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Center aperture detection on magnetically induced super resolution magneto-optical disks

Pei-Yih Liu *, Han-Ping D. Shieh

Institute of Electro-Optic Engineering, National Chiao Tung University, Hsin-Chu 30050, Taiwan, ROC

Abstract

A vector diffraction model has been applied to analyze CAD readout of MSR disks. Numerical results indicate that the read power is optimized with an aperture of the same size as the recorded mark. CNR decreases as recorded density increases even by using optimized aperture. CAD MSR disks applications are limited by the aperture-to-spot ratio of 34%. Also, CNR decreases as the track pitch becomes narrower. The vector model presents a higher sensitivity than the scalar model in analyzing the optical readout characteristics of sub-μm disk structure and 'below-diffraction-limit' aperture of the readout spot.

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1. Introduction

Reducing recording mark size and having proper readout schemes to detect sub-μm marks with adequate carrier-to-noise ratio (CNR) are among the key techniques to increase recording density in magneto-optical (MO) disks. Magnetically induced super resolution (MSR) [1,2] is a 'below-diffraction-limit' readout scheme. A 'below-diffraction-limit' aperture can be formed to readout sub-μm marks by using currently available laser diodes as a light source to enable exchange-coupling at the heated readout region. The recently proposed center-aperture-detection (CAD) scheme, using exchange-coupling to form a readout aperture between in-plane readout layer and perpendicular oriented storage layer, seems to be more practical among MSR schemes [3,4].

Sub-μm marks can be easily recorded by the thermomagnetic effect in a suitable MO disk medium. Likewise, readout of MSR disks can also use the thermo-magnetic effect to create a 'below-diffraction-limit' aperture where recorded marks on the storage layer are duplicated onto the readout layer by exchange-coupling of the two layers. The duplication excludes recorded marks beyond the aperture from contributing in readout. Consequently, the readout signal is sensitive to the aperture size. CNRs of MSR disks have been analyzed by a scalar model as functions of aperture size and jitter of the recorded marks [5]. However, the scalar diffraction theory is only valid as long as the wavelength of incident light is smaller than the characteristic transverse dimensions of the scattering structure. In this study, a vector model based on vector diffraction theory [6] is used to analyze CNR in MO disks readout by CAD scheme.

2. Vector model in CAD disks readout

A readout system using conventional MO optical pickup is one of the advantages of MSR CAD disks. A typical readout system of MO disks is shown in Fig. 1. A light source is emitted from a laser diode passing through collimating and beam-shaping optics to form collimated light. The objective lens then focuses the collimated polarized light onto a diffraction-limited spot on the MO disk. The diffraction-limited spot 'reads out' the recorded marks on the disk based on the polar Kerr effect. The reflected light from the magnetization orientations passes through the half waveplate and beam splitting optics, and is detected by the differential detection scheme.

To simulate the readout signal, the vector model is adopted to calculate the interaction of light on CAD disks. The complex vector electromagnetic field of incident diffraction-limited spot can be written as

$$E_i(x,y) = \hat{x}p(x,y)e^{ik\cdot r} \qquad (1)$$

where $\hat{x}$ denotes the polarization of the electric field and $p(x,y)$ is the point spread function of the diffraction-limited spot.

The complex field of the reflected light is then calculated by the following two steps. First, the Kerr effect is obtained by solving the wave equation that propagates in

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* Corresponding author.

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the MO media. Thus, the vector complex field on MSR disks by CAD scheme becomes

$$\begin{aligned} \boldsymbol{E}_{r1} = {} & A(x,y)\left[\hat{x}\gamma p(x,y)\mathrm{e}^{\mathrm{j}\boldsymbol{k}\cdot\boldsymbol{r}} \right. \\ & \left. \pm\hat{y}\gamma k(x,y)p(x,y)\mathrm{e}^{\mathrm{j}\boldsymbol{k}\cdot\boldsymbol{r}\pm\kappa(x,y)}\right] \\ & +[1-A(x,y)]\sqrt{R}\,p(x,y)\mathrm{e}^{\mathrm{j}\boldsymbol{k}\cdot\boldsymbol{r}} \end{aligned} \tag{2}$$

$$\gamma=\frac{|\gamma_{\mathrm{cw}}+\gamma_{\mathrm{ccw}}|}{2}, \tag{3a}$$

$$k\mathrm{e}^{\mathrm{j}\kappa}=\mathrm{j}\frac{|\gamma_{\mathrm{cw}}-\gamma_{\mathrm{ccw}}|}{|\gamma_{\mathrm{cw}}+\gamma_{\mathrm{ccw}}|}, \tag{3b}$$

$$A(x,y)=\begin{cases}1, & \text{inside the aperture,}\\ 0, & \text{outside the aperture,}\end{cases} \tag{3c}$$

where γ_{cw} and γ_{ccw} are the reflectivity of clockwise and counter clockwise circular polarization incident light, respectively; the Kerr rotation angle $\theta_k \approx k\cos\kappa$; the Kerr ellipticity $\epsilon_k \approx k\sin\kappa$; $A(x,y)$ is the aperture factor; and R is the reflectivity of readout layer.

The reflected diffraction field of alternative polarization, $\hat{x}E_{xr2}(xy)$ and $\hat{y}E_{yr2}(x,y)$, is calculated by vector diffraction theory. Nevertheless, the scalar diffraction model and the Jones matrix are still valid to calculate the reflected diffraction light propagating from disk to detectors. The complex fields incident onto the detectors can then be written as

$$\begin{pmatrix}E_{\mathrm{d}1}\\ E_{\mathrm{d}2}\end{pmatrix}=-\frac{f_{\mathrm{o}}}{f_{\mathrm{d}}}M\begin{pmatrix}E_{xr2}\\ E_{yr2}\end{pmatrix} \tag{4}$$

where M denotes the Jones matrix of the half waveplate and beam-splitting optics, f_{o}, f_{d} are the foci length of the objective lens and the refocusing lens, respectively.

The differential detection output signal is proportional to the difference of the light intensity on the detectors. The time dependent signal is then written as

$$i(t)\propto|E_{\mathrm{d}1}(x-vt,y)|^2-|E_{\mathrm{d}2}(x-vt,y)|^2 \tag{5}$$

where v is the linear velocity of disks. CNR is one of the most important parameters to evaluate the readout system of optical disks. Equivalent CNR is calculated by using Fourier transform on signal $i(t)$:

$$\mathrm{CNR}=\frac{\text{carrier signal}}{\text{noise level}}\approx\frac{I(\omega)}{I(2\omega)} \tag{6}$$

where the second harmonic signal is regarded here as noise.

3. Results and discussion

The CAD readout scheme of MSR disks is analyzed by the vector model as a function of recorded spatial frequency, mark length, and track pitch. The CNR of a prototype CAD disk and an ISO disk was also measured to make a comparison with the numerical results. A light source of 780 nm wavelength and an objective lens with numerical aperture of 0.55 are used in both experimental and numerical calculations. The width of land and groove is assumed to be equal and groove depth is defined to be a quarter of the wavelength. The recorded marks are simplified to either circular shape in intensity modulation or crescent shape in field modulation.

The CNR of different recorded spatial frequencies for various readout apertures is depicted in Fig. 2. The peak value of CNR occurs when the aperture is about the same size as the crescent shape mark for each mark size. Shrinking the aperture decreases the signal intensity while in-

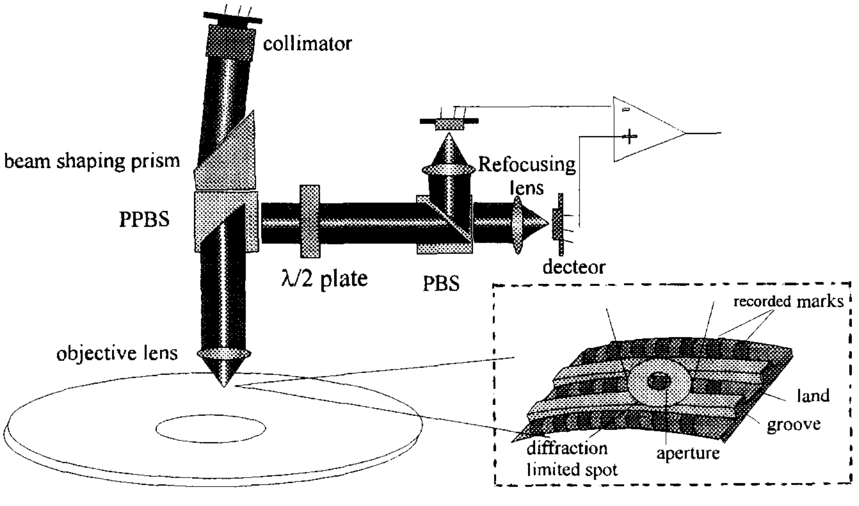

Fig. 1. MO readout system for CAD scheme.

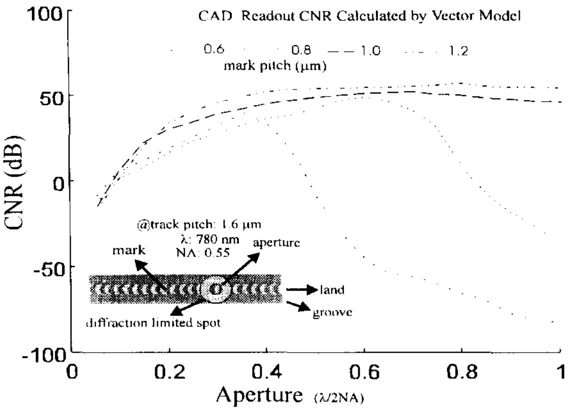

Fig. 2. CNR as function of spatial frequencies and readout apertures.

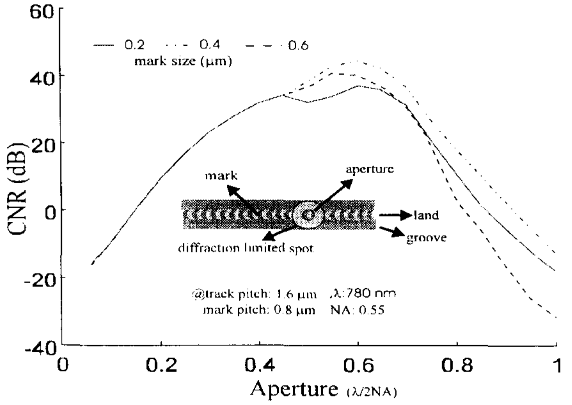

Fig. 3. CNR as function of mark sizes and readout apertures.

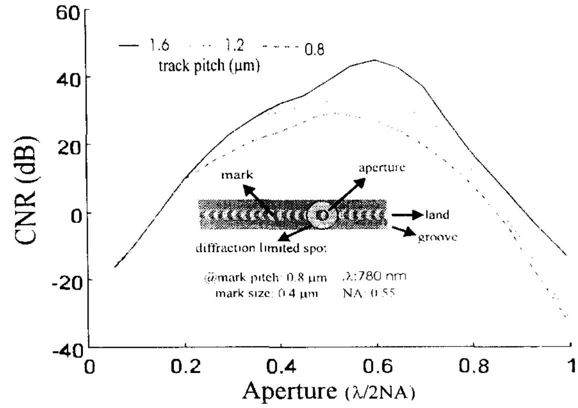

Fig. 4. CNR as function of track pitches and readout apertures.

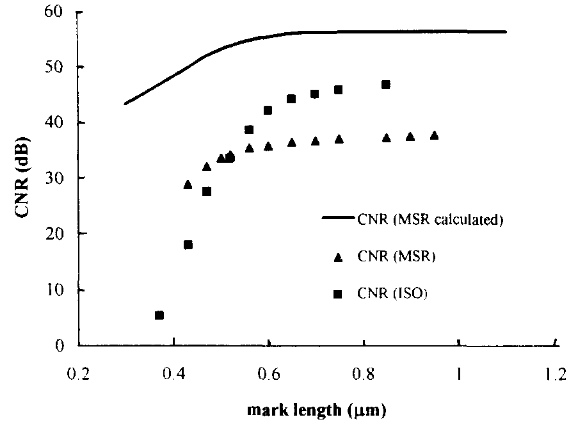

Fig. 5. CNR as function of mark lengths on MSR and ISO disks.

creasing the aperture reduces the resolution of marks. Therefore, CNR decreases gradually as the spatial frequency increases. CNR decreases as recorded density increases even by using an optimized aperture. CNR becomes lower than 45 dB when spatial frequency is higher than three times that of cut-off frequency, i.e., the aperture-to-spot ratio is less than 34%. Furthermore, the peak value −3 dB dynamic aperture margin also decreases as the spatial frequency increases, implying that the read power must be controlled more accurately for the high density recording.

The CNR of different mark sizes, but at the same spatial frequency, is shown in Fig. 3 as a function of aperture. The decrease of CNR peak value ranging from 6 to 10 dB is due to jitter of writing marks. CNR does not change by using smaller apertures as long as the aperture size is comparable to the mark size.

The reduction of land width decreases the effective area. The dependence of CNR on track pitch and aperture size is shown in Fig. 4. CNR decreases severely as the track pitch decreases. Besides, the shrinkage of track pitch results in a larger diffraction angle and subsequently reduces the light intensity reflected back to the objective lens.

A CAD MSR disk using GdFeCo/DyFeCo as exchange-coupled layer was fabricated to make a comparison with the numerical results. CNR of both the CAD and ISO disks was measured at various mark lengths, as shown in Fig. 5. The CNR of the ISO disk decreases sharply for mark lengths less than 0.6 μm, while the CNR of the CAD disk decreases slowly. The numerical results are similar to those in the experiment. The CNR of both numerical and experimental results decreases gradually when the mark length is less than 0.5 μm. The lower CNR value of experimental results is due to the experimental CAD disk not having been optimized for CNR. In addition, for numerical noise only the second harmonic signal was taken into account.

Numerical results of vector model at a low spatial frequency marks are similar to the scalar model. Nevertheless, the vector model shows a narrower -3 dB dynamic margin of apertures and a lower CNR value at high spatial frequency marks than the scalar model. Besides, the vector model is more sensitive to variations of the grating structure on disks and the readout apertures of the spot, as both of them approach a few tenths of μm. Therefore, the vector model is more applicable in evaluating the characteristics of high density disks.

4. Conclusion

A vector diffraction model has been applied in this work to analyze the CAD readout of MSR disks. Numerical results indicate that the read power is optimized with an aperture of the same size as the recorded mark. CNR decreases as recorded density increases even by using optimized aperture. CAD MSR disk applications are limited by the aperture-to-spot ratio of 34%. Also, CNR decreases as the track pitch becomes narrower. The vector model presents a higher sensitivity to the sub-μm grating structure of disks and the 'below-diffraction-limit' aperture of readout spot. Consequently, the vector model is more applicable to analyze the optical characteristics of high density disks.

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