

Application Note #579

Performing Step Metrology with Dektak Stylus Profilers

Numerous processes in semiconductor, optical coatings, and micro-electromechanical systems (MEMS), as well as research in flexible electronics and sensors, rely on precise thickness or etch-depth measurements. Among their many metrology capabilities, Dektak® stylus profilers deliver exceptional sub-nanometer repeatability to enable accurate step height measurements over the nanometer-to-millimeter vertical range. Through precise control of applied load, these systems also can provide

accurate and repeatable metrology for soft matter, such as polymer thin films/coatings and indium-based devices. This application note discusses Dektak metrology capability over vertical dimensions (a wide range of certified step heights), and provides some specifications and case examples to benchmark its performance, showing why these profilers have been consistently helping manufacturers and materials engineers with their surface characterization needs for over half a century.

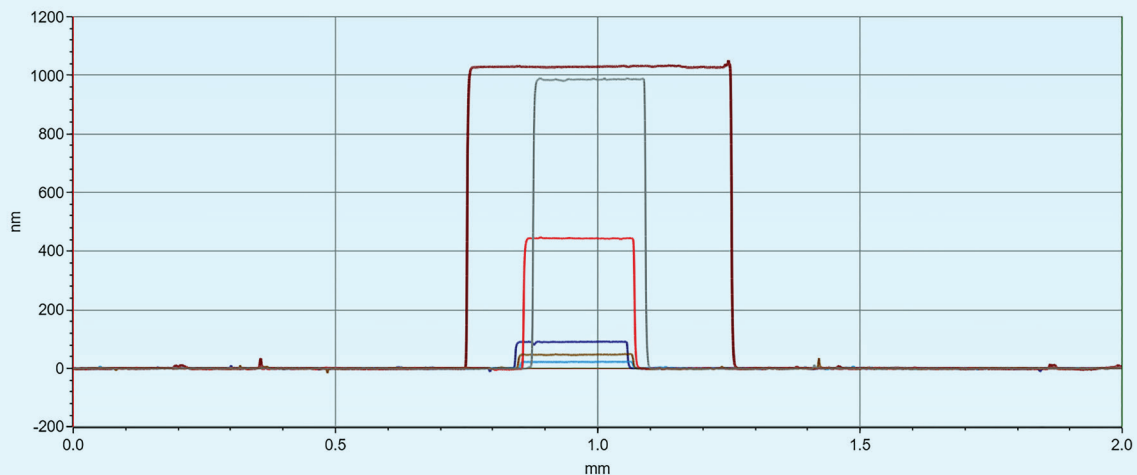


Figure 1. Representation of six steps within the same diagram, default feature from Vision64 software.

Definition of Metrology Terms

Metrology capability defines the performance of a measurement instrument by listing and quantifying sources of error so that a user can assess whether the system is applicable for a specific task. All errors are benchmarked versus standards that are certified by independent metrology reference laboratories, such as NIST in the USA, PTB in Germany, UKAS/NPL in the UK, or NMIJ in Japan.

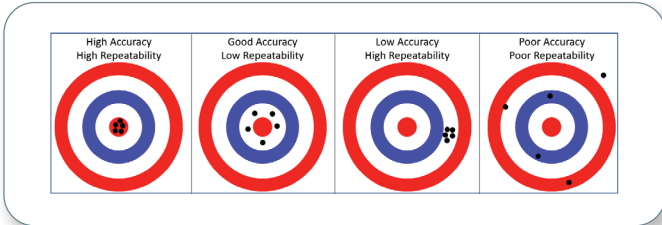


Figure 2. Graphic illustration of Accuracy and Repeatability versus target value.

Sources of error are split into four categories:

1. Bias corresponds to the difference between the output result and its true value, also referred to as accuracy of a measurement.
2. Stability describes the amount of drift of the output result over a certain time period.
3. Repeatability represents the inherent random fluctuation of the output result while measuring the same location over a short period of time, without any user interaction. This indicates the precision of a measurement system, setting the hard boundaries below which no valid measurement can be made.
4. Reproducibility brings the influence of external parameters, such as operator, time, and repositioning into measurement consideration.

While repeatability is inherent to the performance of the measurement system and cannot be improved without hardware changes, reproducibility can be improved through appropriate analysis and automation routines so that the measurement becomes less sensitive to, or even completely independent from, users, time, or location. Likewise, bias or accuracy can be improved through a proper calibration process, while stability improvement would require environmental control and/or a redesign of the measurement system.

Automatic Step Extraction

To diminish user influence, it is crucial to have step heights calculated using automated analysis routines. Dektak systems incorporate Vision64® software's two standard automated analysis routines. The first one is based on the

fixed position of cursors, and the second one is based on automatic positioning of cursors with respect to the step edge. For the latter, the average height difference between the cursor positions defines the film thickness or etch depth. In addition to the above methods, users have the freedom to tailor more advanced analysis by setting up pre-processing of data via an analysis tree.

Influence Factors for Accuracy

Dektak stylus profilers are equipped with the latest generation LIS-3 heads, which are based on Linear Variable Differential Transformer (LVDT) sensor technology.

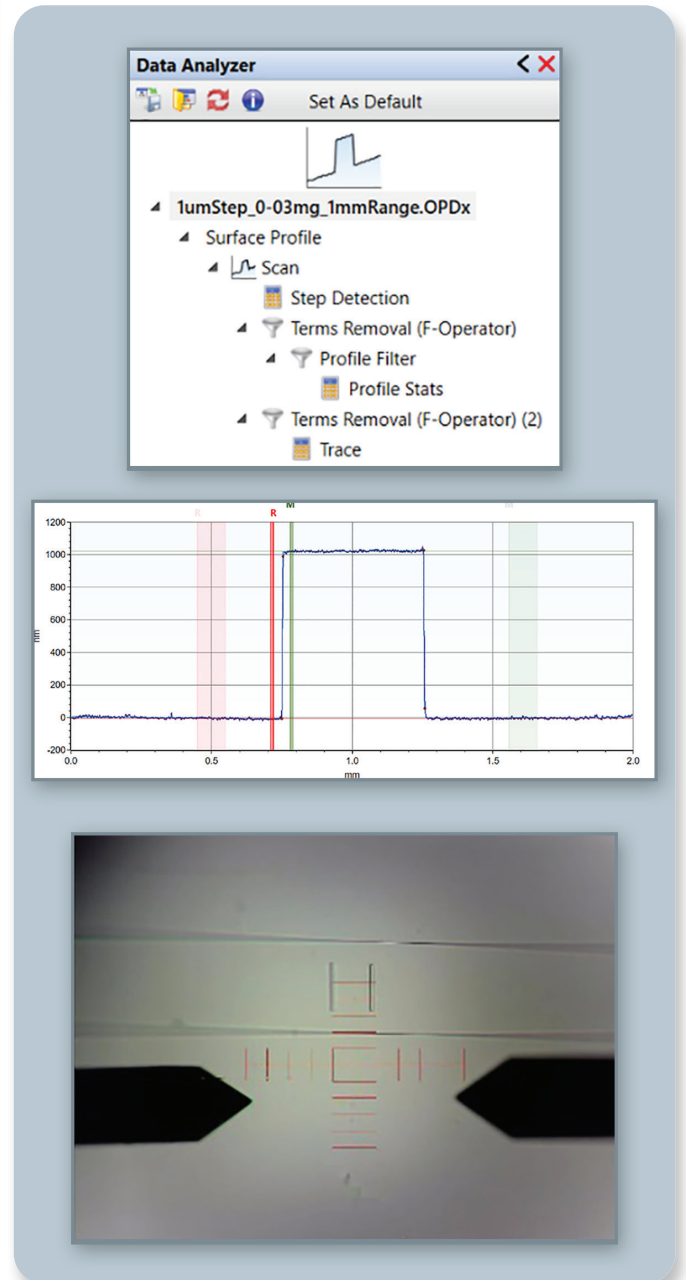


Figure 3. Advanced Analysis setup for automatic step height determination. Multi-tree based Vision64 analysis allows different simultaneous calculations to deliver the best metrology performance and flexibility for a wide range of applications.

This type of sensor is well reputed and widely adopted throughout industry as a robust and linear displacement sensor. Robustness comes from the fact that the magnet core is positioned away from the detecting coils, making it insensitive to large displacement or involuntary shocks. This sensor architecture also explains why Dektak stylus exchange is so fast and worry-free.

Additionally, the sensor head has been designed to keep metrology performance consistent through a very wide vertical range (up to 1mm) and load (from 0.03mg to 15mg) using a single head. This large range enables users to extend the use of Dektak stylus profilers across a wider range of applications.

Influence of Load and Vertical Range

For stylus profilers, load applied between the stylus and the surface is a critical measurement setting since it not only helps tracking of the surface but also the measurement sensitivity and precision. Likewise, the vertical range changes both vertical precision and noise by applying higher or lower signal amplification. It is important to determine the influence of both these parameters versus ability to accurately measure step height.

Evidence of load and vertical range effect is illustrated in Figure 4 where the same certified 1028nm step height was measured 10 times in the same location while varying load and vertical range. All changes were automatically executed without operator assistance through the flexible automation routines provided by Vision64. Graphs represent the dispersion through a box representing 2nd and 3rd quartiles, while the extreme bars point out maxim and minimum. The blue dotted line defines the uncertainty range within the certification, meaning that the exact step value lies within those boundary limits.

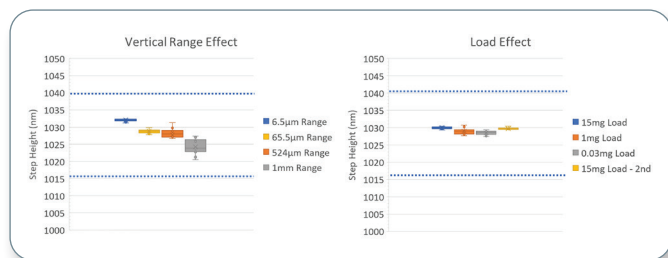


Figure 4. Influence of load and vertical range over 1µm step measurement. The blue dashed lines define the uncertainty range of the calibration sample.

As can be seen, the applied load does not impact the step height measurement and short-term repeatability, even at the lowest calibrated 0.03mg load, with one sigma repeatability within a tight (0.5nm - 0.9nm) range. This illustrates the robustness of the LIS-3 head design and its high-quality software control. It is also noticeable that changing the applied load from lowest to highest does not impact head functionality. Furthermore, this large load range

keeps the reading of step height stable, matching the first applied load.

Vertical range obviously impacts repeatability, which worsens as range increases. This is fully expected, as the measurement signal becomes weaker to accommodate for a larger vertical range. Meanwhile, the measured step height remains well within the certified range, showing that the measurement is still accurate. In conclusion, regardless of the load and vertical range selected, users obtain accurate results for any given step.

Reproducibility

The previous section dealt with short-term repeatability where sample and stylus stayed static while measurements were consecutively recorded without any interruption. This significantly differs from daily use where different operators at different shifts and dates perform measurements. Good benchmark metrology systems rely on providing stable and consistent measurement over time, across different users, and through sample load/unload.

The same 1028nm step was periodically measured during the course of two days with different timing, varying single measurements, and multiple successive measurements. Alignment points were used during the automation recipe to provide a reproducible start position. Figure 5 presents step height data in chronological order with the certification limits, shown with blue dotted lines. The results are definitively reproducible. Looking at the normal distribution, 99% of the step height measurements lie within a ±2.8nm range, which is <0.03% of the step height. While this number appears low, it slightly overshoots previously recorded repeatability, which proves the influence of an external environmental factor, most likely a temperature change.

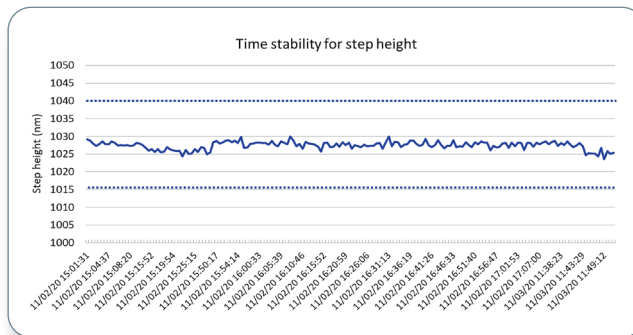


Figure 5. Reproducibility test for 1028nm step over a period of 2 days.

Linearity

Linearity represents the metrology capability for a stylus profiler to give an exact step height value along a certain vertical range. It is a critical parameter since process monitoring usually implies several control points with increasing or decreasing thickness or depth, from which the

extracted step height is used as feedback to adjust process equipment. Linearity of the measurement tool directly determines how tight tolerances in production can be met, making higher Cp or Cpk, and how significantly yield can be improved.

To assess the intrinsic linearity performance of Dektak stylus profilometers, six calibrated steps were measured within the same analysis recipe with a fixed 6.5µm vertical range and constant load. Steps covered a vertical range from nanometers (11nm) to micrometers (1.028µm), which accurately represents the core vertical range for many applications. The largest step of 1.028µm was used to calibrate the range prior to all measurements. The results, shown in Figure 6, clearly demonstrate linear behavior better than 0.1% over 2 decades of vertical range. Furthermore, the absolute bias versus nominal value never exceeds 2nm, which provides verification of nanometer-level accuracy.

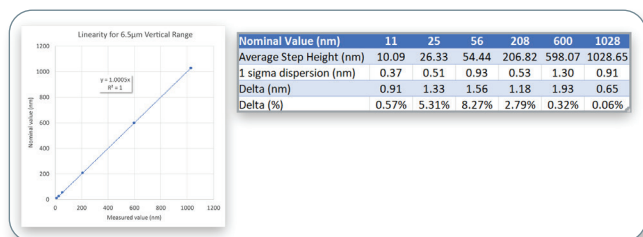


Figure 6. Plot showing linear answer of LVDT sensor over two decades of height (left), and summary tab illustrating accuracy down to the nanometer level (right).

The Dektak LIS-3 LVDT sensor delivers a highly linear response across a single measurement range. To measure a wider range of film thickness or etch depth, each vertical range can be independently calibrated to further optimize linearity at a specific range of interest while preserving the accuracy.

Operation on Soft Surfaces

As a stylus profiling technique, Dektak systems make physical contact with surfaces and exert pressure underneath the stylus. Potential surface wear or damage should be considered as a bias factor through modification of the native surface, with risk to underestimate the real step height. The LIS-3 sensor has been specifically designed to enable measurements on soft materials, such as encountered in flexible electronics, polymer coatings, and microfluidic devices.

To assess this capability, multiple measurements were performed at the same location on a soft, easily scratchable coating containing multiple organic layers (acrylic dispersion with pigments on silicone paper and pressure sensitive adhesive). A 2µm stylus, ISO standard for roughness, and 0.1mg load were deliberately chosen to increase local pressure. The soft multilayer coating was deposited on a hard glass slide to create a consistent baseline prior to

undergoing 30 measurements with an automatic analysis of average step height. As seen in Figure 7, the measurements exhibit stable readings within ±57nm over 15.64µm, which is less than 0.4% variance. This emphasizes how well

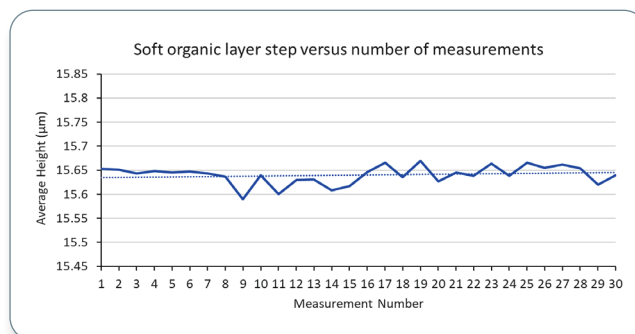


Figure 7. Evolution of measured thickness from a soft organic layer from 30 consecutive measurements.

Dektak stylus profilers can measure fragile surfaces. Even softer samples can be measured using larger stylus radii, up to 25µm, and a lower load, down to 0.03mg to minimize surface deformation.

For this application note, a second example assessment was done based on a PDMS structure used for microfluidic devices. This type of sample further challenges stylus profilers with large and sudden height changes. These structures not only test the Dektak's capability to apply constant load, but also its ability to measure sticky surfaces. This latter property of PDMS can only be overcome through fast scanning speeds, here up to 1mm/s, which requires a high mechanical bandwidth system. The resulting trace (Figure 8) provides clear evidence of proper surface tracking enabled by the low inertia design of the Dektak sensor head. To create a reference point for the measured step

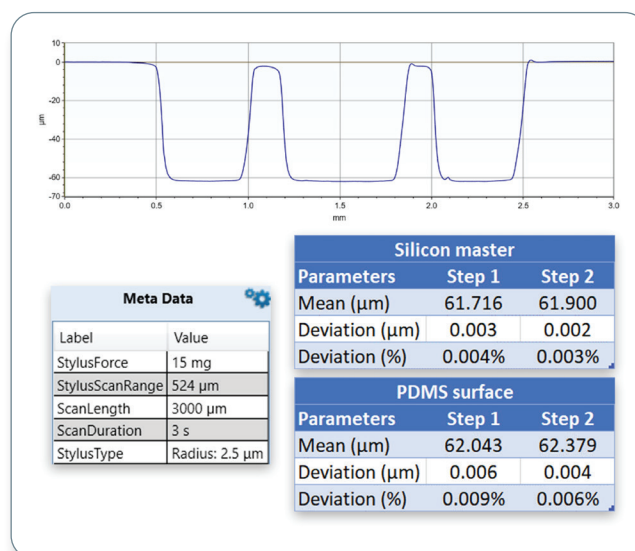


Figure 8. Trace on PDMS microfluidic structure with step results and comparison with silicon stamp master.

height, the master silicon stamp used to imprint PDMS was also measured. The table in Figure 8 shows great agreement between height differences from PDSM and stamp surfaces with a nearly 0.4 μ m offset, fully compatible with the stamping process.

These two case studies provide insightful information on how well the Dektak stylus profiler can be utilized to reliably measure profiles on soft surfaces with high confidence and fidelity.

Conclusion

Throughput this application note, it has clearly been shown that Dektak stylus profilers deliver highly accurate and reliable step height measurements down to the nanometer level. Independent of application, etch or material deposition, soft or hard matter, Dektak systems deliver reproducible results over the full vertical range and applied contact forces. The inherent low-inertia design of the Dektak LIS-3 sensor head provides fast adaptation to sudden surface morphology changes, offers a high linearity with each vertical range, and delivers long-term measurement stability. With over 50 years of innovation and proven, reliable real-world use Dektak profilers are the gold standard for uncompromised stylus profilometry, allowing users to routinely achieve better control over production processes and meet tighter tolerances to increase yield.

Notes

1. Measurements were performed in metrology laboratory with temperature controlled within $\pm 1^\circ\text{C}$.
2. Steps providers: SiMetric, Bruker Probe, VLSI.

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