The Study of Phase-change with Temperature and Electric field in Chalcogenide Thin Film

Sung-Jun Yang, Kyung Shin, Jung-Il Park, Ki-Nam Lee, and Hong-Bay Chung*
Department of Electronic Materials Engineering, Kwangwoon University, Wolgye 1-dong, Nowon-gu, Seoul 139-701, Korea

*E-mail : hbchung@kw.ac.kr

(Received 11 August 2003, Accepted 29 September 2003)

We have been investigated phase-change with temperature and electric field in chalcogenide $Ge_2Sb_2Te_5$ thin film. T_c(crystallization temperature) is confirmed by measuring the resistance with the varying temperature on the hotplate. We have measured I-V characteristics with $Ge_2Sb_2Te_5$ chalcogenide thin film. It is compared with I-V characteristics after impress the variable pulse. The pulse has variable height and duration.

Keywords : Phase-change, Nonvolatile, $Ge_2Sb_2Te_5$, C-RAM, Chalcogenide memory

1. INTRODUCTION

A phase-change memory array based on chalcogenide(C-RAM) materials originally was reported by R.G. Neal, D.L. Nelson and Gordon E. Moore in 1970[1].

It have been studied that electrical characteristics[2] of amorphous chalcogenide semiconductor thin film, and the on-off switch characteristics[3] were active. Improvements in phase-change materials technology subsequently paved the way for the development of rewritable CD and DVD optical memory disks[4]. These advances, coupled with significant technology scaling and better understanding of the fundamental electrical device operation, have motivated the development of chalcogenide based memory technology at the present day technology node[5,6].

C-RAM is nonvolatile used a small volume of chalcogenide alloy material converted between low-resistance poly-crystalline and high resistance amorphous structural phases by resistive heating with programming current pulses[7].

Key advantages of C-RAM nonvolatile technology are: write/read performance, endurance, low programming energy, process simplicity, cost, and CMOS embeddability. The write/read performance is comparable to DRAM[8].

It is widely studied the optical memory device material[9], which Te based chalcogenide material is easily to be vitreous by high speed quenching. It is known to difficult that material is occurred to convert polycrystalline. That means is not stable state but slowly convert to polycrystalline. Therefore the research of increase of crystallization speed for decrease of rewrite speed is actively progressed.

The purpose of study is gets the materials of fast convert to polycrystalline. This study is research about phase-change $Ge_2Sb_2Te_5$ with temperature and electric field in chalcogenide thin film.

2. EXPERIMENT

We prepared $Ge_2Sb_2Te_5$ bulk as same as contributed reference[10,11]. The constituent elements weighed in the appropriate ratio were sealed in evacuated quartz ampoules, which were then placed in a furnace and heated at 500, 700, and 1000℃ for 2, 2, and 24 hours, respectively.

Then the ampoules were constantly stirred every 1 hour to achieve the complete homogenization of the constituents in the melt and quenched successively in air after water. Films of amorphous $Ge_2Sb_2Te_5$ were prepared by thermal evaporation of the bulk at a deposition rate of about 5Å/s on ITO glass kept in vacuum at 1×10^{5} Torr.

The sample structure is shown schematically in Fig. 1. We fabricate 1000Å thin film on ITO-substrate with thermal vacuum evaporator. We used ITO as lower electrode and Al upper electrode[12].

T_c is confirmed by measuring the resistance with the varying temperature on the hotplate. I-V characteristics were measured with Hewlett Packard 4155B semiconductor parameter analyzer. It is experiment that impress the pulse before 0V~10V sweep. The pulse has variable duration. We would to know the I-V characteristics with sweep.

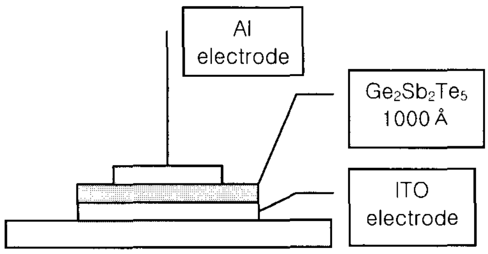

Fig. 1. Schematic illustration of fabricated the sample.

3. RESULTS AND DISCUSSION

When a liquid is cooled, one of two events may occur. Either crystallization may take place at the melting point T_m, or else the liquid will become 'supercooled' for temperatures below T_m, becoming more viscous with decreasing temperature, and may ultimately form a glass.

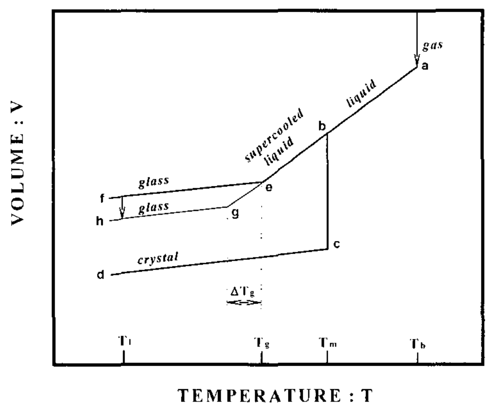

Fig. 2. Schematic illustration of the change in volume with temperature.

The crystallization process is manifested by an abrupt change in volume at T_m, whereas glass formation characterized by a gradual break in slope. The region over which the change of slope occurs is termed the 'glass-transition temperature' T_g[13].

Once the chalcogenide material heat over the T_m, it loses all structure; rapid cooling of the material to below its T_g causes the chalcogenide to be locked into its amorphous phase.

We have experiment with electric method to convert thermal energy to electric field[14]. It is a principle nonvolatile used chalcogenide alloy material converted between low-resistance poly-crystalline and high resistance amorphous structural phases with heating. It is possible to notice vitreous/polycrystalline transition resistance ratio of greater than 100.

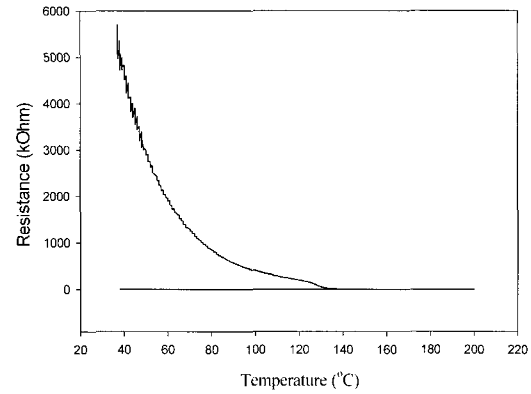

Fig. 3. Resistance change curve with temperature.

Figure 3 shows the resistance change with temperature, which is changed from room-temperature to 200℃ and gradual cooling to the room-temperature after keep 1 hour at 200℃. Fig. 3 shows considerable transition of resistance after heating. The sample has 5.6MΩ before heating, and 219Ω after heating process. Large resistance reduction is owing to crystallization of the sample. Also, Fig. 4 shows the same result which is shown in Fig. 3. Temperature is changed from room-temperature to 133℃ and gradual cooling to room-temperature. The sample has 12MΩ before heating, and 2KΩ after heating process. In result, Fig. 3 and 4 shows the phase-change from amorphous state to crystalline state.

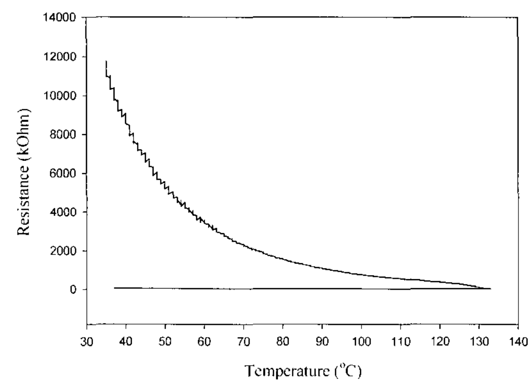

Fig. 4. Resistance change curve with temperature.

On the other hand, Fig. 5 shows reversible change of the resistance with temperature, which is changed from room-temperature to 127℃ and gradually cooling to the room-temperature. When temperature gradually down, resistance is increased with temperature. High resistance state(amorphous state) is remained after temperature down to room-temperature. Result of reversible change shows that heating temperature of the sample did not approach at T_c.

Figure 4 and Fig. 5 show the T_c is placed as approximately from 127℃ to 133℃.

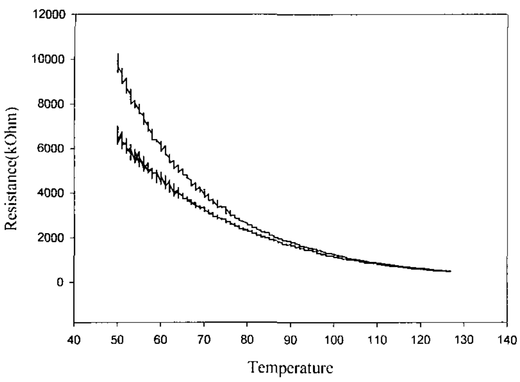

Fig. 5. Resistance change curve with temperature

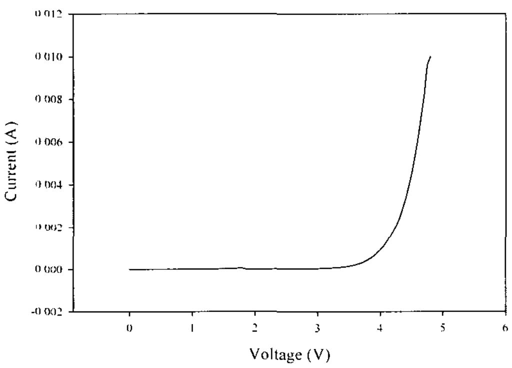

Fig. 6. I-V characteristic curve with 0V~10V sweep

Figure 6 shows I-V characteristic in $Ge_2Sb_2Te_5$. The condition is 0V~10V sweep before impress pulse. It is decided that current limit 10mA to protect the sample. We get the V_{th} between 4V~5V. . For resistance change of the sample, it is required a voltage greater than V_{th}. V_{th} is chosen to be 5V for height of impress pulse. V_{th} is important factor occurred to the phase-change of the sample. If it has enough to heat for phase-change in a $Ge_2Sb_2Te_5$ chalcogenide alloy, sample was converted from amorphous to polycrystalline.

Figure 7 shows I-V characteristics curve 0V~10V sweep after impress pulse has variable duration and 5V height. V_{th} increase gradually as pulse duration comes to be long. At low voltage, the sample exhibits high resistance. Sufficient voltage V_{th} is applied to drive the sample into a memory state. It is occurred I-V characteristics curve that operated heat for the $Ge_2Sb_2Te_5$ thin film.

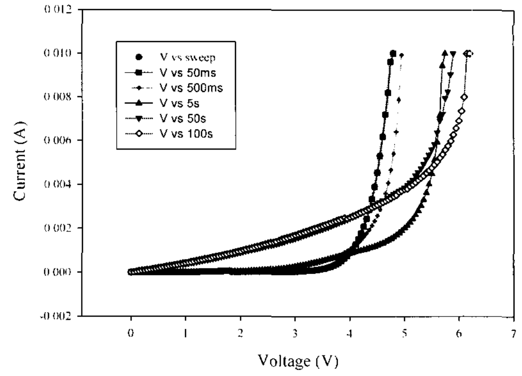

Fig. 7. 0V~10V sweep after 5V height with variable duration

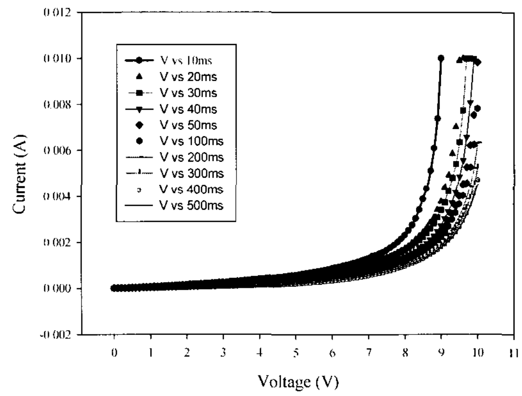

Fig. 8. 0V~10V sweep after 10V height with variable duration

Figure 8 shows I-V characteristics curve 0V~10V after impress pulse has variable duration and 10V height. The result is similar as Fig. 7 shown. But V_{th} is increased, as pulse height 10V than 5V. I-V curve has more stable line. At low voltage, the sample exhibits high resistance. At voltage over V_{th}, it has sufficient voltage applied to drive the sample into a memory state as shown in the Fig. 8.

4. CONCLUSION

In this paper, we have investigated the phase change of amorphous chalcogenide thin film with temperature and voltage. T_c is confirmed by using a hotplate for heating the sample, and transition resistance by impress the pulse with variable height and duration. V_{th} increase gradually as pulse duration comes to be long. Both of before impressed pulse for voltage and impressed the pulse has not transition of electrically resistance. But we are found that $Ge_2Sb_2Te_5$ chalcogenide alloy has different V_{th}, which is increased with impressing the long duration pulse for voltage. It will be possible that the phase-change of chalcogenide thin film by electrical pulse is the element of C-RAM application.

After this, we should study to find the factor of reversible convert vitreous and crystalline, and find the pulse characteristics for transition resistance.

ACKNOWLEDGEMENTS

This work was supported by Korea Research Foundation Grant (KRF-2002-041-D0023)

REFERENCES

[1] R. Neale, D. Nelson, and Gordon Moore, "Nonvolatile and reprogrammable, the read-mostly memory is here", Electronics, p. 56, 1970.

[2] Hong-Bay Chung and Chang-Yub Park, "Electrical characteristics of the thin film interface of amorphous chalcogenide semiconductor", J. of KIEE. Vol. 29, p. 111, 1979.

[3] Hong-Bay Chung, "Transition characteristics of ON-OFF state of amorphous chalcogenide semiconductor", J. of KIT., Vol. 9, p. 59, 1980.

[4] N. Yamada, E. Ohno, K. Nishiuchi, N. Akahira, and M. Takao, "Rapid-phase transitions of GeTe-Sb_2Te_3 pseudo-binary amorphous thin films for an optical disk memory", J. App. Phys., Vol. 69, No. 5, p. 2849, 1991.

[5] G. Wicker, "Nonvolatile, high density, high performance phase change memory", SPIE, Vol. 3891, p. 2, 1999.

[6] G. Wicker, "A comprehensive model of submicron chalcogenide switching devices", Ph.D. Dissertation, Wayne State University, Detroit, MI 1996.

[7] Scott Tyson, Steve Hudgens, Boil Pashmakov, and Wally Czubatyj, "Total dose radiation response and high temperature imprint characteristics of chalcogenide based RAM resistor elements", IEEE Transactions on nuclear sciences, Vol. 47, No. 6, p. 2528, 2000.

[8] Stefan Lai and Tyler Lowrey, "OUM - A 180nm Nonvolatile Memory Cell Element Technology For Stand Alone and Embedded Applications", Intel Corporation, RN3-01.

[9] Young-Jong Lee, "Phase-change characteristics of Te chalcogenide thin film", Kwangwoon Univ. Ph. D Thesis June, 1990.

[10] Jong-Hwa Park, Jung-Il Park, Eun-Su Kim, and Hong-Bay Chung, "Holographic grating formation by wet etching of amorphous $As_{40}Ge_{10}Se_{15}S_{35}$ thin film", Jpn. J. Appl. Phys., Vol. 41, p. 4271. 2002.

[11] Hong-Bay Chung, Sook Im, and Young-Jong Lee, "The optical properties of Te-Ge-Sb thin films with crystallization", Proc. 1996 Autumn Conf KIEEME, p. 144, 1996.

[12] Sung-Jun Yang, Kyung Shin, Jung-Il Park, Ki-Nam Lee, and Hong-Bay Chung, "The study of phase-change according ot temperature and voltage in chalcogenide thin film", Proc. 2003 Summer Conf KIEEME, p. 417, 2003.

[13] S. R. Elliott "Physics of Amorphous Materials", Longman Scientific & Technical, p. 30. 1990.

[14] Byeong-Seok Yi, Hyun-Yong Lee, and Hong-Bay Chung, "Electrical and Memory switching characteristics of amorphous $As_{10}Ge_{15}Te_{75}$ thin films", 1996 Autumn Conf. p. 235, 1996.