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Time- and vector-resolved Kerr microscopy of hard disk writers

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Time-resolved scanning Kerr microscopy has been used to make wafer level measurements of magnetization dynamics within the yoke and pole piece of partially built hard disk writer structures. Three Cartesian components of the vector magnetization were recorded simultaneously using a quadrant photodiode polarization bridge detector. The rise time, relaxation time, and amplitude of each component have been related to the magnetic ground state, the initial torque, and flux propagation through the yoke and pole piece. Dynamic images reveal “flux-beaming” in which the magnetization component parallel to the symmetry axis of the yoke is largest along that axis. © 2011 American Institute of Physics. [doi:10.1063/1.3665957]

The storage capacity of magnetic disk drives continues to increase through reduction of bit sizes, presenting challenges in the design of the writer structure. The writer used in the latest perpendicular recording technology is essentially a planar electromagnet with one wide and one narrow pole piece. It must produce increased fields, confined within an ever-smaller write bubble at the narrow pole tip, that fall and rise on picosecond timescales. It is essential to characterize the magnetization dynamics in all parts of the writer if optimum performance is to be obtained.

Measurement techniques such as magnetoresistive sensing,1 magnetic force microscopy,2–4 and time-resolved scanning Kerr microscopy (TRSKM)5,6 have been used to characterize magnetization processes within the writer. Previous studies have concentrated almost exclusively upon the pole tips and have considered only a single component of the magnetization or the internal field.7–10 However the response of the yoke is also of vital importance in maximizing the write field and minimizing the remanence of the pole tips that can lead to problems such as “erase after write.” So far no direct measurements of the magnetization dynamics within the yoke have been reported. It will be demonstrated that TRSKM can yield simultaneous measurements of all three spatial components of the dynamic magnetization with sub-micron spatial resolution. Time-resolved (TR) magnetic images provide experimental confirmation of the previously predicted process of flux-beaming in which the magnetization of the yoke material reorients most strongly along the symmetry axis (SA) of the yoke and pole piece.

TRSKM measurements are made with an 800 nm wavelength, 80 MHz repetition rate ultrafast laser, Fig. 1. Part of the laser output is passed through a 4 ns optical delay line and then focused by a high numerical aperture (0.85, x 60) microscope objective to a full width half maximum spot of 600 nm diameter, polarized along the writer SA. The back-reflected beam is directed into a quadrant photodiode polarization bridge detector that records all three spatial components of magnetization simultaneously with minimal cross-talk.11

FIG. 1. (Color online) The TRSKM setup for measurements of magnetization dynamics within perpendicular inductive write-head structures. P: polarizer.
avoid irreversible magnetic processes within the yoke measurements were made at a maximum pulse amplitude of 11.2 V above which TR Kerr signals were irreproducible. The pulse width and rise time were 1.6 ns and 553 ± 90 ps (including overshoot), respectively, as shown in Fig. 2(c). The pulsed field was estimated to have maximum possible value of ~90 Oe immediately above the coil windings, although this value is uncertain due to possible impedance mismatches within the microwave circuitry. A piezoelectric scanning stage allowed TR signals to be acquired at selected positions shown in Fig. 2(b) or for images of the dynamic magnetization to be acquired at a fixed time delay.

TR signals acquired at positions A to F are shown in Fig. 3 for the parallel, perpendicular, and polar magnetization components. On the axis of symmetry, point A lies above a via to the lower half of the yoke, B is above the center coil winding 'C2', C is immediately to the left of winding 'C1', D lies within the confluence region while E is at the beginning of the bridge. Points G and F lie on the edges of the flared region. Since the coil windings lie orthogonal to the SA, the generated pulsed magnetic field lies close to in-plane and parallel to the SA above the coil windings and perpendicular to the plane either side of the windings. Prior to the application of the pulse, the magnetization lies predominantly along $H_B$. Therefore, the initial torque exerted by the pulsed field lies perpendicular to the plane at locations above the coil windings and parallel to either the positive or negative $x$-axis to the side of the windings. Consequently, at point B in Fig. 3 the polar magnetization component has a much shorter 10-90 percent rise time of 217 ± 9 ps compared to those of 472 ± 29 ps and 520 ± 26 ps for the perpendicular and parallel components respectively, which are instead comparable to the rise time of the pulsed field. The polar component decreases but remains finite even after the in-plane components have reached constant values, suggesting that there is a small out of plane component of the pulsed field at point B. The signals are presented in units of Kerr rotation, and the in-plane and polar signals appear to be of similar magnitude. However the polar Kerr effect is typically an order of magnitude larger than the longitudinal Kerr effect, so the polar magnetization component is very likely an order of magnitude smaller than the in-plane components.

Figure 3 also shows that outside the coil region the rise times of the perpendicular and polar components are either comparable to or longer than that of the pulsed field, while the amplitude and rise time of the parallel component is more variable. The polar component follows both the rise and fall of the out of plane driving field. In contrast, the in-plane components experience an additional driving field resulting from the magnetic charge generated as the magnetization reorients above the coil windings. Therefore, it seems reasonable that the in-plane magnetization at points A and C-G should lag that at B. Interestingly the perpendicular component does not fall with the pulsed field and does not fully relax during the 4 ns scan period. The small amplitude of the parallel component at positions C, D, and G, where the perpendicular component is large, suggests the presence of a finer scale magnetic structure so that the probe spot acquires a spatially averaged signal from regions of anti-parallel magnetization. The reduced amplitudes of all three components at point E may be related to the fact that the bridge width is smaller than the focused spot size leading to an increased susceptibility to mechanical drift and that because of surface topographical variation towards the pole tip the focus of the probe spot is less optimal than for the main yoke structure. At points F and G the static magnetization is expected to be non-uniform due to competition between the bias field and demagnetizing field near to the edges. Spatial averaging may again lead to a reduced parallel component while the perpendicular component may tend to be suppressed because the demagnetizing fields prevent the magnetization aligning normal to the flared edge under the action of the pulsed field.

Figure 4 shows sets of dynamic magnetic images, together with static reflectivity images, acquired at the time delays indicated in Fig. 2(d). The perpendicular and polar images at ~0.8 ns show no magnetic contrast as expected.
The most striking feature of the presented images is the localization of the perpendicular magnetization component, along the SA of the yoke, and its propagation into the confluence region where it presumably magnetizes the bridge region. These images provide direct experimental confirmation of the “flux beaming” that has been proposed to explain the operation of the yoke. The beaming of the magnetic flux along the SA occurs because the magnetization at the edges of the yoke is less able to rotate in response to the pulsed field since this would induce magnetic charges at the edges and hence additional demagnetizing fields. A well optimized yoke is designed to spread the magnetic flux into a wider path, when moving from the confluence region past the coil windings towards a via at point A, so as to retain high permeability, avoid saturation, and minimize the time for magnetization rotation. Although the flux spreading appears greatest within the confluence region for the single layer yoke studied here, the geometry of the spreading may be controlled in laminated yokes with carefully chosen magnetic anisotropy.

In summary, TRSKM has been used to characterize the magnetization dynamics of partially built hard disk writer structures. The response times of different magnetization components at different locations has been related to the orientation of the static magnetization, the torque generated by the coil windings, and the propagation of flux through the yoke and pole piece. Flux-beaming within the yoke has been confirmed, demonstrating that TRSKM is a powerful tool for the optimization of flux propagation within advanced writer design.

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