MEMS Deformable Mirrors

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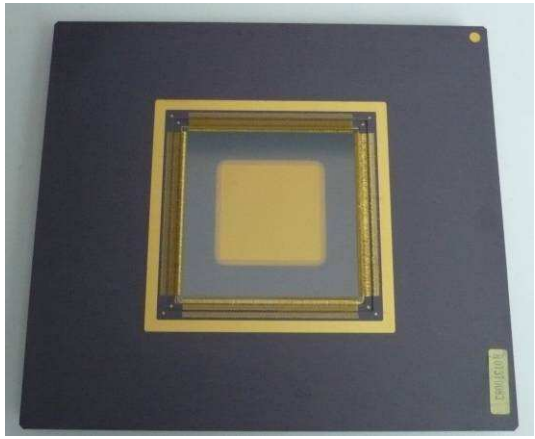
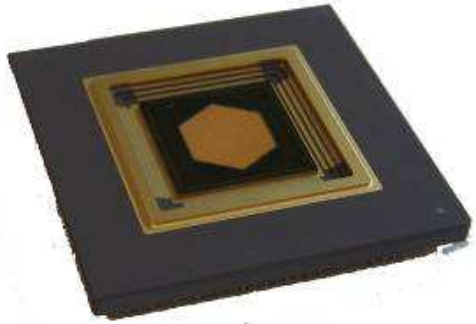


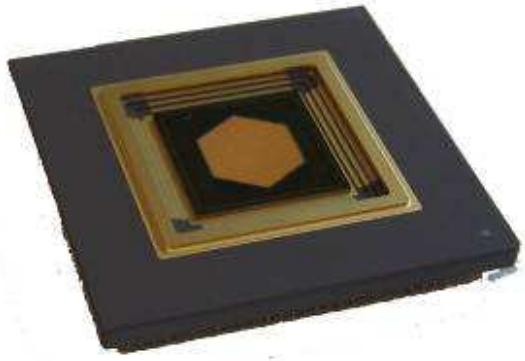


8th Annual Mirror Technology Days
Albuquerque, NM
August 26, 2007

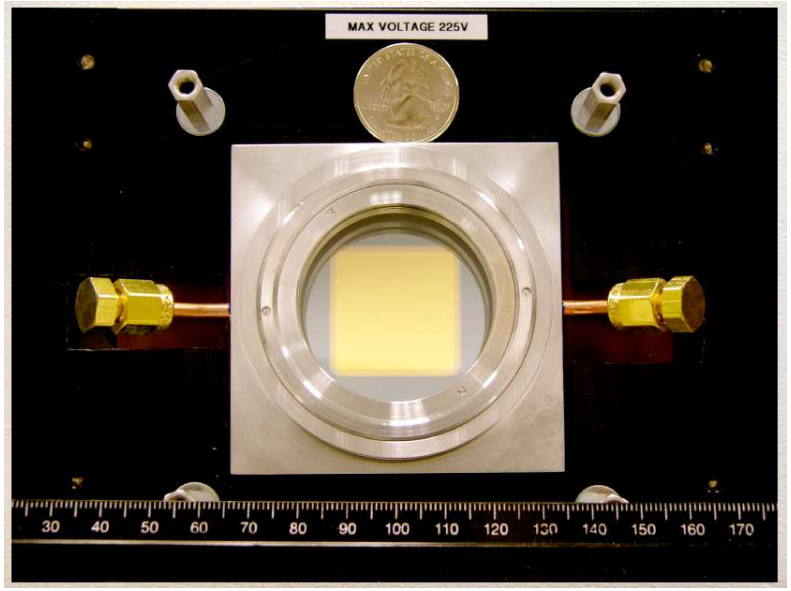
Boston Micromachines Corporation

Outline

- 331 Element Tip-Tilt-Piston DM (NASA SBIR Phase II)
  - Space-based visible nulling coronograph (TPF-C)

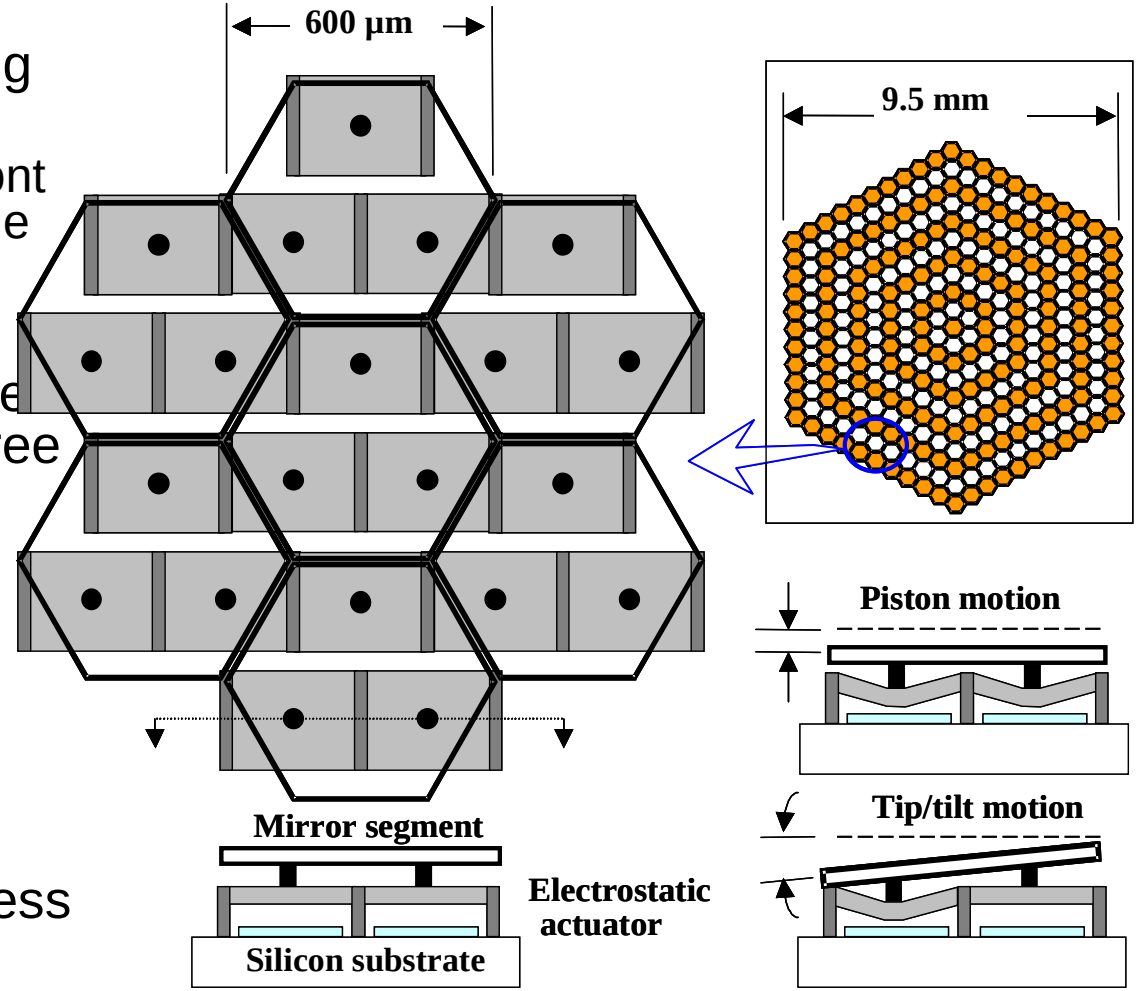


- 4096 Element Continuous Facesheet DM (GPI)
  - Ground based high-contrast imaging system



331 Element Tip-Tilt-Piston MEMS DM

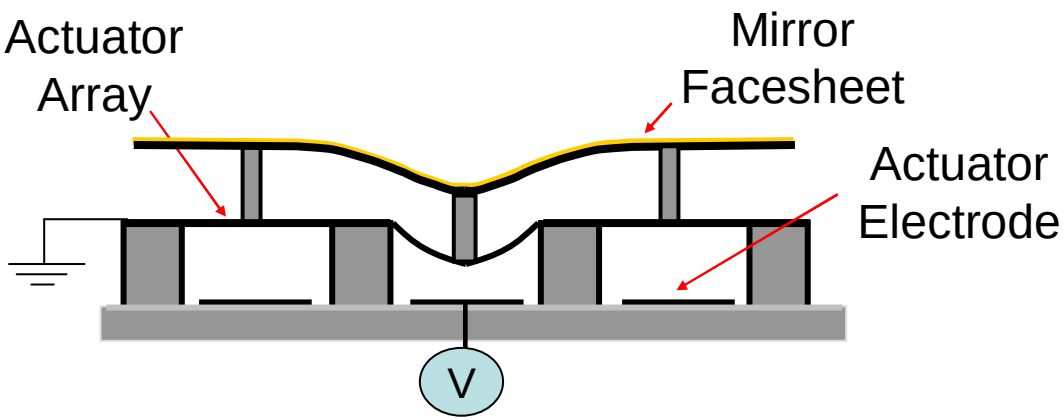
- DM required for visible-nulling coronograph
  - control subaperture wavefront phase (piston) and amplitude (tip/tilt)
- 331 hexagonal elements
- Each mirror segment has three piston actuators, allowing three degrees of freedom
  - 993 actuators
  - 1µm of stroke
  - 3mrad tip/tilt
- <10nm RMS Mirror segment Flatness through range of motion
  - Epi-Poly fabrication process developed for Mirror segments

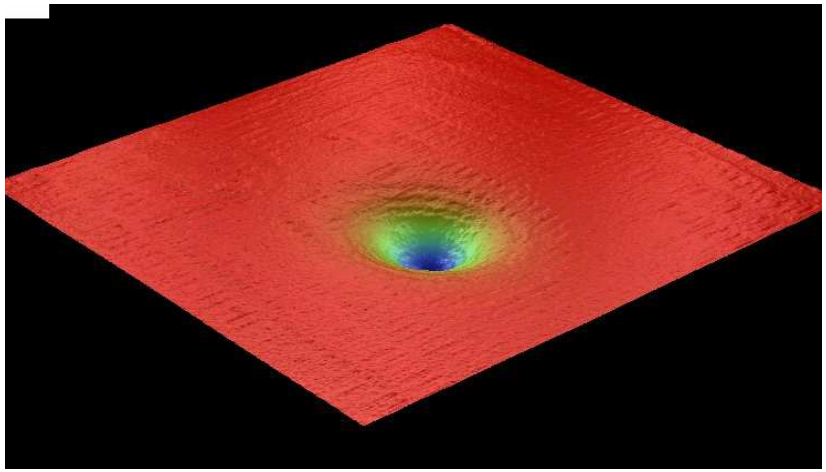


331 segments, pitch ≈ 600µm

TTP limits: +/-6mrad tip-tilt, 2um piston

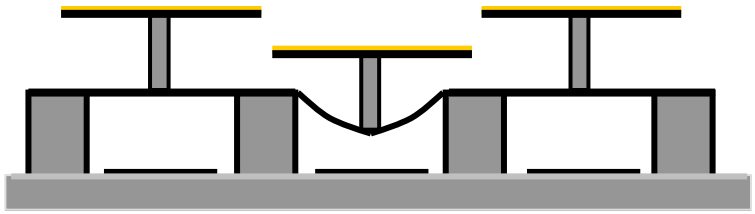
BMC Deformable Mirror Architecture



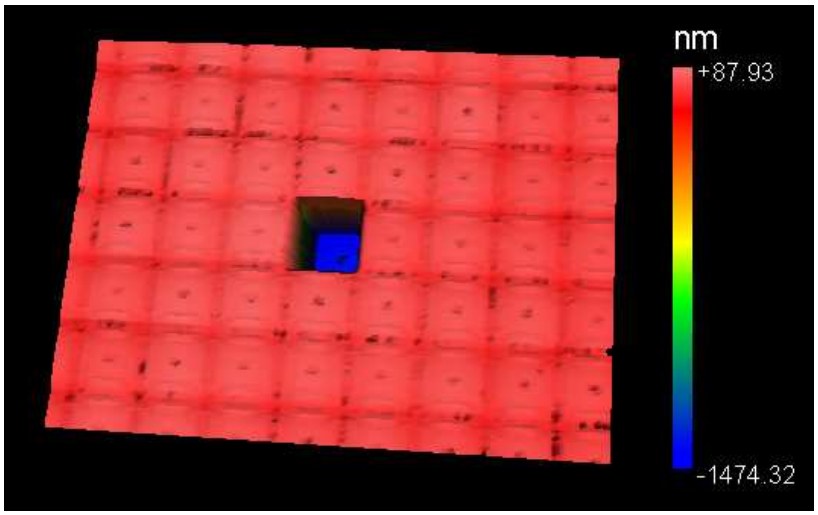


Continuous mirror (smooth phase control)

- Localized Influence Function
- Hysteresis-Free, Electrostatic Actuation
- Scalable and robust Architecture

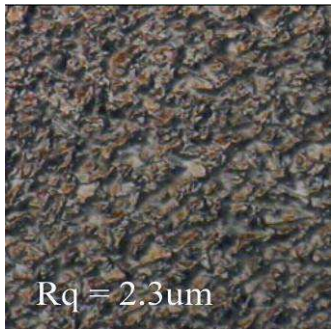


Segmented mirror (uncoupled control)

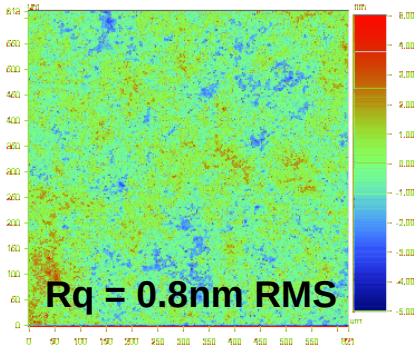


Mirror Segment Design

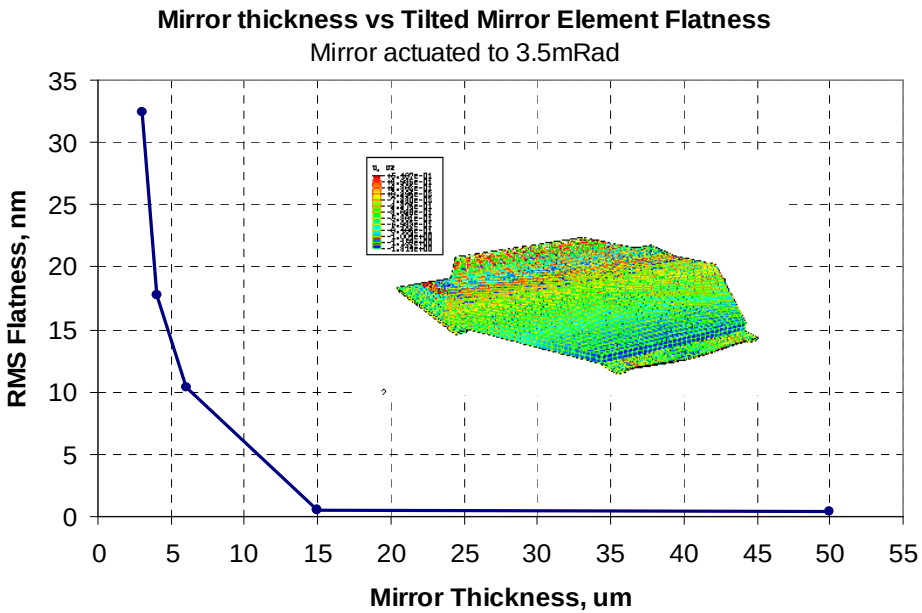
- Thick Structural Film (~10µm) to achieve surface figure requirements
  - Improved polishing
  - Increase segment stiffness



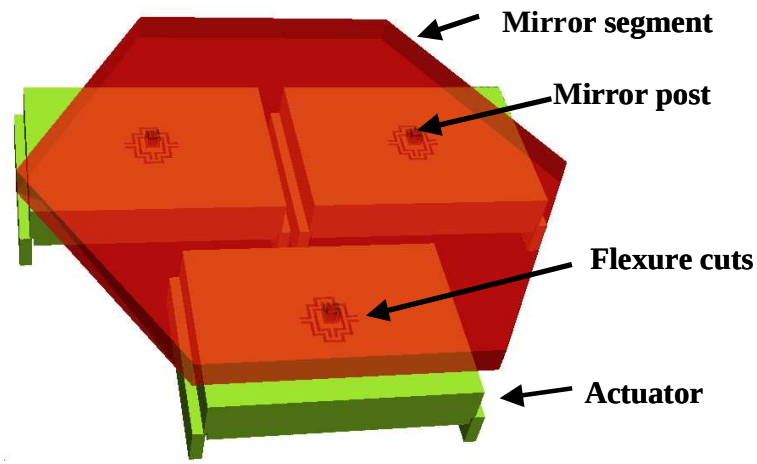
Pre-Polish



Post-Polish



- Flexure cuts introduced around the mirror post connection in double cantilever flexure to reduce mirror segment bending due to mechanical bending moments
- Torsional stiffness (k_T) of the actuator/post interface reduced ~30X



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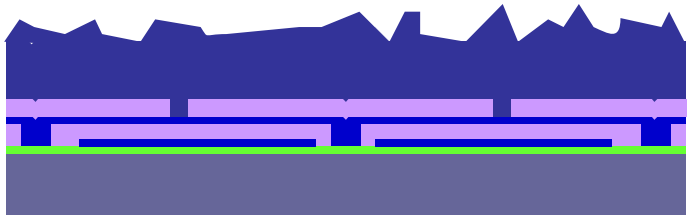
Device Fabrication Process

Start with silicon wafer coated with Nitride dielectric layer

Deposit & pattern polysilicon actuator electrodes

Deposit sacrificial PSG layer and pattern actuator anchors

Deposit 2nd polysilicon layer to form actuators

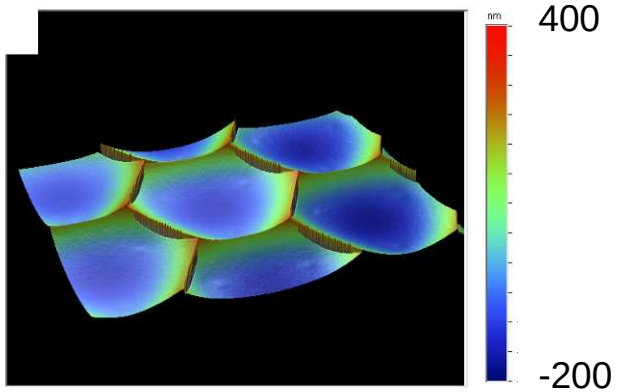


Grow thick Epi-Poly to form mirror layer

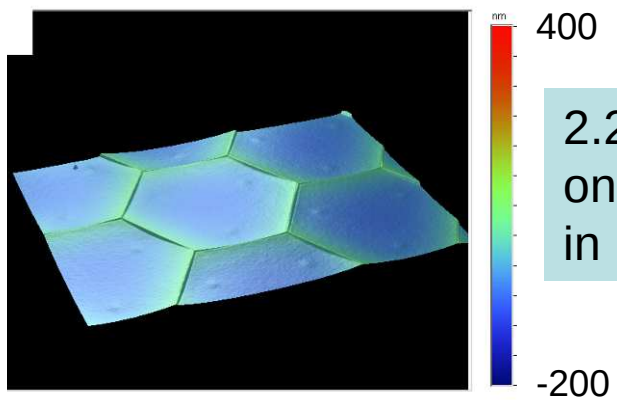
Polish Epi-Poly and pattern hexagonal mirror segments and anneal

HF Release and apply reflective coating

Mirror Curvature Control with Anneal

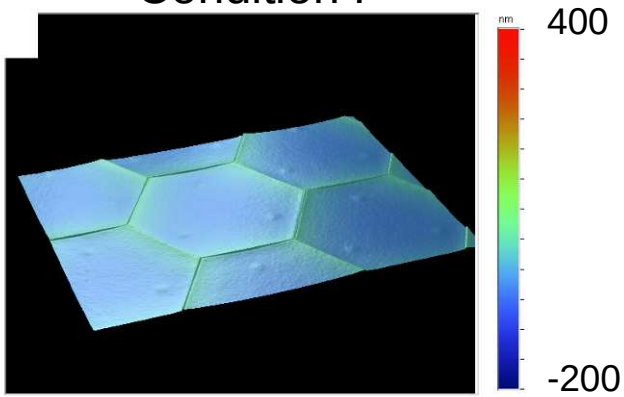


Condition I

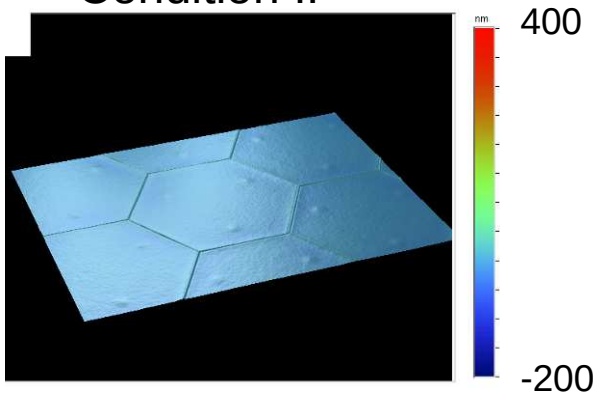


Condition II

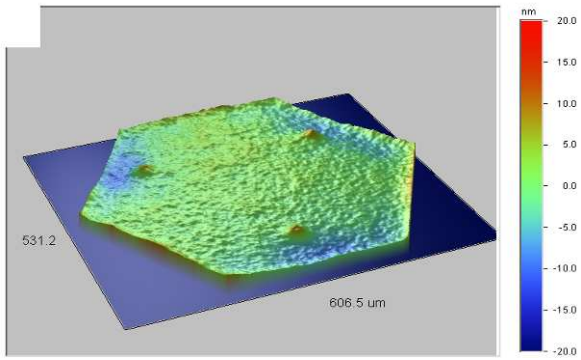
2.2 nm RMS surface flatness on mirror segments achieved in Phase I



Condition III

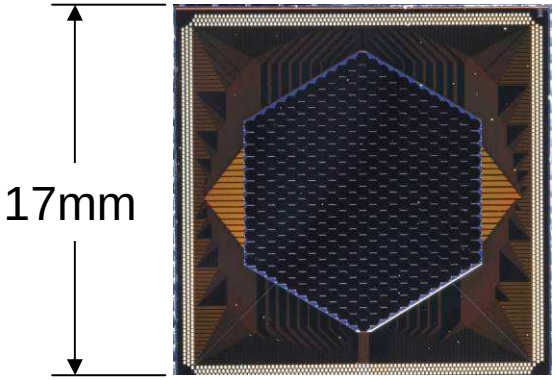


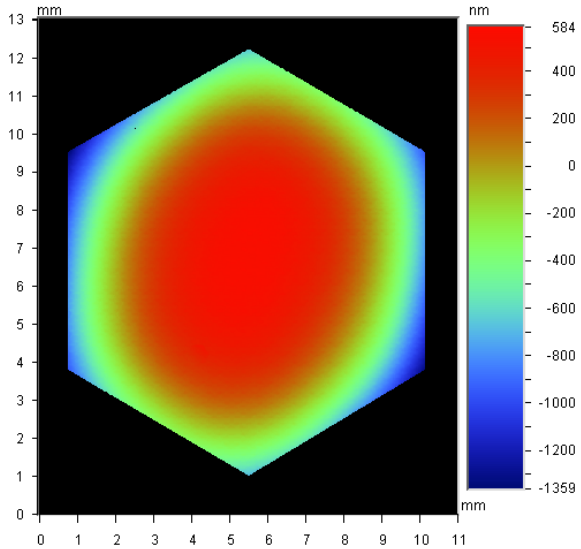
Condition IV



Results – Surface Figure

331 Element DM Aperture

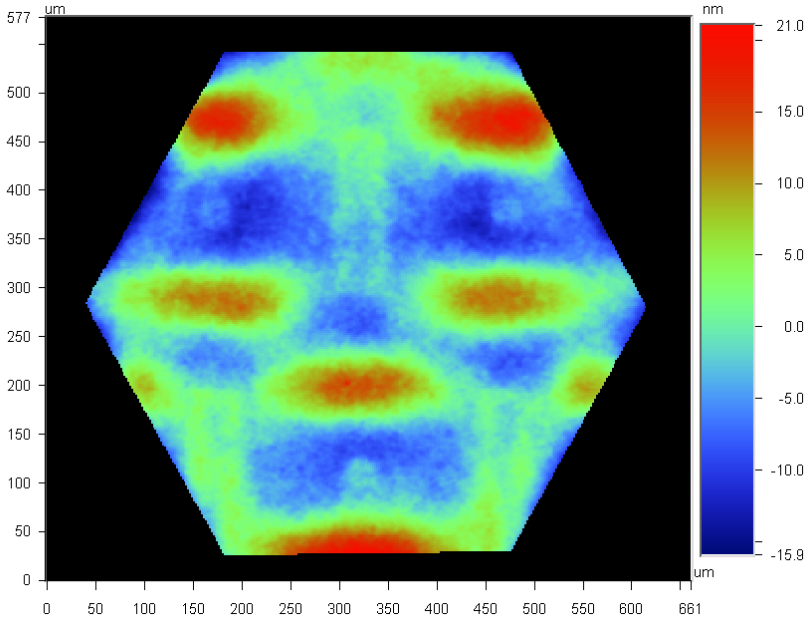




9.8m ROC over aperture (unpowered)
Can be corrected for using DM actuators if needed

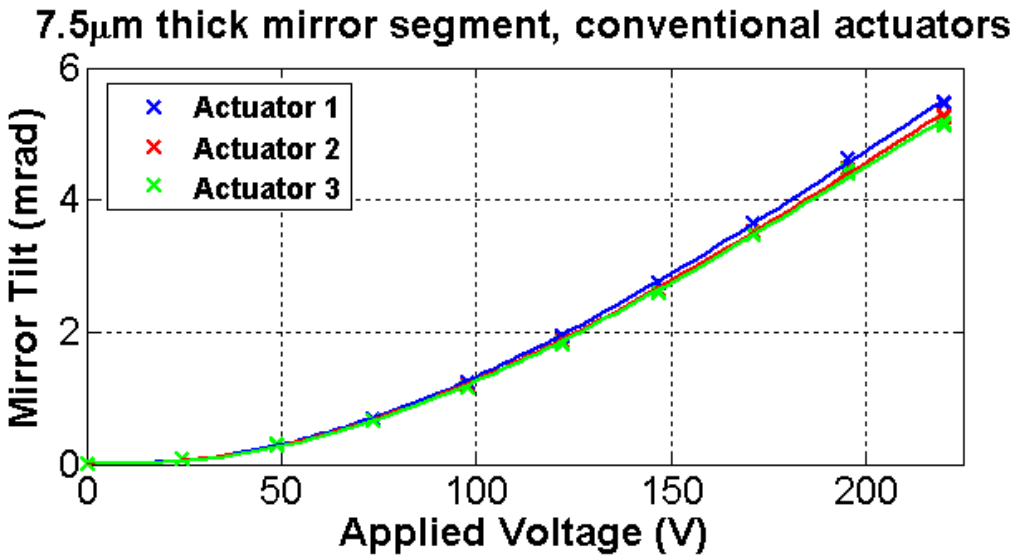
Single Mirror Segment

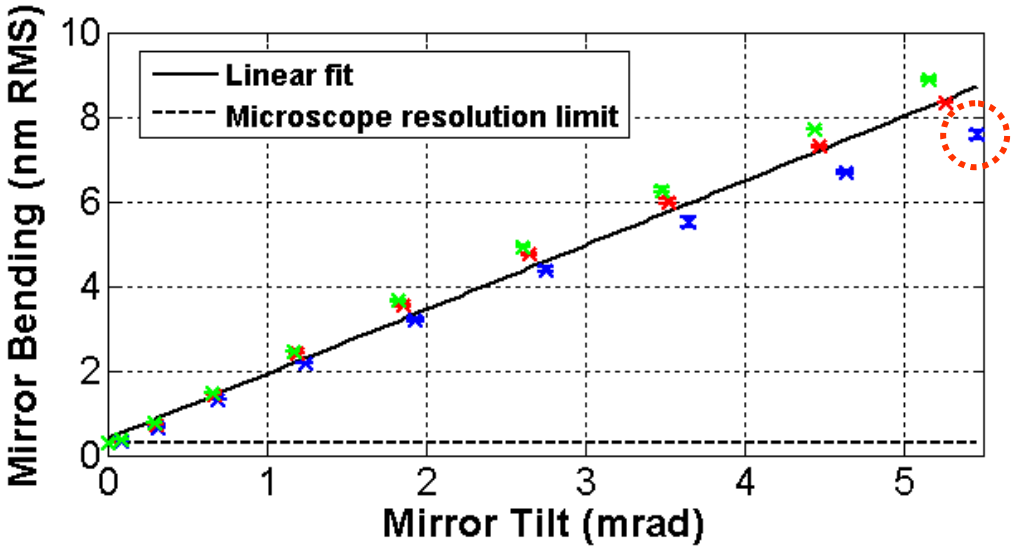
Flatness: 5.2nm RMS
5.9 nm ± 0.2nm RMS over DM aperture

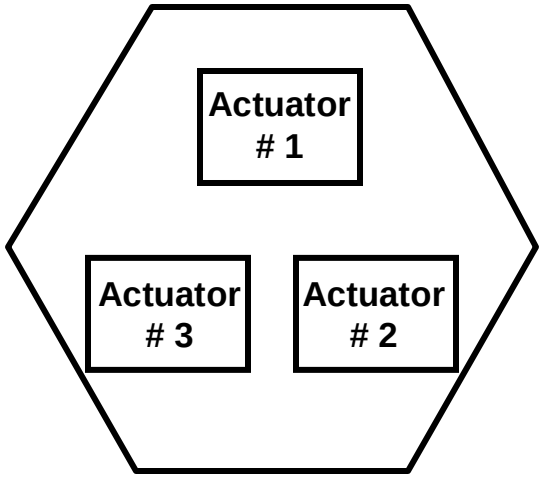


Actual Segment Thickness: 7.5mm
Target Thickness = 9µm

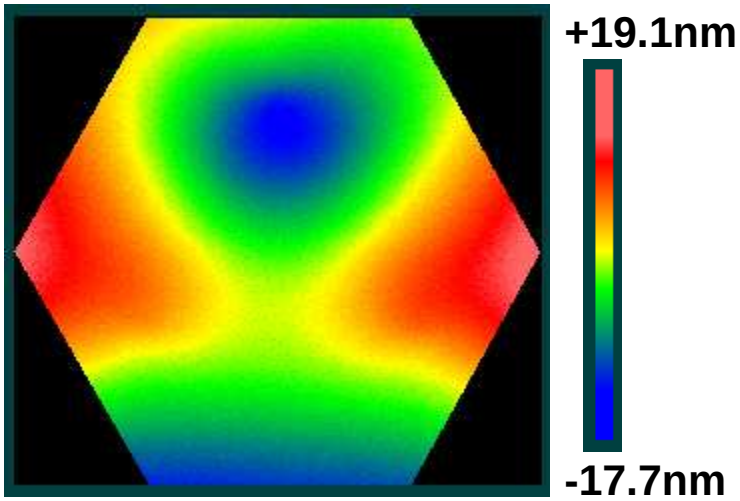
Bending Results – Conv. Actuator





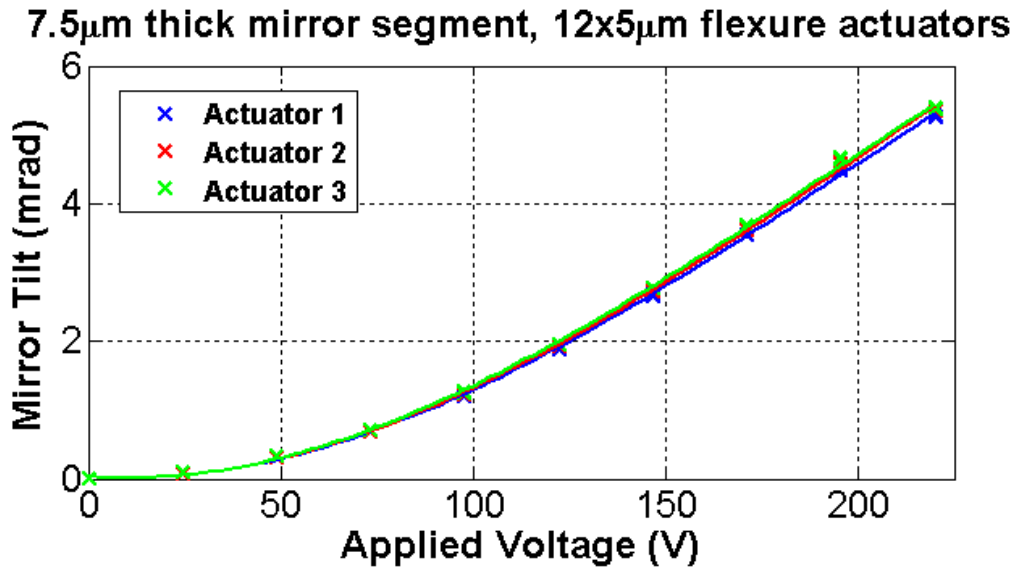


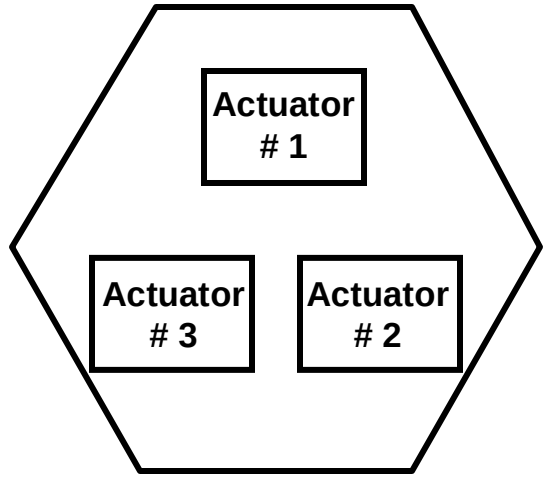
Difference measurement

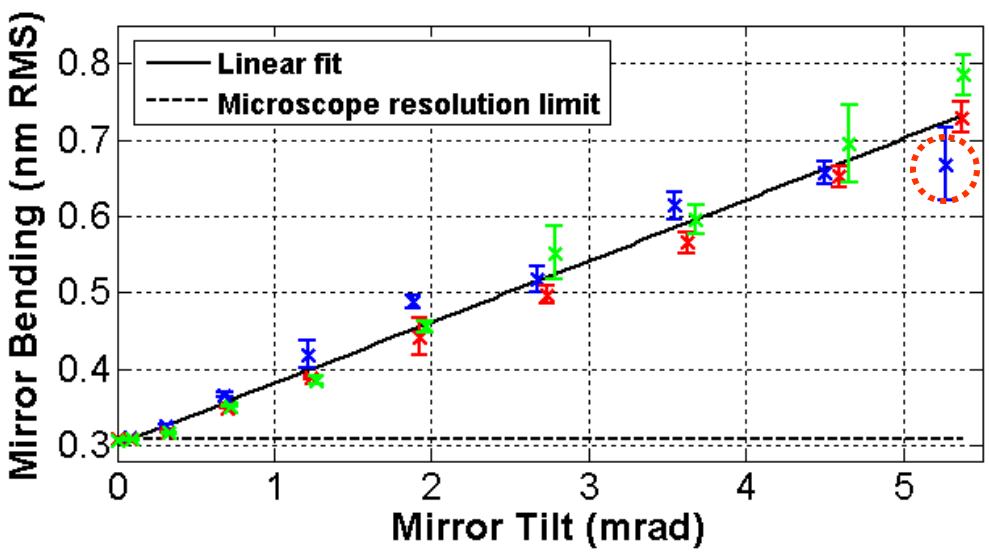


5.5mrad tilt
7.6nm RMS bending

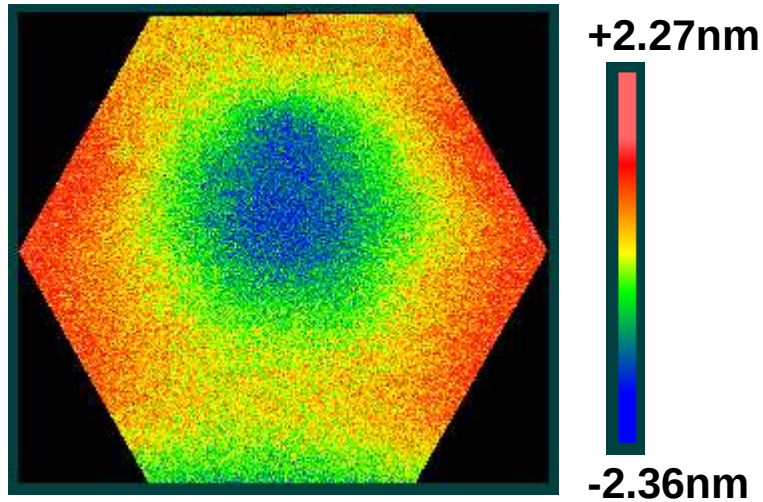
Bending Results – Flexure Actuator







Difference measurement



6mrad tilt
0.68nm RMS bending

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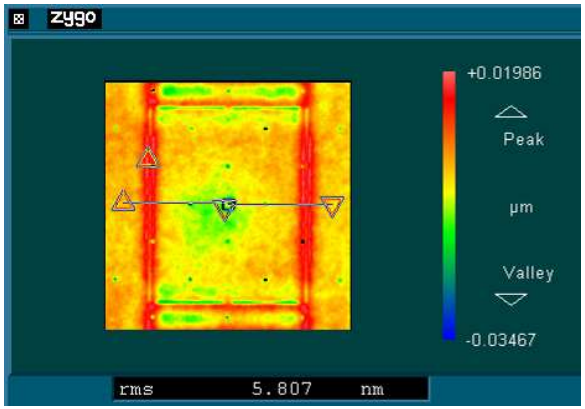
4096 Element Continuous Facesheet DM

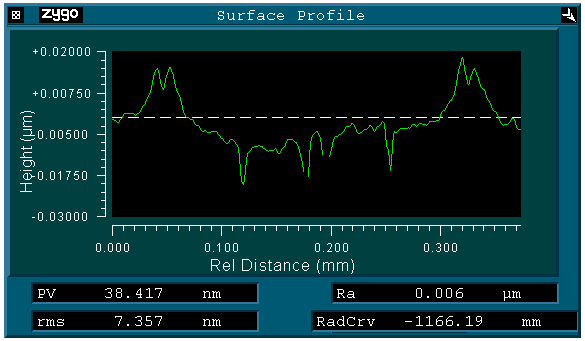
- In development for Gemini Planet Imager (GPI) to enable high contrast imaging

- Device Description
  - Active Aperture: 25.2mm
    - GPI Requirement: 19.2mm (48 actuator diameter)
  - Actuator Pitch: 400µm
  - Array Size: 68x68
    - Active: 64x64
    - 2 inactive rows around periphery
  - Stroke: 3.5µm
  - Inter-actuator Stroke: 1µm
  - Single Element surface finish (RMS): <10nm
  - Fill Factor: > 99%
  - Reflective Coating: Gold
  - Bandwidth: >2.5kHz

Phase II Results – DM Surface Quality

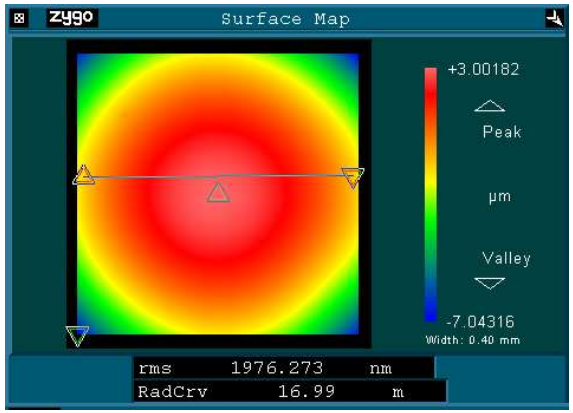
Single Element Surface figure:
<8nm RMS achieved

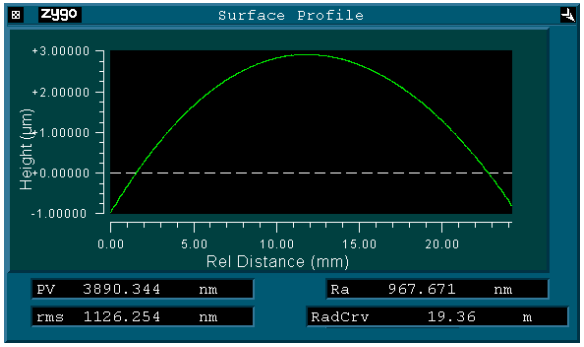




Surface Figure over 25.2mm Aperture

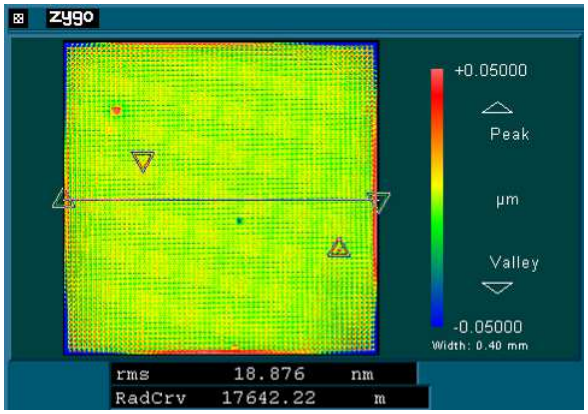
Unfiltered

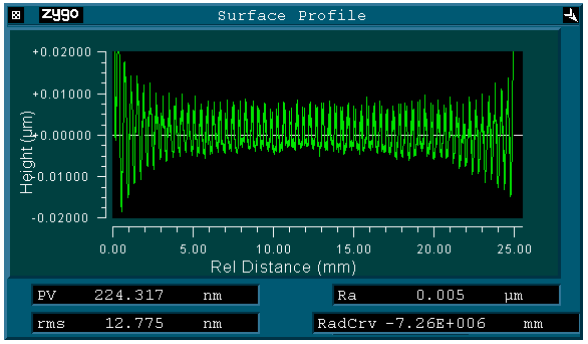




ROC: 17m
(Attributed to wafer bow and CMP)

High Pass filter
(λ = 1.2mm applied)



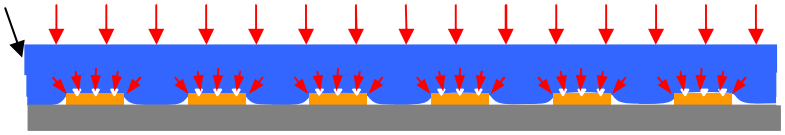


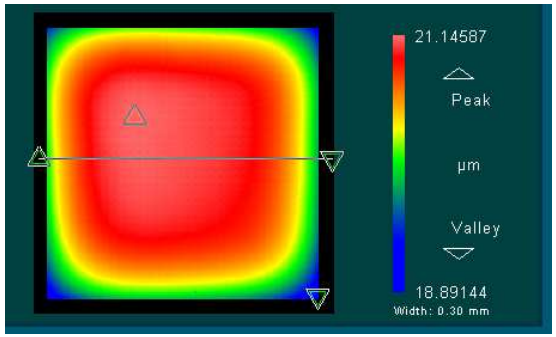
surface figure outside of the control band (>2.5/mm) resulting from residual stress in mirror: <40nm PV

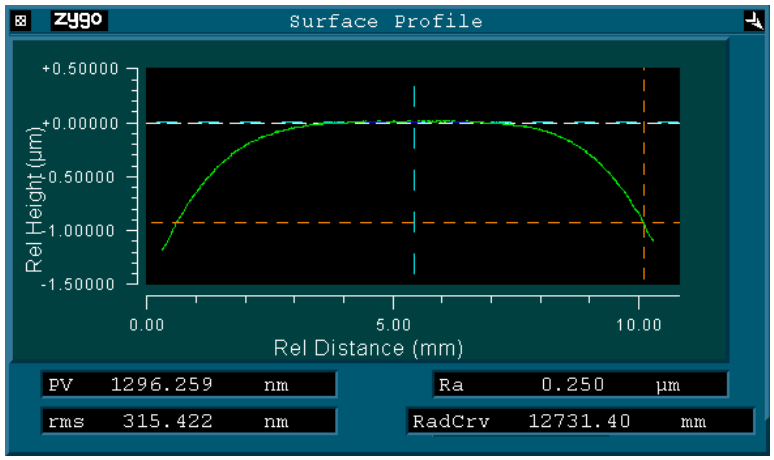
Unpowered DM/SLM Planarization

Baseline DM Design/ Fabrication process

Polishing pad





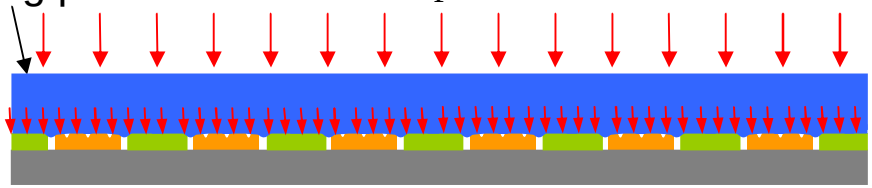


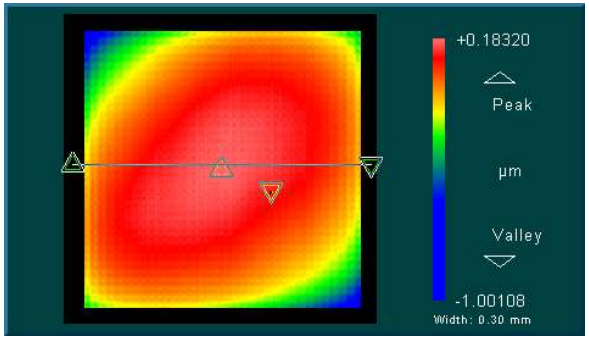
~1.3µm Edge Roll-off

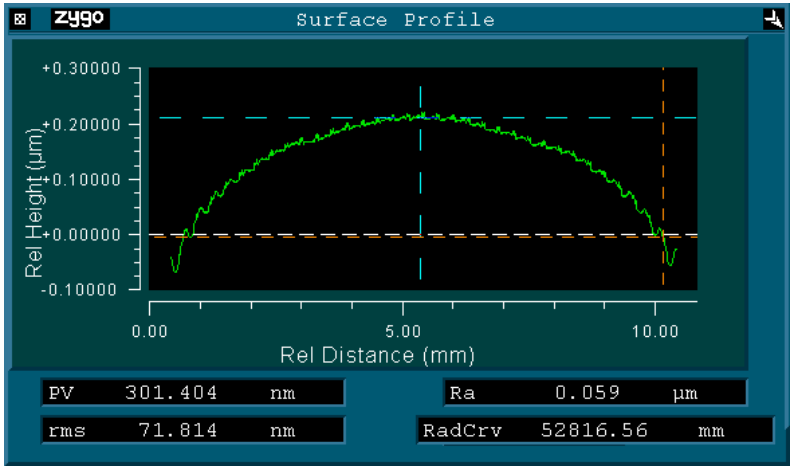
Modified DM Design/ Fabrication process

Polishing pad

P

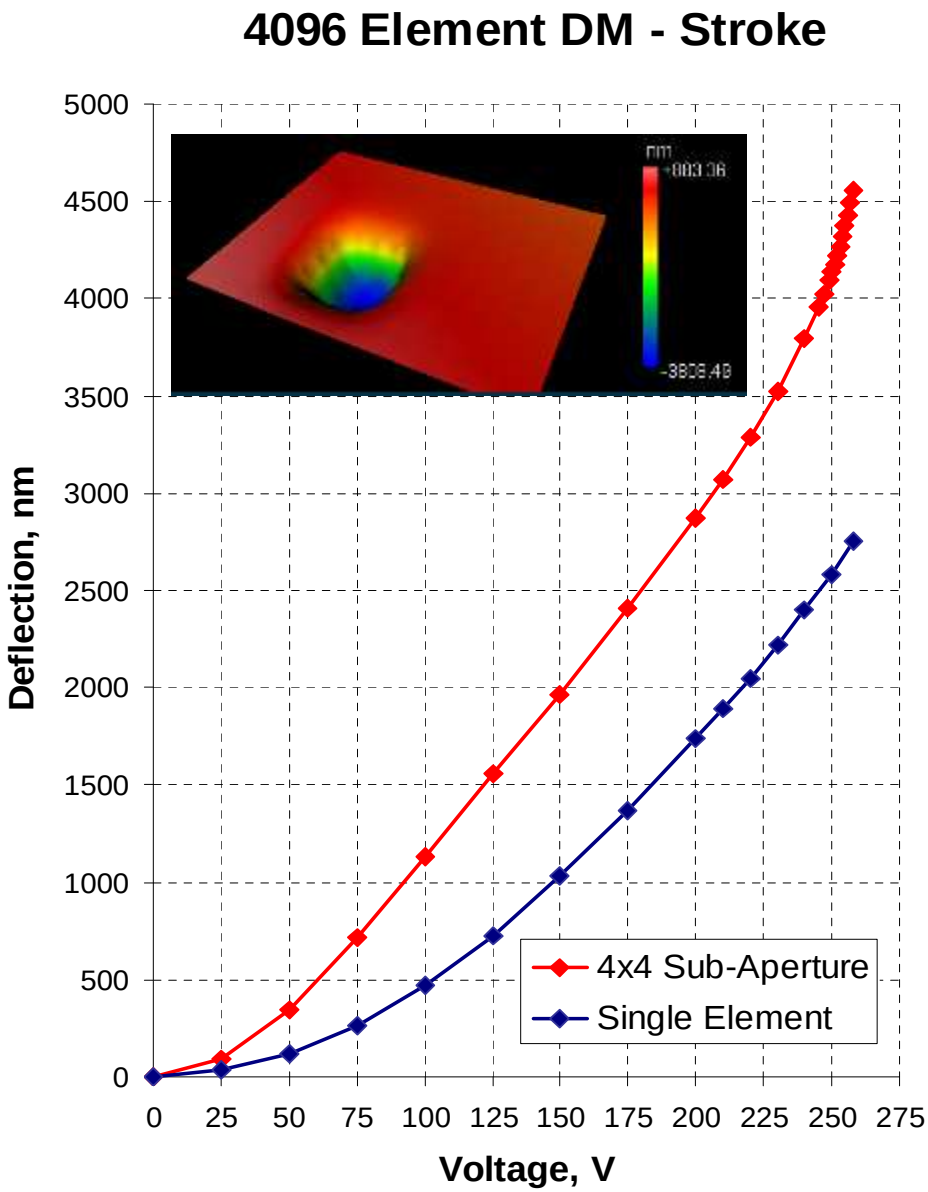




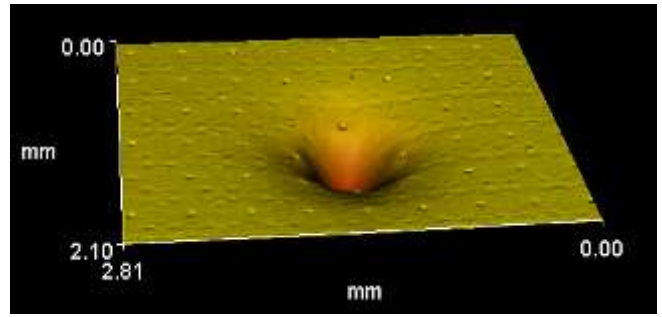


~0.3µm Edge Roll-off

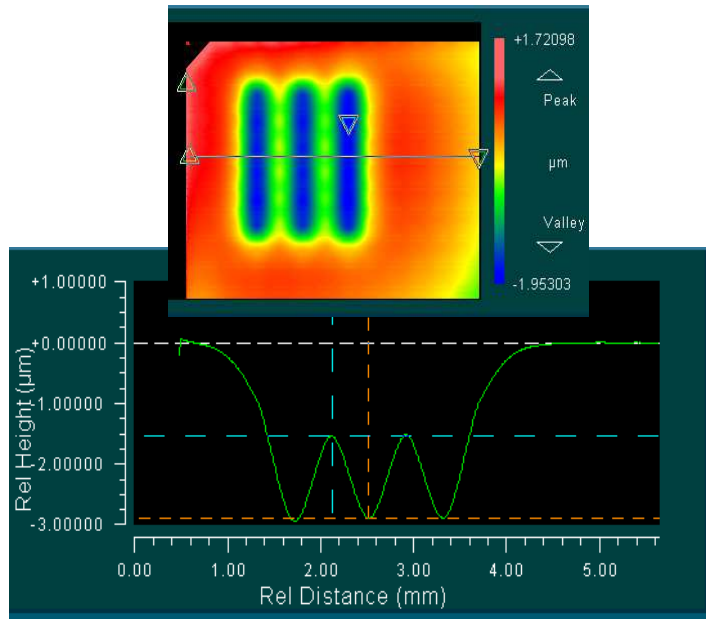
Phase II Results – Electromechanical



Actuator Yield: 98.8%
(48 actuator anomalies out of 4096



28% Influence Function

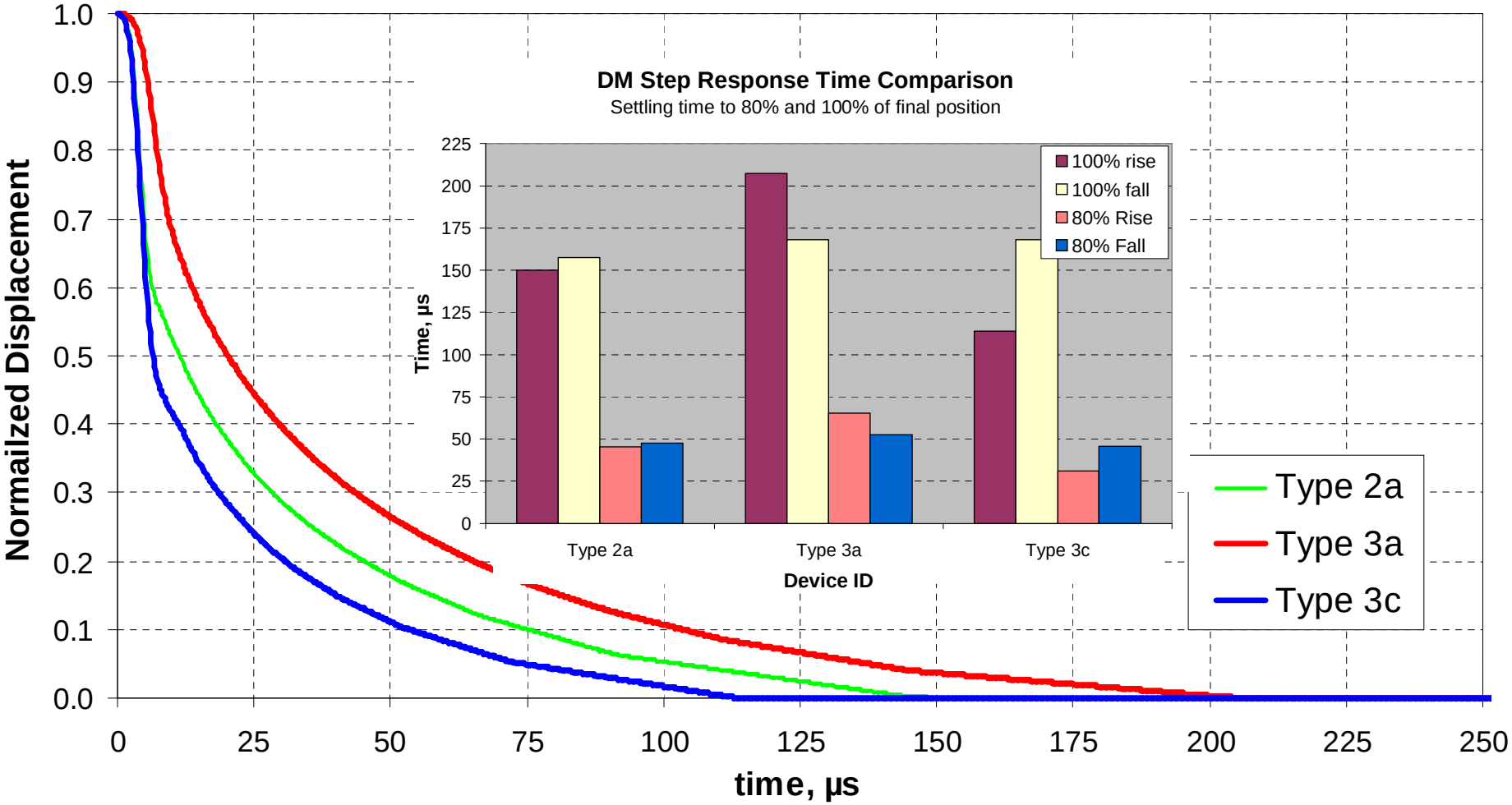


1.7µm inter-actuator stroke

DM Dynamic Response

Step Response

Square Wave Voltage Input ~40-70V (~150nm displacement)



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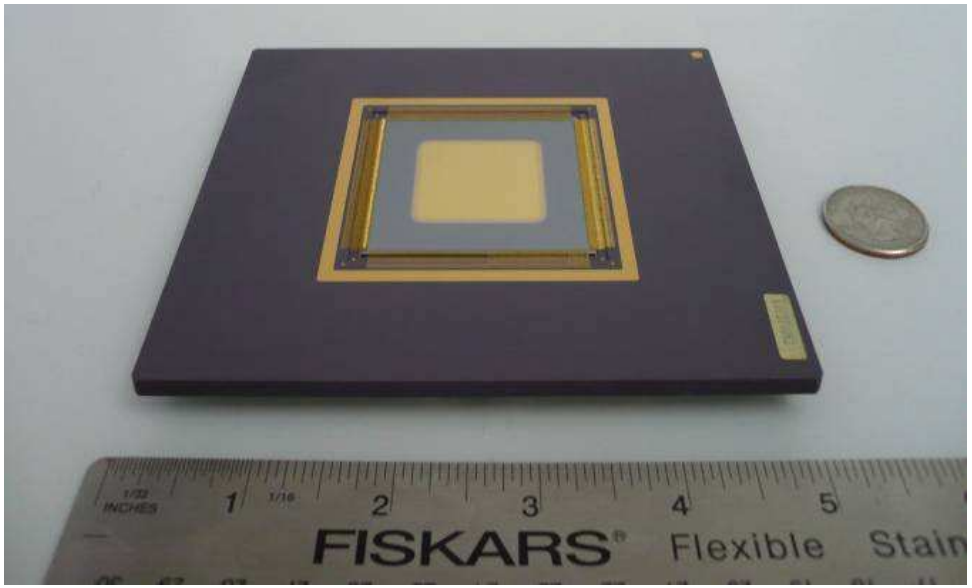
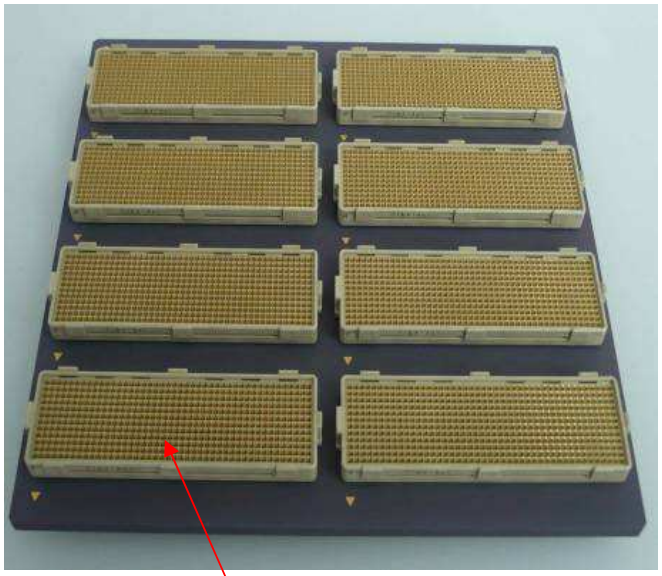
DM Packaging

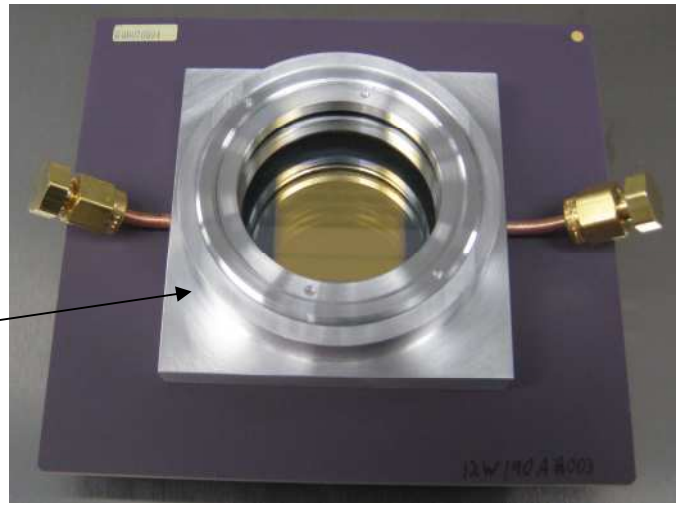


Packaged 4096 element DM



8 x 528 Position connectors

DM Seal



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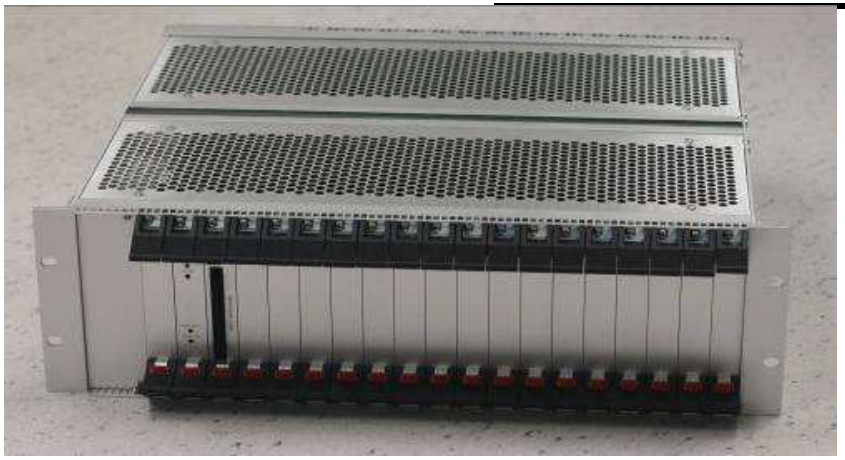
4096 Channel Driver



Requirement	value
DIO Interface	32-bit LVDS (200 MB/s)
Interface HV	16x 300pin Megarray (4096 channel)
Form factor	3U Chassis (5.25” x19” x14”)
Frame Rate	24 KHz
Cross-talk	< 1% peak amplitude
Power draw	40W
Current limitation output	0.7 mA max.
Maximum Output voltage	285V
Resolution	14-bit

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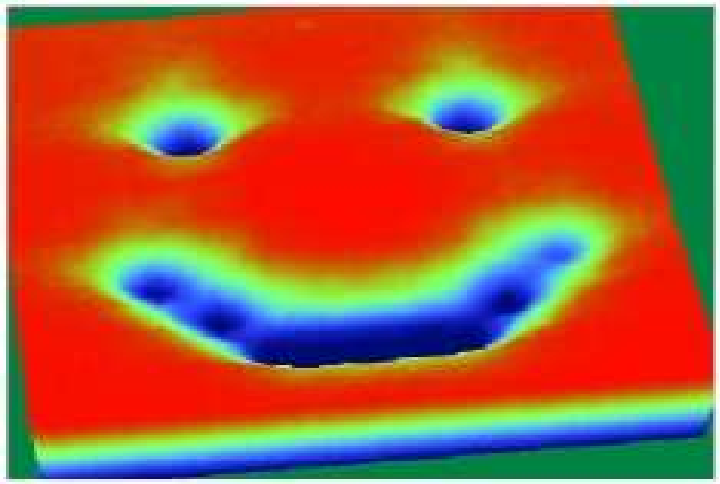
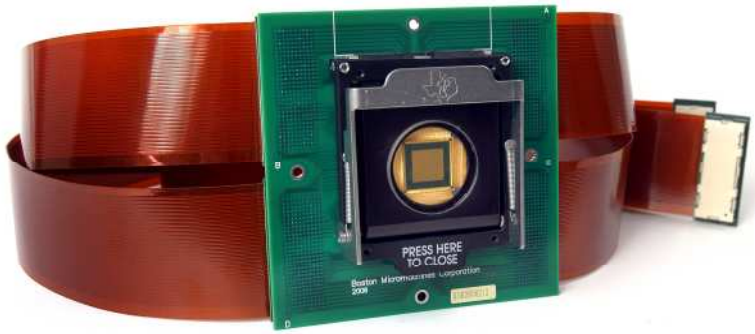
Summary

331 Element Tip-Tilt-Piston MEMS Deformable Mirror to be delivered to NASA JPL in Dec ’08 for use in high contrast imaging testbed



4096 Element Continuous facesheet MEMS DM on track to be delivered Dec ’08 (Engineering DM delivered to LAO)

Boston Micromachines Corporation is advancing and commercializing MEMS deformable mirror technology to meet Adaptive optic needs in astronomy, laser comm, microscopy, and biomedical imaging through SBIR/STTR & other government programs



Work presented funded by NASA, NIH, CFAO, GPI