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# Degeneration of SET-state Resistance Consistency as Si Increases in $Si_xSb_2Te_3$

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**Abstract:** Nanosecond electrical pulses were utilized to program of $Si_xSb_2Te_3$ based T-shaped phase change memory cells. The SET-state resistances of Si-poor $Si_xSb_2Te_3$ based cells exhibit good consistency. As x increases to 3.8 and 4, the SET-state resistance varies in the range of two orders of magnitude, exhibiting an unstable value. And the RESET-state resistance begins to be unstable during cycling when x reaches 4. To ensure a good thermal stability together with suitable operation speed and consistency, $Si_3Sb_2Te_3$ and $Si_{3.5}Sb_2Te_3$ will be good choice for phase change memory application.

**Keywords:** phase change memory; SiSbTe; SET-state resistance; operation consistency

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## Introduction

Phase change memory (PCM) is a rapidly emerging technology for next generation non-volatile memory because it has excellent characteristics, including fast speed, large sensing margin, good endurance and high scalability [1]. In PCM, data storage is realized by electrical pulses including reversible phase change between amorphous (RESET, high-resistance "0" state) and crystalline (SET, low-resistance "1" state) phase of the phase change materials. As the most promising novel memory, PCM has the potential to scale down the cell dimension to 6 nm [2] and to decrease the storage time to 10 ns [3]. Due to the fast operation speed and the characteristics of non-volatile memory, PCM has recognized as the most potential competitor to DRAM and NOR flash [4,5].

The chalcogenide GeSbTe (GST) film is the most widely researched and used phase change medium for optical disk and PCM. However, large writing current is a critical issue before commercial application of PCM. In order to provide more energy to write the data under a certain writing current, raising the SET resistance is accepted as an effective way. SiSbTe materials, which have higher crystalline resistance than that of GST, are the products of reducing the RESET current. In 2006, sketchy performance properties of PCM cells based on SiSbTe materials were firstly reported, focusing on decreasing the power consumption and multiple data storage ability [6,7]. It is reported that amorphous Si in SiSbTe material effectively limits the $Sb_2Te_3$ grain sizes, increases the thermal stability of the amorphous phase, and raises the thermal efficiency by acting like nano-size heaters [8]. Despite these benefits bring about by the amorphous Si, the amorphous Si plays a role of inhibiting the crystallization of the material. By ob-

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serving the voltage snap back process during current voltage measurement, the phase transition phenomenon was found to vanish when Si content exceed 95% for Si doped $Sb_2Te_3$ materials [9]. In order to study the impact of increasing Si on the stability of the SET-state and RESET-state resistance of the SiSbTe based PCM cells under electrical pulse operation, we characterized the electrical properties of $Si_xSb_2Te_3$ (x=3, 3.5, 3.8 and 4) based PCM cells.

$Si_xSb_2Te_3$ films were prepared by cosputtring Si and $Sb_2Te_3$ alloy targets at room temperature under a basic pressure of $2\times10^{-4}$ Pa and a deposition pressure of 0.18 Pa. The composition deviation was tested by means of energy dispersive spectroscopy [EDS; Oxford INCAEnergy equipped in Hitachi S4700 scanning electron microscope (SEM)]. T-shaped PCM cell fabricated by 0.18 um complementary metal-oxide semiconductor technology was ultilized to verify the electrically induced phase change ability of SixSb2Te3 material. The structure of the PCM cell is shown in Fig. 1. The diameter of bottom W electrode is 260 nm. We deposited ~100 nm $Si_xSb_2Te_3$ film on top of the W plug. TiN (20 nm) and Al (300 nm) served as the top electrodes. The resistance-voltage (R-V) and endurance characteristics of the PCM cell were monitored with Keithley 2400 m and Agilent4155B parameter analyzers.

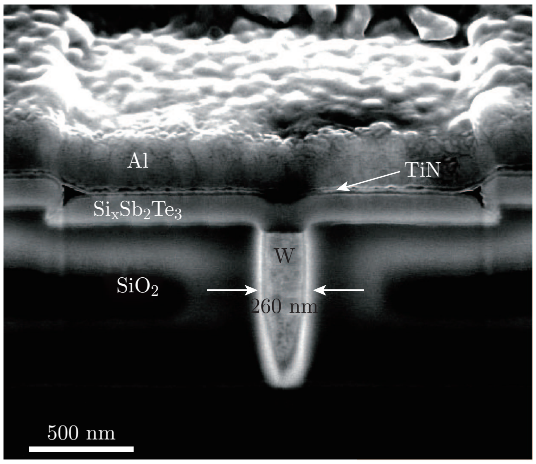

Fig. 1 SEM image of the cross section of a $Si_xSb_2Te_3$ based PCM cell.

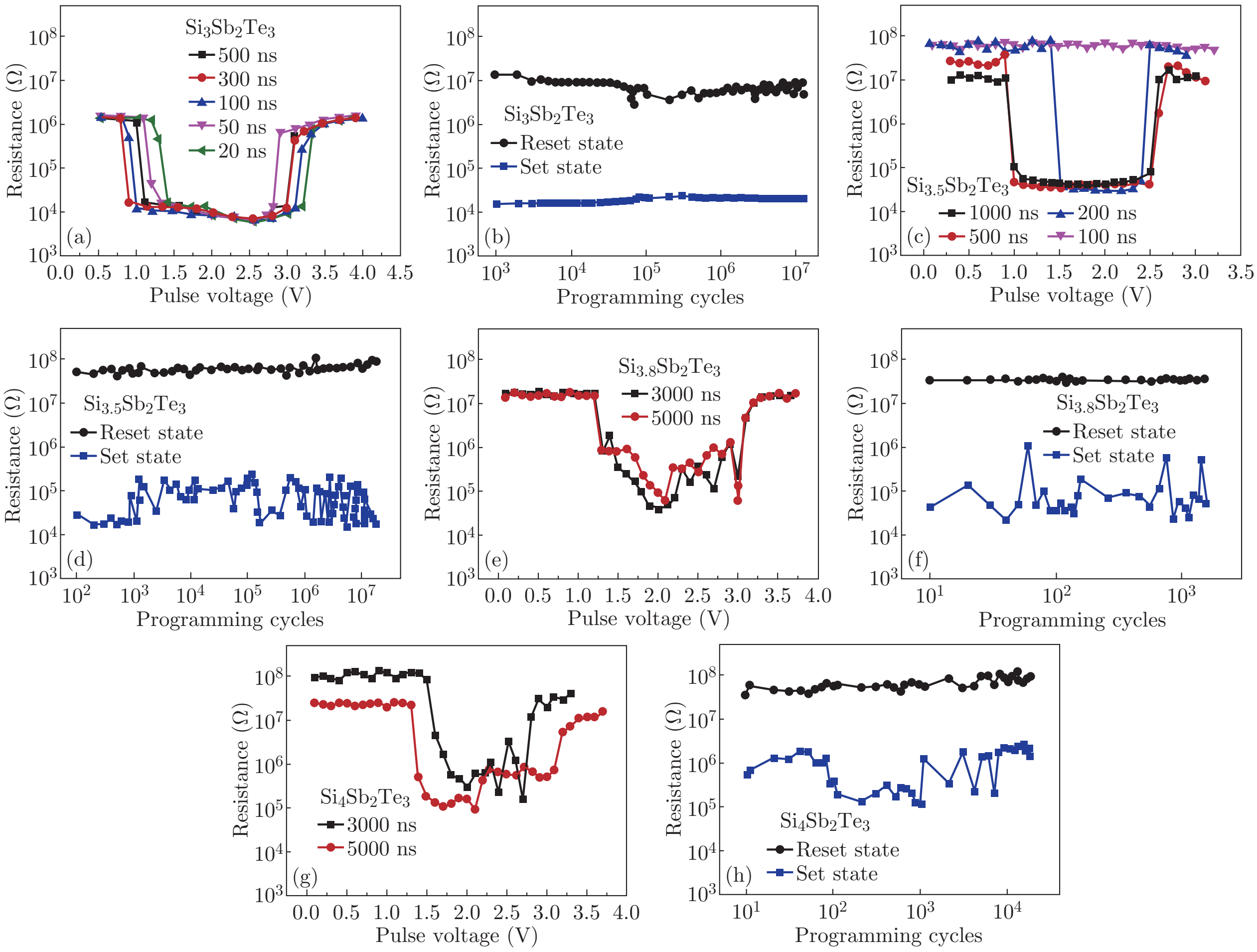

Fig. 2 (a), (c), (e), and (g) are the R-V results of $Si_3Sb_2Te_3$, $Si_{3.5}Sb_2Te_3$, $Si_{3.8}Sb_2Te_3$, and $Si_4Sb_2Te_3$ based PCM cell. (b), (d), (f), and (h) are the endurance results of $Si_3Sb_2Te_3$, $Si_{3.5}Sb_2Te_3$, $Si_{3.8}Sb_2Te_3$, and $Si_4Sb_2Te_3$ based PCM cell.

The results of R-V and endurance tests on $\mathrm{Si_xSb_2Te_3}$ based PCM cells are shown in Fig. 2. The SET speed of $\mathrm{Si_3Sb_2Te_3}$ based PCM cell can be as fast as 20 ns. The voltage needed for the SET operation decreases from 1.4 V to 0.9 V as the pulse duration increases from 20 ns to 500 ns. The resistance of the SET state is slightly lower than $10^4\Omega$. The endurance result of $\mathrm{Si_3Sb_2Te_3}$ based PCM cell is shown in Fig. 2(b). The resistance of cell in SET state during the cycling is consistently distributed between $10^4$ Ω and $9 \times 10^3$ Ω. The resistances of the RESET state also exhibit a concentrated distribution near $10^7$ Ω. The $\mathrm{Si_2Sb_2Te_3}$ based cell does not fail until the number of cycling reaches $10^7$. When Si increases in $\mathrm{Si_xSb_2Te_3}$ from x=3.0 to 3.5, longer time is needed to achieve SET operation. As shown in Fig. 2(c), the SET operation can only be achieved when the pulse duration exceeds 100 ns. The voltage needed for SET operation decreases from 1.6 V to 1.0 V when the pulse duration increases from 200 ns to 1000 ns. The resistance of the $\mathrm{Si_{3.5}Sb_2Te_3}$ based cell in SET state is above $10^4$ Ω, higher than that of $\mathrm{Si_3Sb_2Te_3}$ based one. The endurance result of $\mathrm{Si_{3.5}Sb_2Te_3}$ based PCM cell is shown in Fig. 2(d). The resistance of the cell randomly distributed in the range of $10^4$ Ω to $10^5$ Ω, which is more unstable than that of $\mathrm{Si_3Sb_2Te_3}$ based one. The resistance of the RESET state stays in a very stable value $\sim 5 \times 10^7$ Ω, unlike the fluctuating resistance of the SET state. When x increases to 3.8, the SET operation cannot succeed until the pulse duration reaches several thousand nanosecond. Meanwhile, the fluctuation of the SET-state resistance becomes much greater, which is in the range of $10^4$ Ω to $10^6$ Ω. The required SET voltage is above 1.3 V. In this composition, the RESET resistance is still stable under repeated operation. When x further increases to 4.0, the SET-state resistance increases significantly, which is in the range of $10^5$ Ω to $10^7$ Ω. The pulse for SET operation needs to be as long as several thousand nanosecond and as high as 1.4 V. The SET-state pulse fluctuates greatly during the cycling. At the meanwhile, the RESET-state resistance begins to be unstable.

The operation parameters of $\mathrm{Si}_x\mathrm{Sb_2Te_3}$ based PCM cells are listed in Table 1. In $\mathrm{Si_xSb_2Te_3}$ materials, Si stays amorphous, which plays a role of inhibiting the crystallization. As x increases from 3 to 4, the minimum SET pulse width of $\mathrm{Si_xSb_2Te_3}$ based PCM cell increases from 20 ns to 3000 ns. The minimum SET voltage also increases from 0.9 V to 1.4 V as x increases. Inhibitory effect of crystallization of amorphous Si is reflected in the aspects of lowering speed and increasing power consumption of the SET operation of the PCM cells. In addition, the consistency of the operation of $\mathrm{Si_xSb_2Te_3}$ based cell is degenerated as Si increases. In $\mathrm{Si_3Sb_2Te_3}$ based PCM cell, the SET-state resistance stays at $10^4\Omega$, almost without change during cycling. As x increase to 3.5, the SET-state resistance ranges within one order of magnitude during cycling. When x further increases to 3.8 and 4, the SET resistance ranges within two orders of magnitude. And the RESET resistance begins to be unstable when x reaches 4.

**Table 1 The operation parameters of $\mathrm{Si_xSb_2Te_3}$ (x=3, 3.5, 3.8 and 4) based PCM cells.**

| Storage media | Set Speed (ns) | Set Voltage (V) | Set Resistance (Ω) | Consistency of the Set-State Resistance | Consistency of the Reset-State Resistance |
|---|---|---|---|---|---|
| $\mathrm{Si_3Sb_2Te_3}$ | 20 | 0.9 | $\sim 10^4$ | Very Good | Very Good |
| $\mathrm{Si_{3.5}Sb_2Te_3}$ | 200 | 1.0 | $10^4\sim10^5$ | Good | Very Good |
| $\mathrm{Si_{3.8}Sb_2Te_3}$ | 3000 | 1.3 | $10^4\sim10^6$ | Poor | Very Good |
| $\mathrm{Si_4Sb_2Te_3}$ | 3000 | 1.4 | $10^5\sim10^7$ | Poor | Good |

While the thermal stability of $\mathrm{Si_xSb_2Te_3}$ is enhanced by increasing Si, but it is at the expense of the operation speed and consistency of the PCM cell. A suitable $\mathrm{Si_xSb_2Te_3}$ material for PCM application should promise a good thermal stability, a fast operation speed and a good operation consistency of the PCM. Thus x should not reach or exceed 3.8. $\mathrm{Si_3Sb_2Te_3}$ and $\mathrm{Si_{3.5}Sb_2Te_3}$ are good choices for PCM application.

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