Test Method for Thermally Assisted Magnetic Recording Applying Surface Plasmon Antennas Stacked on Magnetic Layer

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We propose a new test method for surface plasmon antennas applied to thermally assisted magnetic recording. Plasmon antennas were directly fabricated on a CoPtCr granular recording medium to maintain a distance between the antennas and the film. This method also makes it possible to prevent the antennas or media from becoming degraded. A silicon nitride dielectric layer was placed between the antennas and the magnetic layer to maintain a precise distance. We chose a thickness of 3 nm for the dielectric layer. Four hundred triangular Au antennas were formed on the medium with an E-beam lithographic technique. The written magnetic domains below the surface of the plasmon antennas were observed by magnetic force microscopy. Therefore, we were able to test the thermal effect of the plasmon antennas by directly placing them on the magnetic film.

Key words: thermally assisted magnetic recording, TAMR, local surface plasmon, Au antenna, CoPtCr granular medium

1. Introduction

One of the new emerging technologies to improve the memory density of magnetic recording is heat assisted magnetic recording\(^1\), known as HAMR, or thermally assisted magnetic recording (TAMR)\(^1\). This technique uses heat by laser light when magnetic domains are being written on a highly stable magnetic recording film. Magnetic domains can be easily written by the field from a magnetic recording head in the heated region of a magnetic film. The laser spot size is, however, on the order of the wavelength, when a conventional lens is used for focusing laser light. Therefore, we need to use a surface plasmon antenna to confine the light spot to less than the diffraction limit\(^5\). It is very important to control the distance between the plasmon antenna and the recording film, because evanescent light induced by a local surface plasmon antenna is extremely susceptible to distance\(^6\).

We propose a method of carefully evaluating the heat process where surface plasmon antennas are directly placed on the recording film. The thickness of the dielectric layer between the antenna and the film is precisely maintained. The scratching process can be avoided in our method. We observed magnetic domains written on a CoPtCr-SiO\(_2\) granular medium with the proposed process.

2. Structure of antennas on medium

Hundreds of antennas were placed on media with a dielectric layer to evaluate the effect of TAMR, as shown in Fig. 1. The thickness of the dielectric layer corresponds to the distance between the antennas and the magnetic layer. Before testing the new method, we checked that we could observe magnetic domains under the antennas by magnetic force microscopy (MFM). Antennas made of Au were fabricated on a magnetic hard disk that had been removed from a conventional magnetic hard disk drive commercially available on the market. The round area at the center of the MFM micrograph corresponds to the Au antenna shown in Fig. 1. The proposed structure of antennas placed directly on medium.

![Fig. 1 Proposed structure of antennas placed directly on medium.](image1)

![Fig. 2 (a) MFM and (b) morphology micrographs over magnetic hard disk with Au antenna on disk.](image2)
3. Recording medium

CoPtCr-SiO₂ granular media were chosen as the recording film to test the proposed method, because the film consists of well-isolated magnetic grains with appropriate coercive forces and has an appropriate Curie temperature. The layer structure of the CoPtCr medium is shown in Fig. 3. The Co₅₅Pt₃₀Cr₁₅-SiO₂, Co₆₀Pt₃₀Cr₁₀-SiO₂, and Co₆₀Pt₃₀Cr₁₀-SiO₂ magnetic recording films were fabricated with a method of lamination by sputtering. The composition of the magnetic film was controlled by the thickness of each layer. Ru(20 nm)/Pt(6 nm)/Ta(5 nm) under layers for the magnetic layer were fabricated on a glass substrate. The Si₃N₄ film was coated over the magnetic layer. We chose a thickness for the Si₃N₄ layer of 3 nm, which corresponded to the distance between the antenna and the magnetic layer.

The dependence of the saturation magnetic field $H_s$ on temperature is plotted in Fig. 4. The Co₆₀Pt₃₀Cr₁₅-SiO₂ film and the Co₆₀Pt₃₀Cr₁₀-SiO₂ film have higher $H_s$ than that of the other film. It is necessary for the temperature of the Co₆₀Pt₃₀Cr₁₀-SiO₂ film and the Co₆₀Pt₃₀Cr₁₀-SiO₂ film to be raised to more than 300°C to write domains with our recording system with its applied field limitation of 2.5 kOe. However, this high temperature might damage the film due to the thermal effect. Therefore, we chose the Co₅₅Pt₃₀Cr₁₅-SiO₂ film for the experiment.

The dependence of $H_s$, coercivity $H_c$, and nucleation field $H_n$ of the Co₅₅Pt₃₀Cr₁₅-SiO₂ film are plotted in Fig. 5. The film can be used to write domains by the thermal recording.

4. Fabrication of antennas

Four hundred triangular Au antennas were formed on the recording film using the lift-off method with an E-beam lithographic technique. A wide scanning electron microscope (SEM) view and some antenna shapes are shown in Fig. 6. The heights of the triangular shapes selected to be exposed to the E-beam ranged from 200 to 1,000 nm. Antennas shorter than 500 nm strongly enhanced the intensity of visible light at the edge of the antenna based on a simulation of the local surface plasmon effect. Four hundred antennas were fabricated in an area simultaneously, as shown in Fig. 6 (a). The minimum length of the antennas we...
Fabricated was 320 nm, which were exposed to a triangle at a height of 300 nm, and a minimum radius for the antenna apex of 28 nm, as shown in Fig. 6 (b).

5. Recording test

5.1 Thermal recording without antennas

The specimens were initialized by applying a 10-kOe magnetic field at room temperature (RT) before thermal recording. The thermal recording test without antennas was performed under a microscope by irradiation with laser light. The wavelength of the laser was 780 nm, and the spot diameter was ~1 μm. The thermal recording was performed under a variety of recording powers to check the threshold power to write a magnetic domain ranging from 1 to 30 mW; the laser pulse was fixed at 10 μs, under a magnetic field of 700 Oe, whose direction was opposite the direction of the initialization field. Some written magnetic domains observed as bright regions by MFM are shown in Fig. 7. We found that the threshold power to write was 10 mW.

5.2 Thermal recording with antennas

We tried to test thermal recording with the antennas below the threshold power that was mentioned in the previous section, because plasmon antennas locally enhance laser intensity due to the local surface plasmon effect.

A laser spot 1 μm in diameter with a recording field of 700 Oe was exposed over the film with a 0.5-μm pitch, much like a carpet-bombing raid. We expected that the region close to the antenna would be written by the heat effect caused by local surface plasmons, and that the region without antennas could not be written.

The MFM micrographs for laser recording powers of 7.5 and 9.4 mW are shown in Fig. 8. There are no written domains in the film for the laser recording power of 7.5 mW, as shown in Fig. 8 (a). No magnetic domains can be observed, even though the local surface plasmon effect increased power intensity at the edge of the antennas.

Some written areas close to the antennas or below them, on the other hand, can be observed in the MFM micrograph for the laser recording power of 9.4 mW, as shown in Fig. 8 (b). We could not find any magnetic domains in the areas without antennas. This means that the areas close to the antennas or below them could be written by the thermal effect, even though the laser power for writing was lower than the threshold power, which was tested without the antennas.

There are two possible reasons for these results: the first is that the local surface plasmon effect increased optical intensity and heated up the area of the magnetic film close to the antennas. The second reason is that the antennas absorbed more light energy...
than the areas without them.

We also took another MFM micrograph shown in Fig. 9. A domain can be seen at the left edge of the antenna. The optical intensity due to the effect of local surface plasmons must be higher at the left of the antenna than at the right according to the simulation, because the antenna at the left is sharp. Even though the peak optical intensity calculated by Finite-Difference Time-Domain (FDTD) simulation at the edge of the antenna is two times higher than that without the antenna\(^\text{9}\), the threshold laser power difference in the experiment between the film with and without an antenna is really small. The small difference in threshold was caused by the thermal diffusion effect. Therefore, we can try to write domains with the proposed configuration where the antennas are placed on the film, but we should check the surface plasmon effect by exposure with shorter laser pulses to avoid dispersing sharp energy peaks.

6. Conclusions

We proposed a new method of testing local surface plasmon antennas for thermally assisted magnetic recording. Plasmon antennas were directly fabricated on a CoPtCr granular recording medium to maintain a distance between them and the film. The domains close to the antennas were observed after laser writing under a threshold power that was tested without antennas. We were able to maintain a precise distance between the antennas and the recording film in the experiment with this method, which also made it possible to avoid degrading the antenna or the medium. We found that we could test plasmons and the thermal effects of the plasmon antenna by directly placing the antenna on the recording medium; however, we should test the effect by exposure with shorter laser pulses to avoid dispersing the sharp energy peaks by the antennas in the future study.

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