A fast F-number 10.6-micron interferometer arm for transmitted wavefront measurement of optical domes

Doug S. Peterson, Tom E. Fenton, Teddi A. von Der Ahe *

Exotic Electro-Optics, Inc., 36570 Briggs Road, Murrieta, CA, USA 92563-2347

ABSTRACT

An optical train is designed and built to take a Ø1 inch collimated output sample beam from a 10.6 μm wavelength Wyko IR3 interferometer, and by use of a fast aperture-ratio lens, allow the diverging rays to pass through a steeply curved optical test dome, encounter a concave mirror and return to the interferometer for wavefront analysis. The advantage over off-the-shelf hardware is an ability to capture at one instant a large area or even the entire clear aperture, of a dome. The key to the design is the fast, f/0.65, highly-aspheric, diamond-turned, ZnSe lens, and the equally fast, very thick, deeply concave mirror. Other components allow for placement and rotation of the optical dome under test. Operation at 10.6 μm allows loose fabrication tolerances for the surfaces in the visible wavelengths, yet the system is of reference quality in the infrared. The subsystem is modular so that it may be easily removed to gain access to the standard output port of the interferometer for other purposes.

Keywords: Interferometer, dome, germanium, infrared, transmitted wavefront.

1. INTRODUCTION

An increasing number of infrared optical domes require transmitted wavefront analysis over a large instantaneous clear aperture. Off-the-shelf lens element attachments in the infrared are typically rather slow, f/2 or slower, and therefore cover a small portion of a typical modern dome. In order to cover the large rectangular test aperture of a current production dome, and similar large aperture configurations found with other recent dome designs, EEO designed and built a custom subsystem for the standard Wyko IR3 interferometer.

The entire test subassembly is built on a ½ inch thick aluminum plate with carry handles and is keyed to a Newport isolation table so that it may be switched out in a few minutes with another test subassembly. The robust mounting and components assure that a compicated realignment procedure is not required when exchanging test subassemblies.

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2. LAYOUT

As shown in Figures 1 and 2 below, from left to right, the basic layout starts with the Ø1 inch collimated sample beam exiting a beam expander on the interferometer mainframe. The bundle of rays passes through the positive aspheric meniscus lens, through focus, and then diverges. For clarity, the dome itself is not shown in Figure 1. The diverging cone then passes through the sample dome, fixtured so that the rays are normal to the dome surfaces, and reflects off the large concave return mirror, again normal to the surface. The double-pass rays retrace their path, and, now modified by the wavefront errors of the test dome, re-enter the interferometer, where the fringe pattern produced by interference with the internal reference beam may be examined visually, photographed, or, by the use of the frame grabber and software, analyzed via phase shifting or fringe digitization techniques.

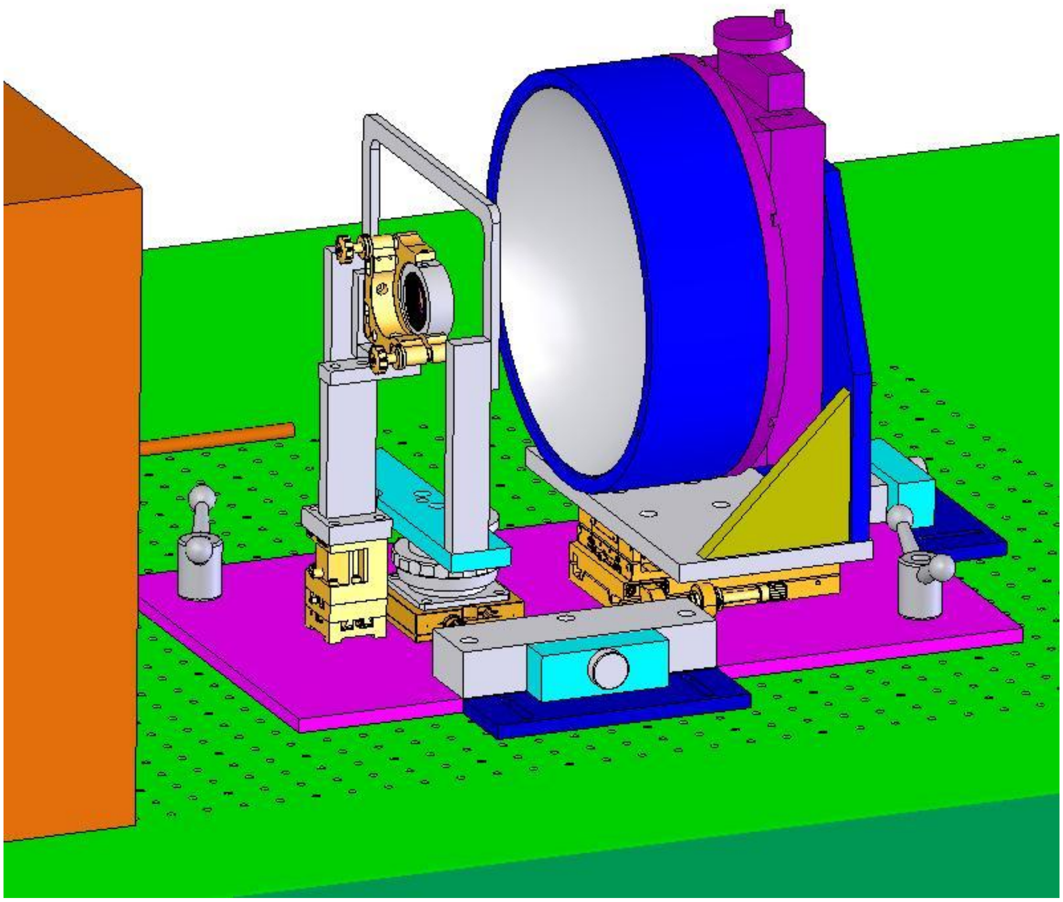

Figure 1. Layout

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Figure 2, below, graphically shows the optical elements without hardware, for clarity.

Also shown, at the bottom of Figure 2, are geometrical demonstrations of the rectangular clear aperture inscribed within the circular beam profile. Masks may be introduced directly in the beam, at the surface or apex of the dome, or generated in software, to define the test aperture.

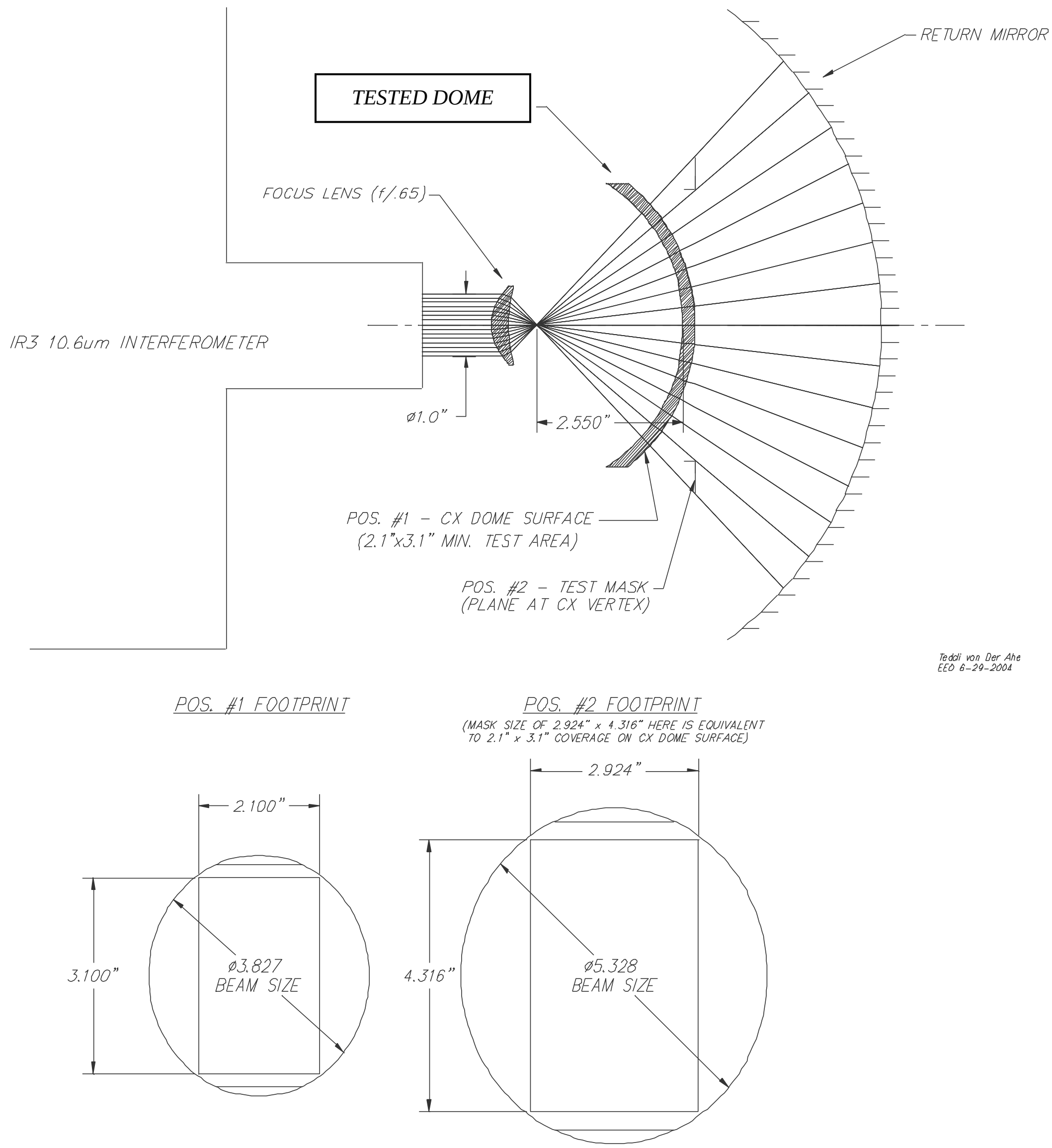

Figure 2. Optical element geometric layout, and test aperture definition.

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The support hardware was designed so that polished domes or sections may be tested at various points in the fabrication sequence: unshaped (near hemispherical), shaped (truncated rectangular, with or without AR coatings), and at the final assembly (installed in an aluminum frame, with all wiring and features).

This is achieved by a universal swivel device installed in the sample space, with replaceable fixture elements to hold the various dome configurations. The adjustable fixturing allows the dome to be rotated about its center of curvature so that the instantaneous rectangular test aperture may be swept across the entire arc-length of the dome.

All of the tip/tilt, translation and rotation devices were off-the-shelf. However, the interface hardware to mate the units under test to these was custom built. The lens and mirror cells were custom built as well.

The fixturing also allows fine-adjustment of the position of the dome in the light cone, by use of return specular reflections off the test-dome surfaces, thus guaranteeing the proper clear aperture placement, and that no misalignment-induced wavefront errors are introduced. Tolerances are held tight so that no realignment is typically necessary when switching from one sample holder to another.

Flexibility was designed-in from the beginning. The aspheric lens has tip/tilt controls, and a Z-axis position adjustment leadscrew. (Z-axis defined as the path of the rays, from left to right in all the illustrations). The sample dome holders allow for rotation about the vertical Y-axis. The return mirror has X, Y, and Z lateral adjustments.

Note carrying handles attached to the plate, alignment blocks for precision placement of the subsystem, and the various adjustments of the optical elements. The relatively massive vertical lead screw adjustment was required due to the cantilevered weight of the mirror in its cell.

3. OPTICAL ELEMENTS

Lens. The ZnSe lens material was selected for several reasons. ZnSe is transmissive at 10.6 μm with a very low absorption coefficient, is easily diamond-turned, and is also transmissive in the visible, which makes alignment in the test system much easier. A sixth order asphere was designed for the convex surface, while the concave is left spherical. Both surfaces are antireflection coated for maximum peak transmission at the interferometer wavelength of 10.6 μm. An equivalent all-spherical design would have required three air-spaced elements, six surfaces coated, with many more variables to control (thicknesses, wedges, tilts, etc.).

Mirror. The concave, 10 inch diameter, aluminized, spherical, Zerodur mirror has a radius of curvature of 6 inches. It is slightly oversized so that the edge of the mirror is not in the light path. Nevertheless, the surface figure measures 0.35 waves PV at HeNe over the entire diameter. At 10.6 μm, the contribution to the final wavefront of the system is approximately:

$$2 * 0.35 * (0.6328 / 10.6) = 0.04 \text{ waves p-v}$$

System. The limitation on the final system wavefront is the lens aspheric profile. Due to temporary tooling limitations during diamond-turning, the lens has a small residual error. The final cavity measurement result is approximately 0.14 waves peak to valley (single-pass).

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The source of the small error in the lens is predictable and well understood. A new lens is planned, and expectations are that the system error will decrease to better than 0.10 waves. At present though, this minor error is academic, as the cavity error may be subtracted in software from the test result, with a repeatability of about 0.006 waves RMS.

4. DOME FIXTURING

The test subsystem allows configuration into three basic setups, each for characterizing a dome wavefront at a key point during fabrication.

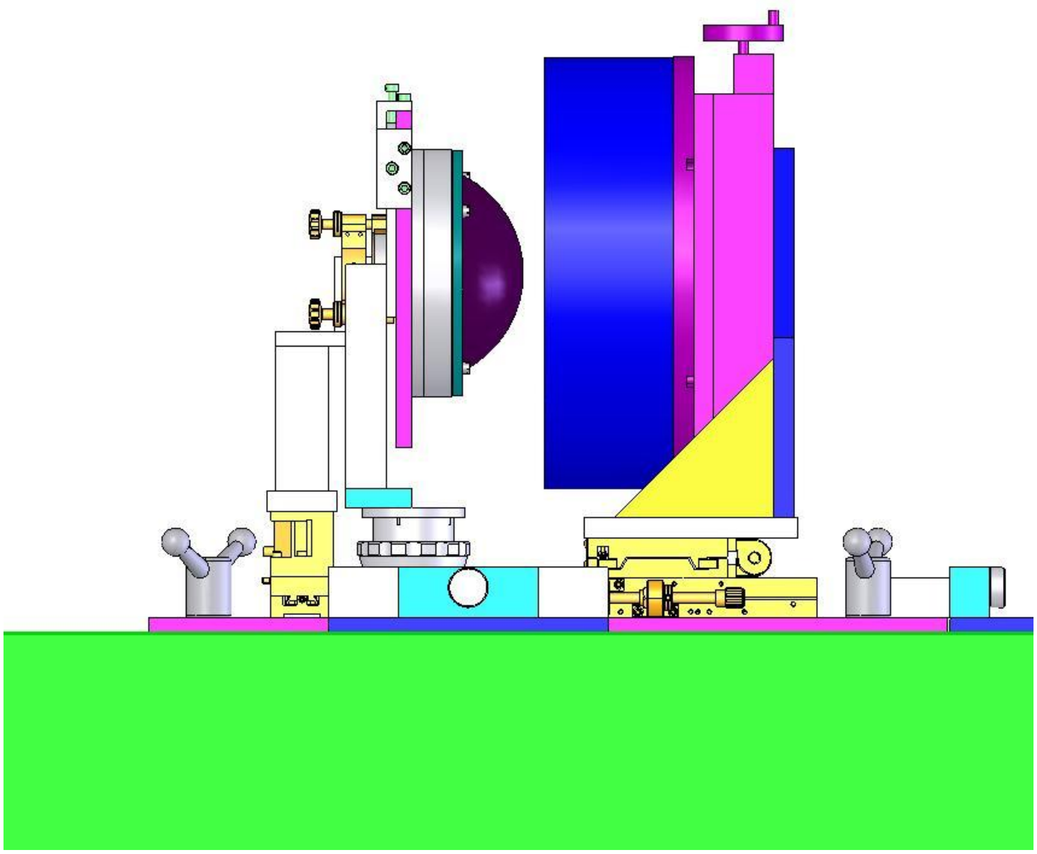

Figure 3. Blank dome under test.

Shown above is the subsystem with the fixturing of an in-process, polished but unshaped, near-hemispheric dome blank, ready for wavefront test. The fixturing places the center of curvature of the dome at the focus of the aspheric lens. The dome may be rotated in the vertical Y-axis, and also rotated about the Z-axis to assure coverage of the entire dome, with very little drift. The ring holding the dome in place is plastic with a felt lining, and is held in place with brass screws.

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The second configuration occurs with a final shaped dome or a truncated rectangular section installed in a plastic holding fixture that in turn takes the place of the full dome. The apex of the dome is in the same location as above. Rotation about the vertical Y-axis by means of the rotary stage immediately beneath allows full coverage of the clear aperture of the dome. The dome is restrained in the plastic housing with plastic clamps (not shown).

The mirror may be manually retracted to the right to allow clearance for safe removal and replacement of the test domes and their fixturing, which are dropped into place from above.

Finally, the subsystem is capable of accommodating a final test assembly installed. Once again, the dimensions and tolerances have been held so that the apex of the dome is placed at the same point in space. Rotation about the vertical Y-axis allows for full coverage of the dome clear aperture with just two measurements, one at each end.

5. CONCLUSION

EEO's interferometer lab maintains two independent computers running two different software programs so that either fringe or phase methods may be used to analyze the video output, depending on application. For instance, static fringe analysis allows manual adjustment of the fringe centers to minimize the impact of internal standing wave fringes on uncoated, high-index materials.

The optical system has been giving very good service in a production environment. The two photos below are of the subsystem operating in a production QA inspection lab along with several visible interferometers, a CMM, and other test equipment.

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Figure 4. The overall system. The 1 inch output is dead center. The subsystem (rear view) is between the two Danger Laser placards. The 12 inch aperture collimator output and return mirror are on the right, unused in this application.

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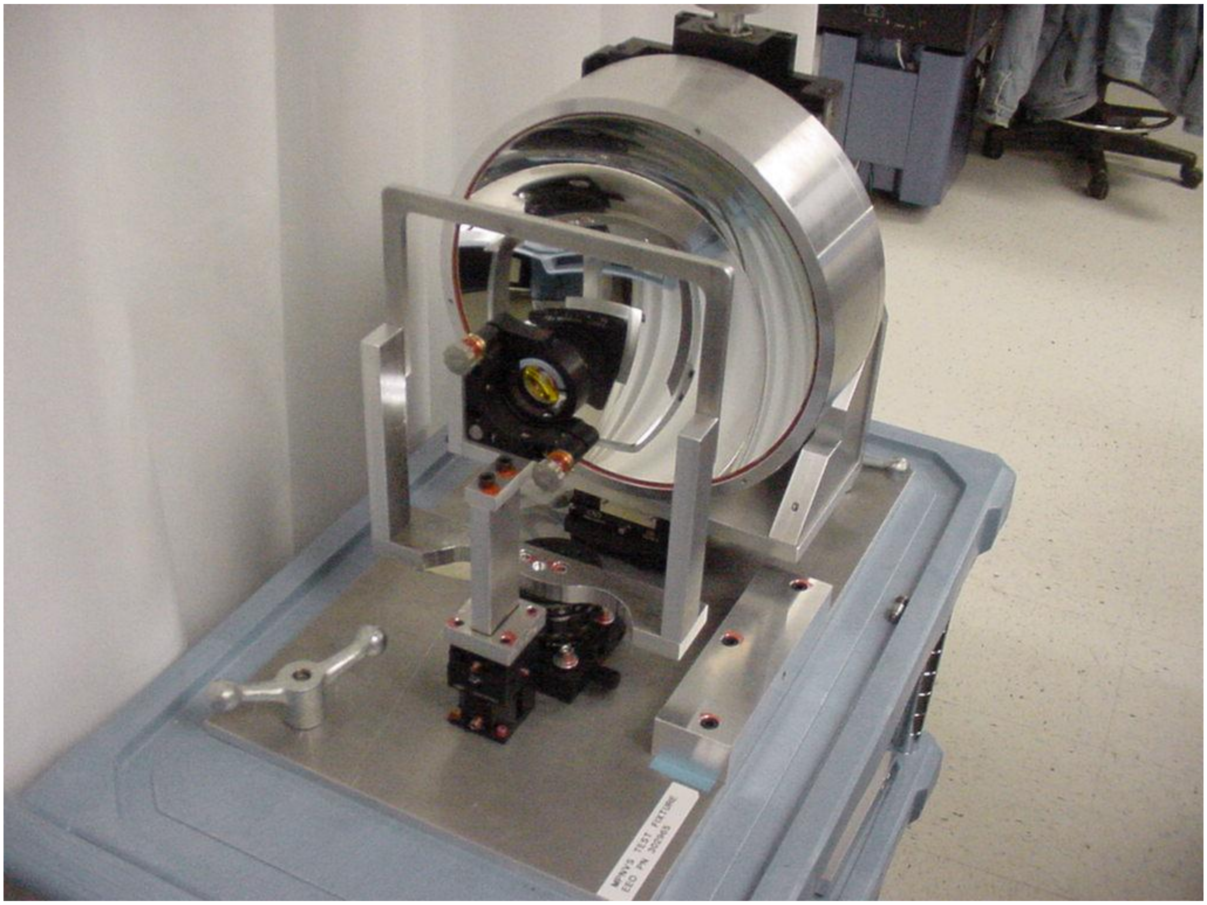

Figure 9. Interchangeability. The subassembly removed and placed on a cart for temporary storage. Removal and replacement are a snap and do not require realignment.

*The authors may be contacted at:
Phone 1 951 926-2994
Fax 1 951 926-3751
dougspeterson@exotic-eo.com
tfenton@exotic-eo.com
tvonderahe@exotic-eo.com

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