Near-field optical data storage: avenues for improved performance

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Abstract. Because they produce small spot size, near-field techniques are applied to optical data storage systems to increase recording density. Two practical near-field implementations are aperture probes and solid immersion lenses (SILs). The basic signal modulation characteristics of these systems are reviewed, and some considerations for improving performance are discussed. Combinations of SILs and apertures could produce data storage systems with ultra-fine resolution and good detection characteristics.
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1 Introduction

Both solid immersion lens (SIL)[1] and aperture[2] systems have been used in conjunction with optical storage media. SIL systems are attractive because they produce spots smaller than conventional optical systems and they exhibit high coupling efficiency to the recording layers. Aperture systems are attractive because they offer the smallest spot size. Several specific SIL and aperture systems are reviewed in a recent publication.[3] Both SIL and aperture systems are compared in terms of basic detection properties, and considerations for improving system performance are listed.

A typical arrangement for near-field optical recording using a SIL is shown in Fig. 1. Light from a laser passes through a beamsplitter and is focused into the recording layers by an objective lens. The recording layers are on a disk that spins under the objective lens. The recording layers contain spiral tracks of mark patterns that differ in reflectivity from the area between marks. As the focused laser beam passes over a mark, the reflected light level changes. Changes in the reflected light level are sensed by using the beamsplitter to direct a portion of the reflected light onto a silicon detector. The detector current, which is a representation of the mark pattern, is decoded to produce digital information. The fidelity of the detector signal determines the amount of data per unit length of track that can be decoded with high reliability.

There are several factors that influence the fidelity of the detector signal. The most important factor for closely-spaced marks is the focused spot size s. Large s blurs the reflected light signal, resulting in a loss of contrast V in the detector signal. Contrast is defined as $V=(I_{\mathrm{MAX}}-I_{\mathrm{MIN}})/(I_{\mathrm{MAX}}+I_{\mathrm{MIN}})$, where I_{MAX} and I_{MIN} are shown in Fig. 1. Conversely, if s is small, changes in the reflected signal are sharp as the marks traverse under the spot. Therefore, as s decreases, the contrast and fidelity increase. Increased fidelity and contrast lead to smaller detectable changes in the mark pattern, so smaller marks can be used and more data can be packed into each track. In systems that are limited by media noise, the signal-to-noise ratio is maximized by maximizing contrast.

Unfortunately, s cannot be made arbitrarily small. Due to the physics of diffraction, the minimum spot size s for SIL systems is a function of the wavelength of the laser λ, the focusing properties of the objective lens, system aberrations, and the thin-film structure used as the recording layer.[4] A simple relationship that is used to estimate the full-width-at-1/e^2 spot size for conventional Gaussian illumination[5] at the stop is $s=\lambda/(n\sin\theta_{\mathrm{m}})=\lambda/(n\alpha_{\mathrm{m}})$, where λ is the wavelength in air, θ_{m} is the marginal ray angle, and n is the refractive index of the SIL. A marginal ray passes just at the edge of the stop, which is the limiting aperture of the system. α_{m} is the direction cosine corresponding to the marginal ray angle, $\alpha_{\mathrm{m}}=\sin\theta_{\mathrm{m}}$. The value of $n\alpha_{\mathrm{m}}$ is the effective numerical aperture $\mathrm{NA}_{\mathrm{EFF}}$ of the system. As $\mathrm{NA}_{\mathrm{EFF}}$ increases or λ decreases, the spot size s gets smaller, and mark density can increase. Given that new laser systems will be developed to reduce λ,[6] we describe how to increase $\mathrm{NA}_{\mathrm{EFF}}$.

A near-field aperture system is shown in Fig. 2. An aperture of diameter $d<\lambda$ is placed in proximity to the recording layer, and the mark pattern is scanned. The illumination for the aperture can be from a fiber waveguide or a lens. The size of the light spot interacting with the marks is mainly determined by d. The reflected light collected by the objective lens is passed to the detectors, where the current signal is decoded to produce digital information. Like with the SIL system, smaller spots yield higher contrast and greater data density. This simplistic model can also be applied to superresolving systems, like SuperRENS media,[7] as a basic description of the device.

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