Tribology of Atomic Layer Deposition Films

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Abstract:

Atomic layer deposition (ALD) is revolutionizing the fabrication of nanoscale devices. ALD employs sequential, self-limiting vapor surface reactions and presents the ability to coat concavities and convexities of a surface uniformly with thin inorganic films. Since ALD films can deposit uniformly on a variety of materials with precise thickness control, they can tune surface properties independent of the substrate. The electrical properties of ALD films have been investigated extensively, yet the films' mechanical traits have not been well characterized. In this work, we investigated mechanical properties such as wear, adhesion and friction of the interface between ALD coatings. Custom micromachined silicon tips on compliant cantilevers were coated with various films using thermal and plasma ALD processes. A scanning electron microscope (SEM) was used to observe tips before and after deposition. The coated tips were tested through laser Doppler vibrometry to monitor friction and adhesion. The knowledge of the mechanical effects of ALD films will improve our ability to fabricate nanoscale electromechanical systems.

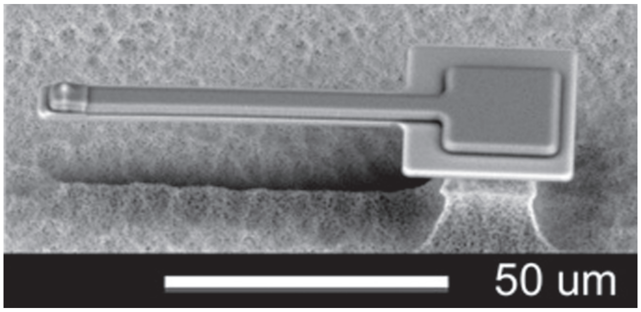

Figure 1: SEM of compliant cantilever.

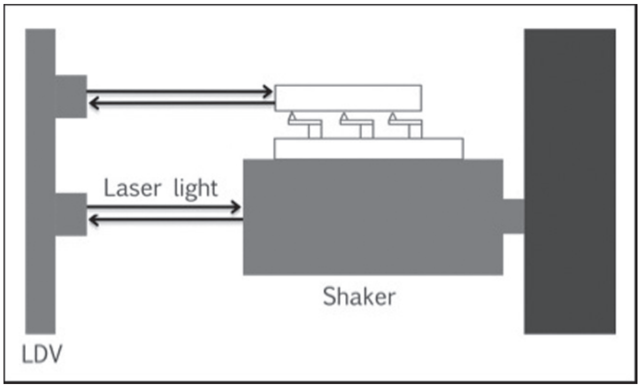

Figure 2: Schematic of laser Doppler vibrometer [1].

Introduction:

Tribology is the study of interacting surfaces in relative motion, which includes properties of wear, friction and adhesion. The tribological test structure in this project examined mesoscopic forces that cause nanoscale friction and were comprised of compliant cantilevers arrays on silicon chips. Figure 1 shows a SEM of a compliant cantilever. Square pieces of silicon, called sliders, rested on sharp tips at the end of the cantilevers. The cantilevers were compliant to ensure all cantilever tips engaged when the slider rested on the array. The wear and friction testing was completed through laser Doppler vibrometry at Hewlett-Packard in Palo Alto, California.

The slider rests unconstrained on the array, and the array moves on the horizontal shaker relative to the slider, causing wear to the tips. Laser light shines on and reflects off the shaker and slider into the laser Doppler vibrometer (LDV). The LDV uses the laser light reflection to calculate the relative motion of the shaker and slider. A LDV schematic is seen in Figure 2.

By coating the cantilever tips and the sliders with ALD films, the mechanical properties of the coatings could be examined. ALD utilizes sequential, self-limiting surface reactions to deposit a thin film of inorganic material on the substrate. The vapor-phase reactants and the self-limiting nature of the reactions cause a uniform deposition on the surface. During deposition, two gaseous reactants, called precursors, are pumped into the reaction chamber in succession. Each precursor reacts with all available reactive sites, and the excess is pumped out of the chamber. The two half-reactions constitute one cycle, and a cycle deposits a thin layer of the new substance on the substrate. Cycles are repeated to obtain the desired film thickness. The mechanical characteristics are dominated by surface qualities at the nanoscale due to the high surface-area-to-volume ratio. Thus, ALD can change the exhibited properties of a material greatly by depositing thin films.

Experimental Procedure:

Custom micromachined silicon tips on silicon wafers were processed to produce the compliant cantilevers arrays. We employed traditional lithography methods to pattern the wafers with cantilevers. Silicon dioxide deposited by low pressure chemical vapor deposition was etched from the wafer's surface through reactive ion etching with CHF_3. The cantilevers were defined from the bulk of the wafer through an anisotropic silicon etch with sequential introduction of SF_6 and C_4F_8 gases. The wafers were diced with a wafer saw. The cantilevers of each individual chip were released from the surface of the wafer through a XeF_2 isotropic silicon etch. The protective oxide on the cantilever tip was removed with a silicon dioxide wet etch of 6:1buffered oxide etchant. The sliders were prepared by removing the protective oxide through a silicon dioxide wet etch.

A carrier wafer was fabricated to secure the chips and sliders within the ALD reaction chamber. After manufacturing several carrier wafer designs, we created a carrier wafer with slots for the chips and sliders etched completely through the 500 μm wafer. The chips and the sliders sat directly on the reaction chamber surface. The chips and sliders were coated with their respective film through ALD. SEM images were taken after each step in the fabrication procedure.

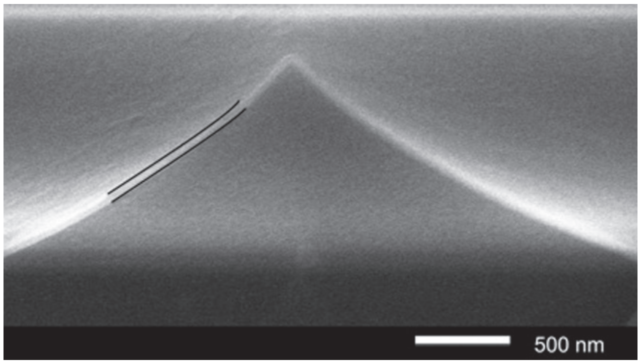

Figure 3: Cross-section of ALD HfO_2 tip. The bright film on the silicon is HfO_2. The two black lines were added to the image to indicate the film thickness clearly.

Results and Conclusions:

Forty nanometers of aluminum oxide and hafnium oxide were deposited on compliant cantilever test structures. Figure 3 shows a cross-section of a hafnium oxide tip obtained with a focused ion beam. The arrays were initially characterized. To begin wear and friction testing, sliders were placed on the cantilever arrays. The initial slider placement damaged the sharp cantilever tip upon impact, as seen in previous tribological studies of silicon-silicon interactions. The coated cantilever arrays were proved as a viable method to examine the mechanical properties of ALD films.

Future Work:

Future work will compile a comprehensive analysis of the mechanical properties of ALD films. The LDV testing of the aluminum oxide and hafnium oxide arrays will be completed, and testing will continue for other ALD films such as titanium oxide, titanium nitride, tungsten nitride, platinum and ruthenium. The differences in mechanical characteristics of plasma ALD films versus thermal ALD films will also be investigated.

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References:

[1] Smith, W. (2010).Shear Adhesion, Friction, and Wear of Multi-Point Micro- and Nano-Scale Contacts. Ph.D. Thesis. Stanford University.