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Research paper

The Effect of Heater Layer (SiC) Thickness for Phase-change Memory Phase Transition

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Abstract

The phase transition of germanium antimony tellurium (GST) using different thickness of heater layer (Silicon Carbide, SiC) was investigated. The separate heater structure of phase change memory (PCM) was selected as a model simulation. However, there is little information about this structure that deal with the low power consumption of PCM. This structure has a potential to achieve the low power consumption of PCM with using the different thickness of heater layer (SiC). From the simulation, the effect of heater layer (SiC) thickness on the PCM was studied by COMSOL Multiphysic 5.0 software. The temperature of GST and phase transition of GST can be obtained from the simulation. The 20nm thickness of SiC can reach the crystalline temperature at 1.2V with 100 ns pulse width. The 100nm thickness of SiC can reach the crystalline temperature at 0.8V with 100ns pulse width. From these results, the thickness of SiC can affect the temperature of GST and phase transition of GST. If the thickness of SiC was increased, the temperature of GST was increased and the rate of phase transition of GST was faster. It can be concluded that the thickness of SiC may have been an important factor in the transformation of GST's phase and the temperature of GST. The low power consumption of PCM can be produced when the thickness of SiC is considered.

Keywords: *GST; Heater layer; low power consumption of PCM; Phase change memory; Separate heater structure; Silicon carbide*

1. Introduction

There are two main types of memory: volatile and non-volatile memory. Non-volatile memory can be broken down into flash memory and phase change memory (PCM). Stanford Ovshinsky (in late 1960s) was apparently the first to use the term PCM when he had reported that the chalcogenide material can change from amorphous state to crystalline state and vice versa [1]. In amorphous state, the atoms are arranged in a disorderly manner. When the heat applied on the chalcogenide material until it reaches the crystalline temperature, the atom will begin an orderly and the chalcogenide is in crystalline state. If the chalcogenide material is heated continuously until it reaches the melting temperature and rapidly cooling down, the chalcogenide material will be transformed to amorphous state back. The atom will be arranged in a disorderly manner. There are many reasons why the PCM has become so dominant in memory industry. These are high endurance, low programmable energy, fast switching speed, and good data retention [2] [3]. Many scholars have been studying about producing PCM with low power consumption by doing improvement on the phase change material, structure of PCM and heating element materials.

The novel PCM with double GST thermally confined structure was proposed by Der-Sheng Chao (2007) to reduce the reset current less than 0.3mA [4]. Je Feng (2007) was used Si doping in GST film to reduce the writing current of PCM [5]. The comparison between GST, N-doped GST and Si doped GST was investigated by them. Cheng Xu (2008) do an improvement on the structure of PCM with used TiO2 layer was inserted between GST and bottom heating electrodes [6]. This method can reduce the reset current of the device cell decreased 68% compared with that without TiO2 layer. Feng Xiong (2011) proposed the low power switching of phase change material (GST) with carbon nanotube electrodes [7]. According this paper, this structure can achieve programming current as low as 0.5uA for SET process and 5uA for RESET process. Yin Y (2012) and Irma R (2013) was used the separated heater structure of PCM with TiSi3 as a heater layer to achieve the low power consumption and multi-level storage in lateral PCM [8][9]. The advantages of separated heater structure of PCM is the temperature of heater layer can be controlled depend on the voltage pulse.

However, few studies have reported on the low power consumption of PCM. But there is little information available on the separated heater structure of PCM especially the material that used as a heater layer. The suitable semiconductor material that can operate at the higher temperature and high power is silicon carbide (SiC) [10]. The other advantages of SiC are wide band gap material, excellent thermal shock resistance, and high thermal conductivity [10]. This paper will discuss the variation of heater layer (SiC) thickness. The objective of this paper is to study the effect of heater layer (SiC) thickness on the low power consumption of PCM structure. From the variation thickness of SiC, the temperature of GST and the phase transition of GST will be determined using the COMSOL Multiphysic software.

2. Experimental

In this work, the simulation was done by using the COMSOL Multipyhsic 5.0 software. The separated heater structure of PCM was used and this structure was proposed by the Irma R (2013).

The difference between this works with the previous researcher is the use of SiC material as a heater layer. This structure consists of substrate, four electrodes (bottom and top electrode), memory layer, insulator layer, heater layer and capping layer. Every layer on this structure used the different material. The thickness of each layer has been set for all simulation except the thickness of the heater layer. The Fig. 1 shows the material and the thickness of material that used in this simulation.

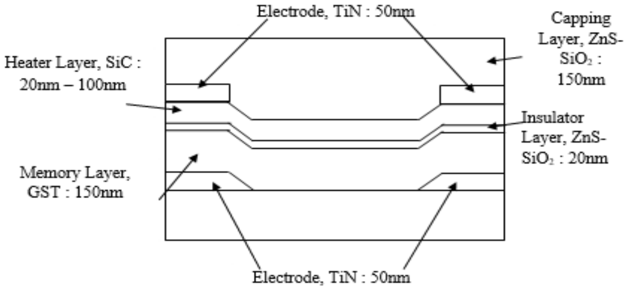

Fig. 1: The thickness for all materials and the different thickness of SiC.

Table 1: The physical properties of SiC.

Material	**Heat capacity (J/kg.K)**	**Thermal conductivity (W/m.K)**	**Density (kg/m^3)**	**Electrical conductivity (S/m)**
Heater, SiC	670	120	3200	4.3X10^4

For this research, the simulation with different thickness of SiC will be simulated to determine the temperature of GST and the phase transition of GST. The thickness of SiC that used in this simulation is from 20nm until 100nm with a rise of 10nm thickness of SIC. The physical properties of SiC's material that used in this simulation can be seen on the Table 1. The applied voltage from 0.5V until 2.3V with 100ns pulse width was applied at the two top electrodes and heated up the heater layer, SiC material. The heater layer was not connected electrically to the memory layer because the insulator layer located between heater layer and memory layer. The heat would transfer from the heater layer to memory layer and the temperature of GST would increase. From the simulation with different thickness of SiC, the temperature of GST and the phase transition of GST were determined. The term "phase transition of GST" is used here to refer to the changes in GST from amorphous state to crystalline state in percentages.

3. Result and Discussion

Table 2 shows the temperature of GST when using the different thickness of SiC as a heater layer. The result of simulation state that the different of thickness of SiC can affect the temperature of GST. The increasing of thickness of SiC can cause the temperature of GST to increase. The temperature of GST at 1.2V with 100ns pulse width is 466.29K when the thickness of SiC is 20nm. While, the temperature of GST at 0.8V with 100ns pulse width is 474.49K when the thickness of SiC is 100nm. The bold values of temperature show that the GST has already changed from amorphous state to crystalline state when the temperature of GST was over 450K, crystalline temperature for GST. The Fig. 2 shows that there has been a gradual increase in the temperature of GST when the thickness of SiC increased.

Table 2: The temperature of GST for the different thickness of SiC

Applied Voltage (V)	**Temperature of GST (K)**								
	20nm thickness of SiC	**30nm thickness of SiC**	**40nm thickness of SiC**	**50nm thickness of SiC**	**60nm thickness of SiC**	**70nm thickness of SiC**	**80nm thickness of SiC**	**90nm thickness of SiC**	**100nm thickness of SiC**
0.5	330.41	340.42	348.93	356.06	362.23	367.3	372.15	376.29	380.51
0.6	345.85	359.91	371.74	381.62	390.14	397.3	404.04	409.68	414.57
0.7	363.29	382.19	397.86	410.59	421.67	430.91	437.78	443.16	448.99
0.8	383.57	407.4	426.28	440.02	449.84	**452.51**	**467.15**	**468.01**	**474.49**
0.9	405.3	433.79	449.89	**465.11**	**472.94**	**480.94**	**496.62**	**503.56**	**512.14**
1	428.32	**456.33**	**472.16**	**491.17**	**506.11**	**518.95**	**530.79**	**536.67**	**549.43**
1.1	447.78	**473.91**	**495.66**	**521.01**	**539.08**	**555.36**	**569.88**	**583.08**	**592.72**
1.2	**466.29**	**500.17**	**529.6**	**554.84**	**575.78**	**595.8**	**608.69**	**621.31**	**637.77**
1.3	**487.49**	**527.79**	**562.7**	**589.29**	**611.56**	**631.69**	**651.18**	**666.92**	**685.85**
1.4	**509.77**	**559.84**	**592.89**	**624.15**	**650.13**	**673.02**	**694.45**	**712.64**	**735.85**
1.5	**532.09**	**587.4**	**628.66**	**661.53**	**688.24**	**716.41**	**739.72**	**760.34**	**779.67**
1.6	**560.37**	**618.26**	**659.68**	**700.55**	**733.16**	**759.35**	**786.14**	**810.77**	**832.37**
1.7	**587.62**	**650.47**	**697.92**	**739.31**	**778.07**	**805.16**	**832.25**	**848.56**	**878.45**
1.8	**614.39**	**683.57**	**730.89**	**779.43**	**818.69**	**849.33**	**881.73**	911.06	931.8
1.9	**641.26**	**709.36**	**771.75**	**822.55**	**862.32**	899.66	925.04		
2	**666.61**	**748.55**	**809.65**	**858.61**	906.94	934.06			
2.1	**695.17**	**780.46**	**843.41**	904.46					
2.2	**727.68**	**811.96**	**892.18**	947.66					
2.3	**759.26**	**852.47**	925.06						

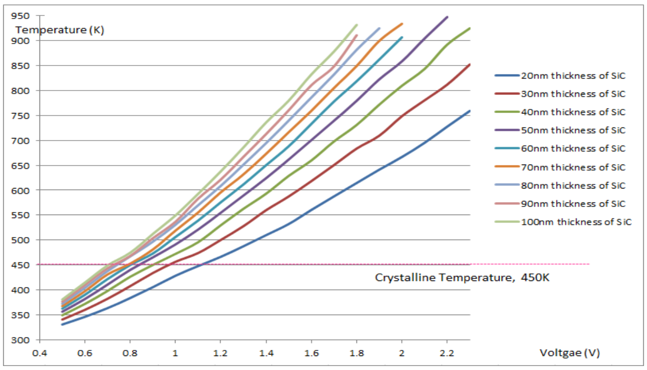

Fig. 2: The temperature of GST for the different thickness of SiC.

Table 3 shows the percentage of phase transition of GST for different thickness of SiC. From the table, the applied voltage that changes the GST to crystalline state increased when the thickness of SiC was increased. Comparison between them are when using the 20nm thickness of SiC, the applied voltage is 1.2V with 100ns pulse width and when using the 60nm, 70nm, 80nm, 90nm and 100nm thickness of SiC, the applied voltage is 0.8V with 100ns pulse width. From this situation, it can be concluded that the increased thickness of SiC will affect the phase transition of GST when the same applied voltage was applied at the top electrodes. The bold percentage of phase transition of GST shows that GST changes to crystalline state.

Table 3: The percentage of phase transition of GST for different thickness of SiC.

	Percentage of phase transition GST for different thickness of SiC								
Voltage (V)	**20 nm**	**30 nm**	**40 nm**	**50 nm**	**60 nm**	**70 nm**	**80 nm**	**90 nm**	**100 nm**
0.7	0 %	0 %	0 %	0 %	0 %	2 %	13 %	29 %	49 %
0.8	0 %	0 %	0 %	18 %	**52 %**	**73 %**	**94 %**	**96 %**	**100 %**
0.9	0 %	4 %	**56 %**	**95 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**
1.0	3 %	**76 %**	**94 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**
1.1	47 %	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**
1.2	**97 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**

The percentage of phase transition of GST at 1.1V and 1.2V with 100ns pulse width for 20nm thickness of SiC are 47% and 97% respectively. It can be seen on the Fig. 2 below. From the Fig. 3, the percentages of phase transition of GST for 100nm thickness of SiC are 49% and 100% respectively at 0.7V and 0.8V with 100ns pulse width. That means, the 20nm thickness of SiC need 1.2V applied voltage to change the GST to crystalline state and the 100nm thickness of SiC required only 0.8V applied voltage to change GST from amorphous state. The Fig. 3 and Fig. 4 show the red color at GST area is in crystalline state and the blue color at GST area is still in amorphous state. From the result of simulation, the increased thickness of SiC will lower the applied voltage for PCM then affect the temperature of GST and phase transition of GST. From this situation, it can be described that the increased thickness of SiC can produce a low power consumption of PCM.

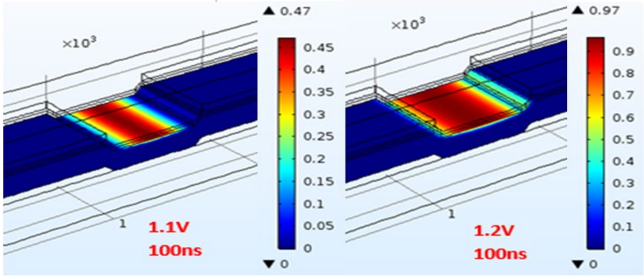

Fig. 3: The phase transition of GST for 20nm thickness of SiC at 1.1V and 1.2V.

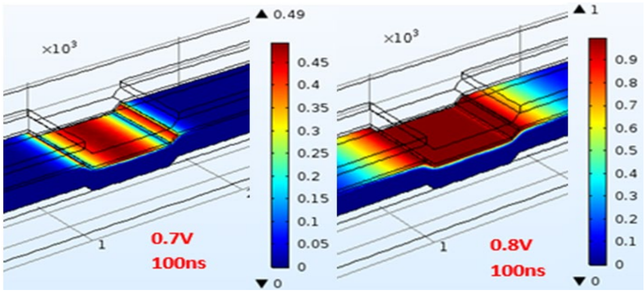

Fig. 4: The phase transition of GST for 100nm thickness of SiC at 0.7V and 0.8V

The following part of this paper moves on to describe in greater detail about the thickness of SiC that can affect the power consumption of PCM. In this paper, the term will be used to describe the phenomenon is heat transfer between two materials. The transfer of heat is normally from the high temperature of material to a lower temperature of material. Fig. 5 shows the different of heat transfer which occur on 20nm and 100nm thickness of SiC. The red arrow shows the heat transfer flow from SiC material to GST material through insulator layer. For example, the P is power or energy that the 20nm thickness of SiC can hold and Q is a power or energy that the 100nm thickness of SiC can hold. The power or energy value, P is less compared with the power or energy value, Q.

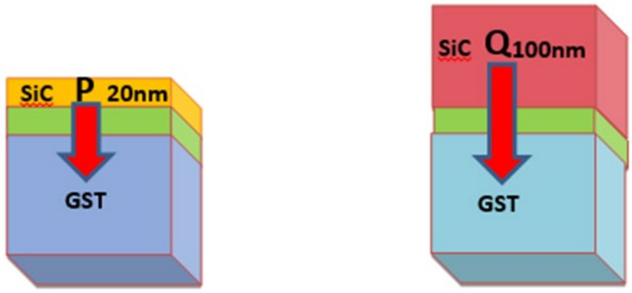

Fig. 5: The different heat transfer which occur on 20nm and 100nm thickness of SiC.

From the explanation above, there is some evidence that thickness of SiC may affect the temperature of GST and phase transition of GST. When the thickness of SiC is thick, the temperature of GST becomes high and the GST will change to crystalline state. Also, it can be concluded that the thickness of SiC can affect the power consumption of PCM.

4. Conclusion

The simulations of separate heater structure of PCM with different thickness of SiC were successfully simulated using the COMSOL Multiphysic 5.0 software. The 20nm thickness of SiC can reach the crystalline temperature at 1.2V with 100 ns pulse width. The 100nm thickness of SiC can reach the crystalline temperature at 0.8V with 100 ns pulse width. The phase transition of GST occurred when the applied voltage was 0.7V at 100 ns pulse width for 20nm thickness of SiC and applied voltage was 1.2V at 100 ns pulse width for 100nm thickness of SiC. From the result of simulation, the thickness of SiC can affect the temperature of GST and phase transition of GST. If the thickness of SiC was increased, the temperature of GST increased too and the rate of phase transition of GST was faster. It is because the power or energy value when the thickness of SiC is 100nm is more compared with the power or energy value when the thickness of SiC is 20nm. It can be concluded that the thickness of SiC may have been an important factor in the transformation of GST's phase and the temperature of GST. The low power consumption of PCM can be produced when the thickness of SiC is considered.

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