

Nanoguided filament approaches for reliable RRAM

G.Niu,^{1*} P. Calka,² M. Auf der Maur,³ F. Santoni,³ M. Fraschke,² P. Hamoumou,⁴ B. Gautier,⁴ E. Perez,² C. Wenger,² A. Di Carlo,³ T. Schroeder^{2,5}

¹ Electronic Materials Research Laboratory, Key Laboratory of the Ministry of Education & International Center for Dielectric Research, Xi'an Jiaotong University, Xi'an 710049, China.

²IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany

³Dept. Electronics Engineering University of Rome "Tor Vergata" via del Politecnico 1, 00133 Roma, Italy

⁴INL, UMR CNRS 5270, INSA de Lyon, 7 Avenue Jean Capelle, 69621 Villeurbanne, France

⁵Brandenburgische Technische Universität, Konrad-Zuse Strasse 1, 03046 Cottbus, Germany

*Corresponding author: ganguiu@xjtu.edu.cn

Abstract

Filament-type HfO₂-based RRAM has been considered as one of the most promising candidates for future non-volatile memories. Further improvement of the stability, particularly at the "OFF" state, of such devices is mainly hindered by resistance variation induced by the uncontrolled oxygen vacancies distribution and filament growth in HfO₂ films. We report highly stable endurance of TiN/Ti/HfO₂/Si-tip RRAM devices using a CMOS compatible nanoguided filament method. Simulations indicate that the nanotip bottom electrode provides a local confinement for the electrical field and ionic current density; thus a nano-confinement for the oxygen vacancy distribution and nano-filament location is created by this approach. The filaments form only on the nanotip region. Resistance switching by using pulses shows highly stable endurance for both ON and OFF modes, thanks to the geometric confinement of the conductive path and filament only above the nanotip. This nano-engineering approach opens a new pathway to realize forming-free RRAM devices with improved stability and reliability.

1. Introduction

Resistance switching random access memory (RRAM) has recently attracted intense interests as a strong candidate of non-volatile storage media for wireless sensor networks and neuromorphic computation applications [1]. HfO₂ based RRAM demonstrates compatibility with complementary metal oxide semiconductor (CMOS) processing, fast and low power switching and excellent scaling capability [2-6]. The low/high resistance states of HfO₂ RRAM devices are achieved by forming/breaking a conductive filament (CF) consist of a chain of oxygen vacancies (V_{O}). A better control of V_{O} distribution dynamics is necessary to improve resistance state variations for reproducible cycle-to-cycle operation.

In this work, we present our recent results on improving the reliability of RRAM devices, particularly using an effective geometric approach to confine the filament location so that we are able to achieve highly stable endurance and retention of HfO₂ RRAM devices.

2. Experimental

The TiN/Ti/HfO₂/CoSi₂/Si-tip devices were processed in a standard 0.25 μ m CMOS process line [3]. The structural properties of the HfO₂ thin films were characterized by X-ray diffraction, transmission electron microscopy (TEM). In order to image the confined leakage currents, tunnelling atomic force microscopy (TUNA) was carried out using a Pt-Ir coated tip. Finite element method (FEM) were used to calculate both the electrical field and ionic current density distributions. The electrical characterization of the devices was achieved with a Keithley SCS4200

semiconductor analyser using the I-V sweep and the pulse modes.

3. Results and Discussion

Fig.1 shows an overview of the device. FEM calculations (Fig. 2 (a)) evidence a local confinement of the electrical field as well as the ionic current density, which reaches a maximum value at the nanotip edge regions. TUNA studies confirm the nanofilament formation above the nanotip electrodes. The nanotip based devices show good RS properties including the forming-free feature (Fig. 2 (b)), the stable endurance (Fig. 3) and retention (Fig. 4).

4. Conclusion

We developed a RRAM device with geometric confinement of the V_{O} distribution and nanofilament location. The nanotip based devices show good RS properties including forming-free, stable endurance and retention. Our results demonstrate a route to CMOS compatible devices and an effective way to control cycle-to-cycle resistance switching in RRAM technology.

References

- [1] K.Zhang, Embedded Memories for Nano-Scale VLSIs (2009, Springer).
- [2] R.Waser, Nanoelectronics and Information Technology 3rd edn, 692 (2012, Wiley-VCH).
- [3] G.Niu et al. Sci. Rep. 6 (2016) 25757.
- [4] G.Niu et al. Sci. Rep. 6 (2016) 28155.
- [5] G.Niu et al. J.Phys. Chem. C, 121 (2017),7005–7014.
- [6] G.Niu et al. Nanotechnology, 28(2017),215702.

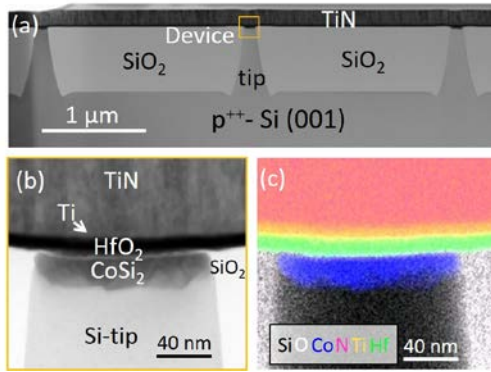


Fig.1: STEM-EDX performed on the cross-section of a TiN/Ti/HfO₂/CoSi₂/Si tip device. (a) STEM image overview showing three Si tips; (b) High magnification STEM image on the squared device part in (a). (c) EDX chemical analysis of the same region in (b).

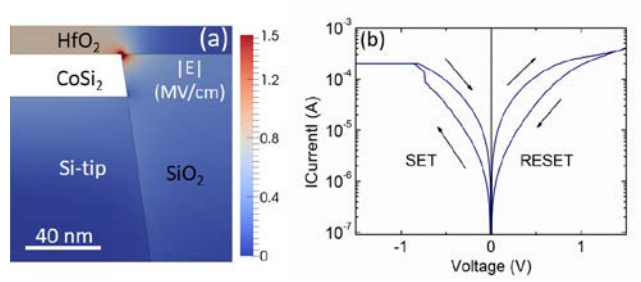


Fig.2: (a) FEM calculated maps of Ti/HfO₂/CoSi₂/Si-tip heterostructure on a 2D slice in 3D cylinder coordinates of the electrical field distribution. (b) Typical DC sweeps showing the evolution of the current intensity as a function of the voltage.

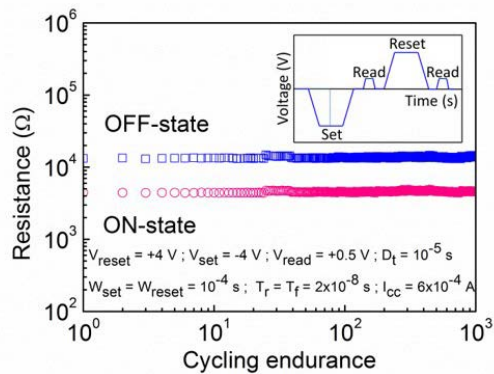


Fig.3: Pulse cycling endurance showing the evolution of the OFF- and ON-resistance states as a function of the number of cycles. The experimental details are shown in the inset and remarks in the figure.

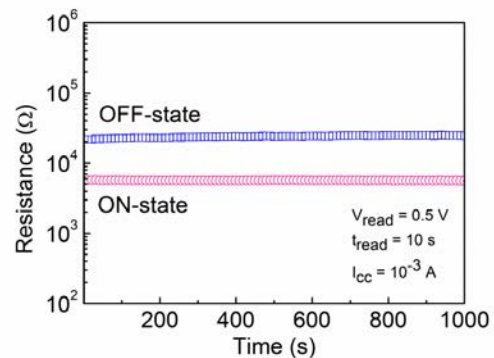


Fig.4: Retention measurement performed at room temperature with experimental details shown in the figure remarks.