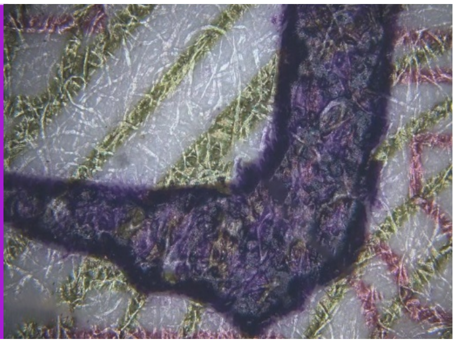
ZDot™ Technology

Zeta™ Optical Profilers



Introduction

Surface profilometry is an essential metrology tool that is used in a wide variety of applications, such as semiconductor packaging, HBLEDs, glass manufacturing, solar cell fabrication, hard disk manufacturing, and many others. Optical metrology has the advantage of providing uniform lateral resolution without contacting potentially delicate surface features. The Zeta™ optical profilers are designed specifically for Å-level vertical accuracy for many different surfaces and device types and are available with enhanced differential interference contrast imaging (ZIC), shearing interferometry (ZSI), vertical scanning interferometry (ZXI), and reflectometry (ZFT).

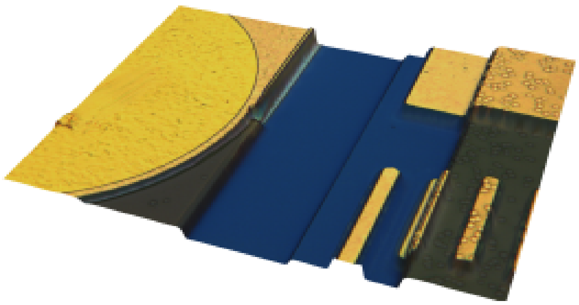


Figure 1. Integrated circuits require step height control and nm-scale metrology over large planar areas.

Optical Resolution

The lateral optical resolution or diffraction limit is the lateral distance between two points that the objective can resolve as two distinct points. It is determined by the numerical aperture (NA) and the illumination wavelength, λ. The optical resolution, δ, is given approximately by:

$$\delta = 0.61\lambda/NA \approx \lambda/2NA \qquad (1)$$

The optical resolution calculated from Equation 1 is the optimum value the objective can achieve. When the feature dimension is smaller than δ, the image will not be able to resolve details, due to the diffraction limited imaging of the optics. Instead, the feature is blurred as a circular shape with diameter δ, regardless of the quality of the other system optical components. When using visible light (λ = 0.55μm) and a 100X objective with NA = 0.9, the optical resolution is ~ 0.37μm.

Note that interferometry cannot use the entire NA due to the presence of reference mirrors in the optical path, which increases the value of δ. Because additional optical components are required for the objective, the ability of an interferometric lens to scan low reflectivity surfaces is further reduced, due to a reduced amount of light reaching the detector.

The vertical resolution of a lens is typically worse than its lateral resolution. In typical optical microscopes, the vertical resolution is of the order of the depth of focus of the objective, which is defined as:

$$DOF \approx 0.61\lambda/(NA^2) \qquad (2)$$

so that for a 100X objective, the vertical resolution is ~ 0.7μm. However, using ZDot™ mode, the vertical resolution of the 100X objective is improved to 0.013μm using the confocal ZDot™ grid.

ZDot™ Technology

To accurately measure depth, the Zeta optical profilers rely on ZDot technology, which utilizes a structured illumination technique, to enhance the vertical resolution of the objective lens. Improved vertical resolution is achieved by enhancing focus across a ZDot grid, which can be thought of as an array of pinholes. With a confocal technique, the light is reflecting through a pinhole as the sample is rastered in XY and Z, and only the light that passes through the pinhole is the signal from the surface. The ZDot grid is similar to an array of 1000s of pinholes, which enables simultaneous measurement of the entire field of view, so there is no need to raster in XY, but instead scan only in Z to determine where each individual grid point provides the optimum signal. The true vertical position of the surface can then be detected based on the optical signal at every point in the grid. Because the ZDot grid is at the confocal focus plane, the true surface is easily determined because the grid is only in focus when the optics are in the correct position relative to the surface. This automated focusing method provides a key advantage over standard optical microscopes.

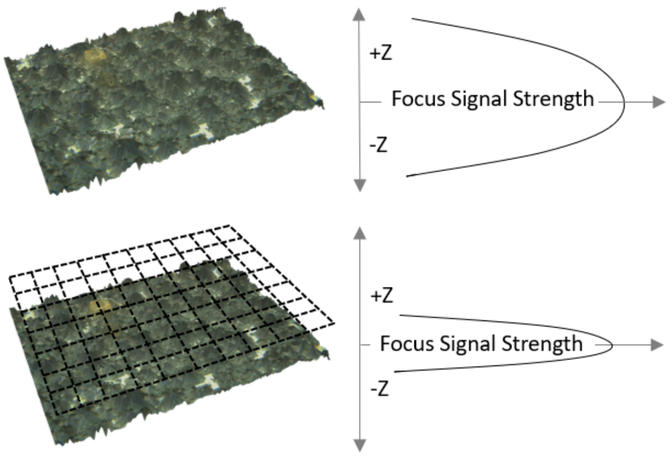


Figure 2. Without ZDot technology (top), the focus signal strength has a wider peak, making it difficult to detect the exact focus height. With ZDot technology (bottom), the exact focus height is determined as the center between the two Z heights of maximum contrast. Note that in optical terms, the signal peak of the Zeta system is narrower than that of a regular optical microscope, but enhanced focal detection is possible because of the 1000s of signal points from the ZDot array.

The precise scanning in the Z direction is based on signal contrast analysis, which eliminates the signal intensity limitation of traditional confocal techniques. Image data is then acquired without the grid in the optical path, thus increasing the amount of light reaching the detector, making it suitable for very rough or very low reflectivity surface measurements.

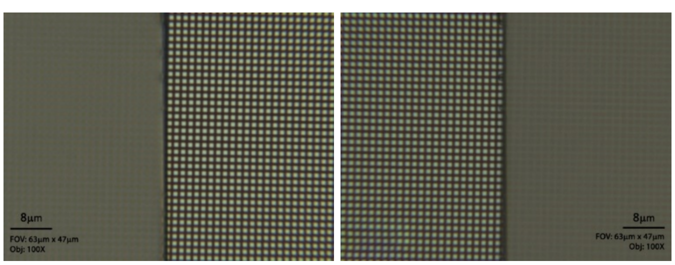


Figure 3. ZDot technology maximizes signal strength at multiple focal planes in order to provide accurate step height measurements. The left image shows the ZDot grid in focus at the top surface of the step (right side of image), and the right image shows the grid in focus at the bottom surface of the step (left side of image).

ZDot technology also includes unique transmissive and dark field illumination methods that enable the Zeta profilers to handle the most challenging applications, such as high roughness surfaces, very dark surfaces, deep trenches, and multi-layer transparent surfaces.

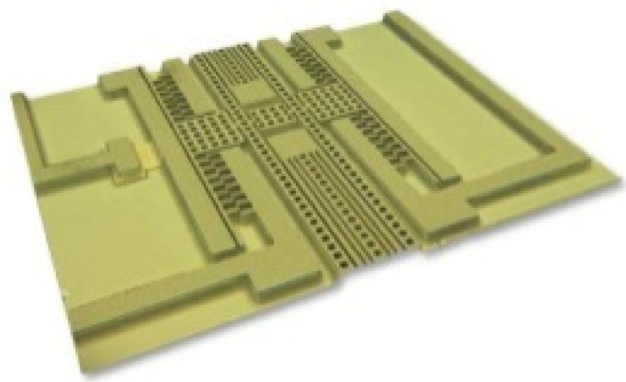


Figure 4. Complex MEMs devices require ZDot™ technology for accurate step height measurements across multiple surfaces.

Applications

For transparent stacked layers such as closed microfluidics channels, height measurements include not only the top and bottom surfaces of the structure, but also the surface height at all interfaces in the stack. Figure 5 shows a microfluidics device with a transparent cover plate enclosing the channel. **ZDot Film** was used to measure this device, generating accurate step height measurements of both the channel depth (59.2µm), and the cover plate thickness (93.4µm). Surface roughness can affect device performance, and surface roughness at the interface layers may induce material stresses that may alter the interior channel dimensions. The ability of the Zeta profiler to quantify the surface roughness as well as step height is important for generating an accurate evaluation of device performance. With its maximized vertical resolution, ZDot is critical to generating precise measurements of step height, film thickness, and roughness for use in materials development, device research, and manufacturing quality control.

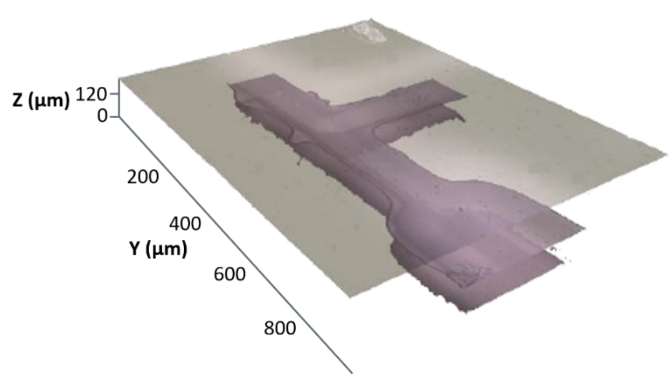


Figure 5. Zeta image of a closed microfluidics channel with a transparent cover plate, showing the top, middle, and bottom surfaces. The cover plate thickness measured 93.4µm, and the channel depth measured 59.2µm.

True Color 3D Imaging

The ZDot focusing technology, combined with the innovative Zeta optical design, eliminates complicated optics and laser and raster design employed by confocal microscopes. The result is not only nm-level Z resolution, but a True Color 3D image. Unlike a confocal microscope, there is no need for periodic system maintenance or laser alignment.

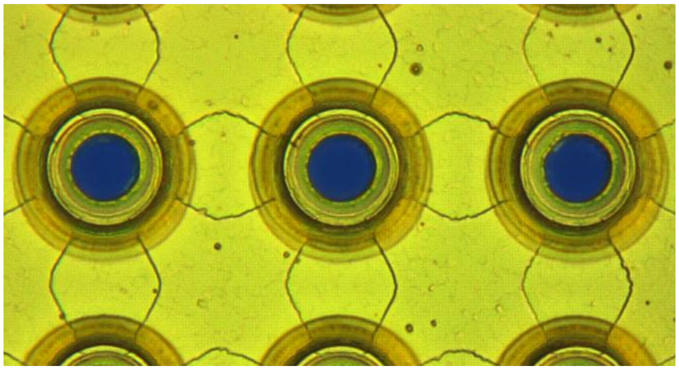


Figure 6. ZDot measurement mode simultaneously collects a high resolution 3D scan and a True Color infinite focus image.

As compared to a conventional microscope, the non-contact Zeta optical profiling combined with Å-level step height accuracy provide an infinite depth of focus, producing 3-dimensional images with all surfaces clearly displayed in sharp focus. This capability is especially important for handling structures with large Z variation, such as MEMS devices, micro lenses, and semiconductor packaging structures.

Multi-Mode Optics

Every profiling technique has its limitations, and the Zeta Multi-Mode optics are designed to maximize optical capability in a single instrument. ZDot technology is further enhanced through use of vertical scanning interferometry (ZXI), interference contrast imaging (ZIC), shearing interferometry (ZSI), film thickness measurement (ZFT) and ZDot Film. For larger-scale surface roughness characterization, even on transparent surfaces with little or no native contrast, ZDot technology can be used. The system detects the focus at each point, generating the height profile of the surface, from which the roughness is calculated. ZXI provides nm-level step height accuracy over large planar areas. ZIC and ZSI utilize Nomarski interference contrast for measuring surface roughness with Å-level Z resolution, with the ZSI especially tailored for nm-level step height measurement. ZFT measures film thickness of transparent or semi-transparent materials using a broadband reflectometer. ZDot Film measures through transparent films to calculate thickness for photoresist, polyimide, and even highly non-uniform films, such as spin-coated photoresist near the edge of a wafer.

The Zeta optical design uses few moving parts, lowering the cost of ownership and rendering the ZDot technology insensitive to external vibration. The system is optimized for productive uptime, using LEDs instead of lasers, providing a significant advantage over laser-based confocal microscopy.

Conclusion

Due to the unique imaging capabilities of the Zeta Multi-Mode optical profilers, surface characterization and dimensional measurements may be made on a variety of device structures. These measurements may be performed quickly and non-destructively at any point in the manufacturing or development process. Using ZDot technology to ensure data accuracy, processes can be more tightly controlled, resulting in improved device performance for a wide array of structures.

KLA Corporation
One Technology Drive
Milpitas, CA 95035
Printed in the USA
Rev 2 2021-04-27