Characteristics of Ge$_2$Sb$_2$Te$_5$ Thin Films Deposited by DC Magnetron Sputtering

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Abstract: Ge$_2$Sb$_2$Te$_5$ (GST) thin films for various data storage systems were prepared by dc magnetron sputtering. The deposition rate, crystalline structure and the optical property of GST films were studied as a function of dc power and annealing temperature. The deposition rate of GST films was linearly increased with increasing dc power. It was confirmed from x-ray diffraction (XRD) and field emission scanning electron microscopy (FESEM) that the phase change took place at the temperature ranges of 150 – 200 and 300 – 350°C. The relative change in the reflectance (ΔR) of GST films was also observed for the temperatures before and after phase change. In particular, GST thin films deposited at higher power of 90 W exhibited high change of reflectance than those deposited at 30 and 60 W.

Keywords: Ge$_2$Sb$_2$Te$_5$, DC magnetron sputtering, data storage, phase change

Introduction

The optical data storage, which can be employed to the information storage and multimedia application, has recently drawn a great deal of attention. In these applications, high-speed and high-density rewritable data storage can be achieved by means of phase change optical recording. The phase change recording particularly is a promising technique for future optical data storage since it is conventionally compatible with present CD-R and CD-RW formats [1-3].

The principle of phase change recording is based on the reversible switching between the amorphous and the crystalline phases. The small areas (bits) of the active layer between the stable crystalline and metastable amorphous phases are reversibly transformed. Applying a short pulse of a laser beam to a crystalline area increases the local temperature above the melting point. When the pulse ends, the molten spot rapidly cools and amorphizes. The amorphous and crystalline phases have different optical properties. Therefore, the data can be read by monitoring the local changes in the reflection or transmission of the media. On the other hand, the erasure is achieved by laser heating to intermediates, which enables the fast recrystallization of amorphous bits. This reversible transformation allows rewritable data storage [4,5].

Ge-Sb-Te alloys are well suited for the application to the data storage since they exhibit the pronounced difference in the optical properties. Among the stoichiometric compositions of this ternary system, GeSb$_2$Te$_5$ (GST) films have been known to be one of the most suitable materials for these applications [6,7]. Microstructure and optical properties of GST thin films are closely related, which can be controlled by changing the preparation conditions of the films. The optical properties after the crystallization of films are also affected by the microstructure of amorphous films. A few studies regarding the temperature of phase change of GST films were reported but they did not present the clear correlation of phase transition with the properties such as crystalline structure, grain structure of films, and the reflectance [3,5,8]. There are various techniques to deposit GST thin films, which contain sputtering, evaporation and ion plating [9].

In this study, GST thin films have been deposited as a function of dc power by dc magnetron sputtering technique. The physical properties such as the crystalline state and microstructure were correlated with the optical properties in order to investigate the optimum dc power of the sputtering technique.

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Experimental

GST thin films were deposited at room temperature on SiO(4000 Å)/Si by dc magnetron sputtering. The dc magnetron sputtering system was equipped with a 1500 L/s turbomolecular pump for the evacuation and three targets could be installed at the same time. The schematic of the sputter system is illustrated in Figure 1. The base pressure of the system was typically $1 \sim 2 \times 10^{-7}$ Torr and the sputtering was performed using a Ar gas at 6 mTorr. The distance between the substrate and target was fixed at 5 cm. The target with a diameter of 5 cm was composed of a stoichiometric composition of Ge : Sb : Te = 2 : 2 : 5. The target was bonded to a copper plate because of its brittleness and was rotated for uniform thickness of the deposited films.

In this study, the deposition of GST thin films was carried out by varying dc power as the major process parameter. The deposition rates of GST films were measured using the Dektak surface profilometer. The deposited films were then heat-treated at the temperature from 150 to 400°C in a furnace in order to study the various properties of the films by the annealing process. The crystalline structure and phase change of GST thin films were examined by x-ray diffraction (XRD) with Cu-Kα radiation. The glancing angle mode in XRD was employed for precise analysis of the film surface. Field emission scanning electron microscopy (FESEM) was utilized for the observation of the microstructure and phase change of the annealed films. The optical property such as the reflectance (R) of the films was obtained using a spectroscopic ellipsometer.

Results and Discussion

The dc power among a few process parameters was chosen as the main parameter in this study and was varied from 30, 60 to 90 W. The distance from the target to the substrate was 5 cm and the working pressure of the chamber was maintained at 6 mTorr. Figure 2 shows the deposition rates of GST thin films as a function of dc power. The deposition rates were changed from 480 to 1250 Å/min and linearly increased with increasing dc power. The deposited thin films were observed using FESEM for microstructure and phase change. They were confirmed to have the amorphous phases deposited at room temperature. Since as-deposited GST films are amorphous, they must be crystallized before use in a data storage device. The deposited GST films were heat-treated at the temperature interval of 50°C from 150 to 400°C in a furnace. The XRD patterns of GST thin films annealed at these temperatures are shown in Figure 3. As the annealing temperature increases, the XRD patterns exhibit clear changes. It is observable from Figure 3 that there are two phase-change regions which are at the temperatures of 150~200°C and 300~350°C. These results are in accord with the previous report that the phase changes of GST films took place around 150 and 310°C [5]. The films with amorphous phase at 150°C were phase-changed to FCC crystal structure of rock salt type by annealing at 200°C. The annealing from 300 to 350°C clearly presented the second phase-change from FCC structure to hexagonal structure, exhibiting new peaks of (103), (106), (210), (206) and (219) instead of (200), (220) and (400) peaks. This phenomenon of
various temperatures are shown in Figure 4. It is evident that the films annealed at the temperatures of 200 and 350°C were phase-changed.

When the phase change of GST thin films takes place, the reflectances of the films are varied and this optical property can be applied to the optical data storage such as DVD-R and DVD-RW. The relative change in reflectance ($\Delta R$) was attained as

$$\Delta R = \frac{R_c - R_a}{R_c}$$  \hspace{1cm} (1)

where $R_c$ and $R_a$ are the reflectances of the crystalline and amorphous phases, respectively [4]. Figure 5 shows the variation of the reflectance of GST thin films annealed at various temperatures. This reflectance variation by phase change could be confirmed at the temperatures from 150 to 200°C and from 300 to 350°C. As shown in Figure 5, the reflectances of the films annealed at 200°C were increased more than those annealed at 150°C for three dc powers. In general, the DVD-RW must have the function of writing, erasing and reading data. As confirmed above, GST films have two

**Figure 3.** XRD patterns of Ge$_2$Sb$_2$Te$_5$ thin films as a function of annealing temperature, dc power: 90 W, chamber pressure: 6 mTorr.

**Figure 4.** FESEM micrographs of Ge$_2$Sb$_2$Te$_5$ thin films as a function of annealing temperature, dc power: 90 W, chamber pressure: 6 mTorr. (a) 150°C, (b) 200°C, (c) 300°C, and (d) 350°C.
different temperatures of the phase change. This characteristic of GST films acts as the disadvantage to the application since these two different crystal structures behave as the different manner to the heating by laser pulses of operation. The FCC structure formed by phase change at the temperature between 150 and 200°C can be easily transformed from the crystalline phase to amorphous phase while the hexagonal structure formed at the temperature between 300 and 350°C is not easy to be transformed to the amorphous phase. This phase change is used for the erasing of data. Therefore, the operation temperature is required to be low for the easy erasing of data [4]. In this study, the deposition of GST thin films by the sputtering was carried out to examine the effect of dc power on the properties of GST films. Among the various dc powers used in this study, GST thin films deposited at 90 W exhibited higher increase of reflectance after the phase change than any other dc power, as shown in Figures 5(a) and 5(b).

**Figure 5.** Reflectance (R) of Ge$_2$Sb$_2$Te$_5$ thin films as a function of annealing temperature, chamber pressure: 6 mTorr.

Ge$_2$Sb$_2$Te$_5$ thin films for the application to the optical data storages such as the information storage and multimedia devices. Among various process parameters, dc power was chosen as the main parameter and varied in the range of 30 ~ 90 W. The deposition rate, crystalline structure and optical property of GST films were examined as a function of dc power and annealing temperature for the characterization of the deposited GST films.

The clear phase change of GST films deposited in this study was observed at the temperatures of 150 ~ 200 and 300 ~ 350°C using XRD, FESEM and the measurement of reflectance. GST films deposited at 90 W showed higher relative change in the reflectance ($\Delta R$) than those deposited at 30 and 60 W. In order to apply to the data storage devices, the relative change in the reflectance ($\Delta R$) should be high. Therefore, high dc power in depositing GST thin films is desirable for easy writing, reading and erasing of data.

**Conclusion**

DC magnetron sputtering was performed to deposit

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References