Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp91-92

Highly reliable ReRAM for embedded memory and beyond applications

Shinichi Yoneda , Satoru Ito, Yukio Hayakawa, Zhiqiang Wei, Shunsaku Muraoka, Kazunari Homma, Ryutaro Yasuhara, Koichi Kawashima, Atsushi Himeno, Reiji Mochida, Hideto Kotani, Kazuyuki Kouno, Takumi Mikawa, Yasushi Gohou, and Toru Kakiage

Panasonic Semiconductor Solutions Co., Ltd.,
1 Kotari-yakemachi, Nagaokakyo, Kyoto 617-8520, Japan
Phone: +81-50-3783-5564 E-mail: yoneda.shinichi@jp.panasonic.com

Abstract

We have developed a 40nm ReRAM technology embedded in a foundry-standard CMOS process for low power applications. Excellent reliability was achieved in 8-Mbit 40-nm ReRAM: 100k cycles and 10 years' retention at 85 ˚C after 10k cycles were demonstrated resistive switching element process technologies and filament characterization methods. The potential to widen the range of ReRAM applications, such as their use in analog neuromorphic devices for low-power neural network processors and hydrogen sensors based on ReRAM technology, are also described.

1. Introduction

In the future, in order to correspond with the IoT era when "things" are connected by the network, it is indispensable to drive low battery powered and high-speed processing devices. For that purpose, a nonvolatile memory of low power consumption, high speed operation, and large capacity is required, and resistance variable type nonvolatile memory (ReRAM: Resistive Random Access Memory) is attracting attention as a promising candidate.

Panasonic started the mass production of 0.18µm ReRAM for wearable and healthcare applications in 2013. We have developed a 40nm ReRAM technology embedded in a foundry-standard CMOS process in order to meet wider application with higher memory capacity and power efficiency [1, 2]. In this paper, we describe process and device technologies that realize a 40nm ReRAM process and its results, using an 8 Mbit ReRAM array as a test vehicle. ReRAM-based devices for artificial intelligence (AI) and solutions for a hydrogen economy (Fig. 1), are also demonstrated.

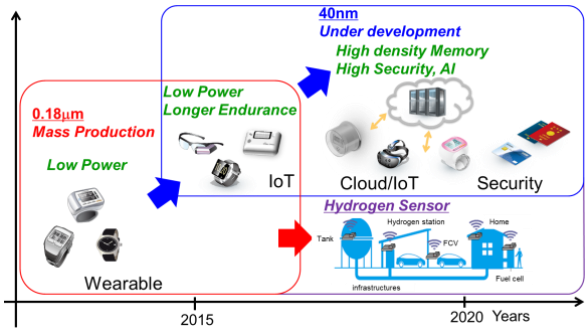


Fig.1. Panasonic ReRAM development and its applications

2. 40nmReRAM reliability

First, we describe the operation mechanism of ReRAM. ReRAM forms conductive filaments in a Ta_2O_5 layer having insulating properties by first performing an electrical process called forming. This conductive filament is formed at one location in the Ta_2O_5 layer. It is considered that the mechanism of the resistance change of the oxidation / reduction type ReRAM is that oxygen ions move in accordance with the voltage applied to the electrode, and the resistance value changes due to the increase or decrease of oxygen defects in the conductive filament (Fig. 2).

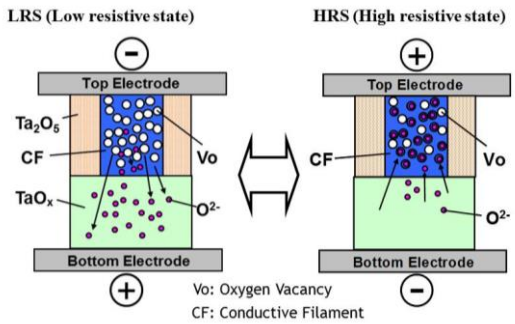
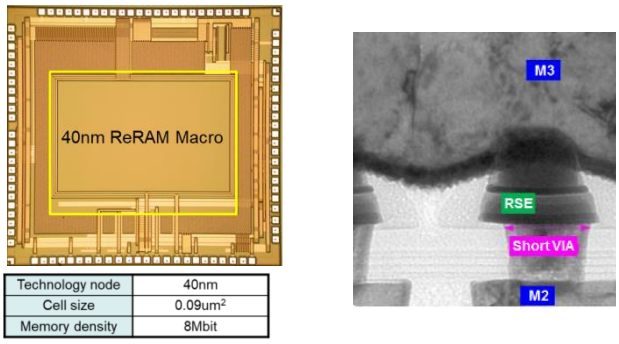


Fig.2. Mechanism for resistance switching of ReRAM

Based on this mechanism, we controlled the parameters of Ta_2O_5 and TaO x and improved the reliability of memory.

The 8 Mbit ReRAM macro chip shown in Fig. 3(a) was used as the test vehicle. Fig. 3(b) was the cross-section of ReRAM cell. The cell's characteristics, endurance and retention properties performances were evaluated.



Technology node	40nm
Cell size	0.09um²
Memory density	8Mbit

(a) (b)

Fig.3. (a) 8Mbit ReRAM macro chip as test vehicle.
(b) cross-sectional TEM images of 40nm ReRAM

Figure 4(a) shows HRS and LRS distributions before testing and their 100k cycle endurance characteristics. A sufficient memory window was maintained after testing. Data retention after 10k cycles is also shown in Fig. 5(b): its corresponding lifetime at 85 ˚C was over 10 years.

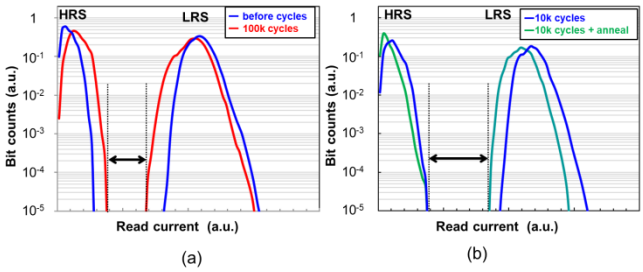


Fig.4.
(a) LRS/HRS cell current distributions after 100k cycle's endurance.
(b) Data retention after 10k cycles over 10years at 85℃.

3. New approaches for beyond applications

Based on our ReRAM mechanism and technologies, we have developed new devices for AI and hydrogen gas sensor.

(1)Resistive Analog Neuro Device (RAND)

Deep neural networks (DNN) are attracting attraction because of their self-learning and highly accurate inference capabilities. On the other hands, power consumption is one of the issues for high performance operations of GPU.

Figure 5 shows a simple example of numeric recognition and the concept of the Resistive Analog Neuro Device (RAND). Analog RSEs and diodes are formed and stacked in multiple layers like a cross-point cell, with each layer acting as a single neural network layer. This RAND device has the potential to realize greater power efficiency than existing GPU/CPU-based processors.

We have designed and fabricated a RAND chip with 0.18μm ReRAM mass production process, which can flexibly implement various NN architectures in a single chip, and demonstrated a good numerical recognition result with high power efficiency [4].

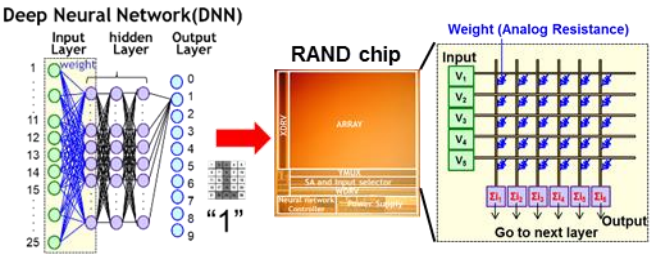


Fig.5. RAND concept

(2) Resistive Hydrogen Sensor (ReH sensor)

Unitizing the resistive switching mechanism in the filament, a novel hydrogen sensor with an optimized 0.18-μm ReRAM process has been developed to enhance the safety of a hydrogen-based economy. Figure 6 shows the concept of this ReH sensor. Pt, because of its catalytic properties, replaces Ir as the top electrode. H+ ions are created from H2 via the Pt electrode, which then react with the oxide in the filament, causing the resistive state of the sensor to change from HRS to LRS. On applying a reverse bias or by exposure to atmospheric air, the sensor returns to the HRS state. It can thus be used repeatedly. Conventional hydrogen sensors require a heater and operate by burning H2, so they are energy-draining and need to operate in an oxygen-containing atmosphere. However, the ReH sensor does not require a heater, and can work in the absence of oxygen, owing to its unique mechanism of action.

We have designed and fabricated a ReH sensor chip.The power consumption of this sensor is less than 1/10,000 of that a conventional sensor with a heater, and good selectivity against other gases. It has potential for ultra-low-power hydrogen-sensing applications, such as battery-operated modules for the IoT[5].

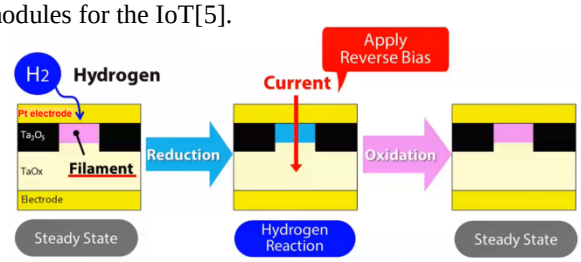


Fig.6. ReH sensor concept

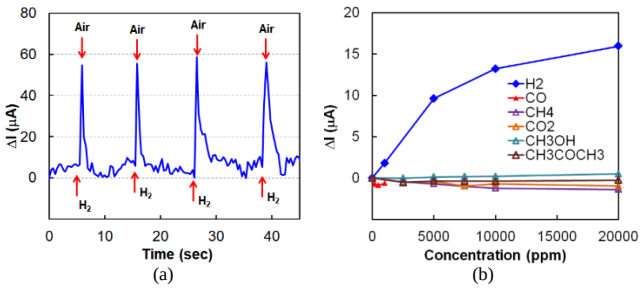


Fig.7. Characteristics of ReH sensor

(a) Repetition property of 100% H2 reaction

(b)Selectivity against other gas

4. Conclusions

Excellent reliability of 100k cycles and 10 years' retention at 85 ˚C after 10k cycles were demonstrated using an 8-Mbit test vehicle which constructed in a mass production line for 40nmCMOS embedded ReRAM.

The new approaches of ReRAM, which are RAND and a ReH sensor, will expand the fields of other applications for ReRAM devices. RAND chip and ReH sensor chip were also demonstrated unitizing 0.18-μm ReRAM process.

Acknowledgements

The author wishes to thank Guo An Du ,Jiann Fu Chen, Stanley PL Yeoh, and Mars HY Chen(UMC),G.S. Kar and L. Goux (Imec), Y. Naitoh, H. Shima and H. Akinaga (AIST) , Y. Konishi, T. Yamada, H. Miyatake, K. Suzuki, and T. Iwami(New Cosmos Electric Co.,Ltd.) for collaboration in this study. "RAND" work in the pa per was supported by NEDO program.

References

[1] Y. Hayakawa, et al., VLSI Tech. Dig. (2015) T14-T15.
[2] Z. Wei, et al., IEDM Tech Dig. (2011) pp.721-724.
[3] S. Ito, et al., IMW Tech. Dig. (2018) 153-156.
[4] R. Mochida, et al., VLSI Tech. Dig. (2018) T175-176.
[5] Z. Wei, et al., VLSI Tech. Dig. (2018) T63-64.