The Effect of SiC Polytypes on the Heat Distribution Efficiency of a Phase Change Memory.

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Abstract. The amorphous to crystalline transition of germanium-antimony-tellurium (GST) using three types of silicon carbide’s structure as a heating element was investigated. Simulation was done using COMSOL Multiphysic 5.0 software with separate heater structure. Silicon carbide (SiC) has three types of structure; 3C-SiC, 4H-SiC and 6H-SiC. These structures have a different thermal conductivity. The temperature of GST and phase transition of GST can be obtained from the simulation. The temperature of GST when using 3C-SiC, 4H-SiC and 6H-SiC are 467K, 466K and 460K, respectively. The phase transition of GST from amorphous to crystalline state for three type of SiC’s structure can be determined in this simulation. Based on the result, the thermal conductivity of SiC can affecting the temperature of GST and changed of phase change memory (PCM).

1. Introduction
Phase change Memory (PCM) is a non-volatile memory but there are many advantages of the phase-change memory such as high endurance, low programmable energy, fast switching speed, good data retention and excellent scalability[1] [2] [3]. The history of phase change memory has began when these device were first proposed by S.Ovshinsky in late 1960s [1]. He had reported that the chalcogenide material can be reversible change in resistivity and reflectivity when changing between amorphous state and crystalline state. The changing of PCM from amorphous state to crystalline state or vice versa allows data can be stored or deleted.

Phase change materials usually exist in an amorphous phase but one or sometime several crystalline phases. The phase change material in amorphous state has characteristic like high resistivity and short range atomic order. While, the phase change material in crystalline state has a low resistivity and long range atomic order. The changing of atom in phase change material will affect the process of amorphous and crystallization. The phase change material that used in this research is Ge2Sb2Te5 (Germanium-antimony-tellurium, GST) because it has high thermal stability with additional of Ge, very high crystallization rate and very good reversibility between amorphous and crystalline phases. It often used in rewritable optical discs and phase-change memory applications. This material has 450K crystallization temperature and 900K melting temperature [5].

Silicon carbide (SiC) is a semiconductor material and may be heated to 600 C in operation and may have a resistivity that does not significantly go down with increasing temperature. In this research, three types of silicon carbide’s structure will be used; 3C-SiC, 4H-SiC and 6H-SiC. These three structures have a different of thermal conductivity. GL Harris 1995 said the 3 types of SiC; 3C-SiC,
4H-SiC, and 6H-SiC have a different thermal conductivity which is 320 W/mK, 370 W/mK, and 490 W/mK respectively but the heat capacity is 690 J/kgK, same for all types of SiC [9]. Golberg et al.2001 said the thermal conductivity for 3C-SiC is 360 W/mK [10]. For this research, the different of thermal conductivity of silicon carbide can affect the temperature of phase change material.

In this paper, the COMSOL 5.0 Multiphysic software was used for simulating the different of structure of silicon carbide as a heater layer. In COMSOL software, the joule heating is a one of multiphysic interface is used to model resistive heating. This multiphysics interface adds a heat transfer in solid interface and electric current interface. These two elements important to produce the result that is almost equal to the actual situation.

2. Experimental

Silicon carbide (SiC) is an interesting material that has found application in a variety of industries. SiC has an exclusive properties to make SiC a perfect candidates for high power, high temperature electronic devices such as high melting point, chemical and thermal stability, high hardness and strength, and high erosion resistance[7] [8]. For this research, SiC was selected as a heater layer for ensure the GST can get enough heat for phase transition from amorphous to crystalline state. The three types of SiC’s structure that used in this simulation is 3C-SiC, 4H-SiC and 6H-SiC. Figure 1 show the different structure of SiC. These three structures have a different thermal conductivity but same heat capacity. Table 1 shows the thermal conductivity and heat capacity for three types of SiC’s structure.

![Figure 1: The three types of SiC with different structure.](image)

| Structure  | 3C-SiC | 4H-SiC | 6H-SiC |
|------------|--------|--------|--------|
| Thermal Conductivity W/m.K  | 320    | 370    | 490    |
| Heat Capacity J/kg.K        | 690    | 690    | 690    |

The separated heater structure was used in this simulation using the COMSOL 5.0 Multiphysics software. Separated heater structure consist of four electrodes, GST as memory layer, SiC as heater layer and ZnS-SiO2 as a capping layer and insulator layer. The function of capping layer is to avoid the thermal energy loss when SET process occurs. The insulator layer used to ensure the heater layer not connected electrically to the memory layer, GST. The figure 2 shows the separated heater structure of PCM [5] [6]. The voltage pulse is applied at the two top electrodes. The heater SiC will be heat the insulator. Heat will be transferred to the GST and change to the crystalline state. With this structure, the power can be controlled depend on the voltage pulse because the Rh is constant (SiC).
From this simulation, the temperature of GST will be measured from 0.7V with 100ns pulse width until the GST was changed from amorphous to crystalline state. The GST will change from amorphous to crystalline state when the temperature of GST reached over 450K. This change is known as a phase transition of GST. The temperature and phase transition of GST from amorphous to crystalline state can be obtained from this simulation.

3. Result and Discussion

From the simulation, the temperature can be obtained using the three types of SiC’s structure. The result of simulation can be seen in the figure 3 below when the voltage is 1.0V with 100ns pulse width. Figure 3 (a) show the temperature is 467K at GST using the 3C-SiC structure, figure 3 (b) shows the temperature is 466K at GST using the 4H-SiC structure and figure 3 (c) show the temperature is 460K at GST using the 6H-SiC structure.
Figure 3 (b): The temperature when voltage 1.0V with 100ns pulse width was applied at 4H-SiC structure.

Figure 3 (c): The temperature when voltage 1.0V with 100ns pulse width was applied at 6H-SiC structure.

From the figure 3 (a), (b) and (c), the temperature of GST was decreased when the thermal conductivity of SiC was increased. The table 2 shows the temperature of GST when voltage 0.7V with 100ns pulse width was applied at the top electrode until the GST was changed to crystalline state. From this result, the thermal conductivity of SiC can affect the temperature of GST. The red color show the GST already changed to crystalline state, while the black color show the GST still in amorphous state.

| Temperature (K) | Voltage (V) | 3C-SiC | 4H-SiC | 6H-SiC |
|-----------------|-------------|--------|--------|--------|
|                 | 0.7         | 392.67 | 391.22 | 389.56 |
|                 | 0.8         | 420.42 | 418.92 | 416.56 |
|                 | 0.9         | 447.55 | 447.2  | 444.44 |
|                 | 1.0         | 467.19 | 466.4  | 460.81 |
|                 | 1.1         | 487.67 | 487.36 | 481.36 |
|                 | 1.2         | 515.79 | 512.29 | 508.21 |
Figure 4 shows the phase transition of GST when voltage 0.9V and 1.0V with 100ns pulse width for three types of SiC’s structure. When the voltage applied is 0.9V, the phase transition of GST will be changed from amorphous but the GST not completely changed to crystalline state. The percentage phase transition of GST for 3C-SiC, 4H-SiC and 6H-SiC are 47%, 44% and 29%, respectively. When the voltage 1.0V, the phase transition of GST for 3C-SiC changed 100% to crystalline state but for 4H-SiC and 6H-SiC the percentage phase transition are 98% and 96%, respectively. Table 3 shows summary of phase transition of GST with voltage 0.9V and 1.0V with 100ns pulse width for three types of SiC’s structure.

Figure 4(a): Phase transition of GST between amorphous and crystalline state when 0.9V with 100ns pulse width for 3C-SiC structure.

Figure 4(b): Phase transition of GST between amorphous and crystalline state when 0.9V with 100ns pulse width for 4H-SiC structure.
Figure 4(c): Phase transition of GST between amorphous and crystalline state when 0.9V with 100ns pulse width for 6H-SiC structure.

Table 3: Summary of phase transition of GST with voltage 0.9V and 1.0V with 100ns pulse width for three types of SiC’s structure.

| Voltage (V) | 3C-SiC | 4H-SiC | 6H-SiC |
|------------|--------|--------|--------|
| 0.9        | 47%    | 44%    | 29%    |
| 1.0        | 100%   | 98%    | 96%    |

4. Conclusion
In conclusion, the thermal conductivity of silicon carbide can affect the temperature of GST and also the phase transition of GST. The structure 3C-SiC has a lower thermal conductivity compared with the structure 4H-SiC and 6H-SiC. The lower thermal conductivity of SiC will caused the temperature of GST increased. The temperature of GST when using 3C-SiC as a heating element is 467K, while the temperature of GST when using 4H-SiC and 6H-SiC as a heating element are 466K and 460K, respectively. The phase transition of GST for 3C-SiC at 1.0V with 100ns pulse width is 100% completely changed from amorphous to crystalline state. For 4H-SiC and 6H-SiC, the phase transition of GST are 98% and 96% only but the data still can be stored at this time. Based on result simulation, the lower of thermal conductivity of SiC can increased the temperature of GST more efficient and phase transition of GST can change from amorphous to crystalline state easily.

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