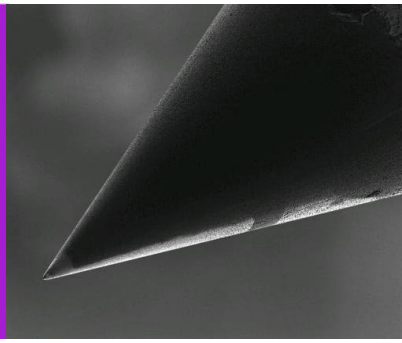
KLA INSTRUMENTS

Stylus Product Line

Alpha-Step®, Tencor™ P-Series and HRP®-Series Profilers



Introduction

KLA Instruments™ stylus profilers may be used with different styli to optimize measurements for specific applications. The KLA profilers, including the Alpha-Step® D-Series, Tencor™ P-Series and High Resolution Profilers (HRP) Series all use the same stylus design. This application note discusses the various types of styli available for these profilers and typical applications for their use.

Table 1 lists styli for currently available KLA stylus profilers. Each stylus has four distinguishing characteristics: band color, tip radius, included angle, and exposure. All styli can be used in any KLA profiler, except for the DuraSharp® and UltraSharp® styli. The use of these styli is restricted to the Tencor P-series and HRP-Series profilers, due to additional stylus protection features. All styli are made from diamond to maximize stylus lifetime.

Table 1. KLA Profiler Styli

Stylus Type	Band Color	Tip Radius (µm)	Included Angle (°)	Exposure (µm)
50 micron	White	50	60	> 400
25 micron	Blue	25	60	> 400
12.5 micron	Red	12.5	60	> 400
5 micron	Yellow	5	60	> 400
2 micron	Green	2	60	> 400
2 micron	Orange	2	45	> 400
2 micron HAR	Dual-Green	2	20	> 400
Knife Edge	Tri-Green	2 x 60	60	> 400
0.5 micron HAR	Tri-Black	0.5	40	> 20
0.2 micron HAR	Dual-Black	0.2	40	> 20
Submicron	Black	0.2	> 90	> 400
DuraSharp	Dual-Red	0.04 ± 0.01	40 ± 5	> 0.7
DuraSharp (L)	Black-Red	0.04 ± 0.01	40 ± 5	> 3
UltraSharp	Dual-Blue	0.02 ± 0.01	20 ± 5	> 0.7

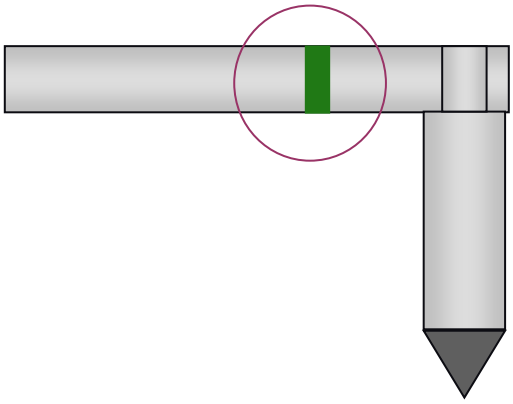


Figure 1. The colored band(s) on the arm indicates the stylus type.

Physical Characteristics

Each stylus can be identified by one or more color bands, as shown in Figure 1 and Table 1. The color band is unique to each stylus and helps the user identify the stylus installed in the system.

The stylus geometry is defined by the radius of curvature and included angle of the stylus tip, shown in Figure 2, as well as the exposure length. All dimensions are qualified in manufacturing by either comparing optically to a standard or with a Scanning Electron Microscope (SEM).

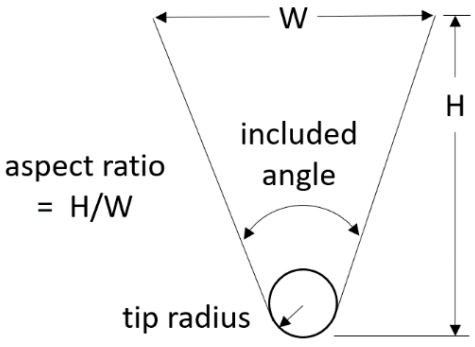


Figure 2. Stylus tip geometry.

The tip radius ranges from 20nm to 50µm and primarily impacts the lateral resolution of the measurement, the pressure applied to the sample surface and, to a lesser extent, the maximum measurement depth. The lateral resolution affects how well small structures are resolved and is generally a concern when measuring roughness. A general rule of thumb is that the lateral resolution is approximately 25% of the tip radius for individual features, and approximately 10% for surface roughness. For a 2µm radius stylus, the lateral resolution of a feature is approximately 0.5µm, and for surface roughness, approximately 0.2µm. The pressure on the sample surface is a function of the applied force and the tip radius, with a larger radius stylus resulting in lower pressure on the sample surface. The pressure is force divided by area (P = F/A), with the contact area approximated from the radius of the stylus ($A = \pi r^2$). As a result, when measuring soft surfaces, a stylus with a larger area (radius) results in lower surface pressure to improve sample measurement capability.

The included angle ranges from 20 to 100° and is the primary factor for determining the maximum measurable depth of trenches or vias (recessed features). Maximum measurable depth can also be expressed by the aspect ratio (H/W), shown in Figure 2. For most 60° styli, the aspect ratio is 1:1, which means that for a 50µm wide trench, the stylus can reach a maximum depth of 50µm. However, in addition to the aspect ratio, accurate step height measurements require capturing, at minimum, approximately 20% of the bottom surface. For a feature that is 50µm wide, an accurate depth measurement is possible when the feature is no more than 40µm deep. Using a high aspect ratio (HAR) stylus increases the maximum measurable depth. The included angle also influences the sidewall measurement capability. For a stylus that is positioned exactly normal to the surface, the maximum measurable sidewall angle is 90° minus half of the included angle. For a 20° included angle, the maximum measurable sidewall angle is < 80°, which is [90° – (0.5*20°)].

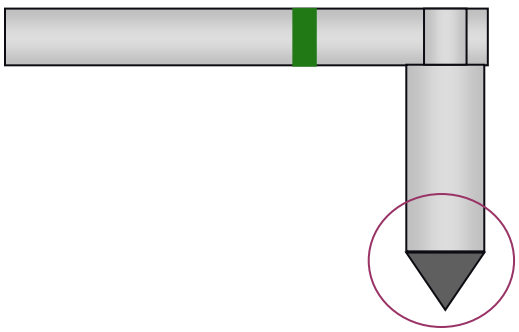


Figure 3. The stylus tips are made of diamond for maximum lifetime.

The exposure length is the angled section of the stylus that is described by the specifications in Table 1, ranging from 0.7µm to > 400µm. The diamond portion of the stylus is circled in Figure 3. For styli with an exposure length > 400µm, the exposure is equal to the total length of the diamond tip. For styli with smaller exposures, the end of the stylus tip has been manufactured to the specified included angle for the length of the exposure, above which the angle and shape of tip change. The exposure of a stylus, along with aspect ratio, is an important factor in determining the maximum measurable trench depth.

For applications where the step height exceeds the total length of the diamond, it is recommended to scan the step from top to bottom. If scanning from the bottom to the top of a step, the lateral force on the stylus can affect the measurement. The lateral force is approximately described as follows:

$$\text{Lateral force} = [C \cdot \sin(\Theta/2)] + [F_{applied} \cdot \cos(\Theta/2)]$$

where C is a constant correlating the lateral speed to the force, given the unknown mass of the stylus; Θ is the internal angle of the stylus; and $F_{applied}$ is the applied stylus force. Typically, when scanning up or down a step, the stylus is touching the sample at a single point. When the sidewall touches only the side of the stylus cone, the force is distributed both vertically and laterally. This situation requires either slower speed or a special stylus design to properly measure the sample.

2-50µm Radius Styli

Figure 4. The standard KLA stylus has a 2µm radius with a 60° included angle.

The standard stylus that comes with the KLA stylus profilers has a 2µm radius with a 60° included angle and is shown in Figure 4. Applications include step height, roughness and stress measurements. Other large radii styli (2, 5, 12.5, 25 and 50µm) are typically used when lower sample pressure is required and/or for very fast scanning speeds. The included angle is 60°, except for the 2µm radius stylus, which is also available with included angles of 20° and 45° for measuring higher aspect ratio step heights.

Knife Edge Stylus

The knife edge stylus has a 2µm radius and 60° included angle, with a 50µm long edge perpendicular to the scan direction. This stylus is primarily used for features that have a rounded top, where measuring across the exact peak of the feature is critical.

To determine the maximum height of a rounded feature with a conical stylus, a 3D scan must be run to ensure measuring the peak in one of the constituent profiles. The knife edge stylus captures the maximum height in a single 2D scan, because the long stylus edge returns the maximum height within 25µm on both sides of the scanning path, as shown in Figure 5.

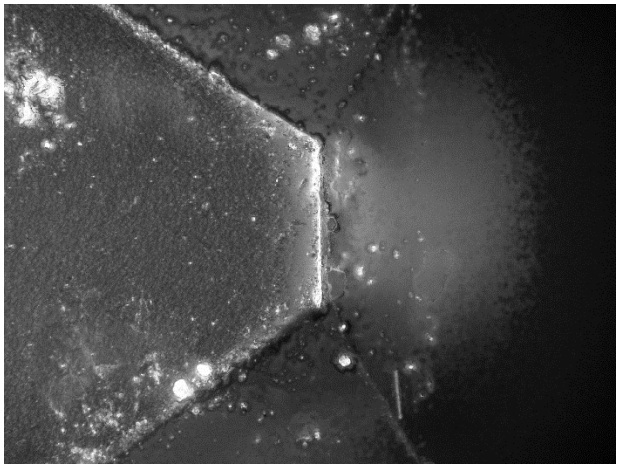


Figure 5. Knife-edge stylus (bottom view)

2µm HAR Stylus

The 2µm HAR stylus has a 2µm radius with 20° included angle, as shown in Figure 6. This stylus supports the measurement of larger, higher aspect ratio (up to 2:1) features, e.g., 50µm wide, 100µm deep. An example application is the measurement of photoresist via etch for a copper pillar process. Measuring the etch depth prior to deposition of the seed layer and the copper allows the user to redo the lithography step to achieve the proper etch depth.

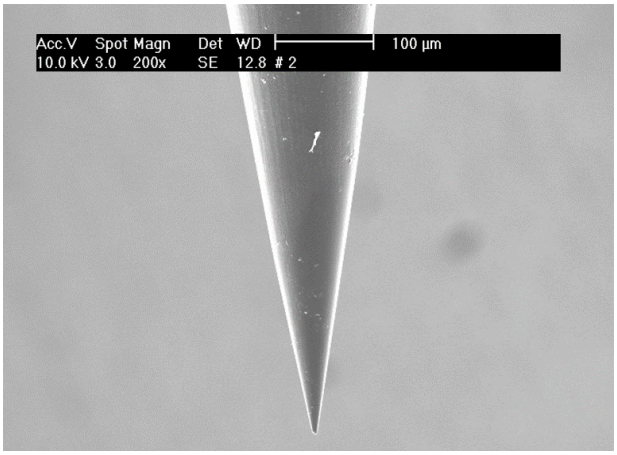


Figure 6. 2µm High Aspect Ratio stylus

Submicron HAR Styli

The Submicron styli have either a 0.2µm or 0.5µm radius with a 40° included cone angle, as shown in Figure 7. This stylus has a faceted pyramidal shape at the tip, which is common for all styli with a tip radius < 1µm. In addition, this stylus has two different angles: the smaller angle for the bottom portion of the stylus up to the exposure length of 20µm. Above the exposure length, the angle is 20°. This stylus is for trench or via depths that have an aspect ratio greater than 1:1 and can also be used for higher resolution roughness measurements.

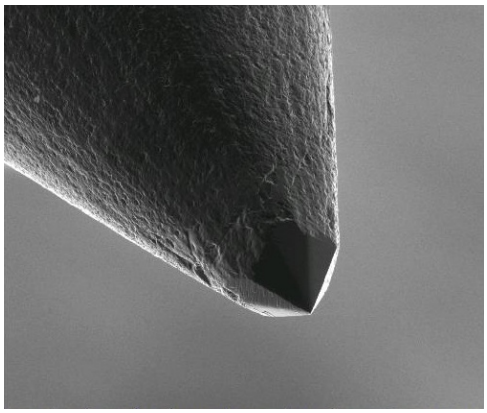


Figure 7. Submicron High Aspect Ratio stylus

Submicron Stylus

The Submicron stylus has a 0.2µm radius with > 90° included angle. This stylus is typically used for higher resolution roughness measurements but can also support standard step height applications.

DuraSharp Styli

The DuraSharp styli have a 0.04 ± 0.01µm radius with 40 ± 5° included angle, as shown in Figure 8. The standard DuraSharp has an exposure > 0.7µm and the long DuraSharp (L) has an exposure of > 3µm. The radius, angle, and exposure of these styli are individually certified, with the exact values shown on the stylus container label.

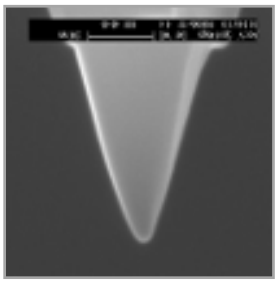


Figure 8. The KLA DuraSharp II stylus has a 40nm radius with 40° included angle.

Figure 9 shows an expanded view of the DuraSharp stylus. The 2µm, 60° stylus is used as the base, with the stylus having a

large, flat area, where the 40nm, 40° portion of the stylus is shown at the center. When measuring features that are taller/deeper than the exposure length, some artifacts on the sidewall will be visible due to the discontinuity in the stylus shape. The UltraSharp uses a similar manufacturing process, with a similar expanded view.

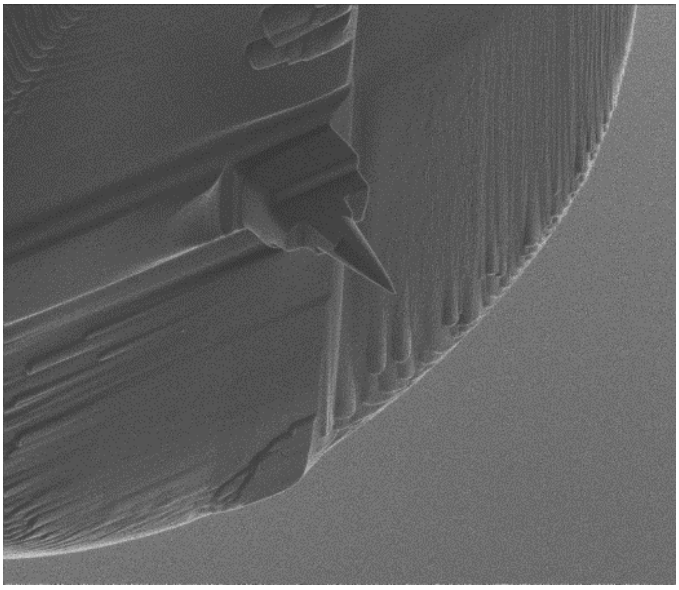


Figure 9. Expanded view of DuraSharp stylus

The DuraSharp can only be used in the Tencor P-Series and HRP-Series stylus profilers. The nanometer-scale tip radius requires extra protections to safely use the stylus. These advanced profilers have variable nulling approach speeds that are set based on the type of stylus installed. Soft-top nulling softly touches the stylus to the sample surface, and a maximum force limit of 0.2mg are both set based on the stylus installed in the system. In addition, the maximum recommended scanning speed is 50µm/s.

The DuraSharp stylus is designed for surface characterization that requires high resolution measurements or small, high aspect ratio features. Examples includes post-CMP surface characterization measurements such as copper dishing, erosion, and recess, shallow trench isolation, tungsten plug recess and local surface roughness characterization of both metals and dielectrics. The DuraSharp also has established applications in metal deposition and CMP for read-write head processing. The DuraSharp, when combined with the HRP scanning stage, can provide very high lateral resolution measurements for analyzing small, high aspect ratio features or metal grain structures.

UltraSharp Stylus

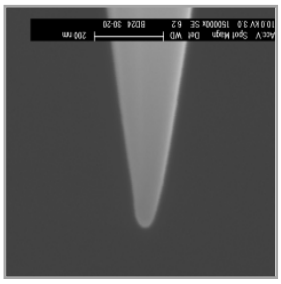


Figure 10. The KLA UltraSharp stylus has a 20nm radius with a 20° included angle.

The UltraSharp stylus has a 0.02 ± 0.01µm radius, a 20 ± 5° included angle, and an exposure > 0.7 µm, as shown in Figure 10. The radius, angle, and exposure of each stylus is individually certified, with the exact values shown on the stylus container label. Due to the small included angle and tip radius, this stylus can only be used with the HRP-Series profilers, using the high resolution scanning stage. This stylus is recommended for applications with shallow sidewalls, such as measuring very high resolution surface roughness and CMP dishing, erosion and recess.

Summary

The KLA Instruments Alpha-Step D-Series, Tencor P-Series, and HRP-Series stylus profilers can be used with many different styli. Each stylus is designed to optimize performance for specific applications, and the KLA applications team is available to answer any questions. If none of the styli discussed here meet your specific application requirements, KLA has 40+ years of stylus development expertise to assist with custom stylus designs.

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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