The Leader in Dynamic Interferometry

Dynamic Laser Interferometry for Disk Shape Characterization

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4D Technology
Measurement at the Speed of Light

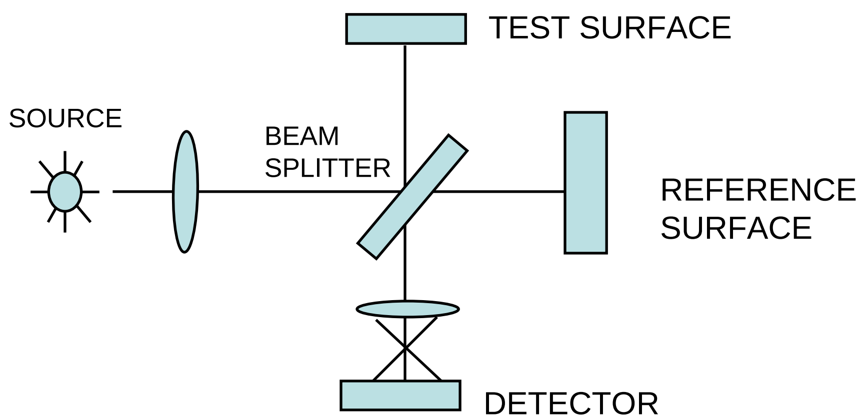
Interferometry Basics

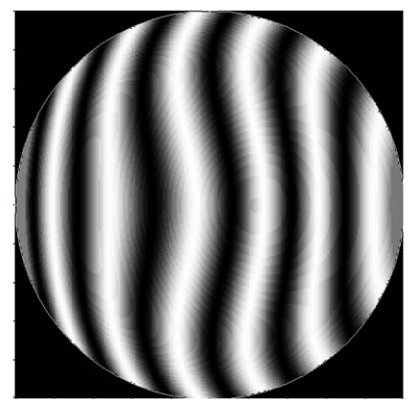
Two Beam Interference

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\alpha_1 - \alpha_2)$$

$\alpha_1 - \alpha_2$ phase difference between interfering beams

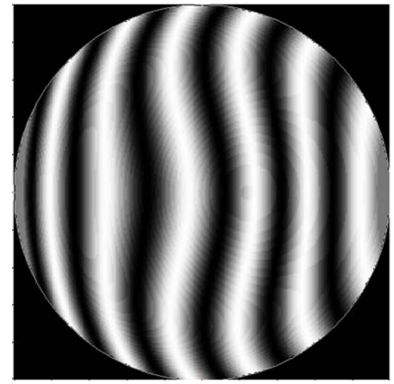
$$\alpha_1 - \alpha_2 = \left(\frac{2\pi}{\lambda}\right) \text{(optical path difference)}$$





Temporal Phase Shifting Interferometry (PSI)

Physical translation of reference surface to generate data.



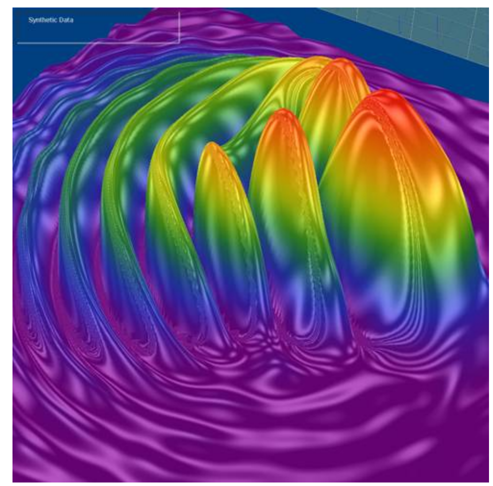
$$I(x,y) = I_0 + I' \cos[\phi(x,y) + \phi(t)]$$

$$I_1(x,y) = I_0 + I' \cos[\phi(x,y)] \quad \phi(0.03s) = 0 \quad (0°)$$

$$I_2(x,y) = I_0 - I' \sin[\phi(x,y)] \quad \phi(0.06s) = \pi/2 \quad (90°)$$

$$I_3(x,y) = I_0 - I' \cos[\phi(x,y)] \quad \phi(0.09s) = \pi \quad (180°)$$

$$I_4(x,y) = I_0 + I' \sin[\phi(x,y)] \quad \phi(0.12s) = 3\pi/2 \quad (270°)$$



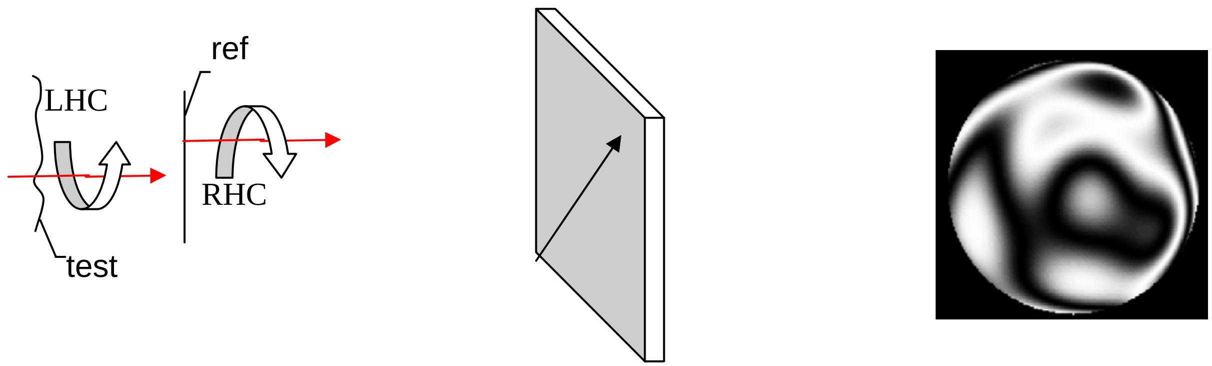
$$\varphi(x,y) = \mathrm{Tan}^{-1}\left[\frac{I_4(x,y) - I_2(x,y)}{I_1(x,y) - I_3(x,y)}\right]$$

$$\text{Height}(x,y) = \frac{\lambda}{4\pi}\varphi(x,y)$$

Note: **Method is camera *frame-rate* limited**
Typical acquisition time is 200 – 400 msec

Dynamic Phase Shift Method

Use polarizer as phase shifter



Circ. Pol. Beams ($\Delta\phi$) + linear polarizer (α) $\longrightarrow$ cos ($\Delta\phi$ + 2α)

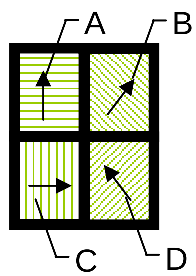
Phase-shift depends on polarizer angle

Kothiyal and Delsile, Appl. Opt. V24 n24 p4439 (1985)
Kemo, et. al, Appl Opt. V41 n 13 p2448 (2002)

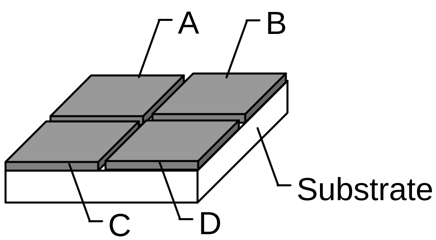
Device Architecture

Unit Cell Layout

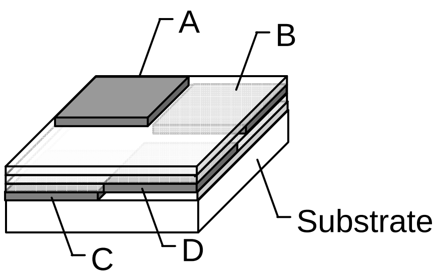
Pol. orientation



Single layer



Multi-layer

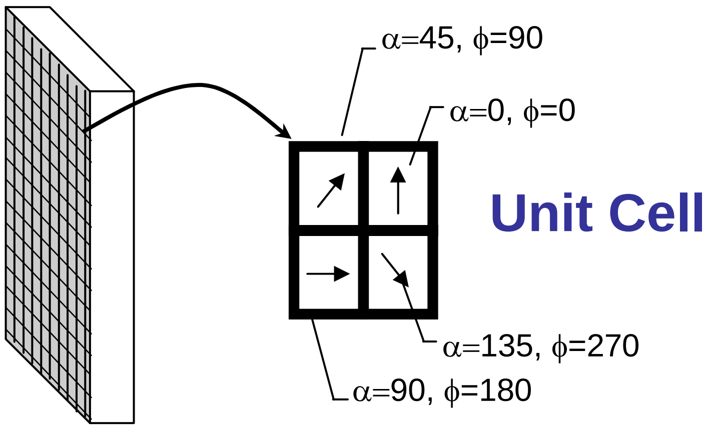


- Fabrication
  - Photolithographic – single layer method
  - High accuracy matching to pixels
  - Contrast ratio >1000:1
  - Wavelengths 400nm - >1 micron

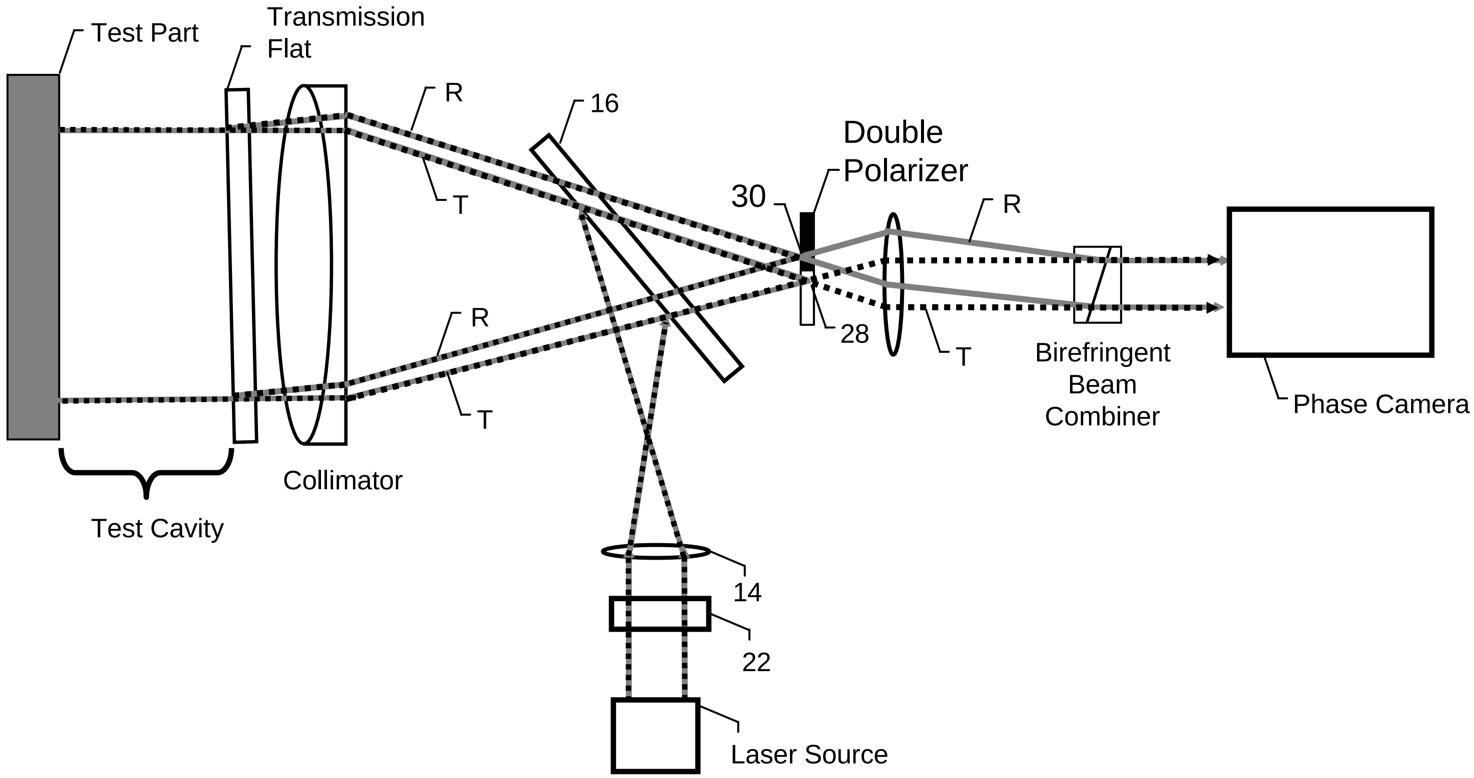
Phase Sensor Array

Array of oriented micropolarizers

Polarizer array
Matched to
detector array
pixels

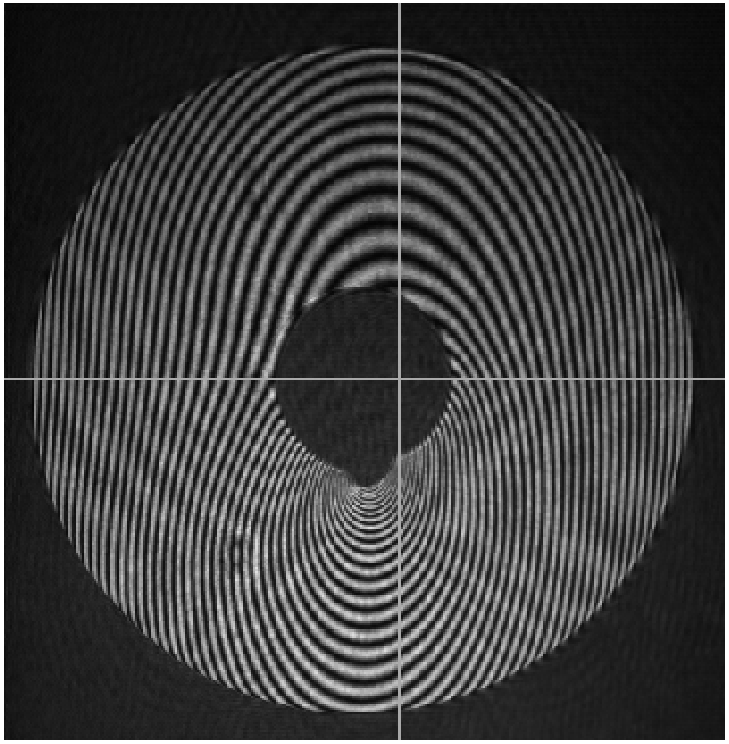


Tilt Beam Fizeau

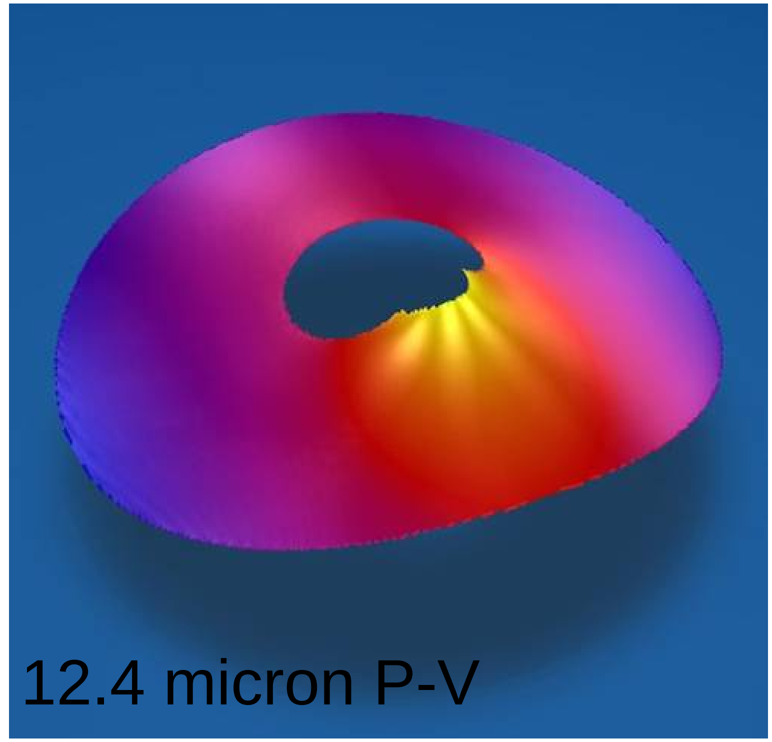


Note: Alignment Arm not shown
Multiple patents pending

Static Shape of Al Disk



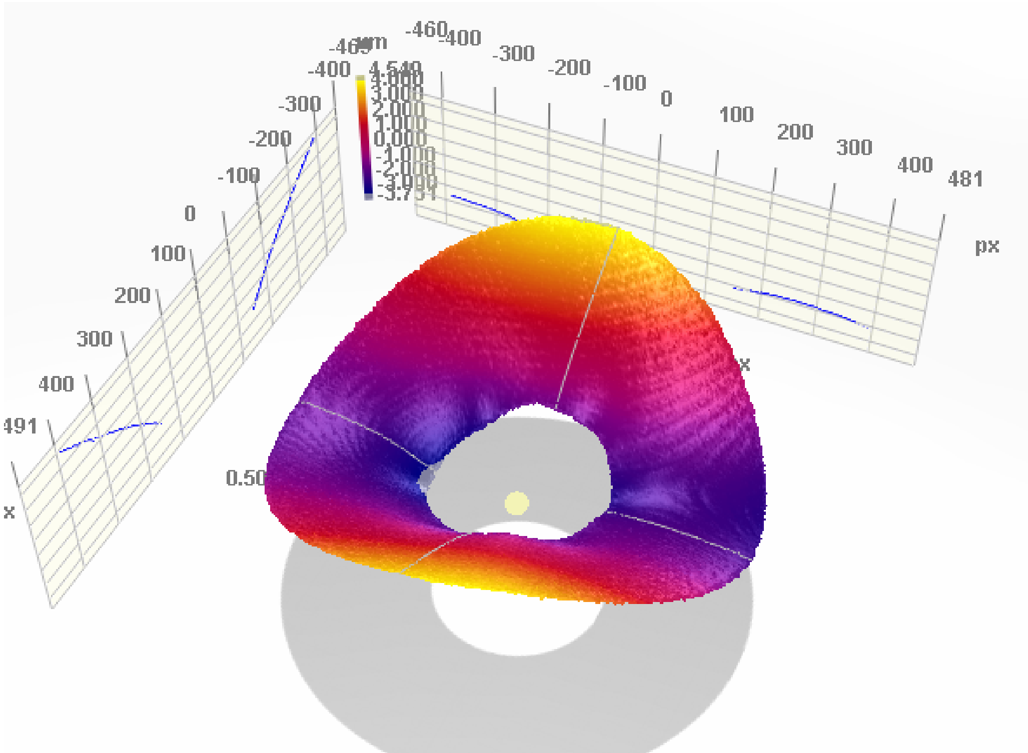
Interferogram



Surface profile

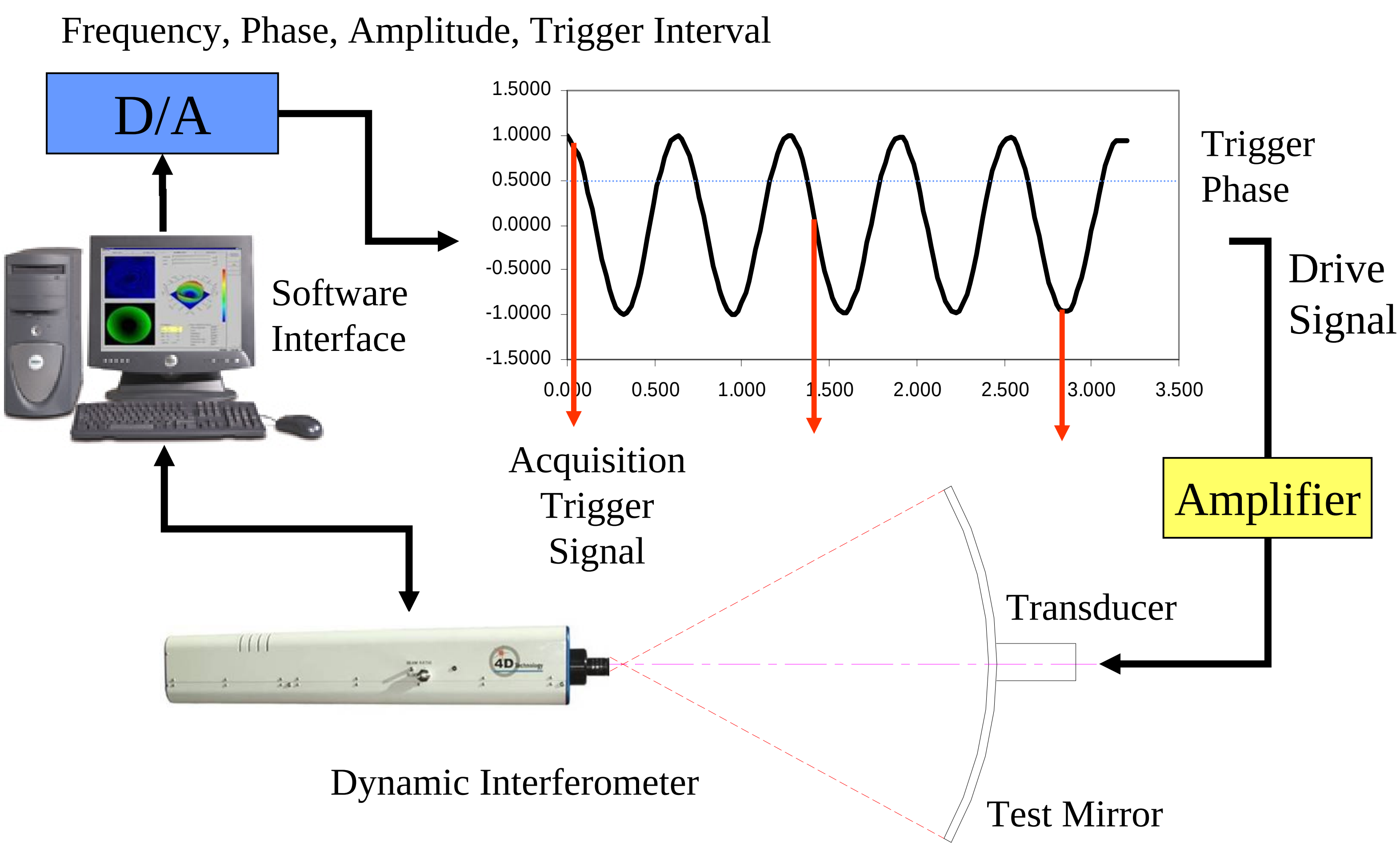
Supports all standard analysis parameters for PV, RVA, Flatness, Waviness

Dynamic Shape of Al Disk



- **Surface Measurements, 5600 RPM**

Modal Analysis Configuration



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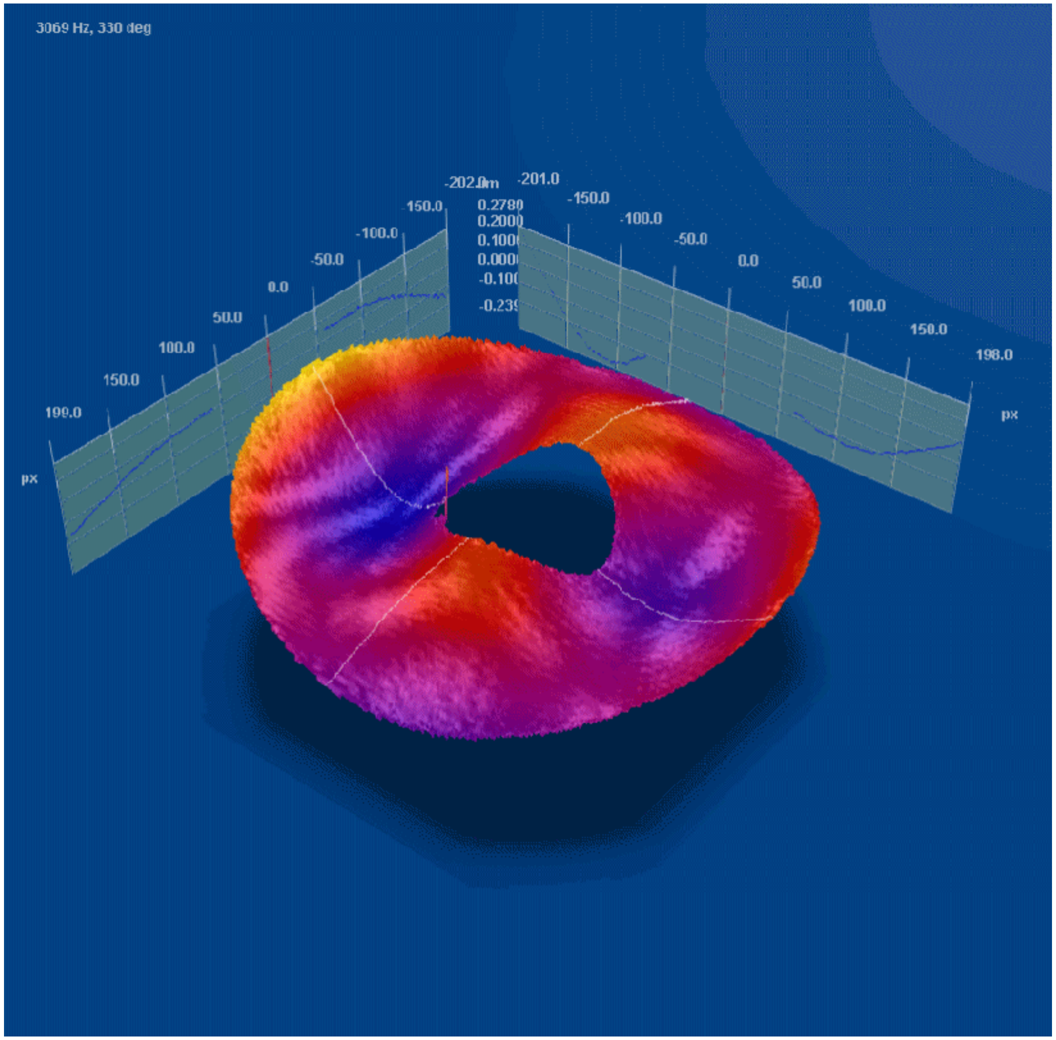
Modal Analysis Phase Movie
3069Hz Resonance



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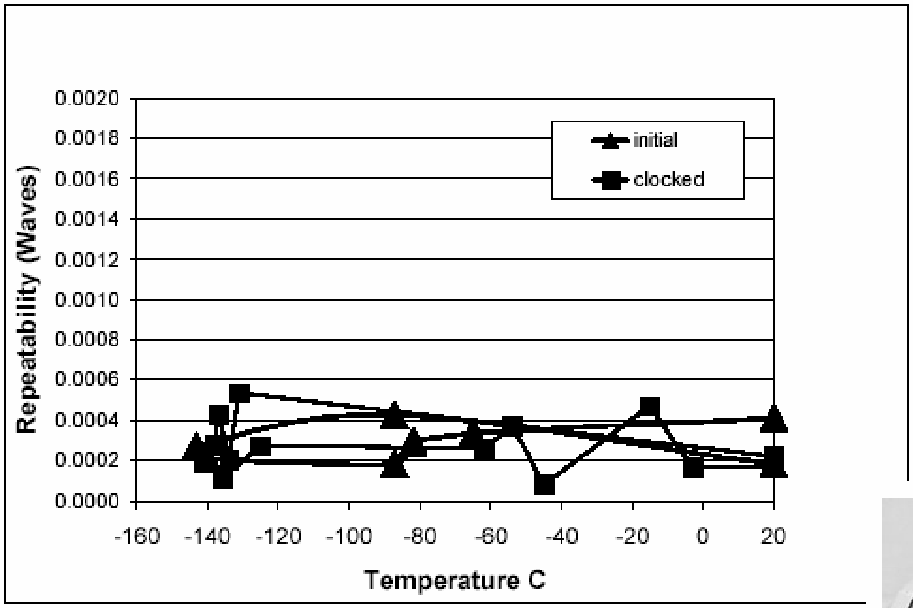
Environmental Testing



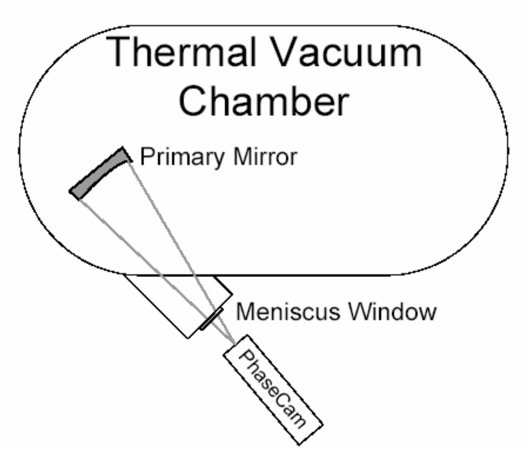
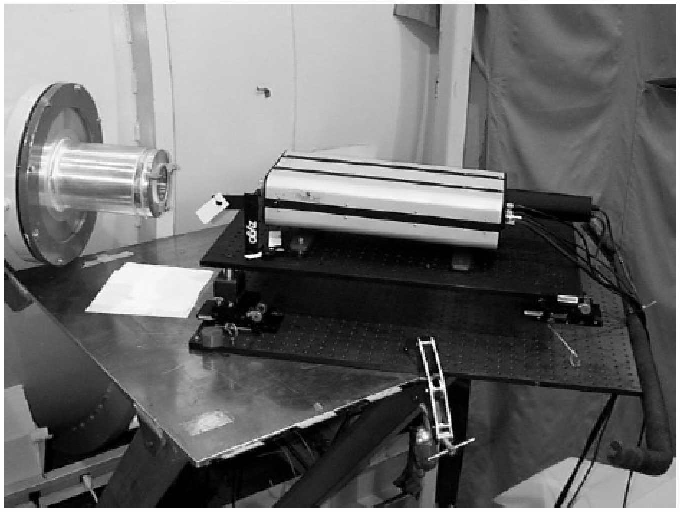
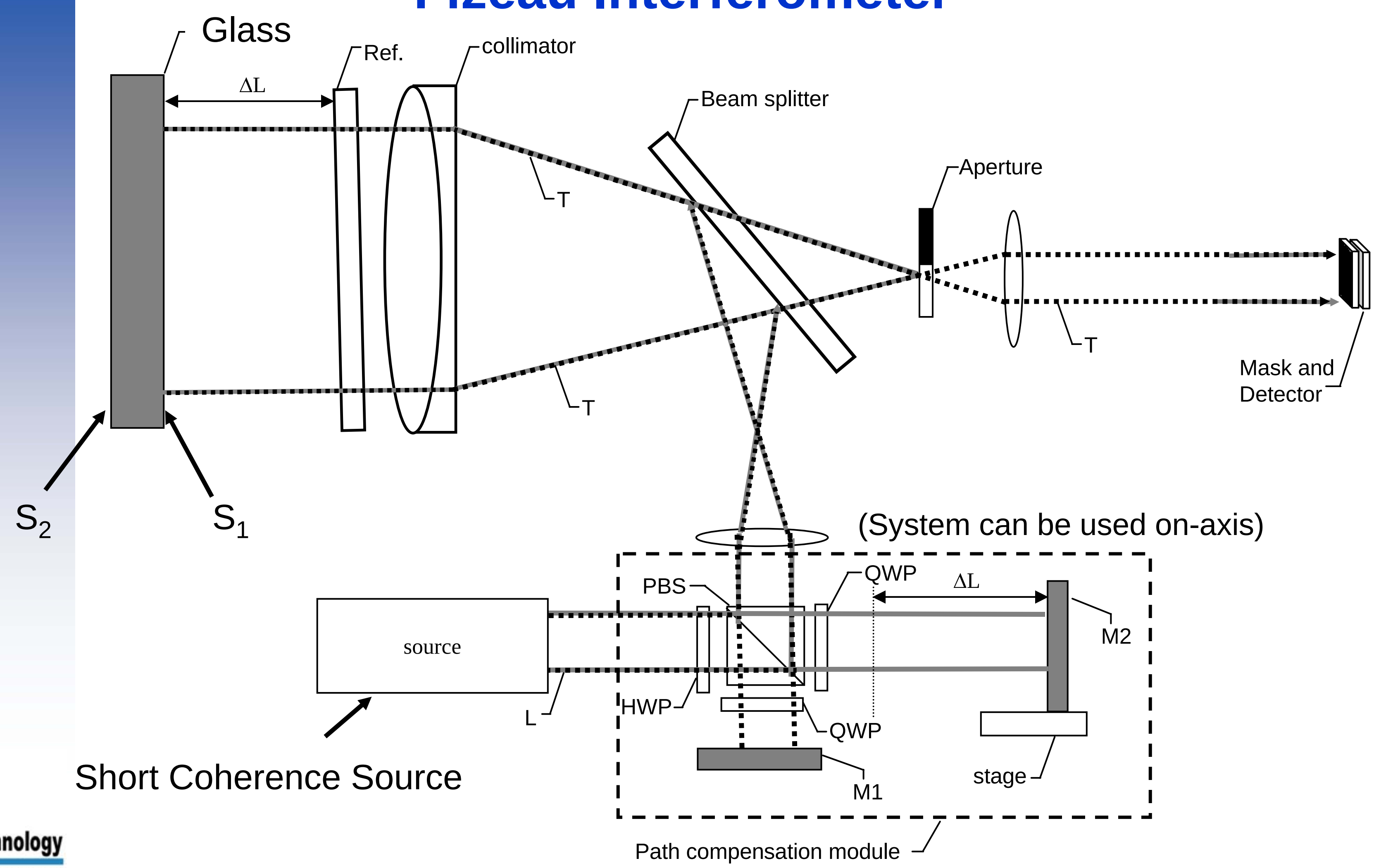


Figure testing of 300 mm Zerodur mirrors at cryogenic temperatures, Baer & Lotz, SPIE 4822-4 July 2002

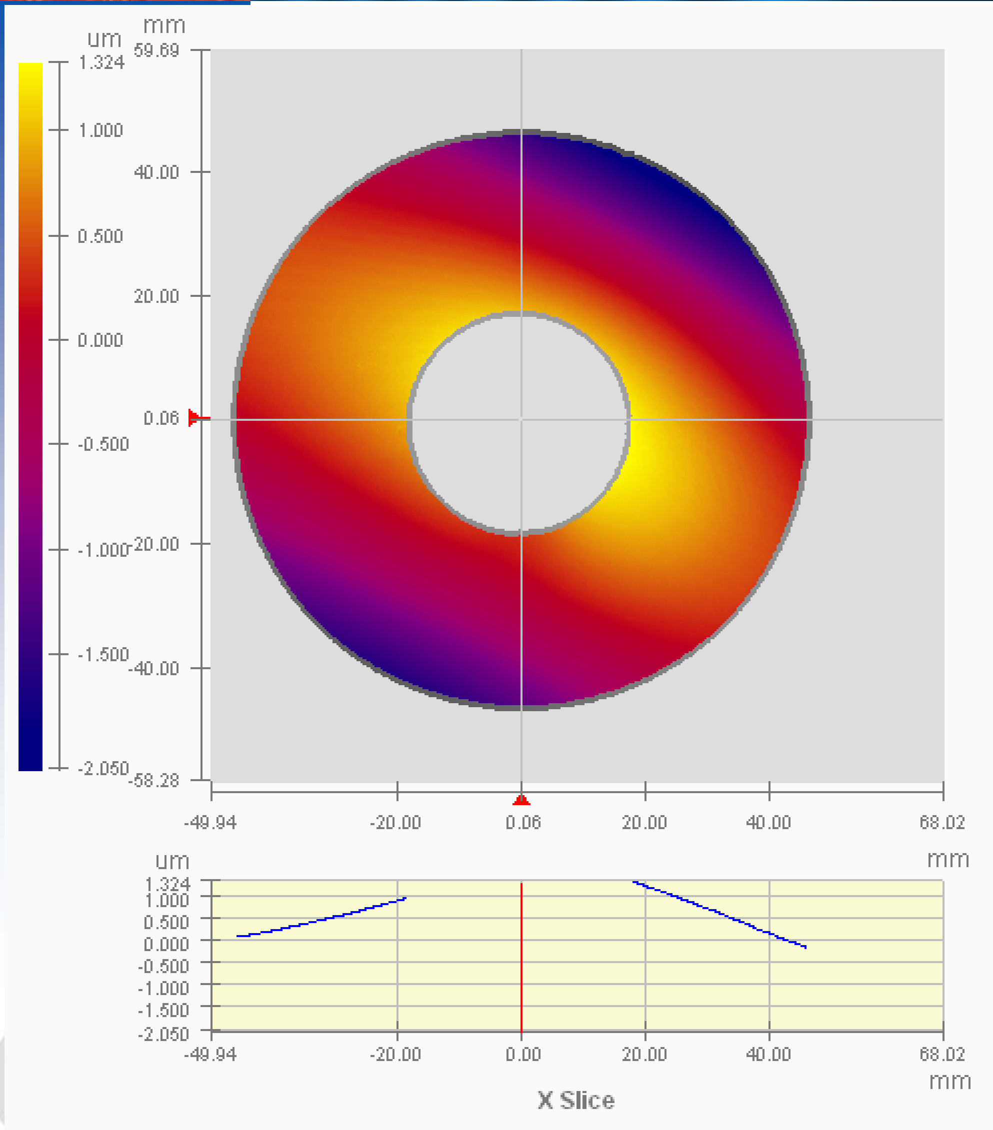


System Configuration For Glass

Fizeau Interferometer

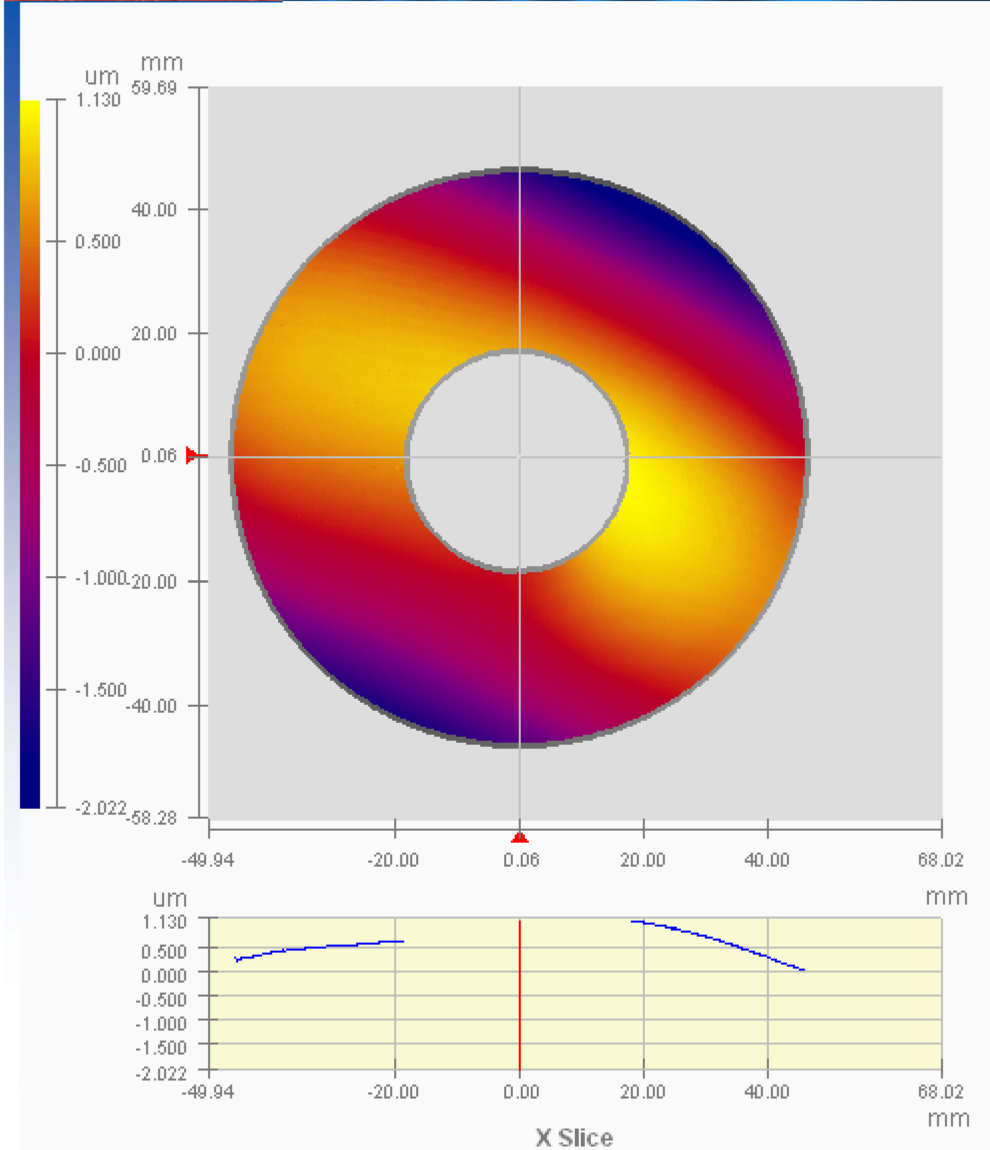


Front Side, 95mm Glass



- **Fringes Focused on Top Surface of Glass Disk (S_1)**
- **Surface referenced to Transmission Flat**
- **Measurement is top surface shape.**
  $M_1 = S_1$

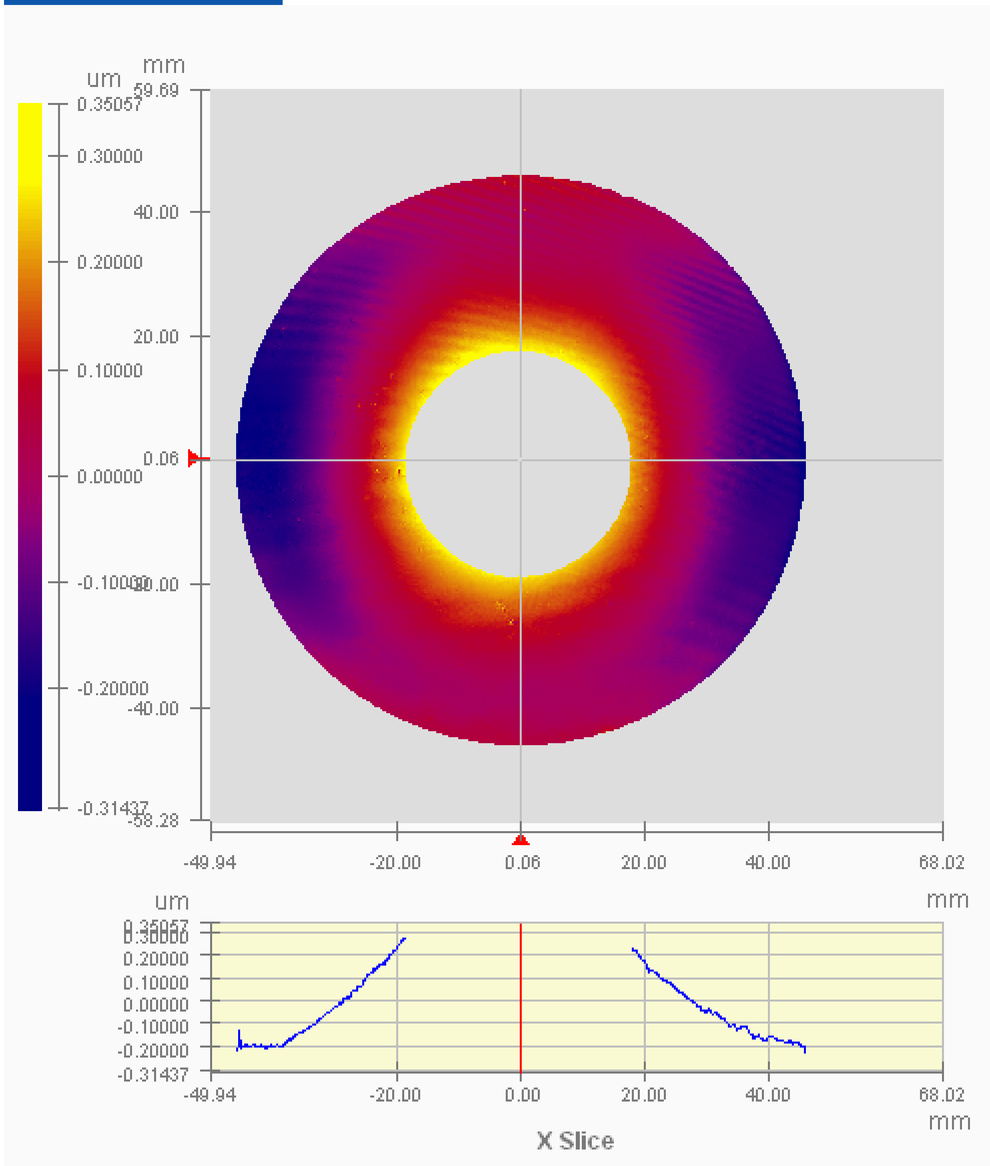
Back Side, 95mm Glass



- **Fringes Focused on Back Surface (S_2)**
- **Measurement is $M_2 = nS_2 - (n-1)S_1$**
- **Back surface (S_2) can be calculated by**

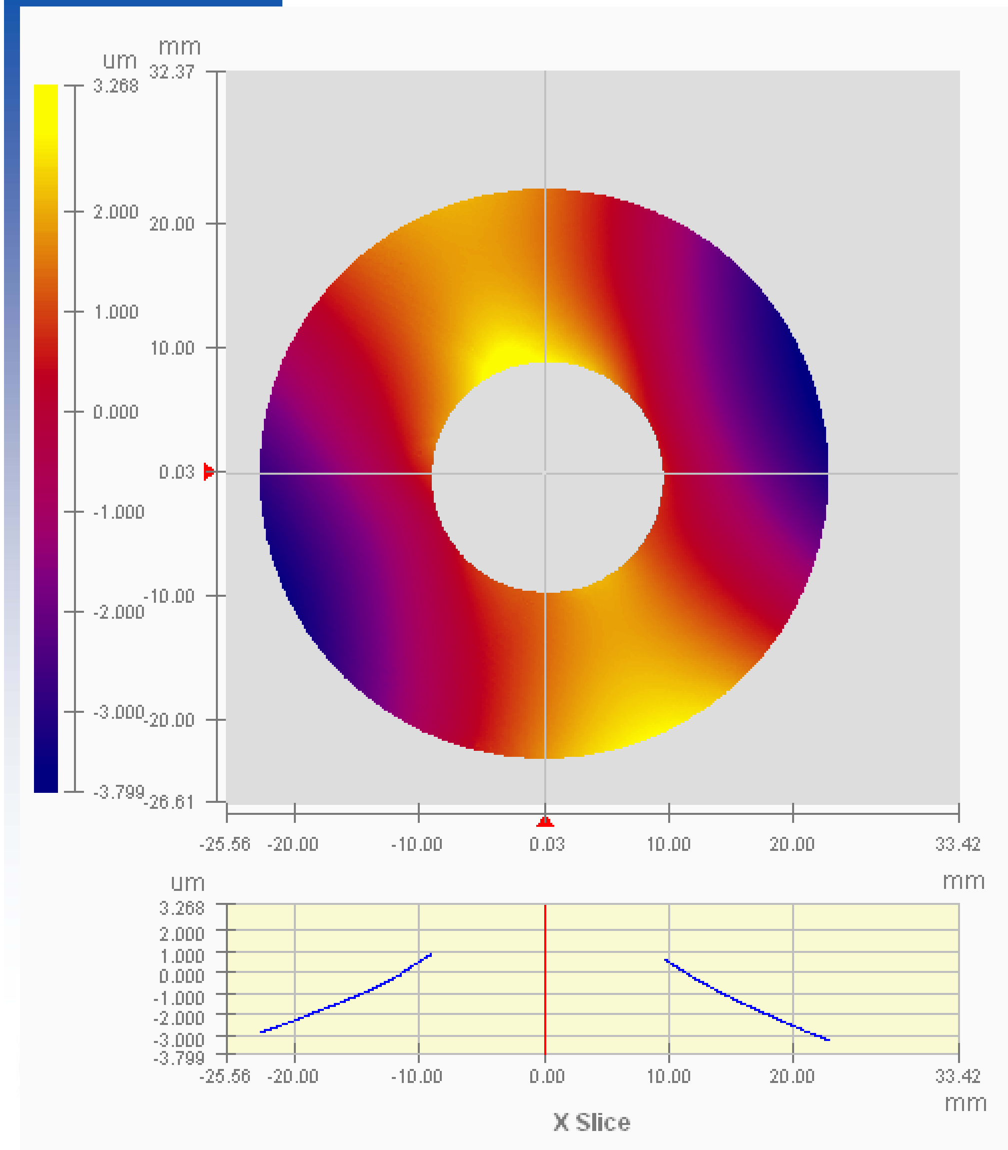
$$\frac{M_2 + (n+1)S_1}{n}$$

Thickness Variation



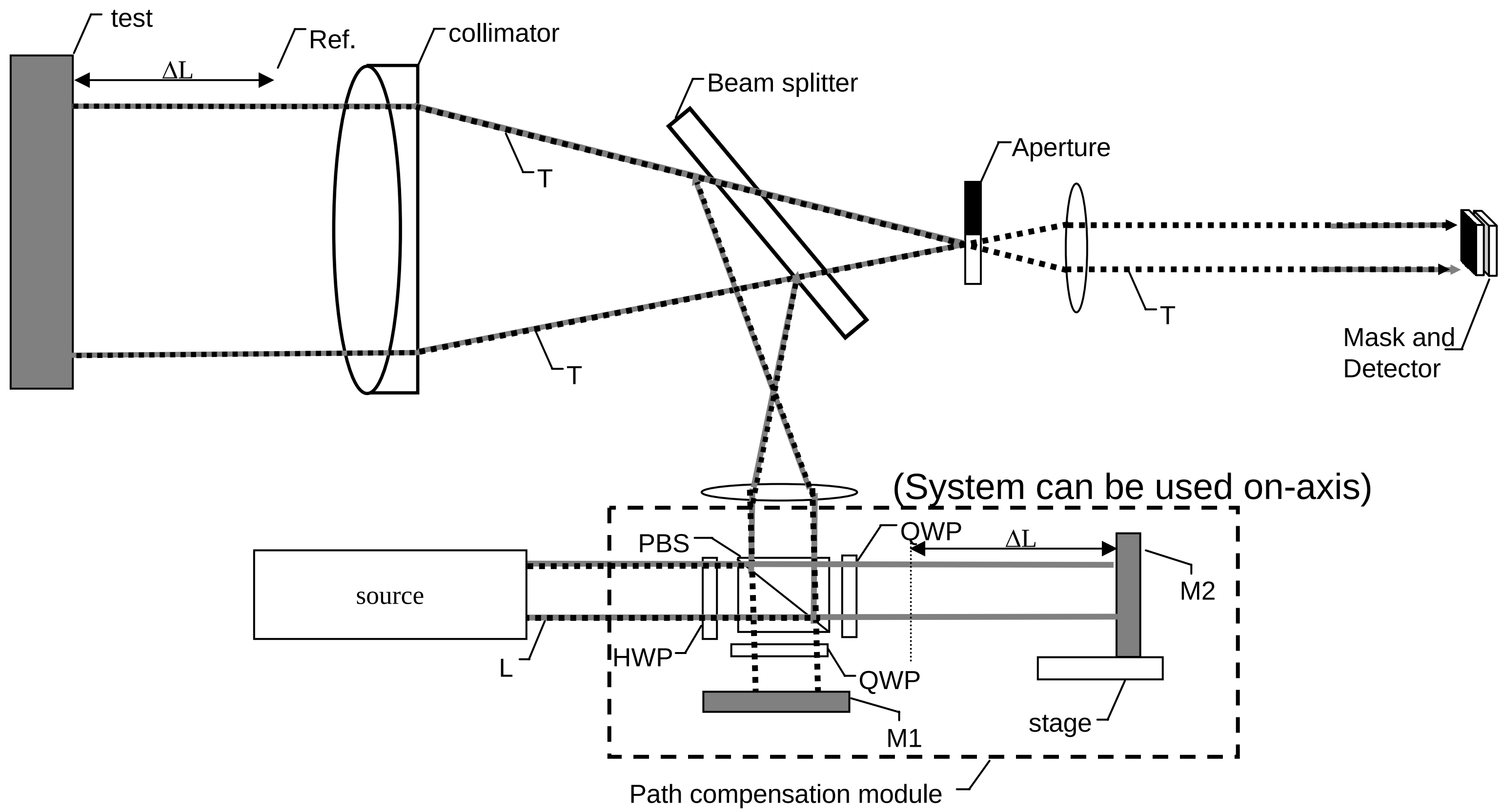
- **Difference of S_2 and S_1**
- **Thickness variation map across sample.**

Al Disk with Short Coherence



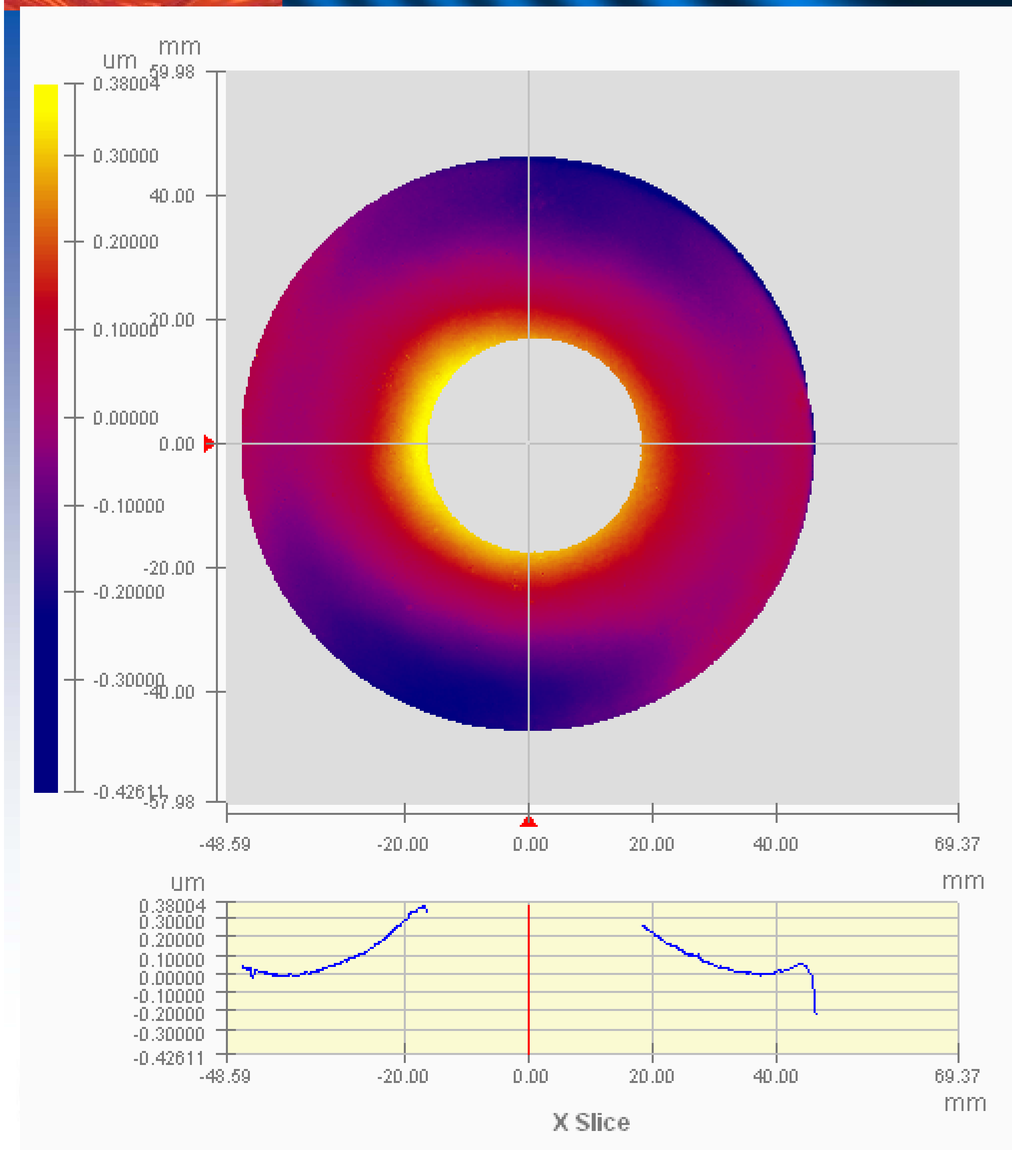
- **Short Coherence Dynamic Interferometry provides flexibility for both Al and Glass measurements.**

Direct Thickness Variation



- **Transmission Flat removed**
- **Front of Glass Disk used as Reference**

Direct Thickness Variation



- **Disk clocked approximately 90˚ from previous measures.**
- **Provides direct measure of thickness variation across glass disk.**

Conclusion

- **Dynamic Interferometry**
  - Static Surface Measurement of Aluminum Disks
  - Dynamic Surface Characterization
  - Environmental Chamber Testing
- **Short Coherence Dynamic Interferometry**
  - Aluminum
    - Front Side
    - Dynamic Surface Characterization
  - Glass
    - Front Side
    - Back Side
    - Thickness Variation
    - Dynamic Surface Characterization