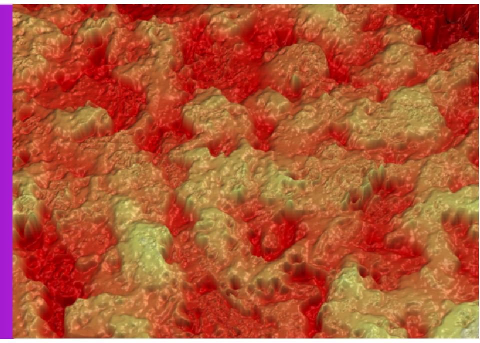
KLA INSTRUMENTS

3D Surface Roughness Characterization

Zeta™ Optical Profilers



Introduction

KLA Instruments™ 3D optical profilers include the Zeta™ series and the Profilm3D series. The Multi-Mode optics of the Zeta series include proprietary ZDot™ technology, and the Profilm3D series tools are designed as low cost, high performance interferometers.

Surface topography is quantified via 2D and 3D parameters such as roughness, skewness, peak and valley distribution, etc. Measurement of these parameters contributes to better understanding of surface topography. The Zeta optical profilers with ZDot™ technology provide a fast and easy solution to measure surface topography and roughness of challenging surfaces such as porous chucks. ZDot enables measurements that can be challenging to measure with interferometry.

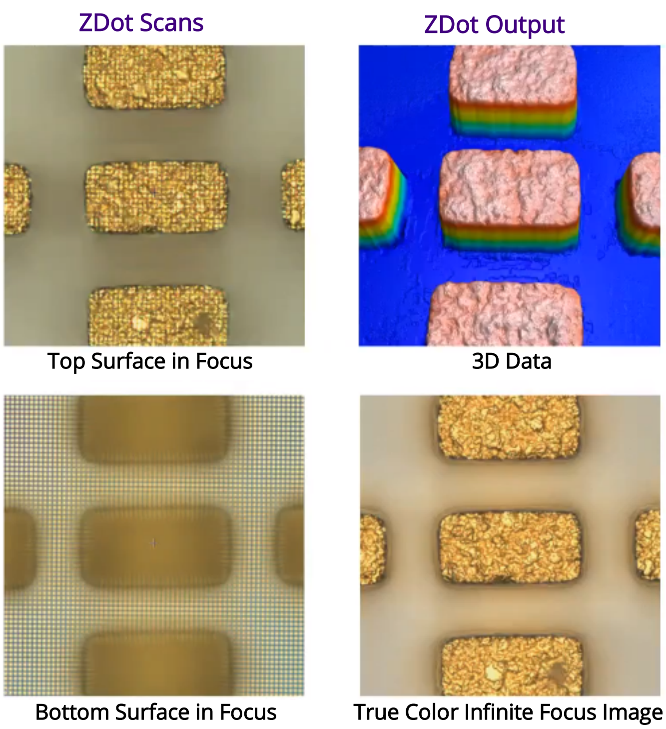


Figure 1. Zeta imaging modes illustrated: the two ZDot images at left show the top and bottom surfaces in focus, the upper right image shows the topography where the Z height is represented as a color scale, and the lower right image shows the True Color infinite focus image. The 3D and True Color images at right are acquired simultaneously.

Zeta Technology Overview

At the core of Zeta optical technology is the KLA-proprietary ZDot measurement technique, which is structured illumination that uses confocal optics. A grid is projected onto the surface at the focal plane, and as the optics move in the Z direction, the projected grid comes into focus at different points along the sample surface height, which provides Z mapping data in the field of view. Figure 1 shows an example of the ZDot grid in focus at both the top and bottom surfaces of a step, as well as the 3D topography and the True Color image. Figure 2 is a schematic of the ZDot optics.

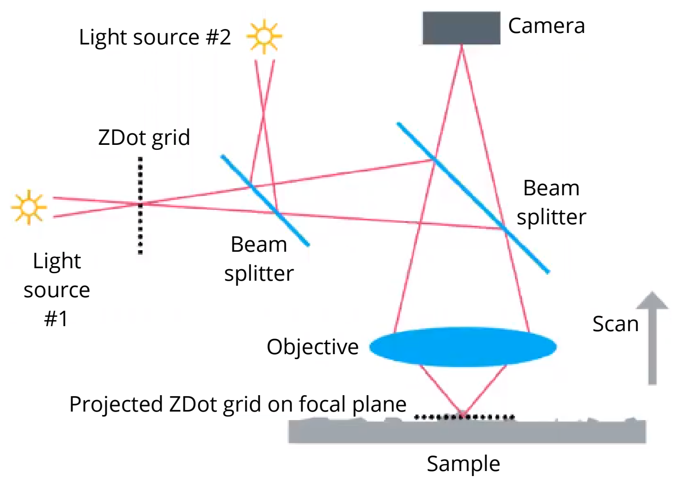


Figure 2. The ZDot optical schematic shows the white light source at left, with the projected ZDot grid at the sample surface. By rapidly switching between the two white light sources, the surface topography is mapped out and the True Color image is acquired simultaneously.

The Zeta optical profiler is a Multi-Mode system with True Color infinite focus imaging combining six different techniques, including ZDot, phase-shifting interferometry, vertical scanning interferometry, broadband reflectometry, defect inspection, and more. These techniques all share a common optical path, simplifying the user experience by enabling switching between techniques without having to change the objective-sample alignment. This design streamlines the technique selection process for the surface of interest.

Measuring Surface Roughness using the Zeta-20

The Zeta-20 is a versatile optical profiler widely used in industrial and scientific applications such as solar cells, semiconductor and compound semiconductor devices, biological applications and more. The Multi-Mode optics enable use of the optimum measurement technique for the specific application of interest.

Zeta optical imaging can also measure surface texture roughness. The ZDot technique is very flexible; it can measure devices and materials exhibiting a wide range of topographic and optical properties, including low reflectivity transparent surfaces such as microfluidics devices, as well as rough, flat and curved surfaces. Vertical scanning and phase shifting interferometry measure very small height differences with high resolution.

Surface Topography of N95 Face Masks

The Zeta-20 was used to measure the surface topography and roughness of the inner filtration layer of a N95 face mask. Measurements were taken prior to and after disinfection treatment by UV exposure. Figure 3 shows the N95 mask surface topography with no UV exposure, where the surface roughness measured 18.2µm.

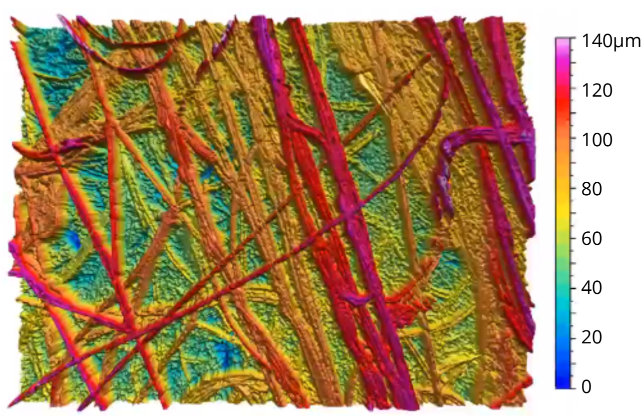


Figure 3. The N95 mask topography, pre-exposure, as measured by the Zeta-20 optical profiler. Surface roughness measured 18.2µm. In this image, the color scale represents the Z height, as shown at the right.

After 155 minutes of UV exposure, the surface roughness measured 24.4µm, and the fiber width narrowed as compared to the pre-exposure sample. Figure 4 shows the surface topography following 155 minutes of UV exposure on the filtration fibers.

Based on these same 3D optical scans, 2D profiles along individual fibers can also be analyzed to measure roughness along the fiber profiles. Figure 5 shows 2D profiles along the lengths of fibers from both the pre-exposed sample and the UV exposed sample. The width of individual fibers was also measured using 2D profiles from the same 3D scans. Fiber width comparison data verified the narrowing of the fibers following UV exposure.

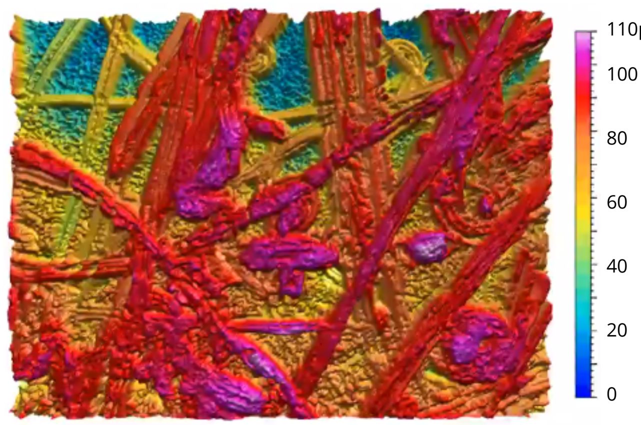


Figure 4. The N95 mask topography following 155 minutes of UV exposure, as measured by the Zeta-20 optical profiler. Surface roughness measured 24.4µm. In this image, the color scale represents the Z height, as shown at the right.

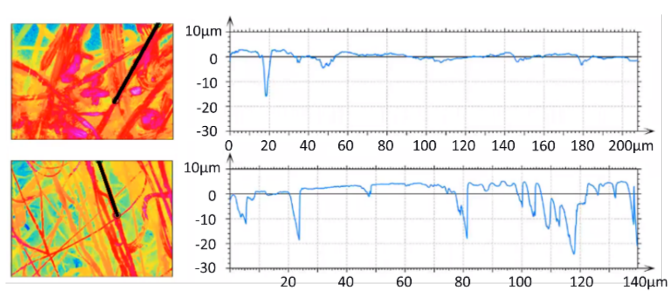


Figure 5. 2D profiles derived from the 3D scans compare fiber roughness for both pre-exposed and UV-exposed samples. Profile roughness for the unexposed fiber measured 0.2µm Rq, and for the UV-exposed fiber, 1.1µm Rq, showing the increase in roughness as a result of the UV exposure.

Surface Roughness of Sapphire Wafers for LED Devices

A single-side polished wafer was analyzed for backside surface roughness. Traditionally, sapphire wafer manufacturers measure roughness using a 2D scan from a stylus profiler, such as a Tencor™ P-17. In this example, P-17 roughness data was compared to roughness data taken by the Zeta-20 optical profiler.

The P-17 was configured with a 2µm radius stylus, which has a resolution of about 1µm in XY, and 1nm in Z. The backside sapphire RMS roughness as measured by the P-17 is shown in

Figure 6 (2D scan, RMS roughness = 1.32µm) and Figure 7 (3D scan, RMS roughness = 1.41µm).

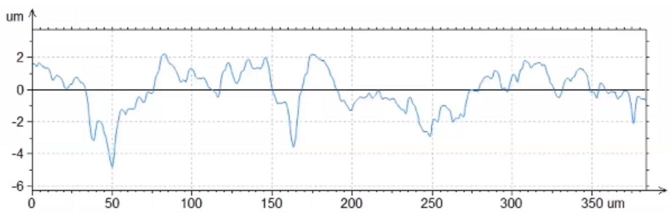


Figure 6. RMS roughness of 1.32µm, measured by a 2D scan taken using a P-17 stylus profiler.

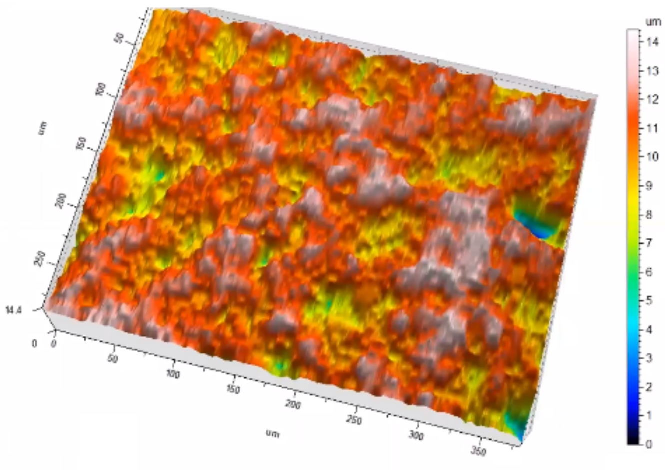


Figure 7. RMS roughness of 1.41µm, measured by a 3D scan taken using a P-17 stylus profiler.

In analyzing the individual P-17 2D scans comprising the 3D P-17 scan, the measured RMS roughness varied between 0.86 – 2.61µm, which suggests that a single 2D scan on this surface may not be representative of the average backside surface roughness. The single 2D scan takes about 10 seconds, whereas the high resolution 3D scan takes over 10 minutes to acquire but provides much higher sampling.

Optical profiling can be used to quickly generate 3D scans on a variety of surfaces. The Zeta-20 was configured with a 20X objective and operated using vertical scanning interferometry to measure a 150mm diameter sapphire wafer. The XY resolution was approximately 1µm. Figure 8 shows the sapphire RMS roughness as measured by the Zeta-20 optical profiler (3D scan, RMS roughness = 1.36µm). The full field of view was imaged in seconds with high resolution 3D sampling.

In comparing the stylus profiler data to the optical profiler data, the 3D roughness results are very similar. Although the measurements can be performed on either tool, the Zeta-20 quickly provides the 3D area data in about the same time it takes to acquire a single 2D scan on the stylus profiler.

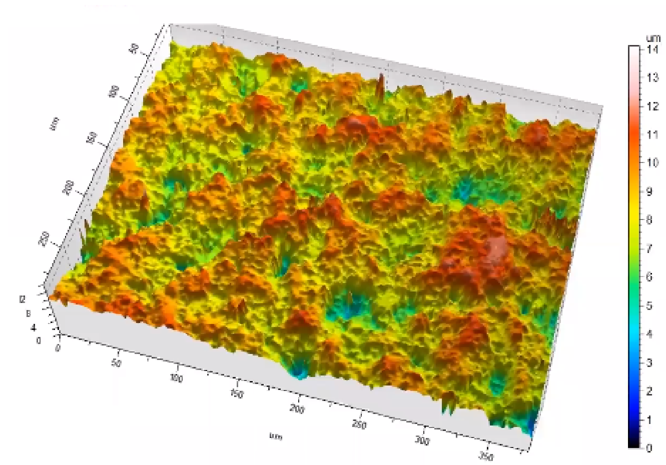


Figure 8. RMS roughness of 1.36µm, measured by a 3D scan taken using a Zeta-20 optical profiler.

Characterization of Porous Chuck Roughness

Porous chucks are utilized as a special type of vacuum chuck where the wafer or sample is held down via vacuum applied through the porous material in the chuck. This type of chuck is used with the Candela® 8720 defect inspection system to measure SiC or sapphire wafers. If the chuck surface is too rough or too smooth, the wafer is not held in place properly when spinning at 5,000RPM. However, porous chucks have traditionally been qualified for roughness by touch alone, and quantitative data is needed to adjust the polishing process.

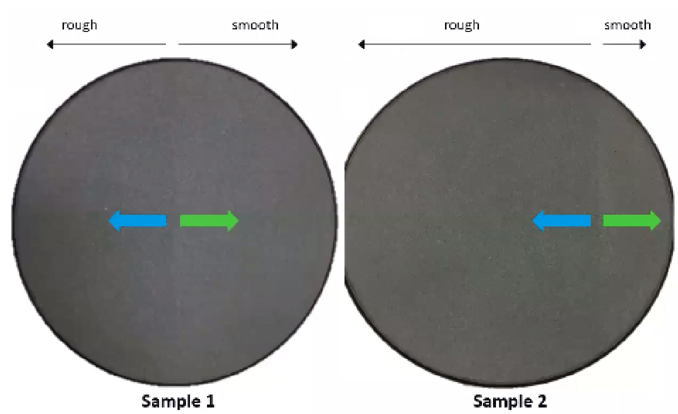


Figure 9. The rougher sections of the two chuck samples are indicated by the blue arrows and a slightly darker color; the smoother sections are indicated by the green arrows.

Two porous chucks (Sample 1 and reworked Sample 2) were measured with the Zeta-20 using a 20X objective and the

ZDot™ structured illumination technique. In Figure 9, the rougher sections of the chucks are a slightly darker color than the lighter, smoother sections. The arrows indicate the border between the sections. The measurement sampling is shown in Figure 10.

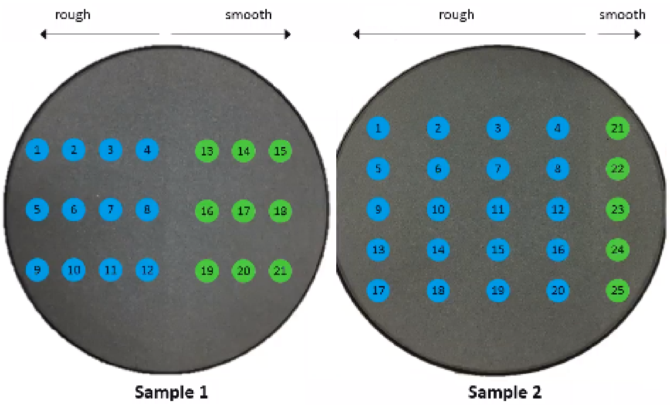


Figure 10. Measurement sampling pattern on the two chucks.

When determining the scan size for the measurement, it is important to consider the size of the features of interest, such as islands or valleys. To avoid under-sampling measurement of the surface, it is recommended to measure with a lateral spatial sampling frequency at least twice the minimum feature size of interest. Stitching can also be used to measure regions that have a lateral dimension greater than a single Field of View. For the example presented here, ten adjacent locations were measured and stitched together to generate a single measured value for each of the sites shown above.

Figure 11 shows the RMS roughness measurements for a chuck that was smooth by touch and for a chuck that was rough by touch. In this case, the RMS roughness of the two chucks were similar, such that the RMS roughness parameter was not adequate to characterize the difference between them.

To better differentiate and characterize the smooth and rough sections, additional parameters may be considered, such as skewness and kurtosis. Skewness of the height distribution, Ssk, is widely used to define asymmetry of the height distribution, and can be quantified (ISO 25178) as:

$$Ssk = \frac{1}{Sq^3}[\frac{1}{A}\iint_A z^3(x,y)\,dx\,dy]$$

where:

- Sq is the RMS roughness
- A is the measured area
- z is the measured height at point (x,y)

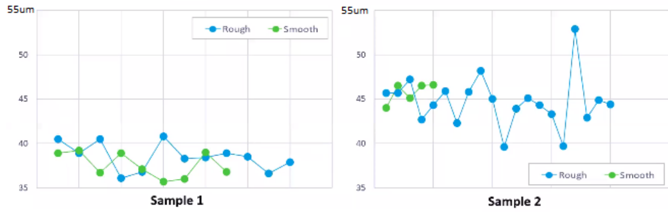


Figure 11. RMS roughness measurements for the sample 1 (left) and sample 2 (right) do not indicate significant RMS roughness difference between the rough (blue) and smooth (green) sections. The roughness is more clearly differentiated by using other roughness parameters such as Ssk, which is illustrated in Figure 12.

A near-zero Ssk indicates a Gaussian distribution, and a negative Ssk indicates that the surface is composed of principally one plateau with deep and fine valleys. A positive Ssk indicates that the surface is composed of principally one planar surface with many peaks on the plane.

Figure 12 shows the height distribution histograms (blue) and Abbott curves (red) comparing the skew for the rough (left) and smooth (right) surfaces of the chuck.

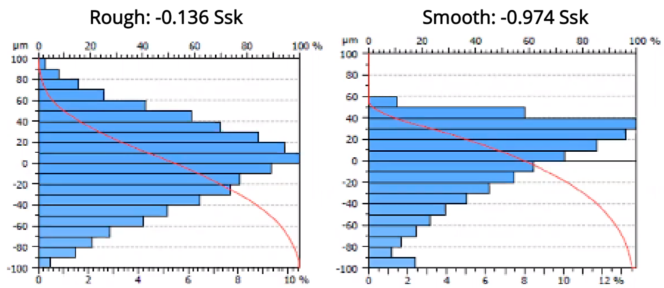


Figure 12. Normalized height histograms (blue) showing percentage of data points recorded at that height (lower x-axis). The Abbott curve (red line) shows cumulative percentage of the population (upper x-axis). A Gaussian-distributed height histogram (rough surface, left) shows a uniform distribution about the peak height, and a negatively-skewed histogram (smooth surface, right) shows a larger amount of data below the peak height.

The height distribution histogram plots heights on the vertical axis and percentage of the whole population on the horizontal axis. The depth distribution reflects the density of heights distribution. The Gaussian-distributed height histogram for the rough surface, shown in Figure 12 (left), indicates that most of the heights were distributed in a nominal plane that has approximately the same number of peaks and valleys. A negatively skewed height histogram for the smooth surface, shown in Figure 12 (right), indicates that the surface has many valleys but few peaks. Figure 13 shows the stitched Zeta-20 scans for both the rough surface (top) and the smooth surface (bottom), with significantly different skew values.

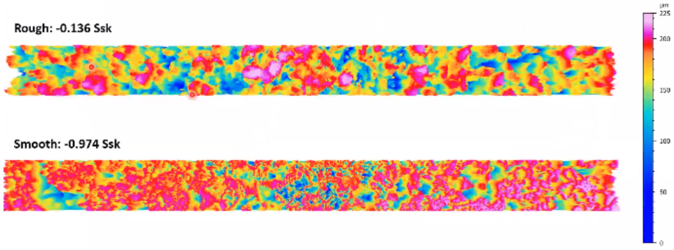


Figure 13. The Zeta-20 stitched scans of the porous chuck surface, from which RMS roughness and skew measurements were generated. The rough surface (top) Ssk = -0.136, and the smooth surface (bottom) Ssk = -0.974. Stitched scan area is 5.28mm x 0.43mm.

Table 1. Comparison of Skew (Ssk) for Porous Chuck Surfaces

	Rough Area	Smooth Area
Sample 1	-0.382	-0.700
Sample 2	-0.687	-0.887

Table 1 shows the average skew results for the two samples, comparing values for the rough and smooth areas of each sample. Sample 1 shows a clear difference in skew between the rough and smooth areas, and the reworked Sample 2 shows less of a difference between the regions.

In summary, 3D RMS roughness can be quickly measured by the Zeta-20 using ZDot structured illumination technique, but for surfaces such as porous chucks, the skew measurements and Abbott curves may be more valuable for quantifying the surface condition.

Conclusion

Surface roughness can be quantified using an optical profiler such as the Zeta-20 or a stylus profiler such as the Tencor P-17. Although 2D profiles can be used as the basis for RMS roughness measurement, it is important to maintain sufficient sampling so that the measured roughness is representative of the surface as a whole. 3D scans can be quickly generated by the Zeta-20 optical profiler, providing additional information to enable better process control. Although RMS roughness can be used as a starting point for roughness measurement, higher order surface roughness parameters can be used to provide more in-depth surface texture analysis.

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