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Effect of Microstructure on Dielectric Breakdown in Amorphous HfO_2 Films

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Hafnium-based oxides are currently among the leading candidates for resistive switching memory (ReRAM) because of their high performance, high scalability and reliability [1]. The physical and electrical properties of an oxide layer have a strong correlation with the microstructural properties of the metal electrodes in a metal-insulator-metal (MIM) structure [2,3]. The physical switching mechanism is mainly controlled by the interface between the oxide layer and the electrodes. Besides the bulk properties, the surface/interface roughness of the metal electrodes also has an effect on the electronic properties of thin-film MIM structures. Hence, it is imperative to gain a better understanding of the microstructure of the device structures to understand their physics of operation. In this study, we investigate the effect of the electrode/dielectric microstructure using atomic force microscopy (AFM) and high-resolution transmission electron microscopy (HRTEM). We show that the dielectric breakdown in Pt/HfO_2/Ti/Pt MIM structure has a strong dependence on the interface roughness of the electrode.

Fig. 1(a) shows a plan-view TEM image with selected area diffraction pattern of a 20 nm thick HfO_2 film grown by atomic layer deposition (ALD) deposited on a Pt substrate, confirming the amorphous nature of the HfO_2 film. Grazing incident-angle x-ray diffraction (GI-XRD) measurements performed on the same film confirmed the amorphous nature of as-deposited HfO_2 (results not shown). The X-TEM image in Fig 1(b), confirms the thickness of layers in the device structure and highlights interface roughness associated with the underlying Pt electrode. Atomic force microscopy (AFM) in tapping mode was used to investigate the surface roughness of the Pt film, as shown in Fig. 2. Scans over 1μm × 1μm, 2μm × 2μm and 5μm x× 5μm were measured and root-mean-square (rms) roughness values were calculated for each scan. Fig. 2(a) and (b) show the topography of the bottom Pt electrode measured by atomic force microscopy (AFM) of the thinnest (25 nm) and the thickest (150 nm) films used in this study. It is evident that the 25 nm thick Pt film has a relatively smooth surface when compared to 150 nm films. The surface roughness of HfO_2 is expected to be influenced by the roughness of the Pt electrode as ALD grown films grow conformally to the substrate surface. Fig. 2(c) and (d) display the topography of 20 nm HfO_2 on 25 nm and 150 nm Pt, respectively. Both Pt and HfO_2 films were also deposited on 300 nm thermal oxide (nominally atomically smooth) substrates for comparison. Fig.2 (e) and (f) show the variation of rms roughness of HfO_2 and Pt films as a function of their thickness, respectively. From the rms values, it is observed that the surface roughness of Pt film increase with film thickness. Fig. 2(g) shows that the breakdown voltage of the 20 nm HfO_2 as a function of the rms roughness of the bottom electrode, showing a clear reduction in breakdown voltage with increasing roughness. Simulations of the breakdown process suggest that this results partly from variations in film thickness with increasing film roughness and from electric field enhancement at electrode protrusions.

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References:

[1] G. D. Wilk, R. M. Wallace and J. Anthony, Journal of Applied Physics **89** (10) (20101), p.5243.
[2] G. Bersuker, J. Yum, L. Vandelli, A. Padovani, L. Larcher, V. Iglesias, M. Porti, M. Nafría, K. McKenna and A. Shluger, Solid-State Electronics **65** (2011), p.146.
[3] K. Yew, D. Ang and G. Bersuker, IEEE electron device letters **33** (2) (2012), p.146.

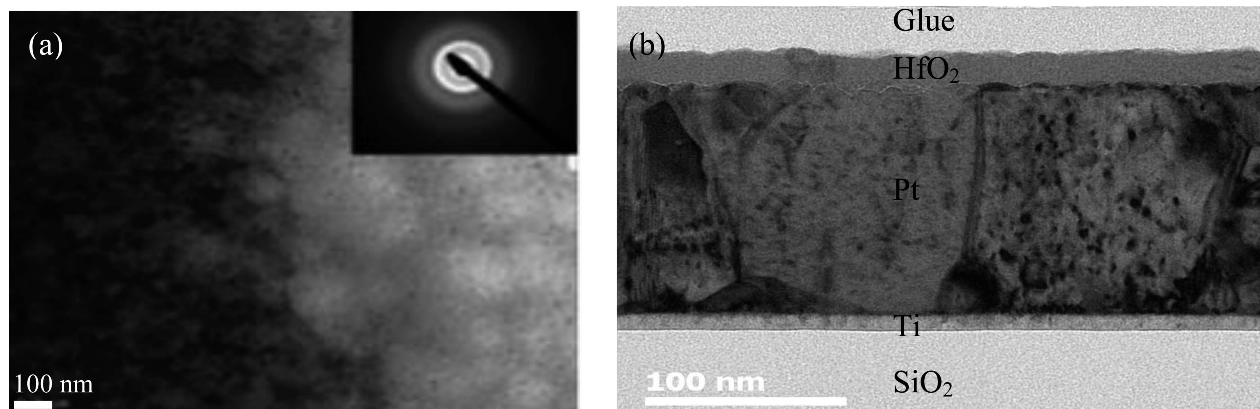

Figure 1: (a) Plan-view TEM image and SADP of as-deposited 20 nm thick HfO_2 film grown by ALD; and (b) X-TEM image of an as-deposited HfO_2 film on Pt showing interface roughness.

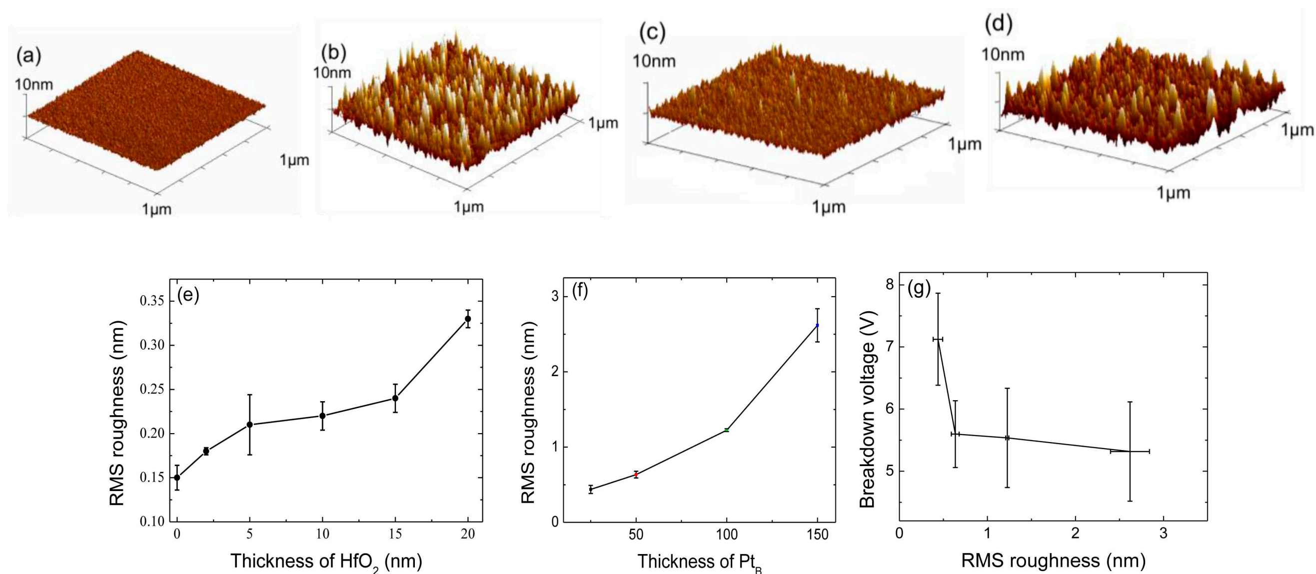

Figure 2: AFM topography images of (a) 25 nm and (b) 150 nm Pt; (c) 20 nm HfO_2 on 25 nm Pt and (d) 20 nm HfO_2 on 150 nm Pt. Variation of rms roughness with (e) thickness of HfO_2 on 300 nm SiO_2 and (f) thickness of Pt on 300 nm SiO_2; and (g) Dielectric breakdown as a function of rms roughness, indicating correlation between the surface roughness and dielectric breakdown.

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