High Speed Test System of Current Pulse for Phase Change Memory Devices

Yuhan Wang1, Ziqiang Zeng2*, Yuchan Wang3, Xia Xu1, Liangling Gu

1School of Electrical and Electronic Engineering, Chongqing University of Technology, Chongqing, 400054, China
2Department of electronic engineering, Chongqing Aerospace Polytechnic, Chongqing, 400021, China
3School of Optoelectronic Engineering, Chongqing University of Posts and Telecommunications, Chongqing 400065, China
*Corresponding author’s e-mail: zzq-8848@163.com

Abstract. The high-speed test system of current pulses for T-shaped phase change memory (PCM) cells has been studied. This system, which is able to provide the narrowest width of 500 ns, can apply direct current source pulses to the PCM device to do SET and RESET operation. The reliability of the system has been verified through the fixed resistor and the real PCM cells. The test results are presented and analyzed.

1. Introduction
Thanks to the high read/write speed, robust cycle endurance, high retention, and good scalability, chalcogenide glass phase change memory (PCM) has been considered as one of the most promising candidates for the future memories. By applying a low and long laser or electric pulse to the device, the memory state can be changed from amorphous to crystalline. This process is SET. Exerting a high and short laser or electrical pulse on PCM devices can make the memory state change from crystalline to amorphous, and this is called RESET [1-5].

The traditional test system for PCM devices uses direct current or voltage pulses to do the SET operation, and uses voltage pulses to do RESET operation [6-8], which makes it very difficult to obtain the dynamic process of the whole operation and difficult to accurately calculate the power consumption. On the other hand, some test system of current pulses reported in the literature can only apply millisecond pulses whose width is too wide for the operation of PCM [9]. In this work, a test system of current pulse for PCM devices is introduced and verified. The test results of PCM devices are also presented and analyzed.

2. Experiments
The new system introduced in this work is to complete the SET/RESET operation on PCM devices by using current pulses. Figure 1(a) shows the experimental setup of the test system. The pulse generator is a Tektronix AWG 5002B pulse generator which can only generate voltage pulses. The current pulses can be generated by a high-speed programmable constant current driver chip. In the whole test system, DC test is used to the current-voltage scanning and sensing the cell resistance while AC test is applied to carry out the resistance-current tests. The conversion between AC and DC programming...
paths is used by the bias tee. The oscilloscope in the system is a Tektronix DPO 7054, which can record the voltage across the PCM device in the test. The applied cells in our test are the T-shape PCM devices, which have been fabricated by 130nm CMOS technology. Figure 1(b) is the transmission electron microscope (TEM) image of the PCM device. The 80 nm tungsten (W) bottom electrode contact (BEC) is fabricated on the W plug, which is taken as the heater. The 100 nm thick Ge$_2$Sb$_2$Te$_5$ (GST) film is deposited on the BEC layer by physical vapor deposition (PVD) [10]. Between the GST film and the W top electrode contact (TEC), is the TiN layer as the adhesive layer.

3. Results and discussion

The reliability of the system has been verified through the fixed resistor firstly, which means the PCM device is replaced by a fixed resistor. In the experiment, the fixed resistor is 500 $\Omega$ which is close to the dynamic resistance of the PCM cell. Figure 2 (a), (b), (c) and (d) show the different results of the output voltage obtained from the oscilloscope by changing the given current amplitude. The given current amplitudes are 1 mA, 2 mA, 4mA and 6 mA, respectively. In the test, the pulses width is set as 100 ns. The theoretical values of the voltage amplitude can be calculated through the equation $V = I \times R$. In the test, the theoretical values are 0.5 V, 1.0 V, 2V and 3V. The actual test results show that the voltage amplitudes are 0.48 V, 0.93 V, 1.8V and 2.75 V, respectively. Comparing the waveforms in Fig. 2, it can be seen that the actual test results of the voltage amplitudes are all basic consistent with theoretical results, and all the results are slightly less than the theoretical values. It can also find that the amplitude attenuation becomes worse as the increase of the current amplitude, while the output waveform is getting better as the increase of the current amplitude. It is suggest that the amplitude attenuation is caused by the system circuit itself, which is inevitable and acceptable.

As shown in Fig. 3 is the result of the output voltage obtained from the oscilloscope by changing the given pulse width. For Fig.3 (a) and (b) the current pulse widths are 100 ns and 500 ns, respectively. The current amplitude is set as 1 mA in the test. There are some oscillations in the rising and falling edge of the pulse in Fig. 3 (a), which may result from the matching problem of the resistors in the system. As increasing the pulse width, the output waveform is getting better, which can be seen from the result in Fig. 3(b). It may be attributed to the drive capability of the high-speed programmable constant current driver chip. According to the above results shown in Fig. 2 and Fig. 3, the new system can generate direct current pulses and works properly when the load is fixed resistor.
Figure 2. Results of the output voltage obtained from the oscilloscope by changing the given current amplitude. The given current amplitudes are (a) 1 mA, (b) 2 mA, (c) 4 mA and (d) 6 mA, respectively.

Figure 3. Results of output voltage obtained from the oscilloscope by changing the given pulse width. The applied pulse widths are (a) 100 ns and (b) 500 ns.

To further verify the reliability of the system, the load is replaced by real PCM devices. Figure 4(a) shows the result of the resistance-current (R-I, RESET) measurement of the GST based PCM. The pulse width of the RESET operation is 500 ns, and the voltage of read operation is 0.1 V. The result indicates that the cell has been RESET successfully, and the current of RESET is about 2.4 mA, which is consistent with the data shown in some reports in the references [11-12]. The inset of Fig. 4(a) shows the current-voltage (I-V) curve of the PCM device, which shows the threshold voltage (Vth) is about 0.8 V. Electric phase switch characteristics of the GST based PCM with 80 nm BEC are shown in Fig. 4(b). The pulse width of the programming current is 3000 ns, and the read voltage is also 0.1 V. The reason to select the wide pulse width is to ensure the SET operation. A significant resistance reduction has been observed upon applying 3000 ns pulses above a threshold value of 0.8 mA. The large increase in resistance has also been observed above a threshold value of 2.2 mA. The R-I curve completely has been confirmed two distinct memory states with resistance varying over two orders of magnitude.
magnitude, as shown in Fig. 4(b). The results shown in Fig. 4 suggest that the test system of current pulses is reliable.

Figure 4. (a) Result of the resistance-current (R-I, RESET) measurement of the GST based PCM. (b) Electric phase switch characteristics of the GST based PCM. Inset in (a) is the I-V curve of the PCM cell.

4. Conclusion
In summary, a high speed test system of current pulses for T-shaped PCM cells, which can provide the narrowest width of 500 ns, has been set up and studied. Firstly, the reliability of the system has been verified through the fixed resistor, and the test results basically consistent with the theoretical value. The R-I test of the GST based PCM cells has been carried out by using the new system, and the results fourth show that the system is reliable and useful.

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