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Resistance random access memory

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Non-volatile memory (NVM) will play a decisive role in the development of the next-generation of electronic products. Therefore, the development of next-generation NVM is urgent as widely applied flash memory is facing its physical limit. Among various next-generation NVMs, Resistive Random Access Memory (RRAM) is a promising candidate for future memory due to its high-efficiency, high-speed and energy-saving characteristics. In recent years, continuous improvement and in-depth investigation in both materials and electrical switching mechanisms have not only lead to a breakthrough in the performance of digital NVM, but also lead to other possible memory functionality. This paper describes new findings and perspectives on various RRAM devices with different laminated structures and materials, and classifies RRAM into four categories according to different resistive switching mechanisms, from which the four elements are (1) anion-type RRAM: redox reaction and migration of oxygen ions, (2) cation-type RRAM: redox reaction and migration of cation ions, (3) carbon-based RRAM: the stretch of C–C bond lengths due to oxygen and hydrogen dual ions, (4) oxide-based electrode: oxygen accumulation in oxide-based electrode.

Introduction

The history of mankind would be unknown, if it were not for records. Humans record and pass down knowledge from generation to generation. The object responsible for receiving and recording information is called memory. Two essential elements, the signal and carrier, must be contained in the memory. To spread knowledge, humans have developed various carriers from natural materials, such as stone, metal, and wood. Throughout human history, storage media have evolved. From knots to slates, from bone and bronze utensils, to bamboo slips. Because these carriers are cumbersome, their records cannot be widely spread. Since the invention of paper in approximately 1 A.D., humanity entered a formal age, which has recorded history using paper as the carrier. The invention of printing allowed knowledge to be readily copied in large volumes, and spread around the world. The development of carriers grants mankind the ability to share achievements and pass them down to the next generation. With the advent of the digital era, we all now have the power to carry a library in our pocket, as shown in Fig. 1a. Since the invention of digital memory, in such forms as punched cards, tapes, hard disks, and now the extensively used flash memory invented by Sze [1,2], the capacity, density, and speed of digital memory have continued to increase.

Striving to enhance memory to pass on knowledge is the responsibility of all mankind; as such, investigation into the next generation of memory technology is required. Next generation novel memory has been extensively researched, such as ferroelectric random access memory (FeRAM), phase-change random access memory (PCRAM), magneto resistive random access memory (MRAM), and resistive random access memory (RRAM), as shown in Fig. 1b [3–14].

In the next generation of digital technology – including forward-looking consumer electronics and the Internet of Things

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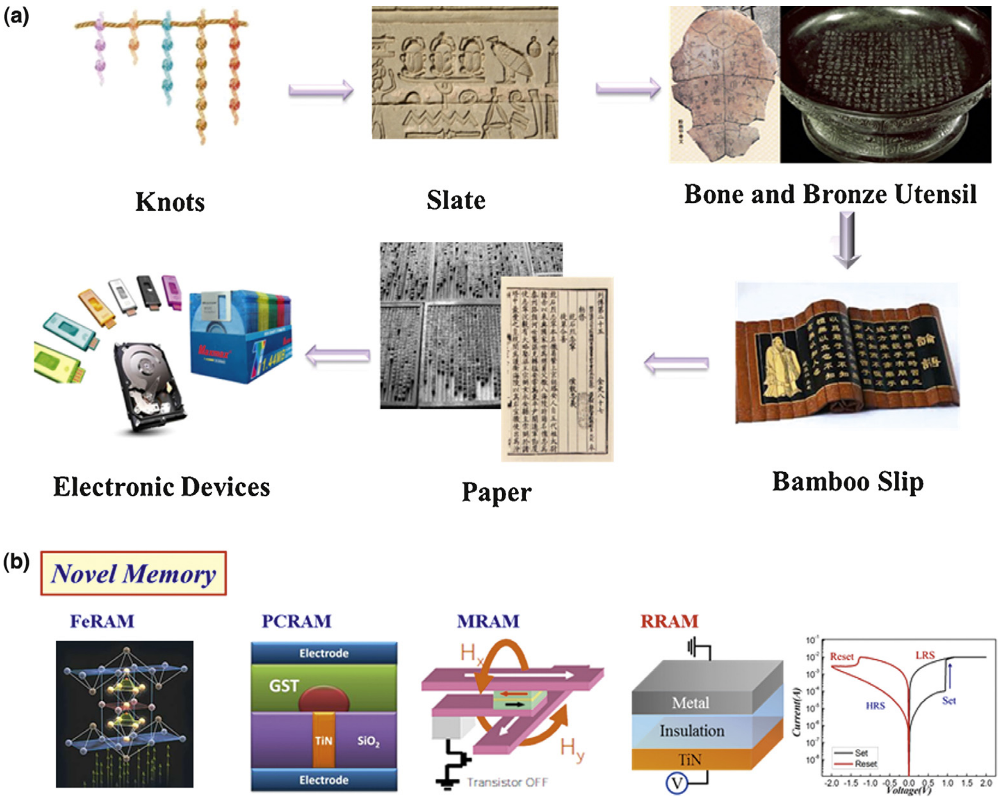

FIGURE 1

(a) A flowchart of the evolution of memory. (b) Next generation non-volatile memory including FeRAM, PCRAM, MRAM, reprinted with permission from [14]. © 2013 IOP Publishing Ltd, and RRAM.

(IoT) – non-volatile memory (NVM) will play a decisive role. Currently, non-volatile flash memory has been widely applied in electronic devices. However, flash memory cannot keep pace with the sustained reduction is dimensions while simultaneously fulfilling storage needs, due to the physical limit of the gate oxide.

RRAM is a good direction for the development of future memory technology. In recent years, continuous improvements and in-depth investigations in both materials and electrical switching mechanisms have demonstrated a breakthrough in the performance of RRAM. Based on the comparison of various digital memories shown in Table 1, RRAM is the most promising candidate for next generation memory due to its advantages in both working memory and main memory. Like working memory, RRAM has very low operation voltage and power, extremely fast write/erase speeds, and great reliability. Like main memory, RRAM is non-volatile, and has great storage capacity. Moreover, due to the excellent compatibility with integrated circuit (IC) processes and scaling capability, RRAM has great potential for commercialization and production [15–23].

In RRAM device research, using the via hole type structure in the manufacturing process to clarify the physical mechanism and electrical measurements is preferable. Moreover, such a structure

TABLE 1

Comparison of properties of various semiconductor memory devices.

Function	Working memory		Both functions	Main memory		
	DRAM	SRAM	RRAM	CD	Hard disk	Flash
Non-volatility	No	No	Yes	Yes	Yes	Yes
Program power	Low	Low	High	High	High	High
Program voltage	Low	Low	Low	High	High	High
Read dynamic margin	100–200 mV	100–200 mV	10×–1000×	Read head	Read head	Delta current
Write/erase time	8–50 ns	1–8 ns	0.3–30 ns	10 ms	10–30 ms	1 μs/1–l00 ms
Read time	50 ns	8 ns	20 ns	0.1 μs	0.1 μs	50 ns
Program energy	Medium	High	Low	High	High	High
Multi-bit storage	No	No	Yes	No	No	Yes
Scalability limits	Capacitor	6T	Litho	Read Head	Read Head	T-Ox/HV
Endurance	∞	∞	10^{12}	OTP	$>10^{12}$	10^{12}