Fabrication and Characterization of Ferroelectric Tunnel Junctions with Different Bottom Electrodes

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ABSTRACT

Ferroelectricity has been reported in the atomic layer deposition (ALD) of HfO_2 with Al, Y, or Si dopants. Previous work (by Joe McGlone) at RIT demonstrated functional FeFETs using silicon doped HfO2 (Si:HfO_2) as the gate dielectric. The recent addition of a Savannah ALD system at RIT has made deposition of doped HfO_2 films possible. Recipes have been developed (by Casey Gonta) for deposition of aluminum doped HfO_2 and, this year, ferroelectricity has been shown in Al:HfO_2 (by Josh Eschle) at RIT. My work follows in the footsteps of the aforementioned research to make a working FTJ. Metal Ferroelectric Metal (MFM) devices were fabricated using Titanium Nitride (TiN) as the top electrode and Tantalum (Ta) or Nickel Silicide (NiSi) as the bottom electrode. The thickness of the Al:HfO_2 layer ranges from 3 nm to 5 nm with only 1 to 2 aluminum doping cycles. Unfortunately, the deposited hafnium film did not display ferroelectric behavior and so by default, capacitors were fabricated and tested.

1. INTRODUCTION

A material is defined as ferroelectric if it has a spontaneous remnant polarization that can be reversed by an electric field. This unique property makes them particularly attractive for non-volatile memory and logic applications. Non-volatile memory devices using perovskite materials, such as Strontium Bismuth Tantalate (SBT) and Lead Zirconate Titanate (PZT) have been studied for many years. Due to their limits on scaling of the ferroelectric layer and incompatibility with CMOS technology beyond the 130nm node, other memory device structures have been preferred for manufacturing. The discovery of doped hafnium oxide (HfO_2) exhibiting ferroelectric behavior has expanded its applications into new ferroelectric devices compatible with CMOS technology, such as the Ferroelectric Field Effect Transistor (FeFET) and Ferroelectric Tunnel Junction (FTJ).

2. THEORY

An FTJ is a tunnel junction in which two metal electrodes are separated by a thin ferroelectric layer (Fig.1). Switching the ferroelectric polarization changes barrier height which induces variations of the tunneling current (Fig.2). The polarization of this layer can be affected by changing the electric field. This process is shown in Fig.3. To start, the polarization is random, after applying a voltage the direction of polarization points in one direction. As the applied voltage is decreased, the polarization begins to flip and when the electric field is zero, there is a net remnant polarization. At the switching field the polarization has become entirely reversed. This ON/OFF property (Fig.4) is what makes these ferroelectric materials promising for memory applications.

3. FABRICATION

A mask of various sized cross-bar array structures was made for possible future ferroelectric memory switch research. Process flow and design layout of the fabricated HfO_2 FTJ devices are shown in Fig.5. After BE layer deposition, 3-5nm thick aluminum doped HfO2 (Al:HfO_2) film was deposited via ALD. Crystallization annealing was performed after TiN deposition at 600C for 30 seconds to induce ferroelectricity in the HfO_2. The ratio of Al to HfO_2 was estimated to be around 2.7% and 3.6% respectively. P-V characteristics show that the HfO_2 did not become ferroelectric(Fig.6).

4. TESTING

Polarization vs voltage measurements were conducted on the fabricated Al:HfO2 capacitors. Figure 6 shows the polarization vs voltage measurements of a 2.7% Al:HfO2 capacitor. The device behaves like a capacitor (linear) when sweeping to 3V. Ferroelectric behavior (hysteresis) should be observed if swept at a higher voltage. However, every device tested at a higher voltage breaks down the dielectric and the polarization curve approaches that of a resistor.

5. CONCLUSION

Poor time management and some over-looked fabrication mistakes lead to no Transmission Electron Microscopy (for FE layer thickness), Electron Energy Loss Spectroscopy (for device elemental composition), and basic I-V, C-V testing. Further electrical testing is needed, as well as more in-depth research into the ALD of such thin HfO_2 and precursor layers to consistently reproduce that ferroelectric behavior. Not too much was done to push the ferroelectric ball at RIT for-

ward but some groundwork was made for future FTJ projects.

6. ACKNOWLEDGMENTS

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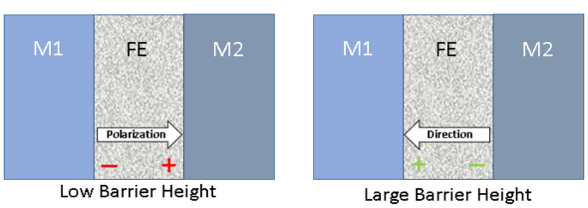

Figure 1. Ferroelectric tunnel junction M/FE/M structure with differing polarization direction.

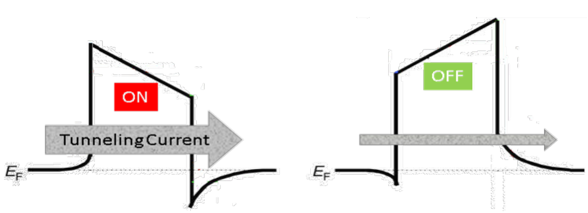

Figure 2. Switching mechanism of FTJs. Modulating the barrier height The barrier induces current switching.

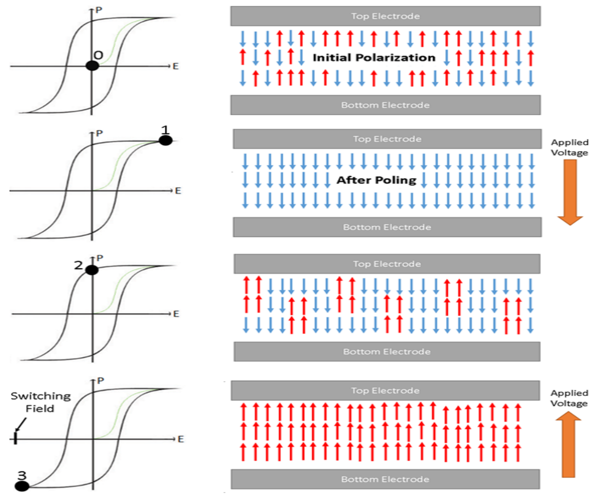

Figure 3. Ferroelectric polarization switching process

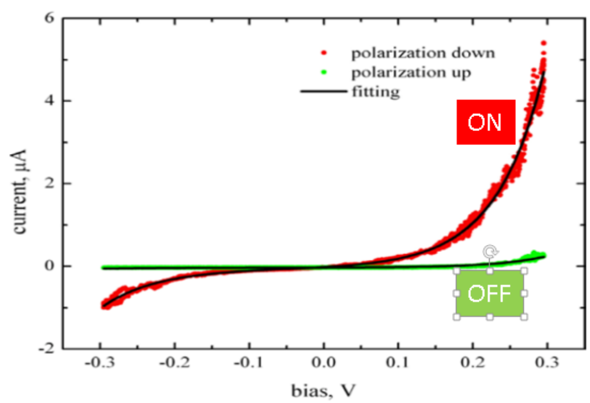

Figure 4. FTJ ON/OFF behavior

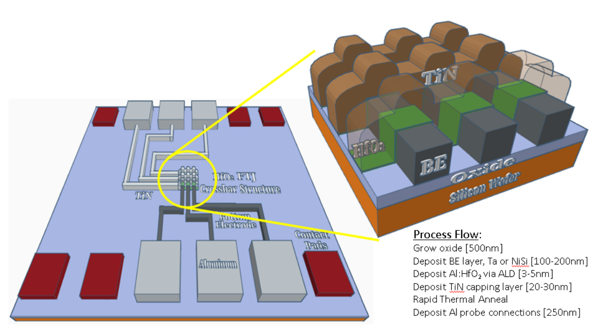

Figure 5. Design Layout

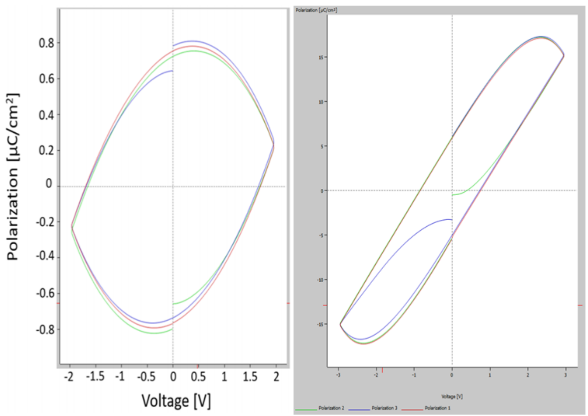

Figure 6. Left: dielectric breakdown resistor behavior [4]. Right: Linear capacitor-like behavior