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# Patterned medium for heat assisted magnetic recording

Kürşat Şendur[1,a)] and William Challener[2]
[1]Sabanci University, Istanbul 34956, Turkey
[2]Seagate Technology, Pittsburgh, Pennsylvania 15222-4215, USA

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Heat assisted magnetic recording (HAMR) is a potential solution to extend the limits of conventional magnetic recording. In HAMR, the heating of the recording medium is achieved with a near-field optical transducer. Although the literature suggests novel transducers, there is little consideration of the optical and thermal aspects of the magnetic medium. In this letter we suggest a recording medium that provides a significant enhancement in optical absorption and localized heating. The thermal profiles of the proposed medium and the conventional medium are compared using finite element method solutions of Maxwell's and the heat transfer equations. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3073049]

The magnetic hard disk drive industry depends on continually increasing areal density. The industry is observing a major slowdown in the increase in areal density as it approaches 1 Tbit/in.$^2$ A potential technique to extend the physical limits of conventional magnetic recording beyond 1 Tbit/in.$^2$ is heat assisted magnetic recording (HAMR).[1,2] In a HAMR system, an optical spot well below the diffraction limit is used to heat the recording medium to reduce its local coercivity. Localized heating of the recording medium is achieved using a near-field optical transducer. The local reduction in the coercivity in the recording medium enables recording by an external magnetic field with a lower amplitude.[2]

There has been a considerable amount of research devoted to obtaining optical spots smaller than the diffraction limit using near-field optical transducers.[3,4] The reduction in optical spot sizes using nano-optical transducers, however, is achieved at the expense of reduced power transmission efficiency. To achieve desired data transfer rates, the power transmission efficiency of a nano-optical transducer still needs to be high enough to be feasible for a practical HAMR[1] system. To achieve large power transmission efficiency in small optical spots, nano-optical techniques such as apertures on metallic conductors,[5,6] bow-tie antennas,[7,8] ridge waveguides,[4,9,10] tapered optical fibers,[11] silicon pyramidal probes,[12] and apertureless microscopy[3] can be used.

Despite research efforts to find a better transducer for light localization and high power transmission efficiency, there has not been significant consideration in improving the optical and thermal performance of the magnetic medium. As we demonstrate in this work, substantial improvements in temperature profiles can be obtained by designing a magnetic recording medium based on the fundamental principles of optical energy transfer and heat transfer. In this study, the basic principles of Maxwell's and heat transfer equations are utilized to obtain a magnetic medium with superior optical and thermal performance compared to a conventional magnetic medium.

To understand the optical energy transfer mechanism at the interface between a near-field transducer and a magnetic medium, the interaction of various electromagnetic field components produced by a transducer with a magnetic medium must be considered. The electromagnetic field distributions at this interface have similarities for different transducers due to Maxwell's boundary conditions for good metals. In a previous study, the $\hat{x}$, $\hat{y}$, and $\hat{z}$ components of the electric field were presented in the magnetic medium when it was in the vicinity of a ridge waveguide.[10] Figures 3–5 in that study suggest that the strength of the perpendicular (i.e., $\hat{z}$) component of the electrical field is comparable to or even larger than that of the transverse (i.e., $\hat{x}$ and $\hat{y}$) components. Since the transducer acts as an electric dipole, it would be expected to produce a significantly stronger transverse component than the perpendicular component. Within the transducer, strong transverse field components are present. Outside the transducer, especially in the space between the transducer and the recording medium, a stronger perpendicular component is present. The presence of a stronger perpendicular component can be best understood by the boundary conditions on good metals. Good metals force the electric field lines to be perpendicular to their surface. Strong perpendicular electric field components are even more prominent for apertureless optical transducers.[3]

In light of this discussion, the main concern for a practical HAMR system is to efficiently couple the strong perpendicular component into the recording medium. Coupling of the electric fields into the recording medium determines the transmission efficiency of the system. The coupling of the electric fields at the interface between the transducer and the magnetic medium is determined by the boundary conditions. Maxwell's equations state that

- the tangential component of the electric field across an interface between two media is continuous, $\mathbf{E}_1^t = \mathbf{E}_2^t$, and
- the perpendicular component across an interface is discontinuous by an amount $\mathbf{E}_1^n / \mathbf{E}_2^n = \epsilon_2 / \epsilon_1$, where $\epsilon_1$ and $\epsilon_2$ are the permittivities of each material.

Since the permittivity of magnetic materials at optical frequencies is significantly larger in magnitude than the permittivity of materials that fill the interface, the perpendicular component of the electric field in the magnetic medium is very low for the conventional magnetic medium. This results in low coupling efficiency for the perpendicular component of the field into a conventional magnetic medium. Since a

a)Electronic mail: sendur@sabanciuniv.edu.

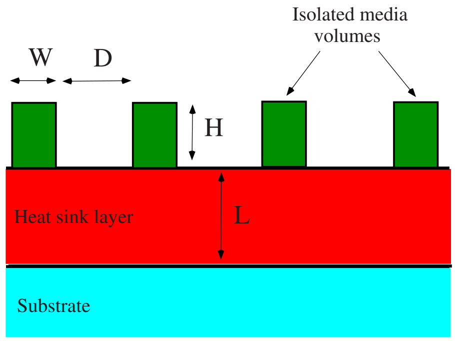


FIG. 1. (Color online) Patterned magnetic medium for HAMR utilizes isolated magnetic volumes to improve the light coupling and temperature profile.

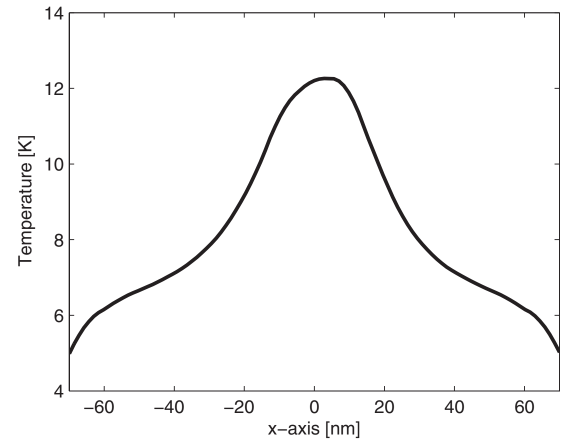


FIG. 2. Temperature distribution in the continuous recording medium.

strong perpendicular electric field is present at the interface between the transducer and the magnetic medium, the discontinuity of the perpendicular component reduces the optical energy coupling from the transducer into the magnetic medium.

The recording medium can be designed so that the coupling of the perpendicular electric field component can be significantly improved. The magnetic medium, shown in Fig. 1, has a number of electromagnetic and thermal advantages over the conventional recording medium, including better electromagnetic field coupling and reduced thermal spread in the lateral direction. The designed medium, shown in Fig. 1, uses isolated magnetic volumes to increase both the light coupling and the thermal response. Isolated metallic volumes are made of magnetic material such as a CoPt alloy. Dielectric volumes are placed between these magnetic grains to isolate them both optically and thermally. The medium utilizes a highly conducting metallic heat sink underlayer, which quickly removes the heat from the medium. Fast heat removal is necessary for high recording data rates.

The improvement of localized heating in the magnetic medium shown in Fig. 1 is demonstrated using numerical simulations. To illustrate the effect of the patterned medium shown in Fig. 1, we obtained three-dimensional (3D) finite element method (FEM) solutions of Maxwell's and the heat transfer equations. The optical source profile in the thermal simulation was obtained from a 3D full-wave solution of Maxwell's equations using FEM. The specifications of the numerical simulation are as follows. The transducer was illuminated with an optical power source of 100 mW. The operating wavelength of the optical source is 700 nm. The peak energy density over the central magnetic bit is $1.1 \times 10^{-4}$ mW/nm$^2$. FEM utilizes an adaptive mesh refinement algorithm, which results in smaller mesh sizes in the regions with high field intensity and large field gradients. In the main region of interest, i.e., around the central magnetic particles, the average mesh size was around 1 nm. The recording medium model in this work is composed of uniformly distributed same-size magnetic particles, which are equally separated from each other. The magnetic particles in Fig. 1 have side lengths of 5 nm. The separation between the particles is 5 nm and the height is 10 nm. A heat sink layer with a 200 nm thickness is placed under the magnetic particles. The thermal and optical properties of the magnetic layer and the heat sink layer are listed in Table I. Figures 2 and 3 illustrate the temperature distribution through a contour on the top surface of the recording medium. As shown in Figs. 2 and 3, a higher temperature and a tighter localization are obtained by using the patterned recording medium instead of a conventional recording medium. Such high temperatures and small spots are essential for HAMR.

TABLE I. Thermal and optical properties of the magnetic layer and the heat sink layer.

| Material | Density (kg/m$^3$) | Specific heat [J/(kg K)] | Thermal conductivity [W/(m K)] | Refractive index (unitless) |
|---|---|---|---|---|
| Magnetic layer | 8 862 | 421 | 99.2 | 0.16+*i*3.95 |
| Heat sink layer | 19 300 | 129 | 317 | 2.30+*i*4.43 |

The higher temperature and tighter localization shown in Fig. 3 are primarily achieved by better optical coupling of electromagnetic waves into the patterned medium shown in Fig. 1 compared to conventional recording medium. In the case of a conventional recording medium, the electric field lines are perpendicular to the medium, as shown in Fig. 4. However, in the case of patterned media, the electric field lines are perpendicular on the top surfaces and tangential on the side surfaces of the medium, as shown in Fig. 5. The perpendicular component of the optical fields will be damped within the magnetic material. The perpendicular component of the electric field across an interface is discontinuous, but the tangential component of the electric field across an interface is continuous. Due to this continuity, the tangential com-

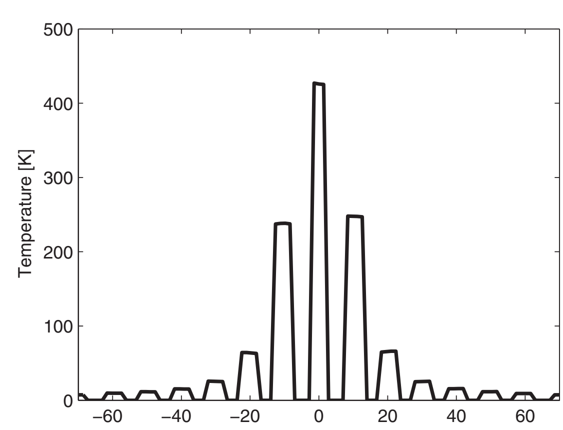


FIG. 3. Temperature distribution in the patterned recording medium.

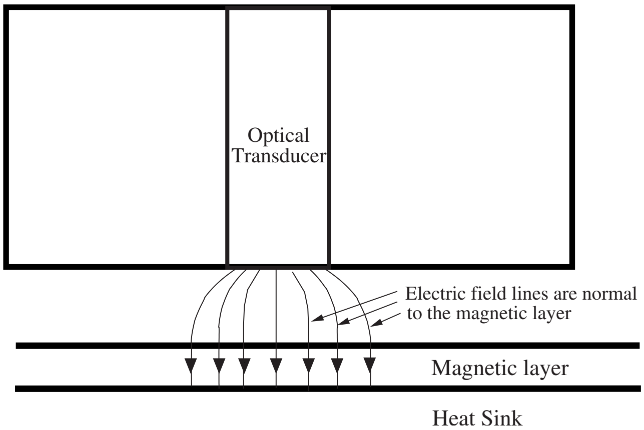


FIG. 4. The field lines are normal to the continuous recording medium.

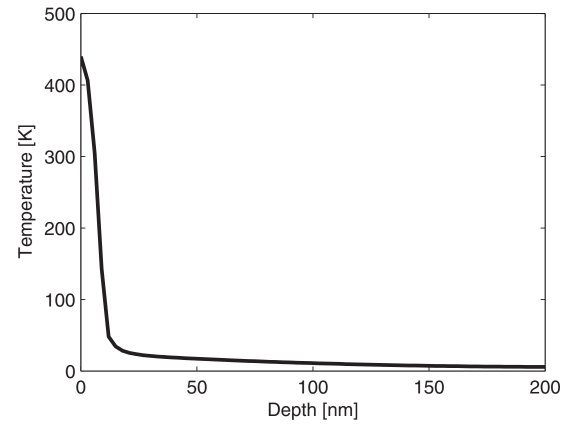


FIG. 6. Patterned medium temperature distribution as a function of depth.

ponents of the field couple better to the medium. Better coupling of electromagnetic fields results in higher optical power absorption in the recording medium shown in Fig. 1. The optical power absorption in the magnetic recording medium is related to the electric field as

$$\mathcal{P}_a(\mathbf{r}) = \tfrac{1}{2}\Re(\sigma)|\mathbf{E}(\mathbf{r})|^2, \quad (1)$$

where $\mathbf{E}(\mathbf{r})$ (V/m) is the local electric field intensity at point $\mathbf{r}$ and $\Re(\sigma)$ is the real part of the conductivity of the magnetic medium. Higher optical absorption in the magnetic volumes results in the higher temperatures obtained in Fig. 3. In addition, the spread of the absorbed power is reduced since the recording medium is digitized in the form of magnetic volumes with electrical insulating material in between the magnetic volumes. The coupling to the adjacent bits is not as good as the coupling to the central bit since the transverse component of the transducer is larger at the adjacent bits. In addition, the relative strength of the optical field produced by the transducer is smaller at the adjacent bits. This results in smaller full width at half maximum spot sizes for the patterned medium.

In addition to better optical coupling, the patterned medium shown in Fig. 1 provides more favorable thermal conditions compared to a conventional recording medium. In the patterned medium shown in Fig. 1, the heat loss via lateral thermal conduction is greatly reduced because of the thermally insulating material between the magnetic particles. A decrease in lateral thermal conduction reduces the heat transfer to adjacent bits, and therefore, increases the temperature in the magnetic particle. The insulating material between the magnetic volumes also helps to prevent the thermal spread in the lateral direction; therefore, tighter thermal localization is achieved in Fig. 3. Cross-talk is also reduced in patterned medium due to the following factors: the perpendicular component is larger at the central magnetic bit, the insulating material between magnetic particles prevents the thermal spread, and the strength of the optical field by the transducer is stronger under the central magnetic bit. Reheating from the heat sink layer back into the magnetic layer is not an issue due to high thermal conductivity of the heat sink. The heat is quickly removed from the vicinity of the magnetic layer by thermal conduction into the heat sink layer both in perpendicular and lateral directions. The thermal profile along the thickness of the film is illustrated in Fig. 6. The heat sink layer is significantly cooler than the magnetic layer.

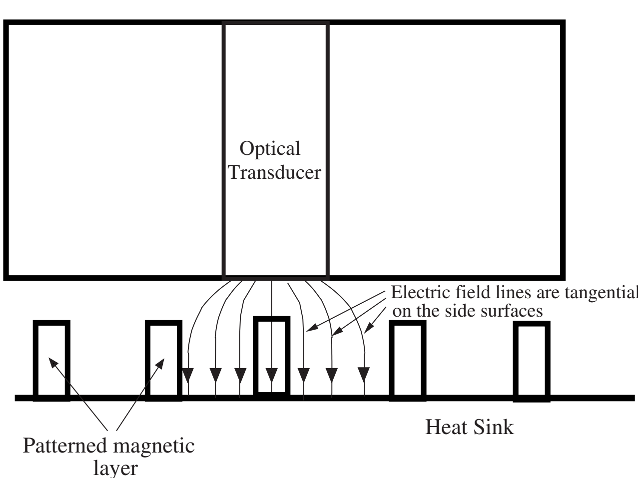


FIG. 5. The field lines are normal at the top surfaces and tangential on the side surfaces to the patterned media.

In summary, optical energy coupling at the interface between a transducer and a magnetic medium was explained via the boundary conditions of Maxwell's equations. Based on this description, a patterned magnetic medium was suggested to increase the optical energy transmission from the near-field transducer to the medium. Optically and thermally isolated particles are used to increase the light coupling and temperature response. A heat sink layer reduces the coupling inefficiency and removes the heat quickly from the medium.

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