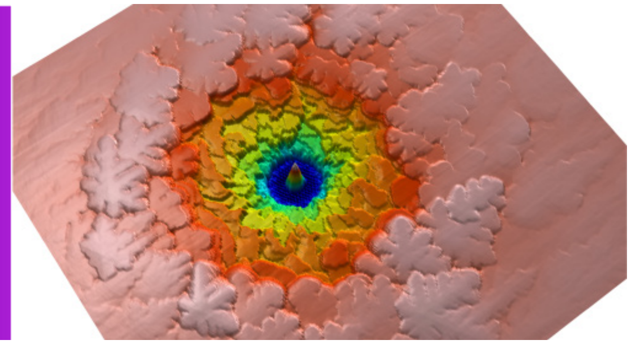
Topography Sensor Technology for Stylus Profilers



Introduction

Stylus profilometry was developed in the 1930s as a method to accurately measure the topography of a sample. This technique is typically used to measure a step height, such as the deposition thickness of a film or the etch depth of a feature, as well as to measure surface roughness. The advantage of a stylus profiler is that it is a direct technique that is not influenced by the properties of the surface. The method to make these measurements has continuously improved, and one critical area of advancement is the topography sensor.

Background

Stylus profilometry sensor design has four main components, shown in Figure 1:

- Topography sensor
- Stylus
- Pivot
- Force compensation

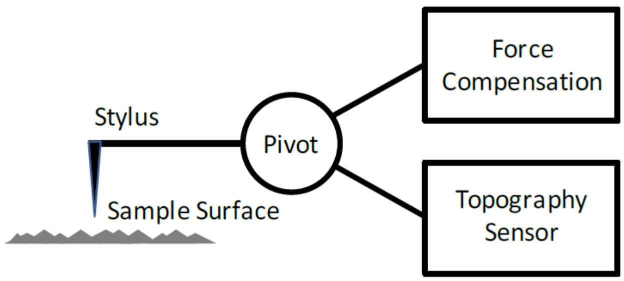


Figure 1. Stylus profiler sensor schematic.

The topography sensor is used to track the surface of the sample being measured. Three major sensor designs in use today are LVDT, Optical Lever and LVDC.

The stylus is used to track the topography of the surface. KLA styli are manufactured from diamond and come in a variety of sizes to support various applications[1].

The pivot connects the stylus to the topography sensor, translating the change in motion from the stylus to the sensor. Low mass, frictionless pivots are used so that the signal read by the sensor accurately represents the surface topography.

The force compensation mechanism is connected through the pivot to adjust the force that will be applied to the sample surface. This force can be applied open or closed loop. Open loop applies a constant force at the pivot, resulting in a variable force on the sample surface as the stylus follows the surface topography. Closed loop applies a constant force on the sample surface by adjusting the force applied to the pivot using a feedback loop from the topography sensor as the stylus tracks the surface topography.

Topography Sensor

There are three main sensor technologies commonly used with stylus profilers, with the design and performance of each discussed individually.

Linear Variable Differential Transducer (LVDT)

Although no longer used in current KLA Instruments™ profilers, LVDT sensor technology was first developed in the 1930s and it is the oldest sensor design used for stylus profilometry. Figure 2 shows the Alpha-Step® IQ (ASIQ) LVDT sensor schematic.

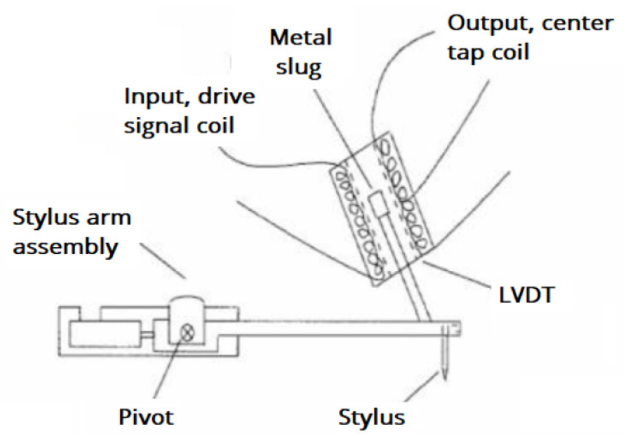


Figure 2. Alpha-Step IQ sensor schematic.

The LVDT sensor tracks the surface topography through changes in voltage[2]. This change results from motion within the coil of an arm with a metal slug. The position of the arm changes as the stylus tracks the surface, resulting in changes in the voltage, which is converted to a topography signal.

The main advantage of the LVDT design is its long history of use in many different sensing applications. The drawback is that the motion of the arm within the coil will heat and cool as a function of usage over time, reducing measurement stability.

Optical Lever Sensor

The Optical Lever sensor technology was developed for AFMs in the 1980s[3]. The design was adapted to stylus profilometry in 2001 with the release of the XP-series stylus profilers. Figure 3 shows the Optical Lever sensor schematic as adapted to the Alpha-Step D-Series.

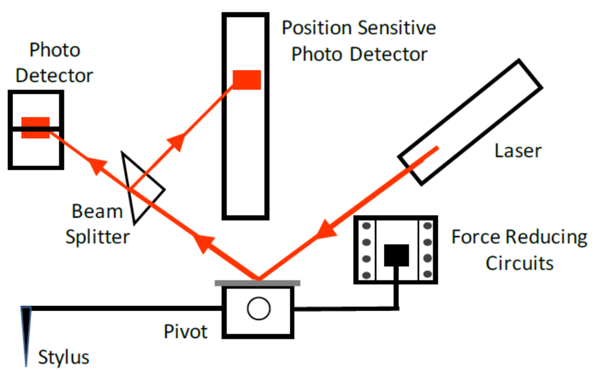


Figure 3. Alpha-Step D-Series Optical Lever sensor schematic.

The Optical Lever sensor tracks the surface topography using a laser beam reflected off the top surface of the pivot assembly. The reflected beam is then projected on a photodetector. For the Alpha-Step, 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 the first detector and measurement of larger steps on the second detector. The deflection of the laser beam changes as the stylus tracks the surface while sensed by the photodetector, and this deflection is then converted to a topography signal.

The advantage of the Optical Lever is the low mass of the entire assembly, enabling low force measurements. In addition, this sensor has a fast response for tracking changes in the surface topography.

Linear Variable Differential Capacitor (LVDC)

The LVDC sensor design technology was developed in the 1990s by Tencor Instruments to solve the limitations of Linear Variable Differential Transducer (LVDT) sensor technology[4,5]. Figure 4 shows the LVDC sensor schematic for the Tencor™ P-Series and HRP®-Series stylus profilers.

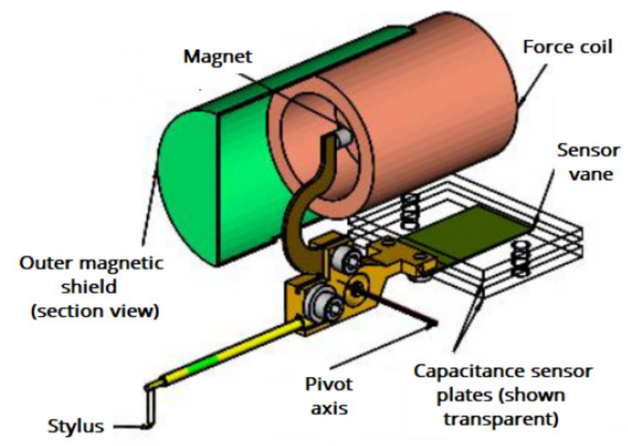


Figure 4. Tencor P-Series and HRP-Series LVDC sensor schematic.

The LVDC sensor tracks the surface topography using a change in capacitance. This change results from the motion of a thin metal sensor vane moving between two capacitor plates. The position of the sensor vane changes as the stylus tracks the surface, resulting in changes in the capacitance, which is then converted to a topography signal.

The advantages of the LVDC design are its low mass and linear motion of the vane, resulting in minimal hysteresis and friction. The design enables precise, stable, high resolution measurements across the full vertical range.

Sensor Technology in KLA Instruments Stylus Profilometers

The stylus profilers from KLA Instruments utilize different topography sensors in order to provide options based on the surface topography requirements.

Alpha-Step D-Series Stylus Profilers

The Alpha-Step D-Series includes the D-500 and D-600, with the D-600 shown in Figure 5. The original D-Series profilers were first developed in 2001 and all utilize Optical Lever sensor technology.

The Optical Lever design on the Alpha-Step profilers can measure features up to 1.2mm in height or depth. These high resolution measurements deliver 0.38Å z resolution in the lowest vertical range. The design uses an electronic force compensation circuit that enables software control of the applied force. The force applied is open loop and allows for a force between 0.03 and 15mg. This sensor design has a fast response to accurately track changes in surface topography, enabling fast measurement speeds.

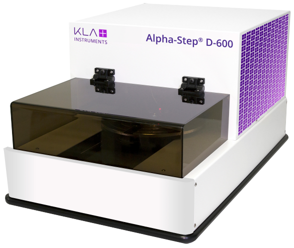


Figure 5. The Alpha-Step D-Series stylus profilers include the D-600.

Tencor P-Series Stylus Profilers

The Tencor P-Series includes the P-7, P-17, P-17 OF, and P-170 profilers, with the P-7 shown in Figure 6. The original P-Series profilers were first developed in 1988 and all current P-Series profilers utilize the LVDC sensor technology.

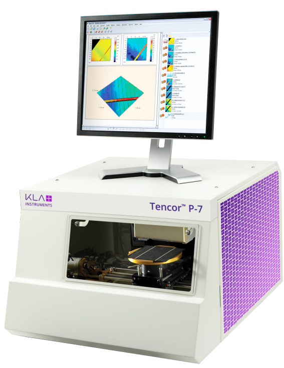


Figure 6. The Tencor P-Series profilers include the P-7.

The LVDC design on the Tencor profilers can measure features up to 1mm in height or depth. High resolution capability delivers 0.01Å z resolution in the lowest vertical range and 0.60Å z resolution in the highest vertical range. The design uses an electronic force coil, enabling closed loop software control of the applied force. This closed loop design enables a constant force on the sample surface between 0.03 – 50mg, as the force applied to the pivot is continuously adjusted as the stylus tracks the surface topography. The sensor design and control enable measurement of soft surfaces with large step heights, such as photoresist etch depth.

LVDC sensor technology has a fast response to accurately track changes in surface topography, enabling fast measurement speeds. The linear response enables precise measurements of small and large step heights. Low hysteresis and low friction enable repeatable measurement results that are stable over long periods of time.

HRP®-Series Stylus Profilers

Figure 7 shows the HRP-260 high resolution stylus profiler. The original HRP-Series profilers were first developed in 1997 and utilize the same LVDC sensor technology as the Tencor P-Series.

Figure 7. The Tencor HRP-260 stylus profiler.

Conclusion

The topography sensor is a significant component to any stylus surface profiler system. Utilizing different topography sensor technologies and precise force control, KLA Instruments profilers have the necessary range of capabilities to address the surface metrology challenges of both R&D and production environments. With over 40 years of success in stylus profilometry, KLA Instruments delivers advanced sensor technology for both current and future surface metrology requirements.

References

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KLA Corporation
One Technology Drive
Milpitas, CA 95035

Printed in the USA
Rev 9 2021-06-14