

Non-contact thickness characterisation of contact lenses in solution with the Phase Focus Virtual Lens®

In this application note, we present a brief summary of the principles of transmission imaging with the Phase Focus Virtual Lens® and discuss its application to thickness characterisation of contact lenses in solution. We demonstrate that the thickness of an entire lens, including edges, can be accurately measured using the technique. Absolute thickness sensitivity is shown to be $<1\mu\text{m}$, with whole lens form accuracy better than $5\mu\text{m}$.

There is a need to measure the thickness of ophthalmic lenses in their wet state in order to ensure adequate oxygen flux to the cornea, and to ensure that the finished product meets the required manufacturing tolerances. Many modern lens designs (particularly torics) have complex spatially-varying thickness profiles that are not well-characterised by conventional centre thickness measurements. Moreover, metrology of whole fully hydrated contact lenses, and high resolution edge thickness measurements, have heretofore been especially challenging.

The Phase Focus Virtual Lens® is a method that uses a phase retrieval algorithm to provide a quantitative measure of how much the phase of an illuminating beam changes as it passes through the lens, and can be used to map lens thickness – simply and rapidly.

The Phase Focus Virtual Lens algorithm, or “ptychographical iterative engine”, has been described in detail in the scientific literature. (A list of references to peer-reviewed publications is available upon request.) It may be implemented in reflection or, as in this application, in transmission mode; and in a completely lensless instrument, or in a lens-assisted geometry (see Technical Brief: TB02 Optical transmission mode imaging.)

In a lens-assisted geometry (such as the example shown above) the fully hydrated ophthalmic lens is typically placed in a cuvette on the microscope stage, and the specimen is then scanned in a fully-automated manner.



Figure 1: Contact lens measurement system based on a standard optical microscope.

The Virtual Lens software generates simultaneously two images:

- A magnitude image that is a quantitative measure of how much of the illumination is transmitted through the lens specimen. This is similar to a conventional brightfield microscope image.
- An optical phase image that is a quantitative measure of optical thickness. This image forms the basis of a wide range of analytic options, including in this case spatially-resolved lens thickness data.

Experimental Procedure

A typical acquisition will produce images and thickness maps from both the whole lens and selected areas at the lens edges. The acquisition is fully automated, with acquisition times of approximately ten minutes for the whole lens area and five minutes for each of the selected lens edge areas. Lateral spatial resolution is typically approximately $15\mu\text{m}$ across the whole lens, and approximately $1\mu\text{m}$ for the edge profiles. Thickness resolution is better than $1\mu\text{m}$. A number of outputs may be provided in addition to thickness maps, and typically include line profiles of the thickness plotted across selected meridians.

Example Data

The data shown on the following pages were obtained from a fully hydrated contact lens contained within a standard cuvette containing 0.9% saline solution.

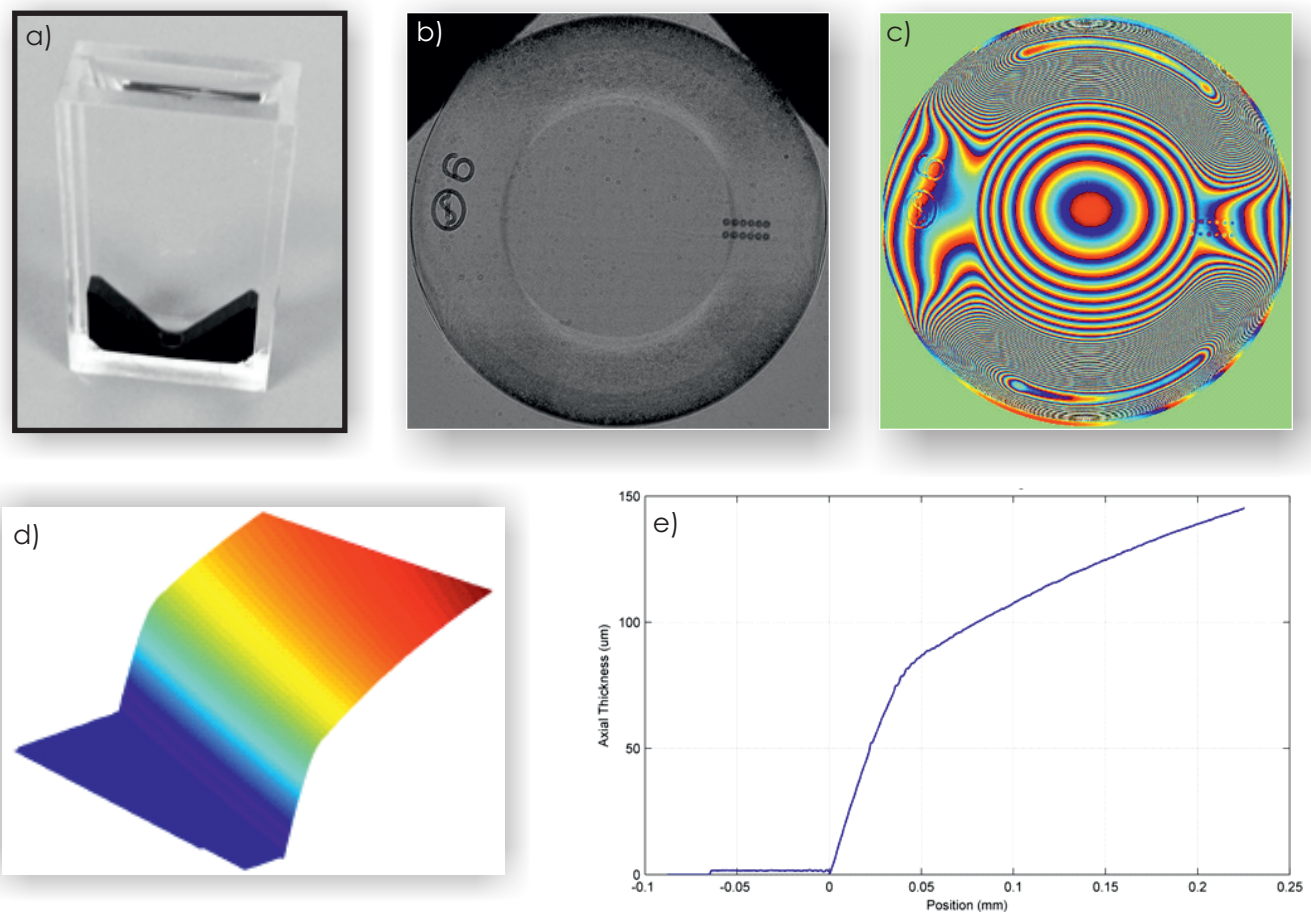


Figure 2: a) Standard cuvette. b) Virtual Lens magnitude image, showing an essentially “normal” brightfield microscope picture of the lens, including surface identification marks. c) Optical phase image; each successive “ring” corresponds to a phase shift of 360° . d) 3D plot of lens edge thickness. e) Thickness profile across the edge of the lens from d).

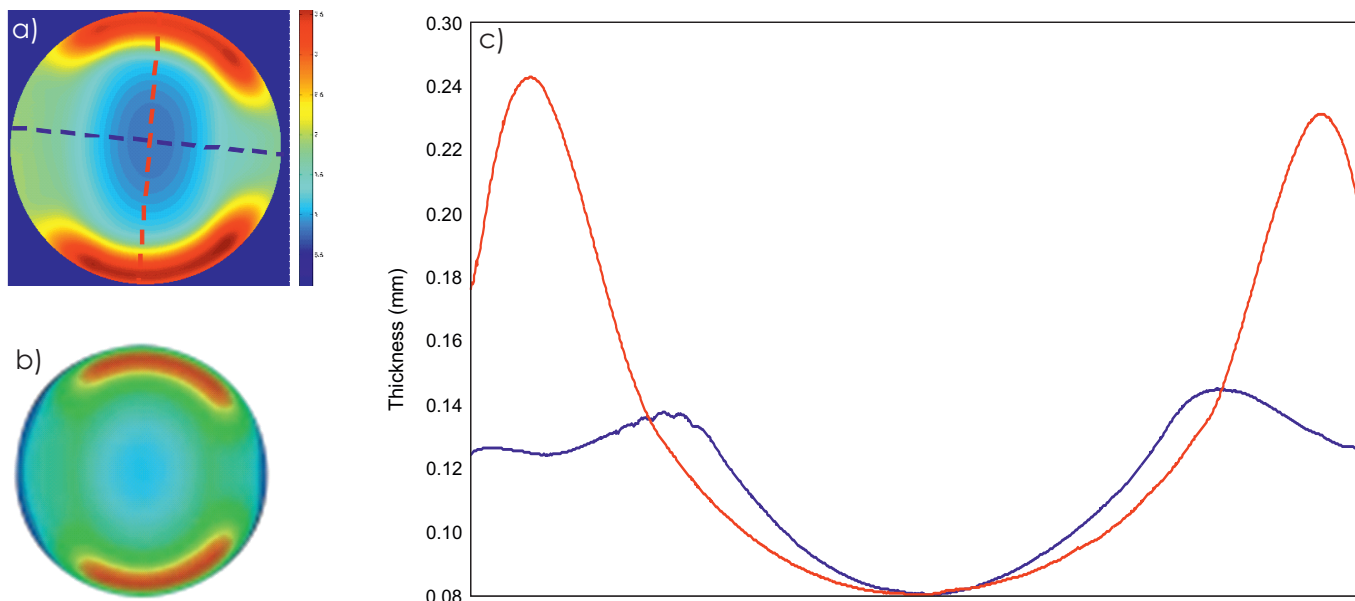


Figure 3: *a) The optical phase data can be further processed to output the thickness map of the lens. b) Published oxygen transmissibility map for the same lens, showing good agreement. c) Thickness data plotted across user-selected meridian; in this case those marked by the dotted lines in a).*

Axial and radial thickness

ANSI and ISO standards for lens thickness refer to radial thickness measurement, however there are no conventional techniques capable of measuring radial thickness across an entire hydrated contact lens in solution. With knowledge of the back curvature of a lens, it is possible to calculate both its axial and radial thickness from the optical phase data, as shown below. This enables for the first time a direct non-contact measure of lens thickness relevant to ANSI and ISO standards.

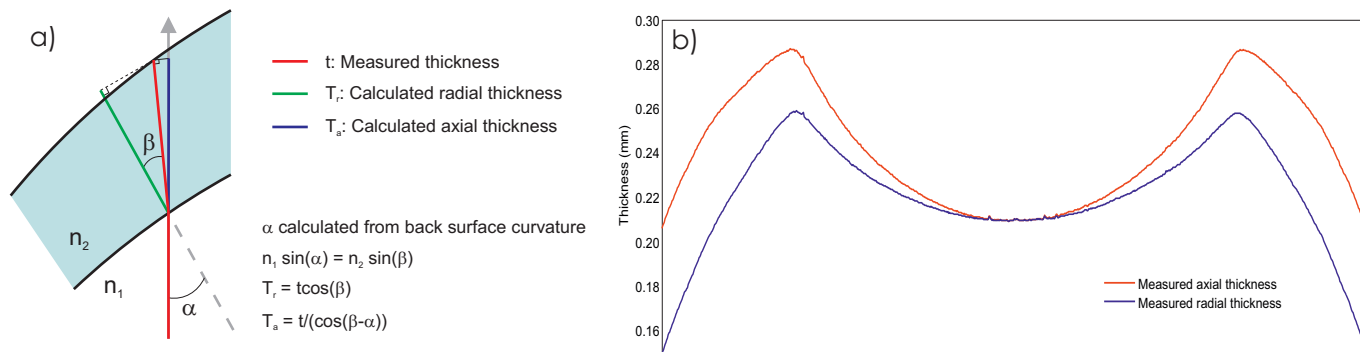


Figure 4: *a) Axial and radial thickness calculations from measured data. b) Comparison of axial and radial thickness for a real lens with simple spherical back surface*

Summary

A fully-automated ophthalmic lens metrology instrument can provide an absolute measurement of hydrated lens thickness across the whole lens, and at selected lens edge areas, with lateral resolution of up to $1\mu\text{m}$ and thickness sensitivity of better than $1\mu\text{m}$. Such data may be used for comparison with manufacturing specifications. Whole lens thickness maps are qualitatively consistent with published oxygen transmissibility data. The data acquisition process is fully automated and may be performed rapidly with minimal technical supervision.

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