Nanoscale Gold Deformation and Characterization

Yaniv Scherson, Mechanical Engineering and Materials Science, UC Berkeley
NNIN REU Site: Nanotech, University of California at Santa Barbara

NNIN REU Principal Investigator: Professor David Clarke, Department of Materials, UC Santa Barbara
NNIN REU Mentor: Jesse Williams & Giuliano Gregori, Department of Materials, UC Santa Barbara
Contact: yanivds@berkeley.edu, clarke@engineering.ucsb.edu

Abstract:
As a soft metal, gold undergoes significant deformation at the contact points in a MEMS switch causing failure after repeated cycles. An adhesion force is created as the indentation into the gold increases, causing the switch to stick in the closed position. Additionally, the gold curiously retains some grain roughness even after repeated cycles of indentation. By replicating the effects of roughness of the gold at a larger scale with the placement of gold columns on a gold substrate and nanoindenting, a better understanding of the deformation is obtained. Greater insight into the mechanics and behavior of the nanoscale gold deformation is achieved through varying the cycles, force, gold feature substrate, and the feature aspect ratio of the nanoindentation.

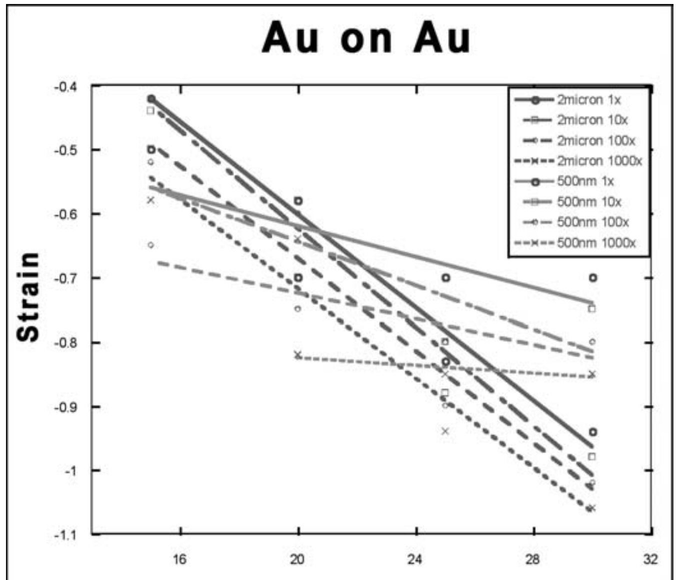


Figure 1

Experimental Procedure:

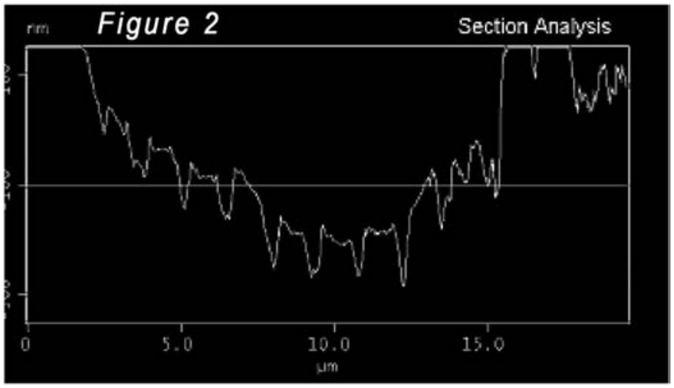
The approach of the experiment was to replicate the effects of nanoscale roughness on gold. Therefore, the main idea of the experiment was to recreate the effects of "gold roughness" at a larger scale by placing small vertically oriented square columns on a thin gold film. The thin film of approximately 15 μm Au was sputtered onto either a hard silicon substrate or a soft gold substrate. Gold square columns are then placed onto the gold film, extending upward. The columns are given three sizes. The largest columns were 2 μm wide and 500 nm in height. The next two sets of columns were 1 μm and a half micron in width, while both had two different heights, 200 and 100 nm.

The samples were then subjected to indentations of varying force and cycle number. Using a 50 μm radius tip indenter, sixteen indentations are made on each sample. Forces of 15, 20, 25, and 30 microNewtons are applied for 1, 10, 100, and 1000 cycles each, thus producing sixteen different indentations. As an example, Figure 4 depicts 1 μm pillars indented under a 25 milliNewton load. As one can see, the spherical indenter creates a depression into the gold pillars where the change in height of the center pillar can be used to calculate strain.

From the indentations, insight into the strain and effects of the hard or soft substrate can be gathered. Most insightful was the change in height of the column features at the center of the indentation. This height change measures the strain which that particular feature undergoes calculated by (height final - height initial) / height initial. Additionally, the final displacement of the substrate helps determine how much of the strain in the indentation was due to feature height displacement versus substrate displacement.

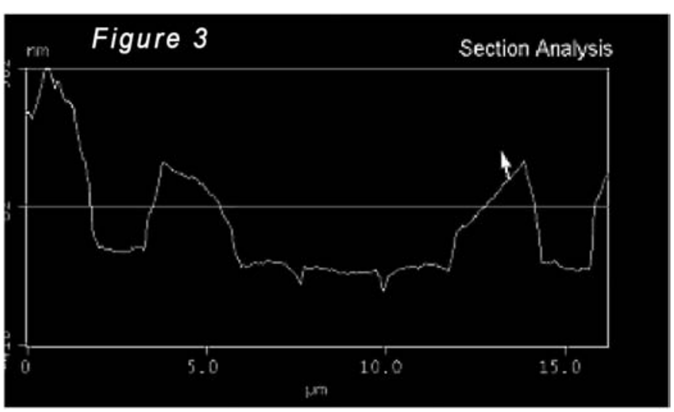
Results:

Of particular interest in the experiment are the effects in strain of the different sized columns and the effects of the silicon vs. gold substrate. Figure 1 depicts the variance in behavior of 0.5 μm columns vs. 2 μm columns by creating linear fits for the load vs. strain data points. The red lines represent the 2 μm columns while the blue lines represent the 0.5 μm columns. Additionally, the more dashed lines underwent a greater number of cycles. Therefore, as seen in the figure, increasing the load as well as the number of cycles of an indentation increases the strain in the columns, as one would expect. However, more interesting was the



varying behavior of the larger and smaller columns. The slopes of the 2 μm columns are steeper than the 0.5 μm columns. This suggests that as the applied load to the columns was increased, the increase in strain was smaller. A smaller change in strain to a higher load implies that the smaller 0.5 μm columns appear to have a higher yield stress, or in other words, appear to be effectively harder possibly due to the distribution of the applied load or constraint to column expansion when compressed by closely lying neighbors. Under the same 30 milliNewton load, the height of the 2 μm column in Figure 3 was displaced all the way down to the substrate while the height of the 0.5 μm columns in Figure 2 didn't displace fully to the substrate. The fact that the 0.5 μm columns maintained a larger height value further demonstrates the smaller columns' greater resistance to height displacement, or in other words, increased strength.

Yet an additional interesting trend was the lack of difference in strain of the columns on different substrates. Columns of equal size and initial height undergoing the same loads and indentation cycle number have no significant difference in strain. This trend was contrary to the expected outcome of a higher strain in the columns that are placed on a harder substrate that would displace less and direct more strain to the columns themselves.



Future Work:

In order to see if the effective higher yield stress observed in the smaller columns was due to an innate increase in yield stress or perhaps more simply constraint effects from neighboring features, the experiment should be run using 0.5 μm or smaller columns with a larger spacing between columns. It is unclear how much the neighboring columns affect one another, but it is obvious that as the smaller 0.5 μm features displace into the substrate neighboring columns smash into one another and impede lateral displacement of material. This constraint effect would give better insight into the reasons why a higher yield stress was observed in the smaller columns.

Additionally, more telling trends and data could be obtained by increasing the range of applied loads, indentation cycle number, and reducing column size, which is currently limited by the fabrication process.

Acknowledgements:

This project would not have been possible without the great help and support of Professor David Clarke, Jesse Williams, Giuliano Gregori, Angela Berenstein, NNIN, NSF, and UCSB.