Fast in-line testing of lenses for wafer-level digital camera technology

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An instrument that provides real-time wavefront analysis in combination with automation algorithms can meet the high-volume demands of lens production for mobile camera phones.

Equipping massive numbers of mobile phones with built-in digital cameras has scaled up demand for miniature lenses residing on wafers. A new ultrafast, automated wavefront analyzer can reliably test such microlens wafers, at a rate of several seconds per lens, assuring quality control for this disruptive technology in micro-optics manufacturing. Assessment of lens imaging quality is ordinarily carried out by computing the modulation transfer function (MTF). However, this method offers only limited information when testing individual lenses. More detail can be obtained from wavefront measurements that provide a spatially resolved map of the refraction properties of the lens, which can be readily compared with design data.

To implement such rapid in-line testing, we employ wavefront sensing technology that makes use of a Shack–Hartmann (SH)-based measurement system. The high dynamic range (>1000) of the sensor enables measurement and analysis of spherical and aspherical optics over the entire aperture. For test equipment in a wafer-level production environment, we use fully automated lens-positioning procedures, including lateral positioning, autofocus, and error compensation.

In our configuration, we employ the WaveMaster PRO Wafer instrument in a reverse projection setup that uses a high-resolution SH sensor. The sample lens is illuminated by a point light source, and the pupil is imaged on the sensor by a telescope system that, in addition, magnifies the wavefront for maximum use of the sensor area and dynamic range (see Figure 1). This system is combined with motorized stages and automation software in a stand-alone instrument (see Figure 2). The software also provides a complete set of tools for analysis of MTF and point spread function (PSF) or Strehl ratio calculated with information from the wavefront map. The wavefront can also be decomposed into a linear combination of Zernike polynomials that describe typical optical properties and lens errors such as defocus, coma, and astigmatism.

Production setup

For wafer production operation, the software uses a tray representation file to find the optimum measurement conditions for each single lens on wafers of the same kind. A loading and alignment tool obviates the need for precision positioning of each

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new wafer prior to measurement. After a wafer is inserted into the wafer holder, the instrument determines rotation as well as lateral offset of the lens pattern with respect to the corresponding tray file (see Figure 3). This results in a reproducibility of the measured wavefronts of better than $\lambda/200\text{rms}$. Algorithms for fine positioning situate each lens optimally before the actual wavefront measurement. In addition to lateral positioning, an autofocus algorithm is applied based on targeting a previously defined defocus Zernike coefficient.\(^3\)

Wafers usually will show evidence of bending due to gravity or internal stress. To prevent imprecise results, a tracking mechanism ensures that the wavefront is always measured in the same plane relative to the wafer surface for every single lens. For this purpose, a distance sensor measures changes in sample height that are then applied to telescopic positioning. For each wavefront, a real-time analysis is performed during measurement, and each lens is immediately classified according to selected pass-fail criteria. A great variety of such criteria may be chosen, including comparison with theoretical lens data or with a master lens. Lenses are analyzed and sorted into different quality classes (see Figure 4).

Conclusion
Several installations of WaveMaster PRO are currently used in industrial settings, measuring large wafers with diameters up to 200mm that contain several thousand lenses. The actual measurement time, at 2–5s per lens with reproducibility of $\lambda/200\text{rms}$, is an improvement over all previous methods and facilitates high-capacity production of spherical and aspherical lenses. Our short-term objectives for further development of the production instrument is to make available in-line testing of both effective and back focal length. These improvements will offer customers a more comprehensive description of the lenses under examination.

Figure 2. WaveMaster PRO Wafer instrument.

Figure 3. View of the sensing head measuring a wafer of lenses.

Figure 4. Typical measurement results showing good, bad, and missing lenses.
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References