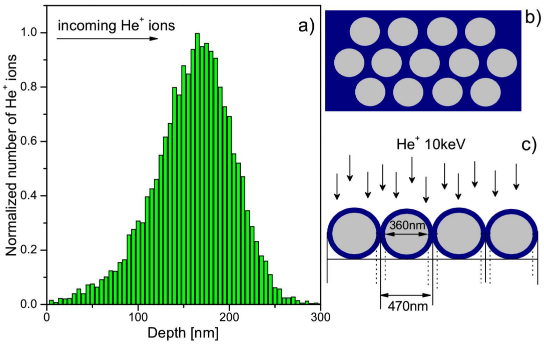

Fig. 3. The depth profile of $\mathrm{He^+}$ ions (10 keV) retained in the polystyrene calculated with SRIM program (a). Schematic distribution of irradiated (dark area) and non-irradiated (gray circles) areas of the sample — top (b) and side (c) views.

Hence, the measured hysteresis loop delivers the information about different kinds of areas, the ones where the properties were modified and the other where the properties remained unchanged. In order to estimate the size of the areas which were not patterned by the ions, the probability distribution of the 10 keV $\mathrm{He^+}$ ion penetration, for certain distances from the polystyrene surface, was determined with the stopping and range of ions in matter (SRIM) program [13]. From the performed simulation (Fig. 3a) it may be concluded that when the polystyrene thickness is larger than 300 nm, all of the ions remain in the material of the mask. Therefore, the circular areas that are 360 nm in diameter with centers arranged in a two-dimensional hexagonal lattice, are entirely protected from being bombarded (Fig. 3b). On the remaining area the ion dose changes in the range of

$0 < D \leq 10^{15}$ He^+/cm^2. Because a possible ion path variation within the polystyrene nanospheres (an effect similar to the one presented in [4]) it is impossible to define the ion dose distribution in the areas reached by the ions. On the basis of our earlier research [6] the anisotropy is expected to be reduced in the bombarded areas. In consequence, it may be anticipated that the domain distribution reflects the surface anisotropy distribution. Figure 4 displays the domain structure images and related Fourier transforms for the reference multilayer (a) (not exposed to the ion bombardment), and for the bombarded one (b)–(d) with an ion dose of 10^{15} He^+/cm^2.

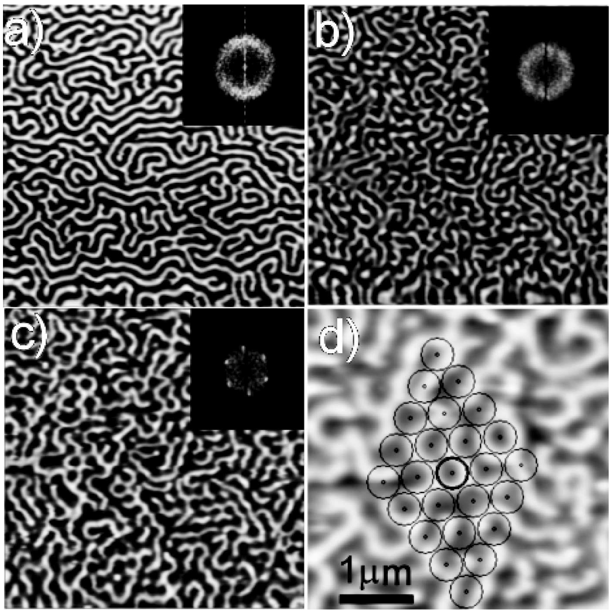

Fig. 4. MFM images (10×10 μm^2) of domain structure: (a) non-irradiated sample, (b)–(d) the irradiated one with He^+ ions through the mask consisting of nanospheres. Insets in (a)–(c) show Fourier's transformations of the corresponding images. The measurements were performed without magnetic field (a), (b) and with magnetic field of 400 Oe applied perpendicular to the sample (c), (d). The part (d) is a magnified part of image (c) (size 4×4 μm^2) with superimposed hexagonal grid of circles corresponding to the location of nanospheres on the sample surface during irradiation.

For the latter sample, the MFM images taken in remanence and in an external magnetic out of plane field of 400 Oe are presented. The domain distributions in remanence for both MLs do not exhibit the two-dimensional hexagonal array. It is, however, clearly visible for the sample that was bombarded through a polystyrene nanospheres mask, when the measurement was performed in the magnetic field ranging from 350 to 450 Oe. The hexagonal symmetry of the domain distribution is also confirmed by the clear sixfold symmetry visible in the Fourier transform image. The fact that the domain distribution reflects the local variations of the magnetic properties only in the presence of magnetic field can be explained from trivial energetic consideration. Without magnetic field the domain period of the sample, modified by ion bombardment, is about 340 nm. The periodicity of the nanosphere lattice is about 420 nm (may be the nanospheres are partially compressed). From hysteresis loop measurements we see that changes in magnetic properties of irradiated/non-irradiated material are not dramatic, so it can be considered as some kind of perturbation. But there is a possibility of a domain period/size adjustment using an external magnetic field, so that in our case at the field of 400 Oe we obtain a period of domain structure equals to the period of the mask.

4. Conclusion

Bombarding the ($Ni_{80}Fe_{20}$-2 nm/Au-2 nm/Co-0.6 nm/Au-2 nm$)_{10}$ multilayers with He^+(10 keV, $D = 10^{15}$ He^+/cm^2) ions through a two-dimensional hexagonally arranged nanosphere lattice results in a local anisotropy reduction. This effect is visible in a specific, regular domain structure with hexagonal symmetry. We have shown that the nanosphere lithography may be applied to the magnetic patterning of the multilayered systems realized by He ion bombardment.

Acknowledgments

P.K. acknowledges a Ph.D. grant of the Polish Academy of Sciences. This work was in part supported by the Polish National Scientific Network ARTMAG: "Magnetic nanostructures for spintronics".

References

[1] C. Chappert, H. Bernas, J. Ferré, V. Kottler, J.-P. Jamet, Y. Chen, E. Cambril, T. Devolder, F. Rousseaux, V. Mathet, H. Launois, *Science* **280**, 1914 (1998).

[2] A. Ehresmann, *Recent Res. Devel. Appl. Phys.* **7**, 401 (2004).

[3] J. Fassbender, D. Ravelosona, Y. Samson, *J. Phys. D Appl. Phys.* **37**, R179 (2004); J. Fassbender, J. McCord, *J. Magn. Magn. Mater.* **320**, 579 (2008).

[4] T. Devolder, H. Bernas, D. Ravelosona, C. Chappert, S. Pizzini, J. Vogel, J. Ferré, J.-P. Jamet, Y. Chen, V. Mathet, *Nucl. Instrum. Methods Phys. Res. B* **175-177**, 375 (2001).

[5] T. Blon, G. Ben Assayag, J.-C. Ousset, B. Pecassou, A. Claverie, E. Snoeck, *Nucl. Instrum. Methods Phys. Res. B* **257**, 374 (2007).

[6] P. Kuświk, J. Kisielewski, T. Weis, M. Tekielak, B. Szymański, M. Urbaniak, J. Dubowik, F. Stobiecki, A. Maziewski, A. Ehresmann, *Acta Phys. Pol. A* **113**, 651 (2008).

[7] J. Lohau, A. Moser, C.T. Rettner, M.E. Best, B.D. Terris, *Appl. Phys. Lett.* **78**, 990 (2001).

[8] A. Dietzel, R. Berger, H. Grimm, W.H. Bruenger, C. Dzionk, F. Letzkus, R. Springer, H. Loeschner, E. Platzgummer, G. Stengel, Z.Z. Bandić, B.D. Terris, *IEEE Trans. Magn.* **38**, 1952 (2002).

[9] H.W. Deckman, J.H. Dunsmuir, *Appl. Phys. Lett.* **41**, 377 (1982).

[10] M. Urbaniak, F. Stobiecki, B. Szymański, A. Ehresmann, A. Maziewski, M. Tekielak, *J. Appl. Phys.* **101**, 013905 (2007).

[11] M. Kisielewski, A. Maziewski, M. Tekielak, A. Wawro, L.T. Baczewski, *Phys. Rev. Lett.* **89**, 087203 (2006).

[12] F. Stobiecki, M. Urbaniak, B. Szymański, J. Dubowik, P. Kuświk, M. Schmidt, T. Weis, D. Engel, D. Lengemann, A. Ehresmann, I. Sveklo, A. Maziewski, *Appl. Phys. Lett.* **92**, 012511 (2008).

[13] J.F. Ziegler, J.P. Biersack, U. Littmark, *The Stopping and Range of Ions in Solids*, Pergamon Press, New York 1985 and SRIM 2003 code: http://www.srim.org.