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Electron Tomography Study on Nanoscale HfO_x/AlO_y-based Resistive Switching Device

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Oxide-based memristive devices, simply metal/insulator/metal structures, are electrical resistance switches (RS) that retain their resistance state depending the previously applied voltage or current. These resistive memory devices are a frontrunner for next generation computer memory, owing to the promise of long endurance, low power, nanoscale device size and fast operation, as well as applications beyond nonvolatile memory such as, logic and neuromorphic computing.[1] The resistance switching mechanism is believed to be the formation and rupture of conducting oxygen vacancy filament corresponding to high and low resistance states. Among the different dielectrics proposed for the resistance switching metal oxide, HfO_2 has attracted extensive interests due to its best tradeoff between existing process technology and RS performance. However, the crystallization in HfO_2 during back end of line (BEOL) processing can diminish switching uniformity due to the fluctuation in grain size on small cell area. To prevent crystallization of HfO_2 layer, doping with trivalent elements (such as Al) has been pursued to suppress crystallization. Furthermore, density functional theory (DFT) calculations show that this doped HfO_2 can have a lower forming energy of oxygen vacancy, which can control the formation of oxygen vacancy filaments along the doping sites and may help improve the RS behavior. Thus, comprehensive understanding the physical and chemical property of HfO_2 and its interaction with electrodes is critical to understand the switching mechanism.

The rapid development of electron tomography (ET) has led to the visualization and analysis of three-dimensional structural and chemical information from materials at the nanometer level.[2] 3D visualization can provide critical information such as pinholes and deformation of the device, which help understanding the working and failure mechanism. The through-focal + tilt tomography based on aberration-corrected STEM has been demonstrated to even break the Crowther limit and reveal sub-nanometer information.[3] We have fabricated RS device with sub-nanometer thick HfO_x/AlO_y using atomic layer deposition on top of a nanoscale titanium nitride (TiN) bottom electrode.[3] Fig.1 shows the chemical analysis from STEM/EDS mapping using probe Cs-corrected Titan. EDS mapping have shown the presence of HfO_x and AlO_y. The 2D projection cannot provide important information such as if the film is continuous and has the same thickness across the device, which cannot be learned by cross-section.

Fig 2 shows the 3D reconstructed image of the RS device using high angle annual dark field (HAADF) STEM tomography. The ET samples were prepared using focused ion beam (FIB) lift-out method. The STEM images were recorded using single-axis tilt series from -80° to +80° with 2° intervals. The 3D reconstruction shows the oxide switching layer (HfO_x/AlO_y) is about 1.5-1.8 nm thick (with 0.3 nm resolution), which is close to the nominal thickness of 1.1 nm. Due to the carbon contamination surrounding the tip, the contrast around the layer is difficult to differentiate HfO_x and AlO_y. Further reconstruction with higher resolution and less sample contamination can help to understand the chemical and structural information of the RS device.

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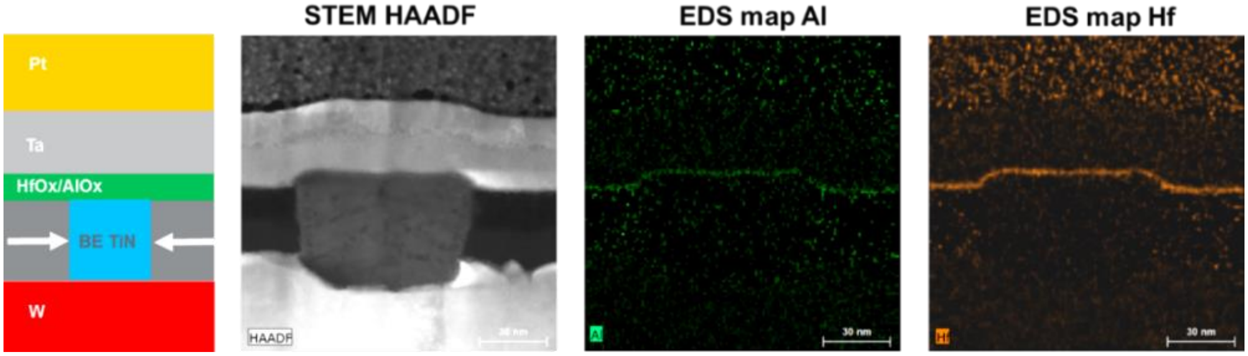

Figure 1. STEM HAADF image and EDS map of the device with HfO_x/AlO_x.

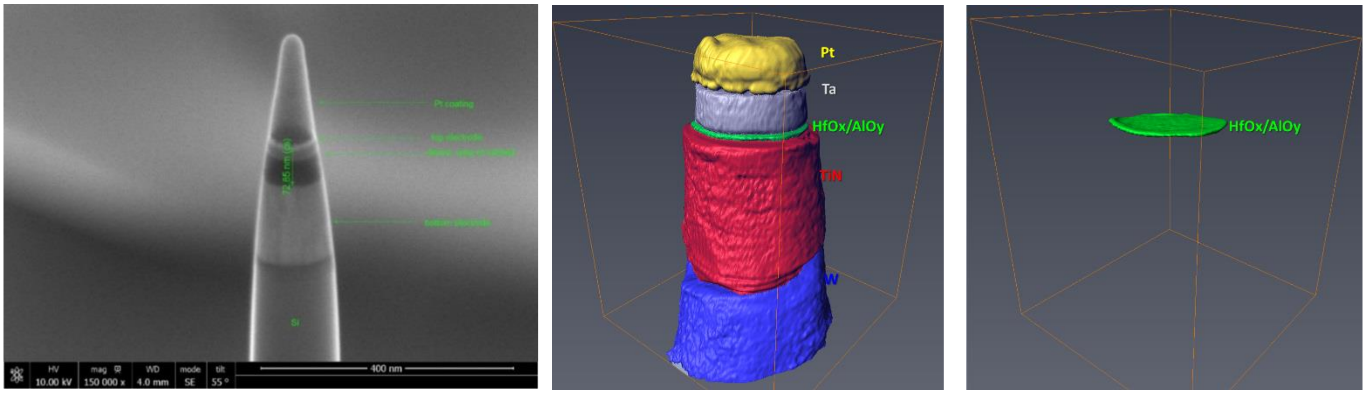

Figure 2. ET sample produced by SEM/FIB dual beam system and 3D visualization of RS device with HfOx/AlOy layer.