

# Interferometer Accessories

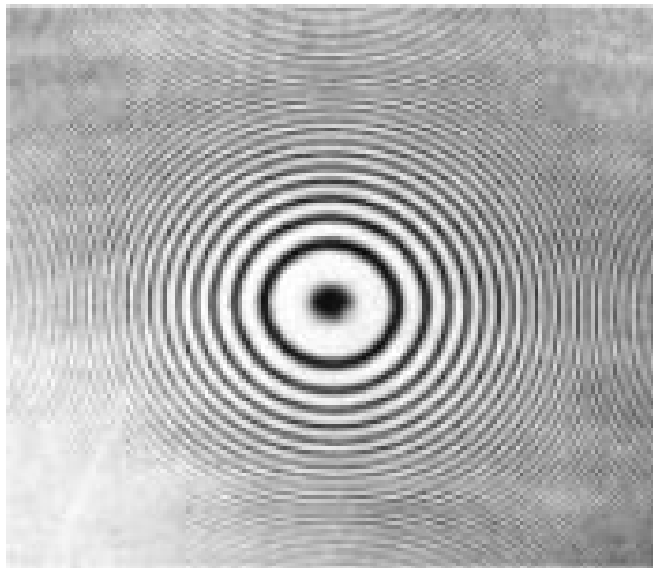
2009

# Presentation Objectives

- Basic wavefront measurement instrumentation and use in testing optical surfaces (surface shape)
- The limits of resolution and accuracy
- Phase Measuring Interferometry
- When to recommend our new accuracy-extending products products

# Interference Effects

- ◆ Newton's Rings
  - Surfaces are in contact (or very near contact), viewed in reflection using quasi-monochromatic illumination
  - Example: Oil films on water, test plates
  - Moving the two surfaces that generate the interfering wavefronts closer together scans the fringes from the highest areas to the lowest areas (the peaks to the valleys)



## The Constructive and Destructive Interference of Wavefronts

$$2Nd\cos\theta = M\lambda \quad \text{“The Interference Equation”}$$

$$d = M\lambda / 2N\cos\theta$$

Where:  $d$  = the physical distance represented by one inter-fringe spacing

$\lambda$  = the center wavelength of the illumination

$M$  = integer numbers (integer multiples of one fringe)

$N$  = the index of refraction of the material in which the interfering wavefronts are located

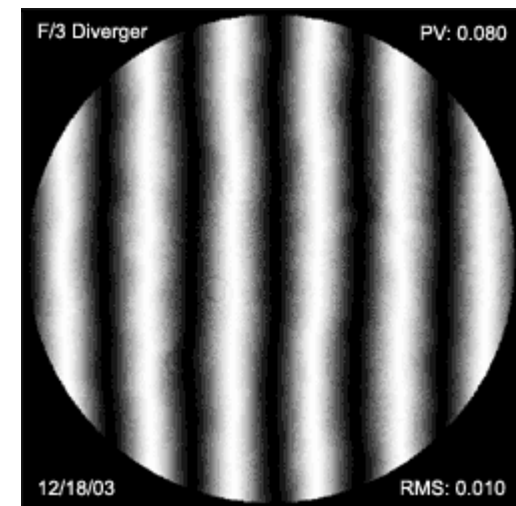
And at normal incidence  $\theta = 0$  degrees, therefore  $\cos\theta = 1$

(The basis of grazing-incidence interferometry is to vary  $\theta$  and therefore to vary  $D$  independent of  $\lambda$ )

Therefore, for  $M = 1$ ;  $d = \lambda/2$ , and when  $\lambda = 632.8$  nm  $d = 0.316$  micrometers

# Interferometry

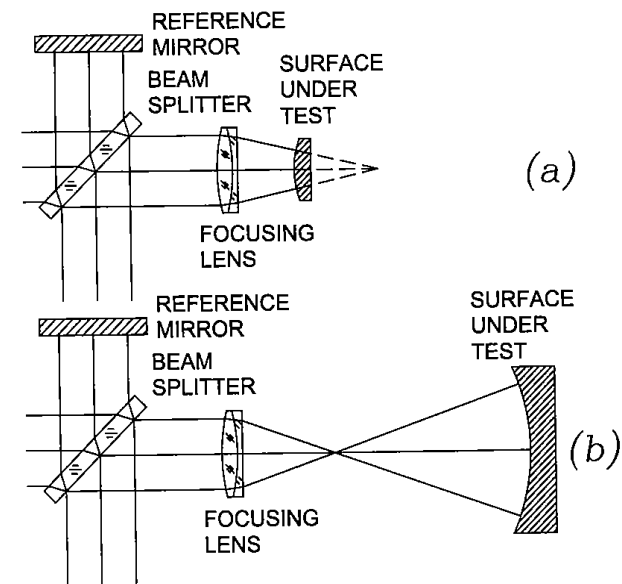
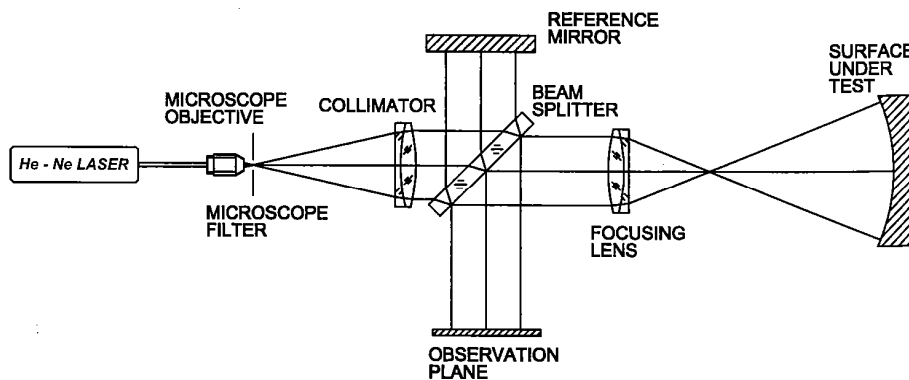
- ◆ Constructive and destructive interference fringes depict the difference in shape (phase) between “known” reference wavefronts and “unknown” test wavefronts
- ◆ Differences in shape or phase are depicted as white and dark “fringes”
- ◆ One fringe =  $\lambda/2$  in a double pass interferometer
- ◆ Summary - Interferometric measurements of surface shape are relative measurement techniques in which the shape of a known or previously measured surface (wavefronts) is compared to that of an unknown surface (wavefronts) and the difference is displayed as a series of interference fringes.



# Interferometer Types

## ◆ Twyman-Green

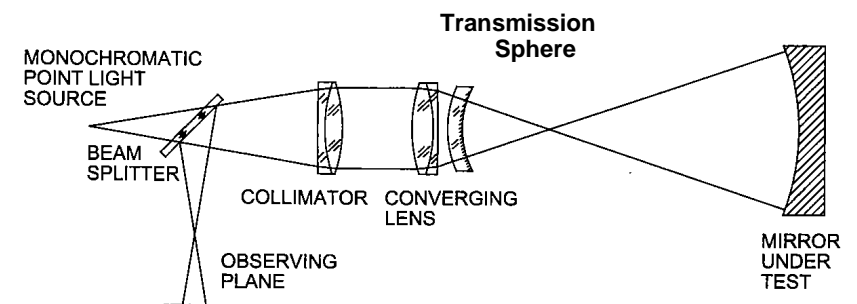
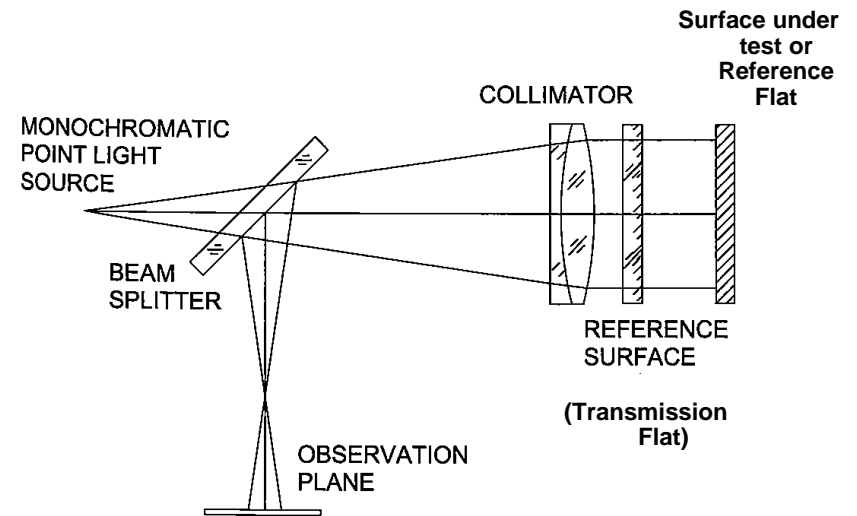
- Modification to the Michelson Interferometer. Patented by Twyman and Green in 1916 for testing prisms and microscope objectives.
- Cost efficient for testing large concave surfaces, ineffective when testing large convex surfaces.
- Beamsplitter divides the beam into reference and test beams.
- Accuracy of interferometer determined by OPD between Reference and Test Arm retro-reflecting or wavefront generating optics.



# Interferometer Types

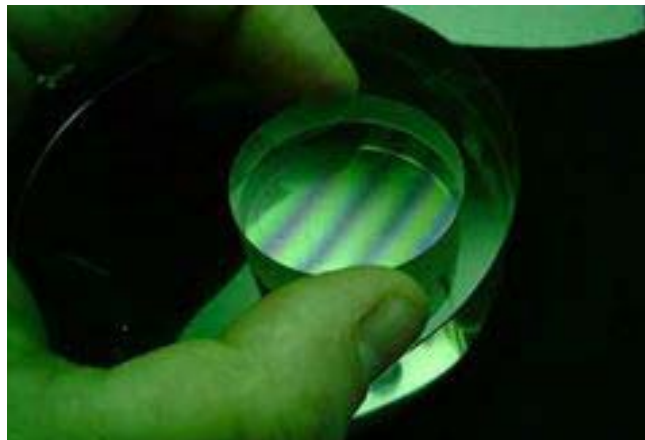
## ◆ Fizeau

- Like a Newtonian Interferometer but longer coherence-length light sources allow fringe contrast to remain at acceptable (visible) levels even for larger air gaps between test and reference surface.
- For testing spherical surfaces, this configuration allows the testing of very large convex spherical surfaces using relatively inexpensive large aperture spherical wavefront generating Fizeau Transmission Spheres.



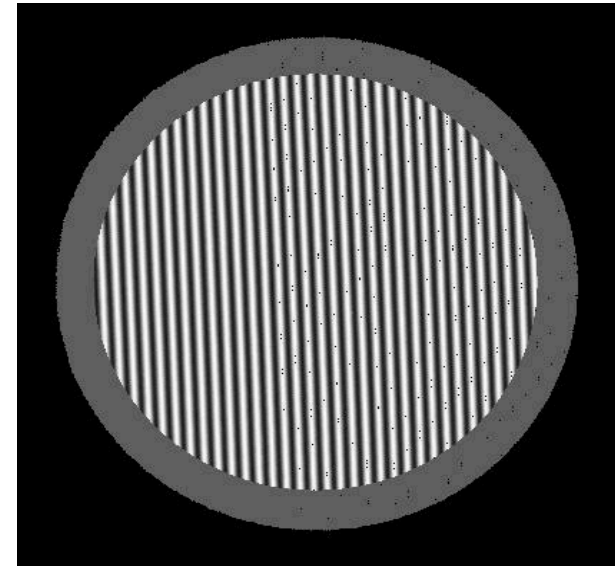
# Evaluating Interference Patterns

- ◆ Manually Evaluating Interference Patterns
  - Before Phase Measuring Interferometry, interference patterns were analyzed by eye or via photographs to measure the deviation from straightness. If the deviation of a fringe equaled the inter-fringe spacing ( $d = \lambda/2$ ) the surface or wavefront error is  $\frac{1}{2}$  the wavelength.
  - Measurement resolution was limited to  $\lambda/4$  to  $\lambda/8$  due to the lack of precision when reading fractional fringe spaces by eye, even with photographic support.



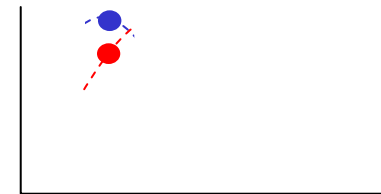
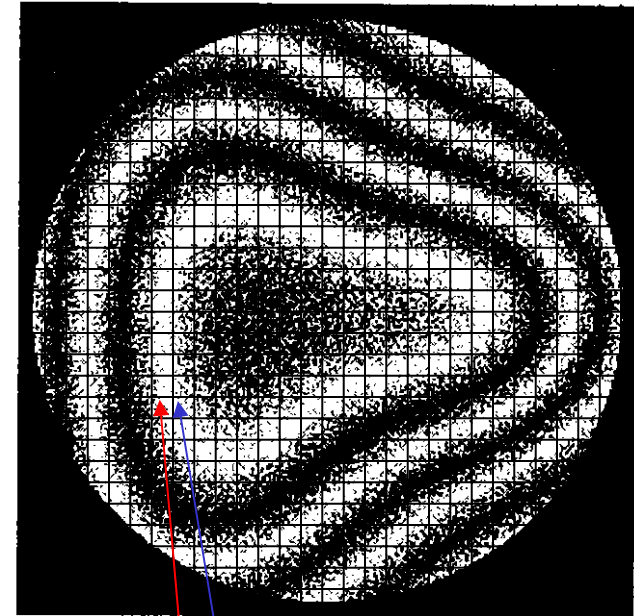
# Evaluating Interference Patterns

- ◆ Automated Interference Pattern Evaluation – Phase Measuring Interferometry (PMI)
  - Phase measuring interferometry is now the most common and most powerful fringe evaluation technique
  - Requires a digital camera, frame grabber, control software, and precision axial (piezo) actuation of the surface creating the reference wavefronts within the interferometer.
  - In operation, the reference surface is scanned along the optical axis in fractional-wavelength increments.
  - Each pixel in the imaging device detects the sinusoidally varying signal levels resulting from the axial scanning of the reference surface.



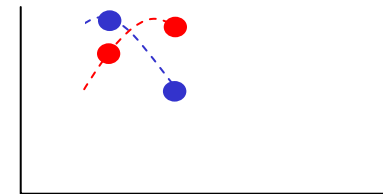
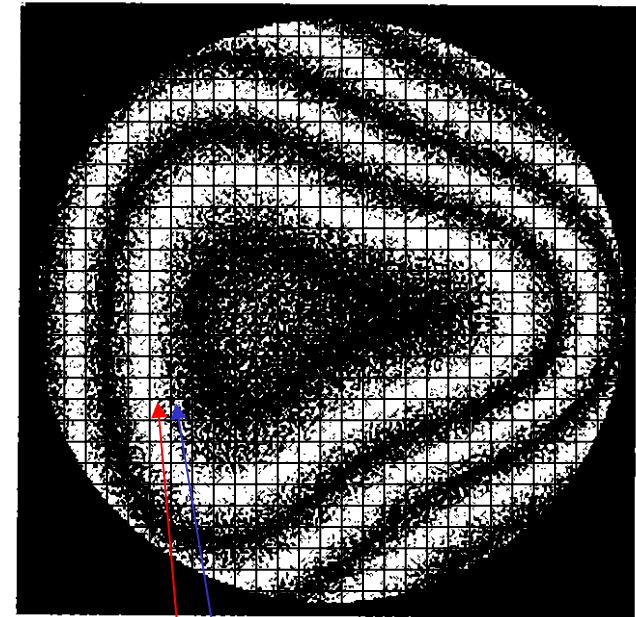
# Evaluating Interference Patterns

- ◆ Automated Interference Pattern Evaluation – Phase Measuring Interferometry (PMI)
  - A sinusoidal curve is fit to the data recorded at each pixel location
  - The relative phase lag or phase shift ( $\phi$ ) of every fitted curve is analyzed simultaneously and compared to a center-located reference phase.
  - Phase shift is correlated to physical distance (wavefront error or surface deviation) by the Interferometry Equation ( $d = \lambda/2$ )
  - Slope errors producing  $>1$  fringe between pixels yield data discontinuities due to  $d = M \lambda/2$
  - Fringe contrast depends upon relative reflectivity of the two surfaces creating the interfering wavefronts.



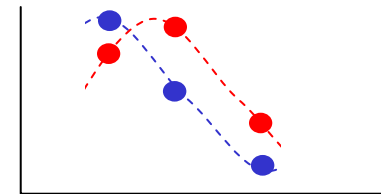
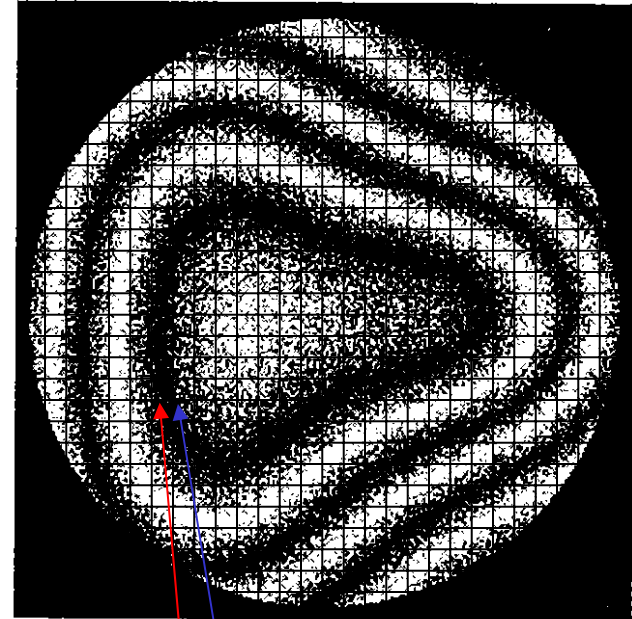
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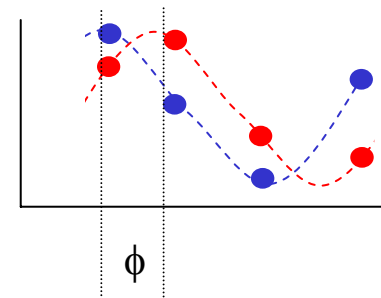
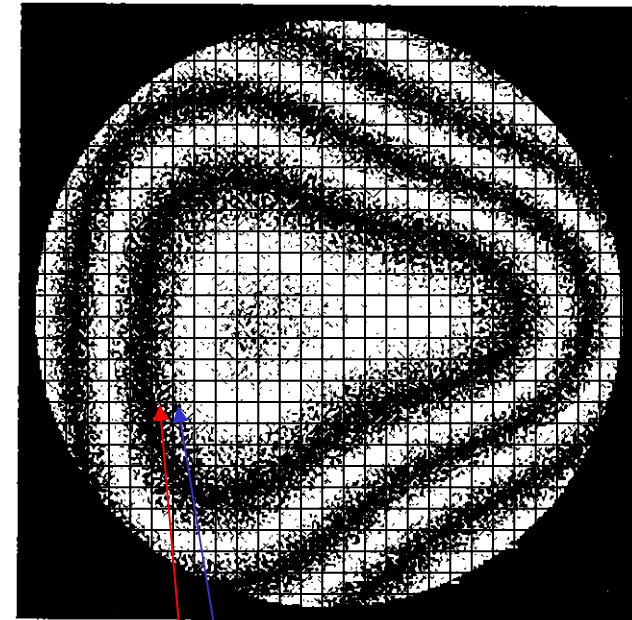
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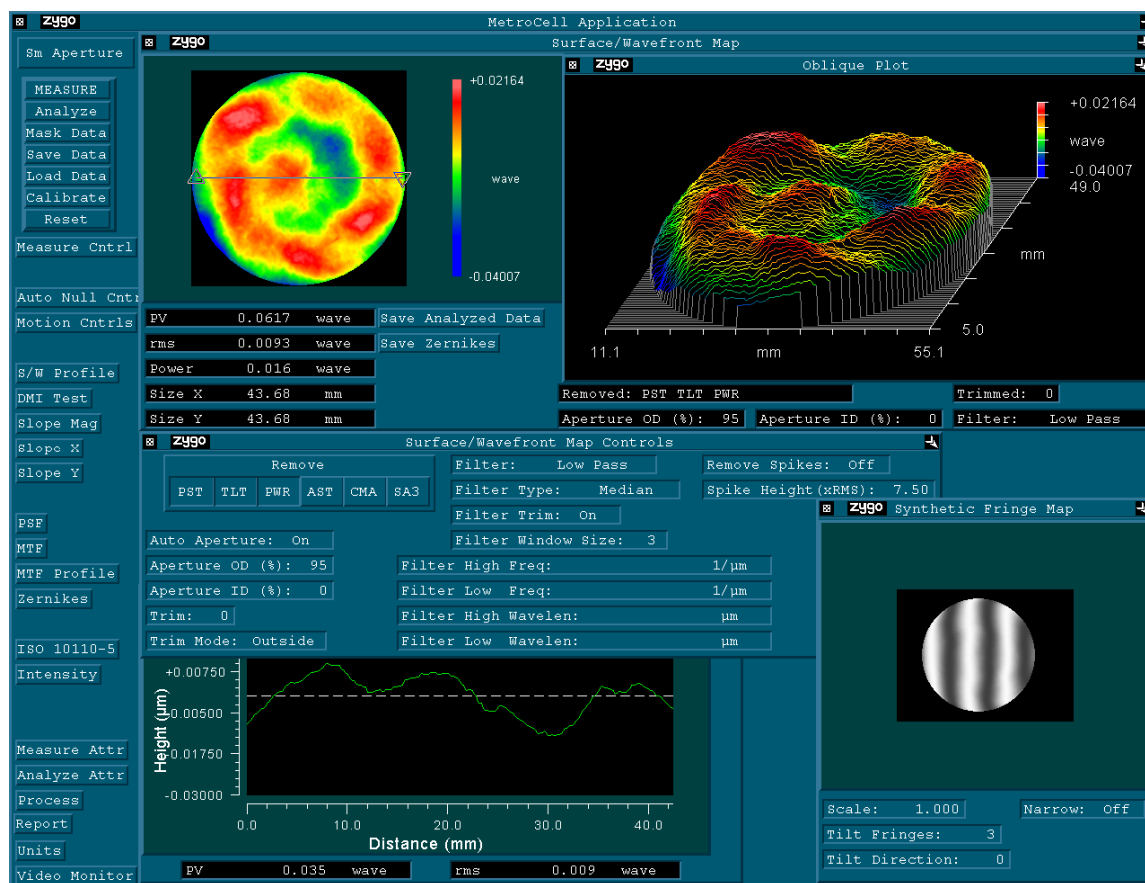
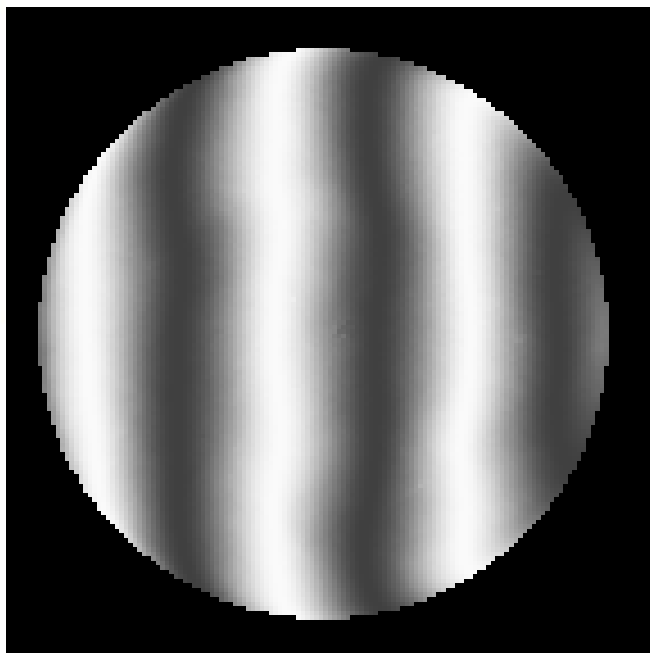


# Example PMI Data Output

$\lambda / 17$  optical surface, P-T-V @ 632 nm

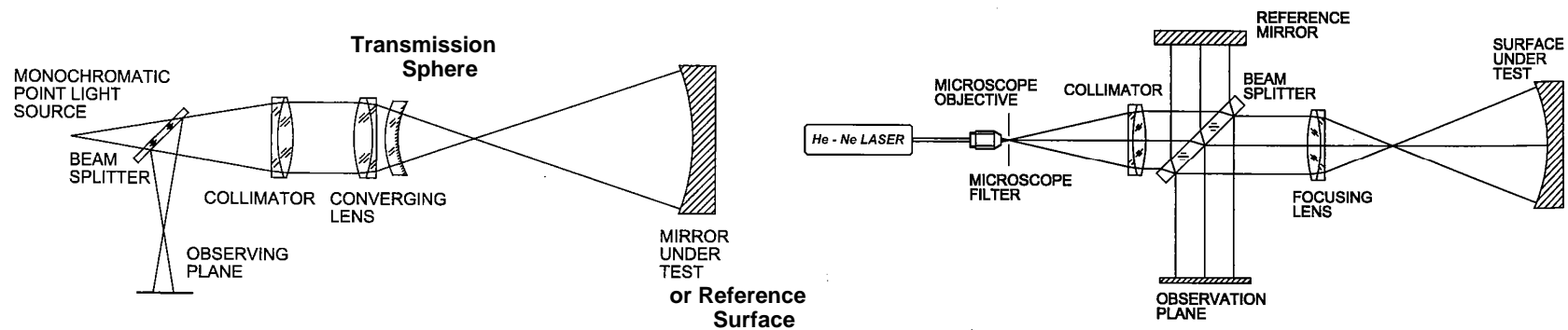
PMI Output Display

Visual fringe interpretation



# Absolute Accuracy

- ◆ Interferometric measurements are comparisons between the test and reference surfaces that generate the corresponding test and reference wavefronts.
  - The interferometer's reference wavefronts are not perfect.
    - Fizeau case – Test accuracy determined by the perfection of the reference wavefront generating surface within the interferometer's Transmission Sphere or Transmission Flat.
    - Twyman Green case – Accuracy determined by perfection of focusing lens (used in transmission), beam splitter and interferometer reference mirror.



# Absolute Accuracy

- ◆ Three methods exist to maximize the accuracy of PMI tests
  - Method #1 - PMI Reference Subtraction
    - Record reference Interferogram using highly accurate ( $\lambda/50$ ) Reference Sphere (certified highly accurate concave spherical test plate)
    - Subtract reference interferogram from subsequent tests of unknown surfaces
    - Example:
      - Interferogram 1 = Interferometer Errors + Ref. Sphere's Errors
      - Interferogram 2 = Interferometer Errors + Unknown Surface's Errors
    - If the Ref, Surface's errors are small;
    - Interferogram 1 – Interferogram 2 = Unknown Surface's Errors
    - Note: The accuracy of the Fizeau interferometer's "Transmission Sphere" is therefore not crucial ( $\lambda/10$  Peak-to-Valley is fine).
    - Product sales opportunity = Fizeau Reference Spheres

# Absolute Accuracy

- ◆ Three methods exist to maximize the accuracy of PMI tests
  - Method #2 – Use of a highly accurate Fizeau Transmission Sphere (Fizeau focusing lens). No reference subtraction.
  - Fizeau Transmission Sphere’s “quality” surface is accurate enough to allow direct tests without having to bother with recording and subtracting reference wavefronts (good to better than  $\lambda/10$ ).
- ◆ Product opportunity = Fizeau Transmission Spheres
  - Method #3 - Absolute interferometer calibration procedures
    - Three or more separate interferograms per test, special data manipulation software, error prone, sensitive to mechanical misalignment, very error prone, very cumbersome.
    - Can take hours to measure one surface
    - Subaperture Stitching interferometry automates much of this process but is a very expensive solution (QED Inc. proprietary technology).

# Interferometer Accuracy Enhancing Accessories

## ◆ Summary

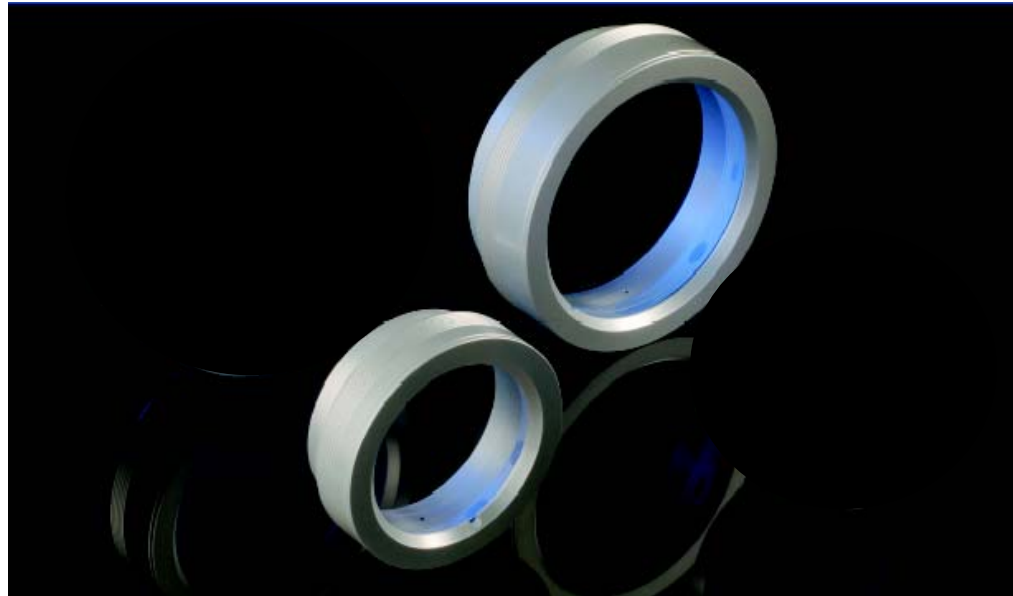
- Globally, several thousand Fizeau-type (Zygo) surface testing interferometers are in use.
- For those that are not automated i.e. lack PMI capability, their factory-supplied Fizeau Transmission Spheres are adequate ( $\lambda/10$ )
- For those with PMI capability;
  - If the user is willing to use reference interferogram (reference wavefront) subtraction, MG Fizeau Reference Spheres are appropriate.
  - If the user is unwilling to use reference interferogram subtraction, to accelerate testing activities in a high-model mix environment, MG high-performance Fizeau Transmission Spheres are appropriate.
  - If the user that desires the utmost in absolute accuracy, both the MG Fizeau Reference and Transmission Spheres are appropriate.
- Use of the so-called “Three-Sphere” and “Three-Flat” methods for obtaining absolute accuracy is not common due to the inherent difficulties and will not impact use of high-performance Fizeau Transmission Spheres and Reference Spheres.

# Transmission Spheres



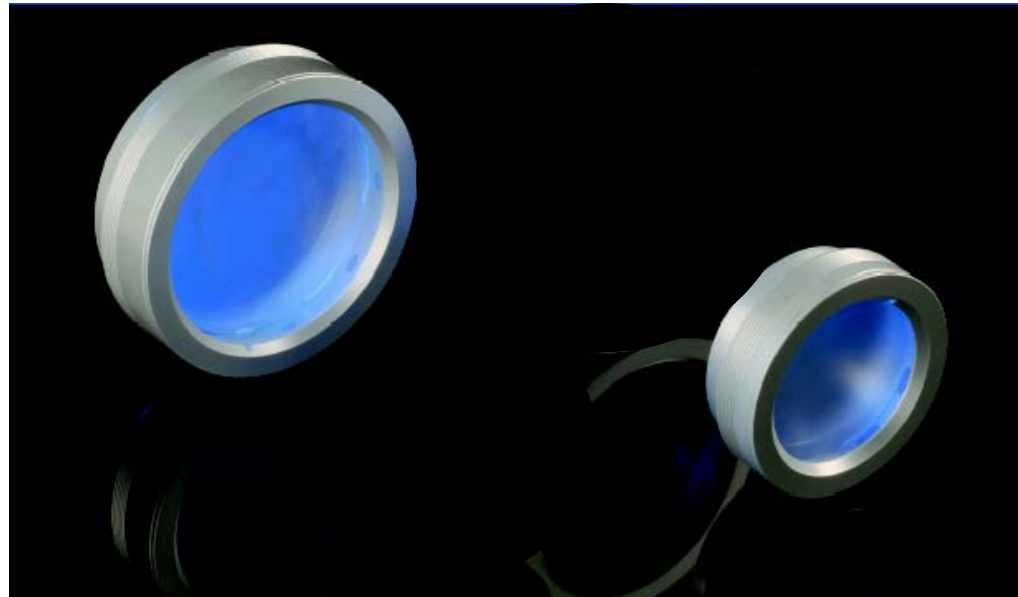
- ◆ Reference surface accuracy:  $<\lambda/40$  both in horizontal and vertical orientations
- ◆ Reflectance of reference surface: 4%
- ◆ Compatible with Zygo® standard bayonet-style mount
- ◆ Accuracy certification data included

## Transmission Flats



- ◆ Reference surface accuracy:  $<\lambda/50$  both in horizontal and vertical orientations
- ◆ Reflectance of reference surface: 4%
- ◆ Compatible with Zygo® standard bayonet-style mount
- ◆ Accuracy certification data included

## Reference Flats



- ◆ Reference surface accuracy:  $<\lambda/50$  both in horizontal and vertical orientations
- ◆ Reflectance of reference surface: 4%
- ◆ Compatible with Zygo® standard bayonet-style mount
- ◆ Accuracy certification data included

## Reference Surfaces



- Reference surface accuracy greater than  $\lambda/50$  P–V at 633 nm in both
- vertical and horizontal orientations
- Calibration standard for transmission spheres as fast as f/0.65
- f/0.6 and f/0.75 models available
- Concave and convex versions for maximum flexibility
- Compatible with Zygo® bayonet-style mount
- Storage case and certification data included

## CVI-MG Competitive Advantages

- ◆ Highest precision standard Fizeau optics
  - MG TS  $\lambda/40$  vs. competitors  $\lambda/20$
  - MG TF/RF/RS  $\lambda/50$  vs. competitors  $\lambda/20$
- ◆ State-of-the-art manufacturing capabilities
  - MRF
  - SSI
- ◆ Advanced QA and test capabilities
- ◆ Stock availability for all standard Fizeau optics
- ◆ Highly competitive prices

# Sales Support Materials

- ◆ Product literature
  - [http://cvimellesgriot.com/Products/Interferometry\\_Accessories.aspx](http://cvimellesgriot.com/Products/Interferometry_Accessories.aspx)
- ◆ Price list
- ◆ System drawings (in PDF and DXF formats)
- ◆ Demo units
  - 09LTS407
  - 09LTF400/123
- ◆ Demo options
  - Customer sight presentation
  - 30-day evaluation PO