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A New Method to Raise Signal to Noise Ratio in Magneto-Optic Discs

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In a special external cavity laser diode, the magneto-optic (MO) film with different magnetization directions has a characteristic of controlling the frequency of incident optical wave. Based on this characteristic, this paper proposes a detection method of frequency method. Modeling the polarization noise resulted from nonuniformity in magneto-optic films and birefrengence of polycarbonate (PC) substrates, we know that, for a detection system with 10 MHz bandwidth filters, the effects of the two kinds of polarization noise on readout singals are very little.

KEYWORDS: Magneto-optic data storage, Kerr rotation angle, amplitude noise, polarization noise, birefringence, frequency shift

§1. Introduction

Up to now, it is amplitude method that be used to detect magneto-optic signals. That is, the change of magnetization direction in magneto-optic films is transformed into the change of light intensity, by using polarized optics. Therefore this kind of detection system is rather sensitive to both of amplitude noise and polarization noise in the system.

The paper proposes a new detection method of frequency method. The system based on this method is insensitive to amplitude noise, and has strong capability of eliminating polarization noise. By theoretical analysis, for 10 MHz bandwidth filters, it is known that the nonuniformity in magneto-optic films within 12% will not be harmful for readout signal quality. In addition, the birefringence of PC substrates has very light effect on the magneto-optic signals, for the maximum relative frequency shift of 2.52×10^{-4}, so it is not necessary to consider the effect of PC substrates.

§2. Principle of detection

The block diagram of detection system with an external cavity laser diode[1] is shown in Fig. 1. In the system, the magneto-optic film and the laser diode form a special device. The device, utilizing different magnetization directions in the magneto-optic film to modulate the frequency of indident optical wave, makes the readout signal frequency accord with the magnetization direction. The frequency-changed signal, through bandpass filters with different center frequencies, activates the double-polar pulse generator to produce positive or negative pulses. So, the polar of output pulse sequence represents the recorded information on the disc.

The readout signal frequency under positive or negative magnetization direction of the magneto-optic film can be expressed as the following, respectively.

$$f_{mo}(+)=\frac{C\Phi}{pL}+\frac{C\theta_k}{2\pi L}, \tag{1}$$

$$f_{mo}(-)=\frac{C\Phi}{pL}-\frac{C\theta_k}{2\pi L}, \tag{2}$$

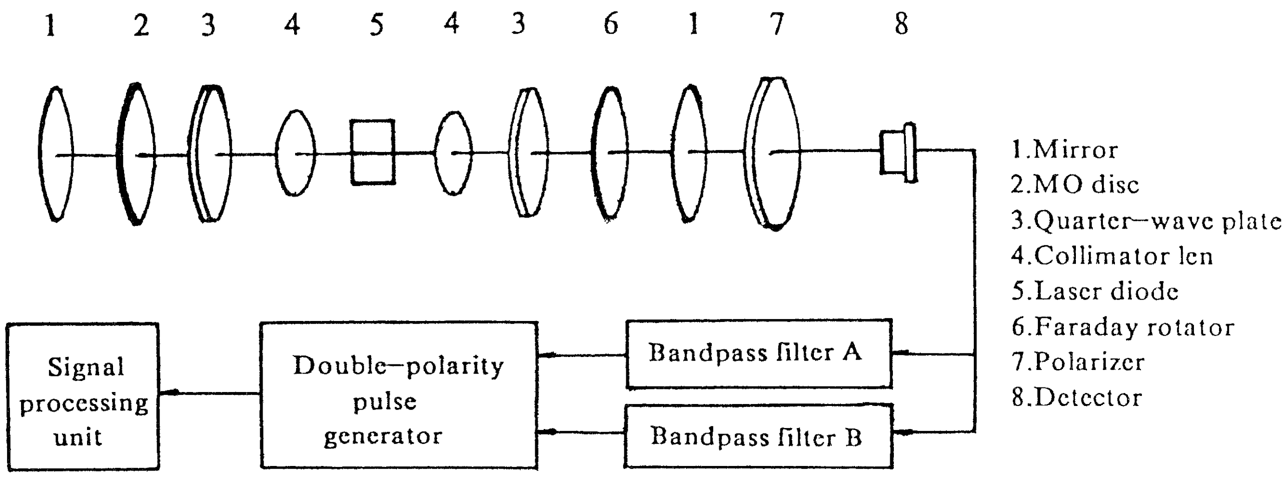

Fig. 1. Block diagram of the system for detecting magneto-optic signals with frequency method.

where,

C: velocity of light in vacuum
θ_k: Kerr rotation angle
Φ: Faraday rotation angle
L: cavity length of external cavity laser diodes.
If $\theta_k=0.5°$, $\Phi=1.8°$, $L=10$ mm,

then

$$df=f_{mo}(+)-f_{mo}(-)=\frac{C\theta_k}{\pi L}=83.3\ \text{MHz}.$$

That is, the frequency difference of readout signals under different magnetization directions is about 83.3 MHz.

§3. Mathematical models of polarization noise

Many kinds of noise in magneto-optic storage systems are resulted from magneto-optic discs, which are classified into two groups of amplitude noise and ploarization noise.[2)]

By analyzing the signal readout process of frequency detection method, it is not difficult to know that, for signal to noise ratio (SNR)>1, frequency method has strong capability of eliminating amplitude noise.

In the following, we emphasize to analyze and model the polarization noise resulted from nonuniformity of magneto-optic films and birefringence of PC substrates.

1) Nonuniformity of magneto-optic films

It $\Delta\theta_k$ expresses the difference of local Kerr rotation angles, using eqs. (1) and (2), we get,

$$\Delta f_{mo}=|\Delta f_{mo}(+)|=|\Delta f_{mo}(-)| =\left|\frac{C}{2\pi L}\cdot\Delta\theta_k\right|. \tag{3}$$

It is shown by eq. (3) that, for $L=10$ mm, $\Delta\theta_k=0.06°$ (relative change 12%), frequency shift is 5 MHz, and it is known that, for the detection system with 10 MHz bandwidth filters, the frequency shift is not harmful for readout signals. Fig. 2(a) shows the relation between the difference of local Kerr angles and the frequency shift of readout signals.

2) Birefringence of PC substrates

We use matrix M_{pc} to express the birefringence effect of substrates,

$$M_{pc}=\begin{bmatrix}\exp i(\delta/2) & 0\\ 0 & \exp -i(\delta/2)\end{bmatrix} \tag{4}$$

$$\delta=\frac{2\pi\Delta}{\lambda}, \tag{5}$$

$$\Delta=d\left(\sqrt{n_1^2-\sin^2 i}-\frac{n_2}{n_3}\cdot\sqrt{n_3^2-\sin^2 i}\right),$$

where,

δ: retard angle,
Δ: retardation,[3)]
λ: wavelength,
n_1, n_2, n_3: principle refractive indices,
d: thickness of PC substrates,
i: incident angle.

For the system shown in Fig. 1, we obtain a conclusion with Jones matrix that the effect of PC substrates will create an additional phase shift δ to incident optical wave.

When the magnetization direction of films is positive for p wave, there is,

$$\frac{4\pi L}{\lambda_p}+\delta+\theta_k+2\Phi=2n\pi, \tag{6}$$

for s wave,

$$\frac{4\pi L}{\lambda_s}+\delta-\theta_k+2\Phi=2n\pi, \tag{7}$$

and,

$$f_p=\frac{nC}{2L+\Delta}-\frac{C(2\Phi+\theta_k)}{4\pi L+2\pi\Delta}, \tag{8}$$

$$f_s=\frac{nC}{2L+\Delta}+\frac{C(2\Phi+\theta_k)}{4\pi L+2\pi\Delta}, \tag{9}$$

$$f_{mo}(+)=f_s-f_p=\frac{C(2\Phi+\theta_k)}{2\pi\left(L+\frac{\Delta}{2}\right)}, \tag{10}$$

similarly, when the magnetization direction is negative, there is,

$$f_{mo}(-)=\frac{C(2\Phi+\theta_k)}{2\pi\left(L+\frac{\Delta}{2}\right)}. \tag{11}$$

Finally, we get the mathematical models for examining the frequency shift of readout signals under different magnetization directions, respectively,

$$df_{mo}(+)=-\frac{C(2\Phi+\theta_k)}{4\pi}\cdot\frac{1}{L^2}\cdot\Delta, \tag{12}$$

$$df_{mo}(-)=-\frac{C(2\Phi+\theta_k)}{4\pi}\cdot\frac{1}{L^2}\cdot\Delta. \tag{13}$$

By analyzing eqs. (12) and (13), it is shown that the effect of the birefringence is different for various magnetization directions, and the effect is stronger for positive magnetization direction.

§4. Results and Discussion

Eqs. (3) and (12) are used to examine the effects of nonuniformity in the magneto-optic film and birefringence of the PC substrate on the readout signal frequency. Under the condition of $L=10$ mm, $\Phi=1.8°$, $\theta_k=0.5°$, and $d=1.2$ mm, for different n_1, n_2, n_3, we get Fig. 2(a) to Fig. 2(d).

Analyzing the four figures, we get the following results:

1) The megnetization nonuniformity of magneto-optic films has stronger effect on readout signal frequency, compared with that of PC substrates. As shown in Fig. 2(a), the change of local Kerr rotation angles of 0.06(deg) (relative change 12%) results in 5 MHz frequency shift which still can be eliminated by 10 MHz bandwidth filters.

2) Fig. 2(b) and Fig. 2(c) show the normal-incidence birefringence of the PC substrate. The maximum frequency shift is 21 KHz, and the relative frequency shift is

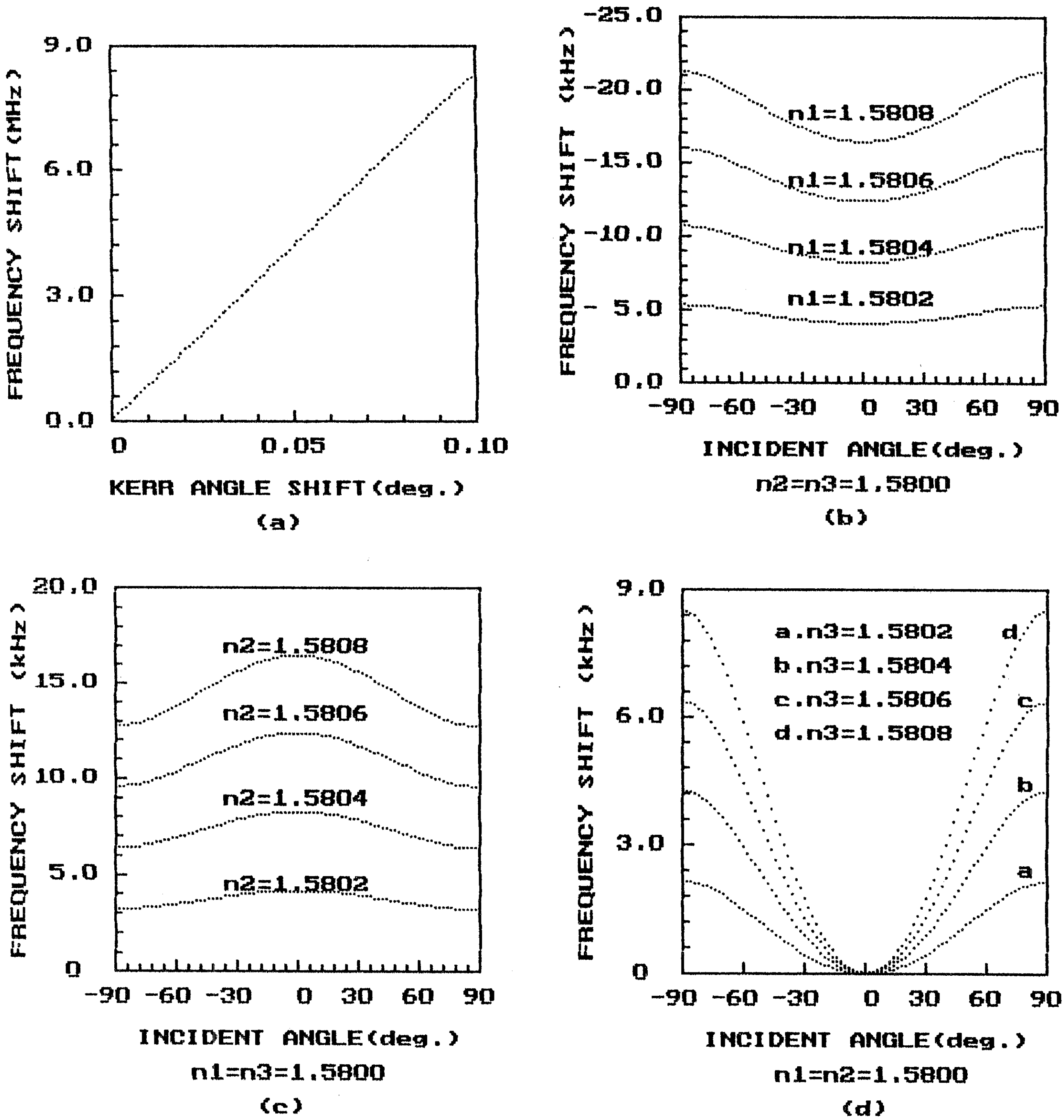

Fig. 2. Polarization noise dependence of frequency shift of readout signals. (a) Frequency shift resulted from nonuniformity of magneto-optic films. (b) to (d) Frequency shift resulted from birefringence of PC substrates, for different refractive indices of n_1, n_2, n_3 and incident angle i.

just 2.52×10^{-4}, resulted from a large difference of n_1 and n_2 of 8×10^{-4}.

3) Fig. 2(d) shows the vertical birefringence of the PC substrate. When the difference of n_1 and n_3 is 8×10^{-4}, the maximum frequency shift is 8.5 KHz and the relative frequency shift is 1.02×10^{-4}.

4) The frequency shift due to both kinds of birefringence of the PC substrate is symmetry to the incident angle i.

§5. Conclusions

From the analysis above, it is shown that frequency method can not only eliminate the amplitude noise but also restrain the polarization noise in the system. Therefore, it gives an effective approach to develop a simple optics with better signal quality, higher data transfer rate, and faster access time.

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