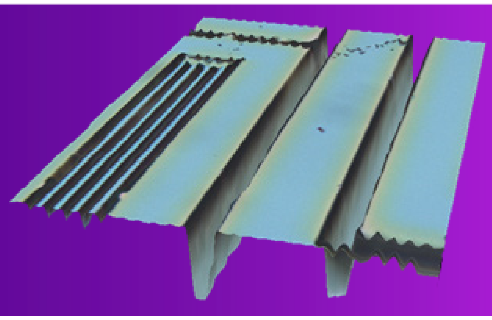
KLA INSTRUMENTS



Multi-Step Analysis Function

Powerful Analytics from KLA Instruments™ Surface Profilers

Introduction

KLA Instruments™ designs and manufactures stylus profilometers, metrology tools used in semiconductor, data storage, material science, LED, display, and other related industries, to monitor the effects of production processes on surface topography. Stylus-based surface profilers from KLA Instruments trace surface contours to acquire topography, including height and roughness information, based on the vertical motion of the stylus. Once a 2D scan is completed, a step, trench or flat curve may be displayed. With simple filtering, leveling and calculation, the step height or trench depth is then shown to user. The current profiler software includes feature detection that automatically determines the cursor locations for measurements of step height.

However, if there are several steps or trenches along the profile, what is the best method to effectively analyze every step? KLA Instruments is the first to address this challenge by introducing an automated multi-step analysis function, which is discussed in this application note.

Single Step Height Analysis

Given a 2D profile that includes a step, the critical dimension is the height of that step. Once data collection is complete, a basic height measurement can be made by first manually leveling the trace using cursor placement, and then by manually adjusting the measurement cursor positions to generate the result.

In many cases, especially for small steps, signal noise and waviness may not be insignificant, in which case it is necessary to apply a noise filter and a waviness filter to improve the measurement result.

To eliminate the complex and tedious cursor positioning adjustment during step height analysis, KLA Instruments originally introduced automated feature detection into the analysis process. Feature detection is used to enable automatic detection of some common classes of profile features, as shown in Figure 1.

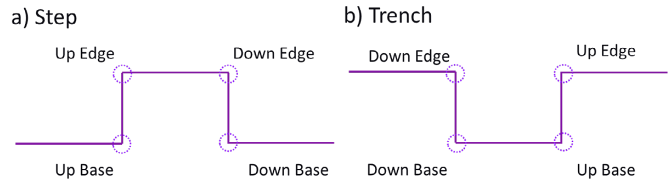


Figure 1. Detectable features for automated step (left) or trench (right) measurement include the up base, up edge, down edge, and down base.

Feature detection enables the profiler software to automatically set the measurement and leveling cursor positions relative to the rising and falling edge of a step feature or the apex of an arc feature. For example, when selecting the up edge as the target feature, the cursors can be placed relative to the up edge of the step. With feature detection, the leveling cursors and measurement cursors are placed relative to the feature, not the starting point of the scan, as shown in Figure 2.

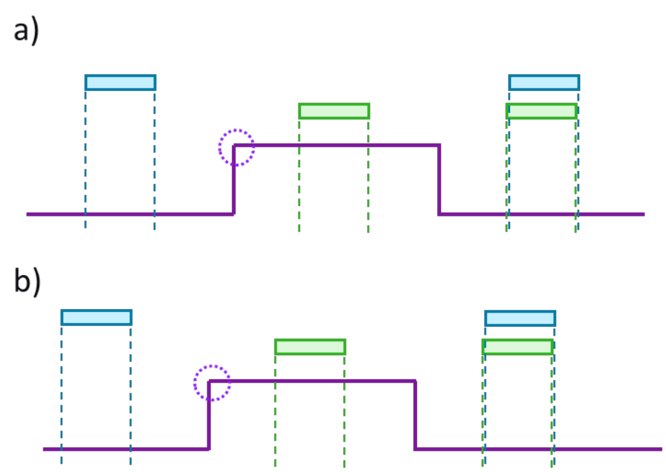


Figure 2. The leveling (blue) and step height measurement (green) cursors are automatically placed relative to the specified feature (up edge, here).

Multi-Step Analysis – Manual Methods

Analysis of multiple steps can be done either fully- or partially manual.

Fully Manual Method with up to 30 Cursor Pairs

To analyze multiple steps in a trace, the KLA Instruments software supports the use of up to 30 measurement cursor pairs. The fully manual method is to specify **user-defined** measurement cursor placement to then define the range and location of each cursor pair. The result summary panel will then display all individual step heights, as well as the step height average, minimum, maximum, and standard deviation.

Manual Method with Feature Detection

With **feature detection** enabled, the cursor size and locations are defined more easily when applied to repeating steps on the scan trace. For this method, the measurement cursor pair range and locations are specified for the first step, and for all other steps, **same for all** is selected. The feature detection algorithm will then automatically place measurement cursors at each step following the same user-defined setting for the first step. Figure 3 shows an example of a multi-step height measurement with feature detection enabled. The five individual step heights and the average step height are shown in the summary panel at the left.

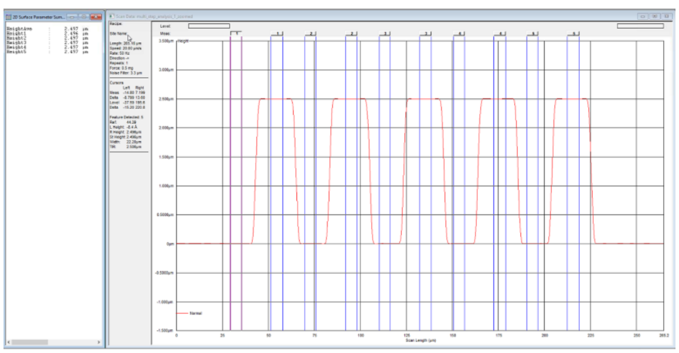


Figure 3. The manual method with feature detection applies the user-defined feature detection to all steps on the scan trace.

This manual method works well when there are just a few steps or trenches on a single trace. However, this method is not optimized for use with many steps of different widths and pitch values.

Multi-Step Analysis – Automated Methods

Automated measurement and analysis of multiple step heights are measured using **Auto Step Detection** and **Auto Multi-Step Analysis**.

Auto Step Detection

To maximize the functionality, the software should automatically adjust the measurement cursor range and location relative to the individual step shape. In other words, software should be able to detect the entire step or trench and then specify the cursor positions relative to it. The profiler software now has the capability to simultaneously detect all four key features: up edge, up base, down edge, and down base.

For a single step, as shown in Figure 4, the software analyzes the derivative of the scan to detect (a) the up base and up edge features using the slope threshold, and (b) the down edge and down base features using the plateau threshold. For a scan segment to be defined as a complete step, the features should be detected in the order of up base, up edge, down edge, and down base. To define a trench, the features should be detected in the order of down edge, down base, up base, and up edge.

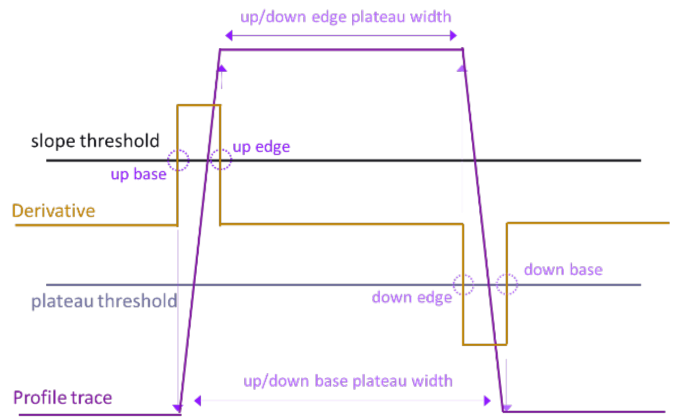


Figure 4. A complete step is defined by analyzing the derivative of the scan trace to detect up base, up edge, down base, and down edge.

Auto Multi-Step Analysis

After determining whether a feature is a step or a trench, the software locates the base and edge components and then calculates the step or trench width based on these locations. Automated step detection has been further enhanced to automatically place a pair of measurement cursors on a step based on a user-defined percentage of the cursor range relative to the whole step or reference area.

When a single levelled trace contains many steps (or trenches), the profiler software can automatically detect each step and define its cursor positions, with no need to pre-define the number of cursor pairs. Combining this multi-feature analysis function with the existing histogram-based leveling, the analysis process of multiple steps/trenches is now fully automated.

Figure 5 shows the automated method result for the same trace shown in Figure 3, with the measurement cursor range defined as 50% of the step width. The cursor range and locations are slightly different for each step, and the results differ by ≤ 0.12%, where the average step height is equal between the two methods.

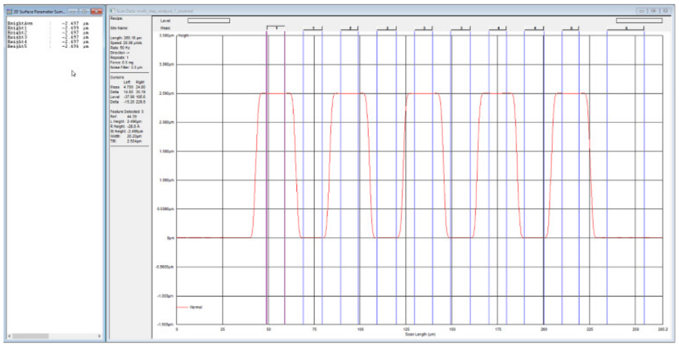


Figure 5. The automated method with multi-step feature detection is applied to all steps on the scan trace, generating the same step height results to ≤ 0.12%.

Table 1 compares the individual and average step height measurements of the five steps for the automated and manual measurement methods. The delta values show a negligible difference between the two methods, which recommends use of the automated method for best time-to-results (TTR). In addition, these analysis results (individual and average height / width / pitch) can be automatically uploaded to a host controller using GEM/SECS, which is available for most KLA Instruments stylus profilers.

Table 1. Step height measurement comparison between automated and manual methods.

	Step Height Measurement Method		
Step No.	**Auto (µm)**	**Manual (µm)**	**Delta (µm)**
1	2.496	2.499	0.003
2	2.497	2.497	0.000
3	2.497	2.497	0.000
4	2.497	2.497	0.000
5	2.497	2.496	-0.001
Average	**2.497**	**2.497**	**0.000**

Application Examples of Multi-Step Analysis

The following section illustrates three different case studies for automated multi-step analysis.

Case Study 1: Printing Line Step Height Uniformity

Several printing lines were created on the surface of a wafer, and the objective was to measure step height uniformity when the step width and pitch are variable.

Previously, this type of measurement required a manually-defined sequence of individual scans at each step. This approach is extremely time-consuming for both recipe building and actual scanning. However, using the new multi-step analysis function, a single scan over multiple steps generates simultaneous step height and width measurements. Figure 6 shows a single trace with about 20 steps of varying width and pitch. After leveling the curve, **Auto Method** can be enabled to quickly run the multi-step analysis, which automatically determines the step number, height, width, and pitch value.

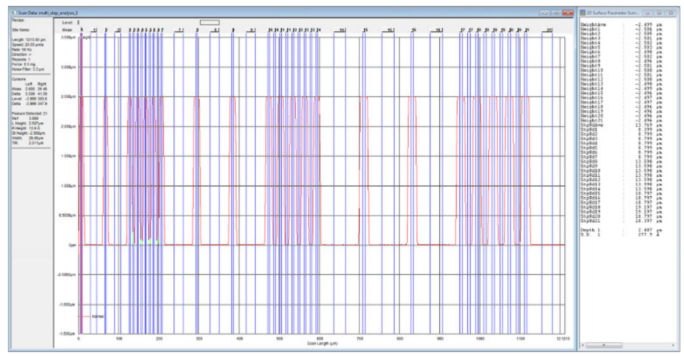


Figure 6. Automated multi-step analysis is used to quickly generate measurements of printing line step height, width and pitch, based on a single scan.

Case Study 2: Ceramic Groove Depth Characterization

Ceramic bars were glued to a wafer, where excess glue created variable-depth trenches between the bars. Trench depth data is then used to optimize the amount of glue applied to the ceramic bars.

The challenge for this example is to measure non-standard trench structures where the reference surface is not flat. In this case, the automated method is not recommended, and the manual method is not practical due to time requirements. The best method for this surface is to use **Feature Detection** to automatically place the cursors relative to the down edge of each trench. **Same for all** can then be enabled to apply the same setting to all trenches along the scan. The results are shown in Figure 7, where the depth of all grooves is displayed.

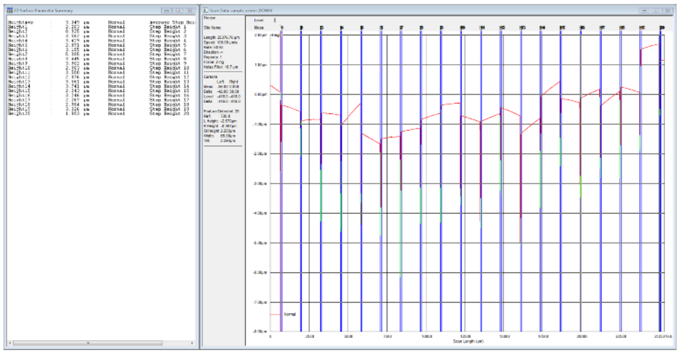


Figure 7. The feature detection function is used to automatically define the trench down edge and can be applied to all trenches in the scan.

Case Study 3: Automated Update of 2D Cross-Sections

The multi-step analysis function may also be useful when analyzing 2D cross-sections of a 3D scan. Once a 3D scan has been completed and levelled, the 3D step height can be calculated, and individual cross-sections may also be analyzed.

Figure 8 shows an example of a box-in-box structure where the 3D result is displayed at the upper right. Here, the 3D step height was calculated using the histogram step height calculation function, and the result is displayed below the scan image. A 2D cross-section may also be specified and measured, as shown at the left.

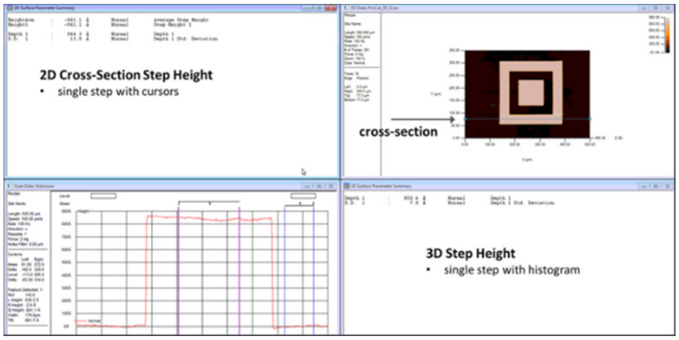


Figure 8. The histogram-based 3D step height measurement is displayed at the lower right, below the image. The multi-step analysis function is applied to a 2D cross-section of a 3D scan, where this particular 2D cross-section includes a single step only.

When enabled for a 3D scan, the multi-step analysis function adjusts cursor placement automatically as the cross-section position is moved across the 3D image. As the number and location of steps changes, the software repositions the cursors and updates the measurement results.

When the cross section lies across the lower part of the 3D scan, as in Figure 8, the profile contains only one step. However, as the cross-section is moved to the center of the 3D scan, the profile contains three steps. Figure 9 displays the new cross-section, where the software has automatically created and adjusted the measurement cursors, and with the mew measurement results automatically displayed.

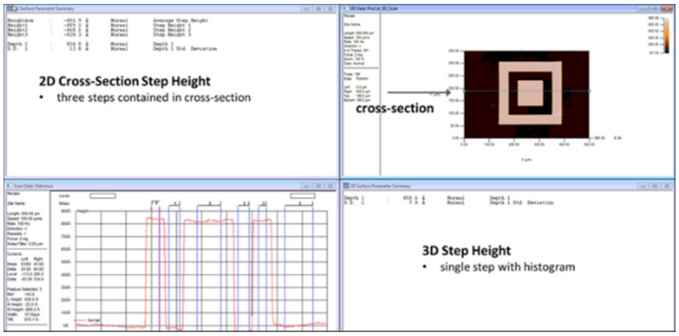


Figure 9. The histogram-based 3D step height measurement is displayed at the lower right, below the image. The multi-step height analysis function is automatically applied as the position of the 2D cross-section changes. This new cross-section at the center of the 3D scan includes three steps, which are automatically measured to display the updated results.

Conclusions

KLA Instruments has introduced the multi-step analysis function to provide automated, simultaneous analysis of multiple steps in a single scan, up to 30 in one trace. The combination of this new function with feature detection can be applied across many types of surface steps and trenches. Along with the high vertical resolution and measurement repeatability, KLA stylus profilers provide excellent performance and powerful, automated analysis tools for a variety of important applications.

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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