Journal of Magnetics 5(2), 55-58 (2000)

Magnetization Distribution in Thin-Film Magnetic Head

Kyung-Ho Shin[1], E. E. Shalyguina[1,2], J. H. Lee[1,3] and K. Rhie[1,3]

[1]*Korea Institute of Science & Technology, P.O. Box 131, Cheongryang, Seoul 130-650, Korea*
[2]*Physical Faculty, Moscow State University, 119899, Moscow, Russia*
[1,3]*Department. of Physics, Korea University, Chochiwon 339-700, Korea*

(Received 25 April 2000)

Local magnetic properties and magnetization distributions on the air-bearing surface of a thin-film magnetic head have been studied by using scanning magneto-optical Kerr microscopy. The examined head was a merged MR read/inductive writing head with a write gap equal to 0.3 μm. Sizes of top and bottom pole-tips on the air-bearing surface of the writing head were equal to 3 μm × 3 μm and 3 μm × 30 μm, respectively. The measured magnetic characteristics on the head air-bearing surface were found to be very sensitive to the head design. In particular, magnetization distributions were discovered to have asymmetrical shape. Maximum magnitudes of the magnetization were located near the shorten pole-tip. So, it was experimentally proved that more magnetic flux emanates just from this part of the air-bearing head surface.

1. Introduction

The magneto-optical Kerr effects (MOKE) are widely used to investigate metallic multilayers, magnetic films, amorphous materials, granular alloys and so on. Many recent MOKE discoveries, such as quantum finite effects [1], oscillations of Kerr effects with magnetic and nonmagnetic layer thickness [2-6], strong correlation between MOKE and magnetic anisotropy [7], indicate its usefulness. MOKE is not only effective tool to obtain unique information concerning the electronic structure of magnetic materials but also a powerful tool to study of magnetic properties and magnetization reversal processes of a near-surface layer of ferromagnetic, ultra-thin magnetic films (with the thickness of several monolayers) and also low-dimensional magnetic structures.

At the last years scanning Kerr microscopy is becoming very popular that is caused by the appearance of novel magnetic microstructures employing in modern microelectronics. This experimental technique (having high spatial resolution) allows to study near-surface distributions of magnetization components in the above-mentioned samples and to control magnetic field behavior of ferromagnetic elements of micron sizes.

The configuration of the magnetic field produced by a thin-film magnetic head (TFMH) is one of the most important factors in write processes. Optimization of this parameter can be realized by changing a design of TFMH. Numerical simulations of the magnetic fields of TFMH are performed sometimes before an achievement of practical solutions. There are many methods for such calculations (see, for example, [8]) but practically at all computations, a magnetization model is developed for the analysis of the write field of TFMH. Scanning magneto-optical microscopy allows to obtain information concerning magnetization distributions on the head air-bearing surface (ABS). Then these data can be used for designing high-performance thin-film magnetic heads. Moreover, an instantaneous comparison of the magnetization on the air-bearing surface of the head to the current in the write coil can be made.

In this article we report results on magneto-optical investigation of magnetization distributions on the air-bearing surface of the thin-film magnetic head (TFMH) at various magnitudes of the current in the head coil. The influence of the design of TFMH on those is analyzed.

2. Experimental

High performance Kerr microscopy system (magneto-optical micromagnetometer) has been developed to investigate local magnetic properties and distributions of magnetization at low-dimensional magnetic structures. Fig. 1 shows a schematic illustration of the experimental set-up. The system has a polarized microscope with × 1200 magnification and a linear resolution of 0.2~0.3 μm. The light from the source (S) going through the polarizer (P) is focused on the studied sample (SS) by the help of lens (O_1) of the microscope. The light reflected from the sample is focused on a light detector (D) by the help of lens (O_2) of the microscope. The light detector (photo-multiplier) is located in the image plane of the microscope. The sample (SS) is situated in a magnet (M). A modulation method of the magneto-

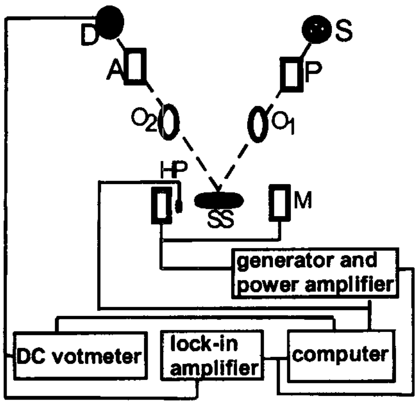

Fig. 1. Diagram of magneto-optical micro-magnetometer. Here S is a light source; SS is a studied sample; M is a magnet; O_1 and O_2 are focusing lens of a microscope; P and A is a polarizer and analyzer, respectively; D is a light detector; HP is a magnetic field detector.

optical signal registration is used in order to increase a sensitivity of MOKE methods. Usually in this case, the sample magnetization reversal is realized under the alternating magnetic field *H*. A generator and a power amplifier are employed to nourish a magnet. Hall probe (HP) located in the magnet gap controls the magnetic field. There are two signals in the detector circuit. The first signal U_{-} is proportional to the intensity of the light reflected from the unmagnitazed sample (I_O). The second $U_{\sim} \propto \Delta = I - I_O$, where I is the intensity of the light reflected from the magnetized sample. The appearance of Δ is caused by the magneto-optical effects. The magnitudes of U_{-} and $U_{\sim}$ are measured by means of a DC voltmeter and a lock-in amplifier, respectively. The magnitude of the magneto-optical signal is determined by the relation:

$$\delta = U_{\sim} / U_{-}$$

Computer is used for data acquisition. The described magneto-optical experimental set-up allows to measure δ with resolution up to 10^{-5}-10^{-6}.

The magnetization curves $\delta(H)$~$M(H)$ and the hysteresis loops for the studied sample are measured by varying the magnetic field from 0 to a saturation field H_S and from H_S to $-H_S$, respectively. Magnetization components perpendicular to the sample surface are detected by means of polar Kerr effects. The studied near-surface area of the sample is determined by the size of the slot that is located in the image plane of the microscope, i.e. this size can be the order of the optical resolution of the microscope. By scanning the slot along the sample image, the near-surface distributions of magnetization components and local magnetic properties are measured at the different magnetic field magnitudes.

The head in this study is a merged MR read/inductive writing head with a write gap equal to 0.3 μm. Fig. 2 displays a schematical illustration of the air-bearing surface (ABS) of the writing head. Sizes of top and bottom magnetic pole-tips of the writing head on the ABS is equal to 3 $\mu m \times 3$ μm and 3 $\mu m \times 30$ μm, respectively. The top and bottom magnetic poles of the examined head are magnetic films with high (15 kG) and low (8 kG) magnitudes of the saturation induction B_S. The head design reflects improvements in head efficiency by shrinking the length of the top pole-tip and increasing B_S of the top head pole so that larger magnetic flux can be achieved from the pole tips per unit drive current.

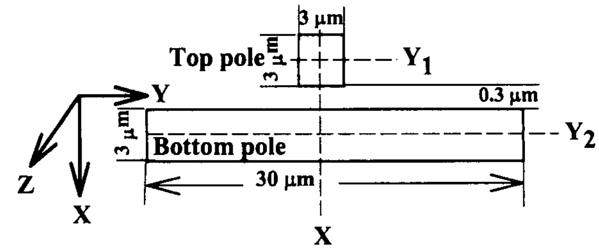

Fig. 2. Schematical illustration of the air-bearing surface (ABS) of the examined thin-film head. Sizes of top and bottom pole-tips of on the ABS of the head are equal to 3 $\mu m \times 3$ μm and 3 $\mu m \times 30$ μm, respectively.

3. Results and Discussion

By scanning the 0.3-μm diameter slot along the ABS image of the head, the measurements of Polar Kerr effect proportional to the magnetization component perpendicular to this surface (M_Z) were carried out. In the given case, the magnetization reversal of the head poles is realized with the help of the head coil.

Fig. 3(a) shows variations of polar Kerr signal δ along X-direction (see Fig. 2) measured at 5, 10 15 and 19-mA current in the head coil. From Fig. 3 one can see that the dependence of $\delta(X) \propto M_Z(X)$ has an alternating-sign character that is an evidence of anti-parallel orientation of the M_Z magnetization component in the top and bottom head poles. At the point of view of magnetostatics, $M_Z \neq 0$ is a clear indication of the presence of magnetic charges on the ABS that generate stray fields. The closure of magnetic flux in the XZ-plane reduces the magnetostatic energy of this magnetic system and causes the anti-parallel orientation of the pole magnetization. The examined head is geometrically asymmetric. Besides, the saturation induction of the top and bottom head poles is different. As a result, the distribution of $\delta(X) \propto M_Z(X)$ has an asymmetrical shape.

It should be pointed out that the experimental dependence $\delta \propto M_Z(X)$ in Fig. 3(a) is quite different from the Karlqvist function which is an analytic approximation to the magnetization component perpendicular to the ABS [9]. According to this calculation (ignoring the finite lengths of the poles and any saturation), the magnetization has been zeroed across the 0.5 μm-spacing from the gap (Fig. 3b). Our experimental data show that the magnetization is unequal to zero for the whole pole-tip.

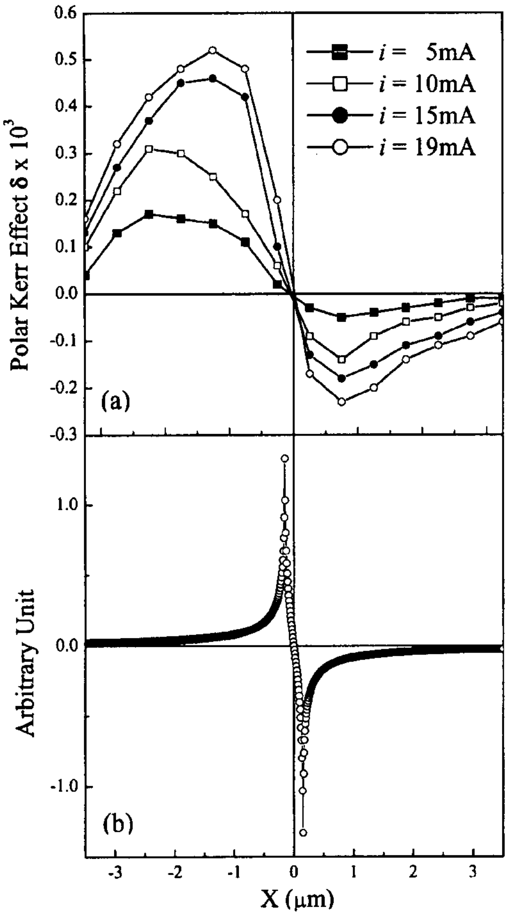

Fig. 3. Variations of Polar Kerr signal $\delta \propto M_Z$ along X-direction (marked in Fig. 2) measured on the air-bearing surface of the head at the 5, 10 15 and 19-mA current in the head coil (a) and Karlqvist function that is an analytic approximation to perpendicular component of the magnetization at the ABS (b).

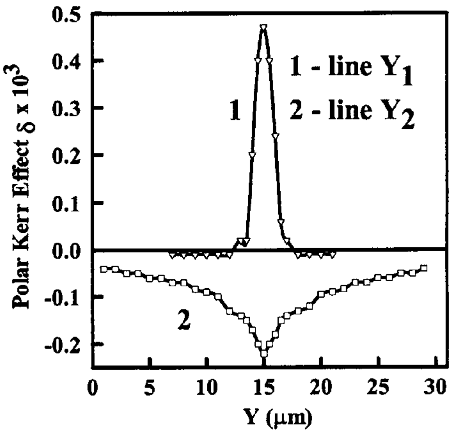

Fig. 4. Variations of Polar Kerr signal $\delta \propto M_Z$ measured along the Y_1 and Y_2-directions (marked in Fig. 2) on the air-bearing surface of the head at the 19 mA-current in the head coil.

The head design influences also on variations of polar Kerr signal δ along the Y-direction (see Fig. 4). From Fig. 4 one can see that maximum magnitudes of δ and, correspondingly, the M_Z magnetization at the top and bottom

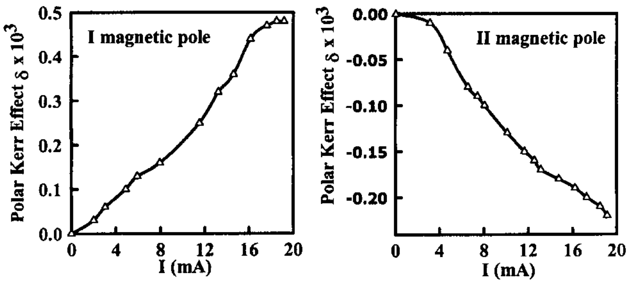

Fig. 5. Variations of polar Kerr signal δ as a function of the coil current for the ABS points where the M_Z magnetization has maximum magnitude.

pole-tips are located at the same Y-read off. This fact indicates that the most part of the magnetic flux emanates in this ABS part.

Variations of polar Kerr signal δ as a function of the coil current at fixed points on the ABS were measured also. It is evident that these variations depend on the location where the measurements are taken. Fig. 5 shows the dependence of polar Kerr signal δ on the current in the head coil measured at the points close to the gap where the M_Z magnetization has maximum magnitude. From Fig. 5 one can see that $\delta \propto M_Z$ increases practically linearly with enlarging the coil current for both pole-tips. Such behavior of the magnetization indicates that the magnetization reversal of the head poles is dominated by a rotation of the magnetization. Besides, the magnetization of the top pole-tip is larger than the bottom (that is caused also by the head design), and in the both cases the maximum magnitude of the magnetization is unequal to the saturation magnetization. The last fact can be explained by the end effect, i.e., the enlargement of the local demagnetizing factor near the ABS.

4. Conclusions

A magneto-optical scanning microscopy was developed to obtain information about the low-dimensional magnetic structures using in modern devices of magnetic recording. The measurements of local magnetization curves and magnetization distributions on the air-bearing surface of the thin film magnetic head were carried out. The strong influence of the design of the TFMH on the examined characteristics was observed. In particular, the magnetization distributions on the head air-bearing surface were discovered to have asymmetrical shape. Maximum magnitudes of the magnetization were found to be located near the shorten pole-tip. So, it was experimentally confirmed that at the given head design, more magnetic flux emanates just near the shorten pole-tip.

Acknowledgment

This work has been carried out within the scientific Korea-Russia Manpower exchange program and sponsored by Korea Institute of Science & Technology Policy and Technology Evaluation and Planning.

References

[1] Y. Suzuki, T. Katayama, S. Yoshida, K. Tanaka, and K. Sato, Phys. Rev. Lett., **68**, 3355 (1992).

[2] W. Geerts, Y. Suzuki, T. Katayama, K. Tanaka, K. Ando, and S. Yoshida, Phys. Rev., **B50**, 12581 (1994).

[3] T. Katayama, W. Greets, Y. Suzuki, D. Fujitani, and N. Okuzawa, J. Magn. Magn. Mat., **156**, 171 (1996).

[4] T. Katayama, Y. Suzuki, and W. Greets, J. Magn. Magn. Mat., **156**, 158 (1996).

[5] E. E. Shalyguina, N. I. Tsidaeva, I. A. Pogrebnaya, O. A. Shalyguina, A. Marty, and B. Gilles, J. Magn. Magn. Mat., **203**, No 1 3, 250 (1999).

[6] E. E. Shalyguina, Kyung-Ho Shin, I. A. Pogrebnaya, and O. A. Shalyguina, IEEE Trans. on Magn., **35**(5), 3142 (1999).

[7] K. Tsushima, and K. Shiugawa, J. Magn. Soc. Jpn. **II Suppl.**, S1 (1987).

[8] Proceeding of International Magnetics Conference (INTERMAG 99), IEEE Trans. on Magn., **35**(5), part I (1999).

[9] H. N. Bertram, Theory of magnetic Recording (Cambridge University Prss, Cambridge, 1994.