AFM Study for Electric Characteristics of Phase-Change Superlattice Film

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ABSTRACT

The phase-change property for the $GeTe/Sb_2Te_3$ phase-change superlattice film was measured by using conductive AFM. The superlattice film was successfully set and reset after applying constant voltage pulse with the metal-coated AFM tip. The superlattice film, however, was reset by a slow cooling pulse, which is not the case for $Ge_2Sb_2Te_5$. It implies that the mechanism of phase change in a superlattice film is different from that in $Ge_2Sb_2Te_5$. We also measured the volume changes after applying a set programming pulse by obtaining topographic images. The volume changes after reset of $Ge_2Sb_2Te_5$ and the superlattice film were 20% and <5%, respectively. It implies that a phase-change superlattice device is damaged less by stress in recording because of less volume change in phase change.

Key words: phase-change, superlattice, conductive AFM, write properties, volume change

1. INTRODUCTION

Phase-change materials have already been installed as recording films in rewritable optical disks and semiconductor memory devices. Recently it was found that the atomic switching phenomenon of Ge atoms by changing coordination number of Te around a Ge atom in the phase-change film of $GeTe/Sb_2Te_3$ pseudo-binary system[1], and have been promoting research of phase-change superlattice material for developing low-power-recording memory devices[2][3].

The microscopic phenomena of the phase-change superlattice film in phase change are not well-known. We have constructed the conductive AFM system to investigate the detailed properties of phase-change superlattice materials. Usage of conductive AFM brings us the advantage that it enables us to obtain some macroscopic and microscopic parameters simultaneously and nondestructively[4].

In this work, we used conductive AFM for measuring the electric properties and the volume change of the $GeTe/Sb_2Te_3$ phase-change superlattice film. We also measured those parameters of $Ge_2Sb_2Te_5$ for reference. The properties of the phase-change superlattice film will be discussed by comparing the experimental results of these materials.

2. EXPERIMENTS

Fig. 1 shows the experimental setup for measuring electric properties of phase-change films by using AFM. A Rh coated AFM tip was equipped and contacted on a phase-change film. The tip radius of Rh coated AFM tips used for this work was 100 nm. Electric pulses from the pulse generator were applied to sample surface by the AFM tip. Electric currents in a phase-change film were measured through I-V converter.

The scan area of the AFM tip on phase-change films during applying voltage pulse was 1 nm square. The contact force of the tip to a sample was fixed to 300 nN. The recording voltage pulse width was varied from 200 to 400 nsec. The rise time and fall time of this system were both 100 nsec. The read-pulse of 0.5 V and 500 nsec was applied to a sample after 1 μsec of the recording pulse. The maximum voltage of the pulse was 8 V in this system.

The structure of the phase-change superlattice film sample used for these experiments is as follows; 10 cycles of [GeTe_1 nm / Sb_2Te_3_2 nm] films are deposited on Sb_2Te_3_10 nm / TiN film (electrode) by sputtering process. A $Ge_2Sb_2Te_5$ film was also used for reference.

3. RESULTS & DISCUSSION

Set and reset properties are measured for both $Ge_2Sb_2Te_5$ and superlattice films. The $Ge_2Sb_2Te_5$ film was set at 5 V (not shown), but could not be reset by applying from 200 nsec to 400 nsec pulse. We can consider two assumptions for this reason. The first one is the recrystallization after melting because of long fall time of reset pulse, that is to say, the slow cooling condition. The second one is that the power was insufficient to heat the film above the melting point. In the phase-change device,

On the other hand, the superlattice film was successfully set and reset both at 200 nsec and 400 nsec pulses. Fig. 2 shows set (Fig. 2 (a)) and reset (Fig. 2 (b)) voltage signals for phase–change superlattice film measured by applying 200 nsec pulse. Almost the same result was obtained also in case of 400 nsec pulse (not shown). It implies that different mechanisms work in recording between $Ge_2Sb_2Te_5$ and phase-change superlattice material.

Volume changes of the films in recording were also measured for $Ge_2Sb_2Te_5$ and GeTe/Sb_2Te_3 superlattice film by AFM. Fig. 3 and Fig. 4 show topographic images of $Ge_2Sb_2Te_5$ (Fig. 3 (a), (b)) and the GeTe / Sb_2Te_3 superlattice film (Fig. 4 (a) and (b)) before and after applying set pulse. The positions of the tip when applying set pulse are indicated by the arrow-marks in each figure. No convex is seen on the $Ge_2Sb_2Te_5$ film surface in Fig.3 (a) whereas a convex appears in Fig.3 (b). The depth of the convex is 10 nm (volume change of 20%) for $Ge_2Sb_2Te_5$. As shown in Fig.4 (b), however, no convex is seen even after the resistance change for the superlattice film. We can put two assumptions for this result. One is that phase change in the superlattice film induces no volume change. Another is that the volume change in below the measurement limit. We can see the surface roughness of about 2 nm in Figs. 4 (a) and (b). Although the reason for this roughness is not clear, there is a possibility that the AFM tip roughened the surface because these AFM topographies were obtained in the contact mode. In this case, we can insist that the volume change in phase change of the superlattice film is, at least, < 2 nm (volume change of 5%). Anyway, these experimental results show that the volume change in phase change of the superlattice film is much smaller than that of $Ge_2Sb_2Te_5$.

This small volume change is a great advantage of the superlattice film. It was pointed out that the film thickness of a phase-change material is reduced in phase change [5] and that the change of the stress around the phase-change memory recording film can cause significant reliability issues such as endurance [6]. From these discussions, we can expect that adopting of the phase-change superlattice materials will improve the endurance of phase-change devices.

4. CONCLUSION

Electric characteristics of the GeTe/Sb_2Te_3 phase-change superlattice film were measured by using conductive AFM. Volume changes of the $Ge_2Sb_2Te_5$ and the superlattice film accompanied by the resistance change were also measured by obtaining topographic images before and after the resistance change. $Ge_2Sb_2Te_5$ was not reset probably because of the slow cooling condition due to the limited rise and fall time of the pulse. On the other hand, the superlattice film was successfully set and reset even in the slow cooling condition. It implies that the mechanism of the resistance change in the superlattice is different from that in $Ge_2Sb_2Te_5$. Volume changes of the $Ge_2Sb_2Te_5$ and GeTe/Sb_2Te_3 superlattice films measured by obtaining topographic images and 20%, less than 5%, respectively. These results imply that the stress of phase change memory of GeTe/Sb_2Te_3 superlattice film is small in recording.

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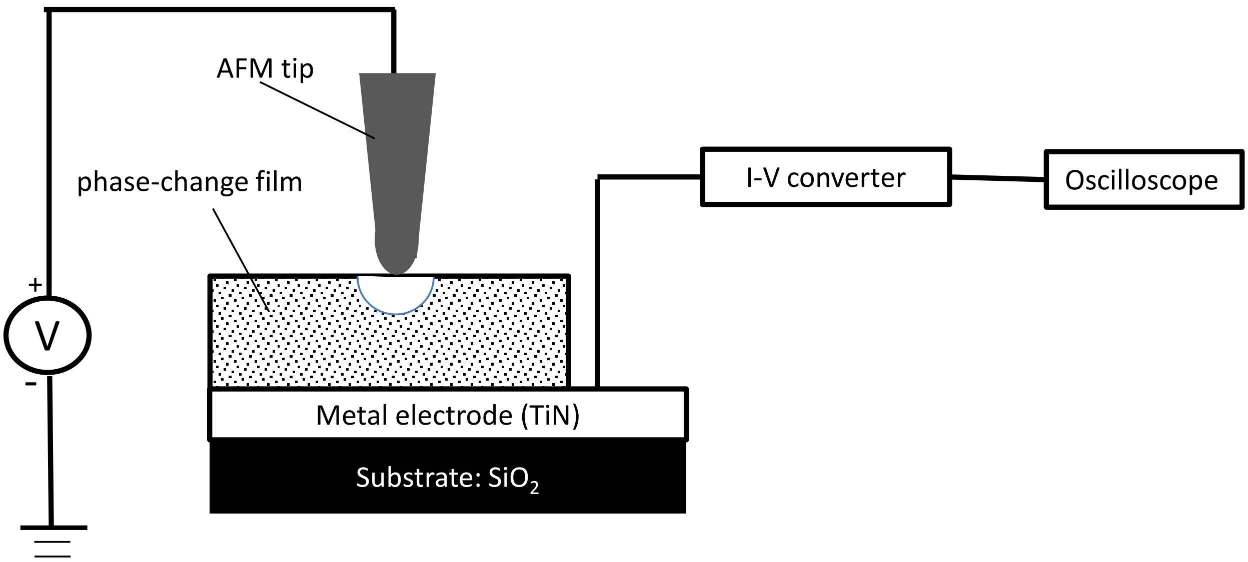


Fig.1 Diagram of the experimental setup to measure current of phase-change films in recording by Conductive AFM.

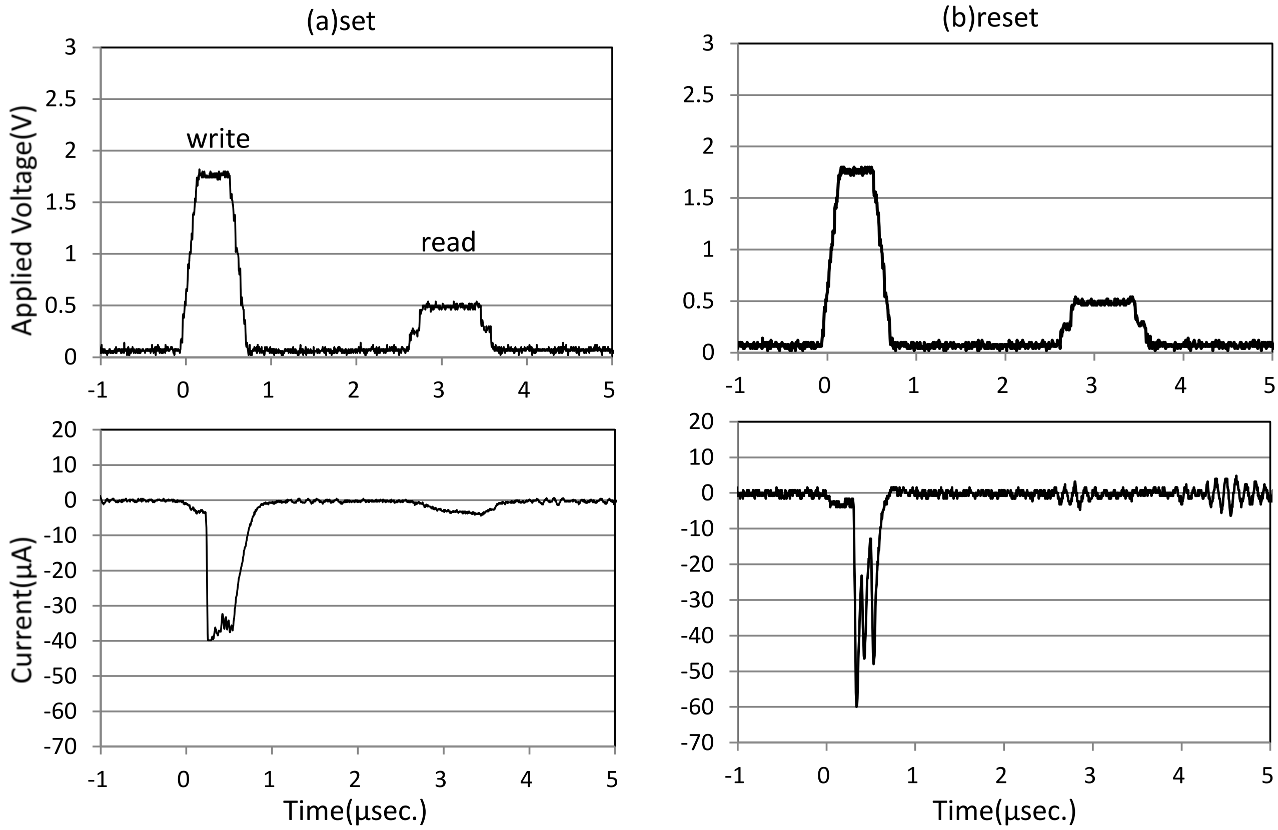
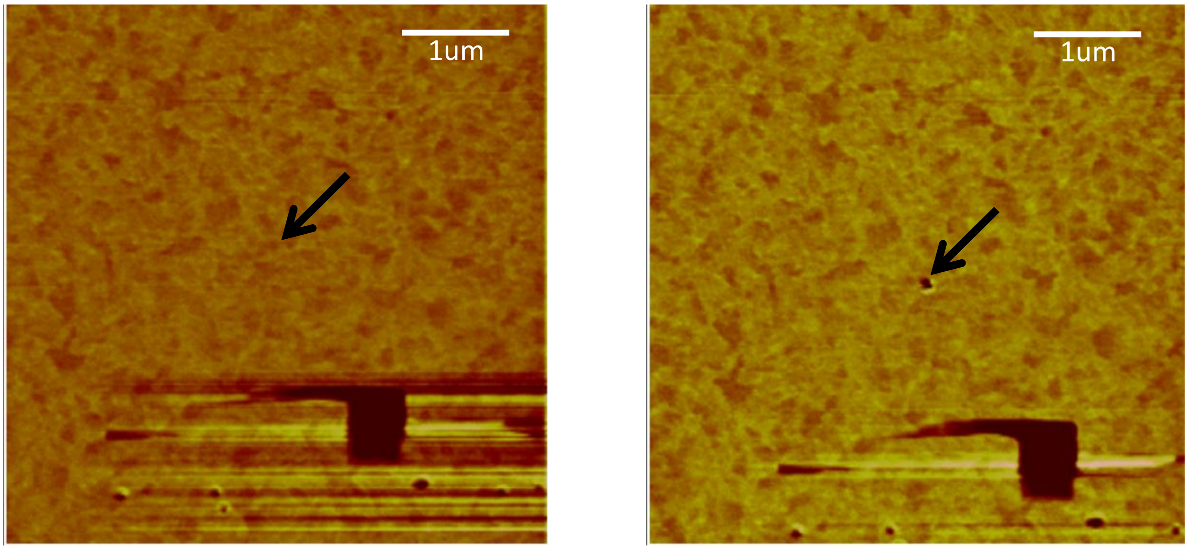
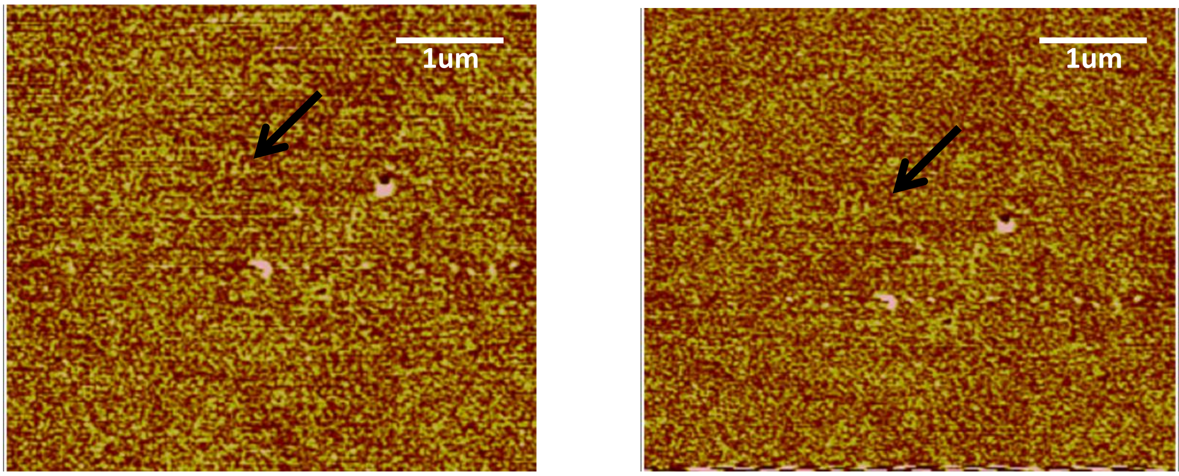


Fig. 2 Time dependent signals of set (Fig. 2 (a)) and reset (Fig. 2 (b)) applied voltage and measured current for phase–change superlattice film.



(a)Before set (b)After set

Fig.3 Topographic images of $Ge_2Sb_2Te_5$ film measured by contact AFM before and after applying set pulse.



(a)Before set (b)After set

Fig.4 Topographic images of $GeTe/Sb_2Te_3$ superlattice film before and after applying set pulse.