Dynamics of laminated write elements

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One concern as storage technology moves to perpendicular recording is the remnant state of the writer top pole. In principal, a remnant state with a substantial magnetization density perpendicular to the recording medium can lead to the unwanted erasure of data. Also, it is desirable to have the writer reach a nonerasing remnant state as quickly as possible. One technique to reduce the magnetization in the remnant state is to laminate the pole tip with some nonmagnetic material [Y. Satoh, A. Ohtsubo, and Y. Shimada, IEEE Trans. Magn. **21**, 1551 (1985); S. Wang *et al.*, IEEE Trans. Magn. **30**, 3897 (1994)]. We have performed fully micromagnetic simulations of write elements with eight, five, four, and two laminates coupled antiferromagnetically. Results are presented for recording fields, as well as for the decay of the magnetization to a remnant state. The two- and four-laminate write elements typically have a vortex induced in the pole tip, and this vortex tends to survive, even in the remnant state. This can give rise both to a slow decay as well as large remnant fields from the out-of-plane magnetization in the vortex. On the other hand, the magnetization of the eight-laminate pole tip decays by "scissoring" of the magnetization in the laminates, with a faster decay to the remnant state. However, locally large divergences of the magnetization density can give rise to "hot spots" with relatively large remnant fields. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2159415]

I. INTRODUCTION

Write elements used in a perpendicular magnetic recording have to be able to deliver the magnetic field and gradients necessary to write information at a required areal density. In addition, in order to write the required data rate, the writer has to respond rapidly as the current to the writer coil is turned on or is cycled. As the current is turned off, the writer also has return rapidly to a remanent state with small enough stray fields that do not lead to unwanted erasure of written information, so-called erase after write (EAW).

One possible way to reduce EAW is by laminating the material in the main top pole. Early work[1,2] suggested lamination as a means of achieving resolution and a sufficient field, by laminating high-moment materials with lower-moment materials. More recent work looked at laminated pole structures as a way to enhance the dynamics of the writer and to control the relaxation to remanence.[3–6] In particular, it was shown[5] that laminating up to eight layers of high-moment FeCo with nonmagnetic Ni–Cr in periodic structures showed a large reduction in EAW, even for write elements with a large throat height. These tend to get stuck in remanent states with large stray fields due to the shape anisotropy of the pole tip.[7]

The benefit of reduced EAW from lamination comes at reduced efficiency of the writer, in terms of the field output for a given current.[7] This then brings up the question of whether there are lamination structures that provide a benefit in terms of EAW, but at a reduced loss of writer efficiency. In this paper, we use micromagnetic modeling to examine laminated write elements that have two, four, five and eight laminations high-moment FeCo, but not in periodic structures. The idea is to investigate lamination structures that improve the remanent state relative to the nonlaminated top pole without paying the same price in efficiency. Our writer elements are approximately 4 μm tall and 4 μm wide. The top pole was 100 nm wide and 200 nm thick with a throat height of 100 nm, and the yoke was 300 nm thick and recessed 700 nm from the air bearing surface. The top pole was laminated by inserting infinitesimally thin layers that promoted a coupling energy of $-1\ \mathrm{erg/cm^2}$ between adjacent layers. Figure 1 shows a cartoon of the lamination structures investigated. The entire writer structure was modeled using a micromagnetic model on a cubic mesh with a cell size of 10 nm. A soft keeper layer was simulated using permeable material of relative permeability 200 located 40 nm below the pole tip. All magnetic fields presented here were calculated in a plane located 15 nm below the pole tip. We will present results for the component of the magnetic field perpendicular to the ABS (H_y), and the Stoner–Wohlfart (SW) effective switching field, $H_{\mathrm{eff}}=[(H_x^2+H_z^2)^{1/3}+H_y^{2/3}]^{3/2}$, and the gradient dH_y/dz. Here, H_x and H_z are the cross-track and downtrack components of the field. We will also present values for the write width, defined as the width of the contour at $H_y=5$ kOe in the cross-track direction. We will use triangles

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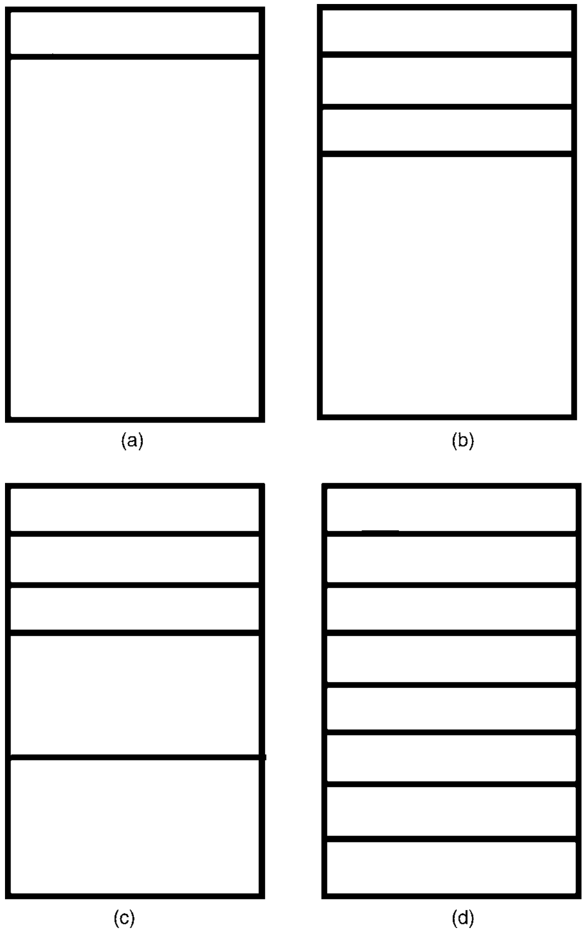

FIG. 1. Cross-section cartoon of the pole tip showing the lamination structures in (a) a two-laminate writer, (b) a four-laminate writer, (c) a five-laminate writer, and (d) an eight-laminate writer. The leading edge of the top pole is at the top of the figure.

(△) for the two-laminate writer, diamonds (◇) for the four-laminate writer, circles (○) for the five-laminate writer, and squares (□) for the eight-laminate writer.

II. RESULTS

Here we will focus on a few key results: the magnitude of the field at the trailing edge, and the dynamics of the field at the trailing edge, in particular, after the write current is turned off. Figure 2 depicts the perpendicular component of the field at the end of a 1 ns long current pulse. The field was evaluated along a centerline of the writer and averaged from the trailing edge location to the leading edge location. In general, we would expect the delivered field to decrease with an increasing number of laminations, and this is indeed the case. The eight-laminate writer delivers the least perpendicular field, but it also has the smallest write width. Correspondingly, the eight-laminate writer also delivers the highest gradient (Fig. 3). However, the five-laminate writer delivers an unexpectedly large field—one would perhaps expect that the plot of the maximum perpendicular field versus the write width would fall on a straight line, but the field from the five-laminate writer departs markedly from this line. Even more interesting is the fact that the effective field from the

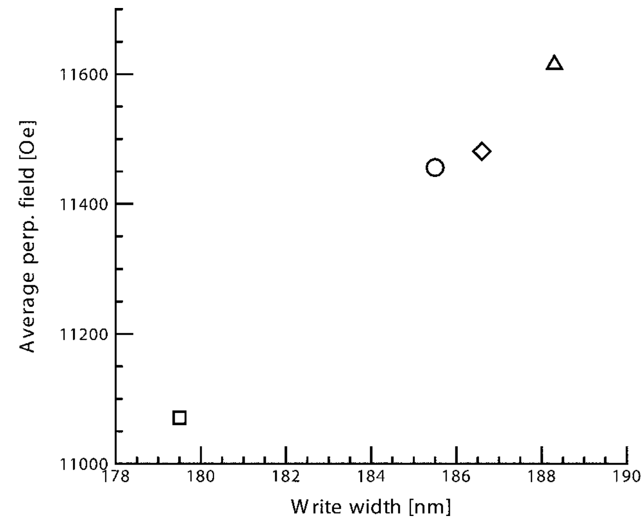

FIG. 2. The perpendicular field component vs the write width for the laminated write elements.

five-laminate writer is approximately as large as the fields from the four- and two-laminate write elements (Fig. 4).

To assess the susceptibility to EAW, we calculated the decay of the field from the pole tip as a function of time after the write current has been turned off. In Fig. 5 are depicted the field at the trailing edge normalized to the value of this field just before the current is turned off. This figure shows that the initial decay is slower for the two- and four-laminate write elements than for the five- and eight-laminate write elements. In addition, the four-laminate writer seems to get stuck in a magnetic state with a relatively high value of the remanent field. A more sensitive indication of EAW susceptibility is the maximum value of the field under the pole tip. Inhomogeneous magnetization states may cause local "hot spots" at which the field is considerably larger than at a single point at the trailing edge. In Fig. 6 are depicted the maximum absolute value of the perpendicular field component as a function of time. In terms of this quantity, the two-

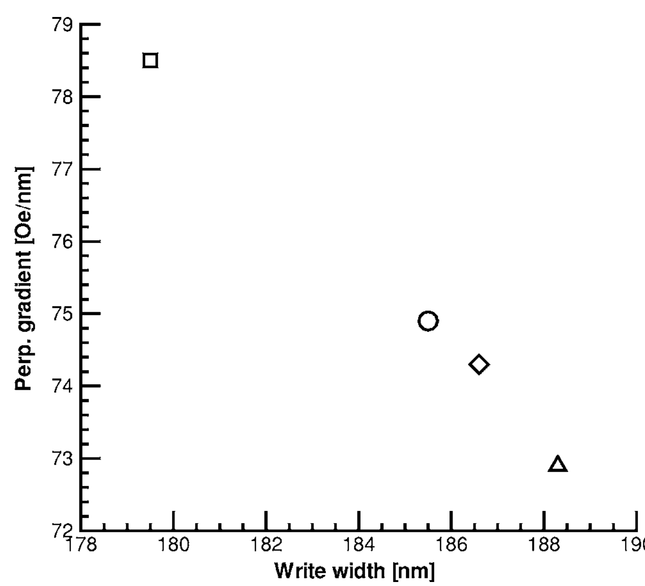

FIG. 3. Gradient dH_y/dz vs the write width for the laminated write elements.

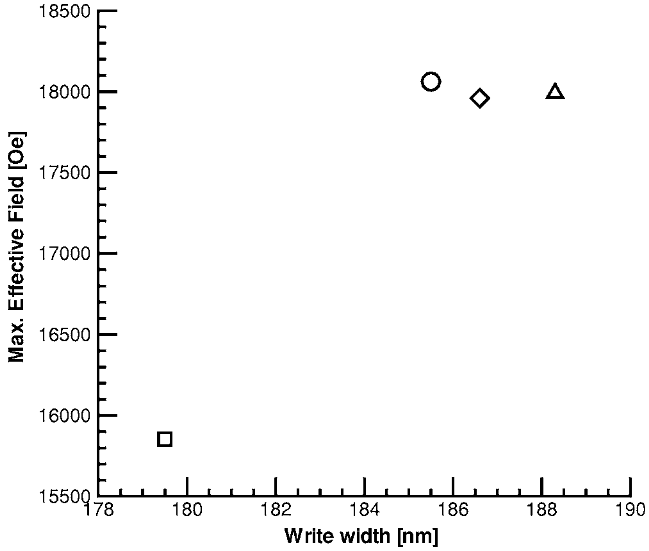

FIG. 4. The effective SW field H_{eff} vs the write width for the laminated write elements.

and four-laminate writer have the slowest initial decay. Again, the four-laminate writer produces the largest field values under the pole tip, with a maximum that settles down at about 2 kOe. But we note that the other write elements, especially the five-laminate write elements, may produce fluctuations with maximum fields approaching 3 kOe. Such hot spots corresponds to locations on the pole tip, where bending the magnetization around corners and laminates produces locally large divergences of the magnetization.

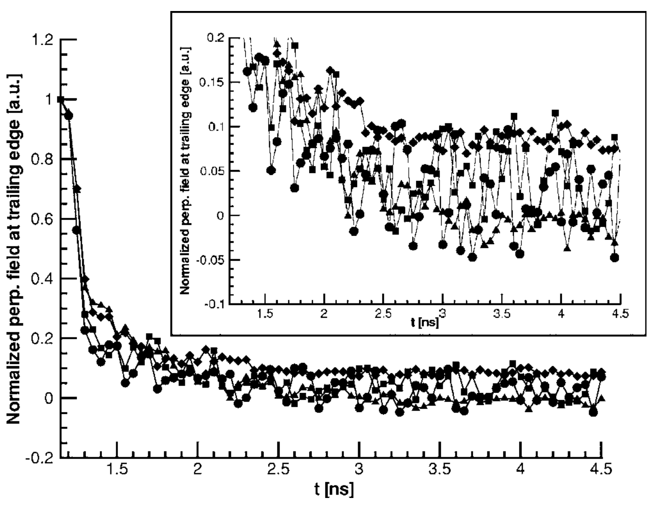

FIG. 5. The normalized perpendicular field at the trailing edge as a function of time. Note that the four-laminate writer (◇) seems to get stuck in a state with a large remanent field. Inset: expanded scale.

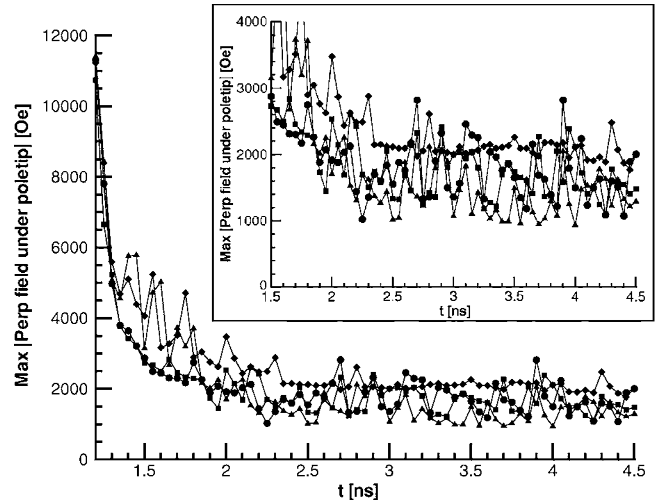

FIG. 6. The maximum value of $|H_y|$ under the pole tip as function of time. The four-laminate writer settles at a large field of about 2 kOe, while other write elements may have fluctuations with $|H_y|$ of about 3 kOe. Inset: expanded scale.

A detailed examination of the magnetization state of the pole tip reveals why the four-laminate writer apparently has less desirable EAW properties than the others. By confining the laminations to the leading-edge half of the writer, the trailing edge half is a square in which the magnetization easily forms a vortex. The vortex core is relatively stable, and the divergence of the magnetization at the vortex core leads to a large stray field. The other lamination schemes effectively break up the pole tip area into regions in which a vortex formation is much less favorable.

III. SUMMARY

We have investigated the writer parametrics and field decay for four different lamination schemes, using micromagnetic modeling. In general, a lamination scheme that prevents vortex formation in the pole tip leads to a more rapid decay of the magnetic field to a remanent magnetic state with low stray fields. However, laminations in a periodic laminated structure reduce the writer efficiency. By laminating the top pole aperiodically, with more laminations at the leading edge and fewer at the trailing edge, the writer efficiency can be increased without introducing a vortex in the pole tip.

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