Nanoscale Magnetostrictive Response in a Thin Film Owing to a Local Magnetic Field

Citation for published version (APA):

DOI:
10.1063/1.125835

Document status and date:
Published: 01/01/2000

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:
www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:
openaccess@tue.nl
providing details and we will investigate your claim.
Nanoscale magnetostrictive response in a thin film owing to a local magnetic field

R. Berger, a) F. Krause, and A. Dietzel
IBM Germany SSD GmbH, Analysis Laboratory, K 4119, D-55131 Mainz, Germany

J. W. Seo
Institut de Physique, Université de Neuchâtel, CH-2000 Neuchâtel, and IBM Research, Zurich Research Laboratory, CH-8803 Rüschlikon, Switzerland

J. Fompeyrine and J.-P. Locquet
IBM Research, Zurich Research Laboratory, CH-8803 Rüschlikon, Switzerland

(Received 29 June 1999; accepted for publication 1 December 1999)

Scanning probe microscope experiments are presented in which thin magnetostrictive films deposited on top of micrometer-sized magnetic write heads as used in magnetic hard disk drives, are used to visualize their emanating magnetic field. The magnetostrictive expansion owing to magnetic writing fields is discussed, together with the transduction mechanisms that lead to the vertical and lateral contrast observed. Experimental results verify that the techniques described have a lateral resolution in the realm of 100 nm. © 2000 American Institute of Physics.

Magnetic read–write heads (RWHs) used for magnetic storage applications are a field of intense research and development that requires extremely sensitive techniques to estimate device parameters critical for further miniaturization and optimization. Various techniques have been applied for local magnetic characterization, such as spin-polarized scanning electron, 1 Kerr microscopy, 2 and scanning near-field magneto-optical 3 or Lorentz microscopy. 4 Scanning probe microscopy (SPM) such as magnetic force microscopy (MFM) techniques have been used to characterize surfaces of magnetic storage disks as well as RWHs. 5, 6 For instance, Proksch and co-workers have demonstrated the gigahertz response of recording heads with MFM techniques. 7 While analyzing an active write element by MFM, which is usually operated in noncontact mode, the high magnetic field generated by the head may attract the tip into contact, or may induce changes in the tip magnetization. 8 Hence SPM cantilevers with high spring constants have been used for MFM imaging, and high coercivity MFM tips that avoid tip magnetization changes have been fabricated. 9 Nevertheless, the above-mentioned artifacts may lead to misinterpretation of MFM images. Development of additional SPM techniques using nonmagnetic tips is therefore highly desirable. The technique we developed here takes advantage of the coupling between the magnetic and mechanical properties of magnetic materials, described for example by their magnetostrictive coefficients.

Magnetostri ctive materials are used, for example, as powerful transducer systems 10, 11 and as one layer of a spin-valve strain sensor to detect small deflections. 12 The magnetostrictive coefficient is determined from the bending of cantilevers coated on one side with a magnetostrictive layer when they are exposed to varying external magnetic fields 13 or by a direct measurement of their extension in a known external magnetic field. Such extension measurements have also been performed by means of scanning tunneling microscopy. 14 In addition, scanning force microscopy (SFM) topography data have been used to calculate the magnetostrictive coefficient from surface deformations in Terfenol–D crystals. 15 In this letter we present experimental data of local magnetostriction in a thin layer deposited on the surface of a RWH.

We used a RWH removed from the production line prior to the wear-protection coating process, 16 the geometry and thickness of which are presented as a schematic cross section in Fig. 1(a). The magnetic field emanating from the RWH can be controlled by varying the write coil current $I_{\text{RWH}}$ using an external ac current source. Magnetic fields of up to $2.0 \times 10^5$ A m$^{-1}$ can be generated between pole tips $P_1$ and $P_2$. A topographic image recorded by SFM and representative of these microstructures is presented in Fig. 1(b). It clearly displays surface features of both pole tips and the magnetic shielding layers. Topographic variations across the layers are typically in the range from 5 to 10 nm. A 150-nm-thick magnetostrictive film, e.g., Tb–Fe, was deposited on

![FIG. 1. (a) Sketch of a typical surface corrugation and layering sequence of the characterized RWH. $U$ is the undercoat, $S_1$ and $S_2$ are magnetic shields, MR is the magnetoresistive sensor including its wiring, $P_1$ and $P_2$ are the magnetic pole tip ends, WG is the writing gap, and $O$ is the overcoat layer. (b) SFM topography of an RWH displayed as a gray-scale image shows typical recession phenomena of such RWH devices (Ref. 17).]
For this magnetostrictive layer at the saturation magnetic field, a maximal thickness change of only \( \approx 0.1 \) nm is calculated, which superposes surface roughness. From the 16-bit resolution of the analog-to-digital converter we calculated a theoretical vertical piezoresolution on the order of 0.01 nm, which is not convenient for measuring the expected deformation. One way to overcome these limits is to modulate the magnetostrictive response \( I_{\text{RWH}} \) in a phase-sensitive amplifier (lock-in). Its output signal, \( V_{\text{VM}} \), for the vertical and \( V_{\text{TM}} \) for the torsional response of the cantilever can then be displayed.

Data of the deflection mode and the torsion mode of the laterally scanned nonmagnetic tip are presented in Figs. 2(a) and 2(b). The maximum response for both modes is located between the two pole tips, which is consistent with magnetic characterizations performed with other techniques. From the normalized values, the response magnitude in the writing gap (WG) was a factor of \( \approx 5 \) higher in the torsional than in the deflection mode [Fig. 2(c)]. The resolution, estimated from the torsional mode line scan, is \( \approx 100 \) nm, i.e., half the peak-to-valley distance (see arrows). Under our experimental conditions, Tb–Fe films are magnetized out-of-plane at zero magnetic fields. With increasing \( I_{\text{RWH}} \) a magnetic field in the WG parallel to the surface is generated. In-plane magnetized domains nucleate and 90° domain walls propagate until saturation magnetization is reached, leading to a local extension of the film’s dimensions along this direction. For \( I_{\text{max}} \), the Tb–Fe film returns to a low remanent magnetization state with out-of-plane magnetization.

Two actuation phenomena may contribute to the observed lateral contrast place: First, adhesion forces may keep the position of the cantilever tip fixed relative to the surface, whereas the film is locally extended. The lateral motion of the surface associated with the rotation of the magnetization at the tip location twists the cantilever, leading to the torsional response. Second, when the tip is not moved with the surface, magnetoacoustic emission coupling into the sensor, owing to 90° domain wall movements during magnetic field switching, might lead to the observed lateral contrast. Near the WG—where the generated magnetic field is too small for in-plane saturation—torsional-mode contrast is observed due to partial rotation of the magnetization at these locations.

To confirm that the observed contrast is not dominated by contributions from thermal expansion or eddy current damping, we performed similar scanning experiments on two uncoated devices. For both devices, \( P_1 \) is made of Ni80Fe20, which has a magnetostrictive coefficient close to zero, whereas \( P_2 \) is made of Ni45Fe55 [Fig. 3(a)] or Ni80Fe20 [Fig. 3(b)]. Ni45Fe55 has a nonzero magnetostrictive coefficient (\( \approx 3 \times 10^{-6} \)), but both materials have similar thermal expansion coefficients and electrical resistivities. Only for the Ni45Fe55-type head was a weak vertical deflection contrast observed on \( P_2 \) (\( \approx 1 \) nm). In contrast to the Tb–Fe film experiment, the contrast observed here is not attributed to domain movements, but to different volume magnetostriction in the heads.

To summarize, this technique is able to visualize locally magnetic fields emanating from a RWH device using a magnetostrictive thin film as a sensor between the device and the scanned SFM tip. The lateral resolution of the magnetic field is in the 100 nm realm. The reconstruction of the magnetic field could be simplified by using piezomagnetic layers having a linear response with magnetic fields and/or by more advanced methods to detect cantilever deformations (deflection, twisting, buckling) in all three directions. Very interesting complementary results, although obtained with other magnetic structures, have been reported recently. We foresee that the reported and related techniques can first be used to characterize a wide range of magnetic materials and also for industrial process control. Second, other properties, such as the magnetoelastic and the piezomagnetic effect, can be used in a similar way to infer magnetic characteristics of microstructures or of magnetic multilayers. Third, the sensing layer can be incorporated into the scanned local probe, allowing characterization of the magnetic field at a well-localized position.
defined distance. In conclusion, the technique described introduces a way to study magnetostriction effects locally.

The authors gratefully acknowledge J. Betz and E. Quandt (Institute of Materials Research I, Forschungszentrum Karlsruhe GmbH, D-76021 Karlsruhe) for Tb–Fe depositions. H. Grimm, G. Persch–Schuy, and A. Wienss (IBM Germany SSD) are acknowledged for helpful discussions. In addition, R. Allenspach, Ch. Gerber, and H. Siegwart (IBM Zurich Research Laboratory) are acknowledged for their support and helpful discussions. H. P. Lang (IBM Zurich Research Laboratory) is acknowledged for preparing and providing SFM cantilevers having reflective coatings.

8 Commercial MFM cantilevers from Digital Instruments have a coercive field of between $3 \times 10^3$ and $3 \times 10^4$ A m$^{-1}$. In-house CoCrPt alloy-coated sensors have a coercive field of approx. $2.0 \times 10^5$ A m$^{-1}$.
18 Nominally 150 nm of Tb–Fe was dc sputtered on top of a RWH head. This material has been chosen because of its high magnetostrictive coefficient of $\sim 700 \times 10^{-6}$ at saturation magnetic fields. The first 20 nm of such a layer is believed to oxidize under ambient conditions, resulting in an effective magnetostrictive layer of 130 nm.