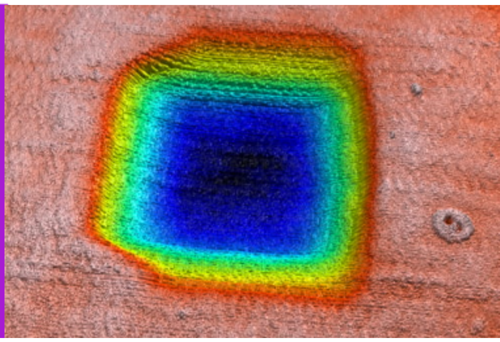
Application Note

KLA INSTRUMENTS

Precision Depth Measurement of Shallow SIMS Craters using a KLA Instruments™ Stylus Profilometer



Introduction

The advancement of engineered materials such as those in semiconductors, thin films and composites, relies on the ability to visualize and measure the relevant structures. Secondary Ion Mass Spectroscopy (SIMS) is a vital technique for the characterization of these material systems. SIMS analyzes trace elements in solid materials as a function of their depth in a device, allowing characterization of impurity concentrations with high accuracy.

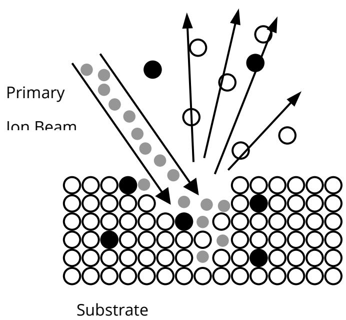


Figure 1. A depiction of an Ion beam sputtering mixed substrate and impurity atoms from a sample.

In a typical SIMS arrangement, the surface of a sample is exposed to a beam of high-energy (several keV) ions in an ultrahigh vacuum, which sputters atoms from the surface of the sample and collects a portion of these secondary atoms in a mass spectrometer. The mass analysis of the sputtered atoms determines the chemical composition of the sample. As time passes, the ion beam mills deeper into the surface, yielding information about impurity concentration as a function of time. In order to correlate the concentration as a function of depth, the depth of the crater in the material must be characterized.

The concentration of the implanted ion with respect to depth, $C_i(x)$, is derived from the depth (D), time (T), and concentration with respect to time $C_i(t)$ which is reduced to equation (1).

$$C_i(x) = D/T*C_i(t) \tag{1}$$

Frequently, the highest uncertainty component is the depth reading, which can be difficult to obtain, particularly when the SIMS craters are shallow (i.e. < 100nm in depth). Stylus profilers offer a method to make high accuracy measurements of SIMS crater depth through contact measurements, allowing full confidence in depth measurement regardless of the composition of the substrate. The objective of this application note is to present a technique to measure the depth of shallow SIMS craters with < 1% deviation from a mean depth using a stylus profiler.

Methodology

We present here several of the methods used to generate precision depth measurements of shallow SIMS craters using Tencor™ stylus profilers, including the Alpha-Step® D-500, Alpha-Step D-600, Tencor P-7, and Tencor P-17. Maximizing the accuracy relies on (a) positioning a scan on a shallow crater, (b) compensating for the relatively high roughness of the surrounding material compared to the shallow crater, and (c) scanning over surfaces with soft, transparent, or multiple substrate materials.

Top and Side View Optics

With SIMS craters often milled into semi-transparent materials, it can be difficult to precisely position scans using a top down view. In optical systems, typically only a top view directly through the objective is available. The D-series profilers offer a side view camera, showing the stylus scan position and clear view of the sample, as shown in Figure 2. The P-7 profilers offer the choice of a top or side view camera, while P-17 profilers offer both top and side view together. Individually, or especially in combination as in the P-17, these views allow easy positioning even on the shallowest craters. Figure 3 shows the top view of the sample surface from the P-17.

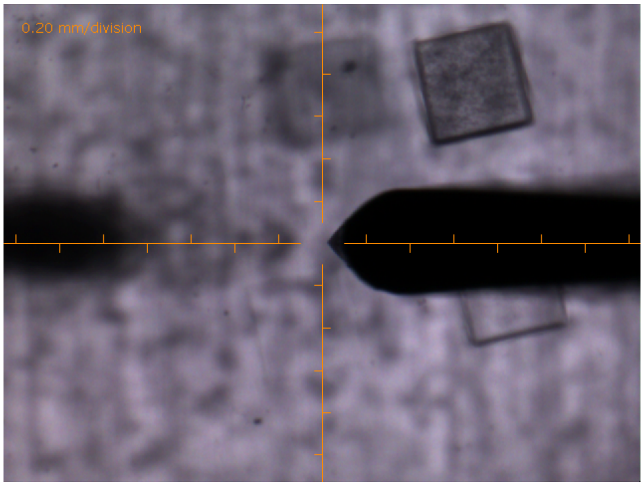


Figure 2. The side view of the stylus near the sample surface, from the Alpha-Step D-600.

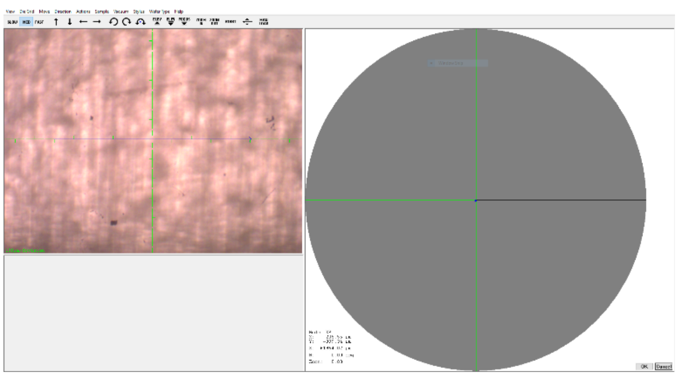


Figure 3. The top view of the sample surface, from the Tencor P-17.

Force Control

All KLA Instruments™ stylus profilers include force control to maintain a feather-light touch with the stylus. D-series profilers offer forces as low as 0.03mg for shallow trenches, and Tencor P-series profilers offer either 0.5 or 0.03 mg force through the entire vertical range, using a constant applied force calibration. P-series profilers are capable of scanning craters as deep as 100µm while maintaining both contact and low force along the deepest trench and highest sidewall, enabling unsurpassed accuracy and fidelity across the entire vertical range.

Edge Detection and Filtering

D-series and P-series stylus profilers automatically detect step edges and place measurement and leveling cursors accordingly. While SIMS craters have relatively rough surfaces compared to the crater depth, and sometimes without a clear step edge, both P-series and D-series tools offer integrated gaussian filtering applied to both the measurement and feature detection.

Roughness Consideration

Figure 4 compares a scan on a region of the substrate near the SIMS crater (top) to a profile of a shallow trench SIMS crater (bottom). The background scan is influenced by the substrate surface roughness, and the environmental acoustic and mechanical noise. The SIMS crater represented in Figure 4 is only about 30nm deep while the Total Indicator Runout (TIR) value (difference between maximum and minimum) of the roughness and noise trace is over 10nm. In order to generate an accurate measurement, it is necessary to use filtering and/or a 3D scan made up of multiple 2D scans.

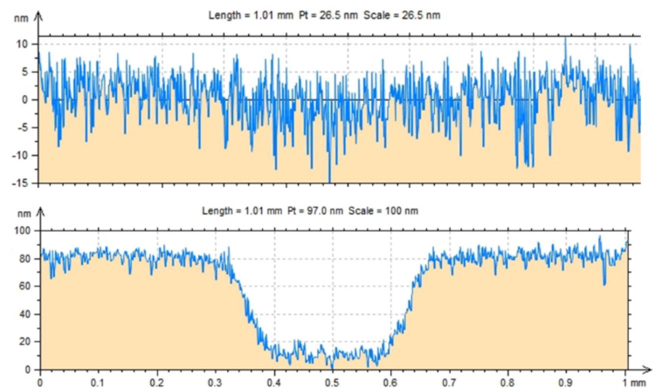


Figure 4. (TOP) Comparison of noise floor profile with Peak-to-Valley value of 27nm and (bottom) shallow SIMS crater with depth measured at 72nm.

Measurements

3D Measurement Example

Figure 5 is a 3D image of multiple SIMS craters with varying depths, as measured by a Tencor P-17 stylus profiler. Using 3D scans allows for confidence in depth measurements made on rough or uneven SIMS craters. Based on a 2D scan, it may be difficult to (a) tell whether a specific profile is representative of the whole crater, or (b) to distinguish the crater from a rough surface. 3D metrology allows for measurement of the entire feature and allows analysis of the individual 2D profiles contained therein. The 3D scan data represents a larger area encompassing several features, while also maintaining the required level of resolution to review subsets of the data individually.

Figure 6 shows an example of the analysis options available in the Apex software. Selecting the shallowest crater from the image shown in Figure 5 and cropping the data to a single

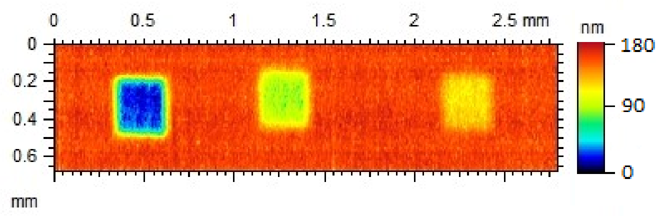


Figure 5. Top-down 3D image of multiple SIMS craters with varying depths.

crater automatically re-normalizes the height and color scale of the shallow crater, allows a much more detailed view.

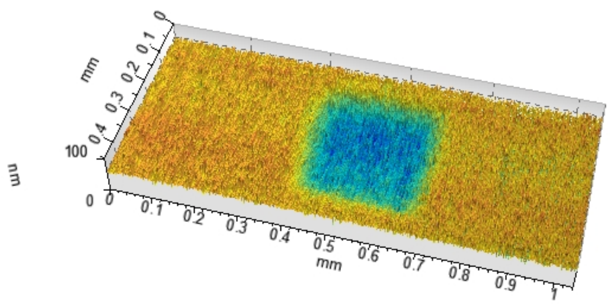


Figure 6. Zoomed area using Apex advanced analysis software.

Figure 7 shows a cross-section from the shallow crater taken along the center line at the lowest point. The Apex analysis package was used to set up an analysis workflow that can be used as a template for future measurements as well as a report format for sharing the results.

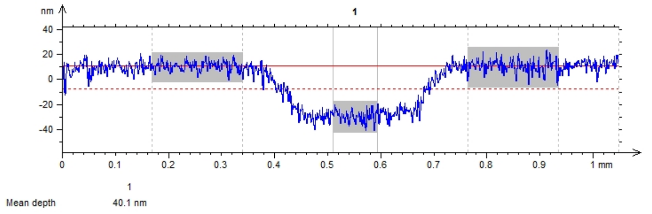


Figure 7. Profile extracted from the deepest profile of the 3D crater envelope shown in Figure 6. The Apex analysis package was used to measure the step height, 40nm.

Figure 8 shows a profile of a shallow crater with depth on the order of 25nm. The data shows a profile that does not have a sharp leading edge feature but has superimposed surface roughness on the order of 10nm. Using the methods discussed previously, the resulting step height measured 23nm.

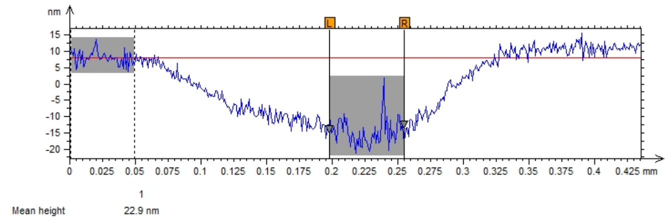
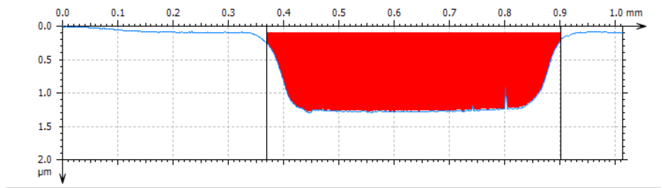


Figure 8. Shallow SIMS crater with 23nm depth measurement.

Figure 9 shows the volumetric analysis of a 2D scan using the Apex analysis software. This method provides additional information about the depth and volume of the measured feature.



Parameters	Value	Unit
Maximum depth	1.212	μm
Area of the hole	567.9	μm²

Figure 9. Volumetric analysis using Apex software.

Conclusion

Secondary ion mass spectroscopy (SIMS) is the most accurate method of measuring impurities concentration as a function of time. To determine impurities concentration as function of depth into the substrate material, a profilometer is required to measure the final depth of the crater created by the primary ions with the highest possible precision. KLA Instruments stylus profilers enable easy scan positioning, automatic measurement cursor positioning, application of filters, and generation of 3D data to allow accurate measurement of any SIMS crater.

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