

# Resistive Random Access Memory

Ke Xiang Wei, Yu Hang Yang

**Resistive Random Access Memory (RRAM)** Shimeng Yu, 2022-06-01 RRAM technology has made significant progress in the past decade as a competitive candidate for the next generation non-volatile memory (NVM). This lecture is a comprehensive tutorial of metal oxide-based RRAM technology from device fabrication to array architecture design. State-of-the-art RRAM device performances, characterization, and modeling techniques are summarized, and the design considerations of the RRAM integration to large-scale array with peripheral circuits are discussed. Chapter 2 introduces the RRAM device fabrication techniques and methods to eliminate the forming process, and will show its scalability down to sub-10 nm regime. Then the device performances such as programming speed, variability control, and multi-level operation are presented, and finally the reliability issues such as cycling endurance and data retention are discussed. Chapter 3 discusses the RRAM physical mechanism, and the materials characterization techniques to observe the conductive filaments and the electrical characterization techniques to study the electronic conduction processes. It also presents the numerical device modeling techniques for simulating the evolution of the conductive filaments as well as the compact device modeling techniques for circuit-level design. Chapter 4 discusses the two common RRAM array architectures for large-scale integration: one-transistor-one-resistor (1T1R) and cross-point architecture with selector. The write/read schemes are presented and the peripheral circuitry design considerations are discussed. Finally, a 3D integration approach is introduced for building ultra-high density RRAM array. Chapter 5 is a brief summary and will give an outlook for RRAM's potential novel applications beyond the NVM applications.

*Resistive Random Access Memory (RRAM)* Shimeng Yu, 2016-03-18 RRAM technology has made significant progress in the past decade as a competitive candidate for the next generation non-volatile memory (NVM). This lecture is a comprehensive tutorial of metal oxide-based RRAM technology from device fabrication to array architecture design. State-of-the-art RRAM device performances, characterization, and modeling techniques are summarized, and the design considerations of the RRAM integration to large-scale array with peripheral circuits are discussed. Chapter 2 introduces the RRAM device fabrication techniques and methods to eliminate the forming process, and will show its scalability down to sub-10 nm regime. Then the device performances such as programming speed, variability control, and multi-level operation are presented, and finally the reliability issues such as cycling endurance and data retention are discussed. Chapter 3

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*Resistive Random Access Memory* Arnab Hazra, 2012-04 Resistive Random Access Memory (RRAM) is a transistor free non-volatile dynamic RAM cell with very simple Metal-Insulator-Metal (MIM) structure and very high switching speed and high density memories. Different types of oxides like Transition Metal Oxides, Perovskite Oxides etc are used as the insulating dielectric layer of the capacitor like MIM structure. This ion-conducting oxide insulating layer can change its resistance by externally stimulated electric pulses with different amplitude and frequency. The steps precondition the system which can subsequently be switched between high conductive ON or Low Resistive State (LRS) and a less conductive OFF or High Resistive State (HRS). In this experimental study Sol-gel derived Titanium Dioxide (TiO<sub>2</sub>) is considered as the ion conducting insulating dielectric material of this RRAM device. Pd (Ag)/TiO<sub>2</sub> /Pd (Ag) Metal-Insulator-Metal structure for RRAM devices have been designed and fabricated and studied in this book. Different analytical models and explanations to establish the mechanism behind the Transition metal oxide based RRAM device and Resistive Switching phenomenon are the addition features of this book.

Study on the Copper-Based Resistive Random-Access-Memory (RRAM) Devices , 2014

Nanotechnology Shilpi Birla, Neha Singh, Neeraj Kumar Shukla, 2022-03-02 This reference text discusses recent advances in the field of nanotechnology with applications in the fields of electronics sector, agriculture, health services, smart cities, food industry, and energy sector in a comprehensive manner. The text begins by discussing important concepts including bio nanotechnology, nano electronics, nano devices, nano medicine, and nano memories. It then comprehensively covers applications of nanotechnology in different areas including healthcare, energy sector, environment, security and defense, agriculture sector, food industry, automotive sector, smart cities, and Internet of Things (IoT). Aimed at senior undergraduate, graduate students and professionals in the fields of electrical engineering, electronics engineering, nanoscience and nanotechnology, this text: Discusses nano image sensors useful for imaging in medical and for security applications. Covers advances in the field of nanotechnology with their applications. It covers important concepts including neuro simulators, nano medicine, and nano materials. Covers applications of nanotechnology in diverse fields including

health sector, agriculture, energy sector, and electronics.

**The Efficacy of Programming Energy Controlled Switching in Resistive Random Access Memory (RRAM)** David Malien Nminibapiel, 2017

**Cerium Oxide Based Resistive Random Access Memory Devices** Cheng-Chih Hsieh, 2017 Resistive Random Access Memory (RRAM) is an emerging technology of non-volatile memory (NVM). Although the observation of metal oxide that can undergo an abrupt insulator-metal transition into a conductive state has been known for over 40 years, researchers started investigating those materials for memory applications in late 1990s. It has been considered as the next generation memory technology to replace current flash memory because RRAM has demonstrated feasible switching characteristics and potential to build high density arrays and also RRAM is also compatible with contemporary CMOS processes, which means RRAM can be integrated into current CMOS chips. While the structure of RRAM is a simple metal-insulator-metal (MIM) device, there are numerous materials that exhibit resistive switching. The switching behavior is not only dependent on the switching layer materials but also dependent on the choice of metal electrodes and their interfacial properties. Many metal oxides such as hafnium oxide, titanium oxide, aluminum oxide, nickel oxide (NiO), tantalum oxide and etc. have been studied in details; however, some materials are unexplored such as cerium oxide. In addition to nonvolatile storage applications, RRAM is considered as one of essential elements for advancing neuromorphic computing because of its analog switching and retention characteristics. This thesis investigated CeO<sub>x</sub>-based RRAMs, from its fundamental device characteristics to neuromorphic applications.

**Nano Hybrids and Composites Vol. 37** Amir Al-Ahmed, Yun-Hae Kim, 2022-08-31 Articles collected in this issue present to readers the results of applied nano research. The various nanoparticles were studied and analysed for applications in microelectronics, sensors, biosensors, and devices for energy storage and conversion. The properties of structural nanocomposites based on graphene and nano cellulose were considered in some articles. There was also an analysis of the use of nanomaterials in archaeological object restoration. This volume will be helpful to specialists in nanomaterials and nanotechnologies applications.

**Understanding of Oxide Based Resistive Random Access Memory Devices with Multi-level Resistance States and Application** Wenbo Chen, 2016 Non-volatile memory (NVM) are broadly used in removable media storage, smart phones, solid-state drive, etc. and flash memory technology has been dominating NVM market for over 20 years. However, further scaling of flash memory beyond sub 20 nm node brings tremendous challenges in device performance. For further scaling of Non-Volatile Memory technology beyond flash memory devices, Resistive Random Access Memory (ReRAM) devices have been proposed as a promising candidate due to its superior device performance and CMOS compatible process flow. This dissertation focuses on three aspects of ReRAM research, multi-level cell (MLC) storage capacity, ReRAM crossbar

array integration, and ReRAM practical application. In MLC part, multi-step forming technology was developed to substitute traditional one step forming in which current overshoot was suppressed and four stable resistance states were obtained. A comprehensive electrical characterization was conducted and trade-offs among different states were studied. In the section detailing crossbar integration, switchable diode based ZnO ReRAM device was identified as one of the promising candidates. Ru/ZnO/TiN/W stack demonstrated forming-free, self compliance-current controlled, non-volatile, switchable diode type ReRAM characteristics in crossbar arrays which establishes potential application as high-density non-volatile memory. Finally, a complete voice cognitive system was built utilizing MLC ReRAM crossbar array to demonstrate functionality at the simulation level. With these contributions, this work has established solid guidance for future ReRAM fabrication and characterization as well as hardware system realization.

Advances in Applied Materials and Electronics Engineering II Brendan Gan, Yu Gan, Y. Yu, 2013-04-24 Selected, peer reviewed papers from the 2013 2nd International Conference on Applied Materials and Electronics Engineering (AMEE 2013), April 19-20, 2013, Hong Kong

**An Investigation of Resistive Random Access Memory** William Barker, 2019 This study evaluates two electron resonance spectroscopy techniques on an emerging memory technology, resistive random access memory. The first is electrically detected magnetic resonance, which is a well established spectroscopic technique used to investigate nanoelectronics. The second technique is near-zero field magnetoresistance, which is a new tool with the potential to provide information and functionally that electrically detected magnetic resonance cannot currently provide. 10 nm tantalum oxide resistive random access memory in a partially formed state was swept across 80 G centered at 0 G and with a 5 G modulation field. This analysis revealed a broad, asymmetric zero-field response, but no resonance response was present above the noise in the system. This study provides a preliminary spectroscopic analysis of resistive random access memory and is the first reported use of near-zero field magnetoresistance spectroscopy on a resistive random access memory device. While it does not provide any substantial evidence to support claims about the controversial formation and switching mechanisms discussed in current literature on resistive random access memory, this study provides clear evidence that further development of near-zero field magnetoresistance spectroscopy will be useful for the investigation of devices that are currently difficult to study with previously established electron resonance spectroscopy techniques.

*Interface Engineering in Binary Metal Oxide Based Resistive Random Access Memory (RRAM) Devices* Sheng-Yu Wang, Tseung-Yuen Tseng, 2011

Resistive Switching Random Access Memory (RRAM) - Scaling, Materials, and New Application Yi Wu, 2013 The demand for solid-state memories has been increasing rapidly in recent years thanks to the increasing demand from portable electronic devices like smartphones and tablets. Semiconductor non-volatile memories (NVMs), such as NAND and NOR

Flash, is the fastest-growing segment in today's solid-state memories. Looking forward, the further scaling of flash memory devices is becoming more challenging: (1) the high electric fields required for the programming and erase operations; (2) the stringent leakage requirements for long term charge storage. While innovations in cell structure and device materials may help extend Flash memory for another couple of technology nodes, alternative memory solutions must be explored for future non-volatile memory applications. There are varieties of emerging memory technologies being researched as possible candidates for next-generation NVM, such as Phase Change Memory (PCM), Spin Torque Transfer Magnetic Random Access Memory (STT-MRAM), and Resistance Switching Random Access Memory (RRAM), etc. Among these candidates, metal oxide RRAM has attracted plenty of attention in the past a few years. It is one of the most promising candidates for future NVM application for its superior scalability, fast speed, low programming current, long endurance, excellent read immunity, and good retention properties. However, in order to meet the practical application requirements, the RRAMs demonstrated to date still need improvements in the following areas: (1) further scaling down the device size; (2) minimize the switching parameters variations; (3) eliminating the forming process. This thesis aims at addressing and elucidating the above challenges and exploring possible solutions through innovations in device materials and structures, new fabrication techniques, and understanding the device physics through comprehensive device characterizations. While RRAM has the potential as a non-volatile memory technology, another emerging application is the use of RRAM as electronic synapse element for hardware implementation of neuromorphic computing. Due to RRAM's multilevel storage capability and low power consumption, it can behave like an analog memory emulating the function of plastic synapses in a neural network. In this thesis, RRAM devices have been investigated as electronic synapses for demonstrating learning rule. To explore the scaling limit of RRAM cells, carbon nanotube (CNT), which is a naturally single-digit-nm material, is utilized as the memory electrode. We report the first AlOx-based resistive switching memory (RRAM) using carbon nanotubes (CNT) as contact electrodes. CNTs with average diameter of 1.2nm effectively localize the conduction filaments (CFs). The Al/AlOx/CNT device successfully switches over  $1\text{E}4$  cycles with less than 5 [microamperes] programming current. Extreme scaling of the device down to  $6\text{nm} \times 6\text{nm}$  is realized by the CNT/AlOx/CNT cross-point structure and  $1\text{E}4$  switching cycles are achieved. Although CNTs have unique properties such as mechanical stiffness, strength, and high thermal and electrical conductivity compared to other materials, it is very challenging to implement CNTs in mass production for its fabrication difficulties and high production cost. A simple process with electron beam lithography (EBL) was used to fabricate devices with active areas from tens of  $\mu\text{m}$  to nm along with atomic-layer deposition (ALD). Scaling trends for forming and switching characteristics are presented. For the smallest device with an active area of a few nm in diameter, AC switching endurance of  $1\text{E}8$  cycles with an over  $100\times$  resistance window is demonstrated. In addition, multiple resistance states are shown to be stable after  $1\text{E}5$  read cycles and  $1\text{E}5$  seconds baking at  $150^\circ\text{C}$ . Because EBL is limited by its low throughput and not adequate for large-scale

memory manufacturing, low-cost and high-throughput block-copolymer self-assembly lithography serves as a promising extension of optical lithography for technology nodes beyond 10 nm. The fabricated bi-layer TiOx/HfOx devices show excellent performance: low forming voltages ( $\sim 2.5$  V) and low switching voltages (1.5 V); good cycle-to-cycle and device-to-device uniformities, reasonable endurance ( $10^7$  cycles) and retention property ( $> 4 \times 10^4$  s @  $125^\circ\text{C}$ ). Furthermore, self-assembly patterned single-layer HfOx-based RRAM devices is demonstrated with faster switching speed ( $\sim 50$  ns), multi-level storage (2 bits/cell), longer endurance ( $> 10^9$  cycles), half-selected read immunity ( $\sim 10^9$  cycles), good retention ( $> 10^5$  s @  $125^\circ\text{C}$ ) compared to bi-layer TiOx/HfOx device. Despite the recent advancement on the performance of RRAM devices, however, aiming at mass production, one of the most challenging tasks is to address the concern on the broad dispersion of switching parameters, i.e. cycle-to-cycle uniformity within one device and device-to-device uniformity, which are generally observed in the RRAM cells. HfOx/AlOx bi-layer RRAM devices show a better switching uniformity of the switching voltages and resistances than the single-layer HfOx devices. Despite the improvements on the uniformity, the forming process is still unavoidable. We also explore the use of TiOx/HfOx bi-layer device to achieve forming-free and better uniformity in switching parameters at the same time. Forming-free TiOx/HfOx devices are reported with good cycle-to-cycle uniformity in one device and device-to-device uniformity. Over  $10^8$  switching cycles is observed. TiOx can be used as an effective buffer layer to improve the uniformity in RRAM device. Finally, AlOx-based resistive switching device (RRAM) with multi-level storage capability was investigated for the potential to serve as an electronic synapse device. The Ti/AlOx/TiN memory stack with memory size  $0.48\text{ [micrometers]} \times 0.48\text{ [micrometers]}$  was fabricated; the resistive layer AlOx was deposited using ALD method. Multi-level resistance states were obtained by varying the compliance current levels or the applied voltage amplitudes during pulse cycling. These resistance states are thermally stable for over  $10^5$  s at  $125^\circ\text{C}$ . The memory cell resistance can be continuously increased or decreased from each pulse cycle to pulse cycle. More than  $10^5$  endurance cycles and reading cycles were demonstrated. We further study the potential using this AlOx-based RRAM as electronic synapse device. Around 1% resistance change per pulse cycling was achieved and a plasticity learning rule pulse scheme was proposed to implement the memory device in large-scale hardware neuromorphic computing system.

**Mechanical and Electronics Engineering III** Han Zhao, 2011-10-27 Selected, peer reviewed papers from the 2011 3rd International Conference on Mechanical and Electronics Engineering (ICMEE 2011), September 23-25, 2011, Hefei, China

*Optical, Electronic Materials and Applications II* Ke Xiang Wei, Yu Hang Yang, 2012-06-04 Selected, peer reviewed papers from the 2nd International Conference on Optical, Electronic Materials and Applications 2012 (OEMA 2012), May 25-26, 2012, Chongqing, China

Materials Science, Manufacturing and Civil Engineering Takashige Omatsu, Zongjin Li, 2022-12-02 Selected peer-reviewed extended articles based on abstracts presented at the 6th ICMEM 2022, 5th ICMDA 2022 and 7th ICCEMS 2022

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**Modern Design Technologies and Experiment for Advanced Manufacture and Industry** Chien Hung

Liu,2015-05-28 Selected paper from the 3rd International Conference on Engineering and Technology Innovation held in Kenting, Pingtung, Taiwan, R.O.C., October 31 - November 4, 2014

**Japanese Journal of Applied Physics** ,2007

**Nanoelectronic Mixed-Signal System Design** Saraju Mohanty,2015-02-20 Covering both the classical and emerging nanoelectronic technologies being used in mixed-signal design, this book addresses digital, analog, and memory components. Winner of the Association of American Publishers' 2016 PROSE Award in the Textbook/Physical Sciences & Mathematics category. Nanoelectronic Mixed-Signal System Design offers professionals and students a unified perspective on the science, engineering, and technology behind nanoelectronics system design. Written by the director of the NanoSystem Design Laboratory at the University of North Texas, this comprehensive guide provides a large-scale picture of the design and manufacturing aspects of nanoelectronic-based systems. It features dual coverage of mixed-signal circuit and system design, rather than just digital or analog-only. Key topics such as process variations, power dissipation, and security aspects of electronic system design are discussed. Top-down analysis of all stages--from design to manufacturing Coverage of current and developing nanoelectronic technologies--not just nano-CMOS Describes the basics of nanoelectronic technology and the structure of popular electronic systems Reveals the techniques required for design excellence and manufacturability

Radiation Damage to Resistive Random Access Memory Kai-Wen Hsu,2016 Resistive Random Access Memory (RRAM), is considered to be a very promising memory technology for the next generation of computer memory has undergone intense research in both industry and academia in the last ten years. As RRAM technology matures and electronic devices using RRAM are likely to be built soon, malfunctions of RRAM caused by cosmic rays and/or other radiation will become an important problem in industry since the size of these devices will continue to decrease. Of primary concern for RRAM are changes in performance and reliability of RRAM due to this radiation. In order to determine the mechanism of the damage produced by irradiation, multiple diagnostics were used to measure the damage level on HfO<sub>2</sub> blanket films and two types of HfO<sub>x</sub> RRAM cells before and after exposure to neutrons and protons. For HfO<sub>2</sub> blanket films, electron-spin resonance (ESR) was used to detect defect-state concentrations before and after exposure. Leakage currents for irradiated HfO<sub>2</sub> films were measured. Changes to crystal structure were measured with an x-ray diffractometer (XRD). For HfO<sub>x</sub> RRAM, forming process, I-V characteristics and endurance were examined before and after irradiation. Displacement damage and followed by annealing effects from neutrons were observed with ESR and leakage current measurements on HfO<sub>2</sub> blanket films. 90% of HfO<sub>x</sub> RRAM cells were formed and end up in the low-resistance state (LRS) under a high neutron fluence which infers neutrons create a conduction path by producing oxygen vacancies. Generation of oxygen vacancies is attributed to

displacement damage by neutron irradiation. On the other hand, an observed increase in the resistance of the high resistance state (HRS) of RRAM may be attributed to an annealing effect. For protons, only the annealing effect was observed from both ESR and leakage current measurements on HfO<sub>2</sub> blanket films. For proton-irradiated HfO<sub>x</sub> RRAM, no forming was observed. However, a similar increase as in the case of neutron irradiation in the HRS was observed. Protons also annealed the HfO<sub>x</sub> film within an RRAM as was also the case for neutron irradiation. The changes in atomic-structure in HfO<sub>2</sub> films were investigated with XRD. The results showed the HfO<sub>2</sub> films become more crystalline after both neutron and proton irradiation. This change results in shifts in values of the set voltage and degradation of endurance for both neutron-irradiated and proton-irradiated RRAM cells. Based on these results, a modified RRAM configuration is proposed and was shown to be more resistant to neutrons and protons than the original RRAM configuration.

Uncover the mysteries within is enigmatic creation, Discover the Intrigue in **Resistive Random Access Memory** . This downloadable ebook, shrouded in suspense, is available in a PDF format ( \*). Dive into a world of uncertainty and anticipation. Download now to unravel the secrets hidden within the pages.

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