Exceptional service in the national interest

SAND2013-7040C

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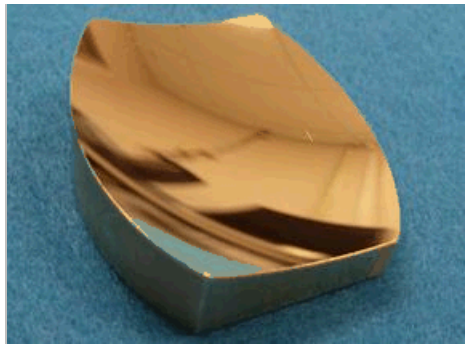

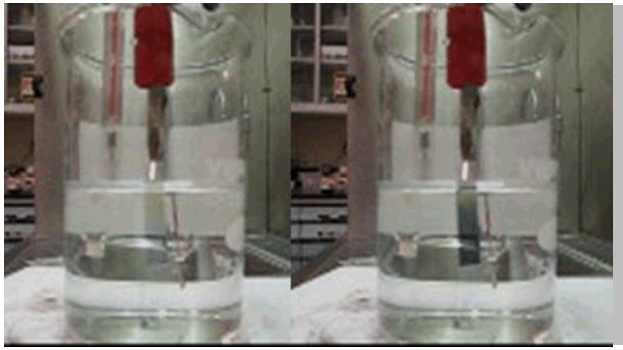

Design of Wearable Binoculars with On-Demand Zoom

Robert Boye, Ron Goeke, Jeff Hunt, Aaron Ison, Bradley Jared, Jamin Pillars, Mike Saavedra, William Sweatt, Ted Winrow, Steve Wolfley, Graham Yelton

Sandia National Laboratories, Albuquerque, NM

SPIE Optics + Photonics - San Diego, CA - August 26th, 2013

U.S. DEPARTMENT OF ENERGY | NNSA

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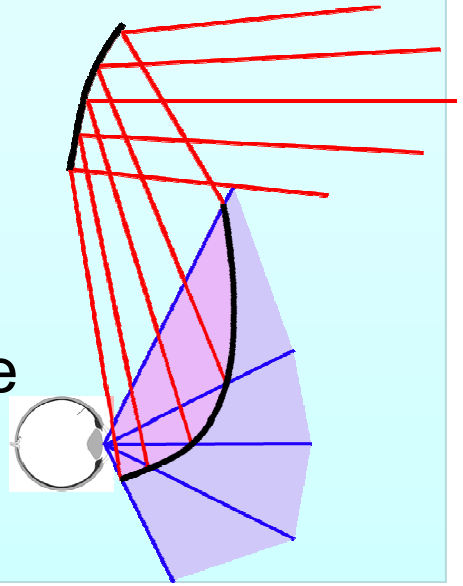
Overview

Project Goal: Design and build head-mounted (lightweight) binoculars for soldiers and switch between normal and zoomed view in ~100 ms.

Proposed solution: An off-axis, reflective telescope with an electro-chromic switchable mirror on final element for hands-free-zoom (HFZ). Specific performance goals of 5x magnification and 30° FOV (at eye).

Outline:

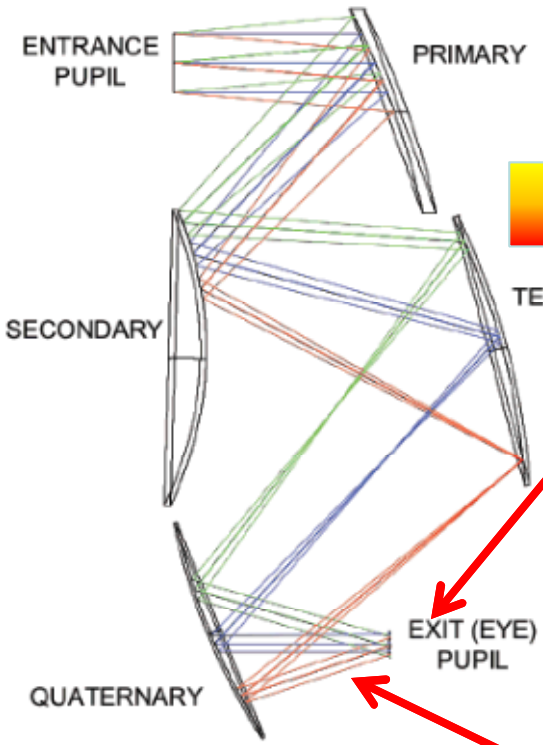
- Optical design – freeform surface
- Mirror fabrication – slow-slide servo
- Prototype assembly, and performance
- Advanced design progress
- Electro-chromic development



Optics Design - Overview

Sandia National Laboratories

Starting Point Design vs. Final



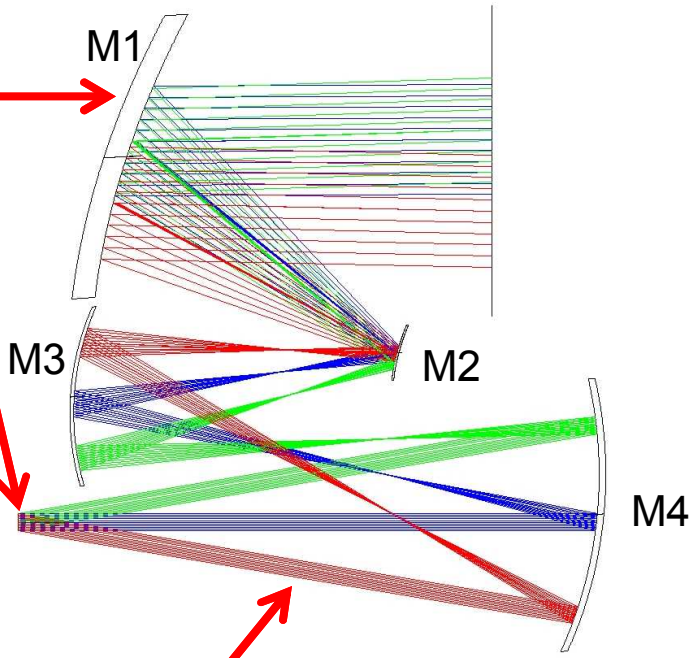
Ref.: Reynold S. Kebo, US Patent No. 4,804,258 (Feb. 1989).

Magnification increased from 3.5x to 6.6x

Freeform surface

Upright image

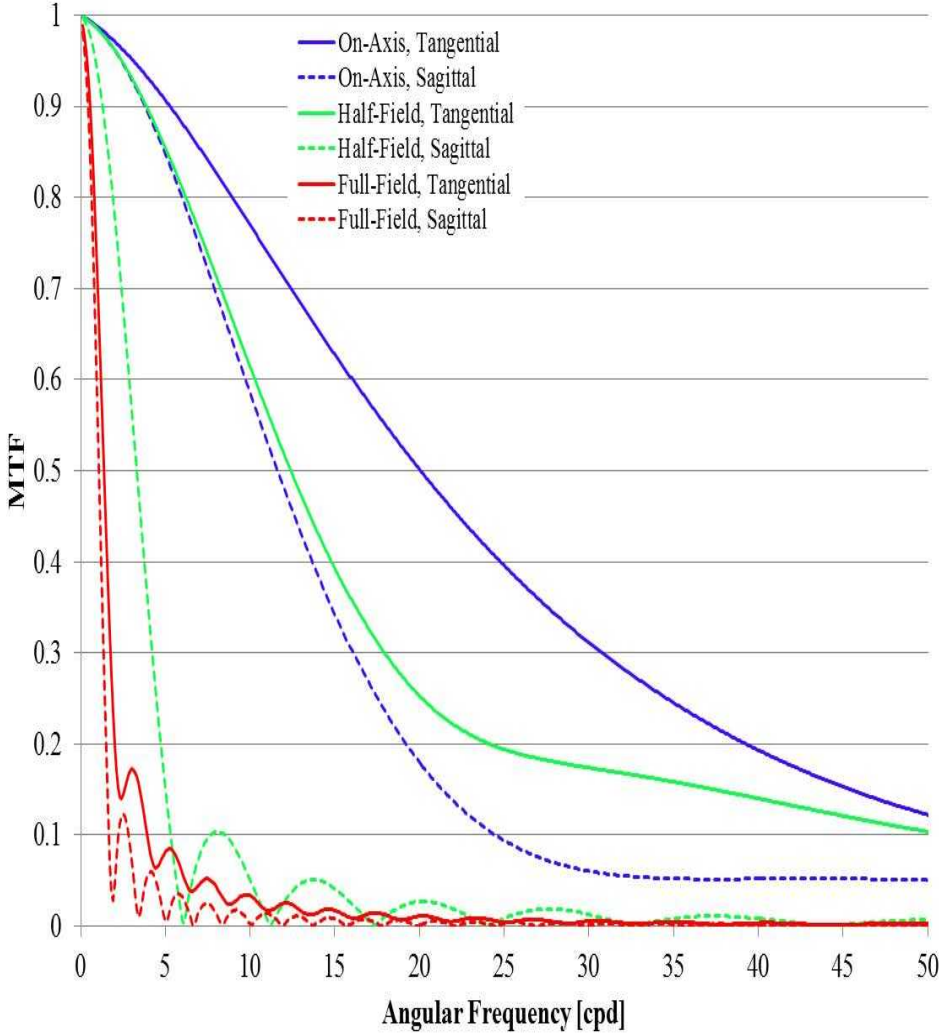
Extended eye relief

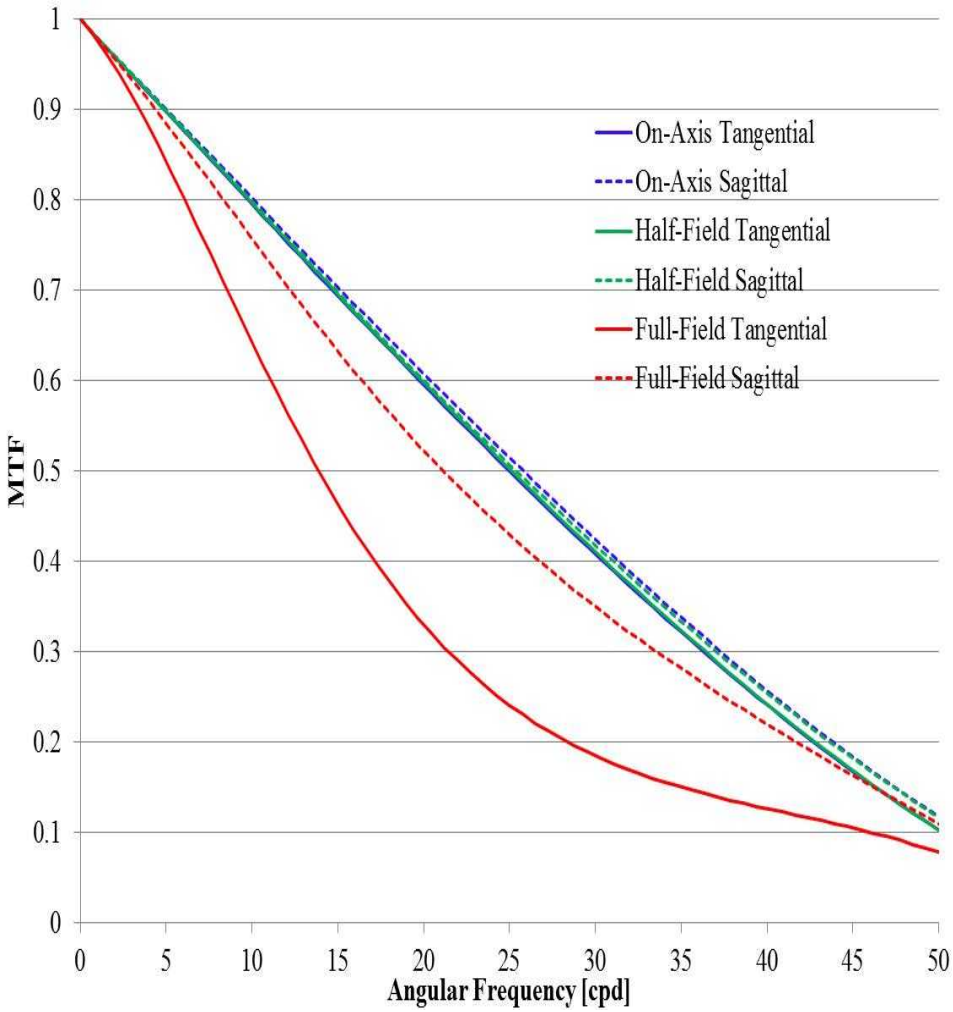


Optics Design - Performance

Sandia National Laboratories

Starting Point Design vs. Final

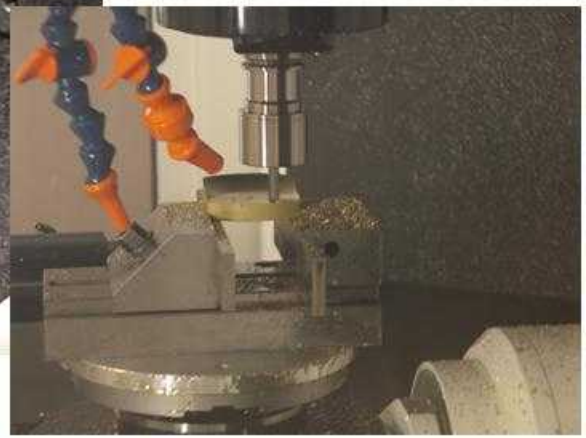




Fabrication – Processing Summary

Wire EDM

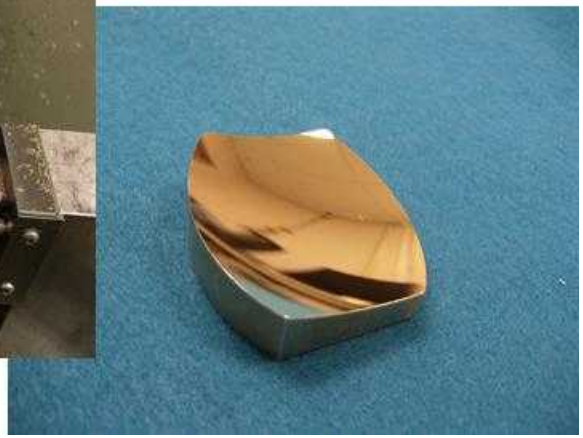
Mirror blank



Precision 5-axis milling

Blank and rough-cut mirror

Diamond turning



Final mirror

Fabrication – Delivered Mirrors

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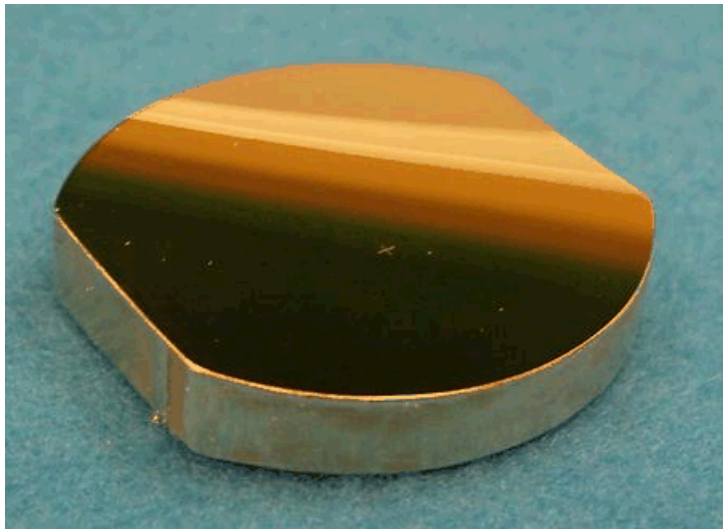
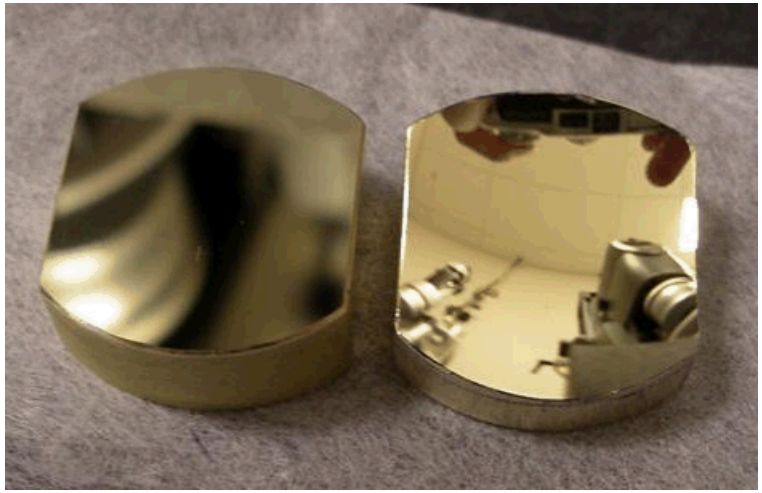
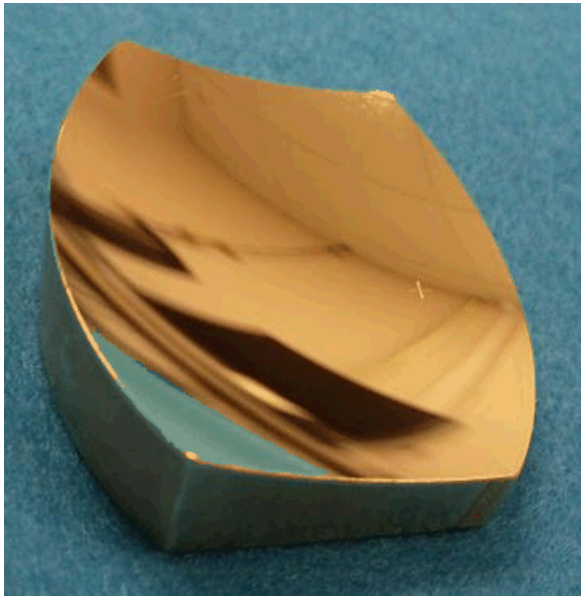
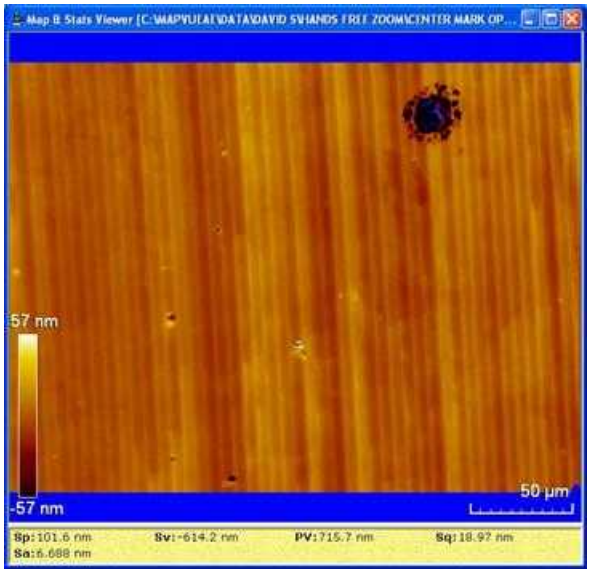






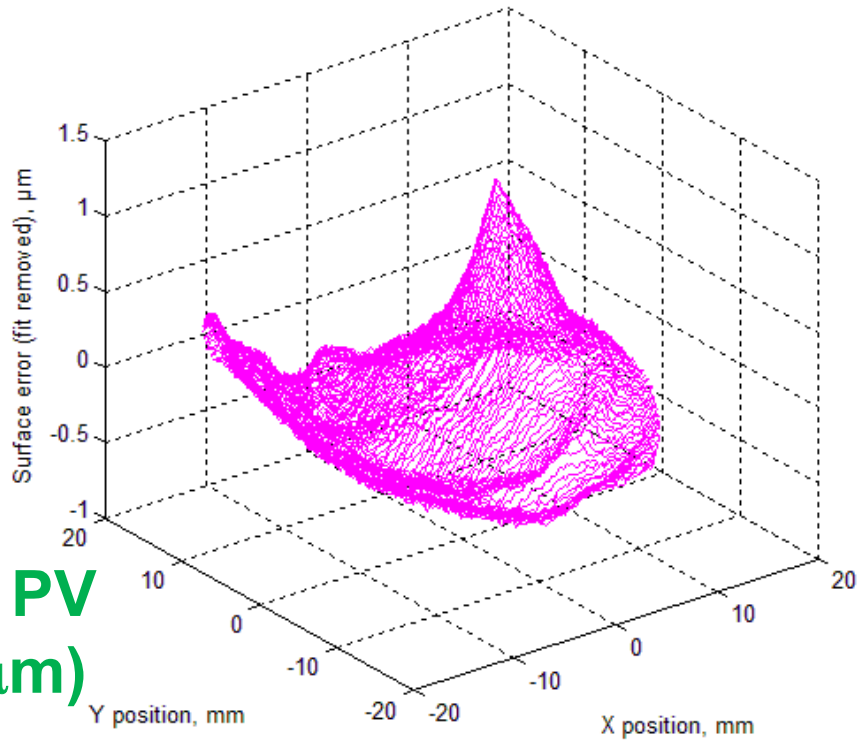
Fabrication – Metrology



Radius = 11 mm

RMS = 6.688 nm

Surface RMS roughness < 10 nm across entire aperture



Surface form error ≤ 1.8 µm PV (majority of aperture < 0.5 µm)

OptoMechanics - Design

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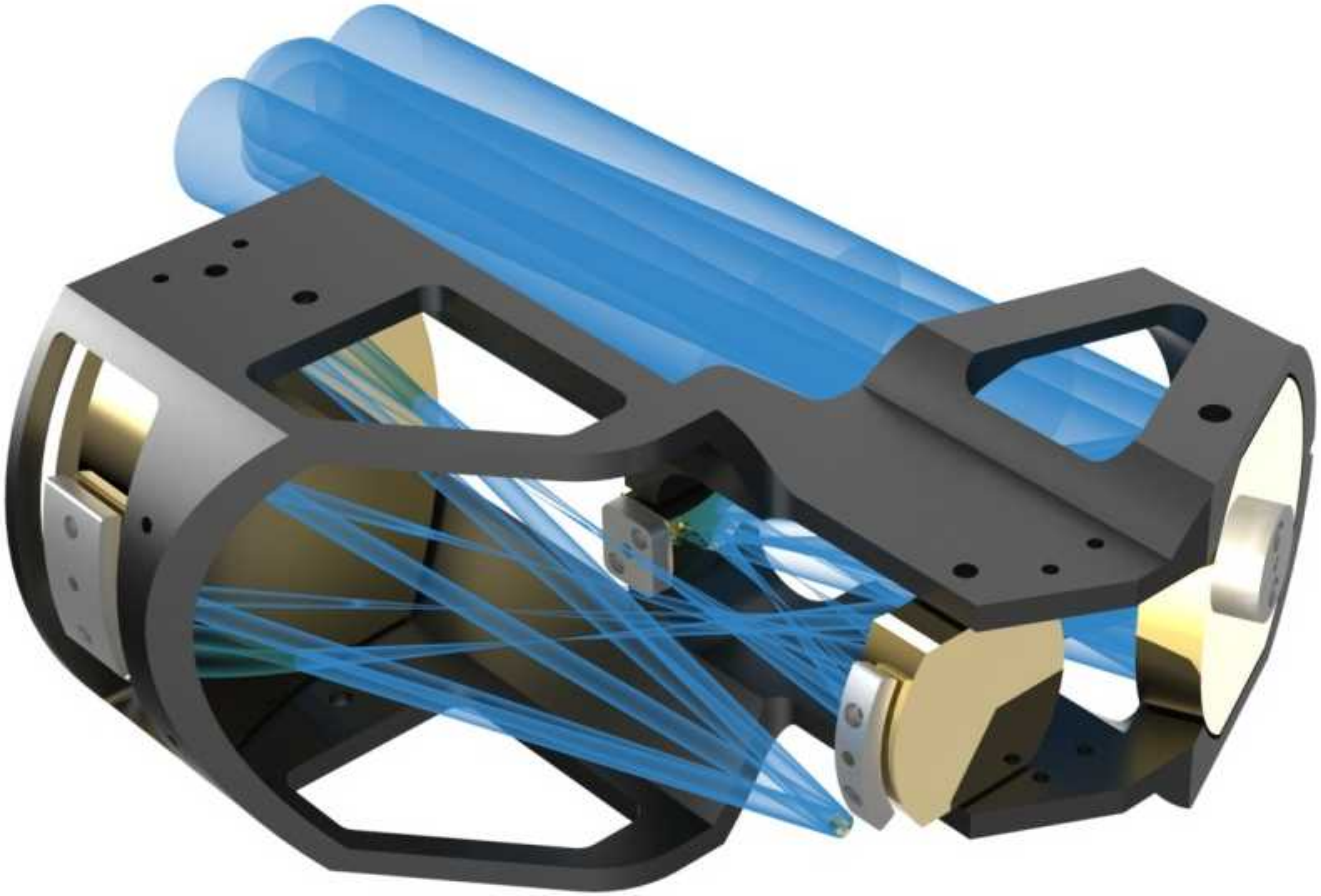

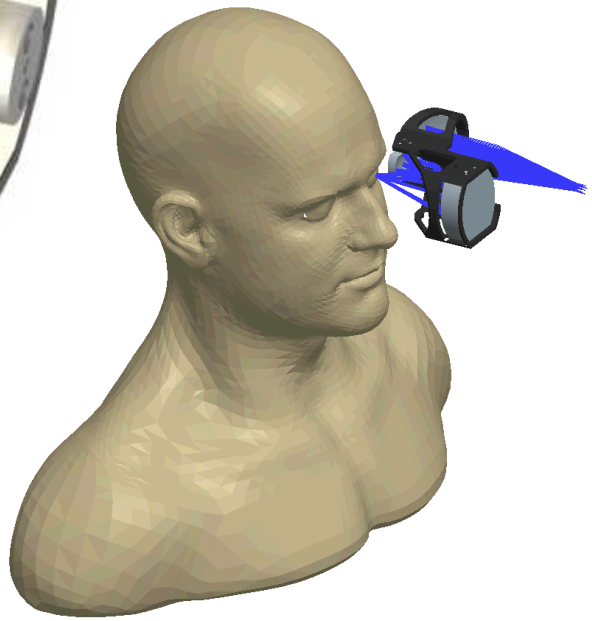

OptoMechanics – Visual Assembly

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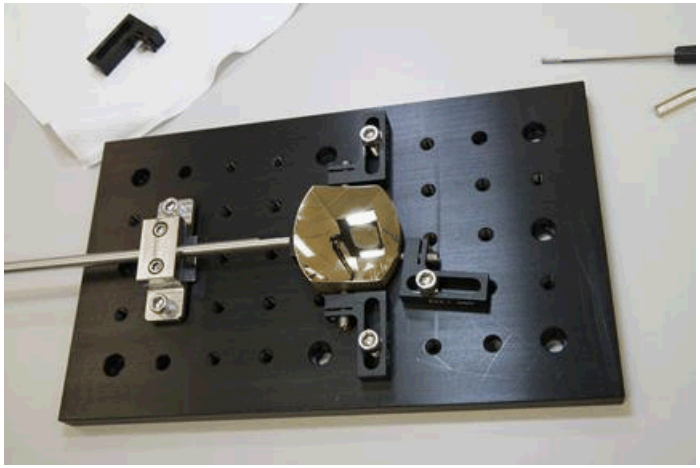
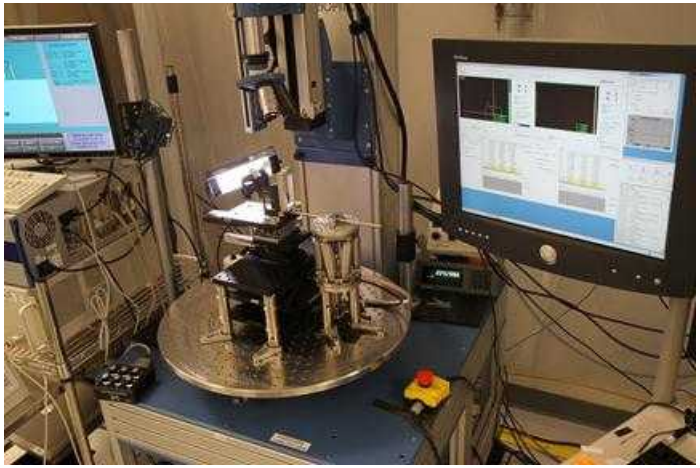
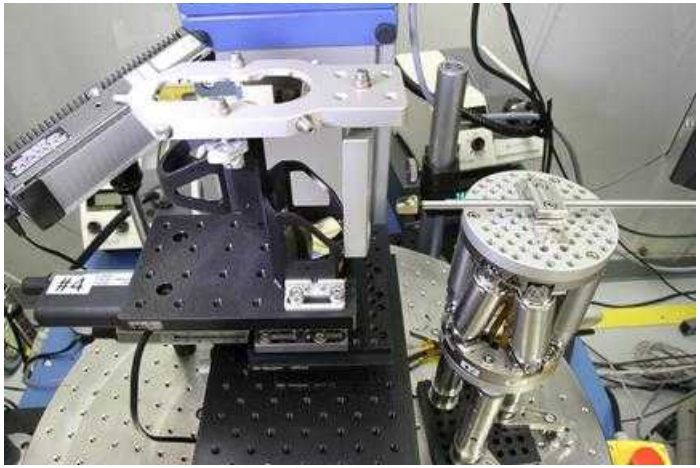


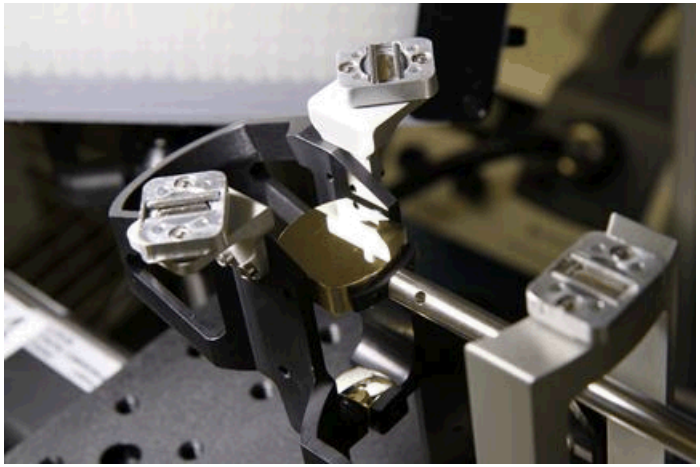
Bond mounting bracket for stinger arm



M4 alignment



M2 alignment, reference mirror in place



M3 alignment, kinematic mounts for reference mirror visible

OptoMechanics – Active Assembly

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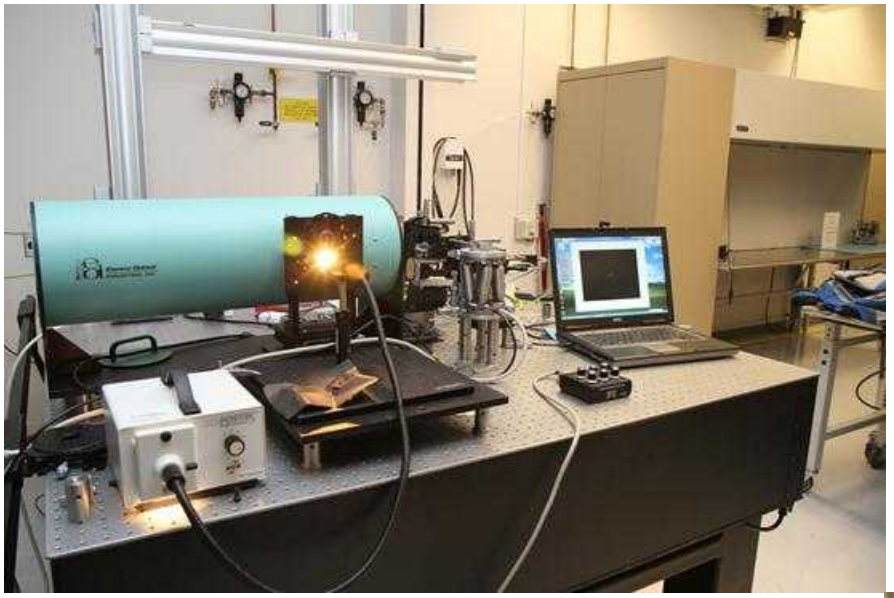
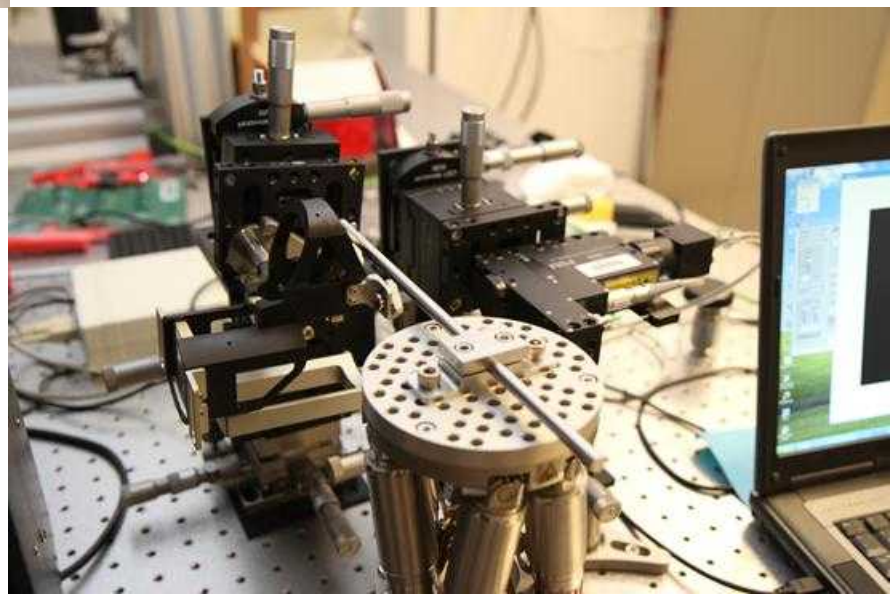


Telescope (green) provides collimated input to asssembly

Separate reference mirror provides proper tilt to assembly and point source microscope at output

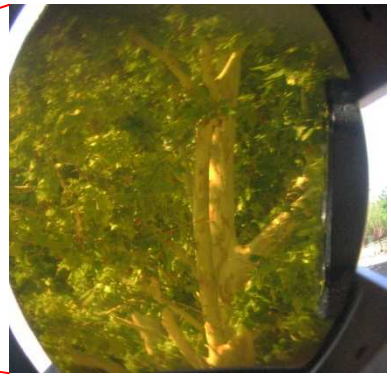
With collimator, assembly and point source microscope aligned to each other, M1 inserted into system

M1 aligned while output monitored



OptoMechanics – Prototype Monocular

First Image Through the System



Prototype Testing – Qualitative Imagery

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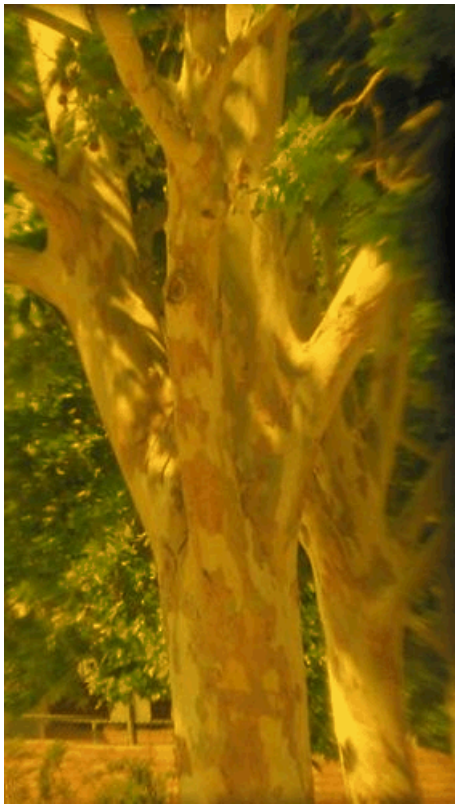
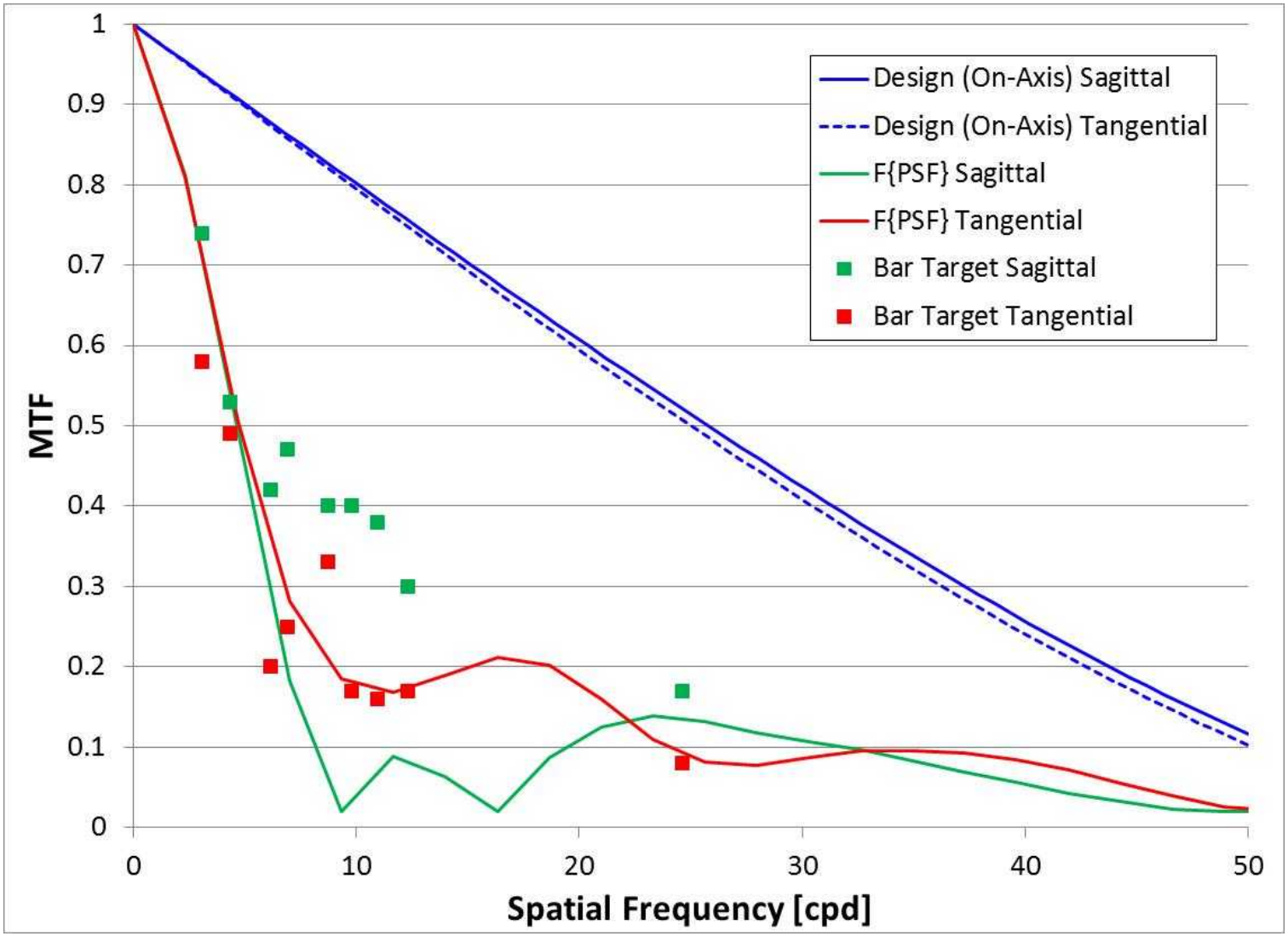
Zoomed
Digital SLR



HFZ with
Point & shoot

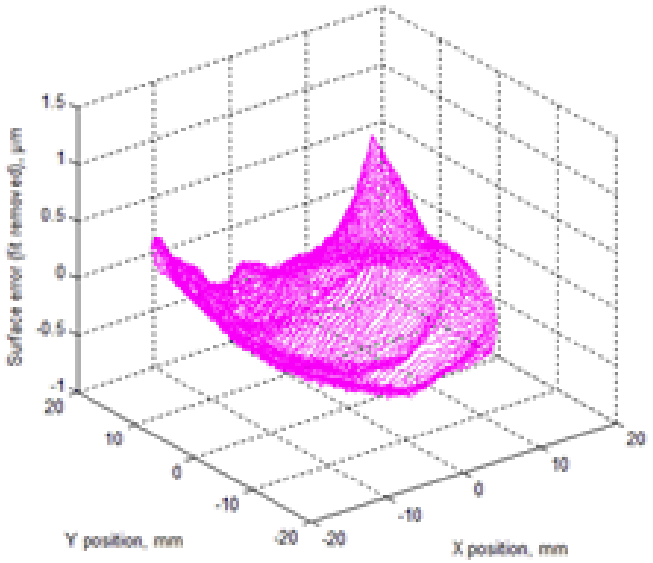
HFZ with
Point & shoot
False Color

Prototype Testing - MTF

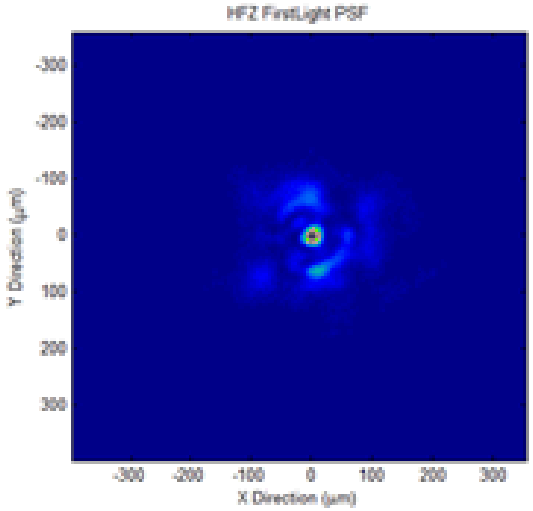


Prototype Testing – Form Error Impact

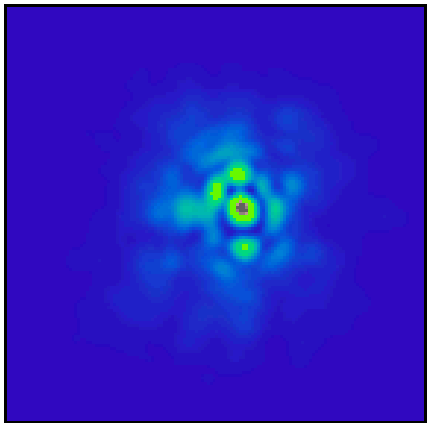
Image performance limited primarily by form error on single mirror



Surface form error of freeform mirror



Measured PSF



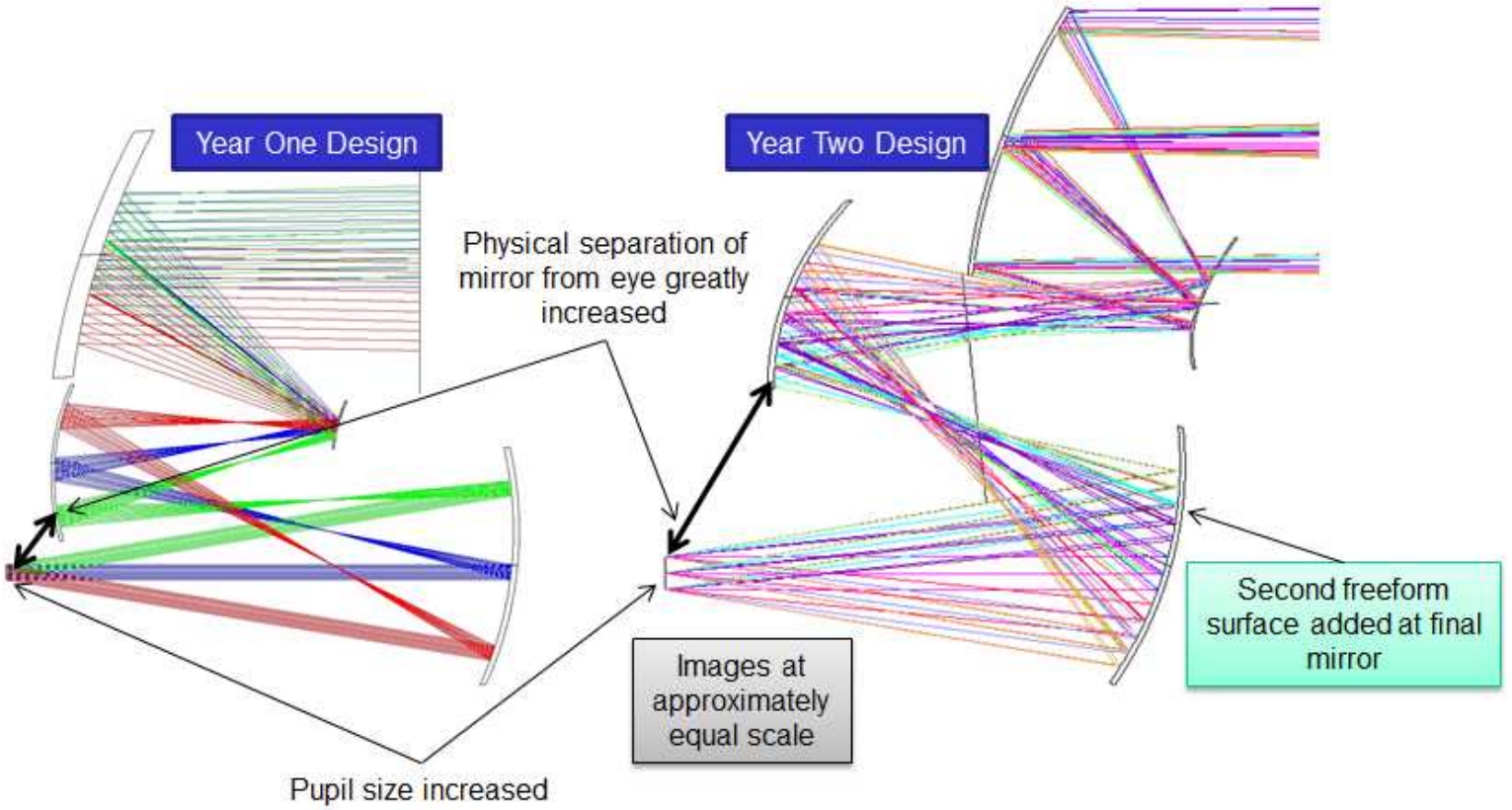
Simulated PSF including measured form error

Prototype Performance

- **Visually, imagery looks excellent**
- Distortion addressed in updated designs
- Causes for scatter and reduction in MTF qualitatively understood
- Mirror form within expectations over majority of aperture
- **Surface finish of mirrors is excellent**
- **Assembly method worked first time**

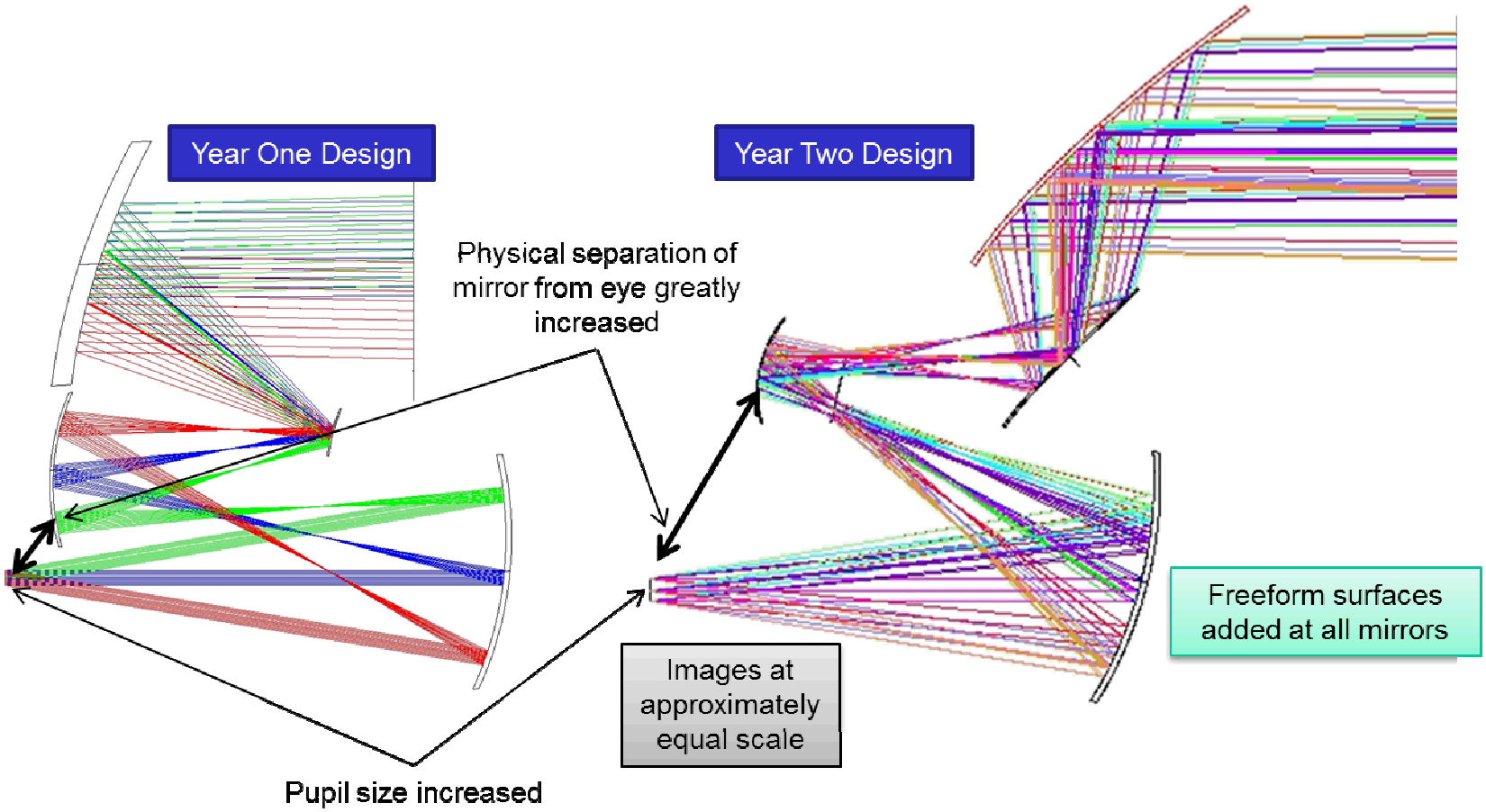
Advanced Optical Designs - 1

- Magnification between 7.5 and 8x
- Pupil size increased from 2.5 to 6.0 mm
- Eye relief (pupil to nearest mirror distance) increased from 10 mm to 40 mm.



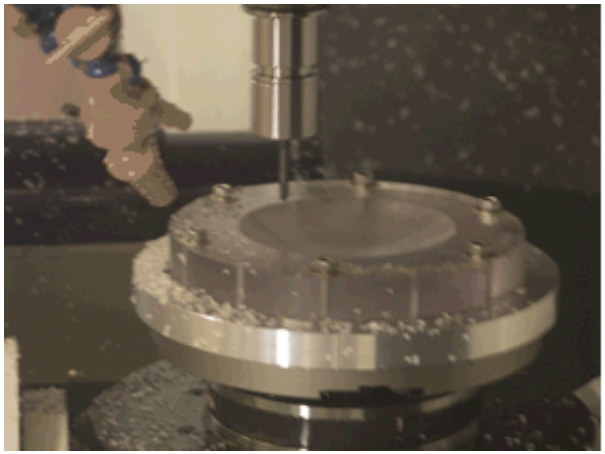
Advanced Optical Designs - 2

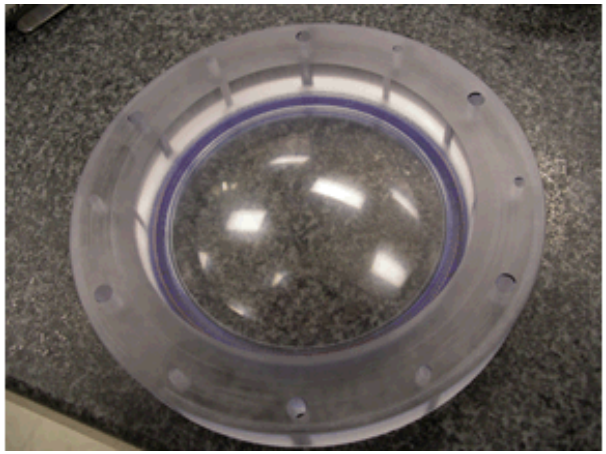
- Additional freeform surfaces significantly reduce distortion (by ~5x)

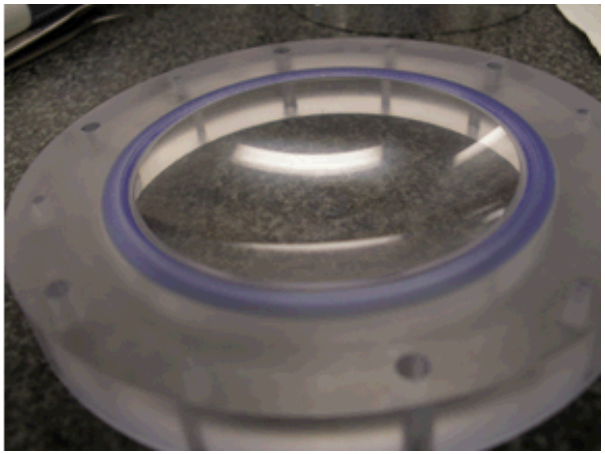


Mirror Fabrication Progress

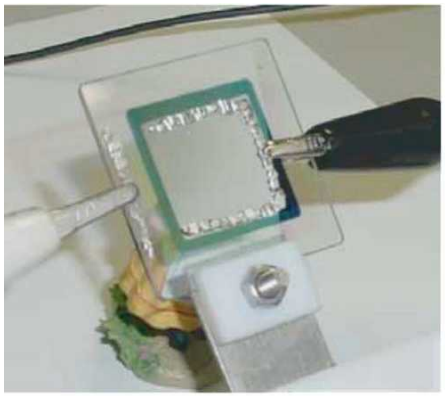
- Two-sided optic blank successfully machined in Lexan
  - Cut process (spindle speed, feed rate, etc.) determined
  - Procedure for two-sided optic
- Optical surface defined before part perimeter (change from prototype)

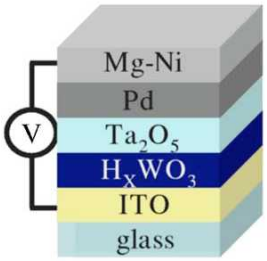


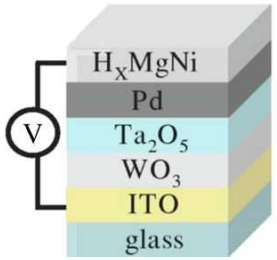




Electrochromics - Baseline Design







Ref.: K. Tajima, et.al., Electrochemical and Solid State Letters, **10**(3) J52-J54 (2007).

Will add Al between Pd and Ta_2O_5 as additional diffusion barrier

REFLECTIVE MODE ELECTROCHROMIC DEVICE

Anodic reaction

Mg_2Ni (reflective state) + $4H_+ + 4e_-$ = Mg_2NiH_4 (transparent state)

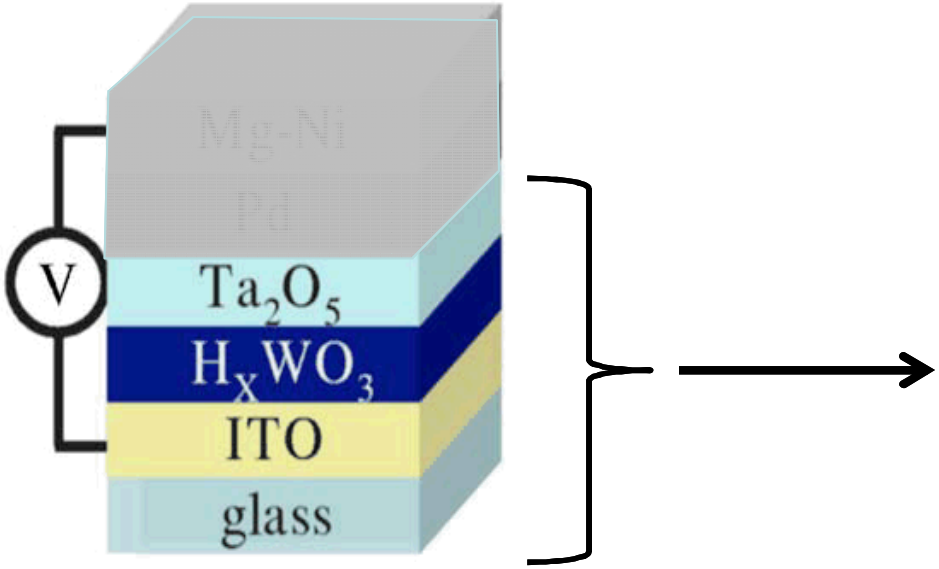
Mg (reflective state) + $2H_+ + 2e_-$ = MgH_2 (transparent state)

Cathodic reaction

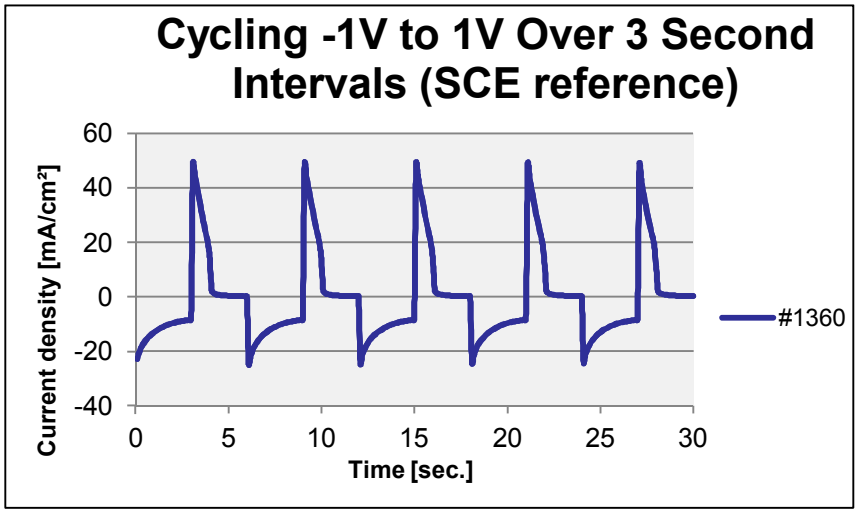
H_xWO_3 (colored state) = WO_3 (transparent state) + $xH_+ + xe_-$

where x is generally $0.05 < x < 0.4$.

Electrochromics – WO_3 Development



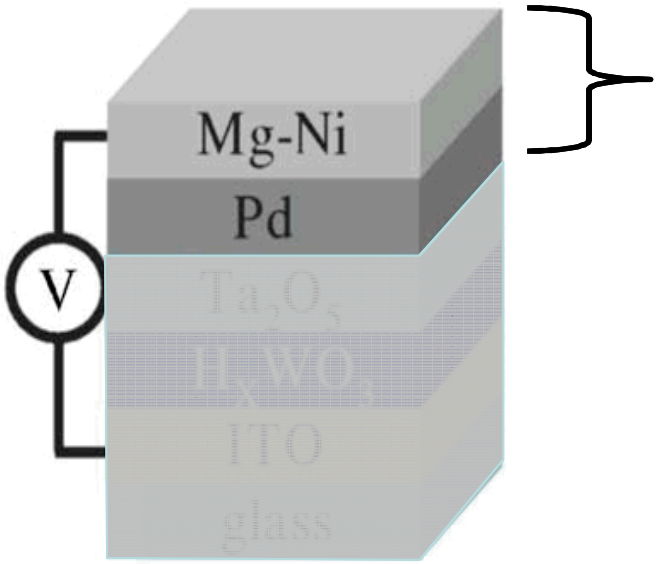
Cycling from -1V to 1V for 3 second intervals



Transmission switching from 12-92%

Transitions as fast as 150 ms

Electrochromics – Mg-Ni Development



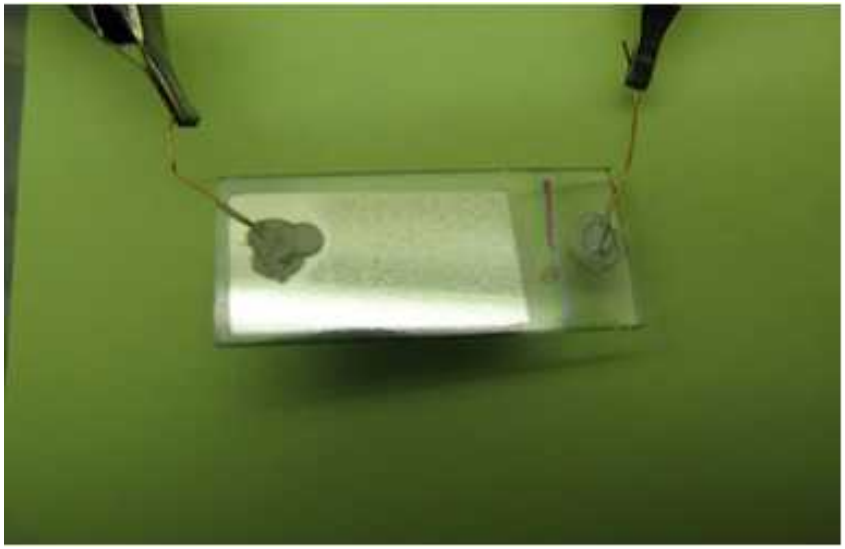
Mg-Ni switching demonstrated in half-cell

2.9% < T < 33%

Switching in ~ 19 sec

Electrochromic Full Device Development

Device in the reflective and transmissive states. The low transmission is due, in part, to the ratio of magnesium and nickel. Further optimization work will look at increasing the magnesium content to allow for higher transmission.



Conclusion

Sandia National Laboratories

- Successful demonstration of unique optical designs
  - Providing 6.6x / 4.5° FOV with single freeform surface
  - Additional freeform surfaces allowed larger pupil or reduced distortion
- Fabrication of freeform mirror using slow-slide servo fabrication
  - Excellent surface finish without post-polishing
  - Good form accuracy
  - Process extended to optical plastic
- Prototype assembly worked first time with excellent image quality
- Electrochromic mirror development
  - Fast switching of absorbtive devices, ~150 ms
  - Demonstration of first full device

This project was supported by DARPA's SCENICC program