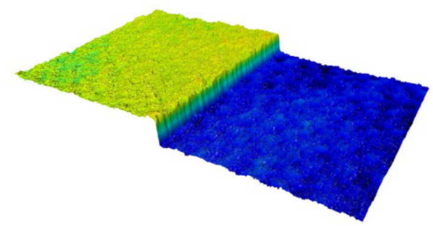
KLA INSTRUMENTS

General Information about Stylus-based Surface Profilers from KLA Instruments™



Introduction

KLA Instruments manufactures and develops stylus profilometers, metrology tools used in semiconductor, data storage, flat panel and other related industries, to monitor the effects of production processes on surface topography. The mechanisms of these profilers that allow precise and automated surface measurements are the focus of this application note.

What is a Stylus Profiler?

Stylus-based surface profilers from KLA Instruments use a stylus for tracing surface contours to acquire height and roughness information. The vertical motion of the stylus is digitized into a topographical map of the surface. Utilizing sophisticated hardware and software, these stylus profilers can accurately measure surface topography with high sensitivity. The hardware consists of the following components: (1) a stylus measurement head with stylus tip and (2) a scan mechanism. Each of these components is crucial to the performance of the profiler, and it is important to understand how each one plays a part in its functionality.

Stylus measurement head

The stylus measurement heads used in KLA Instruments Alpha-Step® D-series and Tencor™ P-Series profilers house a sensor assembly, which includes the stylus, the appropriate sensor electronics and integrated optics.

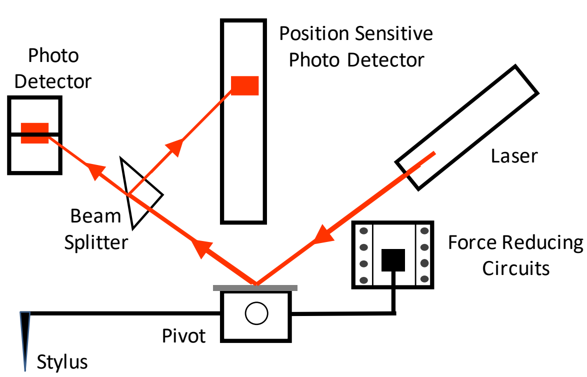


Figure 1. Alpha-Step D-Series sensor schematic

The KLA Instruments Alpha-Step D-Series sensor assembly is based on optical lever sensor technology, which was developed for AFMs in the 1980s[1] and was adapted to stylus profilometry in the 2000s. Figure 1 shows the Alpha-Step D-Series Optical Lever sensor schematic.

The Optical Lever sensor tracks the surface topography by using a laser beam reflected off the top surface of the pivot assembly. The reflected beam is then projected on a photodetector. For the D-Series, the beam is split into two components: one side is projected onto a dual cell photodetector while the other side is projected onto a single cell photodetector. This design enables high resolution measurements of smaller steps on one detector and measurement of larger steps on the second detector. The deflection of the laser beam changes as the stylus tracks the surface, which generates a signal in the photodetector and is displayed as a topographic map.

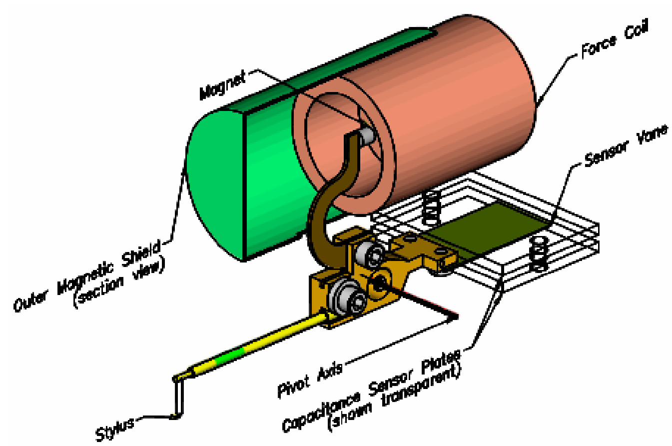


Figure 2. KLA Instruments MicroHead measurement head used in the Tencor P-Series profilers.

KLA Instruments MicroHead stylus measurement heads, found in the Tencor P-Series profilers, use a capacitive sensor assembly, shown in Figure 2, to monitor vertical displacements of the stylus. This sensor assembly design consists of a stylus arm suspended by a flexure pivot and connected to a sensor vane that extends through the center of a highly sensitive capacitive sensor called the Linear Variable Differential Capacitor (LVDC). Vertical movement of the stylus arm in response to the surface topography will result in movement of the vane, which is registered by the capacitive sensor. The analog signal from the capacitive sensor is digitized and displayed in a topographic map.

Force: For both D-series and P-series profilers, as the stylus traces across the surface, it will apply a force to the sample that is dependent on the deflection of the stylus and the spring constant of the pivot assembly. The ability to accurately apply and control this force is critical to the profiler performance. Attached above the stylus flexure pivot is an arm with a permanent magnet mounted to the end. The permanent magnet is held in close proximity to the wire coil, and the coil produces a magnetic field that moves the arm. The applied force pushes the stylus arm past its null position, correlating the displacement voltage to the force applied. The programmable stylus force can be set as low as 0.03mg for Tencor P-series and Alpha-Step D-series profilers.

In Alpha-Step D-series profilers, the force coil applies a constant lifting force, where the applied force is calibrated to correspond to the deflection of the stylus on a flat surface. As the stylus moves through the vertical range, the flexure of the pivot assembly affects the applied force. Tencor P-series profilers use an improved force coil which can apply a lifting or pushing force and a sophisticated digital signal processing feedback circuit to maintain a constant applied force to the stylus. To correct for the pivot tensions, the force is calibrated by servoing the drive current to the force coil to move the stylus to several regularly-spaced positions, with the stylus not in contact with the sample (zero stylus force). A table of stylus position vs. current settings is generated and used to calibrate a polynomial curve fit approximate to the data. A 10^{th}-order polynomial is used to properly correct for the nonlinearity of the position transducer. A digital signal processor then uses the curve fit to dynamically change the force setting as the position measurements are made. This enables the P-series profilers to apply the same force throughout their entire vertical range.

Viewing optics: Alpha-Step D-series profilers offer side view optics with a digital zoom of up to 4x. D-series profilers also utilize a keystone correction which digitally reshapes the angled side-view, giving the appearance of a top-down perspective. Tencor P-7 profilers have top- or side-view optics, while P-17, P-17 OF and P-170 profilers have DualView optics with a zoom of up to 4x. Top-view optics allow a clear view of the sample area for feature location and stylus positioning and are compatible with pattern recognition to aid in automated recipe setup. Side-view optics provide a 45° view of the sample surface and direct image of the stylus as it scans over the measured feature. In the case of the P-17, P-17 OF and P-170, DualView optics provide both top and side views.

Scan mechanism

The sensor assembly monitors the stylus movement as the sample is scanned. The Tencor P-Series and Alpha-Step D-Series profiler scan mechanisms hold the sensor assembly stationary while the sample stage is moved with a precision leadscrew drive mechanism. This drive mechanism, on the X-axis in P-Series profilers and on the Y-axis in D-Series profilers, uses a motor to drive the lead screw, which then moves the stage/sample with guide wires along an optically flat reference. The motion is monitored by an optical encoder and is accurate to 1-2µm. The optically flat reference ensures a smooth and stable movement of the stage across the scan length, while a guide bar provides a straight, directional movement, as shown in Figure 3. This scanning design limits the measurement noise from the instrument (which could impact surface roughness accuracy) by decoupling the stage motion from other motions within the instrument. In Tencor P-7, P-17 and P-170 profilers, the optical flat is 50% larger than the maximum allowable wafer size allowing continuous scan traces across the entire wafer diameter.

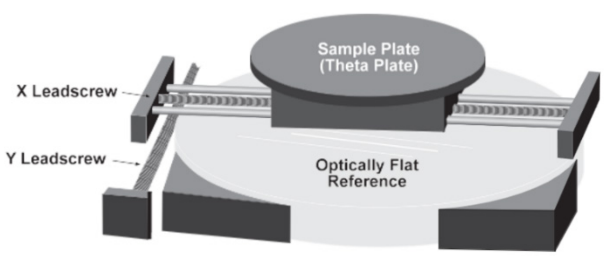


Figure 3. Tencor P-Series profiler scan mechanism.

Table 1. Stage and optics specs for different stylus profilers

	D-500	D-600	P-7	P-17/ P-170	P-17 OF
Stage Type	Manual	Motorized	Motorized	Motorized	Motorized
Sample Stage Diameter	140mm	200mm	150mm	200mm	300mm
X Range of Motion	80mm	150mm	150mm	200mm	200mm
Y Range of Motion	20mm	178mm	150mm	200mm	200mm
Scan Length	30mm	55mm	150mm	200mm	200mm
Optics	Side View	Side View	Top or Side view	Top and Side view	Top and Side view

Three-dimensional scanning: Three-dimensional images can be obtained by acquiring two-dimensional scans in the X direction while stepping in the Y direction, using the Y lead screw for precise sample positioning (this configuration is the opposite for the Alpha-Step D-Series tools). KLA Instruments offers proprietary 3D software, available only on the P-Series, as well as offline analysis software for 2D and 3D surface analysis, including ProfilmOnline, ProfilmDesktop and Apex. The offline analysis software comes integrated into all KLA Instruments stylus profilers and is also available as an option. The 3D image is software-rotatable to allow image viewing from multiple angles. Analysis of the surface can be obtained from either a single line trace on the 3D image or by area analysis.

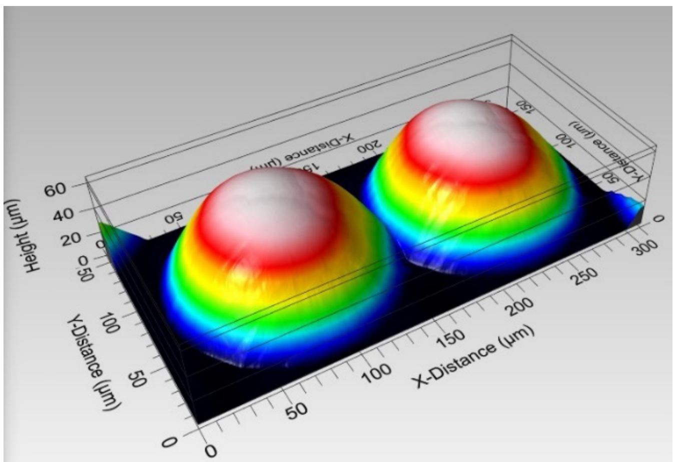


Figure 4. ProfilmOnline rendering software for stylus profilers. This image shows a 3D scan of a Microlens.

Sample size: Each KLA Instruments stylus profiler supports specific sample sizes. The Alpha-Step D-600, the Tencor P-17, and P-170 profilers are all designed to handle 200mm wafers, and the D-500 and P-7 profilers accommodate 150mm wafers. The Tencor P-17 OF (Open Frame) profiler can be configured for 300mm wafers or with a 240 x 240mm chuck.

Stylus

The lateral resolution of the profiler is dependent not only on the resolution of the scan mechanism, but also the stylus tip geometry. Trench measurements also depend on the stylus tip radius of curvature and cone angle. When the stylus is in contact with the sample, features with widths of similar size or larger than the stylus tip radius of curvature can be accurately measured.

The KLA Instruments stylus is a diamond chip tip that is braised to a stainless steel rod mounted to a stylus arm. The diamond chip is cleaved, then ground and polished to a specific dimension. The radius of curvature for the sub-µm stylus tip, which is assumed to be spherical, is measured with a Scanning Electron Microscope (SEM), or against a standard. The portion of the stylus tip that is in contact with the sample surface, along with the known radius of curvature, determines the actual radius of the tip relative to the feature size. The stylus cone angle is determined from the cleave and grind of the diamond chip and is checked optically or against a standard.

Stylus-based surface profilers are used for many types of applications that require styli with different radii of curvature and cone angles. There are multiple options available for use with KLA Instruments stylus profilers, as listed in Table 2.

Table 2. Available profiler styli*

Stylus Type	Radius of Curvature of Stylus Tip (µm)	Included Cone Angle (°)
Standard	2.0	60
2µm-20 deg	2.0	20
2µm-45 deg	2.0	45
5µm-60 deg	5	60
12.5µm-60 deg	12.5	60
25µm-60 deg	25	60
50µm-60 deg	50	60
0.2µm High Aspect Ratio (HAR)*	0.2	20 - 45
0.5µm High Aspect Ratio (HAR)*	0.5	20 – 45
2µm High Aspect Ratio (HAR)*	2.0	20 - 45
0.5µm Submicron*	0.5	40
0.2µm Submicron*	0.2	90
0.2µm Submicron*	0.2	40
DuraSharp® II (1µm exposure)*	0.04	40
DuraSharp® II (3µm exposure)*	0.04	40
UltraSharp*	0.02	40
Knife Edge	2 x 50	60

**Not for use with Alpha-Step D-Series profilers.*

Radius of curvature and cone angle can affect the measurement of small features or trenches. Figure 5 shows an example of a stylus that has a radius of curvature larger than the width of a small feature. It shows the distortion of the measured feature width by the stylus tip, but the height measurement is not affected.

Another typical profiler application involves measuring depths of trenches. Figure 6 shows an example of a realistic scan profile across a trench, where the stylus cone angle and radius distort the edges of the trench, but a clear step is detected. The appropriate stylus for a particular trench application can be selected from known stylus geometries, radius of curvature, and cone angle.

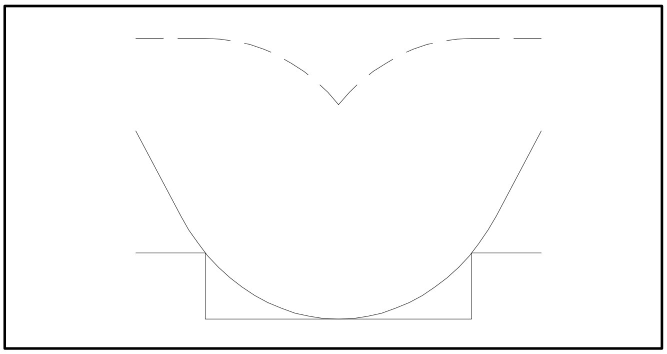


Figure 5. Stylus with radius of curvature larger than width of small feature.

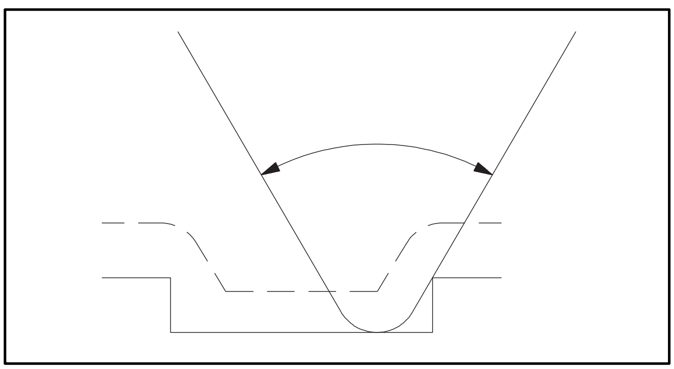


Figure 6. Distortion of trench profile due to stylus cone angle and radius.

The maximum trench depth H_{max} can be determined from the following equations:

When $W \leq 2R[\cos(\theta/2)]$, $H_{max} = R\{1 - \cos[\arcsin(W/2R)]\}$

When $W > 2R[\cos(\theta/2)]$, $H_{max} = R[1 - \sin(\theta/2)] + [W - 2R\cos(\theta/2)]/\tan(\theta/2)$

where: H_{max} = maximum trench depth, W = trench width, R = stylus radius, and θ = stylus tip cone angle. As the stylus radius of curvature decreases, the pressure applied to the sample surface increases, increasing the force per unit area, thus increasing the chance of the stylus marking the surface. Therefore, the proper operating procedure is to decrease the applied force with a decrease in the stylus radius of curvature.

Applications

Stylus profilers are used for various applications in the semiconductor, data storage, flat panel, and other related industries, for monitoring production, development and quality control processes. Primary applications in the semiconductor industry include monitoring film deposition, lithography, pre- and post-etch, chemical-mechanical planarization (CMP), and backside grind processes. Critical to CMP development applications is the stylus profiler's ability to create three-dimensional images, such as those shown in Figure 7, to monitor local as well as global planarization effects.

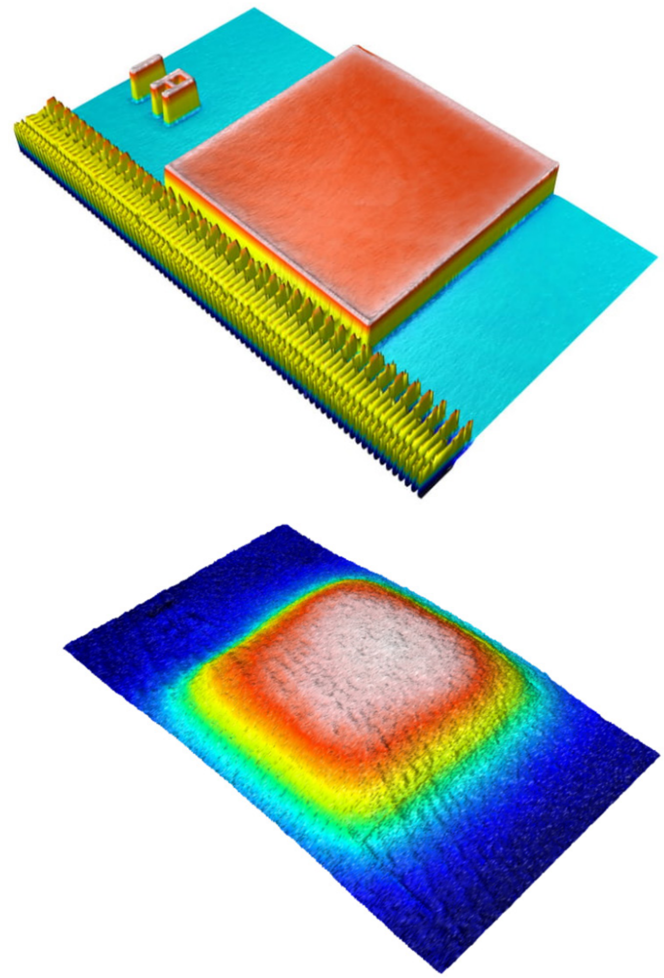


Figure 7. 3D images for SiO_2 CMP process control; pre-CMP (top) and post-CMP (bottom).

The data storage industry uses stylus profilers to monitor hard disk surface roughness, quantify hard disk roll-off (including chamfer angle and depth), thin film head bar roughness, and thin film head pole tip recession. For optimized repeatability in measuring hard disk fine roughness (such as for the surface shown in Figure 8), it is critical to use a small radius of curvature stylus, 0.1 - 0.2µm, as well as the low stylus forces delivered by KLA Instruments profilers, to avoid scratching the surface.

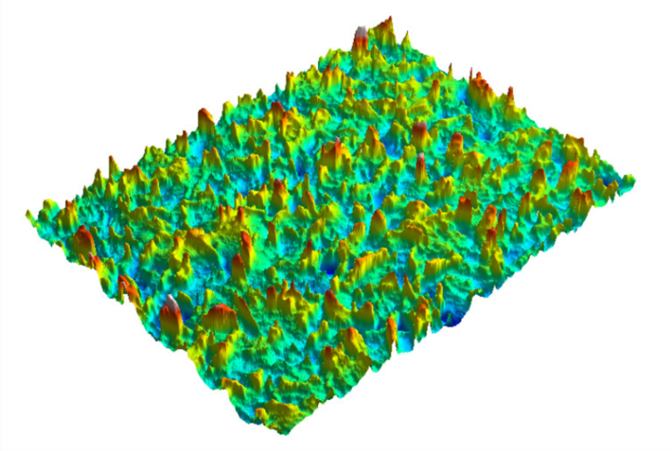


Figure 8. 3D surface roughness measurement

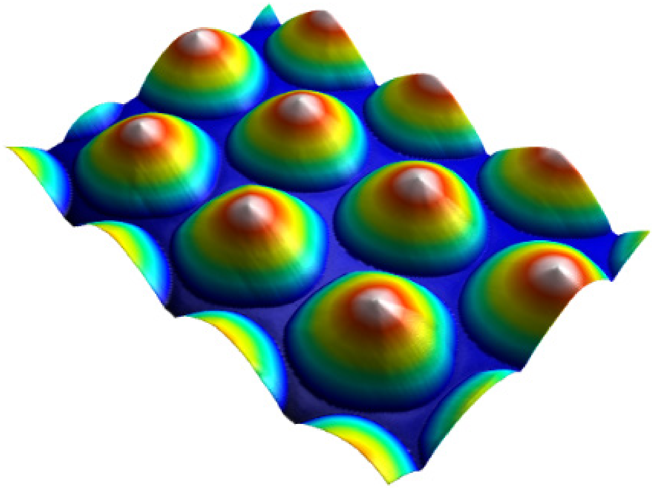


Figure 9. 3D image of a patterned sapphire substrate (PSS) for LED process control

Stylus profilers have wide applications across many industries, ranging from solar, LED, semiconductor and compound semiconductor, automotive, medical devices, MEMS, and data storage, and are also well-suited for general use in universities, research labs and institutes

References

1. G. Myer et al. (1998), Novel Optical Approach to Atomic Force Microscopy. Applied Physics Letters, 53, 1045-1047.

KLA SUPPORT

Maintaining system productivity is an integral part of KLA's yield optimization solution. Efforts in this area include system maintenance, global supply chain management, cost reduction and obsolescence mitigation, system relocation, performance and productivity enhancements, and certified tool resale.

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