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Dynamics of Perpendicular Recording Heads

D. Litvinov, R. Chomko, J. Wolfson, E. Svedberg, J. Bain, R. White, R. Chantrell, and S. Khizroev

***Abstract*—3D modeling and inductance measurements were used to design an ultra-high frequency perpendicular system. Kerr microscopy and spin-stand experiments with focused ion beam (FIB) trimmed perpendicular heads and perpendicular media directly verified the high frequency concepts.**

***Index Terms*—Focused ion beam (FIB), next generation magnetic recording systems, perpendicular recording dynamics.**

I. Introduction

ALTHOUGH perpendicular recording has been proposed since the beginning of magnetic recording, it has not replaced conventional longitudinal recording, because, until recently, it has been at best equal in capability [1]. This situation is changing today when conventional longitudinal recording is approaching its fundamental limit due to superparamagnetic instabilities at approximately 100 Gbit/in^2 density [2]. Perpendicular recording might extend the limit to significantly higher densities due to the use of a thicker recording layer and exploiting the intrinsically higher write fields and stronger playback signal of perpendicular heads due to the use of a soft underlayer [3]–[5]. However, performance of perpendicular recording at high frequencies is a subject that has not been sufficiently explored. The demand for high data rate systems is a consequence of the increasing linear density. Therefore, direct study of perpendicular media dynamics is of fundamental importance. Major open questions to achieving high data rate in perpendicular recording were believed to be magnetization switching in a hard layer with the easy axis oriented perpendicular to the plane of the disk (due to a relatively low torque) and the influence on dynamics of a soft underlayer [6]. Recently, it was shown that the characteristic time for the magnetization switching in the hard layer is the orders of magnitude smaller than the characteristic time for the magnetization switching in soft materials of a system, such as the head material and the soft underlayer. Therefore, the soft materials dominate the time dependent roll-off.

The write driver speed raises a serious concern at data rates at which the characteristic time response is of the order of one nanosecond or less. Nevertheless, the question of the write driver speed limitation is not going to be a subject of this paper. Because this question is as critical in perpendicular recording as is in longitudinal recording, several solutions have already been proposed previously. The purpose of this paper is to study the intrinsic dynamic response of a perpendicular system with the underlayer and compare it with the intrinsic dynamic response of a typical longitudinal system. Realizing that the principal difference is caused by the presence of the soft underlayer in perpendicular recording, the study accentuates on the role of the underlayer.

Three-dimensional (3D) finite element modeling, including micromagnetics, was developed to define the design guidelines for high-speed perpendicular systems. Kerr imaging microscopy was utilized to directly study the magnetic flux dynamics of a recording system with a soft underlayer [7].

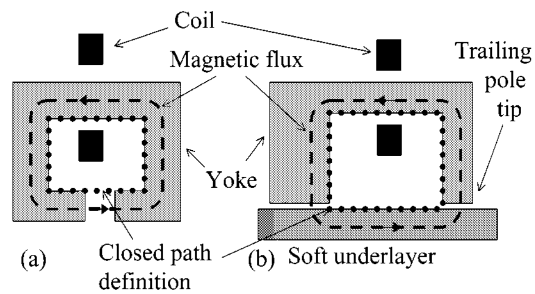

Fig. 1. A diagram showing a closed magnetic flux path in (a) a longitudinal system and (b) a perpendicular system with a soft underlayer.

II. Design of High-Speed Perpendicular Systems

Diagrams showing typical longitudinal and perpendicular systems are shown in Fig. 1(a) and (b). Considering that recording layers are typically orders of magnitude faster than soft materials in a system, the dominant contribution to the frequency roll-off is going to be caused by the head inductance. The head inductance consists of two parts, the write coil inductance and the inductance of the yoke plus the inductance of the soft underlayer in case of perpendicular recording. Effective inductance calculations, incorporating the eddy currents effect, were performed using 3D finite element modeling (FEM). The narrow portions of the recording systems, such as the leading and the trailing pole tips in the longitudinal mode and the trailing pole tip and the underlayer in the perpendicular mode, were modeled micro-magnetically using LLG equation. The head and the soft underlayer were assumed to be made of a FeAlN compound with a B_s of 20 kGauss and a H_k of 10 Oe. A longitudinal ring head design with a trackwidth of 100 nm and a gap length of 60 nm was modeled. An equivalent perpendicular head modeled had a 100 nm wide trailing pole with a 30 nm separation between the air bearing surface (ABS) and the underlayer. The calculated switching time versus the closed magnetic path length of the perpendicular system with different numbers of the coil turns is shown in Fig. 2. The closed path is defined as the yoke length [measured at the inner yoke surface, as shown in Fig. 1(a)]

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D. Litvinov, E. Svedberg, and S. Khizroev are with Seagate Research, Pittsburgh, PA, USA (e-mail: Sakhrat_Khizroev@notes.seagate.com).
R. Chomko is with the University of Miami, Coral Gables, FL, USA.
J. Wolfson, J. Bain, and R. White are with the Data Storage Systems Center, Carnegie Mellon University, Pittsburgh, PA, USA.
R. Chantrell is with the University of Wales, Bangor, UK.
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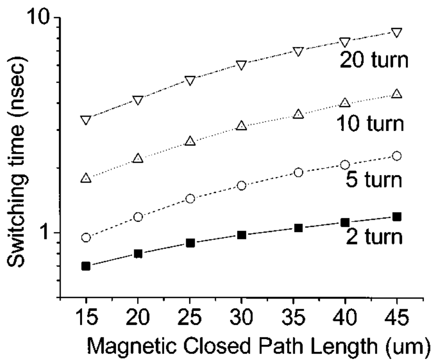

Fig. 2. The switching time versus the magnetic closed path length for perpendicular systems with 4 different numbers of coil turns: 2, 5, 10, and 20.

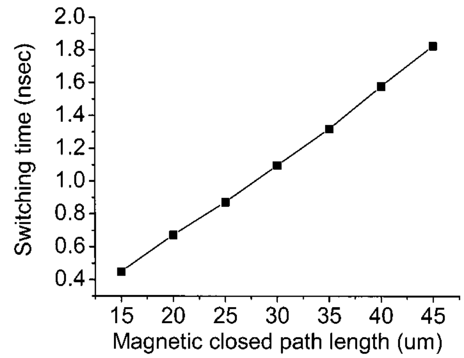

Fig. 4. The switching time versus the magnetic closed path length for a 5-turn coil longitudinal system.

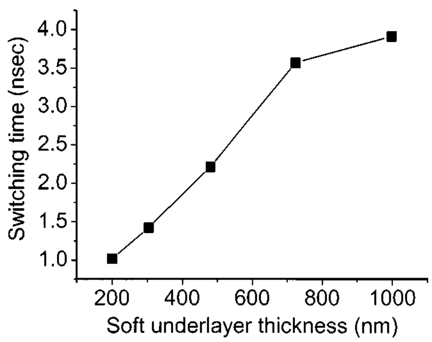

Fig. 3. The switching time versus the underlayer thickness for a 5-turn coil system with a 20 μm flux path length.

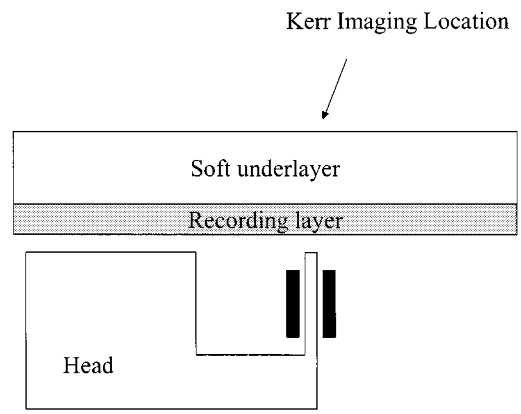

Fig. 5. A system for study of dynamics of perpendicular recording.

plus the length of the soft underlayer under the head, as shown in Fig. 1(b). The underlayer was modeled to be 300 nm thick. The characteristic switching time, $\tau_{\rm sw}$, was defined as the time necessary to generate the magnetic field sufficient to overcome the anisotropy field of the recording layer, H_k. In this work, H_k. of 7 kOe was considered. It is evident that the inductance of the system should decrease with the reduction of the number of coil turns. However, as the number of turns is reduced, the recording field generated is also reduced. Fortunately, the current ultra-compact recording systems, being intrinsically more efficient, require a smaller number of write coil turns [8]. This is especially true for a perpendicular system, which is usually even more efficient due to the soft underlayer [9]. For the particular system design, the minimum number of turns necessary to generate a recording field larger than the hard layer anisotropy field, H_k, was calculated to be two (two turns generate approximately 14 kOe). (Although, the total circuit impedance can be optimized externally, still the number of turns around the yoke is an important factor in determining the impedance of the head itself.) It can be seen that even a five-turn system is capable of the switching time less than 1 nsec if the magnetic path length is less than 20 μm (see Fig. 2).

The switching time versus the underlayer thickness for a 5-turn coil system with a 20 μm thick underlayer is shown in Fig. 3.

To compare longitudinal recording and perpendicular recording, the switching time versus the magnetic closed path for an equivalent longitudinal system with a 5-turn coil is shown in Fig. 4. The switching time for the longitudinal system was determined as the characteristic time necessary to overcome an equivalent longitudinal media with the coercivity field of 7 kOe. It can be noticed that for a perpendicular system comparable switching times can be achieved by adjusting the flux path length.

III. Kerr Microscopy

A Kerr microscope was developed to directly study dynamics of recording systems both with and without a soft underlayer [10]. A Kerr image was taken from a region under the recording pole tip. In the case of a perpendicular system, the image was taken from a region in the soft underlayer, as shown in Fig. 5.

A focused ion beam (FIB) image of a FIB trimmed perpendicular head used for study of perpendicular recording is shown in Fig. 6.

In the experiments a square pulse with a rise time of less than 1 nsec was applied to study the head and underlayer response. A sequence of polar Kerr images taken at increasing times after the field pulse on a perpendicular system and an equivalent longitudinal system are shown in Figs. 7 and 8, respectively. To summarize the results, the normalized write current pulse and the Kerr angle responses at the point of maximum field change are shown for the longitudinal and perpendicular systems in Fig. 9.

It can be seen that the switching time for the both perpendicular and longitudinal systems are approximately 0.750 to 1 nsec.

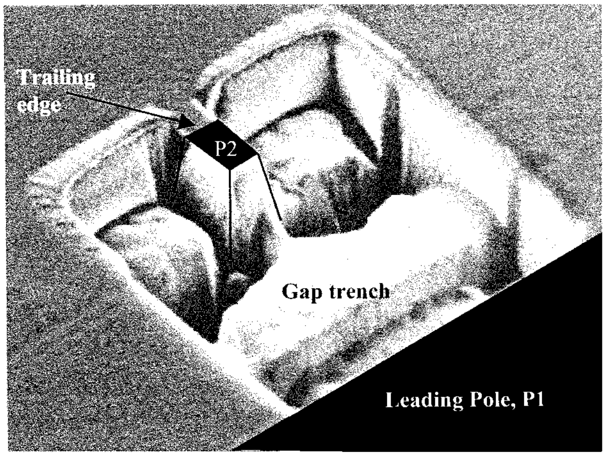

Fig. 6. A FIB image (ABS view) of a FIB trimmed perpendicular head.

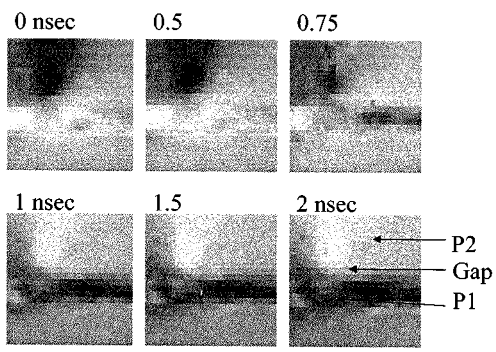

Fig. 7. A sequence of polar Kerr images taken at increasing times after a field pulse on a perpendicular system.

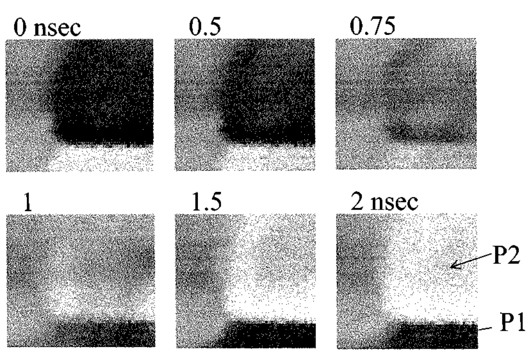

Fig. 8. A sequence of polar Kerr images taken at increasing times after a field pulse on a longitudinal system.

IV. Conclusions

3D Modeling indicated that using a soft underlayer in perpendicular recording is not going to deteriorate its high-frequency performance if the 0.3 μm thick underlayer and head materials are made of a FeAlN compound with a B_s of 20 kGauss and a

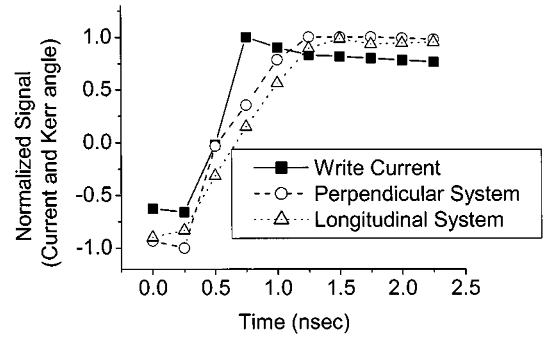

Fig. 9. Normalized current of the write driver and Kerr angle for the perpendicular and longitudinal systems as a function of time.

H_k of 10 Oe. Kerr microscopy was developed to directly study dynamics of the recording process in such a system. The experiments with FIB trimmed heads with a relatively small number of turns were in agreement with the theoretical predictions. As the main conclusion of this work, a perpendicular system, if optimally designed, should not demonstrate fundamentally degraded dynamic performance compared to an equivalent longitudinal system.

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