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C-AFM study on high-k oxide HfO_2 films

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In the emerging semiconductor technology fields, the most important issues reside at the high-k gate oxide/metal gate stack candidates replacing the long-lived silicon oxide/polysilicon gate structure. A lot of efforts from both scientific and application side are devoted to finding the best solution. The current ITRS roadmap require the gate oxide to have i) better leakage current density, ii) better surface roughness and so on. In this point of view, we utilized C-AFM technique to study electronic and structural properties of high-k gate oxide films.

We have grown ultrathin amorphous HfO_2 films on Si substrate by atomic layer deposition technique and sputtering followed by oxidation. The thickness of the HfO2 films is controlled to be the same as 3nm between two samples. The images were scanned in the contact mode with the moderate force of 5nN and the scan rate was set to as slow as 1Hz. The current under bias was measured at the same time ranging from 0.1pA.to 1nA with ultra low noise preamplifier attached to AutoProbe CP Research AFM. Under tip bias voltage applied, the sample current through current preamplifier was measured with its output connected to another ADC channel. To avoid the contamination of moisture, hydrocarbon and the like, we performed the experiment as soon as possible after exposing the samples to air. As shown in the FIG. 1, we compared the topographic and current map data between the samples taken under the same condition : (a) ALD and (b) sputtering and oxidation sample. The topographic data (lower row) show that ALD method provides better surface roughness property than sputtering. And the leakage current characteristic (upper row) is also better in the case of ALD. The dark spots correspond to the leaky points and hence under the same bias voltage more leakage current flows through HfO_2 film grown by sputtering and oxidation method. The scan area is 500nm x 500 nm under bias off and 100nm x 100nm under bias on. These leaky points were not found to be related to the topographic data but the compositional irregularity or grain boundary affect more leakage current characteristics.

In the FIG. 2, the current map of ALD sample was shown under higher bias voltage applied than FIG. 1 and scanned over 500nm x 500nm area. We observed more dark spots but their distribution was found to be dense and uniform. At the higher bias voltage, the weak and leaky points emerged widely over the scan area and hence less probability of breakdown or gate oxide failure was expected. The so-called soft breakdown phenomenon found in the gate oxide problem has strong relation to this leaky point distribution and its integrity or reliability of gate oxide can be easily tested upon charge injection or voltage stress using C-AFM technique.

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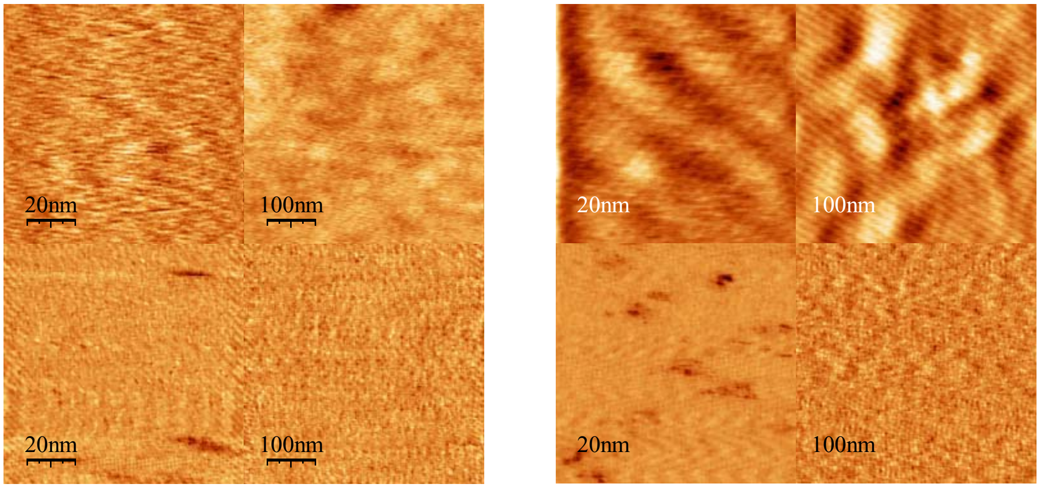

(a) ALD sample (b) sputter & oxidation sample

FIG. 1. Topographic image(upper) and current map(lower) taken under bias voltage applied(left) and off(right).

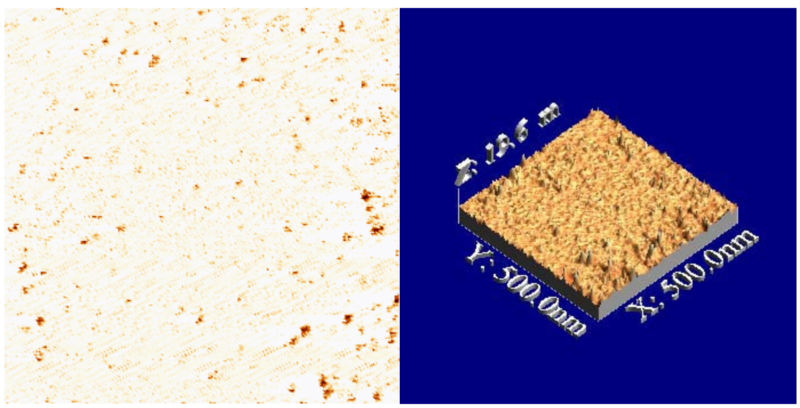

FIG. 2. C-AFM image taken under higher bias voltage applied. The scan area is 500nm x 500nm.

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