Ferroelectric nonvolatile memories: Hafnia Based Ferroelectric Tunnel Junctions

Bhagwati Prasad[1,2], Vishal Thakare[3], Alan Kalitsov[2], Zimeng Zhang[3], R Ramesh[3]

[1]Materials Engineering Department, Indian Institute of Science Bengaluru, India 560012
[2] Western Digital Research Center, Western Digital Corporation, San Jose, USA 95119
[3] Department of Materials Science and Engineering, University of California, Berkeley, CA, 94720 USA

High density, high-speed and low power consuming nonvolatile memories are currently being vigorously explored for use in next-generation computation, particularly due to the performance gap between the logic and memory elements of the current computational architecture. Electrically switchable spontaneous. polarization of ferroelectric materials enables a robust nonvolatile memory solution. Using ultrathin films of ferroelectric materials as a tunnel barrier in metal/ferroelectric/metal trilayer structure, so-called ferroelectric tunnel junctions (FTJ), is being explored widely as a potential nonvolatile memory element. Unlike ferroelectric RAM (FeRAM), FTJ offers nondestructive readout, in addition to low operation energy and high operation speed. In this work, we have demonstrated FTJs with a very large OFF/ON resistance ratio and relatively low resistance area product (RA) with ~ 1 nm thick Zr doped HfO2 (HZO) ferroelectric tunnel barrier. We stabilized ferroelectricity in ultrathin films of rhombohedral HZO (R-HZO) through the substrate-induced compressive strain. The resistance area product at the bias voltage (~ 300 mV) required for one-half of the zero-bias TER ratio is three orders of magnitude lower than the reported value with relatively thick ferroelectric barriers, which significantly improves signal-to-noise ratio (SNR) during the read operation. These results set the stage for further exploration of Hafnia-based FTJs for non-volatile memory applications.

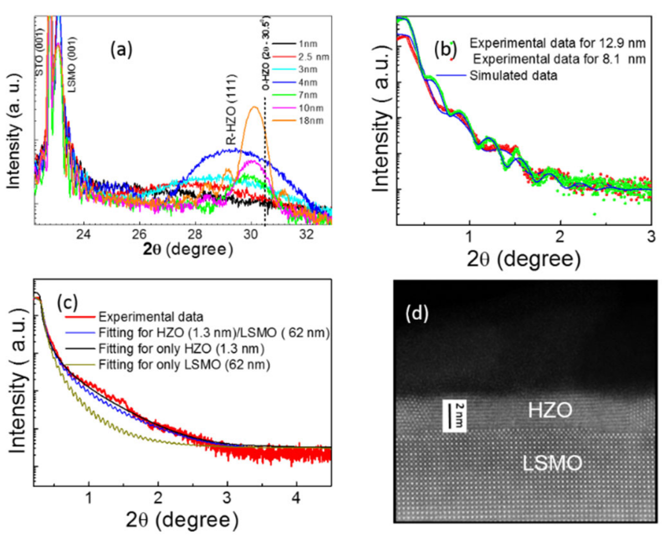

Figure 1: (a) XRD patterns of the HZO films on LSMO-buffered STO (001) substrates with thickness ranging from 1 nm to 18 nm. (b) X-ray reflectivity (XRR) and corresponding fitting analysis (blue lines) of ~ 13 nm and ~ 8 nm of HZO films grown on STO (001) substrate for determining the growth rate of HZO films. (c) XRR fitting analysis of HZO/LSMO bilayer film confirms HZO and LSMO thicknesses are ~ 60 nm and ~ 1nm, respectively. (d) High-resolution transmission electron microscopy image of the HZO (~2.5 nm)/LSMO bilayer, epitaxially grown on STO (001) substrate, verify the growth rate of the HZO layer.

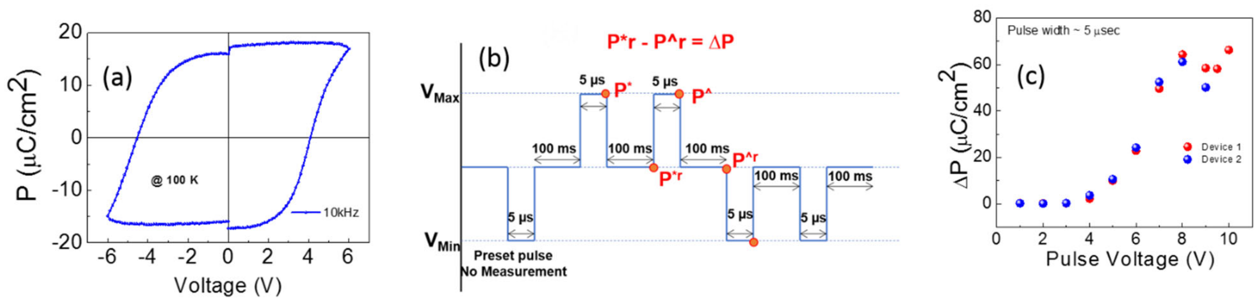

Figure 2: (a) Ferroelectric hysteresis loop at 10 kHz of a 10 nm HZO film, measured at 100 K to reduce the leakage current, exhibits the remanent polarization of ~ 17 μC/cm^2 (b) Schematics of the voltage pulse for PUND measurement to extract the switched polarization, which is typically 2X the remanent polarization from the P-V loop. (c) PUND characterization of ~ 2.5 nm HZO film for two circular capacitor devices (Ø~ 10μm) showing the remanent polarization of ~ 30 μC/cm^2.

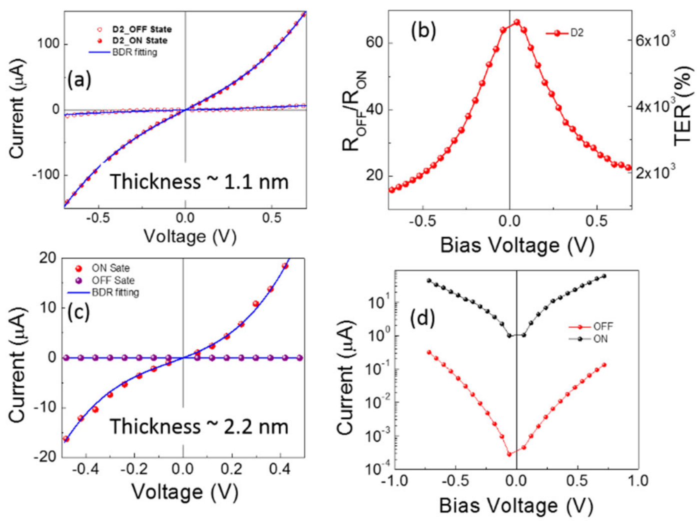

Figure 3: (a) Current-voltage characteristic for OFF and ON states of an FTJ with ~ 1nm HZO tunnel barrier (Ø~ 5μm) and (b) corresponding TER as a function of the read voltage. (c) OFF and ON state current-voltage plots for a tunnel device (Ø~ 10μm) with ~ 2.5nm HZO barrier layer, and (d) corresponding plot in log scale for better visualization. Blue solid lines in Figure (a) and Figure (c) are the fitted plots using the BDR model.

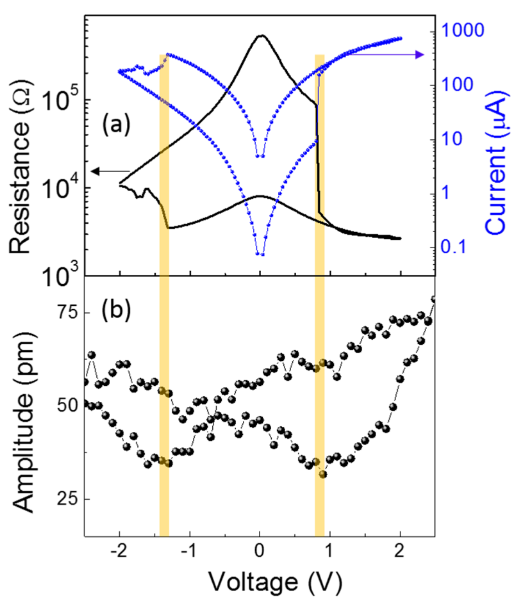

Figure 4: (a) Junction resistance versus write voltage pulse (black) with a width of ~ 1 ms and corresponding current-voltage (blue) characteristics of a FTJ (Ø~ 5μm) with ~ 1 nm HZO barrier layer. (b) The PFM amplitude hysteresis loop of ~ 1nm HZO film, measured with 1ms voltage pulses, emphasizing that the resistance switching in our FTJs is predominantly due to the ferroelectric polarization switching of the barrier layer.