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Optical metrology for immersive display components and subsystems

Peter J. de Groot and Leslie L. Deck
Zygo Corporation, Laurel Brook Road, Middlefield, CT 06455

ABSTRACT

Optical systems for immersive displays incorporate a range of optical components and assemblies that require precision non-contact metrology, including Fizeau interferometry of surface form, new techniques for aspheric microlenses, and interference microscopy for surface structure and texture analysis. Here we consider the problem of evaluating the parallelism and surface form deformation for stacked assemblies of multiple flat glass substrates. Similar structures are common for RGB planar waveguides with slanted sub-wavelength gratings acting as in- and out-couplers. In our experiments, we demonstrate the effectiveness of coherence scanning over a large aperture area using an 100-mm aperture white-light interferometer.

Keywords: Metrology, interferometry, displays, mixed reality, coherence scanning, topography.

INTRODUCTION

Virtual and mixed reality, smart eyewear, immersive multimedia and other forms of computer-simulated visual environments rely on astonishingly complex optical systems. The more advanced devices provide a large field of view with a full-color image with an angular resolution close to the limits of human visual acuity [1].

Immersive displays incorporate a wide range of optical components and assemblies. The more traditional helmet-mounted displays invariably employ off-axis and freeform optical elements [2]. More recently, planar waveguides together with planar waveguides and volume holograms have enabled eyewear display consistent with the demands of current and future consumer products for mixed reality [3]. These component technologies require precision non-contact metrology at several stages of development and production, including full-area surface form measurements with laser Fizeau interferometry [4], metrology of aspheric microlenses [5], incoming inspection of glass wafers [6], and surface texture analysis for uniformity and quality control of diffractive surfaces [7].

PLANAR STACKS

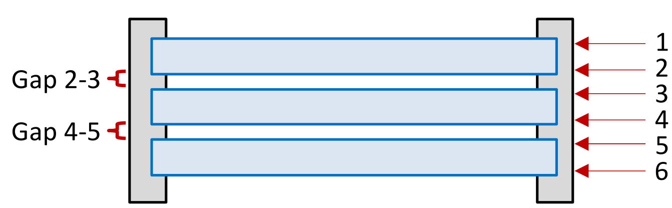

Figure 1. Example structure similar to those used for RGB waveguide module assemblies in digital immersive displays. The six surfaces require form metrology for quality control, particularly of the gaps.

This paper considers the problem of evaluating the parallelism and surface form deformation for stacked assemblies of multiple flat glass substrates. Similar structures are common for stacked RGB waveguides with slanted sub-wavelength gratings acting as in- and out-couplers [8]. Figure 1 is an illustrative example, with three nominally parallel glass plates are arranged with an air gap between the plates. In some proposed geometries, there may be five or more such plates [9]. The aperture of this structure is similar to that of eyeglasses—that is, from about 40 to 80mm in diameter, or perhaps in a lozenge shape of similar area, depending on the design. The assembly process for these plates can result in stresses that degrade the proper operation of the planar waveguides and distort the image field. Consequently, it is of interest to measure the flatness of the plates *in situ*, as well as the gap distances and the gap uniformity.

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Measuring the surfaces within such structures is a challenging problem given the effects of multiple reflections, dispersion within the glass, and the effects of coatings and surface structures. A variety of possible solutions present themselves. A full-field approach is a tuned-wavelength laser Fizeau interferometer, using Fourier methods to identify and then profile the individual surfaces [10]. However, this approach is challenged not only by the narrowness of the gaps (<0.1mm) but also by the presence of multiple gaps of similar size, which makes them difficult to distinguish from each other. An alternative is to use a single-point sensors based on confocal microscopy or optical coherence tomography (OCT) can access individual locations, with lateral scanning to build up a final image [11]. This approach can be either be time consuming or of unsatisfactory lateral sampling density, depending on the chosen trade-off.

A LARGE APERTURE COHERENCE SCANNING SYSTEM

The coherence tomography idea raises the question of whether a coherence scanning interferometry (CSI) microscope could manage the measurement. Best would be a large field of view with low numerical aperture (NA) to minimize the competition between spatial and temporal coherence effects. Such objectives have been constructed for 48-mm diameter fields of view [12], but this does not quite encompass the full range of parts of interest. At some point, it becomes more practical to set aside the microscope platform and try something larger, but with the same measurement principle.

Low-coherence interferometers with large measurement fields of view have been developed for the purpose of isolating the front or back surface of thin (e.g. 1mm) thick glass plates, using phase shifting interferometry in an equal-path geometry [6, 13]. In our experiments for stacked plates, we used a 100-mm aperture system with a modestly-broadband LED light source, and added external staging to enable an axial scan of the part. A 4MP camera made it possible to cover the full range of sample sizes for planar waveguides without optical zoom.

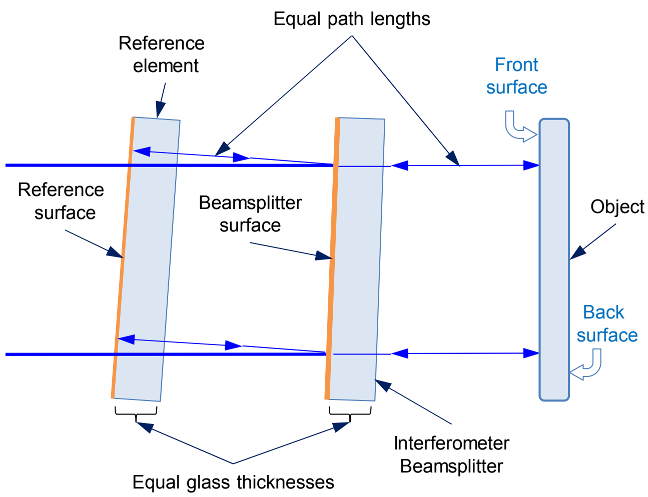

Figure 2. Equal path, low-coherence interferometer. In this diagram, the object is a single plate and is adjusted from the front surface to the back surface for independently measuring these areas without interference from the other surface.

The system pictured in Figure 3 comprises staging for displacing the sample assembly axially while data are acquired with a 4MP camera. The effects of dispersion are compensated in software [14][15]. This system is capable of measuring multiple surfaces over a large range of plate and gap thicknesses. We have successfully measured production planar waveguide stacks using this system with up to 8 plates and over 60mm in size; but for the purposes of this experiment, we created a simple example part with 3 bare 22-mm diameter glass plates approximately 1mm thick with 0.08mm gaps, in a structure similar to that of Figure 1.

In a typical measurement, the first task is to find the surfaces using something akin to an axial OCT scan. The results in Figure 4 show the locations of the surfaces, in terms of optical thickness. Once we have the surface locations, the surface measurement can be done by either phase shifting or coherence scanning techniques. Figure 5 shows an interference pattern from one of the internal surfaces, and Figure 6 is the corresponding surface topography map. With these data, we can also construct maps of the uniformity of the gaps, as shown in Figure 7.

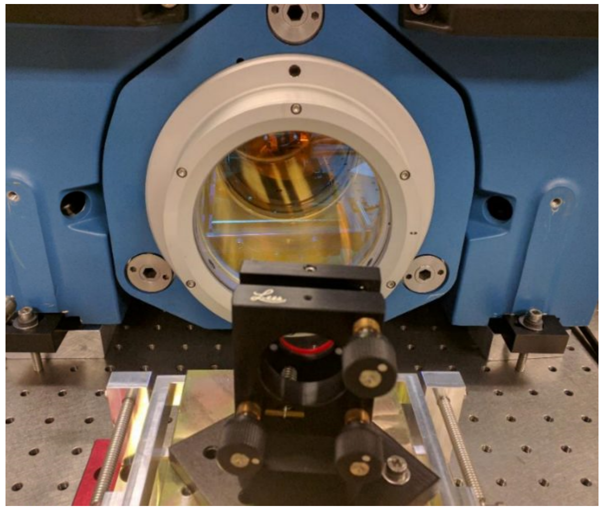

Figure 3. Experimental system for measuring the multi-surface structure shown in Figure 1 using a white-light interferometer and an axial scanning stage supporting the part. The interferometer has a working aperture of 100mm.

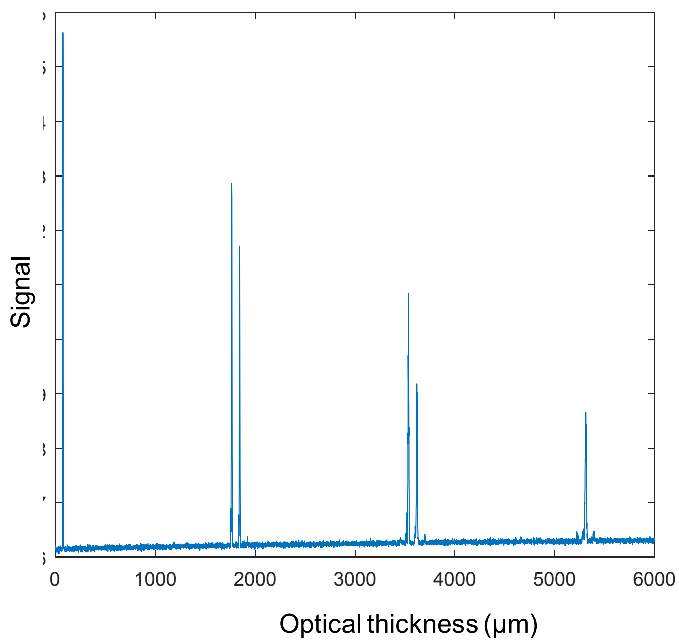

Figure 4. Axial scan showing the six surfaces of a three-plate structure using coherence scanning methods.

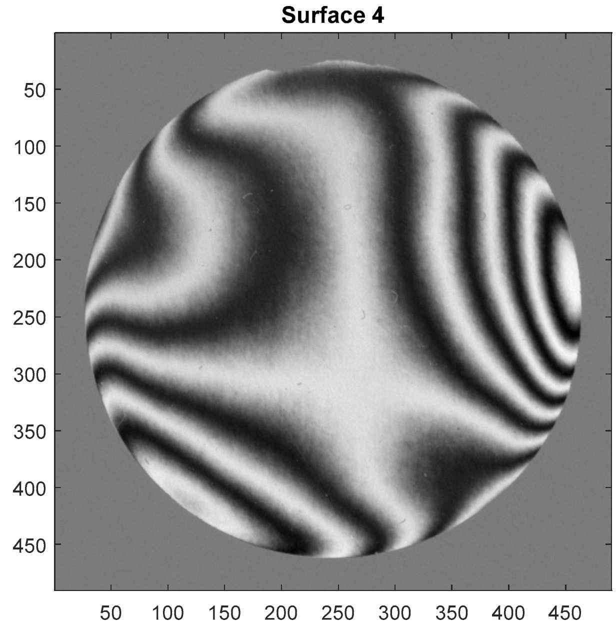

Figure 5. Example interference pattern from an internal surface of the stack. The lateral dimensions are in camera pixels.

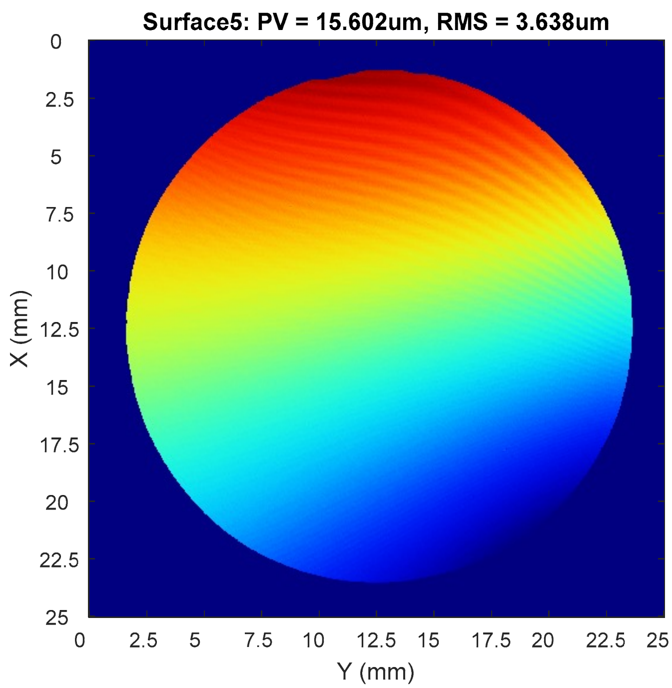

Figure 6. Example interference pattern from an internal surface of the stack. The lateral dimensions are in mm.

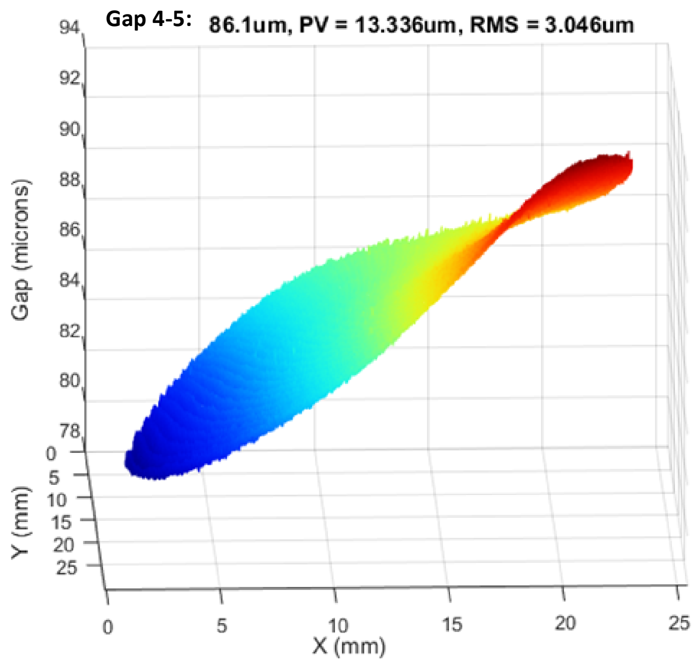

Figure 7. Example interference pattern from an internal surface of the stack. The lateral dimensions are in camera pixels.

SUMMARY

Optical components and assemblies for immersive displays require non-contact metrology for form, texture, and relational measurements such as gap thickness, angularity and alignment. In this experiment, we have shown how a large-aperture coherence-scanning interferometer may be employed to evaluate the parallelism and surface form deformation for stacked assemblies of multiple flat glass substrates, similar to the structure of RGB planar waveguides.

In practical applications, there are surface structures for diffractive beam management as well as coatings to control unwanted reflections. The success of a metrology strategy such as described here depends on the particular style and design of the waveguides, as well as on the mean wavelength of the light source.

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