Measuring Micro-Lens Radius of Curvature with a White Light Optical Profiler

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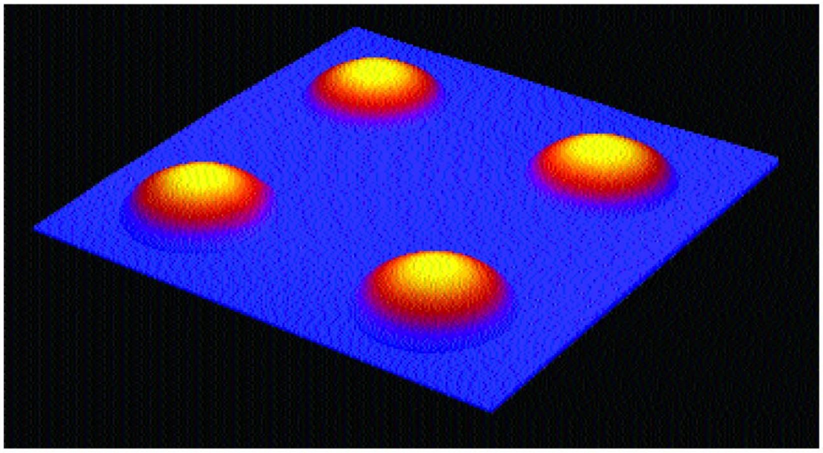

Figure 1. An array of microlenses approximately 20μm in height.

Introduction

Microlenses are discrete or array-based spheres, aspheres and other optics used in a variety of applications, chiefly for focusing light into fibers for optical networking. Microlenses are typically 50μm – 5mm in diameter, with a radius of curvature (ROC) of 0.25 – 2.5mm. Controlling ROC is critical for properly focusing the beam on the fiber, and uniform ROC is necessary to minimize signal loss. Measuring ROC at production volumes is a challenging task; optical profiling provides the combination of speed, resolution and repeatability to serve this role.

Measuring Micro-Lenses

Microlens arrays are created by etching or molding glass, silicon or plastic substrates (Figure 1). The lenses' ROC can vary across the substrate due to uneven resist thickness or changes in the reactive ion beam etching process. With ROC tolerances held to <10μm, even slight process variability can lead to substrate failure.

Optical Profiling (White Light Interferometry) is a well-established technique for non-contact, 3D surface roughness and shape measurement of microlenses and other optical components. Optical profiling enables ROC measurement with less than 1% error, and less than 0.5% error on larger lenses.

Speed is a significant benefit. A typical profiler measurement on a 0.5mm lens array requires approximately 1 second per lens, versus 5-50 seconds for methods such as large area interferometry or stylus profiling. High-speed stage automation, data logging and pass/fail reporting enable sampling across an array/substrate to quickly establish its quality.

Two ROC Measurement Methods

Wyko® NT Series optical profilers (Veeco Instruments Inc.) offer two techniques for measuring microlenses: phase-shifting interferometry (PSI) and vertical scanning interferometry (VSI).

PSI provides fast measurement with sub-nanometer vertical resolution. For a spherical lens, the measurable area is limited by the lens' slope, which must be less than $\lambda/4$ pixel-to-pixel. A narrow-bandwidth filter increases the coherence length to achieve interference fringes over a greater vertical range. Repeatability of 5μm is readily achieved with PSI.

In some applications the entire lens must be imaged, in which case VSI mode is employed. VSI can measure higher steps or slopes over a greater vertical range than PSI. High numerical aperture (NA) objectives, such as those of Wyko NT Series optical profilers, are required to capture adequate data at the edges of the lens. NT Series profilers also include discrete magnification multipliers to maximize the field of view while maintaining lateral resolution—critical to ROC measurement. Data stitching can be used to join multiple VSI datasets, imaging the entire lens or a swatch of the lens as a single large area measurement.

Well-Correlated ROC Measurements

The combination of PSI and VSI techniques affords a flexible solution for highly repeatable, high-resolution ROC monitoring. Though fundamentally different in nature, when properly executed the two methods correlate well to each other. Both methods are also calibrated to traceable standards—PSI to a known wavelength source, and VSI to a step height.

Figure 2 shows PSI data that correlates well with known values. Below are some considerations for ensuring well-correlated measurement results.

Optimize Intensity (PSI and VSI) For both PSI and VSI, the intensity should be set just below the saturation point when the system is focused on the top of the lens. This position provides ample brightness down the edges of the lens without over-saturating the top.

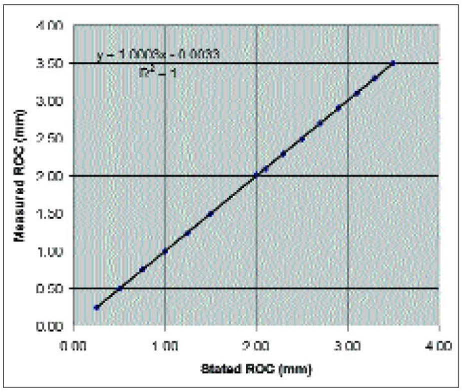

Figure 2. Measured versus stated ROC values.

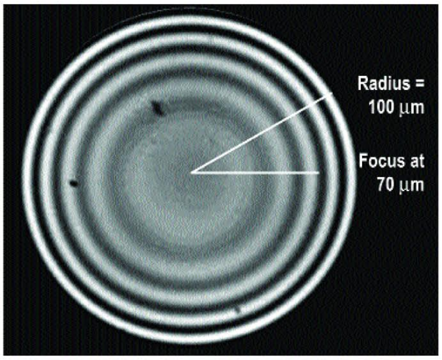

Figure 3. Best PSI focus position is at 70% of the lens radius.

Focus at 70% of the Radius (PSI) Focusing on the lens at a point 70% of the distance to the edge of the lens minimizes the residual wavefront error through the system. Figure 3 shows an example for a 100µm lens. The Camera Autofocus function in the Vision software allows you to focus on the top of the lens, then add an offset to move focus to the 70% position.

Use the Highest Available Resolution (PSI and VSI) Using the highest resolution setting requires a longer measurement time but ensures that the greatest amount of data will be gathered.

Use Enhanced Phase Unwrapping (PSI) Wyko profilers include Vision® analysis software, which offers several phase unwrapping options to optimize measurement results. The "Enhanced 2" phase unwrapping algorithm performs best on the steep slopes of spherical lenses.

Lower the Modulation Threshold (PSI and VSI) Modulation Threshold determines the contrast required for a pixel to be valid. To gather the most data from steep slopes, the modulation threshold should be set below 1%.

Mask with a Zernike Diameter Zernike Polynomial generation is available as part of the Optical Testing Package for Wyko profilers. You can use a Zernike diameter to mask out the substrate region, leaving only the lens data. Unlike a normal circular mask, the Zernike diameter will align itself to the center of the lens for every measurement.

Use a Reference Sphere (PSI and VSI) Measuring the same reference sphere with both modes verifies that they are properly correlated to each other.

Conclusion

Advances in 3D measurement techniques, such as optical profiling, have given engineers, process designers and quality control professionals a significantly improved toolkit for describing surfaces. 3D parameters uniquely differentiate not only surface shape but functionality as well. A careful surface design study results in better understanding of functional characteristics, a more controllable process, and, ultimately, better surface performance.