Freeform optical metrology using a four-beam low-coherence optical probe (Quad-Probe)

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ABSTRACT

Presently there are no commercial methods for measuring strongly aspheric optical elements that deviate from a best-fit sphere by more than 1 mm. To address this need, ASE Optics has developed the Quad-Probe, a four-beam non-contact optical probe. The Quad-Probe is an accessory for the Lumetrics OptiGauge dual-wavelength low-coherence interferometer, enabling the interferometer to measure both the position and orientation of surfaces with respect to the probe. By scanning the probe over the surface of the optic using a five-axis scanner (such as the UltraSurf from OptiPro), a three-dimensional model of the interior and exterior surfaces can be built.

Keywords: surface metrology, optical metrology, freeform optics, conformal optics, aspheric optics, low-coherence interferometry

BODY

The commercial availability of deterministic polishing systems has given optical designers greater freedom to design optical elements that differ significantly from spherical.[1,2] This in turn has spurred the need for improved metrology solutions for freeform surfaces.[3] The ideal metrology solution would simultaneously measure interior and exterior surfaces to sub-micron accuracy and be adaptable to various shapes and sizes without requiring the interchange of expensive reference optics. To address this need, ASE Optics, Inc. has developed a multi-point non-contact optical probe that uses low-coherence dual wavelength interferometry to measure both the position and orientation of a surface with respect to the probe. Scanning the probe in a free-form manner over the object yields a three dimensional model of the object.

Our metrology system consists of the following four key components: specifically a four-beam Quad-Probe, a Lumetrics OptiGauge, and a computer (for motion control, data acquisition, and data analysis), and a five-axis freeform scanning system. These are shown in Fig 1. The Lumetrics OptiGauge is a fiber-based low-coherence interferometer that can simultaneously measure the optical thicknesses of all layers within a multilayer material.The technology was invented at the Eastman Kodak Company and commercialized by Lumetrics, Inc.[4,5] The OptiGauge interferometer emits broadband infrared light centered at 1.3 μm. The interferometer can measure layers with optical thickness as thin as 12 μm and as thick as 12 mm with a resolution of 0.1 μm.

The Quad-Probe is a new probe for the OptiGauge.[6] Instead of a single beam, it projects four beams in a square pattern. This is shown conceptually in Fig. 2 (a). By simultaneously measuring four points on a surface, we are able to determine both the position and the orientation of the measured region with respect to the probe. The measurements from the four beams create a four cornered polygon termed a "facet." The spacing between measurements is generally chosen so that the facets overlap. This creates measurement redundancy that can be useful for detecting (and sometimes correcting) mechanically-induced measurement errors. A close-up of overlapping facets is shown in Fig. 2 (b). This is a top-down view of a three dimensional image, and the facets are color-coded by height, with red being higher than blue in this case.

We have previously published research that demonstrated the Quad-Probe could construct accurate three-dimensional models of the interior and exterior surfaces of planar and spherical objects.[6] We have recently completed construction of a testbed five-axis scanner, consisting of three linear stages in the x-, y-, and z-directions and two rotation axes about the y- and z-axes. (See component (d) in Fig. 1.) This system is capable of measuring freeform optics. We have also designed and built a new version of the Quad-Probe (component (a)

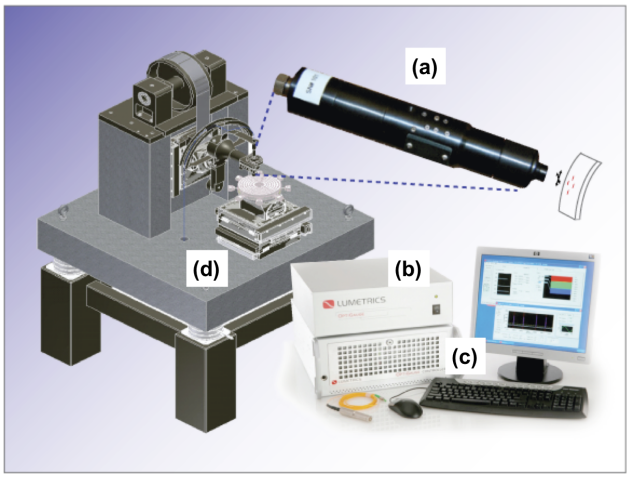

Figure 1. Components of the Quad-Probe freeform metrology system including a Quad-Probe, a Lumetrics OptiGauge, a computer, and a five-axis scanning system.

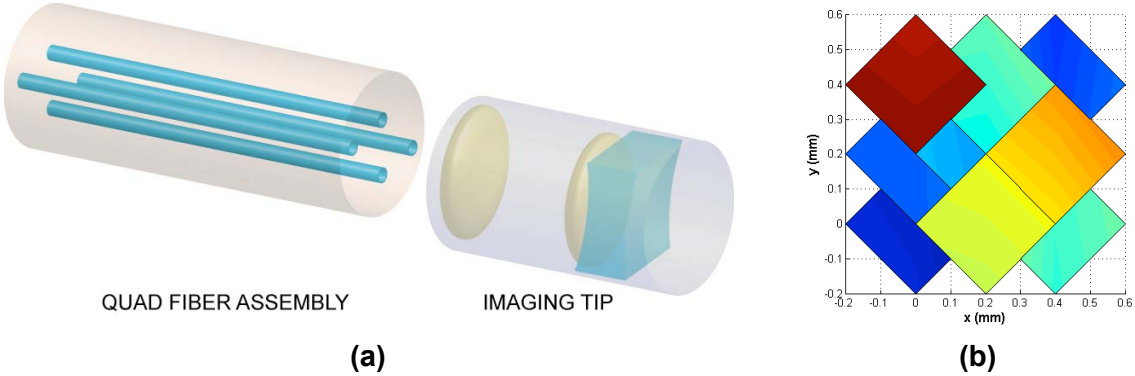

Figure 2. (a) Quad-Probe concept drawing (not to scale) illustrating the four beams, and (b) an example of overlapping Quad-Probe measurement facets.

in Fig. 1) that improves beam alignment, particularly beam skew. The spot pattern for the current Quad-Probe prototype is shown in Fig. 3. The beams are parallel to within 0.1 microradians.

We are presently collaboration with OptiPro Systems to incorporate the Quad-Probe into the UltraSurf, a commercial high-precision five-axis scanner.[7] The resulting system will be able to measure complex freeform surface profiles without contacting the surface and with an accuracy limited by the precision of the OptiGauge and the position accuracy of the scanner. Furthermore, because the Quad-Probe can measure both the position and orientation of the surface with respect to the probe, we envision a system that is capable of creating its own scan pattern without prior knowledge of the shape of the object under test. Such "blind contouring" would be invaluable for measuring the surfaces of objects whose precise surface parameters are not known.

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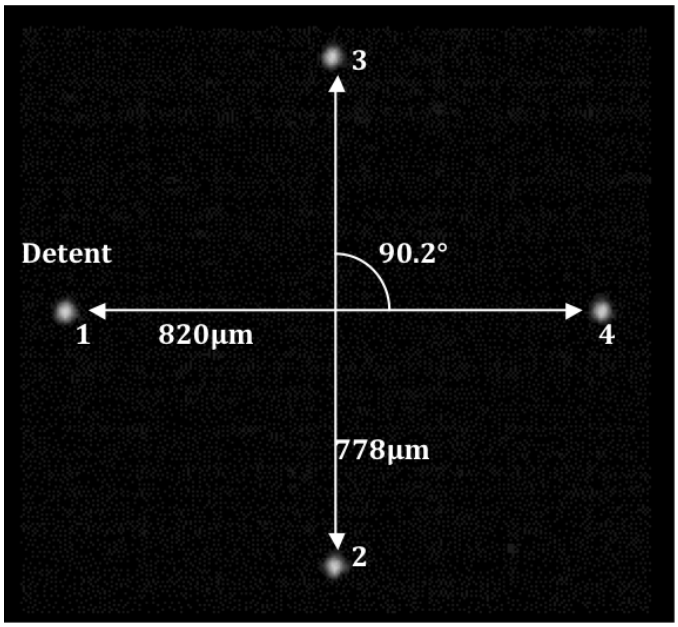

Figure 3. Infrared photograph of the spot pattern generated by the Quad-Probe, showing the angle and spacing between the spots.

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