Low Power Phase Change Memory using Silicon Carbide as a Heater Layer

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Abstract. The amorphous to crystalline transition of germanium-antimony-tellurium (GST) using two types heating element was investigated. With separate heater structure, simulation was done using COMSOL Multiphysic 5.0. Silicon carbide (SiC) and Titanium Sitride (TiSi3) has been selected as a heater and differences of them have been studied. The voltage boundary is 0.905V and temperature of the memory layer is 463K when using SiC as a heater. While the voltage boundary and temperature of memory layer when using TiSi3 are 1.103V and 459K respectively. Based on the result of a simulation, the suitable material of heater layer for separate heater structure is Silicon carbide (SiC) compared with Titanium Sitride (TiSi3).

1. Introduction
The phase change memory (PCM) is a unique behavior of chalcogenide glasses that changes from amorphous to crystalline with application of heat [1]. 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 amorphous have a high resistance and can used as ‘0’ state for data storage. The crystalline have a low resistance and can used as ‘1’ state for data storage [3]. Now, the lower power consumption of PCM is a new creation of technology development.

Phase change material, germanium-antimony-tellurium (GST) is a chalcogenide glass which is widely used phase change memory industry. The advantages of GST are good reversibility between crystalline and amorphous and high thermal stability in room temperature [4]. The melting temperature of GST is about 900K and the crystallization temperature is about 450K [5]. The changing of resistance from amorphous to crystalline state can allow data to be stored. This is a unique characteristic of phase change material.

Silicon carbide (SiC) is one of the suitable semiconductor materials for operating at high temperature and high power [8]. The advantages of silicon carbide are low thermal expansion, high thermal conductivity and excellent thermal shock resistance [8] [9] [10]. Silicon carbide (SiC) is a wide band gap material [9]. That’s mean; the resistance of SiC did not change significantly at higher temperature. Based on this fact, silicon carbide (SiC) is suitable material for heater in this separate heater structure.

In this paper, the COMSOL 5.0 Multiphysic software was used for simulating the separate heater structure of phase change memory. This structure consists 4 electrodes, the memory layer (GST), insulator layer, heater layer (TiSi3 or SiC) and capping layer. The voltage 0.9V-1.1V with 100ns SET pulse were applied to the heater layer to investigate the changes of the memory layer (GST).
A. Lacita et al. (2006) proposed the PCM with 50ns-100ns but memory layer was heated directly by heater [2]. While the Irma R, Kobayashi R, Zhang YL et al (2013) was proposed the phase change memory structure with separate heater using Titanium Sitride (TiSi$_3$) as a heater layer [6]. The voltage 0.5V-3.0V with 100ns SET pulse were applied to phase change memory structure with separate heater to control the crystallization process.

2. Experimental

The structure that used in this simulation is the separate heater structure [6] [7]. Using the COMSOL 5.0 Multiphysics Software, the simulation was made with 2 types of heater, Silicon Carbide (SiC) and Titanium Sitride (TiSi$_3$). Figure 1 shows the simulation model and thickness of materials with GST as a memory layer and SiC and TiSi$_3$ as a heater. Table 1 shows the physical properties of material that used in this simulation.

The structure was designed as a figure 1 for the simulation process [7]. Titanium Nitride (TiN) was used as an electrode material and Zinc Sulfide-Silicon Dioxide (ZnS-SiO$_2$) was used as a capping and an insulator layer with thickness at 150nm and 20nm respectively. GST has 150nm thinned and was used as a memory layer in this simulation. The lastly material that used in the simulation is silicon carbide; SiC and titanium stride TiSi$_3$ as a heater. The heater has 50nm of thickness. The first model uses SiC as a heater and the second model uses TiSi$_3$ as a heater. From this simulation, the difference temperature can be obtained with using different material as a heater.

![Figure 1: The Simulation Model and thickness of material with GST as a memory layer and SiC and TiSi$_3$ as a heater.](image)

| Material                  | Heat capacity (J/kg.K) | Thermal conductivity (W/m.K) | Density (kg/m$^3$) | Electrical conductivity (S/m) |
|---------------------------|------------------------|-------------------------------|--------------------|-----------------------------|
| Capping Layer, ZnS-SiO$_2$| 263                    | 0.657                         | 3650               | 0.02                        |
| Insulator Layer, ZnS-SiO$_2$| 263                    | 0.657                         | 3650               | 0.02                        |
| Electrode, TiN            | 784                    | 22                            | 5240               | 5.0X10$^6$                  |
| Heater, SiC               | 670                    | 120                           | 3200               | 4.3X10$^4$                  |
| Heater, TiSi$_3$          | 800                    | 20                            | 4043               | 1.75X10$^4$                 |
| Memory layer, a-GST       | 202                    | 0.46                          | 6200               | 3.6X10$^{-1}$               |
| Memory Layer, c-GST       | 202                    | 0.46                          | 6200               | 2.0X10$^2$                  |
From this simulation, the lower voltage will be measured when memory layer is changed from amorphous to crystalline state with different heater. The first voltage that makes changes from amorphous to crystalline state at the memory layer is called as voltage boundary. The temperature and voltage boundary can be obtained from this simulation.

3. Result and Discussion

From the simulation, the temperature can be obtained using the SiC and TiSi$_3$ as a heater to heat the memory layer, GST. The result of simulation can be seen in the figure 2 below. Figure 2 (a) show the temperature is 463K at memory layer using the SiC material as a heater and figure 2 (b) shows the temperature is 459K at memory layer using the TiSi$_3$ material as a heater. The SET voltage 0.91V with 100ns pulse width was applied at the SiC as a heater and SET voltage 1.11V with 100ns pulse width was applied at the TiSi$_3$ as a heater.

![Figure 2 (a): The temperature when SET voltage 0.91V with 100ns pulse width was applied at SiC material.]

![Figure 2 (b): The temperature when SET voltage 1.11V with 100ns pulse width was applied at TiSi$_3$ material.]

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From the figure 2 (a), the temperature of structure is widely and spread compared with the figure 2 (b) which is the temperature of the structure is more focused at the center of the structure. The one characteristic of silicon carbide is high thermal conductivity. The definition of thermal conductivity is the rate of heat flow through a material. So, the amount of heat transfer is controlled by the amount of dissipation, the amount of thermal energy present and the nature of the heat carrier in the material. From these factors, the silicon carbide has a number of high heat transfers and make the silicon carbide is a very attractive material for high temperature application.

![Figure 3(a): Changes of memory layer when heated using SiC](image1.png)

![Figure 3(b): Changes of memory layer when heated using TiSi$_3$](image2.png)

The result of simulation can be seen in figure 3 below. The voltage boundary can be obtained when the memory layer will be changed from the amorphous to crystalline state for different heater. Figure 3 (a) shows the changes in memory layer when it is heated using SiC. Figure 3 (b) shows the changes in
memory layer when it is heated using TiSi$_3$. From the figure 3(a), the changes of memory layer are uniformly on the surface when using SiC as a heater compared with the figure (b) using TiSi$_3$ as a heater. Based on the figure 3(a) and 3(b), the changes in memory layer are a difference because the difference characteristic of the heater. When using the silicon carbide as a heater, the changes of the memory layer is wider compared with the TiSi$_3$ as a heater. When there is a change in memory layer from amorphous to crystalline state, the data can be stored. That’s time, the resistance of chalcogenide material is low and it is also known as SET state. These changes allow data to be stored and this process requires a voltage lower than RESET process.

The voltage boundary can be calculated using the following equation:

$$E = \frac{\Delta V}{r} \ldots \ldots (1)$$

Where the $E$ is Electrical Field for the memory layer, $\Delta V$ is different voltage at the 2 point and $r$ is distance between different voltage points. From this equation, the different voltage can be obtained from the applied voltage at electrode and the voltage boundary at the memory layer. The distance can be obtained between the point of the applied voltage and point of the voltage boundary. The value of electrical field can get from the simulation. From this simulation, the result can be concluded as a Table 2 below

| Material of Heater | Applied Voltage (V) | Temperature (K) | Electrical Field (V/m) | Voltage Boundary (V) | Current Density (A/m$^2$) |
|--------------------|---------------------|-----------------|------------------------|----------------------|---------------------------|
| SiC                | 0.91                | 463             | 16531                  | 0.905                | 3.31X10$^6$               |
| TiSi$_3$           | 1.11                | 459             | 20302                  | 1.103                | 4.06X10$^6$               |

Based on result of simulation, the Silicon carbide (SiC) is a good heater than Titanium Sitride (TiSi$_3$). The voltage boundary when using SiC as a heater is 0.905V. That’s mean, the voltage drop when using SiC as a heater is 0.005V equal 0.55% compared with the voltage drop using TiSi is 0.007V equal 0.63%. Using SiC, the voltage can be reduced 0.2V equal 18% voltages can be saved because Silicon Carbide has a high thermal conductivity and high temperature stability, making it suitable semiconductor material for operating at a high temperature. When the voltage can be saved, automatically the power can be reduced and make the structure more applicable.

4. Conclusion
In conclusion, the silicon carbide (SiC) can be categorized as a good heater compared with the titanium sitride (TiSi$_3$). The applied voltage when using SiC and TiSi$_3$ as a heater are 0.91V and 1.11V respectively. With lower applied voltage, the memory layer will be changed from amorphous to crystalline state. The temperature of memory layer will be high when using SiC as a heater compared with the TiSi$_3$ as a heater. From the calculation, the voltage boundary can be obtained and the voltage boundary lower when using SiC as a heater.
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