Optical near-field recording using a planar solid immersion mirror

Chubing Peng, Christophe Mihalcea, Dorothea Büchel, William A. Challener and Edward C. Gage
Seagate Technology LLC Research, Pittsburgh, PA 15222
Dorothea.Buechel@Seagate.com

Abstract

A near-field planar solid immersion mirror (PSIM) has been developed and applied to record and read-out marks in a phase-change material. Light focusing is realized by integrating a two-dimensional parabolic reflective surface in a planar waveguide. Using a PSIM fabricated out of a waveguide consisting of a 0.1 μm Ta_2O_5 core layer and a SiO_2 cladding layer on an AlTiC substrate, we have recorded marks with dimensions of less than λ/4.

Introduction

In conventional optical data storage an objective lens is used for focusing light into a storage medium for writing and retrieving information. The focused spot size is diffraction-limited and the resolution of the optical system is defined by λ/(2NA), where λ is the wavelength of the laser light and NA is the numerical aperture of the focusing lens.
Near-field optical techniques have been proposed to circumvent the diffraction limit enabling an increase of data storage capacity. One approach for near-field recording uses a submicron aperture and places the storage medium in a close proximity to the aperture [1,2]. A drawback of using apertures, though, is their low power throughput since most of the input optical power is lost through heat dissipation or reflection.
Other approaches to decrease the optical spot size utilize a solid immersion lens (SIL) [3,4] or a solid immersion mirror (SIM) [5]. A SIL is formed by placing a truncated dielectric sphere between a focusing objective and a sample, while a SIM uses a curved reflective surface for focusing light inside a dielectric material. By placing such a lens in close proximity to a sample, those optical rays at angles greater than the critical angle for exiting the high index material at the base of SIL or SIM, can tunnel through the air gap between the lens and the sample, forming a small optical spot on the sample surface. To achieve high data transfer rates with such a device it is preferable to fly an optical head with an air bearing over a disk surface with a high linear velocity and without a focusing servo system [6].
Recently Challener et al. [7] proposed a novel device, a planar solid immersion mirror (PSIM), for near-field optical recording. The diffraction-limited focused spot size for the PSIM is ~ $\lambda/(2\beta)$, where β is the mode index of light in the waveguide. This device will be disclosed in further detail. In this article we demonstrate the use of a PSIM for optical recording on a phase-change (PC) optical medium.

Experiments

We demonstrate the application of our PSIM to optical recording by means of a setup shown in Fig. 1. Light exiting from a single mode, polarization-maintained optical fiber is collimated by a ball lens and illuminates the input grating coupler which is integrated in the waveguide for exciting a waveguide mode. The angle of incidence θ is adjusted for maximum coupling efficiency. The beam size in terms of full width at $1/e^2$ intensity is 50 μm. The PSIM device is integrated into an AlTiC slider, which is cut, lapped and polished such that the SIM focal plane is just at the edge of the air-bearing surface of the device. The width of the slider is 200 μm. The slider is suspended so that it just touches the surface of the sample. It can be tilted in order to align its edge parallel to the sample's surface. The sample is mounted on a piezoelectric x-y scanning stage.
Phase-change samples used in this study are r.f. magnetron sputtered and consist of a 0.005 μm thick ZnS-SiO_2 dielectric layer, a 0.02 μm $Ge_2Sb_2Te_5$ phase-change (PC) layer, and a 0.12 μm ZnS-SiO_2 dielectric layer on a glass substrate. The PC layer is in its as-deposited amorphous state. By applying a short laser pulse, the PC material is crystallized locally. To evaluate the recorded marks we use a scanning near-field optical microscope (SNOM). SNOM records the transmission of light while scanning a metal-coated near-field aperture over the sample surface in contact mode. The aperture typically has a size of less than 0.1 μm. For these measurements the light wavelength λ is 0.650 μm.

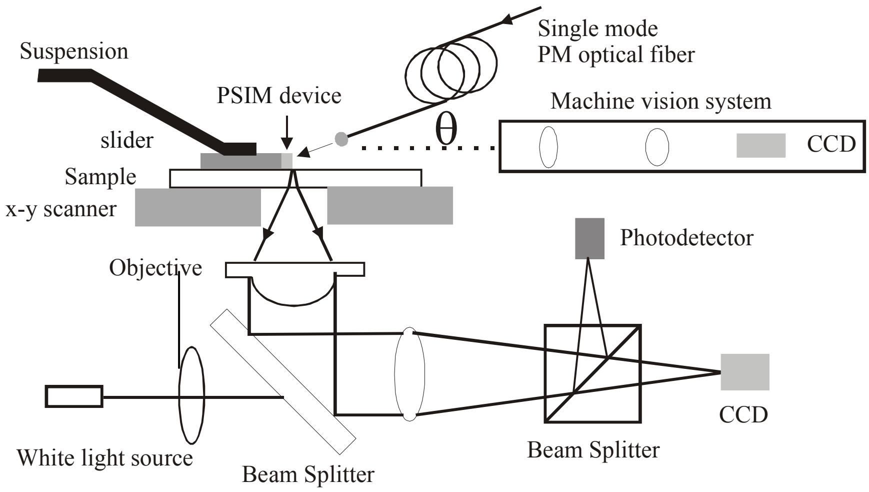

Fig. 1: Schematic of the test setup used for optical storage with a PSIM contacting the sample. It includes illumination optics for excitation of waveguide, a confocal microscope detection module, and a machine vision system for optical alignment.

Results and Discussions

Figure 2 shows the SNOM image of two tracks recorded at λ = 0.830 μm using the PSIM. For the recording experiment the sample was moved normal to the waveguide plane at a linear velocity of 0.5 mm/s and the laser is pulsed with a pulse period of 1 ms and width of 500 ns. Track pitch is 2 μm. The center-to-center distance of two neighboring marks along a track is 0.5 μm. Prior to writing the marks the PC material is in its as-deposited amorphous state. The written marks have a full-width at half-maximum (FWHM) width of ~0.3μm, and a length of ~0.25 μm, which corresponds to λ/3.

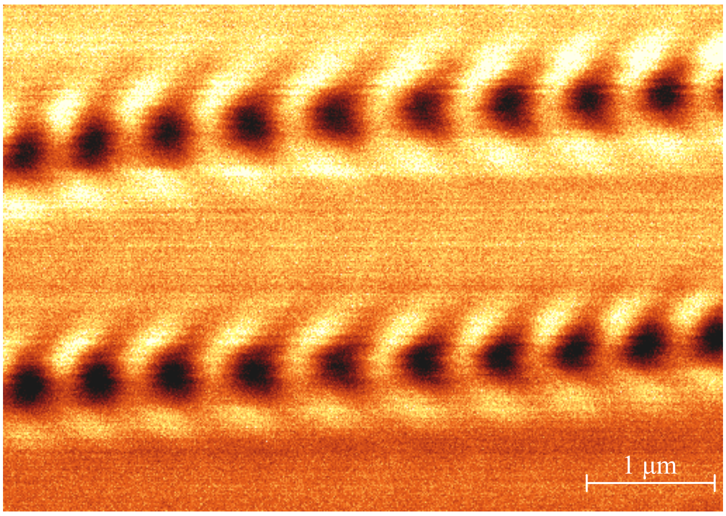

Fig. 2: Marks in a phase-change sample written by a PSIM device at a light wavelength λ = 0.83 μm were read out by SNOM. The center-to-center distance between two recorded tracks is 2 μm and that between two neighboring marks along a track is 0.5 μm.

We carried out similar recording experiments at λ = 0.488 μm using the PSIM. The grating coupler for launching light into the waveguide has the grating period of 0.480 μm while the groove depth is about 0.03 μm. Figure 3 shows the SNOM image of written marks at laser power of 10 mW. Calculations indicate that the optical efficiency for delivering energy into the storage layer for local heating could be substantially improved by using a modified, more efficient grating coupler. The written marks have a FWHM width of 0.1 – 0.12 µm across a track and a length of 0.13-0.15 µm along a track, which corresponds to λ/3 - λ/4. By carefully optimizing the alignment of the PSIM devices we ultimately achieved recording and read out of marks with a size of 0.09 µm FWHM at a wavelength of 0.413 µm, what corresponds to less than λ /4.

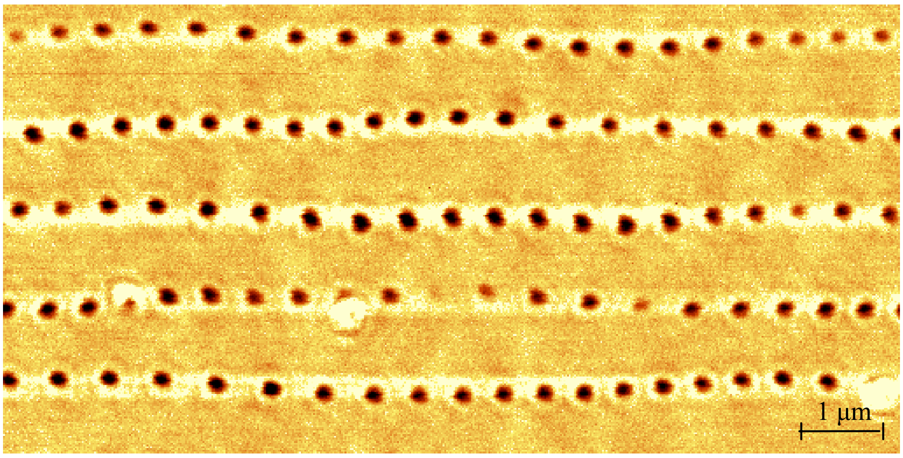

Fig. 3: PC marks written at λ = 0.488 µm. The center-to-center distance between two recorded tracks is 1 µm and that between two neighboring marks along a track is 0.5 µm.

Conclusions

We have demonstrated that, by use of the described PSIM device, light can be focused to a small optical spot and that it can be used to write PC marks with sizes down to λ/4 and smaller. The PSIM was used also for reading PC marks in transmission mode. In addition, the fabrication process of the PSIM device is not significantly different from techniques utilized for conventional magnetic recording heads, enabling mass production at low cost.

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