Optical form and relational metrology of aspheric micro optics

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INTRODUCTION

The last decade has witnessed the rapid growth of a new optics manufacturing industry dedicated to consumer electronics and compact automotive and medical imaging devices. Miniature cameras common to portable devices have evolved into sophisticated optical assemblies of advanced, injection-molded micro optics (FIGURE 1). More than a billion mobile phones shipped in 2016, which required the manufacturing of >15 billion individual lenses, or 40 million lenses a day.

A common metrology strategy for microlenses relies on contact stylus metrology [2], often limited to just two orthogonal cross-sectional profile measurements, sometimes supplemented by optical measurements of some of the alignment features on the lenses.

Manufacturing yield improvements and tighter performance requirements for the aspheric surface form of camera microlenses are driving the industry to ever greater precision and metrology data density. The goal of the present work is to provide full-area metrology for surface form, waviness and texture, as well as metrology of the relative position of lens features with respect to mechanical location features (so-called “relational metrology”) – all in a single instrument, using high data density, non-contact optical metrology [3].

THE INSTRUMENT

We use coherence scanning interferometry (CSI) [4] in combination with five-axis staging for positioning micro-optics (FIGURE 2). The system
includes specialized objectives for form and relational measurements on the same platform. The instrument is integrated in a vibration, air and sound isolation enclosure, and is equipped with software specifically designed for this application.

**SURFACE FORM MEASUREMENTS**

The strategy for measuring aspheric form is to combine a sequence of areal topography maps at high lateral resolution into a full surface reconstruction. This “stitching” concept has been examined in prior work on larger-scale optics, for example, by Thunen and Kwon [5], Fan [6] and in the instrument developments at QED Technologies [7]. Tang [8] and Shimuzu et al. [9] have also considered using stitching methods with a microscope for smaller optics.

A challenge with any image stitching technique is the overall metrology frame, which in most cases requires precise knowledge of stage motions, in turn requiring encoding devices or additional metrology. We have found that stage precision requirements can be significantly loosened by using the correlation of surface microstructure between adjacent topography maps, which is detectable even on super-polished surfaces when using interference microscopy [10].

The measurement sequence consists of individual CSI imaging scans performed over an array of pre-programmed imaging areas, each of which is presented to the instrument with minimal tip and tilt. Once the data are acquired, software adjusts the position and orientation of each map with respect to the others, consistent with the concept of surface form and texture continuity, including the roughness present in each map at micron-scale spatial periods. The result is a full surface topography map with millions of individual data points. Data rates vary according to lens size and shape, but are on the order of several minutes per lens. The software also supports the mapping and discovery of unknown rotationally symmetric surfaces.

**FORM MEASUREMENT RESULTS**

FIGURE 3 illustrates the synthesized 3D Form Map for a microlens approximately 1.5 mm in diameter with an overall sag of 290 μm. The most common data processing entails subtracting the design prescription to show the deviation from the intended surface topography, as in FIGURE 4. A common alternative is to fit and subtract a rotationally symmetric asphere with adjustable parameters to characterize the lens shape.

FIGURE 3. Areal surface topography of a smartphone microlens generated from a mosaic of interference microscopy maps.

FIGURE 4. Same data as in FIGURE 3, after removal of the design aspheric form.

FIGURE 5. Form deviation map showing a manufacturing error (flat area around the apex). The lens diameter is 2.4 mm and the height scale in this image is 1.5 μm.
Often it is of interest to parameterize the deviation map as a series of 36 or more Zernike coefficients for export to optical design packages for analysis. Subtracting the surface form enables further analysis of the surface texture, including residual diamond turning marks, roughness and surface defects.

The new instrument has proven to be an effective means of discovering issues that can affect image quality [1]. FIGURE 5 illustrates a manufacturing problem with the flow and distribution of material during injection molding. In addition to the deviation from the design aspheric form, the material has failed to completely fill the mold, producing the truncated and flattened area near the lens apex.

FIGURE 6 illustrates the benefits of full-field, high-resolution measurements of surface texture. The image shows defects related to the diamond turning process of the lens molds as well as damage from previous measurements using a contact stylus-type form profiler.

FIGURE 8 includes reference datum planes to establish a local geometrical metrology frame. The topographical imaging results shown in FIGURE 9 enable quantitative evaluation of critical alignment parameters [11, 12], including the position of the functional optical surfaces with respect to interlocks and the relative position of the two sides of a lens.

FIGURE 7. Relational metrology features critical to lens function and alignment.

FIGURE 8. Custom part fixtures incorporating reference datum features.

FIGURE 9. Imaging result for relational metrology, showing data collected at the apex of the functional optical surface (in blue) and data collected on outer plano surfaces, including a ring used for controlling lens tilt in the final assembly.
As with the surface measurements, the detailed 3D imaging reveals errors in the molding of mechanical locating features or interlocks that would otherwise go unnoticed until final assembly. FIGURE 10, for example, shows errors in the shape of a mechanical tilt control ring. Such molding errors could be repeated across a batch of many hundreds of lenses for a typical injection molding process. However, CSI-based metrology offers sufficient resolution, accuracy and throughput to identify and correct such mistakes before they significantly affect manufacturing yield.

FIGURE 10. Measured shape and circumferential profile of the tilt control feature of an injection-molded lens. The vertical scale is approximately a micrometer.

SUMMARY

We have developed a new optical metrology system for micro optics based on the integration of interference microscopy, advanced staging, full-surface topography reconstruction and relational metrology techniques. Key benefits of this approach include full-surface imaging at high lateral resolution, and the ability to measure the shape and location of relational features critical to the alignment of completed lens assemblies, as well as the position of the functional optical surfaces with respect to such interlocks.

REFERENCES