Advances in optical fabrication via VIBE

Higher precision, Reduced processing cost, & Lower optical scatter

Presented By:

Matthew Brophy, Ph.D. & Jessica DeGroote Nelson, Ph.D.

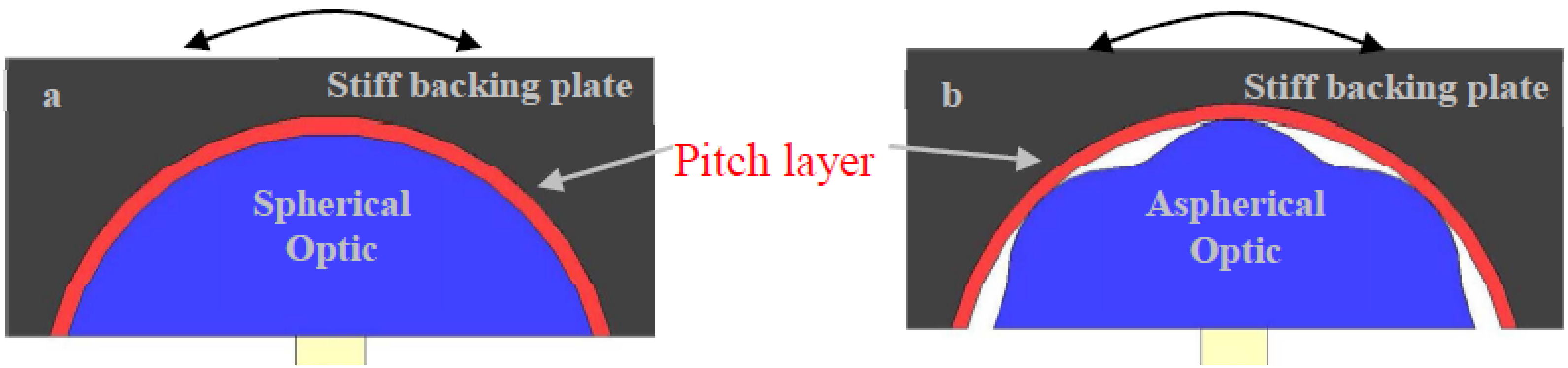
Prototype Optics In One Week

Outline

- Introduction to VIBE
- Manufacturing problems
- The VIBE solution
- Future of VIBE

Introduction to VIBE

Introduction to VIBE

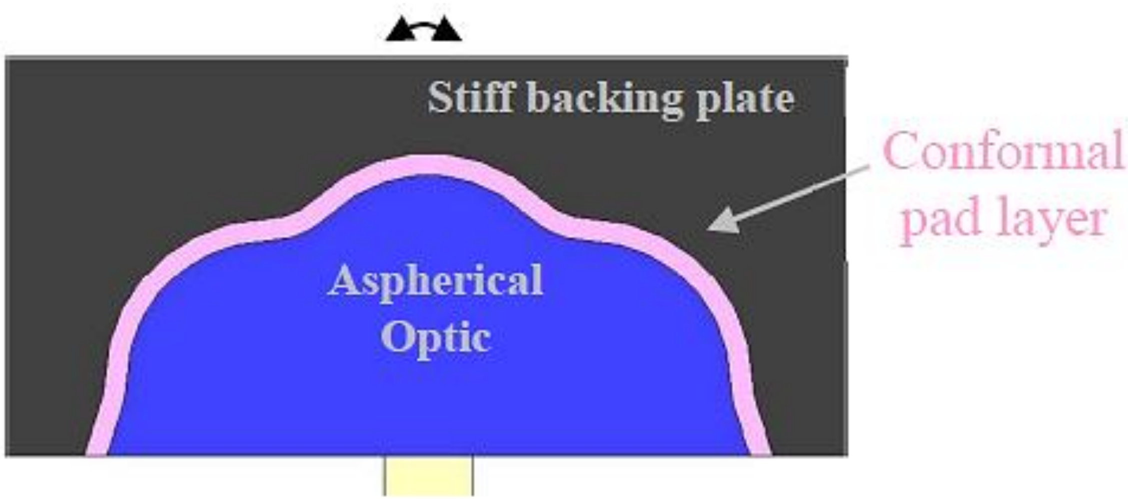


- Pitch tool is exact shape of desired surface
- Long polishing strokes
- Smoothing of high points
- Aspheres and conformal optics extremely difficult

OPTIMAX

Introduction to VIBE

- 1st Innovation: Conformal lap
- 2nd Innovation: Short stroke lengths



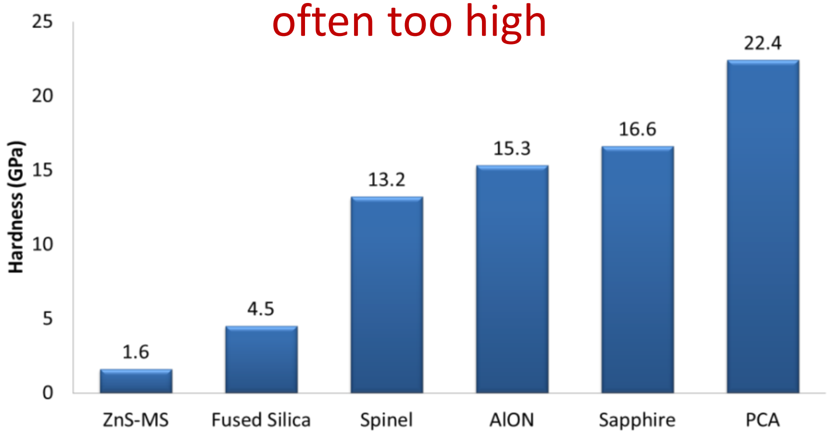
Polishing process that uses a full-aperture, conformal lap that vibrates at high frequencies

Optic slowly oscillates while in contact with vibrating lap

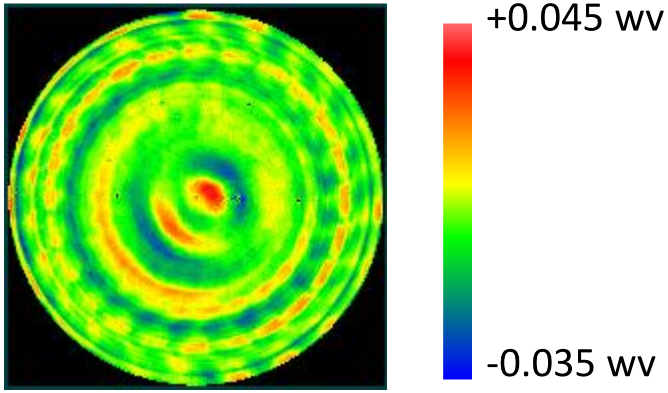
Manufacturing Problems

Manufacturing Problems

Time & cost to process hard materials is often too high

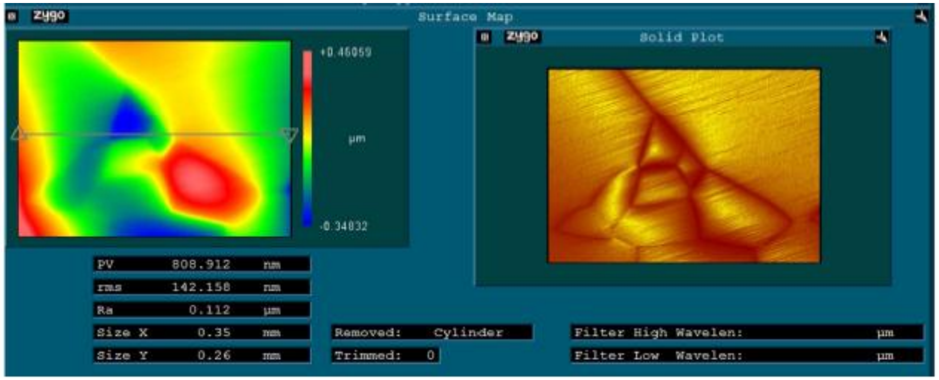


Optical precision to low on aspheres & freeforms



Time & cost to process complex geometries is often too high

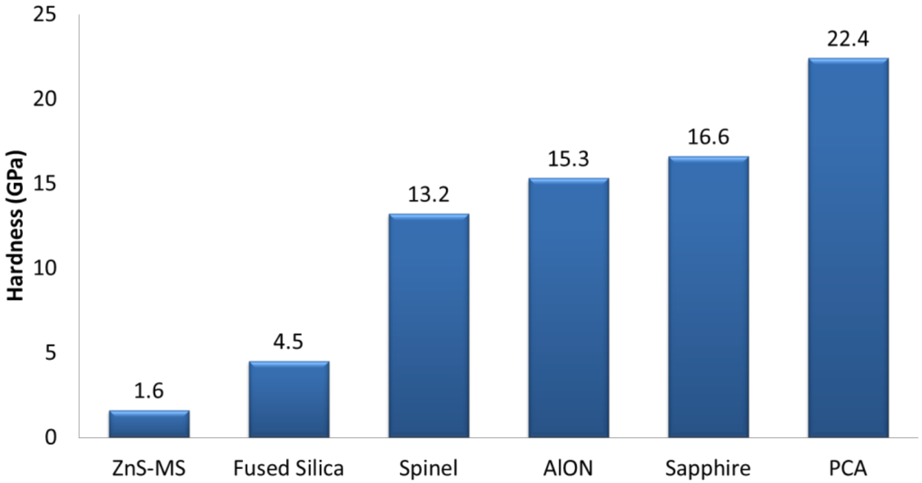
Optical scatter to high on polycrystalline aspheres & freeforms

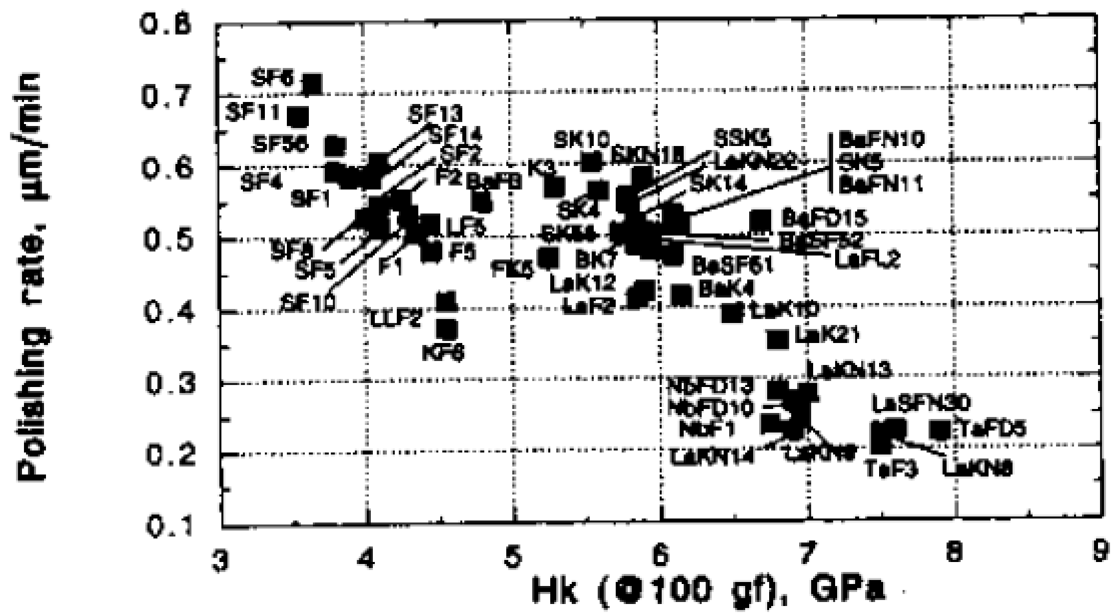


OPTIMAX

Lowering Processing Cost & Time on Mechanically Hard Materials

Statement of Problem



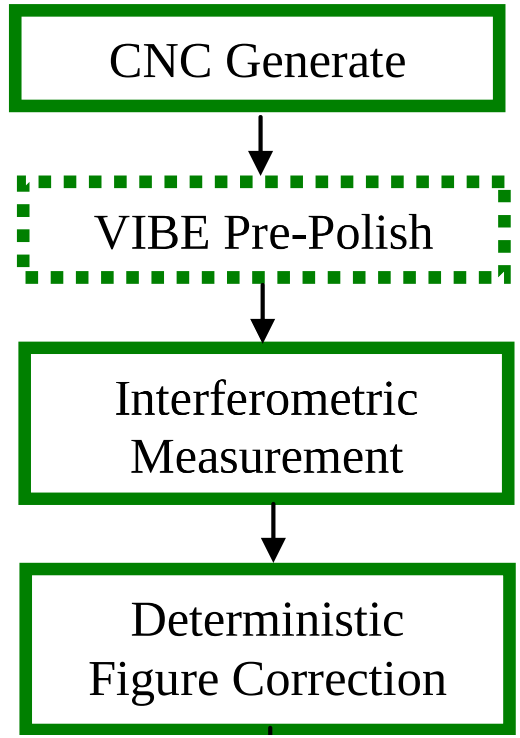


Summary

- Low removal rates on hard materials
- Higher processing cost & time

OPTIMAX

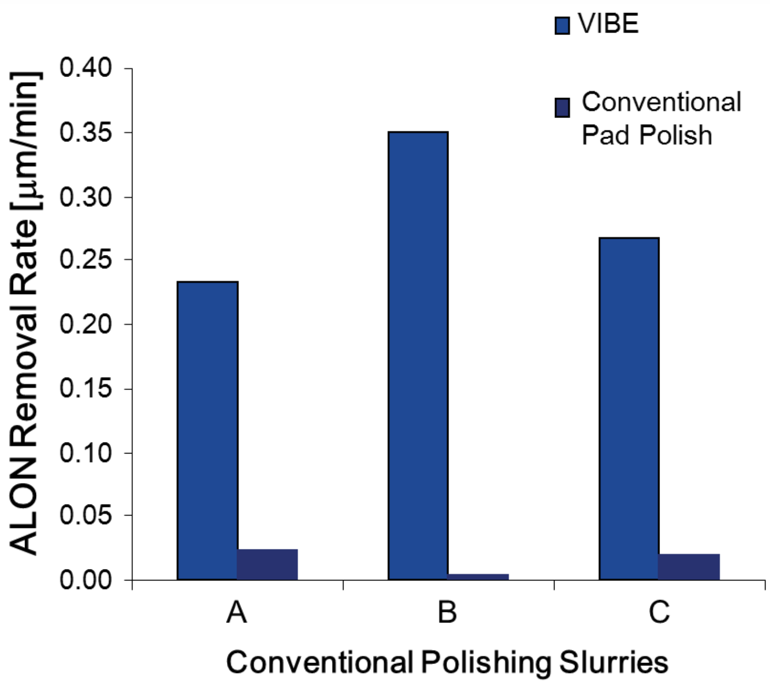
VIBE as a Solution



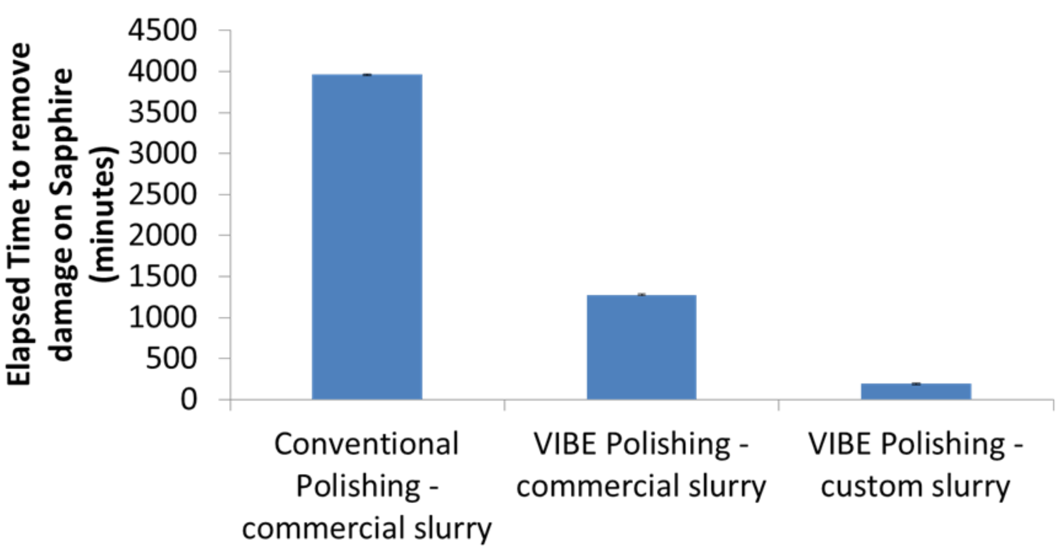
Objective for VIBE pre-polish is to reduce polishing time & maintain surface form

OPTIMAX

Polishing Time Results



How did VIBE do in reducing polishing time?



Summary

5x to 30x increase in removal rate when using VIBE!

OPTIMAX

Surface Form Results

How did VIBE do in maintaining surface form?

Example of VIBE processing a 22.9mm radius spherical optic

Initial 9T alumina ground surface

Areal surface roughness

P-V: 8517.6nm

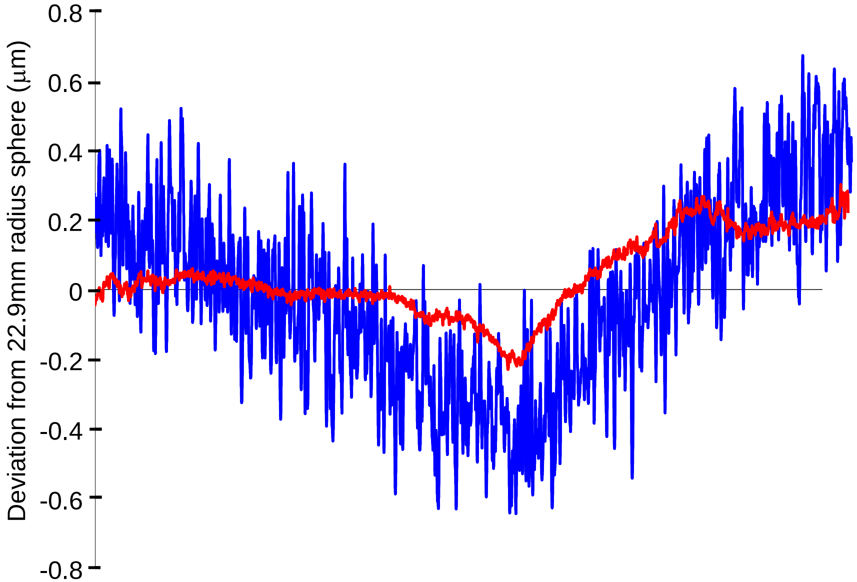
RMS: 756.1nm

After 10 minutes of VIBE polishing

Areal surface roughness

P-V: 12.3nm

RMS: 0.7nm



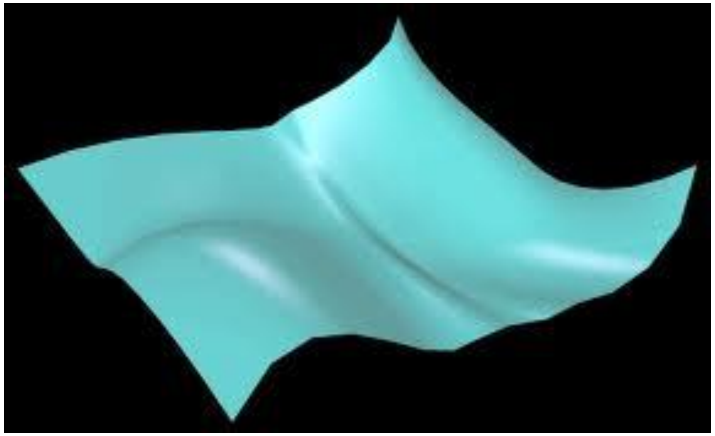
Summary

- Maintained surface form
- Removed 10µm of material in only 10min

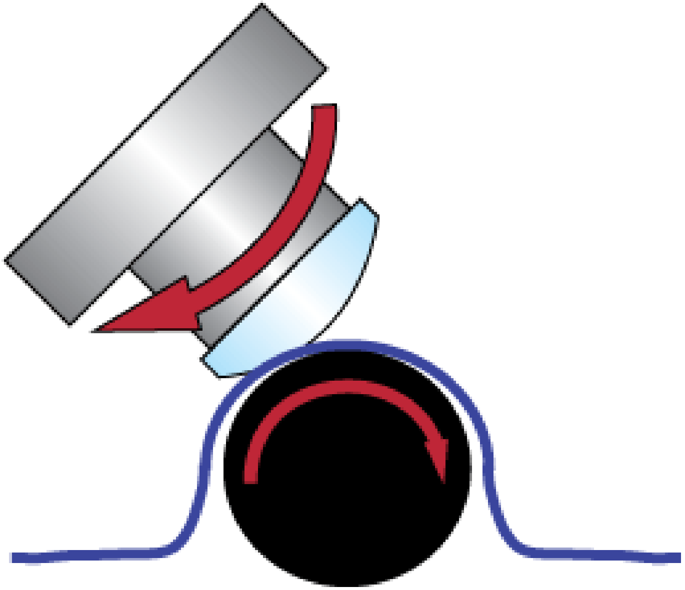
Lowering Processing Cost and Time to Fabricate Complex Geometry Optics

Statement of Problem

- Possible optical designs:
  - Polynomials
  - Splines
  - NURBS
  - Zernikes
  - And many more



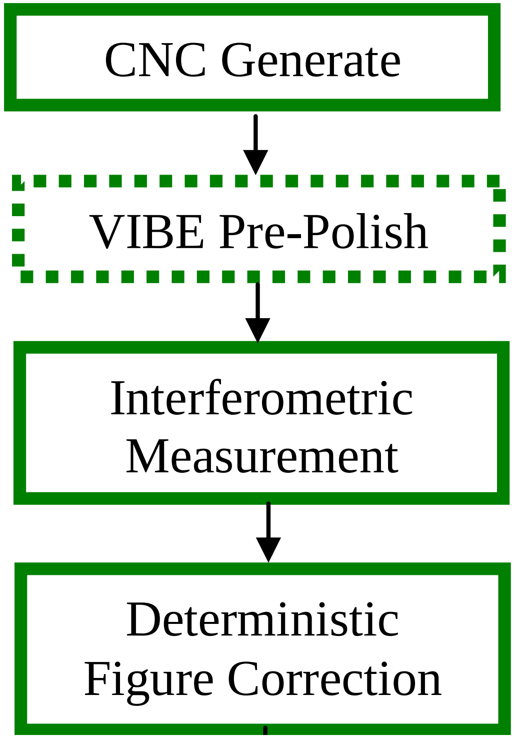
The optical fabricator is forced to use sub-aperture processing to remove grinding damage

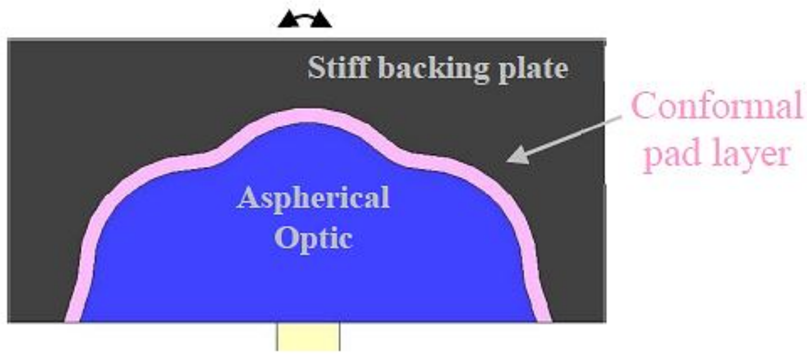


Sub-aperture processes use small spot sizes and thus have longer polishing cycles

VIBE as a Solution

VIBE is a larger-aperture to full-aperture polishing process



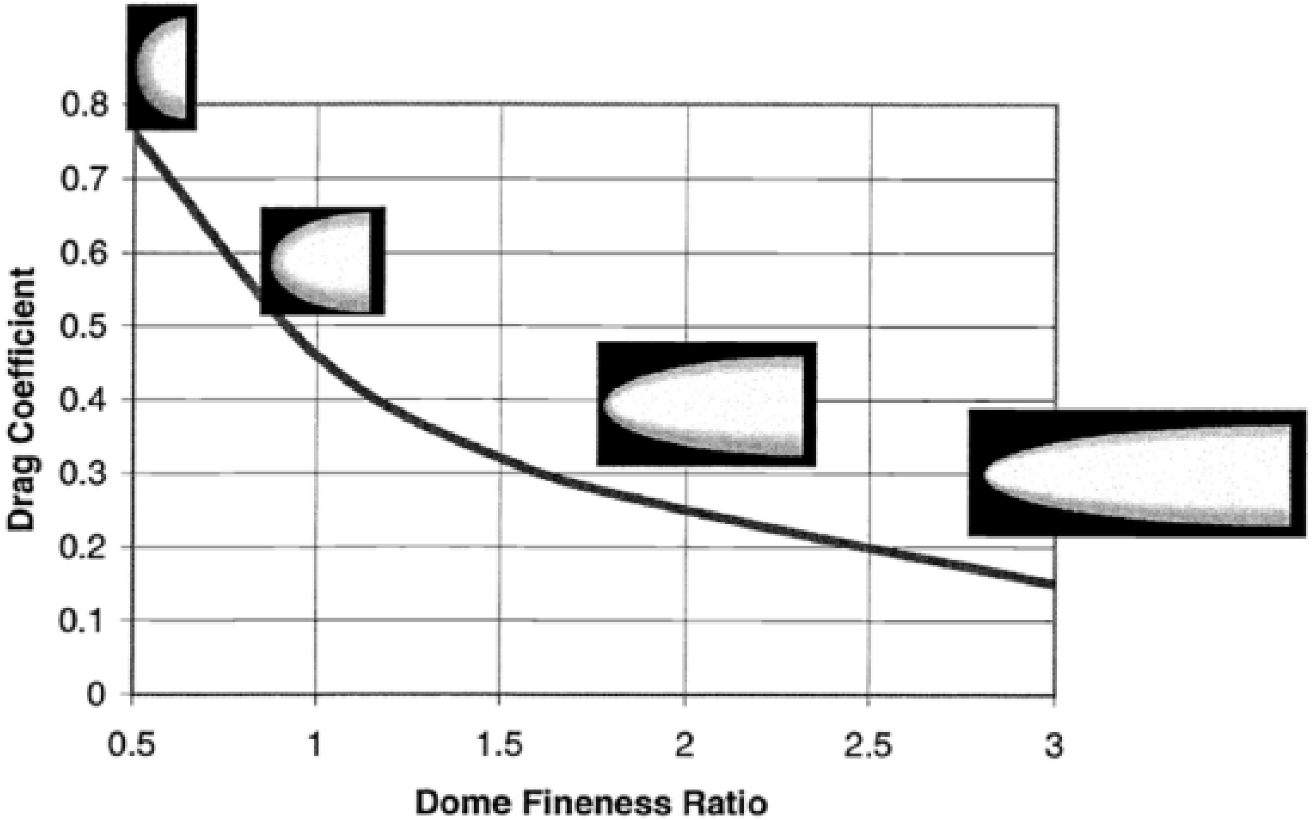


Objective for VIBE pre-polish is to reduce polishing time & maintain surface form

OPTIMAX

Conformal Dome Example

- Can replace hemispherical dome on a missile seeker.



Lower probability of failure due to rain or sand erosion by decreasing impact angle.

Knapp, D.J. Fundamentals of Conformal Dome Design. in International Design Conference. 2002: SPIE.

Generation Results

CNC Generate

↓

VIBE Pre-Polish

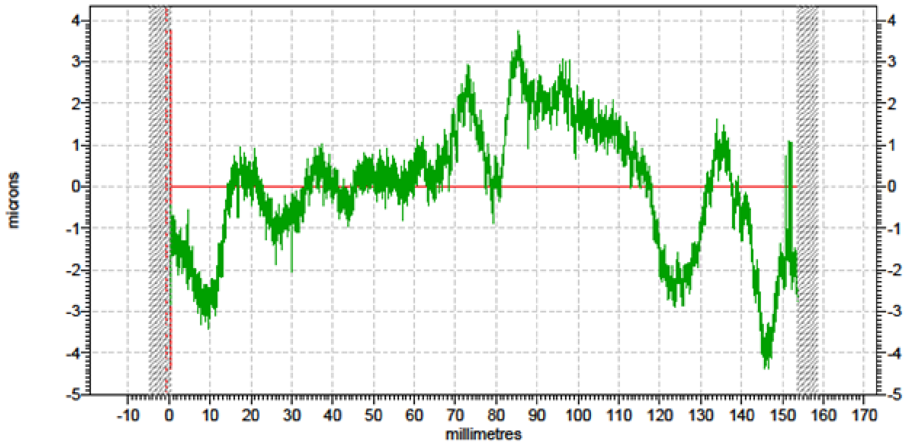
↓

Interferometric Measurement

↓

Deterministic Figure Correction

CNC Generate



VIBE Results

CNC Generate

↓

VIBE Pre-Polish

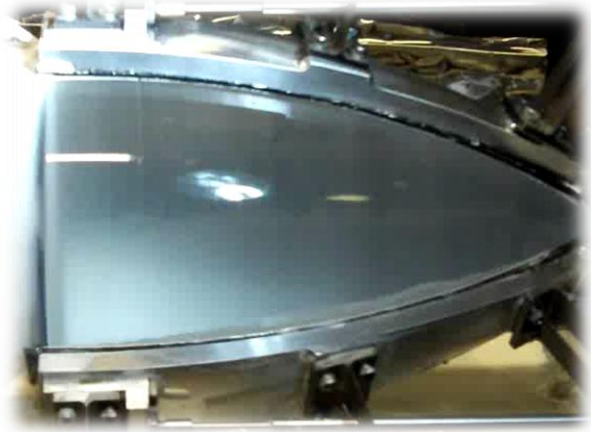
↓

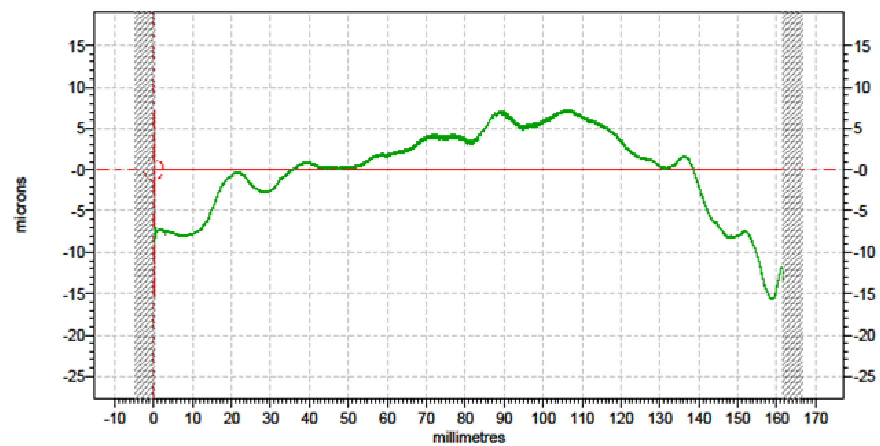
Interferometric Measurement

↓

Deterministic Figure Correction

VIBE Pre-Polish





Summary

Successfully used VIBE to polish conformal domes made of glass & PCA with minimal change in form-error!

Conformal Window Example

- Conformal windows follow a surface shape
- Fuselage of a plane or wing of an aircraft
  - Protect sensors from ballistic or environmental threats

Conformal window made of fused silica & hard, polycrystalline ceramics, such as spinel.

Processing Time Results

VIBE = full aperture

30 hours to polish

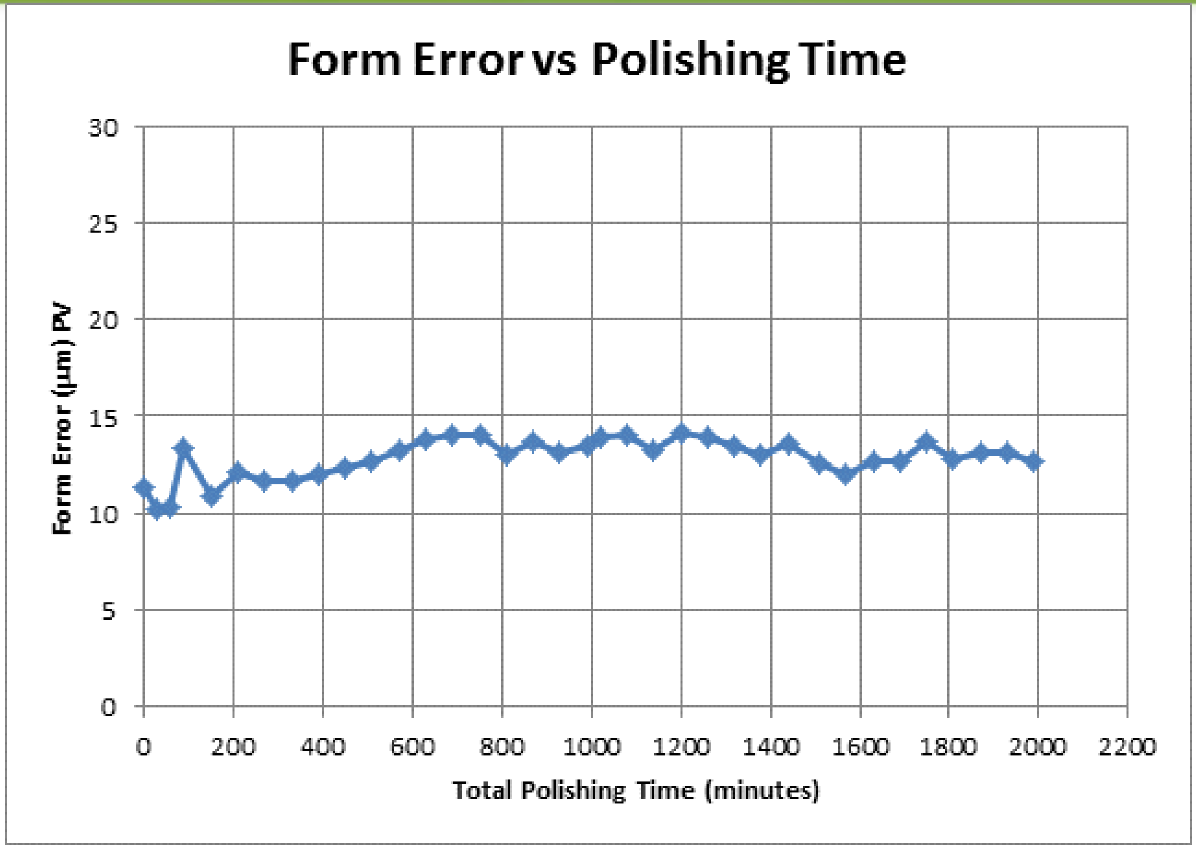
Sub-aperture polishing

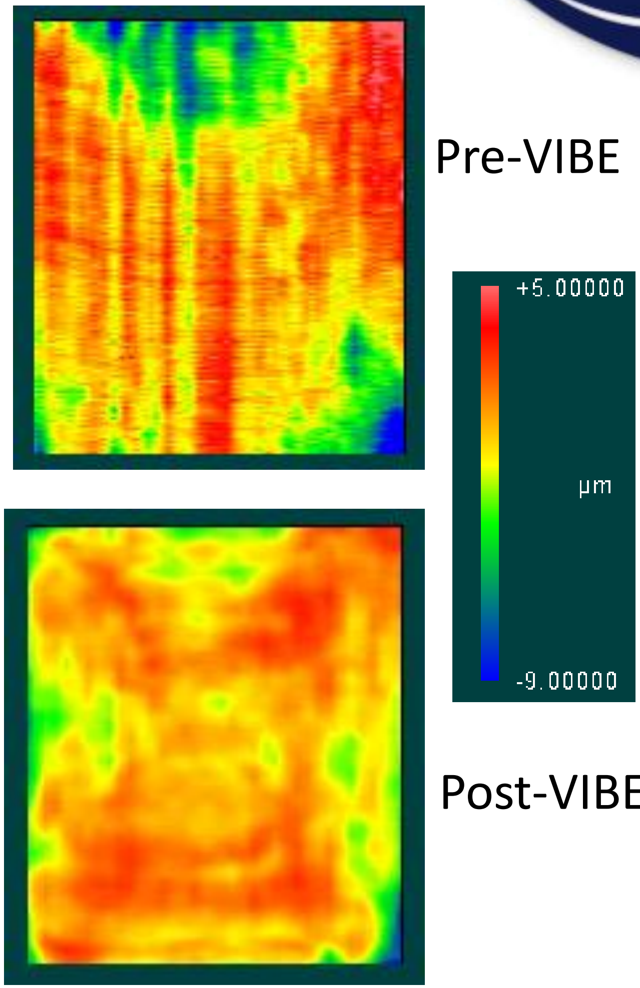
48 hours to polish

Summary

VIBE reduced polishing time by 38%

Surface Form Results





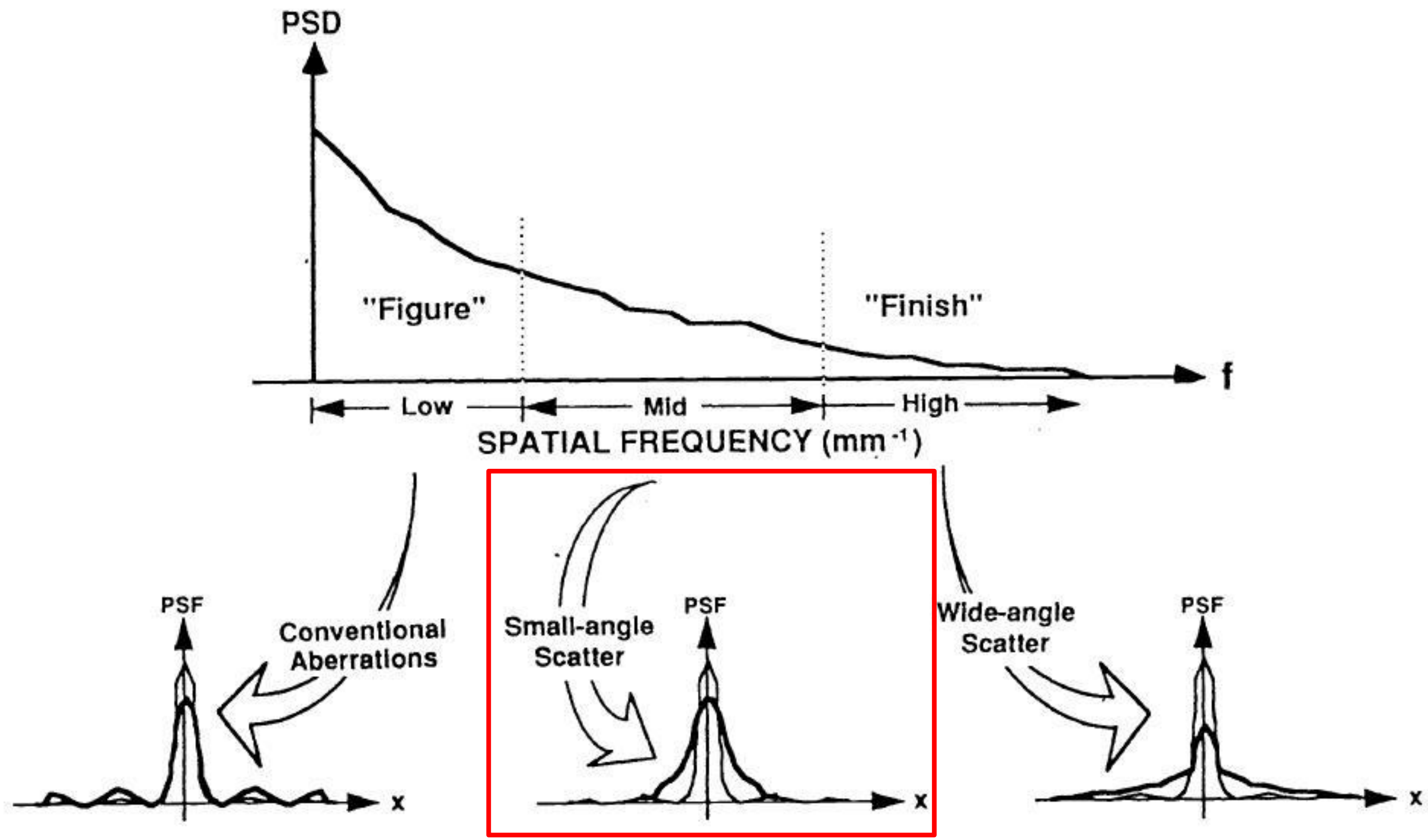
Summary

- VIBE preserved form-error, while reducing total polishing time

OPTIMAX

Improve Precision of Aspheres & Freeforms by Reducing Mid-spatial Frequency Errors (MSF)

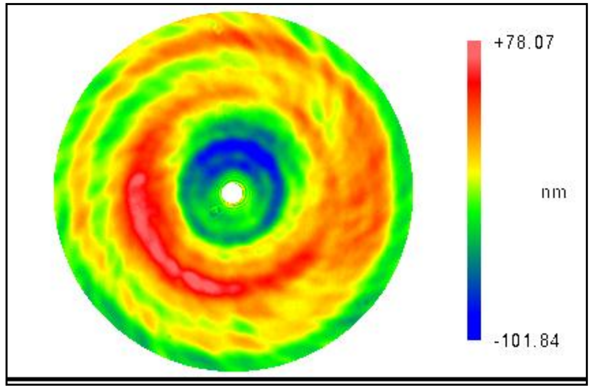
Mid-Spatial Frequency Errors



J.E. Harvey and A. Kotha, “Scattering effects from residual optical fabrication errors, Proc. SPIE 2576-25 c

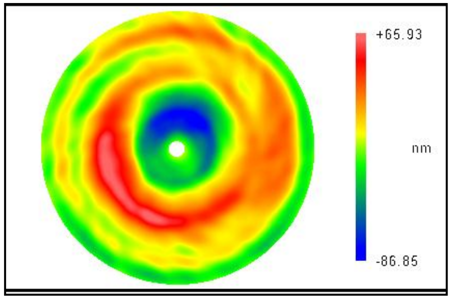
Mid-Spatial Frequency Errors

PV: 179.9nm
RMS: 28.6nm



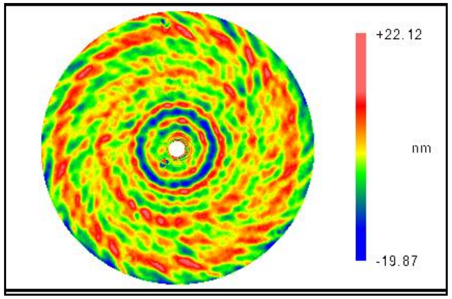
Unfiltered data

PV: 152.8nm
RMS: 26.3nm



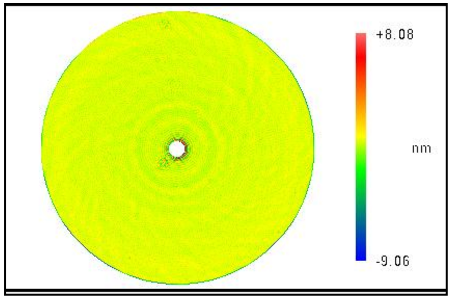
Low spatial frequency (LSF)

PV: 41.9nm
RMS: 4.8nm



Mid-spatial frequency (MSF)

PV: 17.1nm
RMS: 0.6nm



High spatial frequency (HSF)

D. Aikens, J. E. DeGroote, and R. N. Youngworth, "Specification and Control of Mid-Spatial Frequency Wavefront Errors in Optical Systems," (Optical Society of America, 2008).

Statement of Problem

CNC Generate

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Sub-Aperture Polish

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Interferometric Measurement

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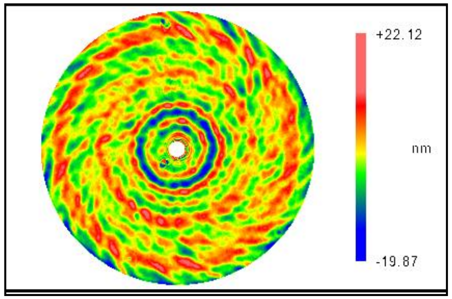
Deterministic Figure Correction

Sub-aperture & Deterministic processes correct LSF errors & often induce MSF errors



(MSF)

VIBE as a Solution

CNC Generate

↓

Sub-Aperture Polish

↓

Interferometric Measurement

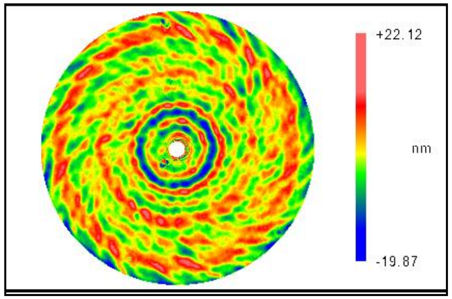
↓

Deterministic Figure Correction

↓

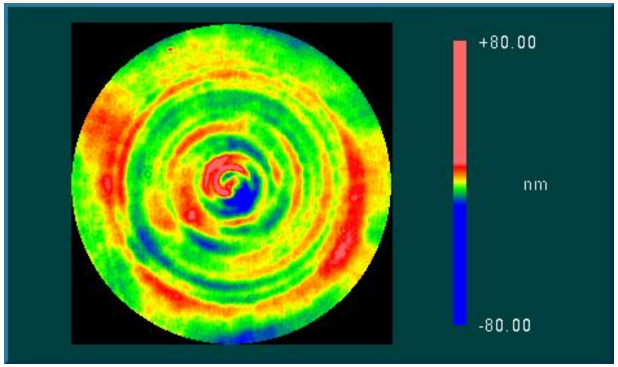
VIBE Finish

Sub-aperture & Deterministic processes correct LSF errors & often induce MSF errors

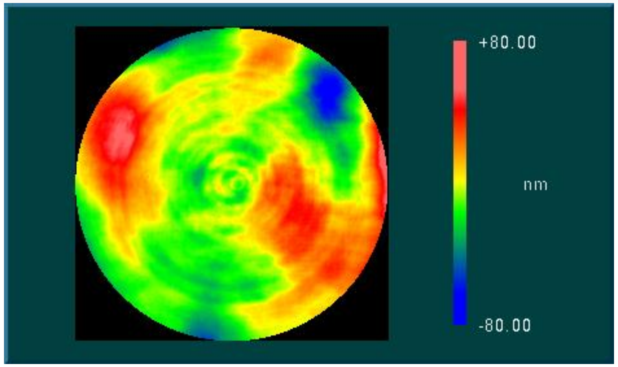


(MSF)

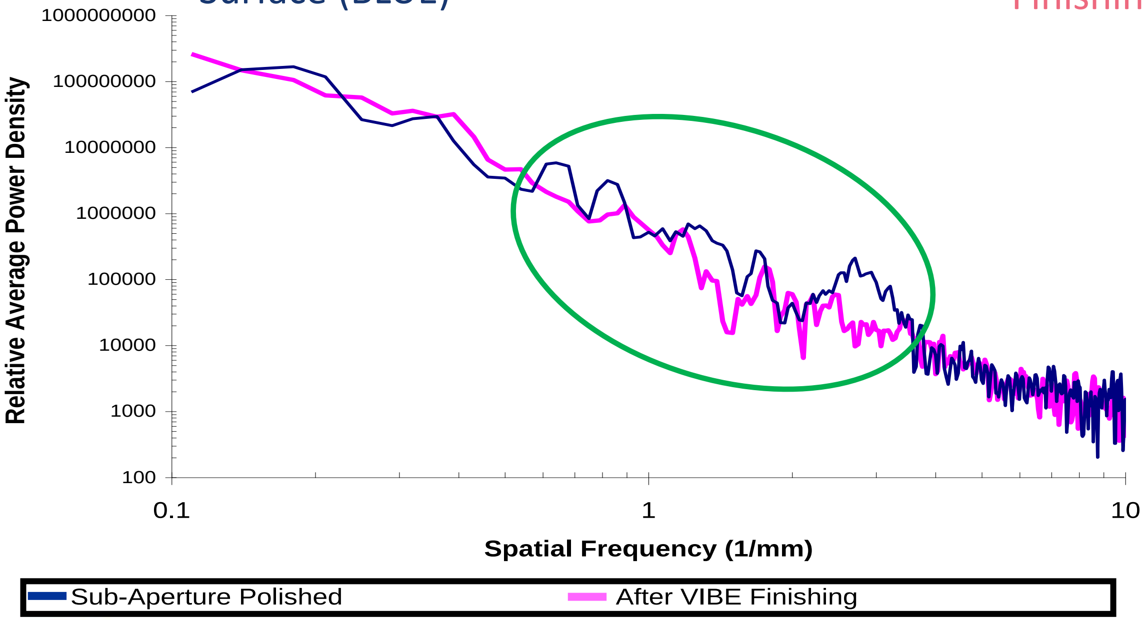
Surface Form Results – Spherical Optics



Initial Sub-Aperture Polished Surface (BLUE)



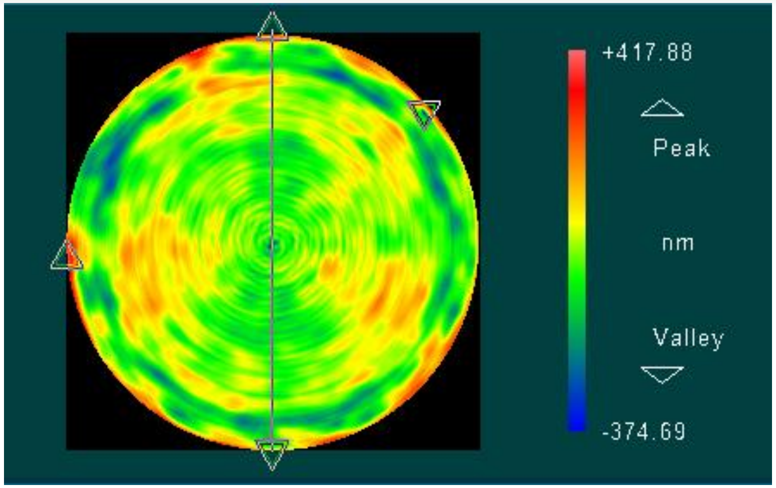
Surface After 60-second VIBE Finishing (Pink)



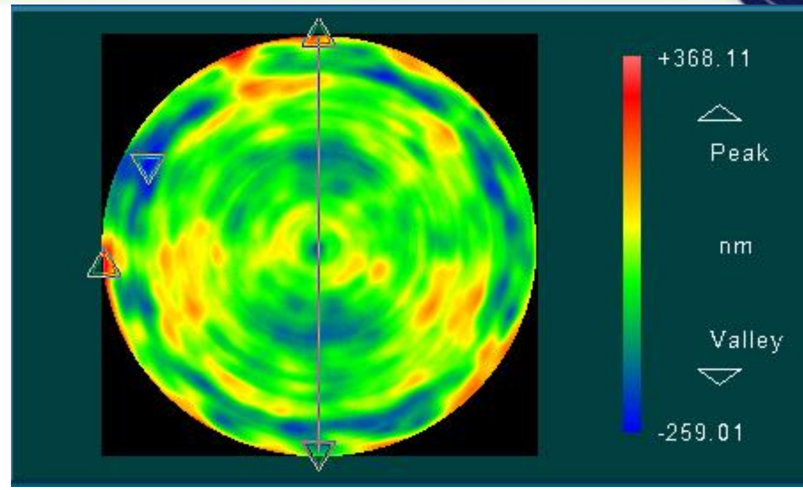
Summary

VIBE finishing significantly reduced MSF errors

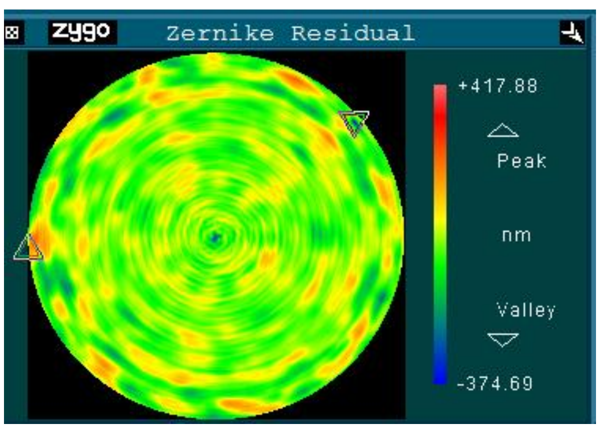
Surface Form Results – Aspherical Optics



PV: 2.51 fringe
RMS: 0.28 fringe

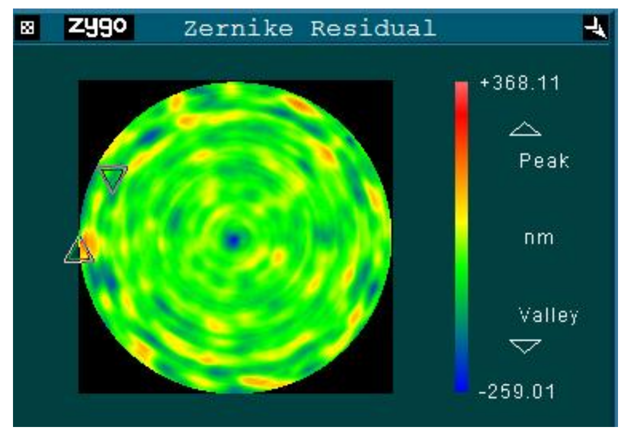


PV: 1.98 fringe
RMS: 0.26 fringe



Zernike Residual RMS: 0.18 fringe

Part characteristics:
Concave glass asphere
200mm diameter
400µm departure



Zernike Residual RMS: 0.16 fringe

Reduce Optical Scatter on Polycrystalline Aspheres & Freeforms

Statement of Problem

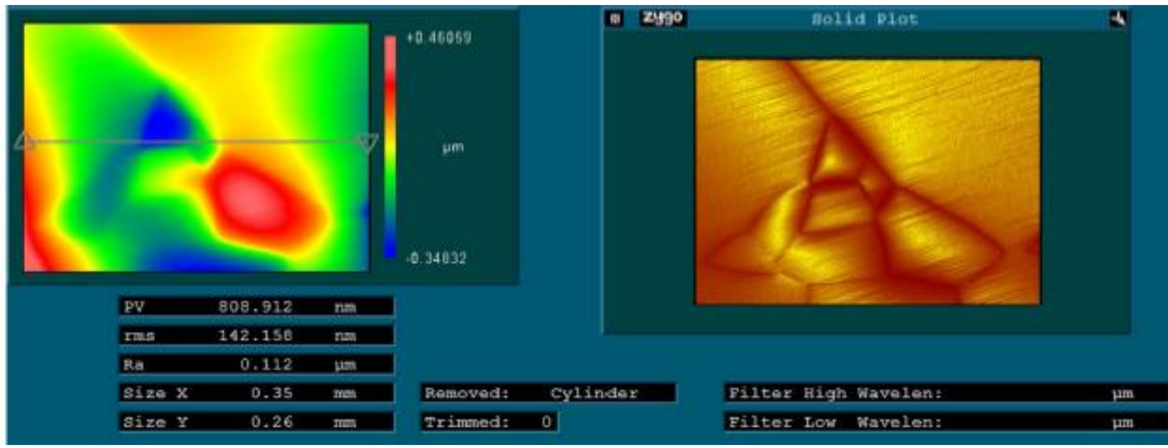
CNC Generate

Sub-Aperture Polish

Interferometric Measurement

Deterministic Figure Correction

Polycrystalline materials grain highlight when using commercially-available sub-aperture polishing processes



VIBE as a Solution

CNC Generate

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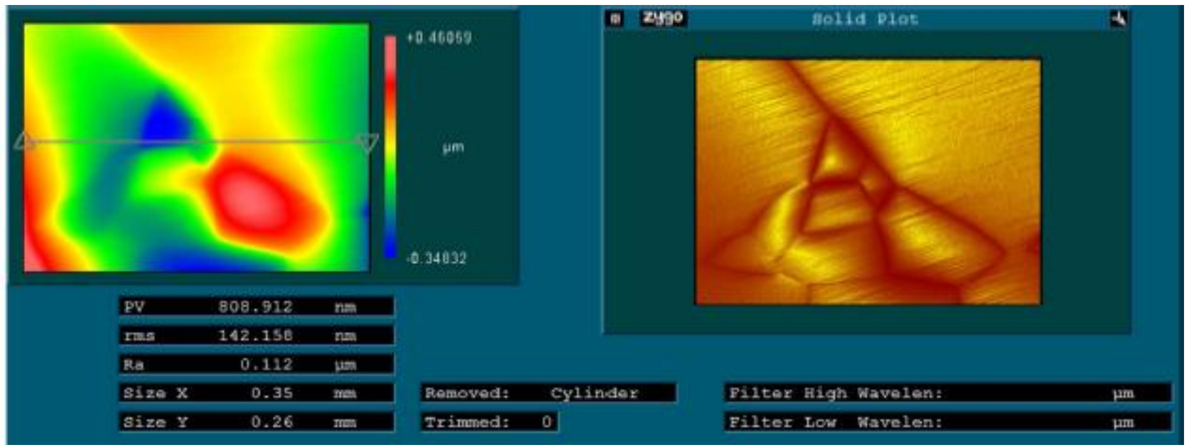
VIBE Finish

Polycrystalline materials grain highlight when using commercially-available sub-aperture polishing processes

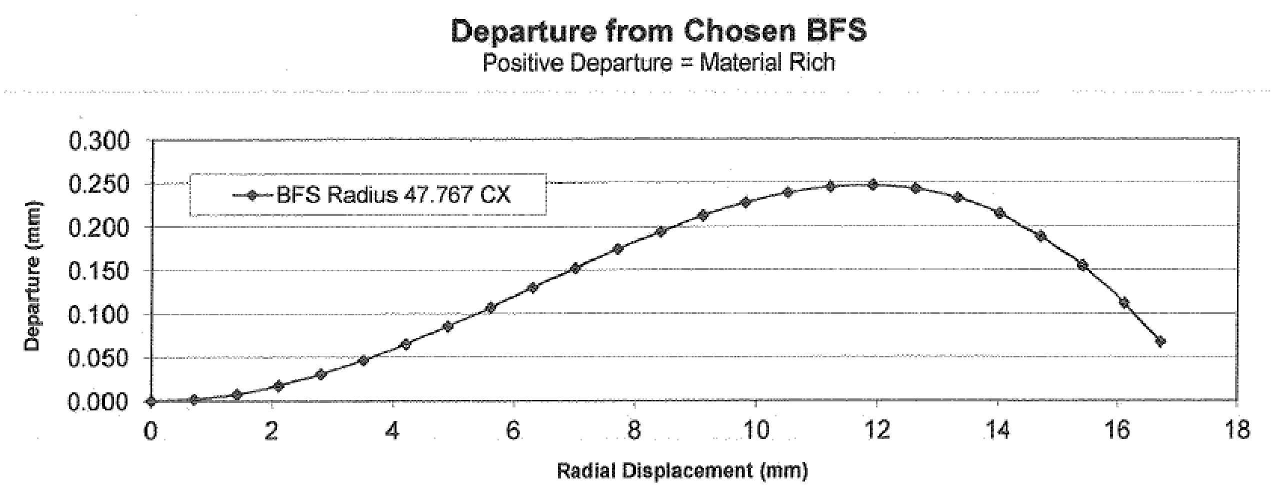


OPTIMAX

ZnS Asphere Example

Convex polycrystalline ZnS asphere

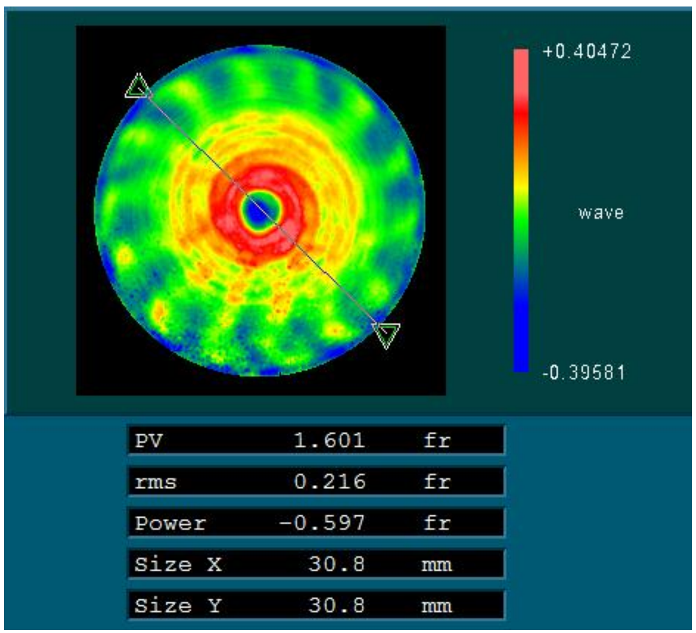
- 250 micron departure from best fit sphere
- 37 mm diameter
- Dimensions chosen based on:
  - Ability to measure interferometrically
  - Required complete aspheric processing



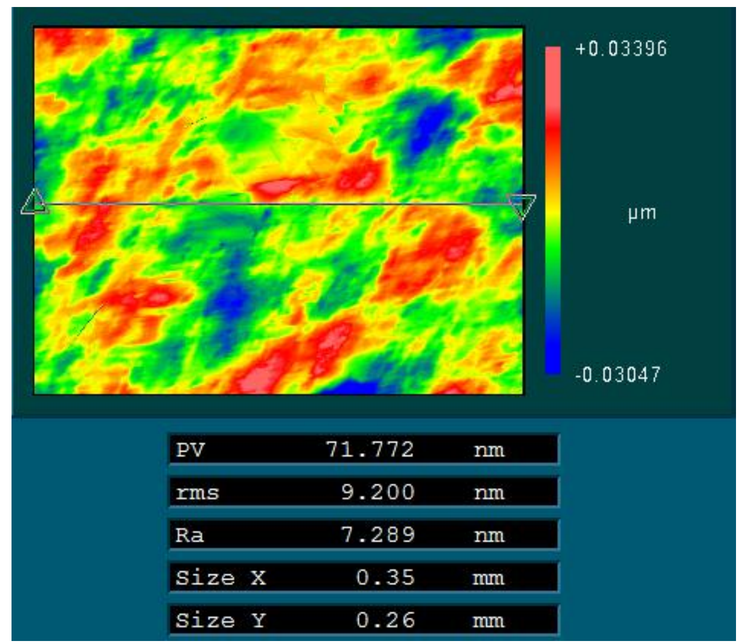
ZnS Asphere Example

After Deterministic Figure Correction:

- ***Irregularity***: 0.216 fr RMS
- ***Roughness***: 9 nm RMS
- ***Appearance***: Visible grain highlighting & scatter



Measured with commercial stitching interferometer



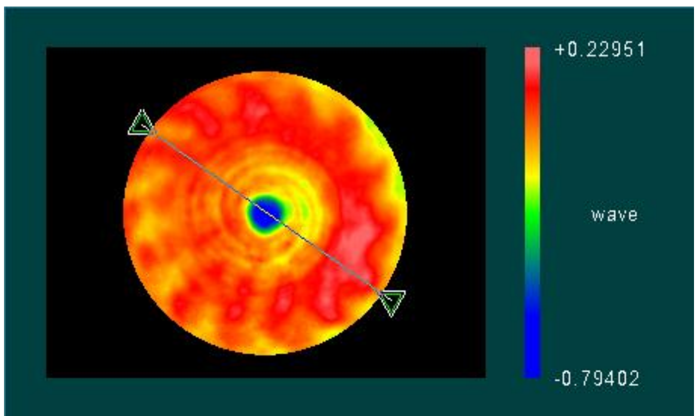
Measured with a white light interferometer, 20x Mirau objective, no filter applied

OPTIMAX

ZnS Asphere Example

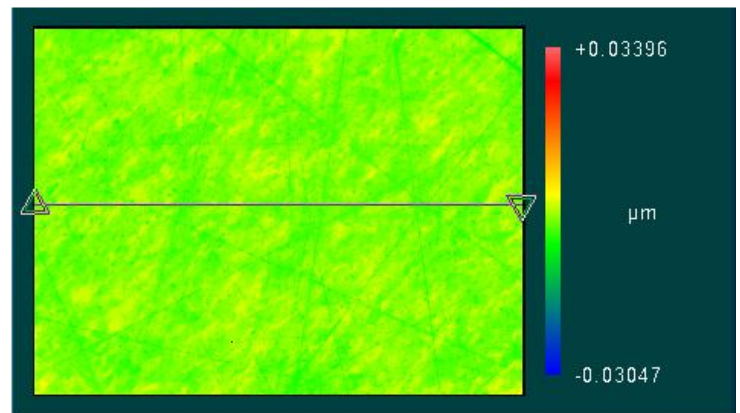
After VIBE Finishing for 6 minutes:

- ***Irregularity***: 0.217 fr RMS
- ***Roughness***: <2 nm RMS
- ***Appearance***: No visible grain highlighting or scatter



PV	2.047	fr
rms	0.217	fr
Power	0.101	fr
Size X	30.8	mm
Size Y	30.8	mm

Measured with commercial stitching interferometer

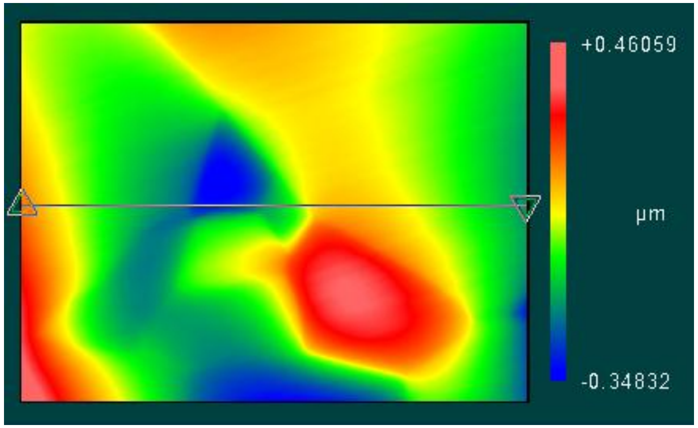


PV	10.699	nm
rms	1.332	nm
Ra	1.057	nm
Size X	0.35	mm
Size Y	0.26	mm

Measured with a white light interferometer, 20X Mirau objective, no filter applied

OPTIMAX

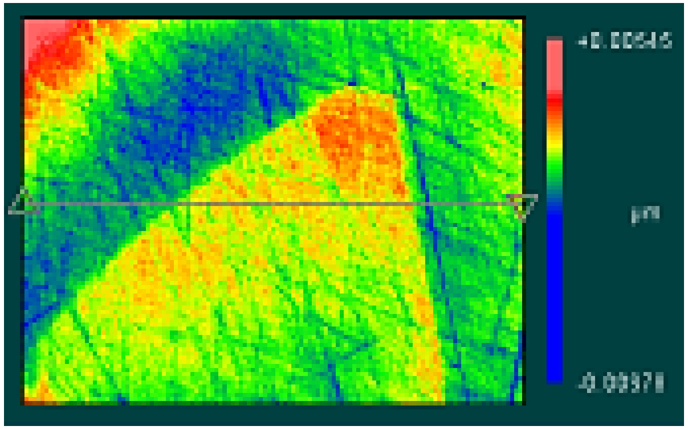
VIBE Finishing Results



Commercial setup

PV = 808nm

Areal RMS = 142nm



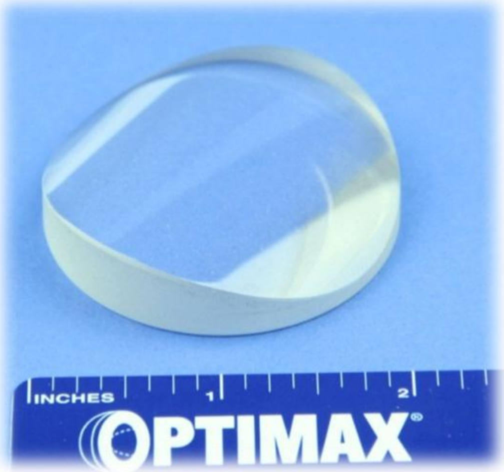
Optimized pad & slurry

PV = 15nm

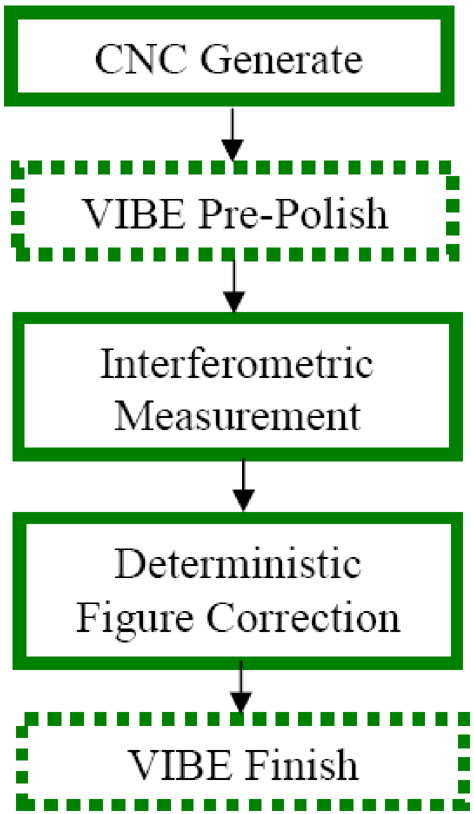
Areal RMS = 1nm

Spinel toroid dimensions

- 50 mm diameter
- 40 mm and 400 mm radii in orthogonal directions



Future of VIBE



1. Lower processing cost & time on hard materials
2. Lower processing cost & time on complex geometry optics
3. Higher precision aspheres & freeform optics
4. Reduced optical scatter on polycrystalline aspheres & freeform optics

Thanks!

Questions?