# Hafnium oxide resistive memory based on cross-bar structures down to sub-20 nm dimensions

M. A. Mohammad[1], H. Tian[1], X. Chen[1], Y. Yang[1], and T.-L. Ren[1,*]

*[1]Institute of Microelectronics & Tsinghua National Laboratory for Information Science*
*and Technology (TNList), Tsinghua University, Beijing 100084, China*
** For correspondence: RenTL@tsinghua.edu.cn*

Resistive random access memory (RRAM) or resistive memory devices are one of the leading candidates for next-generation *universal memory*. Its performance, simplicity, low-cost, and versatility have also attracted widespread interest for applications in logic, neuromorphic circuits, wireless systems, image capturing, and even in e-textiles. Hafnium oxide ($HfO_x$) is one of the more mature, and in-fact leading, resistive switching materials (RSM) with excellent endurance, fast switching speed, low power consumption, and CMOS compatibility [1,2]. $HfO_x$ also has excellent scalability – in the recent past a 10×10 $nm^2$ $HfO_x$ RRAM cell was also demonstrated [3]. Recent trends in $HfO_x$ RRAM development include reducing power consumption, 3D integration, and engineering oxygen reservoir/exchange layers, among others.

In this work, we conduct a systematic study of cross-bar RRAM devices with $HfO_x$ as the RSM with the goal of low power operation for eventual integration with image capturing devices. Cross-bar dimensions of sub-20 nm, 50 nm, 100 nm, 200 nm, and 500 nm were fabricated and tested. A process was developed where three EBL steps (Raith $150^{TWO}$) were performed for the bottom electrode (BEL), RSM, and top electrode (TEL) definition (see design in Fig. 1). The contact metals and $HfO_x$ RSM were deposited using e-beam evaporation and lifted-off. Transferring the $HfO_x$ layer using lift-off was found to be significantly more reliable and repeatable as compared to an etching process. The various material thicknesses are shown in Fig. 1. Although the pad structures span many write-fields, there is no stitching error.

The devices were tested using a probe station and a vector network analyzer (Agilent B1500A). The SEM images and testing results (first SET/RESET curves) of some of our devices are shown in Fig. 2. During the course of this work, various metal thicknesses, oxygen reservoir (TiN) thicknesses, and $HfO_x$ thickness (10, 15, 20 nm) were tested; however, a 10 nm $HfO_x$ layer was found to be the best. Generally, we observe that the SET/RESET current and the voltage are reduced by scaling down the cross-bar dimensions and the $HfO_x$ thickness, respectively. Fig. 3 shows a 12×12 $nm^2$ cross-bar resolution test pattern fabricated using a special cold development, short development time process with PMMA resist. We are currently working towards fabricating and testing sub-10 nm cross-bar devices with sub-10 nm $HfO_x$ thickness as well.

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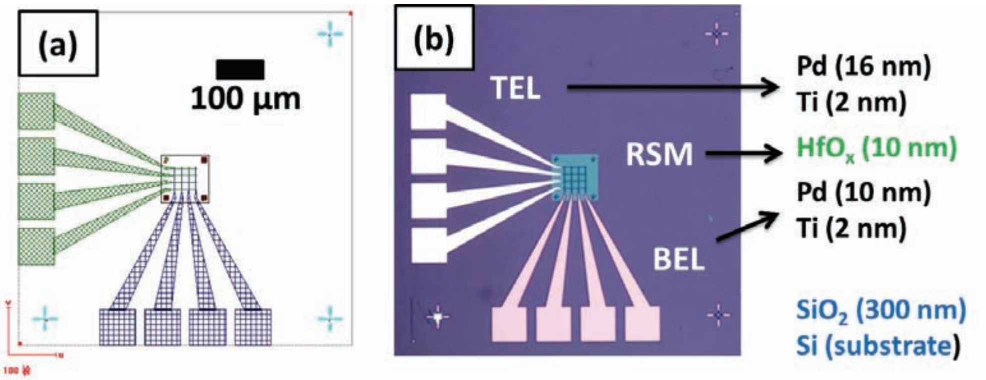

*Figure 1.* The RRAM (a) design, and (b) an optical microscope image of a completely fabricated device. The various layers and thicknesses are labelled.

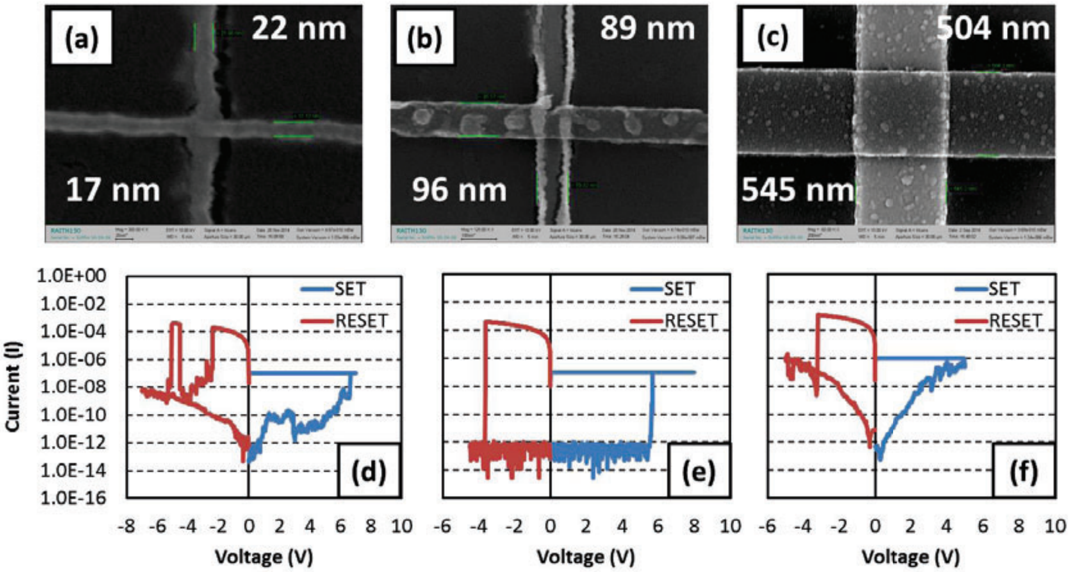

*Figure 2.* Micrographs of (a) 17×22 nm, (b) 96×89 nm, and (c) 545×504 nm RRAM cross-bar devices. The magnifications are 300kx, 125kx, and 60kx, respectively. First SET & RESET curves of nominally (c) 20 nm, (d) 100 nm, and (e) 500 nm devices.

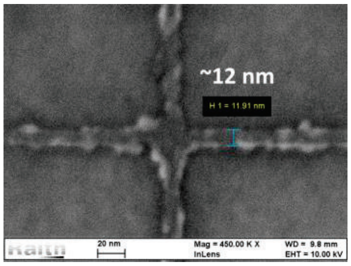

*Figure 3.* Micrograph of a 12 nm wide cross-bar resolution test feature (magnification 450kx). The lifted-off metal is a 3nm/2nm layer of Cr/Ti.