Beam Deflectors for Magneto-Optical Recording Heads

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Beam Deflectors for Magneto-Optical Recording Heads

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ABSTRACT

Nonmechanical beam deflectors, particularly acousto-optical and electro-optical deflectors, are being considered for the access and tracking functions of a magneto-optic recording head. In this report, the suitability of electro-optic deflectors for these functions is explored. For applications requiring modest deflection, electro-optic deflectors require less power and exhibit higher optical throughput than acousto-optical devices. The first phase of this investigation tests commercially manufactured electro-optic deflectors for optical quality, amount of deflection, and maximum number of resolvable spots. In the second phase, detection of a magneto-optic signal in an optical system using an electro-optical deflector is demonstrated.
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1. INTRODUCTION

In the effort to develop magneto-optic recording technology, one issue that is currently being addressed is the refinement of the optical head used for recording and reading. The purpose of this endeavor is to add superior performance to the existing benefits of magneto-optic technology, which are high areal storage densities ($10^8$ bits/cm$^2$) and the ability to rewrite data. One specific refinement that is being sought out is the reduction in seek time and the improvement in tracking robustness.

Presently, mechanical actuators are used to move optical components across the radius of the disk. To find and settle on the target track, the actuator first performs a coarse access to arrive in the vicinity of the desired track (within 200 tracks). Then, the actuator performs a fine access during which the track identification is read. Recent research has produced high performance disk drives with linear actuators that have average access times less than 50 msec.$^1$ Split head drives have been developed that further shorten access time. In these devices, the focusing lens, a mirror, and the focussing-tracking fine actuator are moving in a collimated light beam. In one successful application of this architecture, a flying optical head was found to have an average access time less than 18 msec.$^2$

The primary goal of this project is to further the effort in reducing seek time by investigating nonmechanical positioning methods. Specifically, electro-optic and acoustooptic deflection techniques will be examined as possible ways of scanning the beam. A secondary goal of this project is to utilize read write beams in the blue light wavelength range, which can potentially increase areal storage density through smaller diffraction limited focused spots.
This report can be broken down into three parts. The first part is a survey of two nonmechanical beam deflectors for magneto-optical recording. Principally, the advantages and disadvantages of bulk electro-optic and surface acousto-optic deflectors are discussed.

The next two parts describe experimental evaluations of the feasibility of the electro-optic deflector which is expected to have several advantages over the acousto-optic deflector. The second part reports the characterization of the electro-optic deflector in terms of maximum deflection, number of resolvable spots, and optical quality. The third describes experiments in which the deflector is used in a stationary optical system to demonstrate magneto-optical signal detection.

2. MAGNETO-OPTIC RECORDING HEADS

Magneto-optic recording of data is accomplished through thermomagnetic recording. In this process, a focused laser beam, pulsed to high power for a short time, raises the temperature of the spot to a critical temperature (usually \(>150^\circ\text{C}\)) at which the coercive force on the film is reduced considerably. A magnetic bias field is applied perpendicular to the film, which, when greater than the coercive force, will magnetize the film in the direction of the bias. Through this manipulation of magnetic field and localized temperature, a series of domains, or bits, can be recorded on the film.\(^3\)

The current materials that are being used as media for this process are amorphous rare earth transition metal (RE-TM) films, although polycrystalline bismuth doped garnets are being investigated as media to enhance read signals at short optical wavelengths.\(^4\) The amorphous RE-TM is a ferrimagnetic material. The magnetization of the rare earth subnetwork is in a direction opposite to the magnetization of the transition metal subnetwork. There exists a temperature, called the compensation temperature, \(T_{\text{comp}}\), at which the magnetizations of the two subnetworks are equal and opposite, canceling each
other to result in a net magnetization of zero. Below this temperature, the magnetization of
the RE subnetwork dominates, and above it, the magnetization of the TM subnetwork
dominate. The coercive force, $H_c$, tends toward infinity at $T_{comp}$ and decreases
dramatically as the temperature increases above $T_{comp}$. $H_c$ is the applied magnetic field,
$necessary for the torque $M_{net} \times H_a$ on the domain to reverse the net magnetization,$
$M_{net}$. At $T_{comp}$, since $M_{net}$ is zero, an infinite magnetic field is required. Above and
below $T_{comp}$, since $M_{net}$ increases, the necessary magnetic field decreases. Thus, as long
as the laser heating is localized to the area on which the domain is to be recorded, only that
area will have a lower coercive force and be magnetized in the direction of the biasing
magnetic field.

A sample magneto-optic head that implements the reading and writing process is
shown in Figure 2.1. Note that the one laser is used for both writing, and, when reduced
in power, reading. The reading of information is implemented by a differential detection
system in this figure. The read beam passes through a beam splitter and is reflected by a
mirror through a lens onto the medium. The beam is reflected with a polarization rotated by
the Kerr angle, $\theta_k$, the direction of which is used to determine whether the direction of
magnetization of the domain is up or down. The reflected beam travels up to the
polarization beam splitter. If the polarizer between lens $L_1$ and the beam splitter is set at
45° with respect to the $P$ axis of the polarizing beam splitter, signals will be generated by
the photodiodes that can be subtracted to determine the information on the medium.

The optical grating shown in Figure 2.1a creates two first order beams that are used
for tracking. These beams are focused onto the medium along with the zero order beam
such that a portion of the light reflects off the sides of the track. The photodiodes, $P_5$ and
$P_6$ shown in Figure 2.1c, collect the reflections of the first order beams and generate a
A differential signal that, when deviated from zero, controls a feedback servomechanism that repositions the head so the zero order beam is on the correct track.

The focusing mechanism is a voice coil attached to the objective lens that focuses the zero order beam on the medium for reading and writing. The photodetector that the reflected zero order beam falls on consists of four pie shaped quadrants as shown in Figure 2.1c. When the medium is out of focus, the cylindrical lenses in front of the photodetectors cause an elongation of the beam. The direction of this elongation distinguishes whether the medium is too close or too far. The difference of the sums of the signals from opposite sectors of the quadrant photodetectors is fed back to the voice coil which moves the lens in a path perpendicular to the medium in order to restore focus.
3. NONMECHANICAL DEFLECTOR SYSTEMS

A promising alternative to the optomechanical components of the conventional magneto-optical head design is a nonmechanical optical deflector. Specifically, surface acousto-optical and bulk electro-optical deflectors can replace the voice coils and galvanomirrors that are used in the access and the tracking feedback mechanisms. The primary advantage of these deflectors is their rapid deflection and their lack of mechanical inertia. The maximum deflection angles for both of these are too small to replace all the mechanical actuators in an optical head. However, since the deflection is enough to cover tens of tracks (with a pitch of 1.6 µm or less) on both sides of a central track, these deflectors could prove invaluable to the fine access function of a split head architecture as well as the tracking feedback loop.

3.1 Acousto-optical Deflectors

The acousto-optical beam deflector is a device that has already been investigated for its potential for optical head design. This device operates on the principal of Bragg scattering. Figure 3.1 is a schematic diagram of a typical acousto-optical modulator. The deflection occurs as a result of a diffraction grating generated by a surface acoustical wave (SAW) traveling in a direction equal to the Bragg angle, θ_B, to the perpendicular of the beam of incident light. The Bragg angle is defined by the first order Bragg condition:

\[ 2k \sin \theta_B = \gamma \]  

(3.1)

where \( k \) and \( \gamma \) are the wave vector of the light and the equivalent wave vector associated with the periodic surface wave respectively.
Figure 3.1 Acousto-optical Deflection (Ref. 8)

The SAW is launched from an interdigital transducer, an arrangement of thin film electrodes located on the surface of a piezoelectric material. Application of a time varying voltage produces a time varying stress which excites a propagating surface wave. As the acoustic wave travels across the crystal, the resulting periodic compressions and elongations of the crystal induce corresponding periodic increases and decreases in the refractive index which act to diffract the light.

As the frequency of the acoustic wave is varied within a bandwidth, $\Delta f$, the direction of the deflected beam varies correspondingly within an angular spread, $\Delta \phi$, determined by the following equation:
\[ \Delta \phi = \frac{\lambda \Delta f}{v_{ac}} \]  

(3.2)

Where \( v_{ac} \) is the acoustic velocity of the crystal. If we assume that the crystal is placed at the "waist" of a Gaussian beam with a spot size \( \omega_0 \), then the divergence of the optical beam in free space can be approximated by

\[ \Delta \theta_{\text{beam}} = \frac{\lambda}{\pi \omega_0} \]  

(3.3)

Thus, the number of resolvable spots, \( N \), is approximated by

\[ N = \frac{\Delta \phi}{\Delta \theta} = \Delta f \tau \]  

(3.4)

where \( \tau \) is the transit time required for the acoustic wave to transverse the optical beam.\(^{10}\)

The use of a surface acoustic wave device as an optical deflector for optical disk tracking has already been demonstrated by Arimoto et. al. in 1990.\(^{11}\) The setup that was used is shown in Figure 3.2. Laser light is collimated by a lens and coupled by a prism into the SAW device where it is deflected. The light emitted from the device is collected by a cylindrical lens and sent through a grating to extract the first order beams necessary for tracking. The beams are then focused onto the medium and then reflected back up through another lens where they are refocussed onto a detector assembly.

The deflection bandwidth possible was 40 tracks using one interdigital transducer with an input signal center frequency of 250 MHz. The diffraction efficiency decreases as the deflection from the center beam increases. The 40 track bandwidth includes any spots with a diffraction efficiency over 40%. The deflection speed between two positions was
measured on a streak camera to be 10 μsec. This time ensures that the fine access time is less than 100 μsec.

3.2 Electro-optical Deflectors

The principal of electro-optic deflection is to control the direction of light as it passes through a medium directly by setting up a refractive index gradient. As light passes from one medium to another of different index of refraction, it is deflected, or refracted, at the boundary as determined by Snell's law. If there is an index of refraction gradient with respect to one direction (see figure 3.3), say the x-axis, the deflection angle, θ, is a function of the distance traveled, z, in the medium which is defined by the solution of: \(^{12}\)

\[
\frac{d\theta}{dz} = \frac{1}{n} \frac{dn}{dx}
\]  

(3.5)

if \(n\) varies linearly with \(x\), then
\[
\frac{1}{n} \frac{dn}{dx} = \frac{1}{n_0} \frac{dn_0}{dx} \equiv k = \text{constant} \quad (3.6)
\]

where

\[n = n_0 + \delta \quad (3.7)\]

and \(\delta\) is defined as the change in index of refraction induced by the electro-optic effect.

Thus

\[\theta(z) = k z \quad (3.8)\]

The electro-optic effect is the change of an optical medium's refractive properties induced by the application of an electric field. Crystalline solids that are piezoelectric display a linear relationship between index of refraction and electric field known as the Pockel's Effect. Thus, by controlling an applied electric field, the index of refraction can be

![Figure 3.3 Refraction of a Beam with an Index Gradient (Ref. 12)]
manipulated to form a linear gradient in one direction causing a deflection. By increasing or decreasing this electric field, the deflection can be increased or decreased correspondingly.

One realization of this type of deflection is known as a prism deflector, which is illustrated in Figure 3.4.13. It shows several attached prisms alternately inverted and arranged in a row. The prisms are cut with the c axes perpendicular to the plane defined by h and L and are oriented so that the positive c axis of each successive prism is reversed. When an electric field is applied across the c axes, changes in index of refraction, $\delta$, are induced that are alternately positive and negative for the successive prisms.

As a beam enters this device with polarization along h, it will undergo a series of separate deflections, $\alpha$, for each of the m prisms in the deflector (m=4 in this figure). Now the equation for deflection, $\alpha$, of a prism of index of refraction $n_2$ and an apex angle of $\beta$, surrounded by a medium of index of refraction, $n_1$, is:

![Figure 3.4 Multiple Prism Deflector (Ref. 13)](image-url)
\[ n_1 \sin \frac{\beta + \alpha}{2} = n_2 \sin \frac{\beta}{2} \]  
\[ n_1 = n_0 - \delta \quad \text{and} \quad n_2 = n_0 + \delta \]  

and since \( \alpha \) is small, substituting
\[
\sin \frac{\beta + \alpha}{2} \approx \sin \frac{\beta}{2} + \frac{\alpha}{2} \cos \frac{\beta}{2},
\]
the result is
\[
\alpha = \frac{4 \delta}{n_0} \tan \frac{\beta}{2}.
\]

The total interior deflection, \( \theta(L) \), is \( m \) times this
\[
\theta(L) = \frac{1}{n_0} m \frac{4 \delta}{n_0} \tan \frac{\beta}{2}
\]
from the geometry of the figure
\[
m \tan \frac{\beta}{2} = \frac{L}{2h}
\]

Therefore,
\[
\theta(L) = \frac{2L \delta}{n_0 h}
\]

When the beam emerges into air (\( n=1 \)), Snell's law gives
\[
\theta_e = \frac{2L \delta}{h}
\]
Since the Pockel's Effect is linear

\[
\delta = K \frac{V}{d}
\]  

(3.17)

where \(d\) is the thickness and \(K\) is a constant depending on the symmetry and electro-optic coefficients of the crystal.\(^{14}\) Thus,

\[
\theta_e = \frac{2L}{h} \frac{K}{d} V
\]  

(3.18)

Another way of implementing electro-optic deflection is through a geometry of four parallel rod electrodes arranged in a symmetric quadrupolar array. This generates an electric field distribution that varies linearly in a direction transverse to the beam path. The rods are centered around a medium and alternately charged positively and negatively from a variable voltage source, \(V_0\), as shown in Figure 3.5. If the inner surfaces of the electrodes approximate hyperbolic curves,

\[
x y = \pm \frac{R_0^2}{2}
\]  

(3.19)

then the potential distribution, \(V\), is

\[
V = -\frac{V_0}{R_0^2} x y
\]  

(3.20)

which leads to the following electric field distribution

\[
E_x = -\frac{\partial V}{\partial x} = \frac{V_0}{R_0^2} y
\]  

(3.21)
If the crystallographic axes are oriented such that the electro-optic effect is valid for only one, the latter of these equations, then it is possible to obtain an index of refraction gradient linear with $x$.

\[ E_y = -\frac{\partial V}{\partial y} = \frac{V_0}{R_0^2} x \] (3.22)

Figure 3.5 Cross Section of a Quadrupolar Array (Ref. 13)

A beam of light, polarized in the $x$ direction and traveling in the $z$ direction in a crystal such as potassium dihydrogen phosphate (KDP) oriented as in Figure 3.5, will be deflected toward positive $x$. Reversal of voltage will result in equal but opposite deflection. In this case, the deflection angle $\theta$ is given by

\[ \theta(z) = k z = \frac{K}{n_0} \frac{V}{R_0^2} z \] (3.23)
where

\[ k = \frac{1}{n_0} \frac{dn}{dx} = \frac{K}{n_0} \frac{df}{dx} = \frac{K}{n_0} \frac{V_0}{R_0^2}. \] (3.24)

For an active length, \( L \),

\[ \theta(L) = \frac{KL}{n_0R_0^2} V_0. \] (3.25)

Finally, as the beam exits into air:

\[ \theta_e = \frac{KL}{R_0^2} V_0. \] (3.26)

If, as in the case of acoustic deflection, we approximate the beam divergence by

\[ \Delta \theta_{\text{beam}} = \frac{\lambda}{\pi \omega_0} \] (3.27)

then, the number of resolvable spots, \( N \), is given by

\[ N = \frac{\theta_e}{\theta_{\text{beam}}} = \frac{L}{\lambda} \frac{KL}{R_0^2} \frac{\pi \omega_0}{\lambda} V_0. \] (3.28)

The deflectors that were tested in this project utilize the quadrupolar array of electrodes. There were actually two deflectors that were evaluated. One, using lithium tantalate crystals, has larger deflection but distorts the beam. The other one, using ammonium dihydrogen phosphate crystals, sacrifices maximum deflection angle for better optical quality.
3.3 Comparison and Discussion

In choosing to evaluate the electro-optical deflector instead of the acousto-optical deflector, the advantages and disadvantages of each were weighed against each other. It was concluded that the electro-optical deflector was expected to be more suitable to optical head design.

One major advantage of the acousto-optical deflectors is that they offer a larger deflection over the electro-optical deflectors. The angular deflection of the electro-optic device, though small, has a rapid random access response since it depends on the optical rather than the acoustic transit time. However, since the device is largely a capacitive load, the response is driver limited. The precision and speed with which the beam is deflected is the precision and speed at which a voltage level can be applied to the device.

Another advantage of the electro-optic device is the fact that the entire beam is deflected. In the acousto-optic cells, since deflection occurs through diffraction, the beam deflected to an extreme suffers in transmission efficiency which is, by definition, a function of the deflection. For example, the 40 track deflection of the system demonstrated by Arimoto was defined by the diffraction efficiency greater than 40%. That is, the twentieth spot from the center contained only 40% of the light incident on the deflector. Also, the acousto-optic deflector always has a zero order beam that does not deflect and thus must be eliminated for it not to interfere with the optical signal pick up.

Finally, although the acousto-optic deflector requires less voltage than the electro-optic deflector, power consumption is expected to be less for the latter. One reason for this is that the acousto-optic devices require a constant RF input to maintain an angular position, whereas the electro-optic deflector only requires voltage when changing angles.
The other reason is that the electro-optic deflector is largely a capacitive load and thus does not dissipate as much power as the acousto-optic cell, which is largely resistive.

4. CHARACTERIZATION OF AN ELECTRO-OPTICAL DEFLECTOR

In examining the electro-optical deflector's potential for magneto-optical recording, two commercially manufactured deflectors were tested. A series of experiments were performed on these devices to determine certain characteristics and how well they performed according to their specifications. These characteristics and specifications were thought to be important issues in extrapolating the concept of electro-optical deflection to actual fabrication of a small thin film device for application to a magneto-optical recording drive.

The purpose of these experiments was to evaluate the deflector on the basis of three criteria: Amount of deflection, size and quality of diffraction limited deflected spots, and number of resolvable spots. All of these are important for the requirements of a magneto-optical drive.

An instrument used for measuring these criteria was the Spotscan 0390, a precision knife-edge light beam profiling system that determines the intensity distribution of a finely focused beam along a single axis or two orthogonal axes and quantifies the spot's diameter. In the scan head of the instrument, an array of knife-edge, house shaped apertures scans back and forth a distance that can be set anywhere from 0 to 130 μm at a frequency of 10 Hz. The scan head is placed so that the array is at the focal plane of a lens on which the beam is incident. The scan head is then positioned by micrometers so that one of the edges of one of the apertures scans along the cross-section of the focused spot. For single axis measurements an edge on the lower section of the house is used and for a
dual axis measurement, the upper half of the house is used. The light that passes through during the scan is received by a photodetector and generates a time dependent signal that, when differentiated, represents the intensity distribution of the beam. The instrument gives a direct measurement of the spot size. By observing the intensity distribution, the degree of beam quality that is preserved by the deflector can be assessed.

The intensity distribution can be interpreted as a function of position through the use of a small interferometer laser pulse built into the scan head. Not only does this allow the physical size of the intensity distribution to be observed but it also allows the location of the spot relative to the scan distance to be determined. Thus, if a spot is moved from one position to another, the displacement, as long as it is less than the scan length of the aperture, can be determined.

4.1 Undeflected Beam Quality Measurements

The setup in Figure 4.1 shows an experiment that was used to measure the spot size and display the intensity profile of a beam as it passes through a deflector, thus determining the deflector's effect on beam quality. The spotwidth measurements and profile of a beam traveling through the deflector were compared with those of the beam without the deflector to determine the effects that the deflector had on the beam. This was done for each of the two deflectors that were obtained, one that used Lithium Tantalate, LiTaO₃, crystals and one that used Ammonium Dihydrogen Phosphate, ADP, crystals.

![Figure 4.1 Experimental Setup for Optical Quality](image-url)
The profile of the beam without passing through a deflector is shown in Figure 4.2a. The signal on the bottom is the output of the knife edge, that is, the light collected by the photodetector behind the knife edge array during the scan. The signal above is the actual intensity profile which is determined by the differentiation of the trailing edge of the knife edge signal. The Full Width Half Maximum, FWHM, widths of the beam are 1.55 \( \mu m \) and 1.6 \( \mu m \) for the x and y axes respectively.

The profile of the beam when the LiTaO3 crystal deflector is inserted can be seen in Figure 4.2b. It is apparent that the beam becomes extremely distorted as it passes through the deflector. Measurements for spotwidth are 4.16 \( \mu m \) along one axis and 5.35 \( \mu m \) along its orthogonal. The profile of the beam traveling through the ADP crystal deflector can be seen in Figure 4.2c. Although the FWHM widths, 2.24 \( \mu m \) and 2.32 \( \mu m \), are larger than those of the direct beam, there appears to be very little other distortion and the gaussian shape is left intact.

4.2 Angular Deflection Measurements

The angular deflection of each of the two deflectors was experimentally evaluated on the experimental setup shown in Figure 4.3. The beam is deflected onto a screen a known distance, s, away from the deflector and the distance of deflection, d, is observed. The angular deflection, \( \theta \), is approximated, because of its small size, by the quotient of d over s. The LiTaO3 deflector was tested first and found to have a deflection of 9.5 mrad. The sensitivity specification on the deflector is 13.73 mrad per kV for an AC signal which, when driven by the 800 V power supply results in an expected deflection of 10.98 mrad. This is comparable to the experimental result.
The ADP deflector is rated to have a sensitivity of 3 mrad per kV, which, when used with the 800 V driver results in a 2.4 mrad deflection. The measured deflection was

a. Without Deflector

b. Passing Through LiTaO3 Deflector
2.25 mrad, which is somewhat lower than but still comparable to what was expected. The deflection measurements for this deflector were taken for a spectrum of frequencies as shown in figure 4.4 and found to have a 3 dB rolloff at 150 kHz which is the specification for the bandwidth of the driver.
Further data was taken on deflection through use of the SpotScan and an objective lens in place of the previous screen as shown in Figure 4.5. The expected linear deflection, $L$, is found by:

$$L = 2f \tan\left(\frac{\theta}{2}\right)$$

(4.1)

since $\theta$ is very small, $L$ can be approximated by:

$$L \approx f\theta$$

(4.2)

where $f$ is the focal length of the objective lens used, 2.9 mm, and $\theta$ is the total maximum deflection angle.

Pictures of the SpotScan profiles of the deflection by the LiTaO3 deflector are shown in Figures 4.6a and 4.6b. The spot is distorted heavily as it travels to the extreme deflection positions. In one of the extremes, Figure 4.6b, the peak of the profile is all but eliminated, partly due to distortion and partly due to the nonlinear horizontal scale. However, the position of the beam can still be estimated. Thus, the distance that the spot
Figure 4.5 Experimental Setup for Linear Deflection Measurement

travels from one extreme to the other was 36.45 ± 5.88 μm. From the above equations, the expected distance is calculated to be 35.96 μm from the sensitivity of 15.5 mrad per kV and input voltage of 800 V, which is in agreement with the experimental result.

The ADP deflector has a dramatically less distorted deflected beam as is shown in Figures 4.7a and 4.7b. The distance of the scanned spot is 7.84 ± 1.18 μm which agrees approximately with the expected distance of 6.96 μm calculated from the 3 mrad per kV sensitivity and the 800 V input. As the beam moves to its extreme position, the profile of the beam is enlarged from 2.3 μm to 2.5 μm.
b. Other Extreme

Figure 4.6 Profile of the LiTaO₃ Deflected Beam.

Lower trace represents interferometer pulse. Each pulse is equivalent to 0.372 mm

4.3 Number of Resolvable Spots

The maximum number of resolvable spots, N, of each of the two deflectors can be estimated by their respective deflection distances and spot sizes. This is done using Rayleigh’s criteria:

\[ N = \frac{\text{Linear Deflection}}{\text{Spot Size}} \]  

(4.3)

Thus, the ADP deflector is deflecting 4 resolvable spots. Although the spot quality of the LiTaO₃ is very poor, the number of resolvable spots can be estimated at 7.
The specification for the ideal maximum resolvable spots for the ADP deflector is 98 spots for an input of $\pm 3000$ V. Since the number of spots is directly proportional to the

Figure 4.7 Profile of ADP Deflected Beam

a. One Extreme

b. Other Extreme

Figure 4.7 Profile of ADP Deflected Beam
voltage applied, the ±400 V driver can yield 13 resolvable spots. Thirteen resolvable spots can be arrived at by using a diffraction limited FWHM width of 0.53 μm, calculated from a numerical aperture of 0.55, for the spot size in the above equation and 7.84 μm for the linear deflection. Thus, the number of resolvable spots can be increased, although it is limited to a maximum of 13 spots, by decreasing the spot size. One way of doing this is by filling the aperture of the deflector through beam expansion.

Similarly, the specification for ideal maximum resolvable spots for the LiTaO₃ deflector is 67 spots for a ±400 V input. Again, this specification can be arrived at by decreasing the spot size to a minimum defined by the diffraction limit. Although, in the case of the LiTaO₃ deflector, the actual gaussian shape of the spot is heavily distorted as well as the width increased.

5. FABRICATION OF A STATIONARY MAGNETO-OPTIC HEAD

In the evaluation of electro-optic beam deflectors for magneto-optic recording heads, an experiment was designed to demonstrate reading with the deflector in a static environment. An optical system which included the electro-optic deflector was aligned to detect a magneto-optical signal from a medium consisting of stripe domains. By scanning the beam across the domain with the deflector, the proposed use of beam deflection for magneto-optic heads can be demonstrated.

5.1 Experimental Apparatus

The experimental setup for the optical system is shown in Figure 5.1. An Argon Ion laser emits 800 mW of polarized light at a wavelength of 488 nm. The light is immediately attenuated by an optical filter of optical density three so that the power of the
light incident on the medium is not high enough to write domains. The polarization of the light is then rotated by a half-wave plate before the beam enters the electro-optic deflector in order to facilitate optimum deflection. The beam then passes through a beam splitter and is reflected towards the medium by a dielectric mirror. An objective lens with a numerical aperture of 0.65 and a focal length of 4.3 mm focuses the light down onto the medium. The beam reflected off the medium is then directed by the nonpolarizing beamsplitter to the detection optics.

Figure 5.1 Experimental Setup for MO Signal Pickup

In the detection optics, the light first passes through a half-wave plate to optimize the sensitivity of the detection system. Then a plano-convex lens of focal length 50.20 mm
images the beam onto two photodetectors through a beam splitter as is shown in Figure 5.2. The reason for the imaging is to stabilize the spot projected on the photodetectors regardless of the deflection angle of the beam.

Thus, for a lens of focal length, f, placed a distance, d₀, away from the point of deflection, a constant area, A, will be illuminated on the detector placed a distance of d₁ away from the lens where d₁ is defined by the lensmaker's formula:

$$\frac{1}{d_1} + \frac{1}{d_0} = \frac{1}{f} \tag{5.1}$$

Since, in this experimental setup, d₀ is 914.40 mm, d₁ = 53.14 mm.

The purpose of the polarization beamsplitter cube is to separate the P and S components of the polarization and project them onto the photodetectors D₁ and D₂ respectively. By using this differential scheme, the polar Kerr rotation angle, θₖ, can be determined by the light intensity, I₁ and I₂, on the photodiodes through the following equation:
\[
\tan 2\theta_k = \frac{I_1 - I_2}{I_1 + I_2}
\]

This equation for \(\theta_k\) is most sensitive when, for the absence of a Kerr rotation, the plane of polarization is rotated by the half-wave plate to 45° relative to the vertical. At this point, \(I_1\) is initialized to \(I_2\).

![Figure 5.3 Circuit Diagram of Detection System](image)

Figure 5.3 Circuit Diagram of Detection System

The above equation can be implemented by the circuit shown in Figure 5.3. In this circuit, photodetectors \(D_1\) and \(D_2\) detect intensities \(I_1\) and \(I_2\) from the polarizing beamsplitter and, through their responsivity function, generate the currents \(i_1\) and \(i_2\) which are linearly proportional to their respective intensities. These currents are then converted to voltages through transimpedance amplifiers which, in turn, go to the appropriate inputs of the AD535 chip as shown in the diagram. Note that one of the voltages must be inverted before reaching one of the inputs of the AD535. The AD535 is responsible for the actual quotient function, and its output can be expressed as:
\[ V_{out} = 10V \frac{Z_2 - Z_1}{X_1 - X_2} \] (5.3)

Thus, through the direct proportionality of both the transimpedance amplification and the responsivity, the output of the AD535 is:

\[ V_{out} = \text{constant} \frac{I_1 - I_2}{I_1 + I_2} \] (5.4)

The sample from which the magneto-optical signal was read was a one inch square portion of a GdTbFeCo thin film with a room temperature coercivity of 2.6 KOe, a compensation temperature of 130 °C, and a Curie temperature of 310 °C. On this film were recorded four stripe domains each with an approximate width of 0.6 mm. A photograph of the stripes can be seen below.

Figure 5.4 Photograph of Medium
5.2 Signal Model

As the beam is scanned across one of the stripe domains illustrated in Figure 5.4, the polarization of the light reflected off the medium will alternate between two states depending upon the direction of magnetization. For one state, the angle of polarization will be increased by the Kerr rotation angle, and in the other state, the angle of polarization will be decreased by the same angle. Thus, as the beam crosses the magnetic domain, the plane of polarization rotates causing a signal to occur in the differential detection system.

The length of one of the scans, L, is 10.32 μm, determined by the product of the angular deflection specification for the deflector of 2.4 mrad for an 800 V voltage swing and the focal length of the objective, which is 4.3 mm. The spot being scanned is a gaussian wave form illustrated in Figure 5.6 with a FWHM of 2.3 μm. The stripe domain is the region of vertical magnetization that causes the Kerr effect. The domain walls are fairly sharp, so the crosswise profile of the stripe will be modeled as a step function. As is shown in Figure 5.7, the width of the step is 0.6 mm and the height, which represents the Kerr rotation, is normalized to unity.
As the gaussian waveform travels across the stripe, the output signal, $y(x)$, is the convolution of a gaussian and a step function:

$$y(x) = \int_{-\infty}^{\infty} f(\xi)g(x - \xi)d\xi \tag{5.5}$$

The width of $y(x)$, 5.2 $\mu$m, is calculated from the sum of the FWHM of the spot and the stripe, $d$. Thus the width of the output signal is expected to be about 50% of the scan length.

Shown below are a series of pictures of an oscilloscope display of the output of the detection circuit. Figure 5.8a shows a scan across a region of the sample with no magnetic domain present. Gradually the sample is translated so that the scan includes a stripe.
domain. Figure 5.8b shows an output indicating that the domain is near one of the edges of the scan. Finally, in Figure 5.8c the sample is positioned so that the domain is centered in the middle of the scan. This result shows a signal of 0.2V amplitude at its peak and a width of much more than the 50% cycle that was expected. An explanation for the large width lies in the focusing of the scanned spot. The width of the spot for small movements in the focusing axis can fluctuate from 2.3 μm to 5 μm while the spot appears to be reasonably focused. In this experiment, the large width of the waveform of the detection signal shown in Figure 5.8c suggests that the width of the spot is on the order of 5 μm FWHM.

a. Beam Scan in the Absence of a Domain
b. Domain at Extreme of Scan

c. Domain centered in Scan
d. Domain Scanned at Rolloff Frequency of 5 kHz

Figure 5.8 Output Detection Signal as Stripe Domains are Scanned. Upper trace shows MO signal, lower trace shows scan voltage. The horizontal axis corresponds to a scan distance of 10.32 \( \mu \text{m} \). The scan frequency was 100 Hz unless otherwise noted.

Figure 5.8d is a picture of the output of the scan at a roll off of 5 kHz. This frequency is a reflection of the bandwidth of the detection circuitry. As was previously shown in Figure 4.4, the deflection bandwidth of the deflector-driver system currently set up is 150 kHz, which is a limitation of the driver - not the deflector.
6. CONCLUSION

In order for magneto-optic recording technology to become more feasible for today's data storage needs, there must be improvements in the design of the optical head to facilitate faster access time. Of the various proposals of ways to decrease this access time, the nonmechanical deflection techniques show particular promise. One of these techniques, acousto-optical deflection, can offer relatively large deflection angles and a large number of resolvable spots. Acousto-optical deflection has been demonstrated to function as a tracking servomechanism.

Electro-optical deflection, on the other hand, offers many practical advantages. Since it relies on the electro-optic control of a crystal's refraction properties, instead of a diffraction grating, it offers a better transmission efficiency and lower power consumption. Currently manufactured electro-optical deflectors can reach up to 66 resolvable spots for an input voltage swing of less than 1 kV. Detection of a magneto-optical signal using a commercially manufactured electro-optical deflector has been demonstrated. Thus, electro-optical deflection has proven to be feasible for scanning a read-write head in an isolated experimental environment.

To fully assess, however, both the feasibility and practicality of electro-optic beam deflectors for magneto-optic recording heads, further refinements are needed. In particular, the number of resolvable spots can be increased by filling the aperture and improving the optical quality of the deflector. The next phase of this study is to demonstrate magneto-optic reading and writing on a dynamic test stand. The ultimate goal is to realize a thin film deflector operating on much lower voltages.
REFERENCES


