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Wide-Bandwidth Scanning Kerr Microscope for Measurement of Write Head Dynamics

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We have developed a wide-bandwidth scanning Kerr microscope to diagnose magnetic heads using an optical sampling technique. Using an externally triggerable pulse diode laser, the temporal response and frequency dependence of the write head magnetization behavior can be easily evaluated. The developed system has a 5 GHz measurement bandwidth and a 0.2 μm spatial resolution.

1. Introduction

The recent severe competition in hard disk drive (HDD) development has been conducted in two areas. One is the recording density, and the other is the data transfer rate. Although both areas are important in HDD technology, the latter needs an understanding of the magnetic behavior of the write/read head and the recording media in the high-frequency region. Unfortunately, the performance of the available conventional diagnosis tools has not kept up with the amazing progress in HDD development. Therefore, new high-performance-measurement apparatus is strongly demanded. Furthermore, conventional evaluation techniques, for example, the nonlinear transient shift method, are able to evaluate only the total performance of the write head, recording media, and read head of a disk system. Although the total performance is important, it is difficult to resolve any critical issues from the results of such an evaluation. From this viewpoint, the scanning Kerr microscope[1),2)] has the potential to play an important role in write head diagnosis, provided it has sufficient measurement bandwidth. The basic configuration for using the magnetic Kerr effect for magnetization observation is illustrated in **Figure 1**. Two new methods have been proposed to apply an optical sampling technique to a Kerr microscope system to expand the measurement bandwidth.[3),4)] In these methods, a dye laser or a solid-state laser with a second harmonic generation (SHG) crystal is used as the pulse light source. Although these lasers expand the measurement bandwidth remarkably, such systems only measure at a fixed head-driving frequency owing to the fixed oscillation frequency of the laser. To overcome this restriction, we have developed a wide-bandwidth

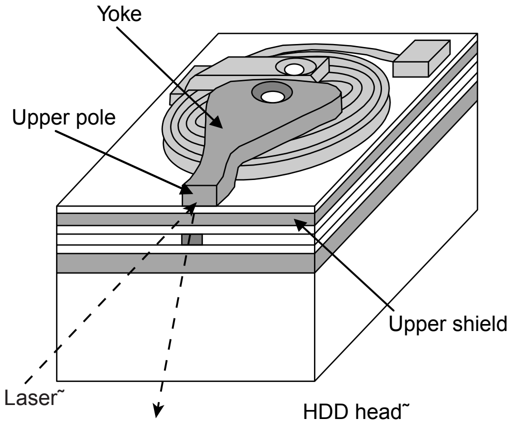


Figure 1
Configuration for observing HDD head magnetization.

scanning Kerr microscope for write-head analysis using a pulse-diode-laser source.[5),6)] This paper describes the development concept, prototype system configuration, and basic performance of this microscope.

2. Development concept

The main reason for the response limitation of the conventional Kerr microscope is the limited bandwidth of its photodetectors. To overcome this limitation, two methods are easily imagined. The first is to use a faster photodetector. Although high-bandwidth detectors are commercially available, a major drawback with their use is the degradation of the anti-vibration performance owing to the small detector size. The second method is to use a well-known optical sampling technique for observing high-speed phenomena. This method can be used to achieve high-bandwidth measurement simply by replacing the continuous wave (CW) laser with a short-pulse laser. Solid state pulse lasers, for example, the Ti: Sapphire laser, are widely used for this method. However, such lasers emit laser pulses at a fixed oscillation frequency, so the head driving frequency must be synchronized to that frequency. Consequently, the frequency response of the magnetization behavior is barely observable. On the other hand, when combined with an externally triggerable semiconductor pulse laser, the optical sampling technique can be flexibly synchronized to the driving frequency of the test device. In other words, the laser source can be synchronized to the head-driving signal. Therefore, we decided to use a semiconductor pulse laser source for the developed apparatus.

3. System configuration

Figure 2 shows the block diagram of the measurement system. The laser beam ($\lambda = 650$ nm) is focused onto the HDD head surface through the objective lens and reflected back to photodiodes through a beam splitter and polarization beam splitter. The incident angle of the laser is 90 degrees with respect to the head surface. Therefore, only the polarization rotation due to the polar Kerr effect is detected. A pulse-pattern generator (PPG) supplies the test patterns to the head via a conventional driving circuit. The PPG also provides the trigger signal to the timing electronics, which control the laser emission and data acquisition. Therefore, the laser pulse timing is accurately synchronized to the driving signal.

This system consists of two parts: 1) the measurement optics and 2) a computer and control electronics. The measurement optics, shown on the right side of **Figure 3**, are based on a com-

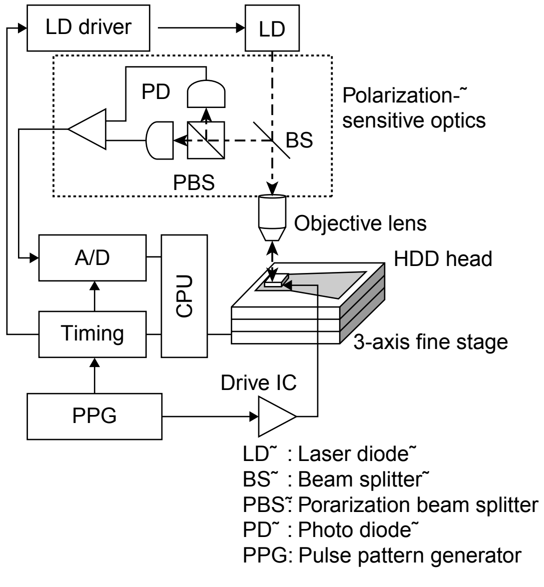


Figure 2
Block diagram of the system.

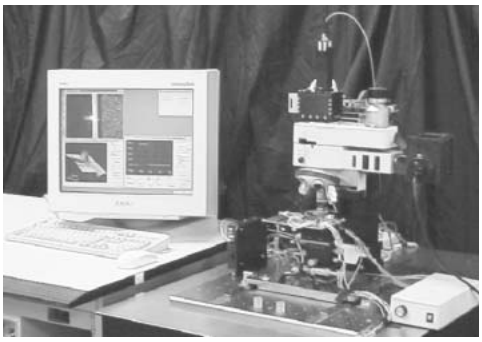


Figure 3
Photograph of the prototype system.

mercial microscope. The pulse diode laser source and the polarization sensitive detection optics are packed into a shielded case and fixed to the top of the microscope tube in place of the regular eyepiece. Several objective lenses are provided for measurement at different magnifications. The HDD head, which is mounted on a suspension, sits on a 5-axis movable stage. Piezoelectric actuators are used to precisely position the stage in the xyz axes. All of the optics and the sample stage sit on an anti-vibration table. The control software was specially developed for this system. A graphical user interface (GUI) ensures ease of operation.

4. System performance

The spot size of the focused laser beam was examined using a knife-edge method and was determined to be 0.3 µm at the beam waist with a high-power oil-immersion objective lens (× 100, NA 1.4). Therefore, the maximum spatial resolution of the system is 0.3 µm. A finer spatial resolution could be achieved by using a shorter wavelength diode laser, for example, a “blue laser” (this is discussed later). However, we could not obtain an appropriate standard sample having a known magnetization response that was fast enough for bandwidth evaluation. We therefore evaluated the bandwidth using a ZnTe electro-optic (EO) crystal, the polarity of which can respond to electrical signals above 100 GHz. The measured bandwidth was determined by using two different methods. The first was a direct method: a variable frequency sinusoidal electrical signal was applied to the EO crystal and the magnitude of the polarization change was measured. The bandwidth measured with this method was about 5 GHz (**Figure 4 (a)**). The other method was a rather indirect method that calculated the bandwidth from the temporal response (**Figure 4 (b)**). The rise time measured with this method was 80 ps, and the rise time of the applied pulse was 45 ps. The response time of the system, *Trs*, can be calculated from the measured response and the applied signal by using the equation $Trs = \sqrt{Trm^2 - Tra^2}$, where *Trm* and *Tra* are the rise times of the measured waveform and the applied electrical pulse, respectively. The calculated response of the system was 66 ps. This corresponds to a frequency of about 5 GHz. These values agree with each other, and we therefore believe that the measurement bandwidth of the system is around 5 GHz.

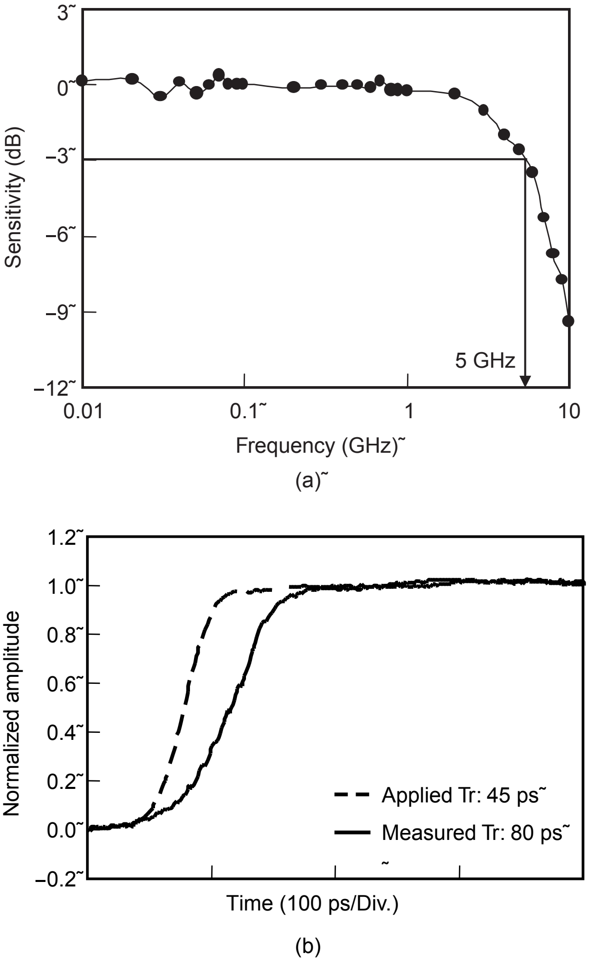


Figure 4
(a) Frequency response of the system.
(b) Measured waveform for temporal response evaluation.

Although, as described above, the new system has a remarkable observation ability, a higher spatial resolution is needed to keep up with the rapid increase in HDD storage densities; that is, to keep up with the rapid shrinking of magnetic pole tips. The spatial resolution of the prototype

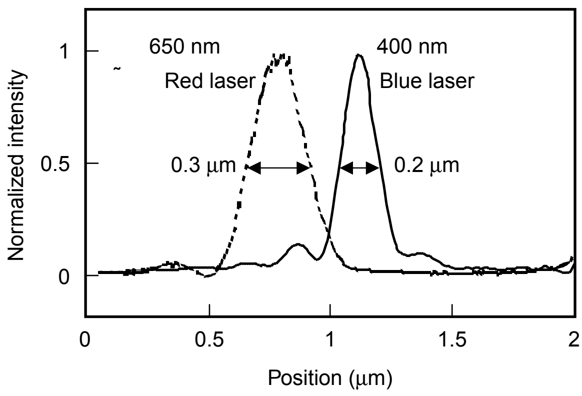


Figure 5
Intensity profiles of the laser spots.

system was restricted by the diffraction limit of the microscope optics. Therefore, at least one of the following can be used to improve the spatial resolution:

1) A shorter wavelength laser source
2) An objective lens with a higher numerical aperture (NA)

However, it is difficult to obtain an objective lens with a higher NA than the oil-immersion objective lens, which has an NA of 1.4. On the other hand, a shorter wavelength (400 nm) semiconductor laser, or “blue laser,” is commercially available from Nichia Corp. Since we have successfully produced a short laser pulse of about 40 ps by the gain switching operation, we decided to use a blue laser in the improved system. We therefore installed a blue laser in a prototype system and evaluated the spatial resolution. **Figure 5** shows the intensity profiles of the laser spots of the blue laser and the conventional red laser. The spot sizes were 0.2 μm and 0.3 μm, respectively. Therefore, a 0.2 μm spatial resolution was realized.

5. Measurement results

The magnetization behaviors of a commercial HDD head were observed using the system. **Figure 6 (a)** shows the reflected-laser-power distribution from the pole tip area of the HDD head. The 0.3 μm gap between the pole tip and the upper shield can be clearly seen. The five measurement points are shown in the figure. **Figure 6 (b)** shows the temporal variations of the Kerr signal at each point. Waveforms 1 and 2, measured at the pole tip and upper shield, respectively, were in antiphase with each other. The other waveforms had somewhat smaller amplitudes. This indicates that the magnetization change is concentrated at the edge of the pole tip and therefore the edge area plays an important role in the high-frequency write process. **Figure 7 (a)** shows the magnetization waveform at the pole tip near the gap. **Figures 7 (b)** to **(d)** show the Kerr signal intensity distributions at the times indicated in Figure 7 (a). The bright and dark areas indicate strong magnetization, but of opposite polarity. It is clearly seen that the magnetization change starts from near the gap and

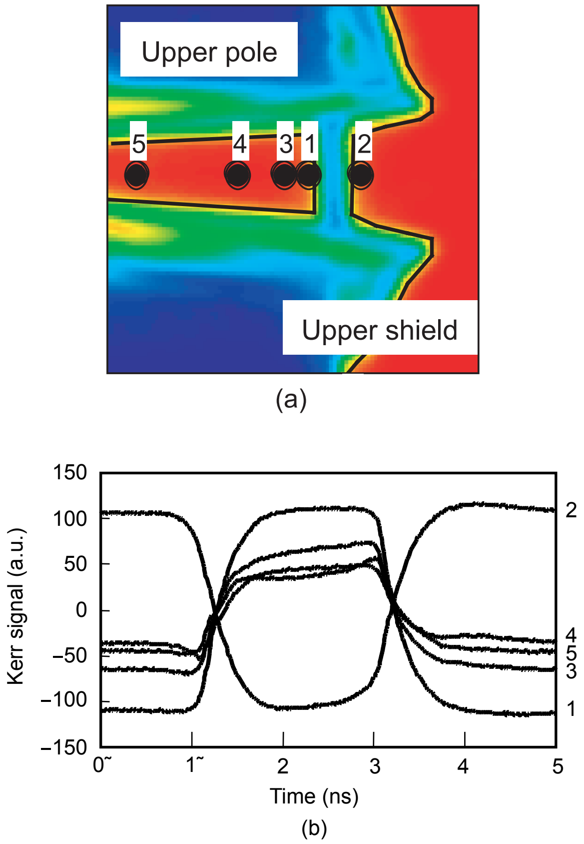
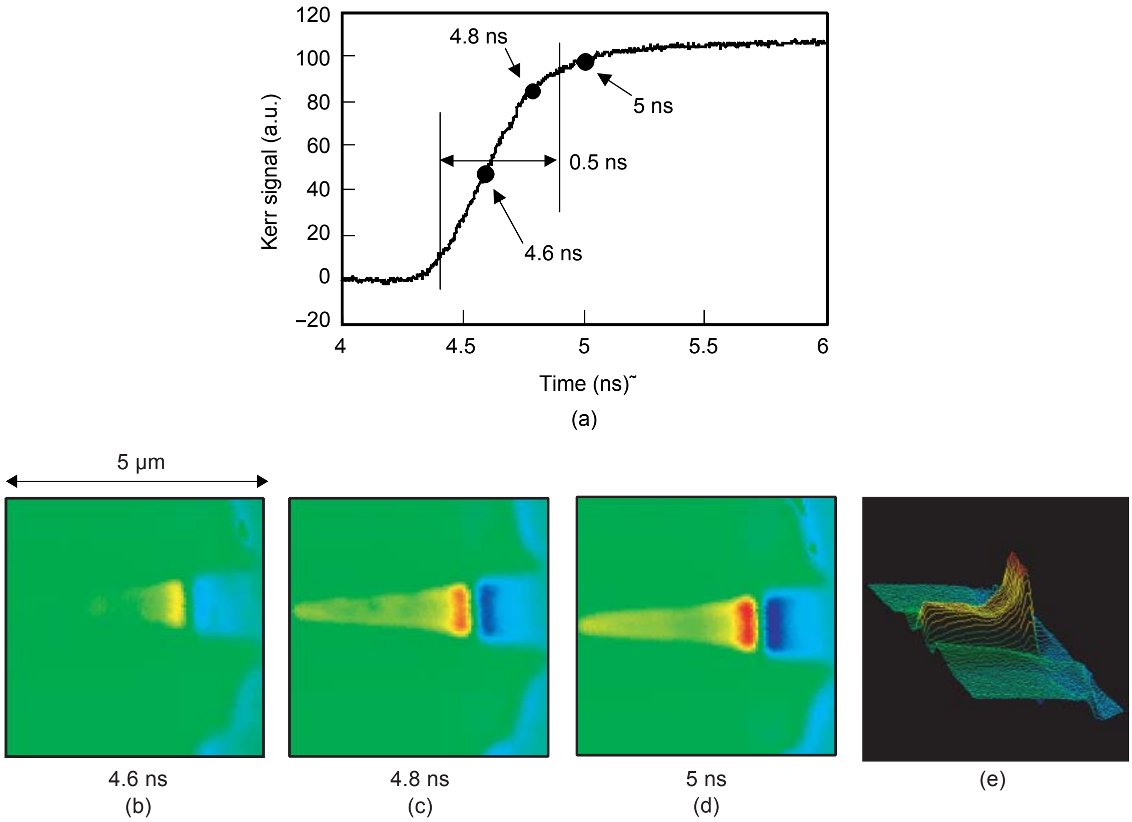


Figure 6
(a) Distribution of reflected laser intensity.
(b) Magnetizaion waveforms measured at locations shown in Figure 6 (a).



4.6 ns
(b)

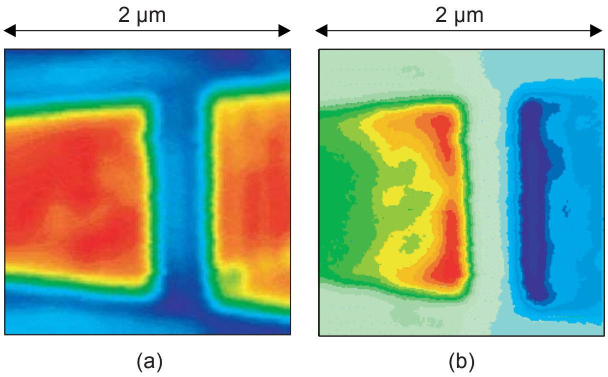
4.8 ns
(c)

5 ns
(d)

(e)

Figure 7
(a) Magnetization waveform measured at pole tip near the gap. Black dots indicate the timings of the magnetization distributions shown in Figures 7 (b), (c), and (d).
(b), (c), and (d) Distributions of magnetization at different timings.
(e) 3-dimensional representation of magnetization distribution.

the amplitude is maximum near the gap. Furthermore, the magnetization intensity around the edge is higher than it is at the center area in the pole tip. These results might indicate the presence of the magnetic skin effect. **Figure 7 (e)** shows a 3-dimensional view of Figure 7 (d) to better illustrate the distribution of magnetization. The vertical axis denotes the strength and direction of magnetization at the head surface. Note that the measured signal was the only vertical component of the magnetization under evaluation and that it might be different from the total magnetization amplitude.



(a)

(b)

Figure 8
(a) Distribution of reflected beam intensity acquired with 400 nm laser.
(b) Distribution of magnetization acquired with 400 nm laser.

Figures 8 (a) and **(b)** show the spatial distribution of the reflected laser power and magnetization, respectively, as acquired with the blue laser source. The shape and magnetization around the edge of the magnetic pole tip are much easier to see than in Figure 6 (a) and Figure 7 (d) and clearly show the effect of the spatial resolution improvement. This improvement ensures the usefulness of this measurement system for future

Table 1
System performance.

Spatial resolution˜	~ 0.2 µm˜
Measurement bandwidth˜	~ 5 GHz˜
Measurement speed	< 15 s/waveform˜ < 5 min/frame

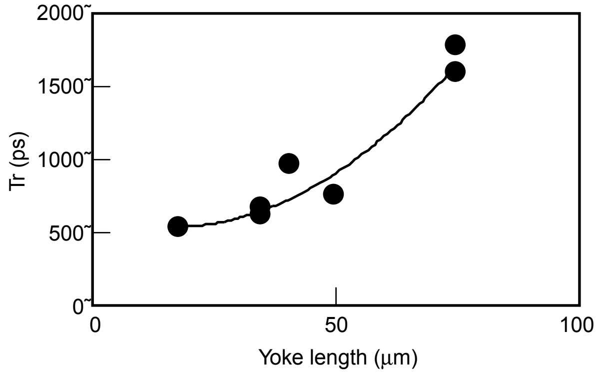


Figure 9
Relationship between yoke length and the rise time of the magnetization transient waveform.

HDD development.

The measurement time was around 15 s/waveform for the temporal measurement and around 5 min/frame for the distribution measurement. Since the measurement time was strongly dependent on the driving frequency and the measurement conditions, it was difficult to estimate precisely. Therefore, the above values should be treated as a reference only. The measurement performance of the system is summarized in **Table 1**.

Figure 9 shows the relationship between the yoke length of the HDD heads and the rise time of the magnetization transient waveform as an example of the measurement performance. It is clearly confirmed that, as expected, shortening the yoke gives a faster magnetization response.

6. Conclusion

We have developed a wide-bandwidth scanning Kerr microscope based on optical sampling using an externally triggerable pulse diode laser source. The microscope can be used to observe the temporal variation and spatial distribution of magnetization in an HDD write head material at a variable head driving frequency. The measurement bandwidth obtained was about 5 GHz, the maximum spatial resolution obtained was about 0.3 µm, and a spatial resolution of 0.2 µm was realized by adopting a shorter wavelength laser source. We believe that this measurement system will be invaluable for developing an understanding of the high-frequency magnetization behavior of HDD write heads. Therefore, it could be an indispensable tool for developing high-transfer-rate HDDs.

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