



## Application Note #581

### Full Characterization of Microlenses Using White Light Interferometry

Microlenses are used in many applications, from coupling light into fiber optics and improving light source uniformity in microdisplays to focusing light onto imaging sensors in mobile phone cameras. Variations on the simple spherical microlens design are being investigated to reduce such effects as distortion, astigmatism, and diffraction and to tailor a given microlens to a specific use case. This application note discusses the use of Bruker white light interferometry (WLI) platforms for accurate and efficient characterization of microlenses, especially those that are not perfectly spherical.

Microlenses are now widely used in imaging applications, such as mobile phones, automobiles, and virtual reality goggles. The simplest microlens, a spherical lens, has a fixed radius of curvature. Spherical lenses tend to be replaced by more complex aspheric shapes for sharper focusing, less distortion, and astigmatism correction. Aspheric lenses do not have a constant spherical shape, which can make characterization more challenging. Fresnel microlenses introduce new diffraction effects but can be used to minimize chromatic aberration. Free-form optics are even more complex in design but enable improved performance and new functionality while potentially reducing size, weight, and cost. All of these lens types are typically fabricated by etching or molding glass, silicon, infrared crystals, or plastic substrates to create an array of microlenses like that in Figure 1.

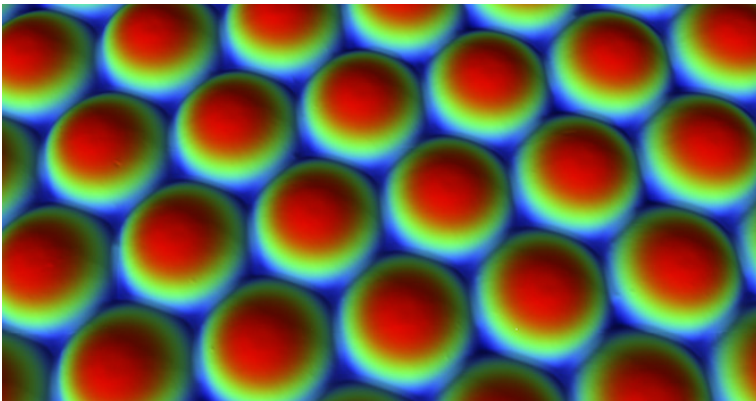


FIGURE 1

Microlens array used for light focusing onto sensor.

Optimal microlens shape and high surface quality are critical for focusing light correctly and efficiently onto an intended surface, e.g., a camera array. Radius of curvature (ROC) is the most critical of the shape parameters, defining whether the lens is convex, plano, or concave, and determining the optical path length of the rays. High lens surface quality helps to avoid light diffraction while maintaining the highest modulation transfer function (MTF), a quantification of an imaging system's contrast and resolution performance. Some of the common defects that lower surface quality are scratches, pits, digs, bubbles, and inclusions. To understand or predict the performance of a microlens, both the radius of curvature and the defect architecture must be fully characterized.

## White Light Interferometry

WLI, also known as coherence scanning interferometry, uses an optical microscope with special interferometric objectives that create moiré fringes based on the constructive and destructive interference of a split light beam. The pattern of these moiré fringes is used to determine sample height. A schematic of a typical white light interferometer is given in Figure 2. To obtain complete topographical information, image stacks are generated by either (a) scanning optics through focus to create a fringe envelope (VSI/USI measurement modes) or (b) phase-shifting fringes by  $90^\circ$  (PSI measurement mode).

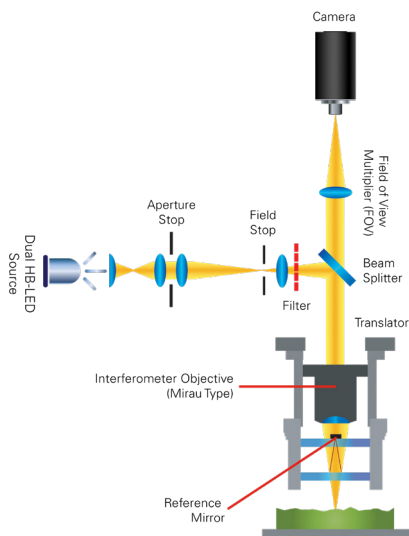


FIGURE 2

Schematic of a typical white light interferometer.

With a large field of view, sub-nanometer height resolution at any magnification, and micron-level lateral resolution, WLI is an ideal technique for non-contact, 3D surface shape and roughness measurements of microlenses and other optical components.

## Bruker's WLI Data Collection

As compared in Figure 3, there are three different WLI measurement modes that can be used for microlenses, each with different strengths:

- **Vertical scanning interferometry (VSI)** is the most versatile mode and can measure features from 100 nm to 10 mm.
- **Universal scanning interferometry (USI)** is highly repeatable and can measure down to angstrom-level heights. Both VSI and USI use the moiré fringe coherence envelope created by the interferometric objective, but USI also uses other known fundamentals such as intensity and modulation to provide superior resolution on microlenses.

- **Phase shifting interferometry (PSI)** is the fastest and most-repeatable measurement mode. PSI phase-shifts the coherent light by  $90^\circ$  to obtain sub-angstrom gauging.

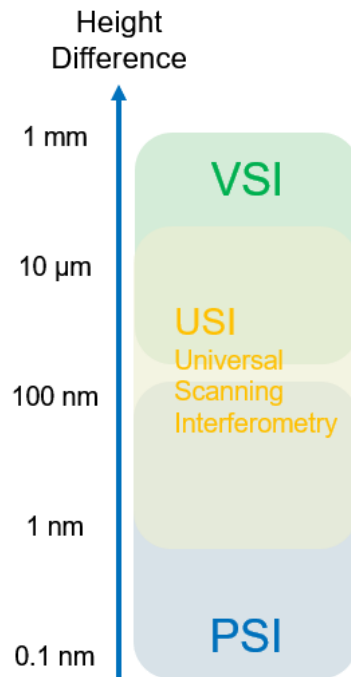


FIGURE 3

Measurement mode  
bridging below 1 mm.

If the microlens does not fit into a single field of view, multiple images can be stitched together. Instead of a using standard rectangular grid, the stitched image for a microlens is collected by starting at the apex of the lens then stepping down, spiraling down around the lens.

Along with the spiral stitching, Bruker has introduced numerous other speed improvements for data acquisition, including:

- Autofocus — automatically find the surface
- Auto Tip Tilt — automatically set the fringe orientation
- Autoscan — automatically stop the scan once all data is obtained
- Home Scanner — start the next scan where data was obtained on the last measurement
- Pattern Matching — automatically align or center the lens

# Bruker's Microlens Analysis Tools

## Radius of Curvature Analysis Using SureVision

Radius of curvature (ROC) can vary across a microlens array due to uneven photoresist thickness, changes in the reactive ion beam etching process, etc. When ROC tolerances are tight, even slight process variability can lead to substrate failure. Analysis of ROC on a microlens array is fast and easy with WLI using this areal technique with a large field of view.

The simplest analysis for performing ROC is to remove the spherical shape and report the ROC removed. More advanced is Bruker's SureVision analysis package, which can automatically detect, align, and analyze the microlens and output the ROC, height, and diameter of that microlens. Figure 4 shows the SureVision analysis result outputs of ROC, surface finish, and conic parameters.

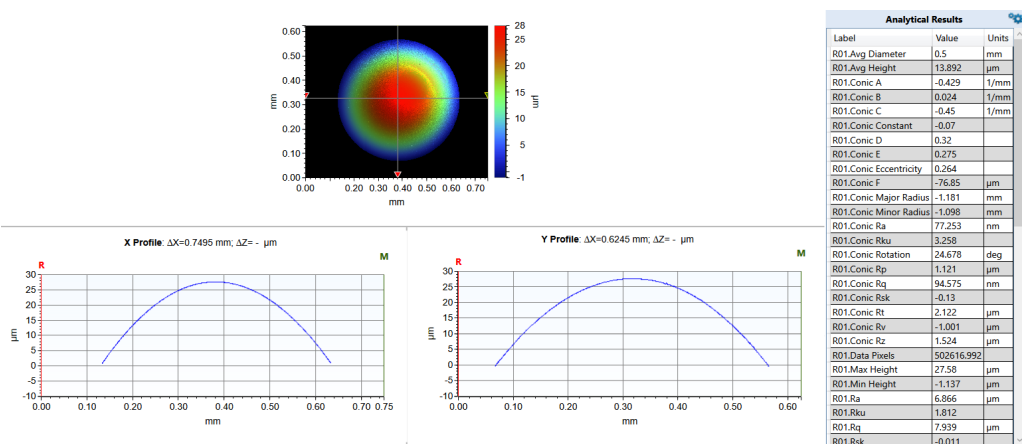


FIGURE 4

Automatic extraction of lens parameters.

## Multiple Region Analysis for Arrays and Defect Detection

Microlens arrays contain multiple lenses formed in a one-dimensional or two-dimensional array on a supporting substrate. Pitch, diameter, and height are critical measurements for a microlens array. Multiple Region (MR) analysis can automatically detect and analyze up to 42 different relevant array parameters (including pitch, diameter, and height) on the detected microlenses. An example microlens array measurement is given in Figure 5, showing individual analysis for each lens as well as overall values for the whole array of measured lenses.

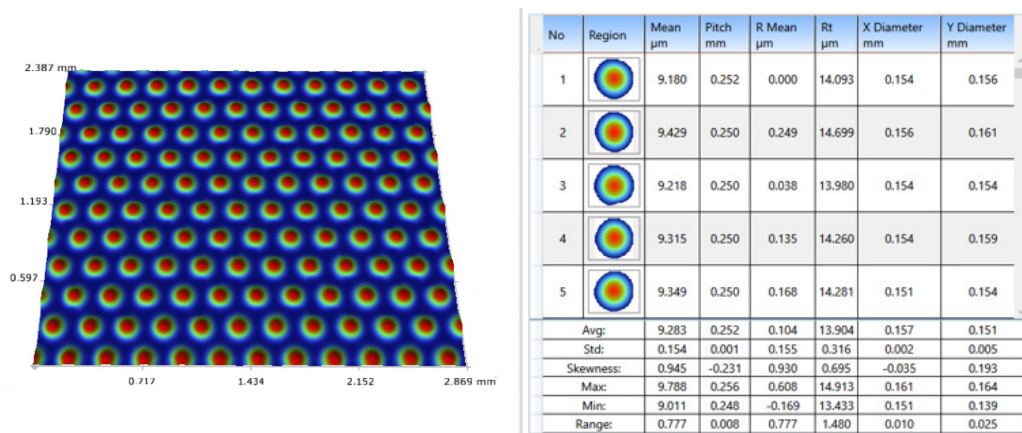


FIGURE 5

Microlens array analysis using Multiple Region including some selected output parameters (Raw image and MR analysis).



Once the form of the microlens is properly removed using one of the many algorithms built into Bruker's Vision64® software, MR analysis can be used to look for defects. MR can be set to automatically detect abnormalities on the surface. A depth and/or height threshold can be set that will trigger the detection of those features exceeding the threshold, and results for each detected defect are given with a variety of relevant parameters, including those seen in Figure 6.

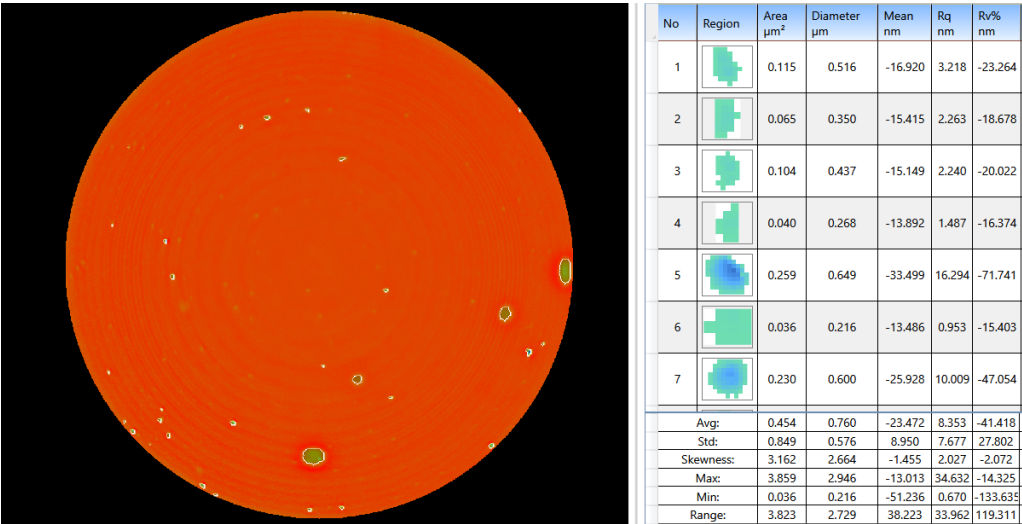


FIGURE 6

Defect detection, circled in white, using Multiple Region analysis with characterization of those defects.

Specialized Lens Analyses

- **Zernike Analysis** — Fully automated Zernike analysis can locate a lens, align to center the lens, crop off the substrate and perform data analysis. Zernike analysis uses an orthogonal circular-function fitting to remove the form and report up to 36 Zernike parameters, as seen in Figure 7. Also reported are the standard radius of curvature and surface texture parameters.

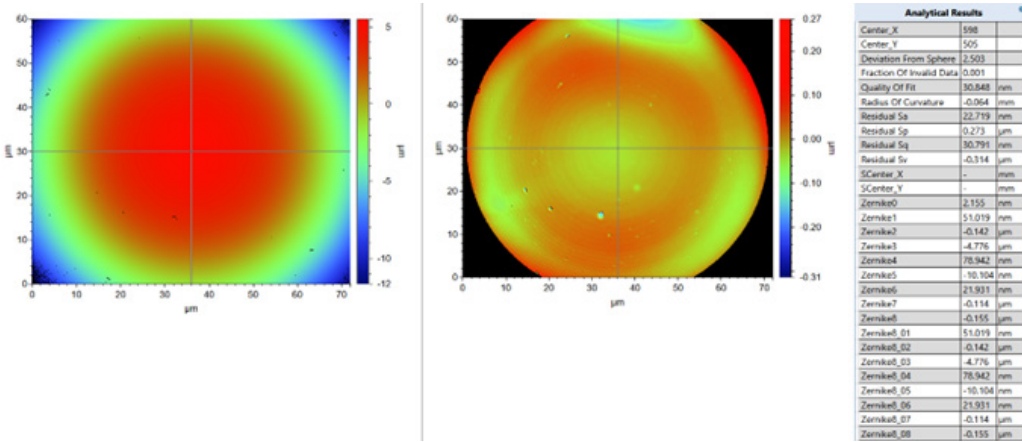


FIGURE 7

Zernike analysis showing before and after form removal while reporting some of the output parameters.

■ **Asphere and Zernike Generation and Subtraction** — Asphere and Zernike wavefronts can be generated from the optic design print and subtracted from the measured microlens. An automated Subtract Asphere algorithm can report the ROC removed as well as surface texture parameters. The general subtraction function can also automatically align the generated wavefront from the actual measurement for further analysis. The residual image (e.g., Figure 8) can then be run through the many built-in automatic analyses from form to surface analysis.

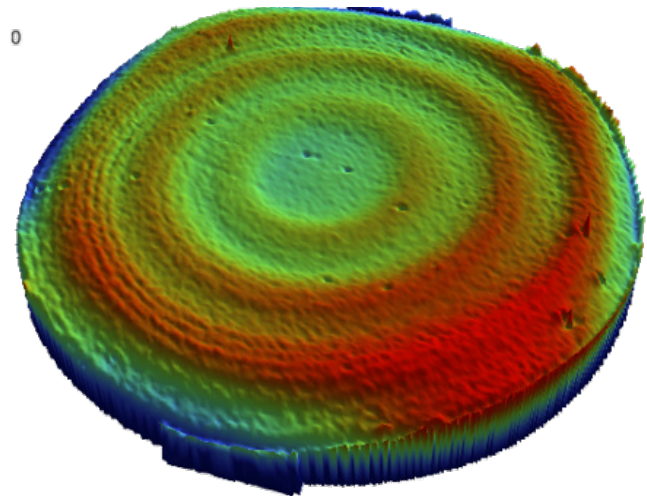
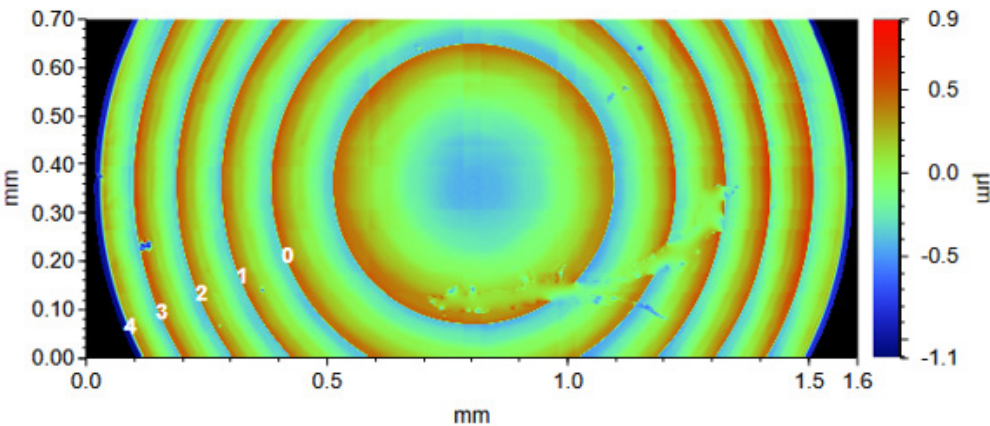


FIGURE 8

Generated asphere wavefront subtracted from measurement showing the residual of the subtraction.

■ **Fresnel Analysis** — Fresnel analysis can automatically detect and report the step depths of up to 14 steps on diffractive-type microlenses like the one in Figure 9. If analysis is required on more steps, the Multiple Region analysis can be used to detect and report these heights.



Analytical Results		
Label	Value	Units
Step 0	-0.855	$\mu\text{m}$
Step 1	-0.871	$\mu\text{m}$
Step 2	-0.928	$\mu\text{m}$
Step 3	-0.862	$\mu\text{m}$
Step 4	-1.202	$\mu\text{m}$

FIGURE 9

Fresnel analysis of a diffractive optic showing the analysis and step heights.

## Conclusion

Fully characterizing microlenses can enable predictions of functionality, leading to improved designs and increased reliability. White-light interferometry is an accurate and efficient 3D non-contact optical profiling technique that can be used to quantify and visualize microlens shape and surface texture. Evaluating microlenses is particularly easy and user independent with Bruker's improvements to the measurement and analysis workflows, including multiple measurement modes, spiral stitching, SureVision, Multiple Region analysis, and specialized lens analyses. With a wide range of tool types available—from benchtop to self-calibrating and fully automated systems—Bruker WLI-based profiler configurations offer a solution for every microlens characterization need.

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