



The Effect of Channel Length on Phase Transition of Phase Change Memory

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Abstract

The phase transition of germanium antimony tellurium (GST) and the temperature of GST were investigated using COMSOL Multiphysics 5.0 software. Silicon carbide was used as a heater layer in the separate heater structure of PCM. These simulations have a different channel of SiC. The temperature of GST and the phase transition of GST can be obtained from the simulation. From the simulation, the 300 nm channel of SiC can change the GST from amorphous to crystalline state at 0.7V with 100 ns pulse width. The 800 nm channel of SiC can change the GST from amorphous to crystalline state at 1.1V with 100 ns pulse width. Results demonstrated that the channel of SiC can affect the temperature of GST and the GST changes from amorphous state to crystalline state. As the channel of SiC decreased, the temperature of GST was increased and the GST was changed to crystalline state quickly.

Keywords: Phase change memory; Separate heater structure; Silicon carbide; Channel of SiC; Heater layer.

1. Introduction

A non-volatile memory (NVM) is one of the technologies that plays an important role in the semiconductor market. Phase change memory (PCM) is one of the non-volatile memory. The history of phase change memory has begun when these devices were first proposed by S.Ovshinsky in late 1960s [1]. Phase change memory has a unique behavior of phase change material that can change from amorphous to crystalline using application of heat. The change from amorphous to crystalline enables data to be stored and the change from crystalline to amorphous allows data to be deleted. The research of PCM is enhanced over the decades due to high endurance, low programmable energy, fast switching speed, good data retention and excellent scalability [2], [3] [4].

PCM is based on repeated switching of phase change material between crystalline and amorphous state. Many types of phase change material used in semiconductor industry such as GeTe, GST, SbTe and many chalcogenide glass [5], [6]. Germanium-antimony-tellurium, $\text{Ge}_2\text{Sb}_2\text{Te}_5$ (GST) is a chalcogenide glass which is widely used in phase change memory industry [7]. High resistive and short-range atomic order are the characteristic of GST in amorphous state. However, when the GST is in crystalline state, it has a low resistivity and long range atomic order. The GST has a very high crystallization rate and very good reversibility between amorphous and crystalline phases [8]. The addition of Ge in GST can produce GST that has high thermal stability. The crystalline temperature of GST is 450K and the melting temperature of GST is 900K.

The heater layer that used in this work is silicon carbide (SiC) because this semiconductor can operate at the high temperature, high power, excellent shock resistance, low thermal expansion and the resistance of SiC did not change significantly at higher temperature [9], [10], [11]. The COMSOL Multiphysics 5.0 software was used for simulating the separate heater structure of PCM that

consist the memory layer, insulator layer, heater layer, 4 electrodes and capping layer [4], [5]. A. Lacita et al. (2006) proposed the PCM with 50ns-100ns but memory layer was heated directly by heater [8] whereas the Irma R, Kobayashi R, Zhang YL et al (2013) proposed the phase change memory structure with separate heater using Titanium Nitride (TiSi_3) as a heater layer [4], [5].

2. Experimental

In this work, the separate heater structure of PCM was used to obtain the temperature of GST and phase transition of GST. The advantage of this structure is the power can be controlled depend on the voltage pulse. This structure was simulated by using a COMSOL Multiphysics 5.0 software. The COMSOL Multiphysics 5.0 software has been used for finite element analysis, solver and simulation software for various physics and engineering applications. The figure 1 shows the material and the thickness of material that used in this simulation.

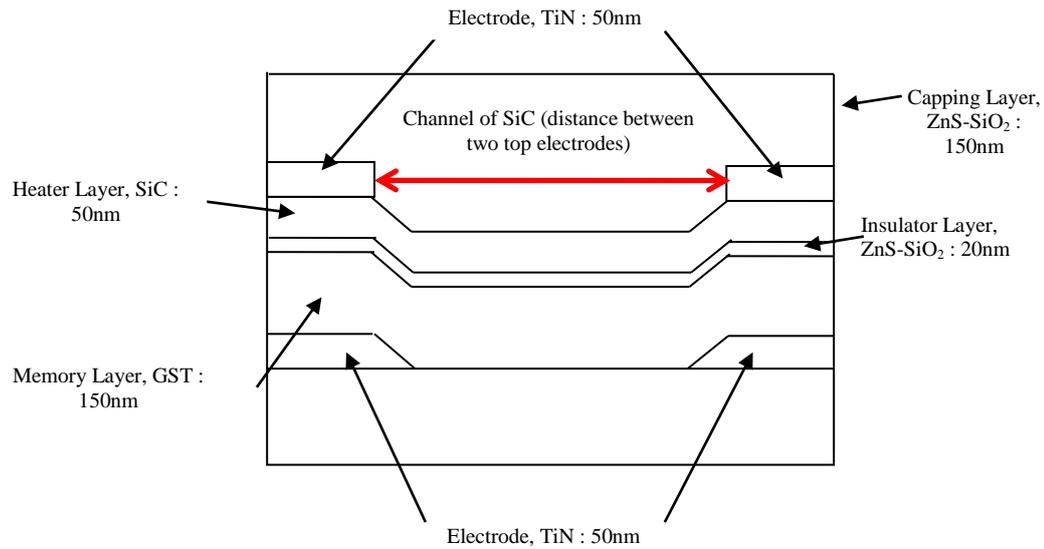


Fig. 1: The thickness for all material and the different channel of SiC that used in this simulation.

Table 1: The physical properties of material that used in this simulation.

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
Memory layer, a-GST	202	0.46	6200	3.6X10 ⁻¹
Memory Layer, c-GST	202	0.46	6200	2.0X10 ²

In this work, the simulation with different channel of SiC was simulated to determine the temperature of GST and the phase transition of GST. There are six differences thickness of channel of SiC: 300 nm, 400 nm, 500 nm, 600 nm, 700 nm and 800 nm were applied. Channel of SiC is a distance between the two top electrodes as can be seen at the Figure 1. The physical properties of material that used in this simulation can be seen on the table 1. The applied voltage with 100 ns pulse width was used at the two top electrodes. This voltage pulse heated up the heater layer and SiC material. The function of insulator layer is to ensure the heater layer not connected electrically to the memory layer, GST and the heat transfer occurred which cause the temperature of GST to increase. On the other hand, the temperature of GST and the phase transition of GST determined for every voltage that has been applied at the two top electrodes.

3. Result and Discussion

Table 2 shows the temperature of GST when using the different channel of SiC. The result of the simulation revealed that the different of channel of SiC could affect the temperature of GST, which the decreasing channel of SiC caused the temperature of GST increased. It is observed that the temperature of GST at 0.7V with 100ns pulse width is 468.39K when the channel of SiC is 300nm meanwhile the temperature of GST at 1.1V with 100ns pulse width is 468.22K when the channel of SiC is 800nm. Furthermore, the red color of temperature indicates that the GST already change from amorphous state to crystalline state. The WRITE process can be done and data can be stored. The figure 2 shows the temperature of GST with different channel of SiC.

Table 2: The temperature of GST when using the different channel of SiC.

Applied Voltage (V)	Temperature (K)					
	300nm channel of SiC	400nm channel of SiC	500nm channel of SiC	600nm channel of SiC	700nm channel of SiC	800nm channel of SiC
0.5	396.4	376.95	363.34	356.06	345.23	338.58
0.6	436.05	410.57	391.71	381.62	366.78	357.01
0.7	468.39	443.99	423.71	410.59	391.19	379.06
0.8	503.01	469.22	450.33	440.02	417.4	402.11
0.9	544.65	502.95	472.58	465.11	444.25	427.86
1	589.74	542.22	508.71	491.17	465.54	449.25
1.1	634.3	581.64	539.61	521.01	487.3	468.22
1.2	682	622.43	579.66	554.84	517.46	493.15
1.3	736.17	667.66	615.28	589.29	544.26	517.54
1.4	785.94	710.65	655.58	624.15	576.54	543.21
1.5	843.94	758.54	697.5	661.53	604.98	570.87
1.6	899.03	804.7	737.02	700.55	637.47	603.33
1.7	960.87	848.07	774.82	739.31	675.43	633.58
1.8		903.5	818.17	779.43	717.15	663.37
1.9			860.87	822.55	743.02	699.51
2			911.39	858.61	778.47	731.43
2.1				904.46	816.18	765.65
2.2				947.66	853.05	795.51
2.3					897.54	834.57

2.4				935.17	859.61
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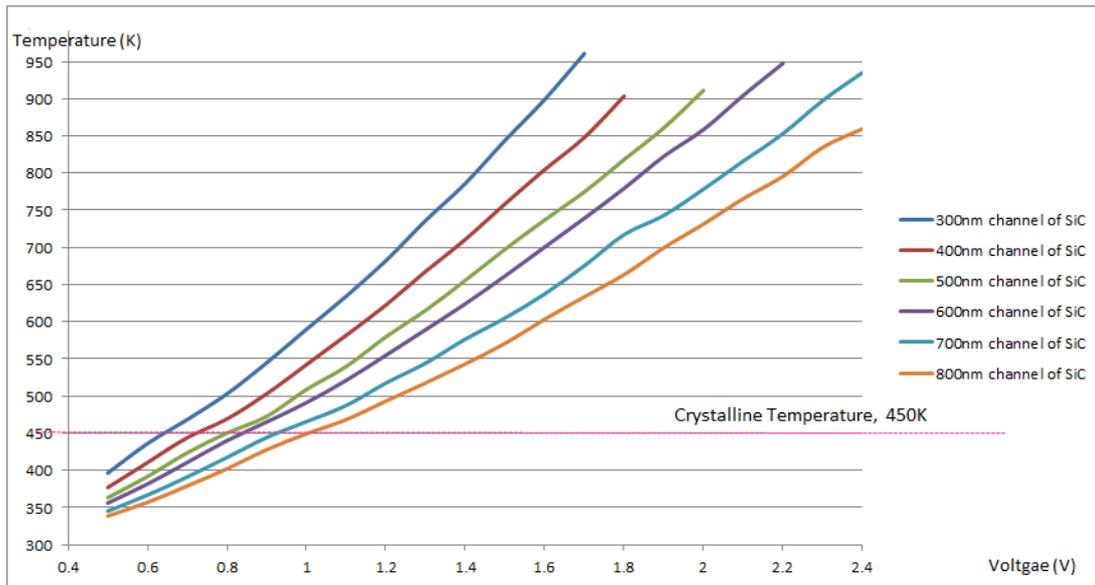


Fig. 2: The temperature of GST with different channel of SiC.

The table 3 shows the percentage of phase transition of GST for different channel of SiC. As can be seen, the applied voltage that changes the GST to crystalline state became increased when the channel of SiC decreased. Comparison between the results are when using the 300nm channel of SiC, the applied voltage is 0.7V with 100ns pulse width and when using the 800nm channel of SiC,

the applied voltage is 1.1V with 100ns pulse width. Therefore, the closer distance between the two top electrodes can make the GST changed to crystalline state quickly. The red color percentage represent the phase transition of GST whether the GST changes to crystalline state completely or not.

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

Applied Voltage (V)	Percentage of phase transition of GST for different channel of SiC					
	300nm channel of SiC	400nm channel of SiC	500nm channel of SiC	600nm channel of SiC	700nm channel of SiC	800nm channel of SiC
0.6	12%	0%	0%	0%	0%	0%
0.7	100%	32%	0%	0%	0%	0%
0.8	100%	100%	60%	18%	0%	0%
0.9	100%	100%	100%	95%	31%	0%
1.0	100%	100%	100%	100%	98%	52%
1.1	100%	100%	100%	100%	100%	100%
1.2	100%	100%	100%	100%	100%	100%

The figure 3 shows the phase transition of GST when the applied voltage is 0.6V and 0.7V with 100 ns pulse width for 300 nm channel of SiC. Figure 3 shows the phase transition of GST when the applied voltage is 1.0V and 1.1V with 100 ns pulse width for

800 nm channel of SiC. The red area at the Figure 3 and 4 show that the GST changes to crystalline state and blue area shows that the GST still in amorphous state.

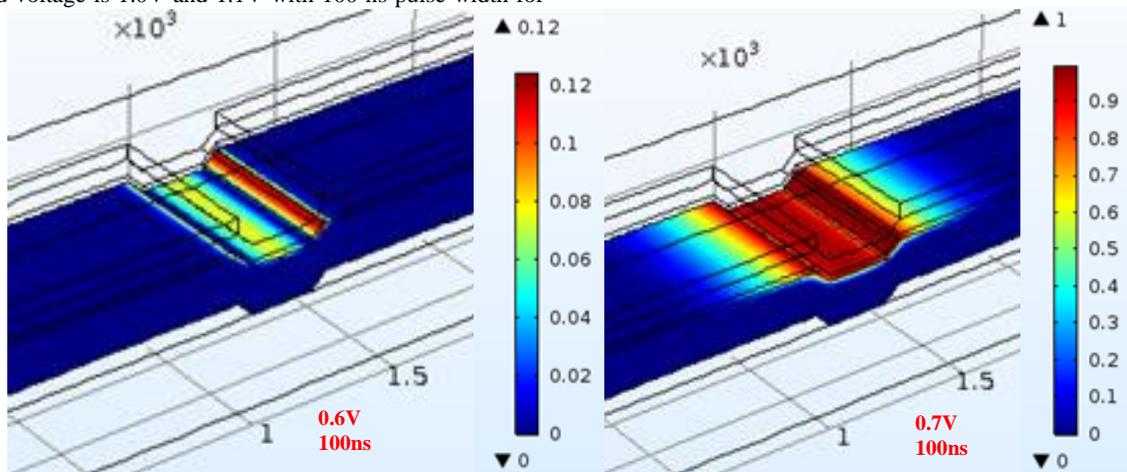


Fig. 3: The phase transition of GST for 300nm channel of SiC at 0.6V and 0.7V with 100ns pulse width.

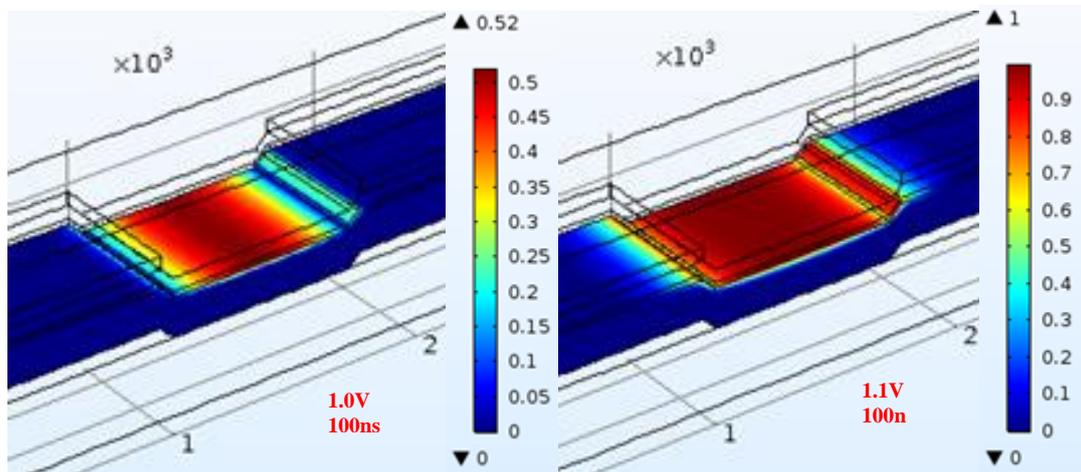


Fig. 4: The phase transition of GST for 800nm channel of SiC at 1.0V and 1.1V with 100ns pulse width.

From the figure 5, the ability of current to flow between the two top electrodes must be considered in this situation. If the two top electrodes are close, the ability of current to flow is very easy when the applied voltage was applied at the two top electrodes. When the current is flowing through the two top electrodes, it would heat up the SiC. As the temperature of SiC increase the joule heating process occur. The GST would be heated by the

heater layer (SiC). If the channel of SiC is slightly far, the ability of current to flow is very hard. It takes a time to heat up the heater (SiC) and also the GST too. The GST could change from amorphous state to crystalline state with an application of heat. This explain the channel of SiC is closely related to the ability of current to flow through the two top electrodes in this simulation.

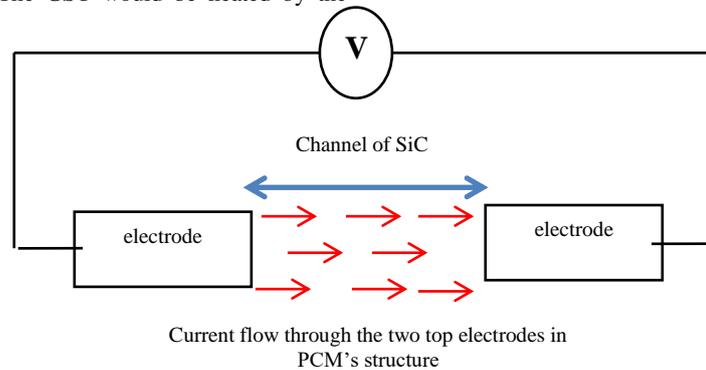


Fig. 5: The flow of current through the two top electrodes.

4. Conclusion

The simulations of separate heater structure of PCM with different channel of SiC were successfully simulated using the COMSOL Multiphysics 5.0 software. The 300 nm channel of SiC can reached the crystalline temperature at 0.7V with 100 ns pulse width meanwhile the 800 nm channel of SiC can reached the crystalline temperature at 1.1V with 100 ns pulse width. The phase transition of GST occurred when the applied voltage is 0.7V at 100 ns pulse width for 300 nm channel of SiC and applied voltage is 1.1V at 100 ns pulse width for 800 nm channel of SiC. The channel of SiC can affect the temperature of GST and phase transition of GST. The decreasing channel of SiC lead to the increase of GST temperature and the rate of phase transition of GST become faster. It can be concluded that the channel of SiC play an important role in the transformation of GST's phase and the temperature of GST.

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