ELSEVIER
Journal of Magnetism and Magnetic Materials 209 (2000) 224–227
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Relaxation of pinned domains in patterned magnetic thin films

Te-Ho Wu[a,]*, J.C. Wu[b], Y.W. Huang[b], L.X. Ye[a], Bing-Mau Chen[c], Han-Ping D. Shieh[c]

[a] *Department of Humanities and Sciences, National Yunlin University of Science and Technology, Touliu 640, Taiwan, ROC*
[b] *Department of Physics, National Changhua University of Education, Changhua 500, Taiwan, ROC*
[c] *Institute of Electro-Optic Engineering, National Chiao-tung University, Hsinchu 300, Taiwan, ROC*

Abstract

We have shown in previous papers that the magnetic domains could be pinned inside the artificially patterned hole arrays under suitable geometry aspect ratio. Nevertheless, we have found that if we reverse the magnetization directions through domain wall motion, the confined domains expand from smaller territory into larger territory for some samples. In addition, the pinned domains maintained the same moment's orientation after the domain expansion. The possible reason for the pinned domains to retain the same moment's orientation maybe those pinning holes that act as high anisotropy defects. Thus, domain wall motion was around the high anisotropy sites and only peeled away the domain in the land area while the enclosed domain of the hole area maintained the same orientation. Moreover, the feasible reason for the expansion domains is the coercive force, which is perpendicular to the side-walls and pinning the domains inside the holes, are relaxed and thus causing the domains growth. This phenomenon is called the relaxation of pinning domains. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Magnetic pinning; E-beam lithography; Domain expansion; Domain wall motion

1. Introduction

In magneto-optical (MO) recording, the recording and erasure processes rely on the creation and annihilation of reverse-magnetized domains under the influence of external and/or internal magnetic fields. However, high-density recordings are achieved only when the recorded domains are small and uniform, have smooth boundaries, and are precisely positioned. Thus, a knowledge of magnetization-reversal dynamics is desirable in order to control domain size, while avoiding nonuniformities and jagged boundaries, in magnetic and thermo-magnetic recordings. However, the traditional study of magnetization-reversal lacks direct observations of definite domain growth and contraction. Our previous papers have shown that the magnetic domains could be pinned within artificially patterned hole arrays under suitable geometry shape and magnetization value [1–4]. The pinned domains acquire the shape of the holes and the sharpness of their boundaries depends on the size of the holes. Thus, it motivates us to use the artificially patterned hole arrays to study the magnetic domain behaviors under magnetization-reversal. We have found that if we reverse the magnetization directions via domain wall motion, the confined domains expand from smaller territory into larger territory. This phenomenon is due to the relaxation of the pinned domains. In this paper, we will address the phenomena of domain relaxation and explain the possible reason for domain expansion.

2. Sample preparation

Regular arrays of shaped holes were fabricated using electron-beam lithography. An electron resist, polymethyl methacrylate (PMMA), was spun onto a SiN-coated Si-wafer. Arrays of square-, circle-, and star-shaped holes

---

*Corresponding author. Tel.: + 886-5-534-2601 ext. 3166; fax: + 886-5342601 ext. 3166.
E-mail address: wuth@flame.yuntech.edu.tw (T.-H. Wu)

0304-8853/00/$ - see front matter
PII: S0304-8853(99)00694-0

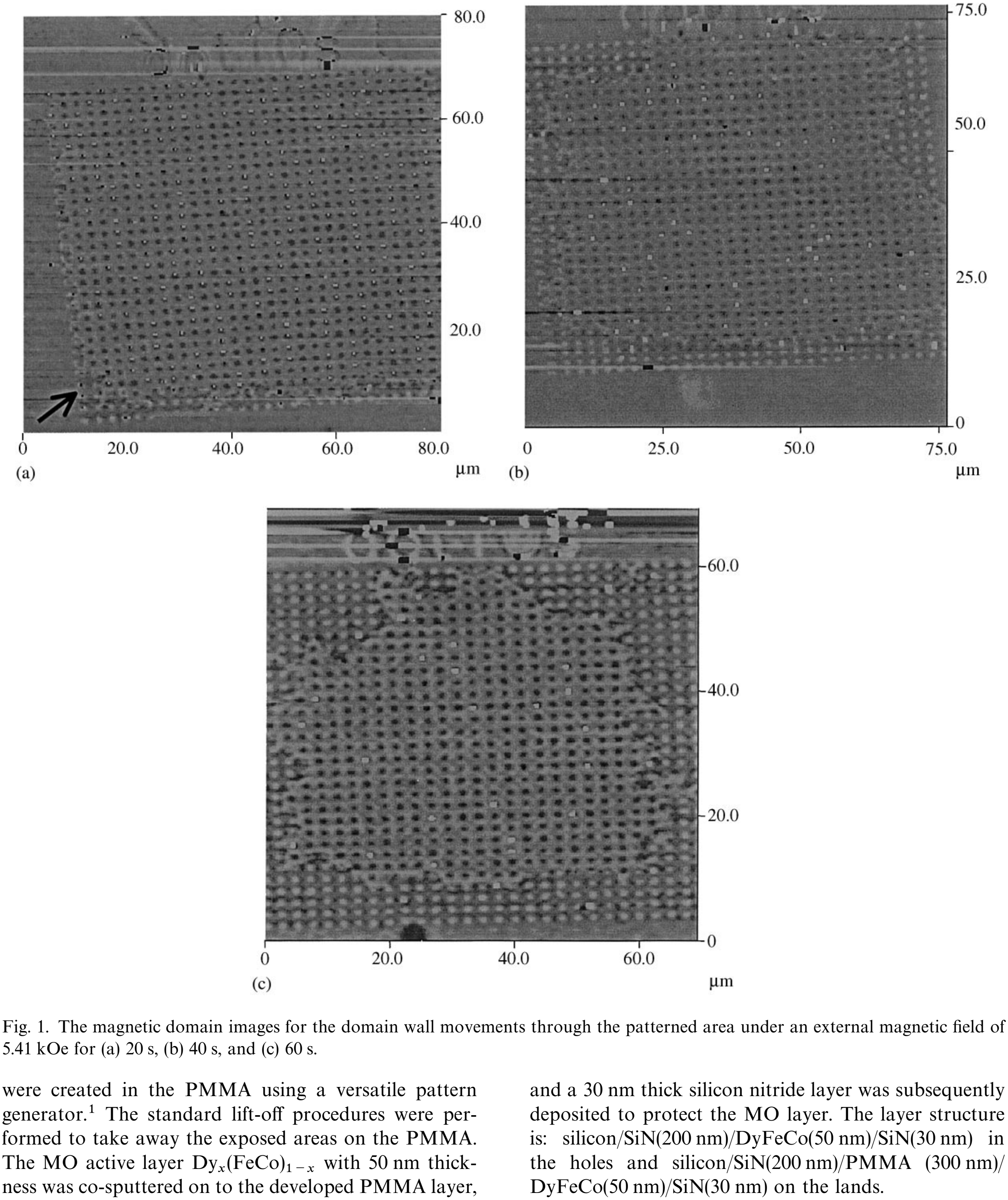

Fig. 1. The magnetic domain images for the domain wall movements through the patterned area under an external magnetic field of 5.41 kOe for (a) 20 s, (b) 40 s, and (c) 60 s.

were created in the PMMA using a versatile pattern generator.[1] The standard lift-off procedures were performed to take away the exposed areas on the PMMA. The MO active layer $Dy_x(FeCo)_{1-x}$ with 50 nm thickness was co-sputtered on to the developed PMMA layer, and a 30 nm thick silicon nitride layer was subsequently deposited to protect the MO layer. The layer structure is: silicon/SiN(200 nm)/DyFeCo(50 nm)/SiN(30 nm) in the holes and silicon/SiN(200 nm)/PMMA (300 nm)/DyFeCo(50 nm)/SiN(30 nm) on the lands.

3. Experiments

The sample's morphology and magnetic domain structure were observed by employing a magnetic force

---

[1] A 30 kV of Hitachi S2460N SEM equipped with a versatile pattern generator is used for the structure fabrication in this study. The writing software, Nanopattern Generator Systems (NPGS), is produced by JC Nabity Lithography Systems, Bozeman, MT59717.

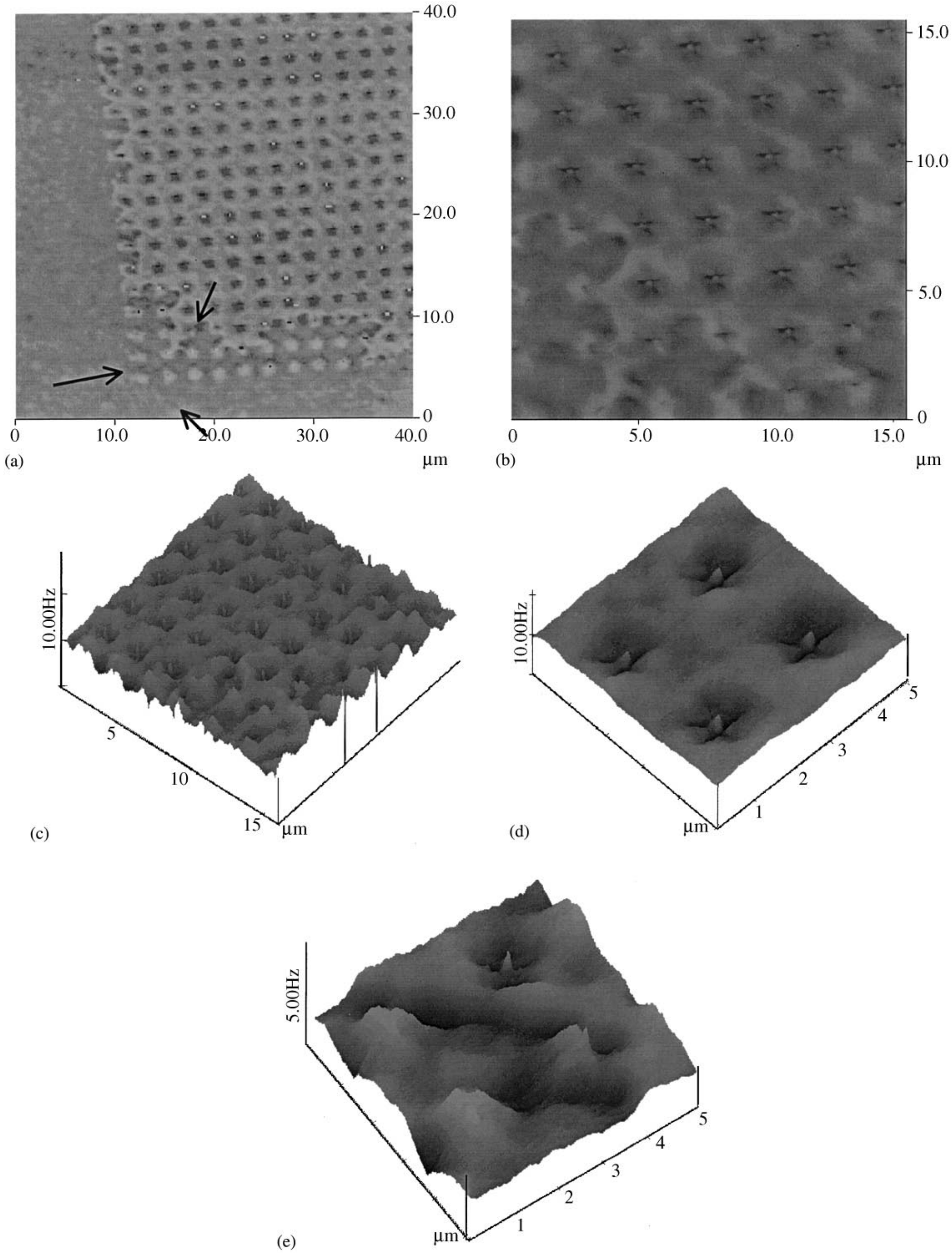

Fig. 2. Zoom-in images of Fig. 1. (a) The zoom-in image of the right lower corner of Fig. 2(a). (b) The closer zoom-in image of the left lower corner of Fig. 2(a). (c) 3-D view of Fig. 2(b). (d) The further closer look of Fig. 2(c) image of four pinned domains. (e) Image of further closer look of Fig. 2(c) of one pinned domain and three relaxation domains.

microscope (MFM). A Digital Instruments Nanoscope IIIa MFM, equipped with phase extender [5] was used in this study. The magnetic tip with a CoCr-coated Si tip magnetized along the tip axis was used to scan the magnetic domain structures in tapping-lift mode [6]. Domain images represent the detected frequency shifts of the vibrating cantilever. Before taking the MFM measurements, the samples were either magnetized or demagnetized in magnetic fields perpendicular to the film plane [7]. During the perpendicular demagnetization process a polar Kerr microscope, equipped with an electromagnet of maximum field capability of 8 kOe, was used to monitor the developing magnetic domains.

4. Results and discussions

The relaxation of pinned domains was investigated by observing the magnetic domain wall movements across the pinning hole arrays. The experimental results can be best seen from Figs. 1 and 2 for the thin film $Dy_{21}(Fe_{80}Co_{20})_{79}$. The way in which the images shown in Figs. 1 and 2 are produced is as follows. The magnetic moment of a sample was first saturated in one direction, out-of-plane, by applying a magnetic field much greater than the sample's coercivity. The applied field was then increased in the reverse direction and allowed to approach coercivity, where it caused domain wall creation. As visualized under a Kerr microscope, the domain nucleated outside the patterned area and moved toward the patterned area. When the domain walls moved toward the boundary and/or moved further near to the center of the patterned area, the applied magnetic field was turned off. Pinned magnetic domains were then imaged by MFM.

Figs. 1(a)–(c) show the star-shaped magnetic domain images for domain wall movements across the patterned area for 20, 40, and 60 s under an external magnetic field of 5.41 kOe, individually. Note that, in Fig. 1(a), the pinned domains maintained the same moment's orientation and expanded after the domain walls moved across the pinning holes, as the arrow indicated. The domain growth manners of Fig. 1 can be seen in detail from their zoom-in images, as shown in Fig. 2. Fig. 2(a) shows the zoom-in image of the right lower corner of Fig. 1(a), as the arrow indicates in Fig. 1(a). One can see clearly that when the magnetic wall begins to move from outside the patterned area into the patterned area, the domains expand, as the arrows indicate in Fig. 2(a). Figs. 2(b) and (c) display the closer zoom-in and the corresponding 3-dimensional (3-D) images of the left lower corner of Fig. 2(a), respectively. Fig. 2(d) shows the further closer look of Fig. 2(c) image of four pinned domains. Moreover, Fig. 2(e) displays the image of further closer look of Fig. 2(c) of one pinned domain and three relaxation domains. By comparing Figs. 2(d) and (e), it is obvious that domains expand from smaller territory into larger territory after the domain wall movement across the hole regions.

5. Concluding remarks

We have found that if we reverse the magnetization directions through the domain wall motion, the confined domains expand from smaller territory into larger territory. This phenomenon is due to the relaxation of the pinned domains. The feasible reason for the pinned domains to retain the same moment's orientation may be the fact that those pinning holes act as high anisotropy defects and hinder domain wall movement. Thus, domain wall motion roundabout the high anisotropy sites and only peeled away the domain in the land area while the enclosed domain of the hole area maintained the same orientation. In addition, because of the coercive force, which is perpendicular to the side-walls and pining the domains inside the holes, are relaxed and thus causing the domains growth.

Acknowledgements

This work is supported by the National Science Council, the Republic of China, under Contract No. NSC 88-2112-M-224-001

References

[1] Te-Ho Wu, J.C. Wu, B.M. Chen, H.P.D. Shieh, J. Magn. Soc. Jpn. 22 S2 (1998) 145.

[2] Te-Ho Wu, J.C. Wu, B.M. Chen, H.P.D. Shieh, IEEE Trans. Magn. 34 (1998) 1994.

[3] Te-Ho Wu, J.C. Wu, Y.W. Huang, B.M. Chen, H.P.D. Shieh, J. Appl. Phys. 85 (8) (1999) 5980.

[4] Te-Ho Wu, J.C. Wu, B.M. Chen, H.P.D. Shieh, J. Magn. Magn. Mater. 193 (1999) 155.

[5] K. Babcock, M. Dugas, S. Manalis, V. Elings, Mat. Res. Soc. Symp. Proc. 355 (1995) 311.

[6] K. Babcock, V.B. Elings, J. Shi, D.D. Awschalom, M. Dugas, Appl. Phys. Lett. 69 (1996) 705.

[7] Te-Ho Wu, J. Appl. Phys. 81 5321 (1997) 5321.