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Analysis of scanning near-field optical microscope point heating for ultrahigh density recording

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Heating processes in scanning near-field optical microscope (SNOM) phase-change recording were studied using the thermal diffusion equation. Two major heating mechanisms are used for recording; evanescent wave heating and thermal conduction heating. The calculated results indicate that thermal conduction heating is the dominant process, though evanescent wave heating is suitable for ultra-high density recording. Using a high conductivity material as a coating metal of a SNOM probe such as silver, it can be considered that a fine probe is obtained because the effect of thermal conduction heating is decreased.

1.INTRODUCTION

Nano-structure formation using a scanning near-field optical microscope (SNOM) has potential for ultra-high density data storage. An evanescent wave emanating from an aperture of a SNOM probe is used to form nano-structures in a sample. Betzig et al. reported the formation of 60 nm magnetic domains in Pt/Co multilayered magneto-optical film using SNOM(1), demonstrating the possibility of ultra-high density data storage. Hosaka et al. also tried to form nano-structures using SNOM in a GeSbTe phase-change recording media.(2) They formed 60 nm phase-change domains in the sample. Both these experiments were done by heating samples locally using energy from a SNOM probe. Comparing these techniques, phase-change recording is considered to be more suitable for ultra-high density data storage than magneto-optical recording because no polarizers are needed to detect phase-change domains and much power of the reflected (or transmitted) light of SNOM can be utilized in detection compared with magneto-optical recording.

In this paper, we focused on Hosaka's experiments and analyzed SNOM heating mechanisms of a phase-change recording media using the thermal diffusion equation. We also discuss the condition of a SNOM probe suitable for forming fine structures.

2.CALCULATION

in SNOM sample heating, Four processes are considered in SNOM sample heating: 1) evanescent wave heating, 2) far-field light heating, 3) thermal conduction from the probe, and 4) radiation from the probe. Among them, the contribution of far-field light heating and radiation from the probe is negligible. This is because far-field light power is very small when the size of the aperture at the probe is less than a tenth of the wavelength of the incident light, and the radiation power calculated using the Stefan-Boltzmann radiation equation is also small. Thus we calculated the temperature increase of the sample due to the other two heating processes; evanescent wave heating and thermal conduction heating.

To evaluate the temperature increase, we used the following thermal diffusion equation;

$$C \times \rho \times \partial T(x,y,z,t)/\partial t = \mathrm{div}(\kappa \times \mathrm{grad}T(x,y,z,t))+Q, \quad (1)$$

where C is the specific heat, ρ is the density, T is the temperature, κ is the thermal conductivity, and Q is the writing power. In the experiment of Hosaka et al., used 0.5 - 5.0 ms as the pulsed width of the laser light. Following this experiment, we assumed that the pulsed width of the incident light was large enough to saturate the thermal diffusion. Then the time differential term of T in eq. (1) can be neglected, resulting in

$$\mathrm{div}(\kappa \times \mathrm{grad}T(x,y,z))+Q=0. \qquad (2)$$

By varying the laser power Q and the positions of the heat source, the temperature increases of the phase-change media were calculated by the finite element method with the Differential Equation Solver Language (DEQSOL) program.(3)

Figure 1 shows a schematic diagram of the model used in the calculation. For simplicity, the SNOM probe was assumed to be a 200×200×900 nm^3 quartz rod coated with a 100-nm-thick Al layer. The bottom of the quartz rod is also coated with Al. The quartz rod and the Al layer represent the sharpened optical fiber and the Al coat of the SNOM probe, respectively. The sample is a phase-change recording media consisting of three films (ZnS · SiO2 film, GeSbTe film, and ZnS · SiO2 film) and a polycarbonate substrate. The thickness of these films are 20 nm, 30 nm, and 150 nm, respectively. The phase of the GeSbTe film changes from amorphous to crystalline when heated to above 200℃. This sample structure is the same as that used in Hosaka's experiment. The thermal conductivities of the materials are given in Table 1.

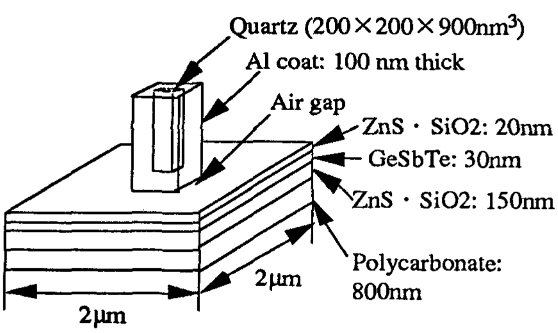

Figure 1. Schematic diagram of simplified model of the tip and the sample.

Table 1 Thermal conductivity of each layer.

Layer	Thermal Conductivity (W/mK)
Quartz	1.9
Al	240
Air Gap	0.024
ZnS · SiO_2	0.66
GeSbTe	0.58
Substrate	0.22

As discussed above, we consider two kinds of heating, evanescent wave heating and thermal conduction heating. The power Q in eq. (2) for each type of heating is applied in the following way. The evanescent wave power is absorbed only in the GeSbTe film. This is because the air gap and the ZnS · SiO2 films are transparent, thus no other absorption can occur. With a 780 nm incident laser light, the absorption rate of the GeSbTe film was calculated to be 0.35 by Maxwell's equations based on the electromagnetic boundary conditions of the film.(4) Here we assumed that the lateral power distribution of the evanescent wave is Gaussian and its deviation is half of the tip aperture, i.e., 30 nm. This is because, in our calculation, the distance between the tip and the GeSbTe film varies from 30 nm to 50 nm (the thickness of the air gap layer plus the ZnS · SiO2 layer). At this distance, the power distribution of the evanescent wave is approximately the Gaussian, as derived from the report by Leviatan.(5) The attenuation of the evanescent wave power as a function of the distance from the aperture was also derived from Ref. 5. On the other hand, the power of the thermal conduction heating is applied in the aperture area of the Al film. All the incident light power is assumed to be localized in the 60 nm×60 nm×100 nm area at the bottom of the Al film. By applying such powers, the temperature increases of the GeSbTe film were calculated.

3. RESULT

3.1. Temperature increase of GeSbTe film

Figure 2 shows the calculated result of the temperature increase at the center of the GeSbTe film with an air gap of 10 nm. The propagation efficiency of the evanescent light through the aperture of the SNOM probe was set at 0.005. This value was

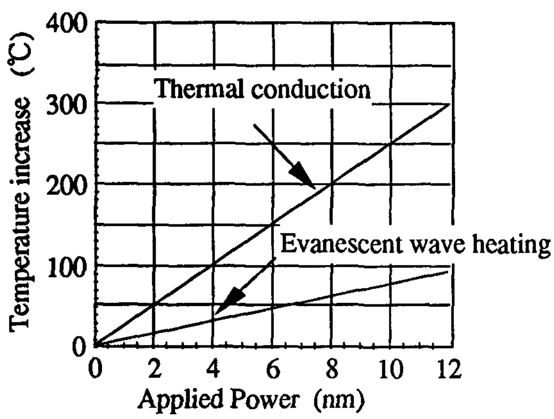

Fig. 2 Temperature increase of the center of the GeSbTe film.

estimated from the output current detection of the photomultiplier.(2) Comparing the two heating, thermal conduction heating was found to be dominant.

Figure 3 shows the dependence of the temperature increase on the gap between the probe and the sample surface. The temperature was calculated at the center of the GeSbTe film. The temperature increase due to thermal conduction heating has a strong dependence on the gap around 10 - 30 nm, while that due to evanescent wave heating is less influenced by the gap. This indicates that, in thermal conduction heating, a gap fluctuation causes a change in the temperature of the sample, and thus this mechanism is less stable than evanescent wave heating.

Figure 4 shows the lateral profile of the temperature increase of the center plane of the GeSbTe film due to thermal conduction heating and evanescent wave heating. The conditions of calculation were that the gap between the tip and the sample is 10 nm, and the applied power is 8 mW. Comparing the two profiles, the effect of evanescent wave heating produces a much sharper profile than that of thermal conduction heating. This indicates that evanescent wave heating is a better process for heating the sample locally.

3.2. Suppression of thermal conduction heating

Evanescent wave heating was found to be suitable for an ultra-high density recording using SNOM. To suppress the effect of thermal conduction heating, we studied the dependence of the temperature increase on the thermal conductivities of the coating materials. Figure 5 shows the lateral profile of the temperature increase of the center plane of the GeSbTe film due to thermal conduction heating with different coating materials. For materials with high thermal conductivities, the temperature increase of the sample due to thermal conduction heating is decreased. When Ag is used as the coating material,

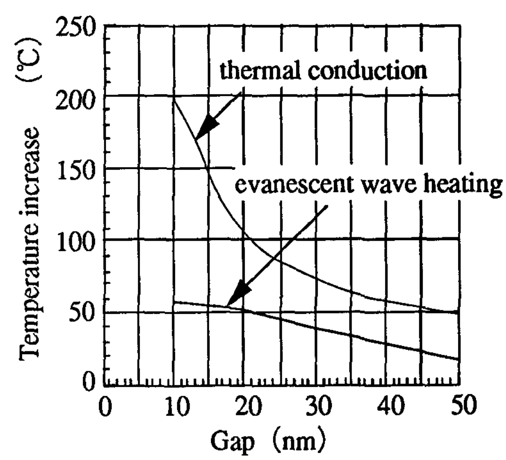

Fig. 3 Dependence of the temperature increases on the gap between the tip and the surface of the sample.

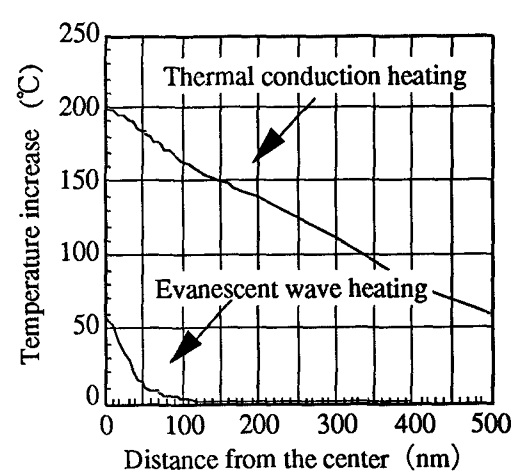

Fig. 4 Lateral profile of the temperature increase of the center layer of the GeSbTe film. The gap is 10 nm and the applied power is 8 mW.

the temperature increase at the center of the GeSbTe film is reduced to 134 ℃. This can be explained by much thermal energy being transferred through the coating material and the amount of energy for the sample is reduced.

The lateral profile of the temperature increase due to both mechanisms with different coating materials is shown in Fig. 6. Each line is arranged to start from the point (0,174) by changing

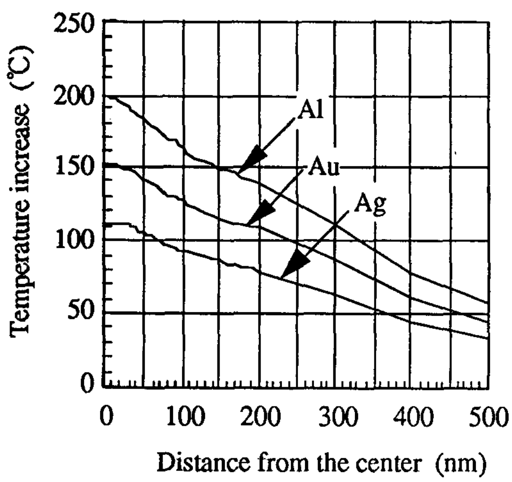

Fig.5 Lateral profile of the temperature increase of the center layer of the GeSbTe film with different coating material was changed. Thermal conductivities of Al, Au, and Ag are 240, 310, and 422 WmK, respectively.

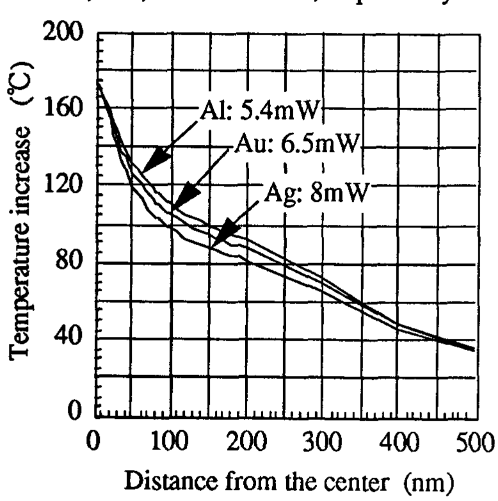

Fig. 6 Lateral profile of the temperature increase due to the sum of two heating with different coating materials. Each line is arranged to start from (0,174) point by changing the applied power.

the applied power. It was found that using Ag as the coating material, a much sharper temperature profile, i.e. a fine SNOM probe, can be obtained.

4. CONCLUSION

Calculation were performed using the thermal diffusion equation, mechanisms for local sample heating using SNOM were studied. Comparing these two SNOM heating mechanisms (evanescent wave heating and thermal conduction heating), it was found that thermal conduction heating is a dominant process though evanescent wave heating is suitable for ultra-high density recording. Moreover, the influence of thermal conduction heating can be suppressed by using Ag as the coating material of the probe and we proposed a fine probe of SNOM for ultra-high density recording.

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REFERENCES

(1)E. Betzig, J. K. Trautman, R. Wolfe, E. M. Gyorgy, P. L. Finn, M. H. Kryder, and C. H. Chang: Appl. Phys. Lett. 61 (1992)142.

(2)S. Hosaka, S. Hosoki, T. Hasegawa, H. Koyanagi, T. Shintani, and M. Miyamoto: J. Vac. Sci. & Technol. B13(6) (1995) 2813, Jpn. J. Phys. Vol. 35 (1996) 443, S. Hosaka, T. Shintani, M. Miyamoto, A. Hirotsune, M. Terao, M. Yoshida, K. Fujita, and S.Kammer: Jpn. J. Appl. Phys. Vol.35 (1996) 443.

(3)C. Konno, M. Saji, N. Sagawa, and Y. Umetani: Proc. the Fall Joint Computer Conference, November 2-8 (1986).

(4)M. Born and E. Wolf: Principle of Optics (Pergamon Press, 1980) 6th ed., Chaps. 1 & 5.

(5)Y. Leviatan: J. Appl. Phys. 60(1986) 1577.