

Design of a Near-Field Probe for Optical Recording Using a 3-Dimensional Finite Difference Time Domain Method

Kusato HIROTA¹, Tom D. MILSTER², Yan ZHANG² and J. Kevin ERWIN²

¹Electronic and Imaging Materials Research Laboratories, Toray Industries Inc., 1-1-1 Sonoyama, Otsu 520, Japan

²Optical Science Center/Optical Data Storage Center, University of Arizona, Tucson Arizona 85721, USA

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Tapered dielectric near-field probes are designed for optical recording by means of a 3-Dimensional finite difference time domain (FDTD) method. Probe fabrication is attempted with a double-exposure holographic technique.

KEYWORDS: optical data storage, near-field optics, near-field recording, super resolution, vector diffraction, finite-difference time domain

1. Introduction

Near-field optical techniques using evanescent light are being developed to overcome the diffraction limit of far-field optics. In particular, Betzig *et al.*¹⁾ applied a scanning near-field optical microscope (SNOM) for magneto-optical recording. The resolution of the metal coated tapered SNOM probe is limited by the aperture size and not by the far field diffraction limit. A resolution less than 60nm is demonstrated. However, low efficiency of the throughput of this probe limits the speed of read-out and recording. In other research, Terris *et al.*²⁾ developed near-field optical recording optics using the solid immersion lens (SIL). An advantage of SIL lenses is high optical throughput, which is several orders of magnitude larger than that of a conventional SNOM probe. However, there is technical difficulty in keeping the position of the relatively large flat bottom of the SIL in the near field of the recording medium. Recently, Ghislain *et al.*³⁾ developed a tapered SIL whose bottom is a sharp conical shape to improve the positioning of the SIL probe.

In this paper, we design an alternative tapered probe whose bottom is flat, table shaped and $1/n$ wavelength in diameter. This diameter is large enough to propagate the incident light without significant decay of the amplitude, and the diameter is significantly smaller than the spot size achievable with SIL lenses alone. This probe shape can be easily made by using a conventional lithographic technique and can be applied to a flying head for near field optical recording. The probe shape and optical configuration are schematically illustrated in Fig. 1.

In this study, we employ a three dimensional (3D) FDTD model to compute the electromagnetic field around the probe optics.⁴⁾ A full-vector computation method, which is based on the Maxwell's equations, is necessary to design a practical near-field probe. Arbitrary probe shapes and geometries can be modeled using the 3D-FDTD method.

2. Numerical Models

We examine two types of material for the probes: (a) LaSFN9 glass ($n = 1.843$), and (b) GaP ($n = 3.3$). The diameter of the bottom surface of the probes are 320 nm and 180 nm, respectively. The wavelength of the incident light is $\lambda = 650$ nm. In this study, we assume that the truncated gaussian light beam is focused by an aberration-free lens with $NA = 0.6$, and the beam is focused through a hemispherical lens surface, as shown in Fig. 1. The focal point in each case is located at the entrance of the tapered portion of the probe.

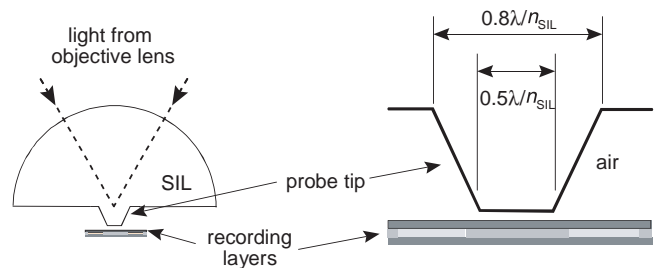


Fig. 1. Geometry showing dielectric probe and SIL combination.

The gaussian beam is emulated by 42 voltage excitation ports on the meshes at the top of the plane in the computation-cell space. The incident electric field is a sinusoidal wave. In this study, a y-polarized incident beam is used. In order to simplify the computation model, the recording medium in this study is a dielectric object, whose refractive index is 2.15. Additionally, a recorded mark, which consists of a perfect electric conductor (PEC), is set into the dielectric medium in order to calculate the scattered field from the mark.

A commercial FDTD code 'XFDTD Ver. 5.0' is used for the FDTD computations. Some part of the pre-processing and post-processing are done on the OPTISCAN Ver. 5.0 and MATLAB Ver. 5.2. The number of the cells in the FDTD geometry is 101(x) X 101(y) X 91(z). The cell size is 10 nm for model (a) and 5.6 nm for model (b). The outer boundary of this cell-space is covered with 6 perfectly matched layers (PML). The total time steps for computation is 1500 steps, and the typical computation time is 60–120 minutes using a 300 MHz-clock PC.

3. Numerical Results

3.1 LaSFN9 glass probe

The steady state electric field amplitude plots (not time domain snap shot) of the TE-direction (x) and TM-direction (y) are illustrated in Figs. 2(a) and 2(b), respectively. The beam profiles in the dielectric medium at 50 nm from the surface are illustrated in Fig. 3. The radiated beam profile in the TE direction is slightly narrower than that of the TM direction. The attenuation of the electric field in the probe is relatively small. The beam diameters (in $1/e^2$ maximum intensity) in the TE and TM directions at the inside of the dielectric layer are 480 and 500 nm, respectively. These sizes are smaller than the wavelength of incident light $\lambda = 650$ nm.