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Effect of fly height and refractive index on the transmission efficiency of near-field optical transducers

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Heat-assisted magnetic recording is a potential remedy to extend the limits of magnetic recording. A high temperature with a steep gradient is used to reduce the local coercivity of the magnetic medium. To achieve such a thermal profile, an intense optical spot well below the diffraction limit is necessary. Transmission efficiency of a near-field optical transducer is affected by various factors at the head-medium interface. Effect of fly height and presence of high refractive index material at the head-medium interface is investigated. Favorable conditions are identified. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2180440]

The magnetic data storage industry is observing a slowdown in the pace of the areal density growth. Perpendicular recording[1,2] could extend the areal density limit of longitudinal recording to 1 Tb/in.^{2}.[3,4] A potential technique to extend the physical limits of conventional magnetic recording beyond 1 Tb/in.^{2} is heat-assisted magnetic recording (HAMR). In a HAMR system, an optical spot well below the diffraction limit is used to heat the recording medium to reduce its coercivity and enable recording by an external field. To achieve a density of 1 Tb/in.^{2} an optical spot with a full-width half maximum (FWHM) size of 25 nm is necessary for a bit-aspect ratio of 1.

The minimum spot size that can be obtained by an optical lens is limited by the diffraction limit. Due to the diffraction of electromagnetic waves, the FWHM spot size at the focal plane of an optical lens is given by

$$d \approx \frac{0.51\lambda}{\mathrm{NA}}, \tag{1}$$

where λ is the wavelength of the optical source and NA is the numerical aperture of the lens. Even with a blue laser and a perfect optical lens (NA=1), the minimum spot size that can be obtained by an optical lens is about 200 nm, which is too large to achieve a density of 1 Tb/in.^{2}

To achieve smaller optical spots, near-field optical transducers can be used. A near-field optical transducer is an optical probe that is operated in close proximity to a sample. This distance is usually much less than the decay length of the emitted energy by the probe. Recent advances in near-field optics achieve spatial resolution significantly better than the diffraction limit. Solid immersion lenses,[5,6] apertures on metallic conductors,[7,8] bow-tie antennas,[9,10] ridge waveguides,[11–14] tapered optical fibers,[15] silicon pyramidal probes,[16] and apertureless near-field microscopy[17] are among the possible ways to achieve small spots. In a recent study, two near-field techniques are combined[14] in a condenser-transducer configuration to achieve an intense optical spot with a FWHM size of 31 nm, which is well below the diffraction limit of an optical lens.

Transmission efficiency of a near-field transducer is another important concern in HAMR. Transmission efficiency in a HAMR system can be defined as

$$\text{Transmission efficiency} = \frac{\text{Transmitted power to the magnetic medium}}{\text{Input power of the optical source}}. \tag{2}$$

While achieving small optical spots, near-field transducers usually suffer from poor transmission efficiencies. Although recent nano-optical systems provide promising transmission efficiencies,[14] the tolerance of the designs is tight and there may not be much power to spare by ineffectively selecting the fly height and material at the head-media interface. In this letter, the effect of fly height and presence of high refractive index material on the transmission efficiency of the near-field optical transducers is investigated. The ridge waveguide transducer (RWT), shown in Fig. 1, is used as the near-field optical transducer in this study. The RWT is composed of an rectangular aperture on a metallic film with a rectangular metallic extension into the aperture. This metallic extension is called a ridge. The RWT generates an intense electric field in the gap between the ridge and the opposite surface of the waveguide. The intense electric field produced by the RWT is highly localized around the ridge. If another object, such as magnetic medium, is brought within the vicinity of this localized field, an optical power distribution

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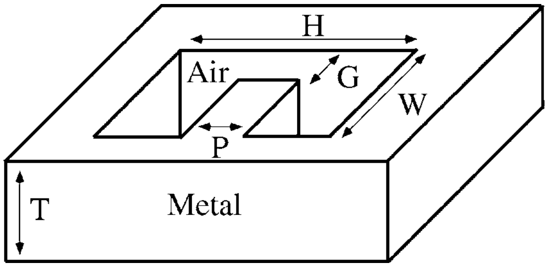

FIG. 1. The ridge waveguide transducer.

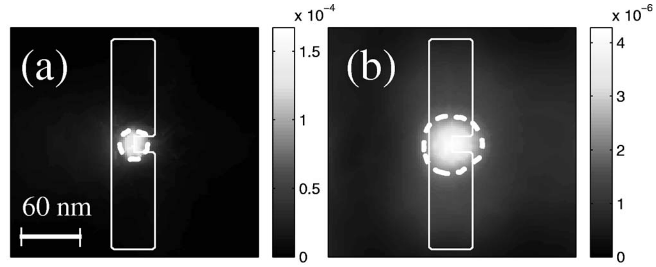

FIG. 3. Transmitted power (mW/nm^3) on the top surface of the magnetic medium for a fly height of (a) 8 nm and (b) 25 nm. An outline of the ridge waveguide is displayed with a thin white contour for reference. The FWHM contour is emphasized with a thick dashed line.

with a size well below the diffraction limit can be obtained within the object due to this localized field.

The fly height determines the clearance between the flying slider and magnetic medium, and therefore, is a crucial parameter in terms of magnetics and tribology. In Fig. 2 the transmitted power to the magnetic medium is given as a function of the fly height. To capture the effect of all parameters, a 3D full-wave solution of the Maxwell's equations is necessary. To calculate the transmitted power in this study, a frequency-domain based finite element method[13,18,19] is used for the solution of Maxwell's equations. In this calculation the RWT parameters are selected as $H=220$ nm, $W=40$ nm, $T=65$ nm, $P=20$ nm, and $G=20$ nm based on a previous study.[13] Silver, cobalt, and gold are used for the RWT, magnetic layer, and heat-sink layer, respectively. The refractive indices of the materials in this study are taken from the literature[20] as $0.130+i\times 3.063$, $1.952+i\times 3.654$, and $0.617+i\times 2.111$ for silver, cobalt, and gold, respectively. The top surface of the RWT is placed at the focus of an optical system with 100 mW power. Figure 2 shows that the transmitted power increases with decreasing fly height. Therefore, a smaller fly height is better to increase the transmitted power to the magnetic medium.

The increase in the transmitted power with fly height reduction is expected and can be explained as follows. The intense electric field obtained by the RWT is composed of two components: evanescent and propagating fields. In the near-field, which is the main focus of this study, the evanescent field is stronger than the propagating field. The evanescent field rapidly decays as the observation point gets farther away, which has been theoretically shown by Bethe[21] for an aperture on a metallic film. When the magnetic medium is brought within the vicinity of the transducer, the evanescent fields are dissipated in the lossy magnetic medium. Therefore, a stronger power dissipation is obtained in the magnetic medium when it is placed closer to the transducer. This power dissipation is the source of transmitted power to the magnetic medium.

As the fly height increases, the optical spot size gets larger. Figure 3 illustrates the transmitted power to the magnetic medium for a fly height of 8 and 25 nm. The FWHM spot sizes are 31 and 57 nm, respectively. In addition, the transmitted power for the 8 nm fly height is 39 times stronger than that for the 25 nm fly height. Based on these findings, the RWT would be placed at the air bearing surface on the slider. The RWT would be placed close to the magnetic recording head near the pole at the trailing edge. An optimum placement of the RWT with respect to the magnetic head should be determined based on the system requirements.

Another important factor that impacts the transmitted power is the refractive index of the material filling the head-medium interface. Figure 4 illustrates the transmitted power as a function of the refractive index of the material filling the head-medium interface. Selecting the refractive index of the material as 1.5 increases the transmitted power density by about 35% over the selecting refractive index as 1.0. To increase the transmitted power to the magnetic medium, a material having an index of refraction, n, between 1.3 and 1.5 is preferable. This can be partially achieved by coating the magnetic medium with a material with a high refractive index. Although such an overcoat would provide an increase in transmitted power, further improvement can be obtained by filling the head-disk interface with an optical fluid having a refractive index between 1.3 and 1.5.

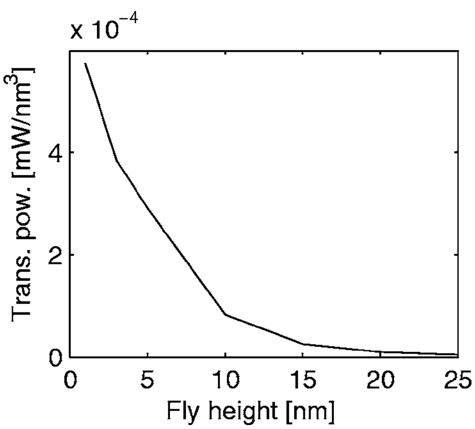

FIG. 2. Transmitted power to the magnetic medium as a function of the fly height.

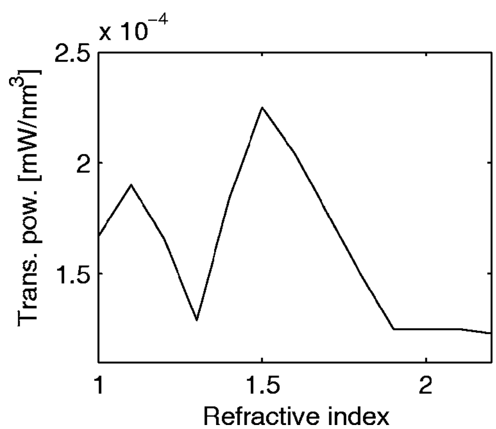

FIG. 4. Transmitted power to the magnetic medium as a function of the refractive index of the material filling the head-media interface.

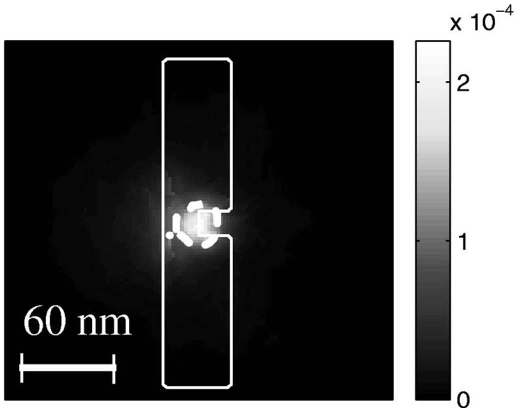

FIG. 5. Transmitted power (mW/nm^3) on the top surface of the magnetic medium for a material with a refractive index of 1.5.

The fluid used for this application must meet various criteria, in addition to having the correct refractive index. Some of these requirements are correct molecular weight and viscosity ranges, low volatility, and good tribological functionality. Various fluids are known to meet these criteria and have been successfully used in similar applications. For example, perfluoropolyethers (n may range from 1.1 to 1.3) or high thermal stability lubricating optical fluids (such as polyphenylether, PPE, $n \approx 1.5$) can be supplied in various molecular weight ranges. Their viscosity and low volatility span the required range and can be altered through suitable chemical means.

Currently, the slider, which houses the magnetic head, is maintained above the rapidly spinning magnetic disk with an air bearing. The separation of slider and magnetic disk is achieved by the geometric structures built on the surface of the slider. By filling the space between the head and magnetic medium with fluid, we expect an increase in viscous drag on the slider. This would require the design of new structures on the slider surface to maintain the proper head-medium spacing.

Although the transmitted power to the magnetic medium increases with an increasing refractive index, the FWHM spot size remains unchanged. Figure 5 illustrates the transmitted power on the top surface of the magnetic medium for a material with a refractive index of 1.5. The size of the optical spot, 31 nm, is the same as the size of the spot when the refractive index is 1.0, which was shown in Fig. 3(a).

In summary, the transmission efficiency of the RWT is significantly affected by the fly height and material at the head-disk interface. Reducing the fly height significantly increases the transmitted power to the magnetic medium. Furthermore, reducing the fly height decreases the FWHM spot size in the magnetic medium. A high refractive index material in the head-media interface increases the transmitted power to the magnetic medium without changing the FWHM spot size.

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[1]H. N. Bertram and M. Williams, IEEE Trans. Magn. **36**, 4 (2000).
[2]M. Mallary, A. Torabi, and M. Benakli, IEEE Trans. Magn. **38**, 1719 (2002).
[3]D. Weller and A. Mosser, IEEE Trans. Magn. **35**, 4423 (1999).
[4]*Perpendicular Magnetic Recording*, edited by S. I. Iwasaki and J. Hokkyo (IOS, Amsterdam, 1991).
[5]S. M. Mansfield and G. S. Kino, Appl. Phys. Lett. **57**, 2615 (1990).
[6]B. D. Terris, H. J. Mamin, and D. Rugar, Appl. Phys. Lett. **68**, 141 (1996).
[7]F. J. G. de Abajo, Opt. Express **10**, 1475 (2002).
[8]R. Wannemacher, Opt. Commun. **195**, 107 (2001).
[9]R. D. Grober, R. J. Schoelkopf, and D. E. Prober, Appl. Phys. Lett. **70**, 1354 (1997).
[10]K. Sendur and W. Challener, J. Microsc. **210**, 279 (2003).
[11]X. Shi and L. Hesselink, Jpn. J. Appl. Phys., Part 1 **41**, 1632 (2001).
[12]A. V. Itagi, D. D. Stancil, J. A. Bain, and T. E. Schlesinger, Appl. Phys. Lett. **83**, 4474 (2003).
[13]K. Sendur, W. Challener, and C. Peng, J. Appl. Phys. **96**, 2743 (2004).
[14]K. Sendur, C. Peng, and W. Challener, Phys. Rev. Lett. **94**, 043901 (2005).
[15]M. Ohtsu and H. Hori, *Near-Field Nano-Optics* (Kluwer Academic, New York, 1999).
[16]C. Mihalcea, W. Scholz, S. Werner, S. Munster, E. Oesterschulze, and R. Kassing, Appl. Phys. Lett. **68**, 3531 (1996).
[17]A. Hartschuh, E. J. Sánchez, X. S. Xie, and L. Novotny, Phys. Rev. Lett. **90**, 095503 (2003).
[18]J. M. Jin, *The Finite Element Method in Electromagnetics* (Wiley, New York, 2000).
[19]All the FEM calculations in this report are performed with High Frequency Structure Simulator (HFSS™) from Ansoft Inc.
[20]E. D. Palik, *Handbook of Optical Constants of Solids* (Academic, San Diego, 1998).
[21]H. A. Bethe, Phys. Rev. **66**, 163 (1944).