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Rapid Communication

Structural change of laser-irradiated $Ge_2Sb_2Te_5$ films studied by electrical property measurement

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ABSTRACT

Sheet resistance of laser-irradiated $Ge_2Sb_2Te_5$ thin films prepared by magnetron sputtering was measured by the four-point probe method. With increasing laser power the sheet resistance undergoes an abrupt drop from 10^7 to 10^3 Ω/□ at about 580 mW. The abrupt drop in resistance is due to the structural change from amorphous to crystalline state as revealed by X-ray diffraction (XRD) study of the samples around the abrupt change point. Crystallized dots were also formed in the amorphous $Ge_2Sb_2Te_5$ films by focused short pulse laser-irradiated, the resistivities at the crystallized dots and the non-crystallized area are 3.375×10^{-3} and 2.725 Ω m, sheet resistance is 3.37×10^4 and 2.725×10^7 Ω/□ respectively, deduced from the *I–V* curves that is obtained by conductive atomic force microscope (C-AFM).

1. Introduction

Phase-change materials based on chalcogenide alloys are found to be suitable for optical and electrical memories due to its fast reversible crystallization. The operation principle of these devices is based on the ability of the active materials to undergo very fast reversible transformation between amorphous and crystalline phases which go with big changes of optical and electrical property [1]. Among these alloys, $Ge_2Sb_2Te_5$ exhibits the best performance indicated by extensive experimental studies using different methods, such as atomic force microscopy (AFM) [2], transmission electron microscopy (TEM) [3], differential scanning calorimetry (DSC), X-ray diffraction (XRD) [4–6], Raman spectroscopy [7] and coherent phonon spectroscopy [8]. But most of these studies used the thermal-induction method to crystallize the $Ge_2Sb_2Te_5$ phase-change material, the structural and electrical changes of laser-irradiated $Ge_2Sb_2Te_5$ films is lack. The heating rate of a pulse laser can reach 10^{10} °C/min [9], therefore laser-irradiation of the amorphous $Ge_2Sb_2Te_5$ thin films could embody truly the process of structural change in the films than thermal-induced crystallization. In this work, we examined the crystallization behavior and electrical property of $Ge_2Sb_2Te_5$ phase-change films using laser beam of Hitachi Computer Peripherals POP120-5F initializer at various laser powers, van der Pauw Measurement system, XRD, respectively. The resistance and *I–V* curves of the focused-short-pulse-laser-crystallized dots and non-crystallized area also were studied to confirm the structure of $Ge_2Sb_2Te_5$ phase-change films for the first time. Mytilineou and Ovshinsky [10] tried to realize electrical–optical hybrid cognitive behavior, but they could not achieve the course of focused pulse laser induced phase-change to form a conductive path. This paper dedicated to study structural change of laser-irradiated $Ge_2Sb_2Te_5$ films by electrical property measurement.

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2. Experimental

Stack films PC/ $Ge_2Sb_2Te_5$ (100 nm)/SiO_2 (25 nm) were deposited on 1.2 mm thick polycarbonate (PC) disk substrates by magnetron sputtering at an Ar pressure of 0.6 Pa. The background pressure is below 6.0×10^{-4} Pa, and the sputtering power is 150 W. Laser-irradiation of $Ge_2Sb_2Te_5$ films was performed in a POP120-5F initializer (Fig. 1) made by Hitachi Computer Peripherals Co. Ltd. The laser power was changed from 300 mW to 850 mW, with the increase step of 10 mW and a fixed initialization velocity at 4.0 m/s (CLV mode). The laser wavelength is 810 nm, the beam size of laser is 1 μm × 192 μm, and the laser spot feed per rotation (radius) is 96 μm. To prepare the test samples, the stack films was first cut into small pieces, and then a 3 M scotch tape was applied to peel off the upper SiO_2 dielectric layers. The film resistance was measured with a four-point probe following the procedure proposed by van der Pauw [11]. For XRD experiments, Cu Kα (λ = 0.15418 nm) radiation was used. The XRD pattern was taken at room temperature using a Rigaku D/MAX 2550 V diffractometer. Stack films were also deposited on Si wafer substrates as Si/Ag (200 nm)/$Ge_2Sb_2Te_5$ (100 nm) by sputtering. The Ag layer for conduction was deposited at an Ar pressure of 0.6 Pa. Focused short pulse laser was used to irradiate the stack films, its wavelength is 650 nm, pulse width is 500 nS, power density is 7 J/μm^2, numerical aperture of the objective lens is 0.65, and electrical property of the laser-crystallized dots and non-crystallized area were measured by CAFM, and current map was also obtained by CAFM scan.

3. Results and discussion

3.1. Electrical resistance and structural change of $Ge_2Sb_2Te_5$ films during laser-irradiation

Fig. 2 shows the sheet resistances change after the laser-irradiated $Ge_2Sb_2Te_5$ film. Sheet resistance of the film first decreases with increasing laser power until a sudden drop occurs at 580 mW. Around 580 mW the resistance exhibits a pronounced change from 10^7 to 10^3 Ω/□. With the further increasing in laser power the resistance stabilizes at about 1023 Ω/□.

Samples 1, 2 and 3 around the abrupt change point were selected for XRD measurement. These samples were irradiated at the laser power of 510 mW, 580 mW and 720 mW, respectively. The XRD results are shown in Fig. 3. The non-crystalline peaks belong to the polycarbonate substrate, sample 1 has no crystalline peak, sample 2 has a few weak *fcc* crystalline peaks, while sample 3 possesses crystalline peaks *fcc(111)*, *fcc(200)*, *fcc*(220), *fcc*(222), showing that sample 3 has changed into face-centered cubic (*fcc*) phase. The very weak crystalline peaks in sample 2 are due to quenching of the relaxation state.

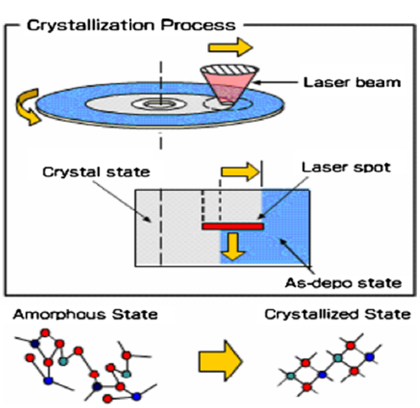

Fig. 1. Working principle of the initializer (POP120-5F).

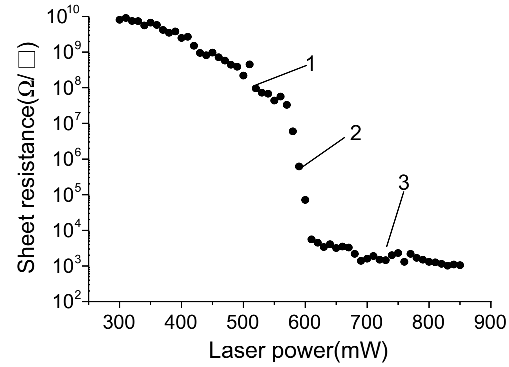

Fig. 2. Sheet resistance of laser-irradiation $Ge_2Sb_2Te_5$ films as a function of laser power.

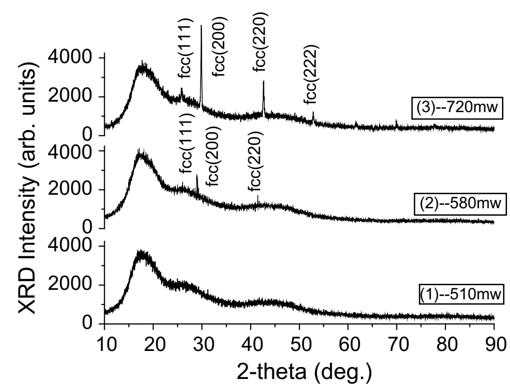

Fig. 3. XRD patterns of samples 1, 2 and 3.

From the above experimental results, we can see that at low laser power (300–580 mW) the $Ge_2Sb_2Te_5$ film is non-crystalline, the slow decrease in resistance from 10^9 to 10^7 is due to the improvement in surface defect and roughness of the films with laser-irradiation, non-crystalline $Ge_2Sb_2Te_5$ is a low-conductivity phase due to the conduction of localized electron. The charge carriers of an amorphous semiconductor mostly belong to localized electron which need to overcome localized potential barriers, this kind of leap conductivity needs phonon-assisted tunneling which results in low conductivity of the non-crystalline state. At about 580 mW the $Ge_2Sb_2Te_5$ film is in the relaxation state from disordered structure to ordered structure, increasing numbers of the extended state electrons make the conductivity improve and the sheet resistance decrease. When laser power is over 600 mW the $Ge_2Sb_2Te_5$ film is crystalline, the charge carriers of a crystalline semiconductor mostly belong to extended electrons which move freely, so in this case the $Ge_2Sb_2Te_5$ film has high conductivity because the film is in the crystalline state. Since the *fcc* $Ge_2Sb_2Te_5$ films exhibit semiconductor properties and the hexagonal $Ge_2Sb_2Te_5$ films exhibit metallic properties, when the laser power is higher than 600 mW the sheet resistance stabilizes at about 1023 Ω/□, commonly the magnitude of sheet resistance of the crystalline $Ge_2Sb_2Te_5$ films is ten to the power of three, based on the result of XRD pattern and sheet resistance as a function of laser power we think the $Ge_2Sb_2Te_5$ films become crystalline and no transformation from the amorphous state to the hexagonal state takes place with the laser power further increasing, it maybe is big difference of their structures.