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# Detecting transition regions in magneto-optical disk systems

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Several combinations of incident polarization and detection schemes suitable for direct detection of transitions in magneto-optical disk systems are described. One such combination uses a circularly polarized light with a single split detector in the far field. Another scheme uses linear polarization in conjunction with differential detection. In the first scheme the medium must be optimized for Kerr rotation while the second method requires maximum ellipticity.

The standard differential detection scheme for magneto-optical disk storage systems utilizes the polar Kerr effect.[1-3] In this scheme a linearly polarized beam of light is reflected from a perpendicularly magnetized medium where, upon reflection, the state of polarization becomes elliptical and the major axis of the ellipse rotates away from the incident direction of polarization. The senses of both rotation and ellipticity depend on the state of magnetization and constitute the magneto-optical signal. The differential detector converts this signal into a waveform which tends to be a good reproduction of the pattern of magnetization of the disk.

The purpose of this letter is to introduce a new readout scheme for the magneto-optical disk systems with certain potential advantages. One implementation of the new scheme, depicted in Fig. 1, utilizes circularly polarized incident light and relies on diffraction from domain boundaries in order to detect transitions of the magnetization state. One advantage of the proposed method is that, as in compact disk and write-once systems, the reflected beam can be directed away from the laser. In this way the laser feedback noise can be substantially reduced. Other advantages include compatibility with read-only and write-once pickup systems, total utilization of the laser power during recording and erasure, simpler optics, and direct detection of the transition region between oppositely magnetized neighboring domains (i.e., no need for differentiation of the readout signal). A disadvantage of the new technique is its smaller signal (by about 6.5 dB) as compared with differential detection. However, the advantages outlined above may outweigh this disadvantage in practice. In the remainder of this letter we derive the magnitude of the readout signal for the proposed scheme.

*1. Preliminaries.* A magnetic medium with perpendicular magnetization reflects right circularly polarized (RCP) light differently from left circularly polarized (LCP) light. If $r_1$ and $r_2$ (complex numbers) are the corresponding reflectivities in the "up" magnetized state of the medium, their roles will be reversed in the "down" magnetized state. We define $r^+$, $r^-$, $\rho$, and $\phi$ as follows:

$$r^+ = \tfrac{1}{2}(r_1 + r_2), \tag{1a}$$

$$r^- = \tfrac{1}{2}(r_1 - r_2), \tag{1b}$$

$$r^-/r^+ = \rho e^{i\phi}. \tag{1c}$$

The incident beam may be polarized in a variety of ways, but any state of polarization can be represented as a mixture of RCP and LCP, namely,

$$A_0 = a(\hat{x} + i\hat{y}) + b(\hat{x} - i\hat{y}). \tag{2}$$

Here $a$ and $b$ are complex numbers that represent the amplitudes of the two circularly polarized components and $\hat{x}$ and $\hat{y}$ are unit vectors in the Cartesian coordinate system. The incident beam propagates along $\hat{z}$.

When the incident beam is linearly polarized along the $x$ axis, $a$ and $b$ must be equal. The reflected amplitude from a uniformly magnetized region will then be

$$\hat{A}_0 = a(r_1 + r_2)\hat{x} + ia(r_1 - r_2)\hat{y}. \tag{3a}$$

With reference to Eq. (1), Eq. (3a) is rewritten as

$$\hat{A}_0 = 2ar^+(\hat{x} + \rho e^{i(\phi + 90)}\hat{y}). \tag{3b}$$

Thus $\phi = \pm 90°$ corresponds to a medium which exhibits pure Kerr rotation, whereas $\phi = 0°$ or $180°$ represents a medium with pure ellipticity. In practice, $\phi$ can be adjusted by either multilayering or external phase compensation. The *intrinsic* Kerr angle $\theta_k$ is related to $\rho$ as follows:

$$\rho = \tan\theta_k. \tag{4}$$

Finally, the intensity of the beam with amplitude $A_0$ as given by Eq. (2) is

$$I_0 = \tfrac{1}{2}(|A_x|^2 + |A_y|^2) = |a|^2 + |b|^2. \tag{5}$$

*2. Reflection of a focused beam from the transition region between two domains.* For simplicity we restrict this analysis to a one-dimensional case. Let the medium be up magnetized in the region $x > 0$ and down magnetized in the region $x < 0$. The transition is thus along the $y$ axis. For circularly polarized incident light, the amplitude reflectivity of the medium will be

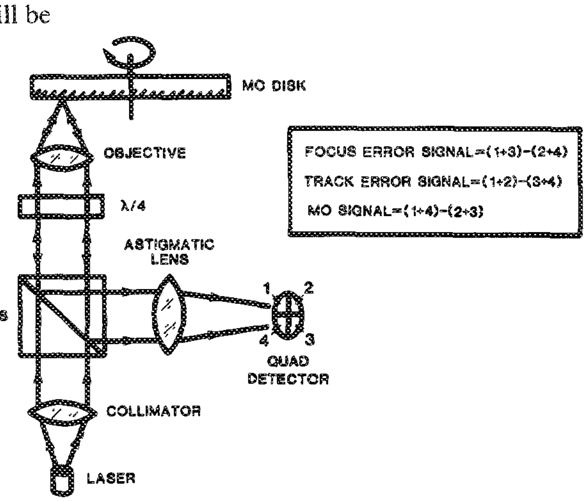


FIG. 1. Schematic diagram of the readout system utilizing circularly polarized light. In principle the servo signals for focus and track error can be obtained from the same quad detector used for detecting the magneto-optic signal.

$$r(x) = r^+ \pm r^- \operatorname{sgn}(x), \tag{6}$$

where the upper sign corresponds to RCP and the lower sign to LCP. The function $\operatorname{sgn}(x)$ is $+1$ for $x > 0$ and $-1$ for $x < 0$.

The focusing lens has focal length $f$ and numerical aperture $NA$. In this one-dimensional analysis the lens is cylindrical with the cylinder axis parallel to the $y$ axis. Let the distribution at the entrance pupil be circularly polarized with amplitude

$$A_1(x) = \frac{1}{\sqrt{2fNA}} \operatorname{Rect}\left(\frac{x}{2fNA}\right), \tag{7}$$

where $\operatorname{Rect}(x)$ is the rectangular function of $x$ which is equal to 1 when $|x| < 1/2$ and 0 otherwise. The amplitude distribution at the focal plane is

$$A_2(x) = \frac{\sqrt{\lambda}}{\sqrt{2NA}} \left(\frac{\sin(2\pi NAx/\lambda)}{\pi x}\right). \tag{8}$$

The reflected distribution is the product of Eqs. (6) and (8). The Fourier transforms of $r(x)$ and $A_2(x)$ (after scaling by $\lambda$) are

$$\hat{r}(s) = r^+ \delta(s) \mp ir^-/\pi s, \tag{9}$$

$$\hat{A}_2(s) = \frac{1}{\sqrt{2NA\lambda}} \operatorname{Rect}\left(\frac{s}{2NA}\right). \tag{10}$$

Here $s$ is the independent variable of the Fourier domain and $\delta(s)$ is Dirac's delta function. Convolving Eq. (9) with Eq. (10) yields the Fourier transform of the reflected distribution as

$$\mathscr{F}[r(\lambda x)A_2(\lambda x)] = \frac{1}{\sqrt{2NA\lambda}} \left[r^+ \operatorname{Rect}\left(\frac{s}{2NA}\right) \pm \frac{ir^-}{\pi} \ln\left|\frac{NA - s}{NA + s}\right|\right]. \tag{11}$$

With proper scaling and normalization the above equation represents the far-field pattern of the reflected beam. Noting that the diffracted rays beyond the lens aperture are blocked, we obtain the final distribution as follows:

$$A(x) = \frac{1}{\sqrt{2fNA}} \left(r^+ \pm \frac{ir^-}{\pi} \ln\left|\frac{fNA - x}{fNA + x}\right|\right) \operatorname{Rect}\left(\frac{x}{2fNA}\right). \tag{12}$$

The upper and lower signs correspond to RCP and LCP incident light, respectively. When the incident polarization is given by Eq. (1), the reflected beam must be resolved into its $x$ and $y$ components. In the far field we have

$$A_x(x) = \frac{1}{\sqrt{2fNA}} \left((a+b)r^+ + \frac{i}{\pi}(a-b)r^- \ln\left|\frac{fNA - x}{fNA + x}\right|\right) \times \operatorname{Rect}\left(\frac{x}{2fNA}\right) \tag{13a}$$

$$A_y(x) = \frac{i}{\sqrt{2fNA}} \left((a-b)r^+ + \frac{i}{\pi}(a+b)r^- \ln\left|\frac{fNA - x}{fNA + x}\right|\right) \times \operatorname{Rect}\left(\frac{x}{2fNA}\right). \tag{13b}$$

The total reflected power is

$$\begin{aligned} P_r &= \int_{-\infty}^{\infty} \frac{1}{2}(|A_x|^2 + |A_y|^2)dx \\ &= (|a|^2 + |b|^2)\left[|r^+|^2 + \frac{|r^-|^2}{\pi^2}\int_0^1 \ln^2\left(\frac{1-x}{1+x}\right)dx\right] \\ &= I_0(|r^+|^2 + \tfrac{1}{3}|r^-|^2). \end{aligned} \tag{14}$$

*3. The case of circularly polarized incident beam.* Here $a = 1$ and $b = 0$. The readout system is identical to the read channel for the compact disk as shown in Fig. 1. The signal is the difference between the two detector halves and is obtained from Eq. (12) as follows:

$$\begin{aligned} \Delta S &= \int_{-\infty}^{0} |A(x)|^2 dx - \int_0^{\infty} |A(x)|^2 dx \\ &= \frac{4 \ln 2}{\pi}(|r^+|^2 \tan \theta_k)\sin \phi. \end{aligned} \tag{15}$$

The signal is maximized for $\phi = \pm 90°$, i.e., the medium must be designed for maximum Kerr rotation and no ellipticity.

*4. The case of the linearly polarized incident beam.* Here $a = b = 1/\sqrt{2}$. The readout system uses standard differential detection, but each detector is split in two halves and the read signal is the difference between the two halves of each detector. The signals obtained from the individual arms of the system are identical and can be added in order to double the signal level. The polarizing beamsplitter in the differential detection scheme effectively superimposes the $x$ and $y$ components of the reflected beam and the detectors sense the sum (or the difference) of the fields in Eqs. (13a) and (13b). The signal is thus given by

$$\begin{aligned} \Delta S &= \int_{-\infty}^{0} \frac{1}{2}|A_x(x) + A_y(x)|^2 dx \\ &\quad - \int_0^{\infty} \frac{1}{2}|A_x(x) + A_y(x)|^2 dx \\ &= \frac{4 \ln 2}{\pi}(|r^+|^2 \tan \theta_k)\cos \phi. \end{aligned} \tag{16}$$

The maximum signal is obtained for $\phi = 0$, i.e., when the medium is optimized for maximum ellipticity and no Kerr rotation.

There are other ways to mix RCP and LCP in the incident beam in order to detect the transition regions. It seems, however, that all these techniques, when optimized, yield the same signal. The selection of one system over the other is, therefore, dictated by practical constraints of implementation, cost, and complexity. Finally, let us mention that the peak-to-peak signal of the standard differential detection is $8|r^+|^2 \tan \theta_k$. This result does not include the losses incurred at the beamsplitter where the incident and reflected beams are separated.


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