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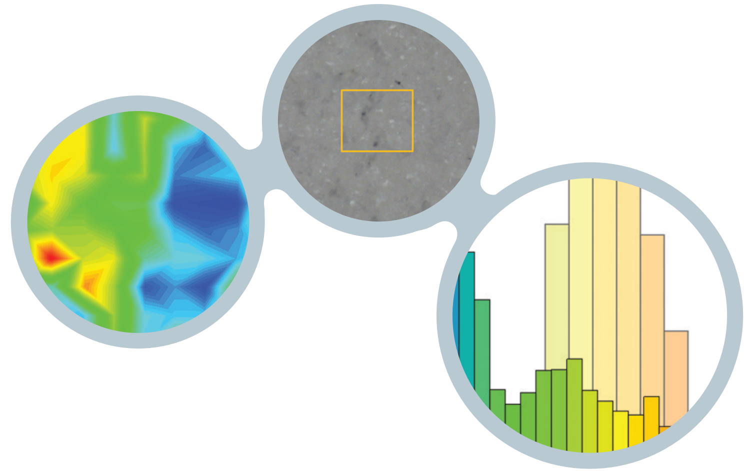

Application Note #1540

Utilizing Nanoindentation to Characterize CMP Pads

Chemical mechanical polishing (CMP) is currently used for interlayer dielectrics and metal layer planarization and plays a very critical role in today's microelectronics industry.[1] Pads are a key consumable in the CMP process, where the wafer surface is slid on a relatively soft polymeric porous pad that is flooded with chemically active slurry containing abrasive particles. The mechanical properties of the polishing pad and its surface morphology control the quality and efficacy of the CMP process, including the intentional inclusion of pores that enable slurry storage.[2]

Procedure

It is important to measure and understand the mechanical and viscoelastic properties of CMP pads, which are currently characterized by such techniques as dynamic mechanical analysis or Shores hardness.[3] These metrologies provide non-localized, average values of hardness and modulus for large volumes of the sample, including the pores, which is often not sufficient for proper quality analysis and control.

Nanoindentation, however, is a technique that can be used to quantitatively measure these properties at small scales, with full control over the indenter loading and unloading rates, dynamic oscillation, peak load, and other test parameters. The small contact size, ability to target small areas, and to map the surface stiffness minimizes the influence of pores on the final measurement.

Here, we investigated the near surface properties of a commercially available CMP pad, classified as a 100 MPa "hard pad" using Bruker's Hysitron® TS 77 Select, an automated benchtop nanomechanical test instrument. Dynamic indentation was used to measure properties such as the storage modulus, loss modulus and tan delta as a function of depth. Automation enabled large grids of indents, which then allowed for both statistics and mapping of regions containing pores.

CMP Nanoindentation Testing

A Hysitron TS 77 Select with a standard berkovich indenter probe was used to investigate the mechanical and viscoelastic properties of a hard CMP dry pad. An approximately 1 cm^2 piece of the self-adhesive pad was cut and adhered to steel discs for magnetic mounting on the sample stage. Standard quasistatic tests were performed, at a peak load of 70 µN. Viscoelastic properties of this hard pad were measured with a *Constant Strain Rate CMX* load function, with peak load reaching 500 µN, while continually measuring properties such as, the storage modulus, loss modulus, and tan delta. A 10x10 grid was setup for both loading conditions. A 10 µm spacing between the indents on the top surface of the pad was used. Large lifts at the start of the test kept the probe completely out of contact prior to loading to ensure an accurate zero point.

Results and Discussion

Several features of CMP pads complicate the test results, including surface roughness, internal porosity, and variations in the mechanical properties. All these lead to data that make defining a single modulus number for a pad difficult. This is apparent when 100 quasistatic tests are performed in an area that is reasonably flat in the optics (see Figure 1). Here, the peak load of 70 µN shows a large variation in response, with some tests simply collapsing a sub-surface pore. Roughly 75 percent of the data in this area involves tests indicating pore collapse. These tests, which show large hysteresis, can be discarded when measuring the modulii.

Even in regions that do not show obvious pore collapse, there is variation in the viscoelastic properties where the constant strain rate dynamic indentation test results can be seen (see Figure 2).

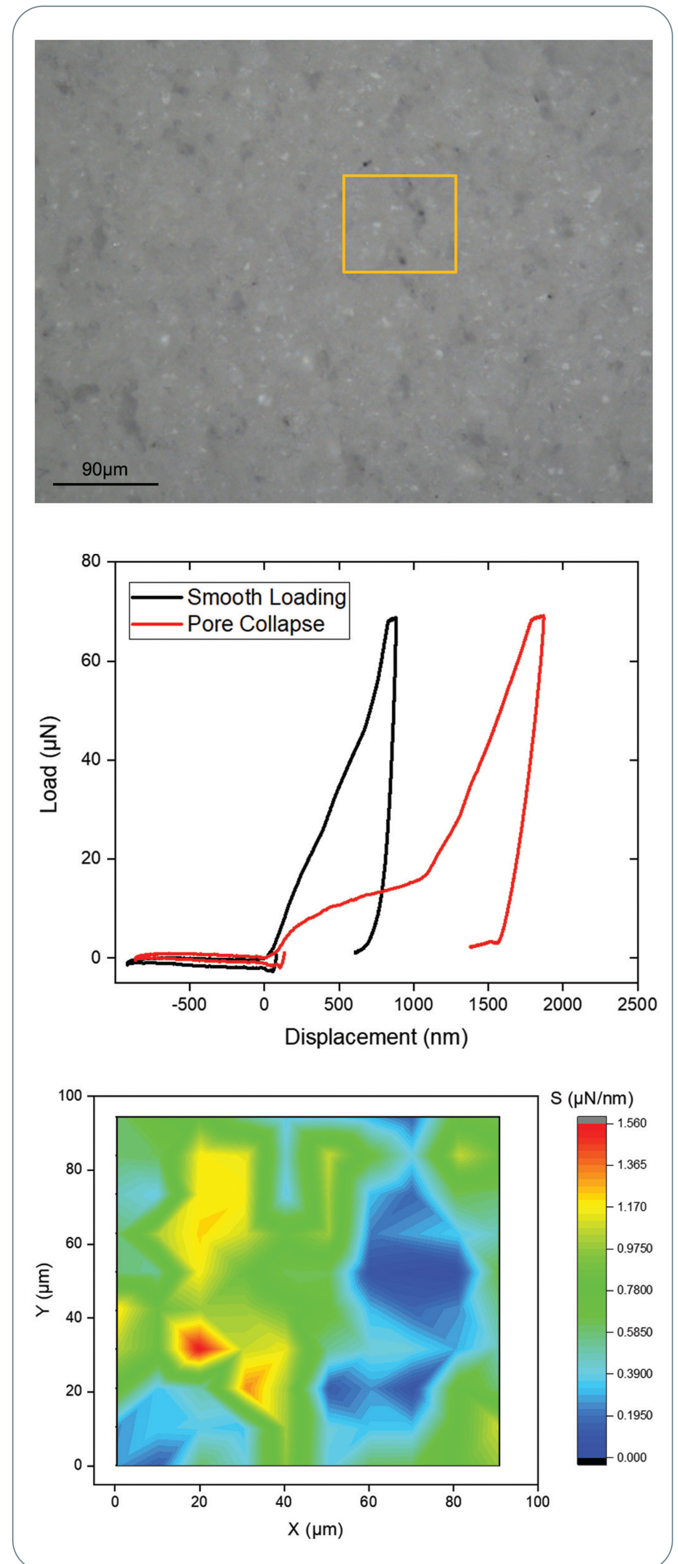

Figure 1. Top: Optical image of the top surface of the hard pad, showing the region of 10x10 grid for Quasistatic tests. Middle: Load vs. Displacement curves of quasistatic tests at a peak load of 70 µN, showing smooth loading vs pore collapse. Bottom: Contour map of the stiffness, from 10x10 matrix of quasistatic tests.

The spread in data can be attributed to two known causes, the roughness effect, and any intrinsic variation in the local mechanical properties. The effect of roughness is typically seen as a chi-squared-type distribution curve. The data from Figure 2 can be averaged between contact depths of 200 to 600 nm, and plotted as histograms to determine the distribution (see Figure 3). Rather than a single peak, with a chi-squared distribution, the histograms show an obvious bimodality, each with their own roughness effect. Interestingly, the ratios of E″/E′ result in a unimodal distribution of the tangent δ.

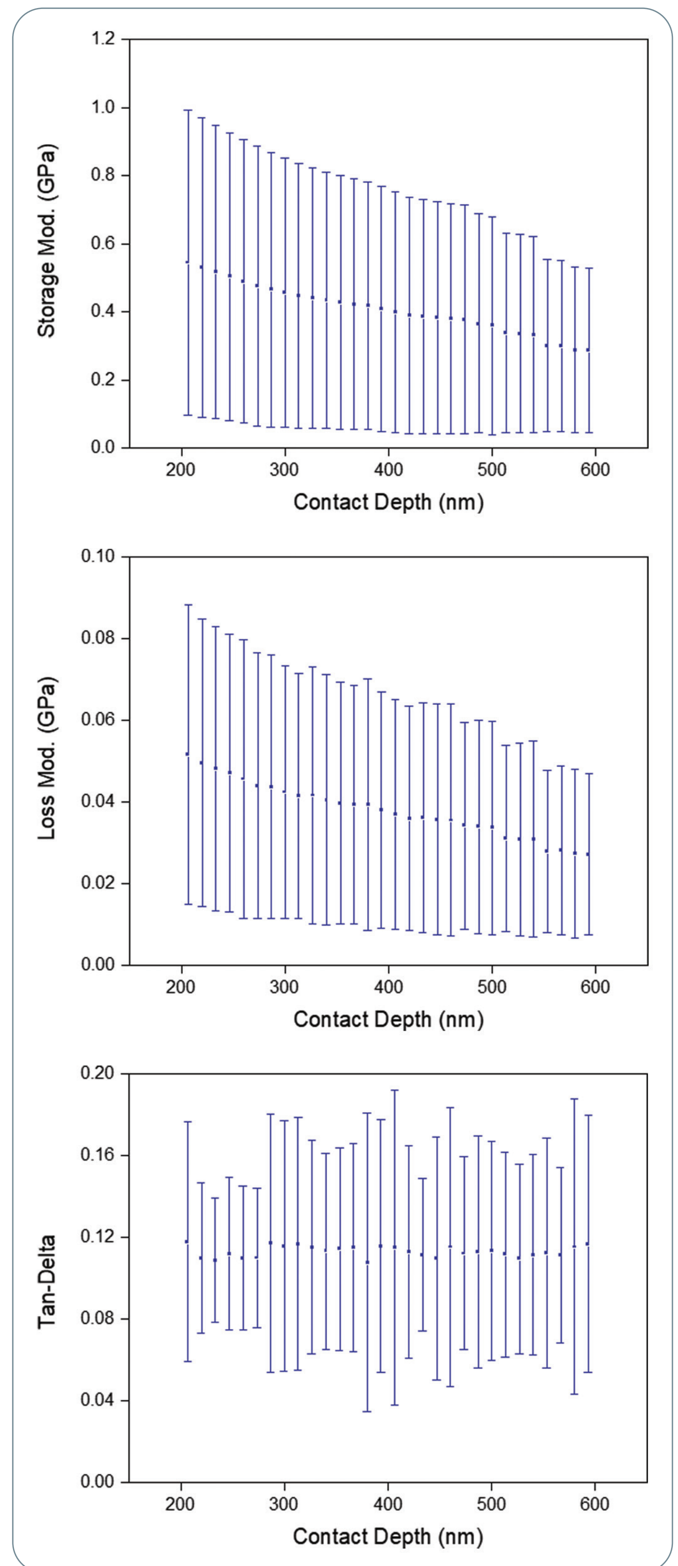

Figure 2. Viscoelastic properties of the hard pad showing storage modulus, loss modulus, and tan delta between 200 and 600 nm of contact depth.

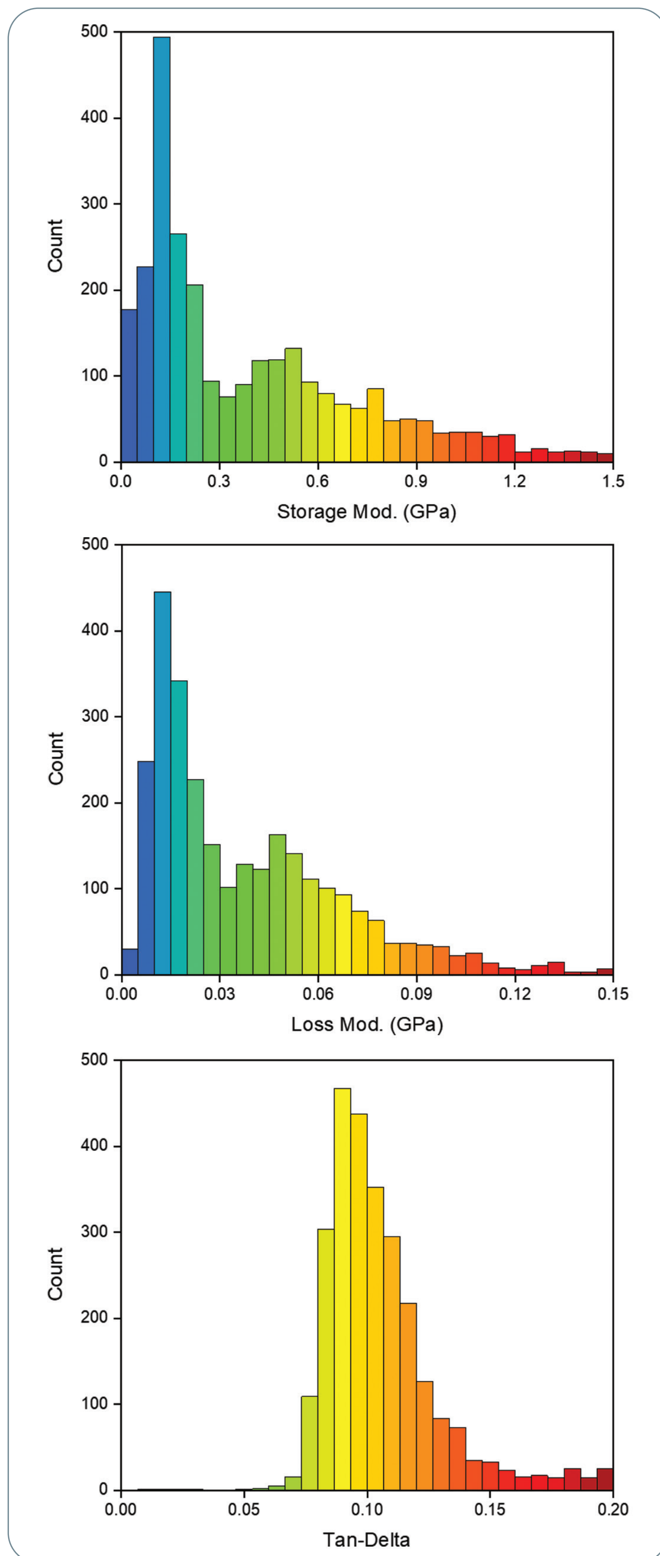

Figure 3. Histograms of storage modulus, loss modulus, and tan delta for the hard pad, for contact depths 200 to 600 nm.

Conclusions

The TS 77 Select, in combination with dynamic nanoindentation, was successfully used to quantitatively measure the viscoelastic properties of a CMP hard pad. This testing setup maintained full control over the indenter loading and unloading rates, peak load, and other test parameters. *Constant Strain Rate* dynamic indentation tests on the top surface of this pad resulted in depth profiles of storage modulus, loss modulus, and tan delta. By indenting away from pores, but using a large number of indents, there appears to be a structural variation in the pad that produces a bimodal distribution to the modulus. The methodology presented here can be adopted to quantitatively measure various properties of such pads, including their cross sections. The end result is a robust and reliable approach to better understanding CMP pad surface quality and processes.

References

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