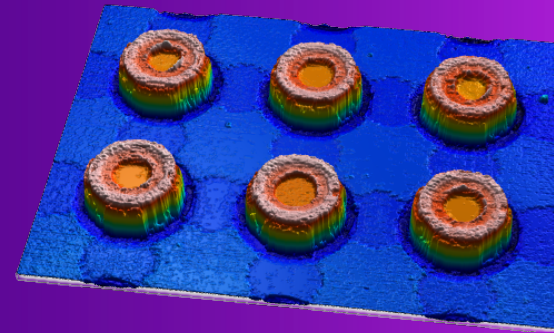KLA+ INSTRUMENTS

Apex Software
Advanced 2D/3D Surface Data Analysis

Apex is state of the art software based on Digital Surf's Mountains® technology for the analysis of 2D and 3D surface data. Intuitive and easy to use, Apex provides complete and detailed analysis of all scanned surfaces including wafers, thin-film heads, MEMS, disks, ceramics, SIMS craters, micro lenses, displays and precision-machined surfaces of any kind. Integrated with all KLA Instruments™ Tencor™ P-Series and HRP® stylus profilers, Apex's 2D and 3D surface topography visualization combined with its comprehensive analysis and reporting features, helps operators present data minimizing yield impact issues or defects in their processes.

Advanced 2D and 3D surface visualization and analysis capabilities. Apex contains a comprehensive suite of data optimization tools, data analysis and visualization tools for surface texture and surface characterization. Apex offers precise analysis of step heights, surface microroughness, microwaviness and overall form error of surfaces such as thin film coatings.

Wafer surface showing backgrinding defect

Thin film surface, 80µm x 80µm x 0.3µm

Part of wafer with CMP defect, 285µm x 240µm x 3.4µm

Supports current and forthcoming international standards. Apex supports industry standard parameters and calculation algorithms for both ISO and ASME, and also supports other international standard methods either as defined parameters or as customizable functions.

Powerful 2D/3D Imaging. Visualization of surface topography in photo-realistic, color-coded and rotatable 3D maps or 2D sections, using Open GL technology.

Preprocessing before analysis. A full set of intelligent algorithms for resampling data to improve imaging, correcting lines, leveling surfaces, thresholding, retouching surface points, filling in non-measured points, etc.

Complete set of user-selectable filters. The software provides a powerful range of data filters for 2D and 3D data sets. Commonly used examples include roughness and waviness separation; gaussian, spline, and kernel filters; FFT, form removal and other advanced filters are also available.

Full range of studies. Analysis of specific data characteristics includes depth distribution, vertical slicing, fractional analysis, spectral analysis, PSD plots, histograms, measurements (distances, angles, areas, volumes), statistics, grains and particles analysis.

Before/after analysis. The surface subtraction feature allows the user to compare a surface before and after a process to present the difference of the two datasets as an image for further analysis.

Tolerance checks. Apex allows the user to apply tolerance limits to the results, creating pass/fail criteria or a tolerance window for tracking over time.

Report generator. Allows users to define their own reports for data presentation. This feature provides a high level of customization and allows the user to define reusable templates for repeated analyses and to import images, format text, present results and export to PDF. The report generator also allows export of ASCII data to spreadsheets for additional formatting or analysis.

Automatic processing of measurements. Allows users to apply the same analysis to multiple measurement files automatically.

**Easy to use.** Intuitive user interface to ensure accurate and consistent analyses and allow an operator to analyze data with minimum supervision.

Interactive help. Apex software includes an interactive help tool that provides definitions, descriptions and examples on every topic.
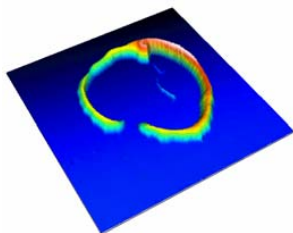
Multiple language support. Apex includes multi-language support for users working in an international or multi-lingual environment.
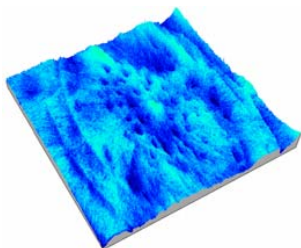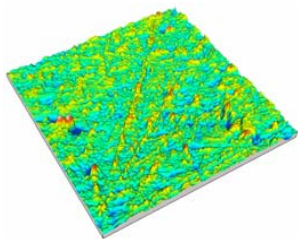
2D Studies

Raw profile curve Graphical representation of profiler raw data.

Roughness/waviness profile curves Display roughness/waviness curves.

Depth distribution histogram and Abbott-Firestone curve Statistical distribution of depths of points on profile.

Interactive Abbott curve Bearing ratio for a given depth or depth for a given bearing ratio.

Fractional analysis Analysis of a profile in terms of its fractional geometric complexity.

Graphical study of Rk parameters Characterizes the roughness depth of the core or kernel (Rk), peaks (Rpk), valleys (Rvk) and other related parameters graphically.

Rk calculation profiles Displays the intermediate profiles used during the calculation of the Rk parameters (using a selected filter and cut-off).

Distance measurement Horizontal/vertical/oblique distance between 2 points on profile, angle and slope of segment connecting 2 points, average height of profile between 2 points, etc.

Area of a hole/peak Maximum depth/height and area of hole/peak between 2 points.

Morphological envelopes Upper and lower envelopes calculated by a morphological opening and closing operation, using a line segment or a disk as the structuring element.

Step height measurement Dedicated to the analysis of profiles having positive or negative steps, typically used in the analysis of etches.

Frequency spectrum Shows magnitude and phase of each frequency/wavelength in the profile's spectrum (obtained by Fourier transform).

Averaged power spectrum density Shows dominant wavelengths in the profile and their amplitudes.

Studies on series of profiles Profile curves of the series, statistical parameters and trend plot for a parameter.

Example 2D Parameters

Roughness Ra, RSm, Rq, Rp, …
Raw profile Pa, Pq, Pp, Pv, …
Waviness Wa, Wq, Wp, Wv, …
Rk Rk, Rpk, Rvk, MR1, …
R&W R, Rx, Pt, AR, …
Straightness STRt, STRp, STRv, STRq.
Roundness RONt, RONp, RONv, RONq, …

2D Operators

Operators for preprocessing data before analysis Leveling, zoom on section of profile, symmetries (invert one or both axes), retouch surface points/fill in non-measured points, thresholding (removal of excessive peaks or holes), resampling (enhance image quality, e.g., after zooming)

Filters Waviness + roughness (Gaussian, 2CR, 2CR-PC, cubic spline, double Gaussian, robust Gaussian) with optional end effect management, morphological filtering (closing filter for filling valleys, opening filter for opening valleys and reducing peaks, sequence of filters for denoising), direct edition of the FFT (Fast Fourier Transform).
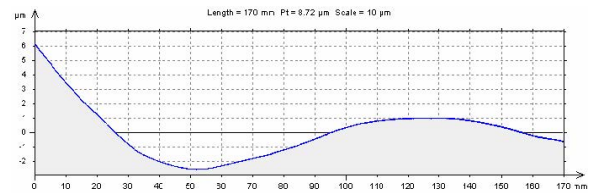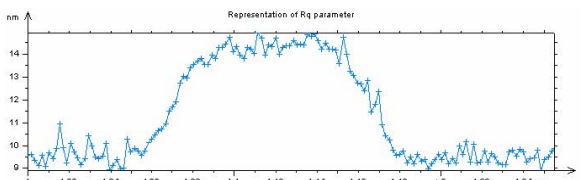

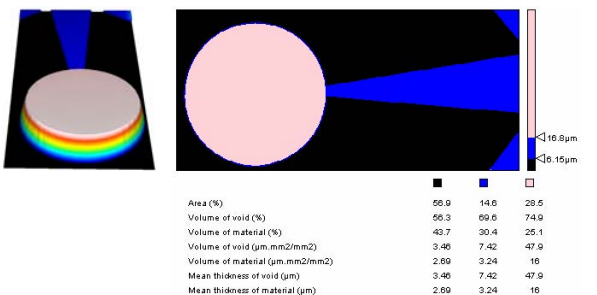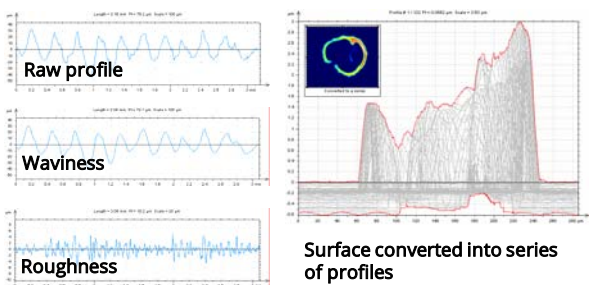Profile from flat panel display
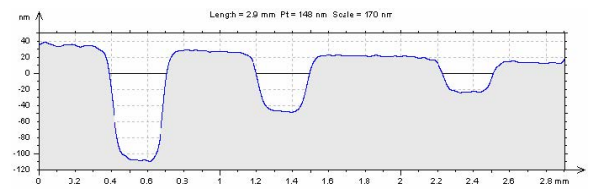
Step height measurement of SIMS craters. Text box stating that Step is within tolerance limits.

Mean height = 138 nm
Step1 is in specs.
Low limit: 136 nm
High limit: 140 nm

Control charts for selected parameters over multiple (or series of) profiles.

Raw profile

Waviness

Roughness

Surface converted into series of profiles

MEMS: 2mm x 1mm x 100µm study of 3 vertical slices with material area, material and void volume and mean thickness.

3D Studies

Imaging Pseudo color image, photo simulation, contour diagram, meshed axonometric, continuous axonometric (using Open GL).

Color altitude coding Relative heights of surface features.

Depth distribution histogram and Abbott-Firestone curve Statistical distribution of depths of points on the surface.

Interactive Abbott curve Bearing ratio for a given depth or depth for a given bearing ratio.

Fractional analysis Analysis of a surface in terms of its fractional geometric complexity.

Graphical study of Sk parameters Characterizes the roughness depth of the core or kernel (Sk), peaks (Spk), valleys (Svk) and other related parameters graphically.

Slices Divide surface into three vertical slices and calculate parameters for each slice: surface %, void and material volume (% and per surface unit), mean thickness of void and material.

Distance measurement Horizontal/vertical/oblique distance between 2 points on surface.

Horizontal angle Made by any three points on surface.

Step height measurement Analysis of step heights on a line joining two or more points on a surface.

Volume of a hole/peak Surface area, volume and maximum depth/height of a hole/peak.

Frequency spectrum Shows frequency / wavelength at each point on the surface and its magnitude and phase, revealing periodicity and orientation of any motifs on the surface (obtained by Fourier transform).

Averaged power spectrum density Shows dominant wavelengths on the surface and their amplitudes.

Peak count distribution Histogram showing peak height distribution over surface.

Vectorization of microvalleys network Maximum depth, mean depth and mean density of grooves in a microvalley network, separation of primary and secondary grooves with respect to depth.

Texture direction Analysis of surface isotropy, displaying polar graph of main directions built from surface spectrum (obtained by Fourier transform).

Texture isotropy Isotropy, periodicity, period and direction of period at selected depth.

Grain and particle morphology and statistics Single grain morphology, statistics on sets of grains, parameter distribution over set of grains.

Example 3D Parameters
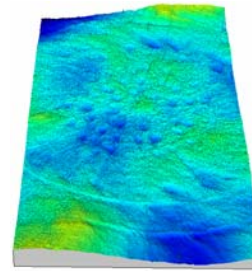
Amplitude Sp, St, Sz, ...
Hybrid Sdq, Ssc, Sdr, ...
Spatial SPc, Str, Sal, ...
Functional Sk, Spk, Svk, ...
Functional indices Sbi, Sci, Svi, ...
Volume Vmp, Vmc, Vvc, Vvv, ...
Flatness FLTt, FLTp, FLTv, FLTq, ...
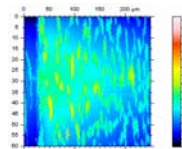

Amplitude Parameters
Sq = 0.259µm   Sv = 1.07µm
St = 3.64µm   Ssk = -0.14
Sa = 0.194µm   Sku = 4.05
Sp = 2.57µm   Sz = 1.82µm

Flatness Parameters (ISO 12781),
LSPL, Gaussian Filter, 0.51mm
FLTt = 1.72µm   FLTv = 0.958µm
FLTp = 0.76µm   FLTq = 0.249µm

Wafer 40mm x 20mm x 3.6µm
**Calculation of Amplitude and Flatness parameters.**


Mean parameters on 54 grains
Total area occupied by the grains:
    $927µm^2$ (6.19%)
Density of grains: 0.00361 grains/$µm^2$.
Area = 17.2 ± $21.3µm^2$
Perimeter = 14 ± 13.3µm
Equivalent diameter = 3.84 ± 2.66µm
Mean diameter = 5.55 ± 3.09µm
Min diameter = 3.71 ± 1.98µm
Max diameter = 9.59 ± 6.49µm
Form factor = 1.82 ± 1.69
Aspect ratio = 2.53 ± 0.976
Roundness = 0.163 ± 0.0971
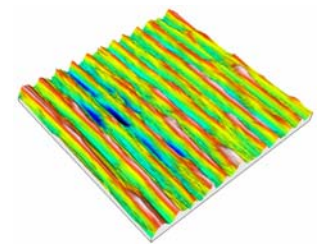Compacity = 0.393 ± 0.092
Orientation = 105° ± 53.6°
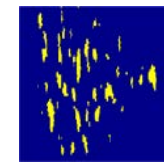
Analysis of grains on a polymer sample (after binarization of surface).
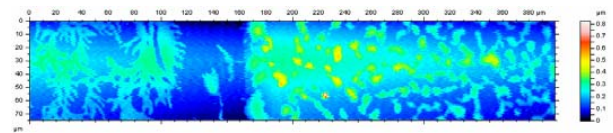
Polymer sample with peak height and depth distribution histograms.
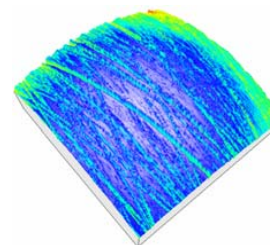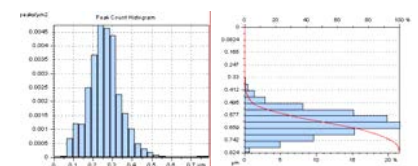
Ball
600µm x 600µm x 11.5µm

Precision-machined surface
3mm x 1mm x 80µm

3D Operators

Operators for preprocessing data before analysis Leveling (with option to include/exclude zones), zoom on section of profile, symmetries (mirror in x, y or z), rotation of surface/alignment of texture with x or y axis), retouch surface points/fill in non-measured points, thresholding (removal of excessive peaks or holes), resampling (enhance image quality, e.g., after zooming), line correction.

Filtering Waviness + roughness (Gaussian, cubic spline, robust Gaussian) with optional end effect management, morphological filtering (dilation, erosion, closing filter, opening filter, sequence of filters), spatial filtering (smoothing/denoising: median, arithmetic mean, Gaussian; min/max; edge detection: Laplacian, Sobel X, Sobel Y, gradient), form removal (with option to include/exclude zones), direct edition of the FFT (Fast Fourier Transform), Fourier Transform Modulus.

Autocorrelation Represents similarity of surface to itself under translation, helps to distinguish between isotropic and anisotropic surfaces and to detect surface periodicity.

Thresholding Select and analyze data points based on their relative height; recommended for analysis of grains/particles.

Profile extraction East-West, North-South, oblique, zigzag, circular, surface or profile resolution.

Surface subtraction Analyze the differences between two surfaces, e.g., during before/after studies.

**Series of profiles** Convert into a surface.

Benefits

Powerful surface imaging Powerful 3D rendering provides designers and engineers with complete surface visibility, often giving them a better idea of a feature or the cause of a problem than a series of numbers.

Comprehensive visual analyses and reports A wealth of 2D and 3D studies, operators and parameters in accordance with current and forthcoming international standards.

Ergonomy and productivity without compromise Easy to use, intuitive desktop publishing environment, ability to apply same analysis to multiple measurements automatically.

Worldwide reference Apex is based on Mountains technology, used by leading industrial groups worldwide.

Continuous improvement In addition to the 2D and 3D parameters listed here, many more are available, and Apex software continues to add new capabilities.
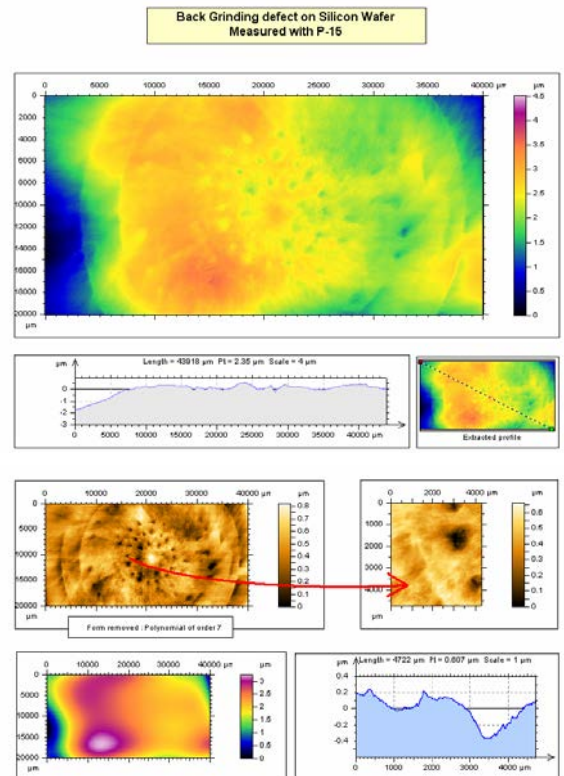
Intuitive desktop publishing environment for comprehensive and visual quality reports