Quantitative relationship between contact stress and magnetic signal strength in perpendicular recording media

Yuliang Liu, Shaomin Xiong, Jia Lou, David B. Bogy, and Guangyu Zhang

Citation: Journal of Applied Physics **115**, 17B725 (2014); doi: 10.1063/1.4865880
View online: http://dx.doi.org/10.1063/1.4865880
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/115/17?ver=pdfcov
Published by the AIP Publishing

JOURNAL OF APPLIED PHYSICS 115, 17B725 (2014)

Quantitative relationship between contact stress and magnetic signal strength in perpendicular recording media

Yuliang Liu,[1,2,a)] Shaomin Xiong,[2] Jia Lou,[3] David B. Bogy,[2] and Guangyu Zhang[1]
[1]*School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, 150001, China*
[2]*Computer Mechanics Lab, Mechanical Engineering, University of California at Berkeley, Berkeley, California 94720, USA*
[3]*Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Dong Nanhu Road 3888, 130033 Changchun, China*

(Presented 7 November 2013; received 21 September 2013; accepted 12 November 2013; published online 19 February 2014)

A series of nanoscratch experiments is conducted using constant loading scratch profiles to apply mechanical contact stress on perpendicular magnetic recording (PMR) media to cause its magnetic signal strength decay, which is characterized by the magnetic force microscope. The dependence of the magnetic signal strength on the applied normal load is quantitatively investigated. The results indicate that an increase of the applied normal load leads to a decrease of the magnetic signal strength. In addition, in order to obtain a more complete understanding of the results, a 3D finite element model is created to calculate the stress under different normal loads. Finally, the quantitative relationship between residual shear stress and magnetic signal strength is identified. [http://dx.doi.org/10.1063/1.4865880]

I. INTRODUCTION

For ultra-high areal density of magnetic recording, over 2 Tb/in.^{2} in the shingled or two dimensional magnetic recording,[1] the spacing between the slider and disk needs to be reduced to less than 2 nm. But the probability of intermittent contact increases with lower spacing. These contacts can result in scratches on the disk surface. Also, stress-induced demagnetization may occur around the scratches and this leads to read errors of the data stored in the hard disk drives (HDDs). In the past years, several groups have studied the phenomenon of stress-induced demagnetization in the perpendicular magnetic recording (PMR) disk.

Lee *et al.*[2] observed that irreversible and permanent magnetic damage in the magnetic recording layer could occur when a nanoscratch was applied on the surface of a PMR medium. Furukawa *et al.*[3,4] revealed that the scratch-induced demagnetization in PMR disks was mainly caused by plastic deformation, which results in magnetic grain tilt. Moreover, Lee *et al.*[5] investigated the plastic yield and magnetic degradation of ferromagnetic films under contact stress by the means of nanoscratch experiments and analytical simulations. Their results showed that the magnetic degradation was more susceptible to the applied contact stress than the plastic yield.

The above investigations provide a qualitative relationship between the stress and the demagnetization, and thus they help give a good understanding of the data loss in HDDs. However, in order to further improve the reliability of the data storage and avoid data loss in HDDs, it is important to obtain a direct quantitative relationship between stress and magnetic signal strength. The designers for hard disk media can obtain the stress after a numerical simulation of actual slider-disk contacts, then they can determine if magnetic signal strength decay occurs according to this quantitative relationship. When finding the magnetic signal strength decay occurrence, they may optimize the material properties and the structural dimensions of hard disk media to improve its mechanical performance so as to avoid the data loss.

In this study, we performed a series of nanoscratch experiments to investigate the relationship between the normal load and magnetic signal strength. Furthermore, a 3D finite element model was established to obtain the corresponding stresses under different loads. Thus, the quantitative relationship between stress and magnetic signal strength can be identified.

II. EXPERIMENTAL PROCEDURE

Samples from a commercial PMR aluminum disk with randomly pre-written magnetic recording patterns were used in this study. To apply mechanical scratches on the disk surface, we carried out systematic nanoscratch experiments using the TS70 Hysitron Triboindenter. The associated diamond tip was of the Cono-Spherical type that had a radius of curvature about 1 μm and an included angle of 90°. When nanoscratch experiments were performed using constant loading scratch profiles, the scratching velocity was constant at 0.5 μm/s. Since this scratching velocity was very low, the frictional heat effect could be neglected.[3–5] Also, the applied normal load for scratching the PMR samples ranged from 80 to 600 μN. The stress induced by the applied normal load during the nanoscratch experiments is comparable with that induced by slider-disk contacts.[6] The mechanical material properties and the thicknesses of the various layers in the sample, and the mechanical material properties of the diamond tip are listed in Table I. Fig. 1 shows a schematic diagram of the scratches after the nanoscratch experiments. Every scratch length is 8 μm and the scratch pitch is 5 μm. The marker dot patterns, which were formed by static indentations, were used to find the location of the scratch patterns

a)Author to whom correspondence should be addressed. Electronic mail: liuyuliang8301@gmail.com.

TABLE I. Mechanical material properties and thicknesses of Al-Mg layer, NiP layer, CoFe based soft magnetic underlayer (SMUL), Ru based intermediate layer (IL), CoCrPt based PMR layer, and DLC layer of sample, and mechanical material properties of diamond tip.

	DLC	PMR	IL	SMUL	NiP	Al-Mg	Diamond
Thickness, t (nm)	4	20	30	60	10 000	∼1(mm)	–
Density, ρ (kg/m^3)	2150	8900	12 300	8514	8000	2700	3500
Young's modulus, E (GPa)	168	150	135	120	114	71	925
Yield strength, Y (GPa)	13	3.4	3.9	3.7	3	0.67	18
Poisson radio, ν	0.3	0.3	0.3	0.3	0.31	0.33	0.2

because the scratches are very small to be observed using optical microscopy.

By using these markers we could accurately locate the scratches by the optical microscope. And then, the residual scratch depth and width were analyzed using an atomic force microscope (AFM) and the magnetic contrast intensity was measured using a magnetic force microscope (MFM).

III. RESULTS AND DISCUSSION

Figs. 2(a) and 2(b) show the topography and magnetic contrast intensity images for a typical nanoscratch experiment. In this study, we used the magnetic signal strength at the deepest place of the nanoscratch to evaluate the magnetic variation of the sample after a nanoscratch experiment. In order to quantify the magnetic signal strength for a random magnetic pattern, we extracted the root mean square (RMS) values of the magnetic contrast intensities from the deepest place of the nanoscratch and an unscratched place by MFM, respectively. The magnetic signal strength δ is defined as the ratio of the RMS value at the deepest place of the scratch to the RMS value at the unscratched place. In Fig. 2, the magnetic signal strength is calculated as 0.89 under a nanoscratch with 200 μN normal load.

According to the above, the quantitative relationship between applied normal load and magnetic signal strength can be summarized in Fig. 3. These results were obtained from at least five repetitions of nanoscratch experiments. Considering that the maximum standard deviation of the magnetic signal strength measurements is about 0.06 in Fig. 3, the graph can be divided by a horizontal magenta dashed line $\delta = 94\%$ into two areas: demagnetization area and non-demagnetization area. In particular, when the applied normal load reaches 120 μN, the demagnetization starts to occur. Throughout the demagnetization area, the dependence of magnetic signal strength on applied normal load after the nanoscratch is observed. As expected, an increase of the applied normal load leads to a decrease of the magnetic signal strength in the experimental area.

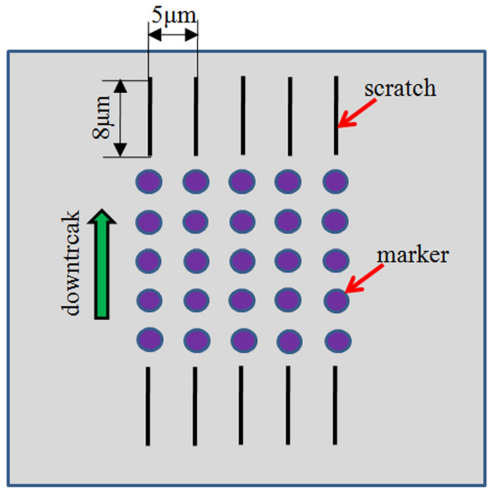

FIG. 1. Schematic diagram of scratches after nanoscratch experiments.

IV. FINITE ELEMENT SIMULATION

Here, we developed a finite element model to calculate the stress due to the scratches. In this way, the effect of the stress on demagnetization can be investigated.

Fig. 4 shows the 3D finite element model for the scratch experiments which was analyzed using ABAQUS/Explicit Ver. 6.12. The modeling parameters were consistent with those in the experiment. The coefficient of friction was set to be 0.3 in the simulation, which was measured using the Hysitron Triboindenter system. Due to the symmetry of the problem, only one half of the model was established. In addition, proper convergence of the numerical simulation was tested by refining the mesh size (increasing the number of elements) until a change of less than 3% occurred for the maximum shear stress, the maximum principle strain, and the maximum contact force.

Fig. 5 shows the profiles of the scratches under 150 μN normal load from an experiment and a simulation. Comparing the results of residual scratch depth and width in the experiment and numerical simulation, we conclude that they quantitatively agree with each other. The other results under different normal loads also have similar behavior as the 150 μN normal load case. So the application of this 3D finite element model is verified.

According to Refs. 3 and 4, the scratch-induced demagnetization in PMR disks is related to the magnetic grain tilt.

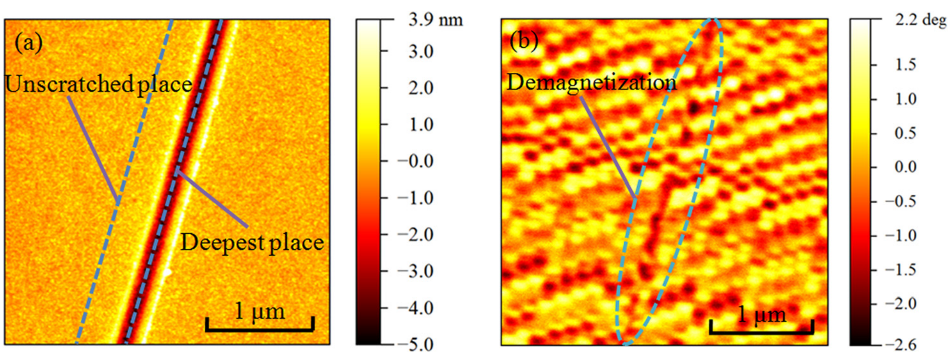

FIG. 2. (a) AFM and (b) MFM images after a nanoscratch experiment with 200 μN normal load.

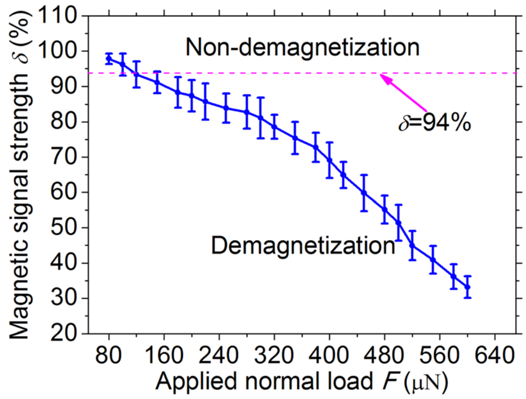

FIG. 3. Average and standard deviation values of the magnetic signal strength vs. the applied normal load.

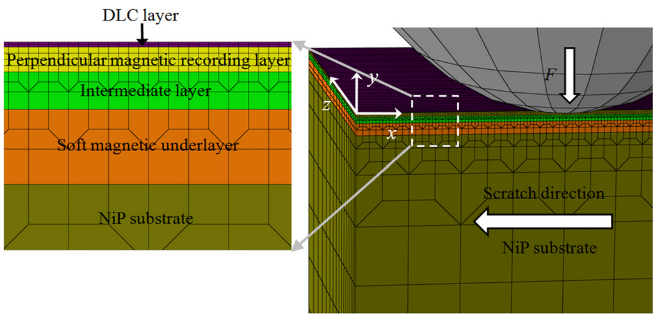

FIG. 4. 3D finite element mesh of a Cono-Spherical tip scratching on a magnetic disk. Model dimension (length × width × height): 10 μm × 3 μm × 5 μm.

A residual shear stress in the magnetic layer represents the distortion of the magnetic structure, which results from the magnetic grain tilt. So we can use a residual shear stress in the magnetic layer to evaluate the demagnetization of the magnetic recording layer. Here we choose an average residual shear stress along the magnetic recording layer at the deepest place of the nanoscratch to exhibit a comprehensive effect on demagnetization of the magnetic recording layer.

Fig. 6 shows the residual shear stress contour plot for the PMR medium at 150 μN normal load. The average residual shear stress close to the deepest place of the nanoscratch in Fig. 6 is 23.4 MPa. Finally, the quantitative relationship between the average residual shear stress and magnetic signal strength is plotted in Fig. 7. The results show that the larger applied normal load leads to the larger average residual shear stress and more magnetic signal strength decay. Moreover, since the orientation of the magnetic grains in PMR media is originally perpendicular to the surface of a hard disk, the magnetic grains tilt easily under such a stress, resulting in demagnetization of the stored data.

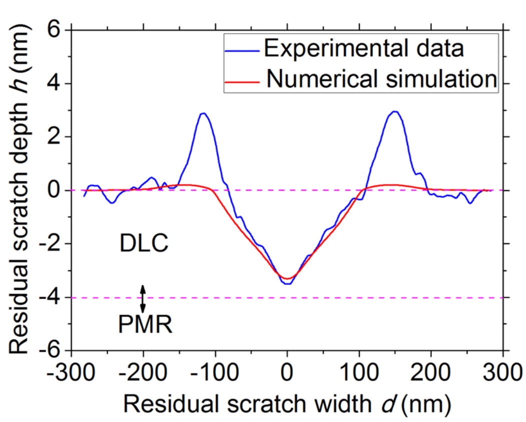

FIG. 5. Typical profiles of the scratches under 150 μN normal load from experimental measurement and simulation calculation.

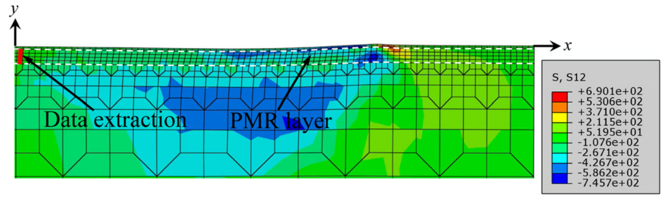

FIG. 6. Residual shear stress contour plot for the PMR medium at 150 μN normal load. Unit: MPa.

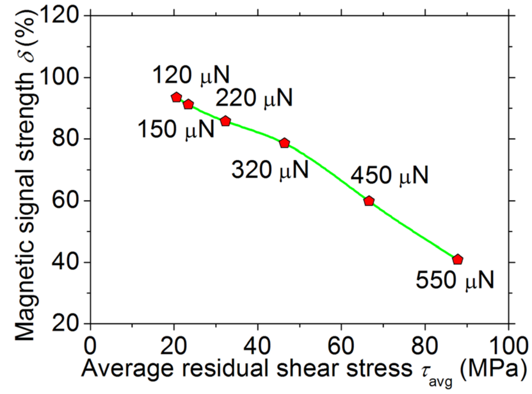

FIG. 7. Relationship between average residual shear stress and magnetic signal strength.

V. CONCLUSIONS

To achieve a more reliable PMR media for HDDs, the scratch-induced magnetic signal strength decay was quantitatively investigated from the two perspectives of experiment and simulation. It was found that the average residual shear stress has a close relationship with magnetic signal strength. When the average residual shear stress is equal to the threshold of 20.6 MPa, for the disks studied here, the magnetic signal strength decay starts. Therefore, in order to avoid the magnetic signal strength decay, the average residual shear stress should be controlled below 20.6 MPa by optimizing the PMR disks.

ACKNOWLEDGMENTS

This work was supported by the Computer Mechanics Laboratory (CML) at UC Berkeley and the China Scholarship Council (CSC).

[1]S. Greaves, Y. Kanai, and H. Muraoka, IEEE Trans. Magn. **45**, 3823 (2009).
[2]S. C. Lee, S. Y. Hong, N. Y. Kim, J. Ferber, X. D. Che, and B. D. Strom, J. Tribol. **131**, 011904 (2009).
[3]M. Furukawa, J. Xu, Y. Shimizu, and Y. Kato, IEEE Trans. Magn. **44**, 3633 (2008).
[4]M. Furukawa, J. Xu, Y. Shimizu, and Y. Kato, Microsyst. Technol. **16**, 221–226 (2010).
[5]S. Lee, M. He, C. D. Yeo, G. Abo, Y. K. Hong, and J. H. You, J. Appl. Phys. **112**, 084901 (2012).
[6]A. Y. Suh, C. M. Mate, and A. A. Polycarpou, Tribol. Lett. **23**, 177 (2006).