Film Making in Digital 3D: Selective Area Atomic Layer Deposition

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Abstract:

Atomic layer deposition (ALD) is commonly used to deposit thin films in integrated circuits and other micro- and nano-devices. However, these films still require patterning via photolithography. Selective area ALD can be achieved on substrates with areas of differing surface chemistries to grow thin films on the desired surface but not the other. This can overcome the limitations of traditional ALD and eliminate the need for patterning steps directly proceeding thin film deposition by ALD. In this experiment, tantalum nitride (TaN) was deposited on both silicon dioxide (SiO_2) and copper (Cu) using ALD to determine if selective growth could be achieved. Specifically, growth of TaN was desired on SiO_2 but not on Cu. The resulting TaN thin films were analyzed using spectroscopic ellipsometry, atomic force microscopy (AFM), and x-ray photoelectron spectroscopy (XPS). A growth rate of 0.431Å/cycle was determined for the deposition of TaN on SiO_2. An analysis of the roughness of the Cu samples after various cycles of TaN deposition suggests that the roughness of the thin film increases with increasing process temperature. Although at 255 and 300°C there was a significant amount of TaN deposited on the surface of the copper samples after 10 cycles, at 225°C there was very little deposition, suggesting the possibility for selective area ALD for less than 10 cycles.

Introduction:

When making electronic devices, thin films can be created with precise control over thickness using ALD. Although the resulting thin films are highly uniform and conformal, if they could be selectively deposited according to an inherent pattern on the substrate, additional patterning steps, used in making devices such as transistors, may not be necessary. In integrated circuits, copper (Cu) is commonly used as the interconnect material between transistors. However, Cu diffuses easily into SiO_2 and other dielectric materials that surround the Cu. In Cu metallization schemes, TaN is deposited onto the dielectric before the Cu interconnects are placed to prevent this diffusion.

If possible, it would be ideal for TaN to grow on the dielectric but not on the Cu so as not to increase the electrical resistance of the Cu line. Selectivity may be achieved by manipulating the differences in the chemistries (such as the number of nucleation sites) of two different materials. This may allow for growth of a thin film on one material and not on the other.

Experimental Procedures:

The goal for this experiment was to examine growth on two materials (SiO_2 and Cu) and thus determine if selective area ALD is possible for these two materials.

Deposition on Chemical Oxide. Bare Si samples were treated with BOE for total of four minutes and Nanostrip for 30 minutes to produce a 3 ± 0.1287Å thick SiO_2 layer, which will be called chemical dioxide. TaN was deposited onto chemical oxide at 255°C via ALD, varying the ALD cycle count, using the Oxford ALD FlexAL tool in Cornell NanoScale Science and Technology Facility (CNF). The thin film thicknesses were then analyzed using a Woollam spectroscopic ellipsometer.

Deposition on Copper. TaN was deposited onto as-received Cu thin films with 0, 10, 20, 30, 40, and 50 cycles of deposited TaN at 225, 255, and 300°C. The surface roughness of the Cu samples was determined using AFM in tapping mode. The surface composition was analyzed using XPS with a fixed photoelectron takeoff angle of 38.5°.

Results:

Deposition on Chemical Oxide. Using spectroscopic ellipsometry, a TaN growth rate of 0.431Å/cycle was determined. This value corresponded to a TaN growth rate of 0.41-0.46Å/cycle found in the ALD tool data sheets at CNF.

Deposition on Cu Samples. AFM showed that after 10 cycles there were virtually no change in roughness for all temperatures examined. However, there was a noticeable decrease in roughness between 0 cycles and 10 cycles. This suggests that an interesting phenomenon occurs between 0 and 10 cycles. Furthermore, there was an increase in the roughness of the thin film with increasing temperature. Further experimentation would be necessary to propose a cause for these observations.

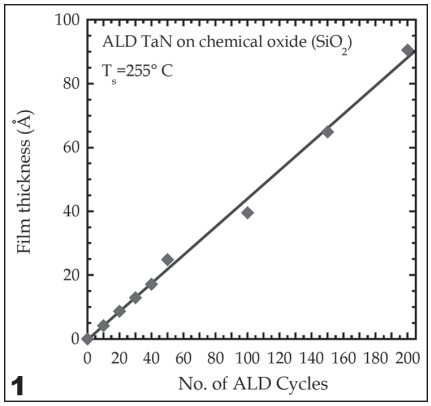

Figure 1, left: TaN film thickness with varying ALD cycle counts on chemical oxide at 255°C.

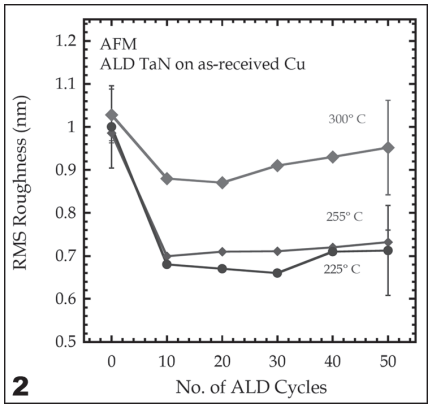

Figure 2, right: RMS roughness of TaN thin films on Cu vs. number of TaN ALD cycles.

XPS revealed an increased amount of deposited TaN on the surface of the copper samples with increasing temperature. At 50 cycles, the Ta 4d peak of the film deposited at 225°C was smaller than at 255 and at 300°C. Figure 4 compares the integrated intensities of the Ta (4d) feature from XPS at different cycle counts and temperatures and shows that there is comparatively very little deposition of TaN on Cu at 225°C. Therefore, it may be possible to achieve selective area ALD of TaN on SiO_2 and Cu at 225°C at cycle counts less than 10. However, this selectivity does not occur for a cycle count greater than 10 at any of the examined temperatures.

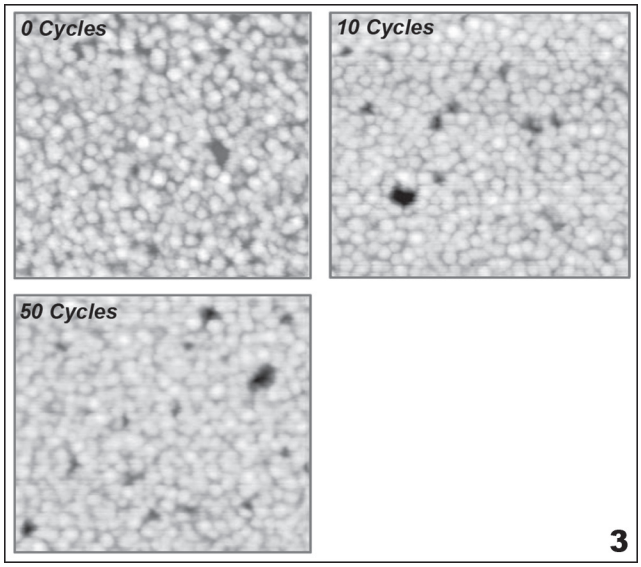

Figure 3: AFM images of surface roughness of Cu samples after 0, 10, and 50 cycles (left-right) of TaN deposition at 300°C.

Conclusions:

Thin film deposition on SiO_2 occurred after 10 cycles at 255°C. For TaN deposition on Cu, AFM suggests that the roughness of the thin film increases with increasing temperature. At 255 and 300°C, there was a substantial amount of TaN on the Cu surface after 10 cycles. At 225°C there was very little deposition. This may allow for selective ALD for less than 10 cycles. In the future, the growth rate of TaN on Cu at lower cycle counts on both SiO_2 and Cu can be analyzed to determine the lack or presence of such selectivity.

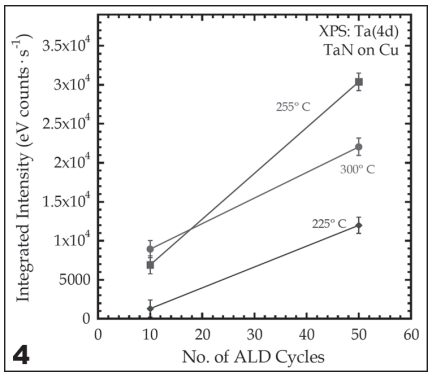

Figure 4: Integrated intensity of the Ta(4d) XPS feature vs. number of ALD cycles.

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