Application Note

Fusion™

Visualizing the Electrical Switching Mechanism in ZnO-Based ReRAM Devices

Introduction

Resistive random access memory, or ReRAM for short, is a state-of-the-art, non-volatile memory technology, and a front-runner to replace current non-volatile memory technologies such as flash. Researchers have shown that ReRAM is faster, capable of less than 10 ns switching time, and more energy efficient than conventional non-volatile memories. It can be scaled down to dimensions smaller than 30 nm making it compatible with future semiconductor processing nodes. ReRAM can also be integrated into three-dimensional device structures, which dramatically increases its density and versatility.

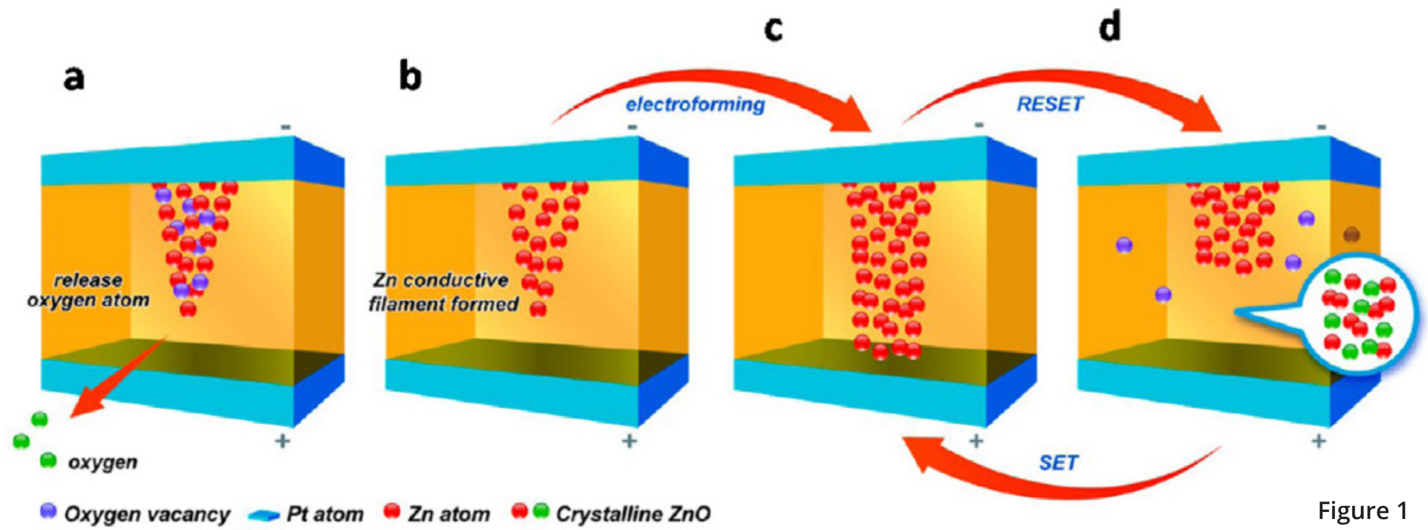


Figure 1

The basic structure of a ReRAM device consists of a thin insulator or semiconductor layer sandwiched between two metal layers. This structure is commonly called a metal-insulator-metal or MIM device. Researchers have explored several types of insulator materials, and found that certain oxides work well for ReRAM devices, including TiO_2, NiO, TaO_2, SiO_x and ZnO.

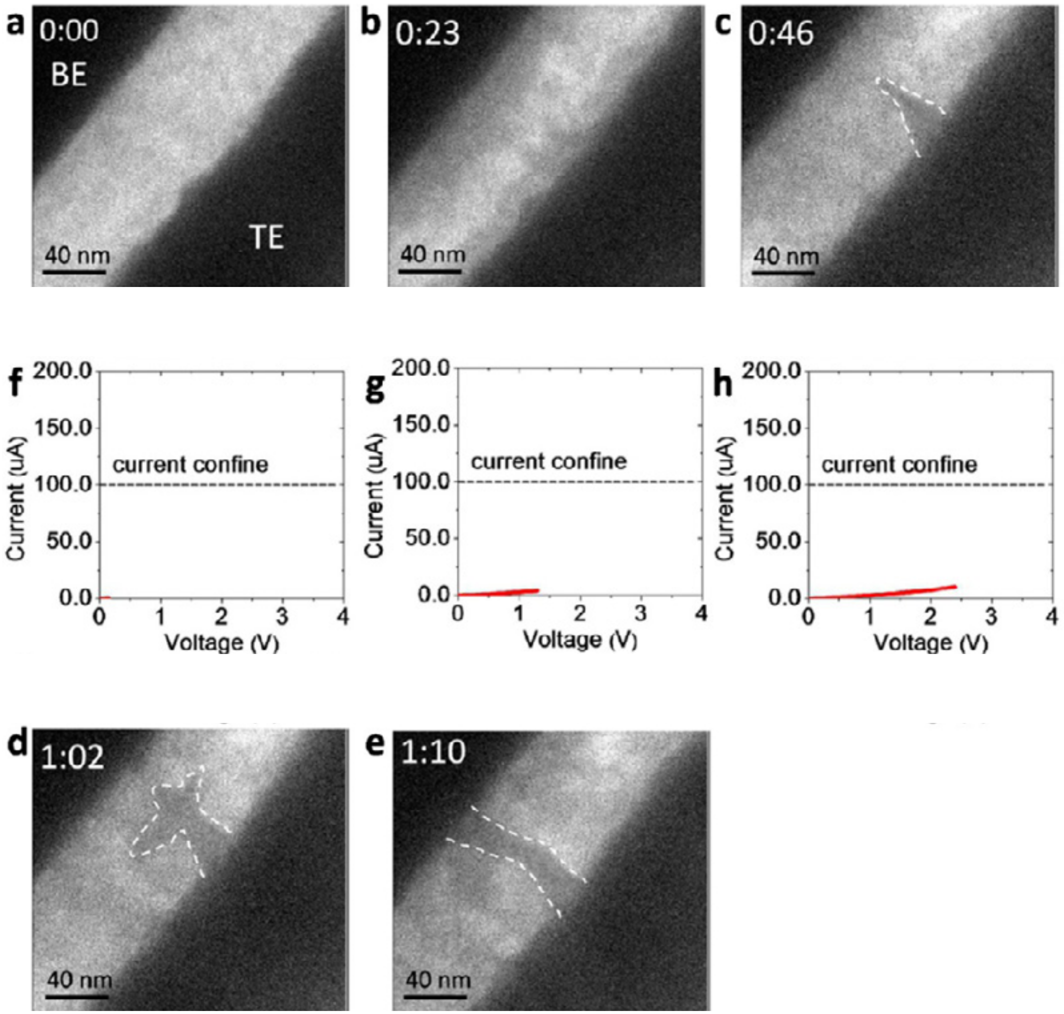
Modern electronic systems rely on devices that operate in two distinct states — “on” and “off”. This on-off functionality is the basis of binary code, which consists of “1”s (on) and “0”s (off), and is the language of electronics. ReRAM devices also operate in two distinct on and off states. ReRAM achieves this on/off functionality from the insulating layer, which acts as a variable resistor. When the device is off the insulator has a large resistance, which impedes the flow of electrical current. When it is turned on, a low resistance pathway is created allowing electrical current to more easily pass between the metal electrodes. Research groups have postulated that the “turn on” mechanism results from metallic filament formation, where electrical current can flow.

The Protochips Fusion heating and electrical biasing system is well suited to analyze electrical devices through *in situ* electron microscopy. Using the custom Fusion electrical biasing software, voltage and current measurements on devices can easily be obtained. Users can simultaneously image a sample and correlate the electrical measurements with TEM and SEM observations, such as structural changes, diffraction, chemical changes in electron energy loss (EELS) and energy dispersive x-ray (EDS) spectra.

Experiment

In the experiments described here, researchers from National Chiao Tung University in Hsinchu, Taiwan created a thin sample from a ReRAM device, which consisted of a ZnO layer sandwiched between two Pt electrodes. The layer of ZnO was 100 nm thick and deposited via RF magnetron sputtering. In order to create a sample suitable for TEM, a focused ion beam (FIB) system was used to cut out a small section, and thin it to ~50 nm. Electrical connections from the metal leads on an E-chip to the device were made using FIB induced metal deposition.

After the device was inserted into the TEM, the researchers used the electrical biasing tools built into the system to apply a voltage to the device while measuring the current *in situ*. They concurrently watched the behavior of the device in real time using



Reference: Chen, et al., Nano Lett., 13, pp3671–3677, 2013

a JEOL 2100F TEM operating in bright-field mode, and analyzed the ZnO structure changes using dark-field imaging, diffraction, EDS and EELS.

Discussion

The researchers imaged Zn filament formation in multiple areas of a device, and the behavior observed matched well with previous reports. Moreover, given the ability to directly visualize Zn filament behavior in real time and control the electrical stimuli, the researchers were able to describe the switching mechanism more clearly, and posit a model to explain the behavior. They also described the physical and chemical behavior of filament formation, by tying together information from high-resolution images, diffraction data and EELS spectra to support their proposed model. The Zn filament forms as a result of a redox process, where oxygen atoms migrate, leaving oxygen depleted regions of ZnO_{1-x} and Zn. Previous reports support this observation, by showing that oxygen species are more mobile than Zn in an electric field. The filament formation and redox process is visually described in the schematic on the previous page. When the filament forms, it usually begins with a conical shape and morphs into a dendritic shape, as shown in Figure 2. This is a result of the electric field enhancement at the tip of the cone, causing the filament to branch out. By applying an appropriate voltage, the device can be reset to its original state, and the process visualized multiple times.

Applications

As feature sizes of electronic devices become ever smaller, the TEM becomes a more useful tool to analyze the operation and behavior of these devices, because it can resolve features down to the atomic scale. The resolving power coupled with the *in situ* heating and electrical biasing capabilities of the Fusion system make new and existing TEMs a more valuable analysis tool. Contact us to discuss the full range of capabilities of the Fusion platform with the thermal and electrical biasing E-chip sample supports. We can be reached at (919) 377-0800 or contact@protochips.com.

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