Advances in MEMS Deformable Mirrors and Spatial Light Modulators

Steven Cornelissen
Paul Bierden
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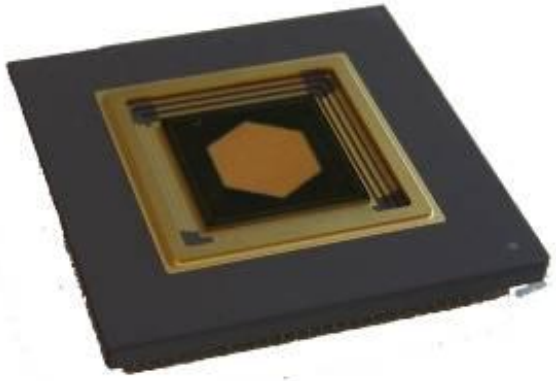
Boston University



7th Annual Mirror Technology Days
Albuquerque, NM
August 1, 2007

BOSTON MICROMACHINES CORPORATION

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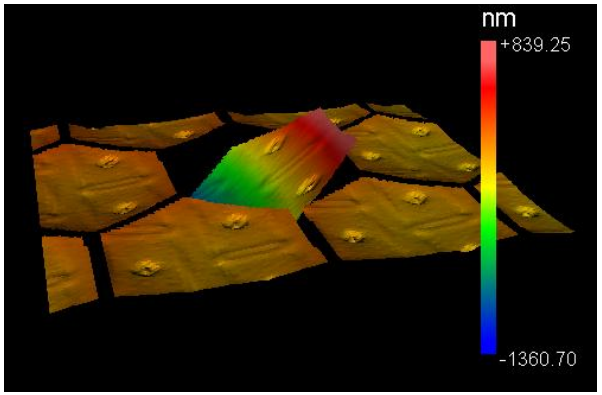
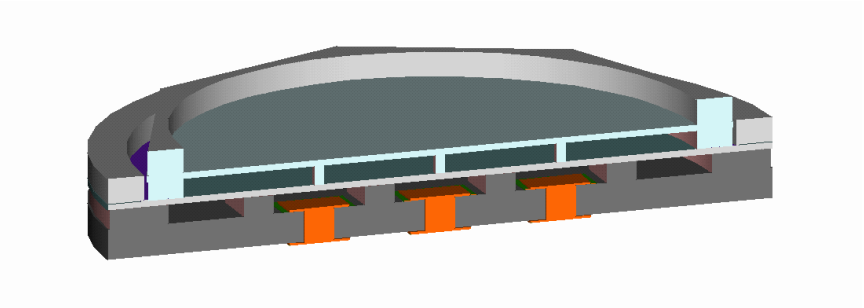
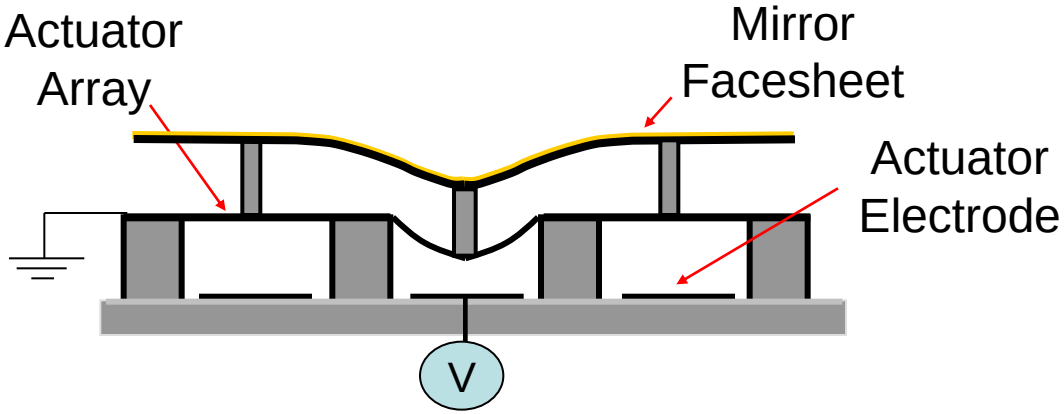
Ongoing MEMS DM development at BMC

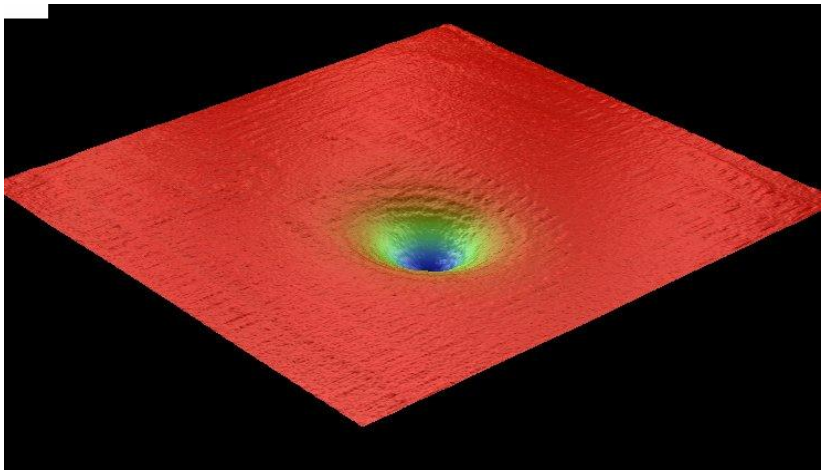
- 4096 Element Continuous Facesheet DM (GPI)
  - Ground based high-contrast imaging system
- 331 Element Tip-Tilt-Piston DM (NASA SBIR Phase II)
  - Space-based visible nulling coronograph
- Large Aperture Continuous facesheet MEMS DM (NASA SBIR Phase II)
  - Space-based Adaptive Optics





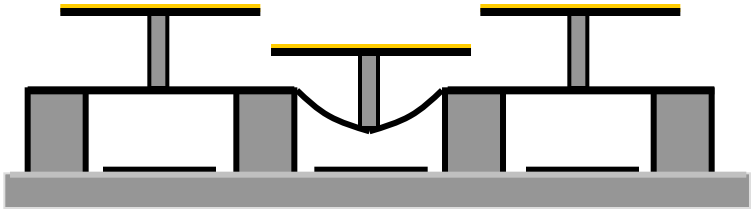
BMC Deformable Mirror Architecture



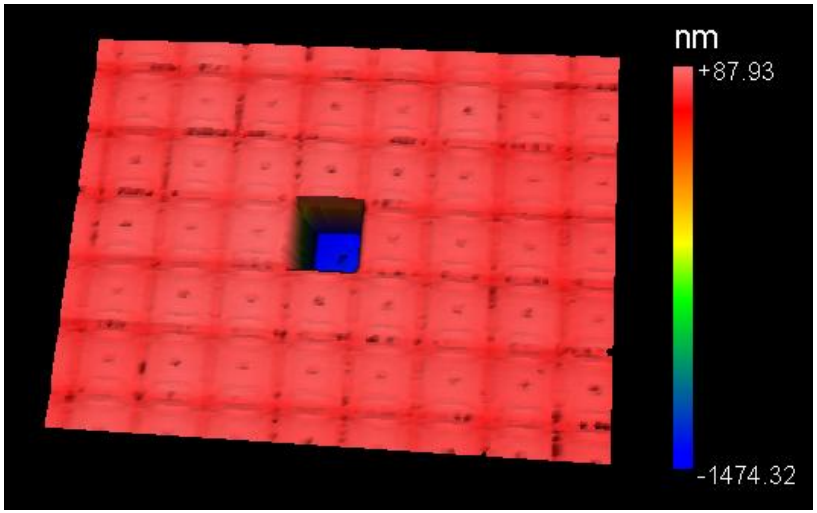


Continuous mirror (smooth phase control)

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



Segmented mirror (uncoupled control)



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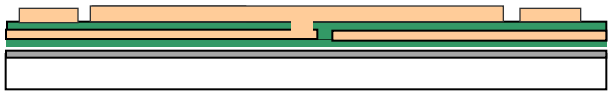
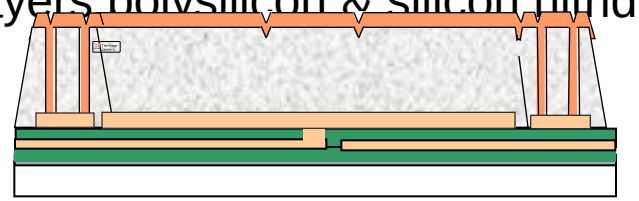
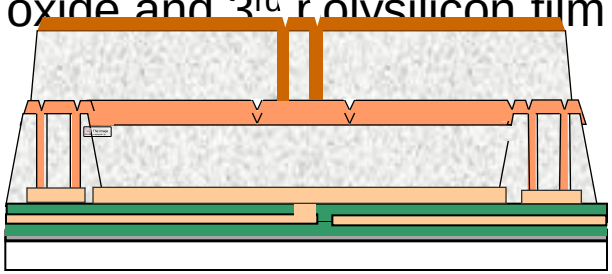
MEMS DM Fabrication



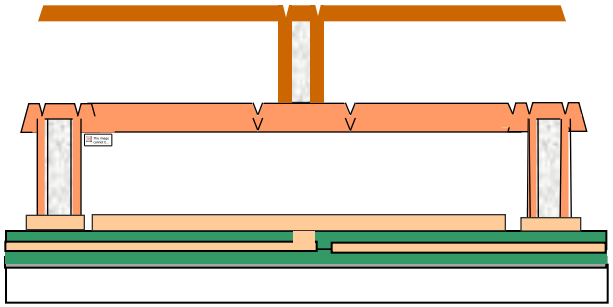
1. Electrodes & wire traces:
Deposit, pattern, etch alternating layers polysilicon & silicon nitride



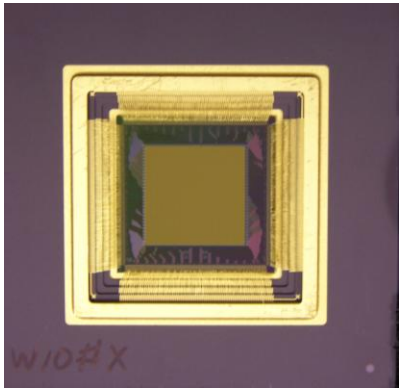
2. Actuator array:
Deposit pattern, etch sacrificial oxide and 3rd polysilicon film



3. Mirror membrane:
Deposit, pattern, etch 2nd sacrificial oxide and 4th Polysilicon film



4. MEMS DM:
Etch away sacrificial materials, CPD, and apply reflective coating



5. Electrical Interconnects:
Die Attach and wirebond to custom ceramic chip carrier

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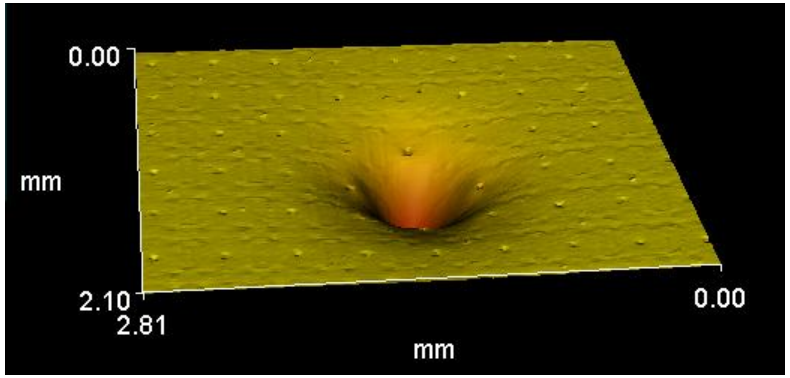
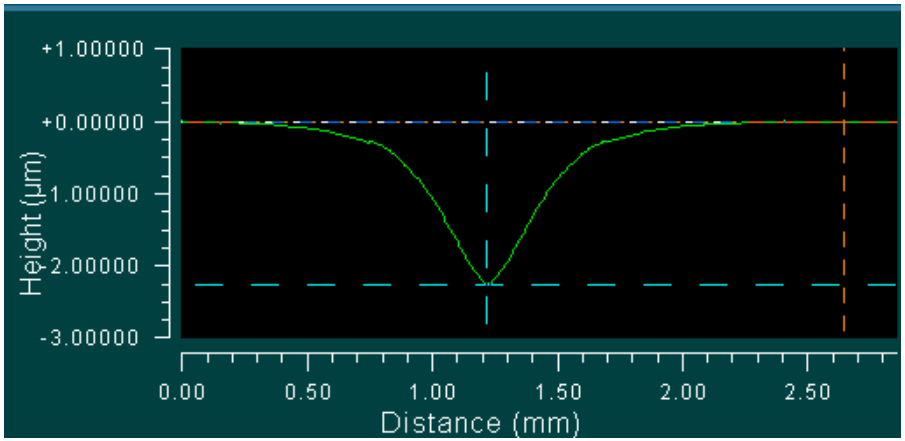
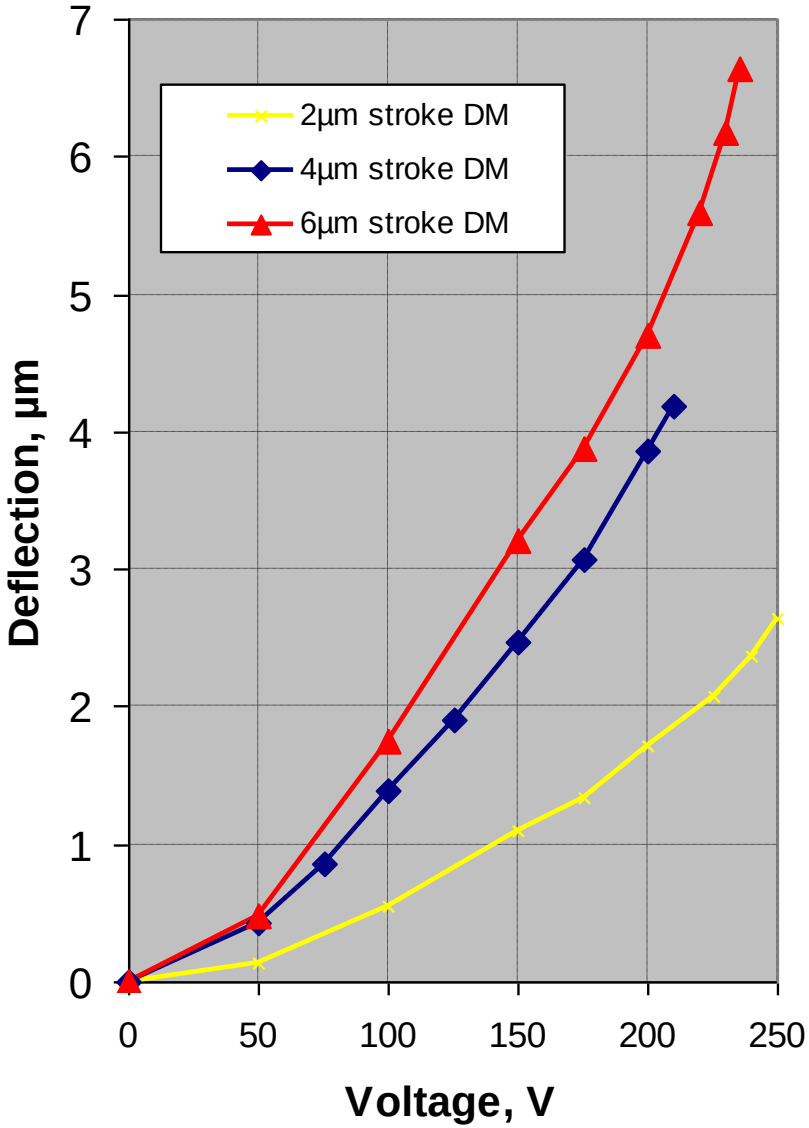
MEMS DM Characteristics

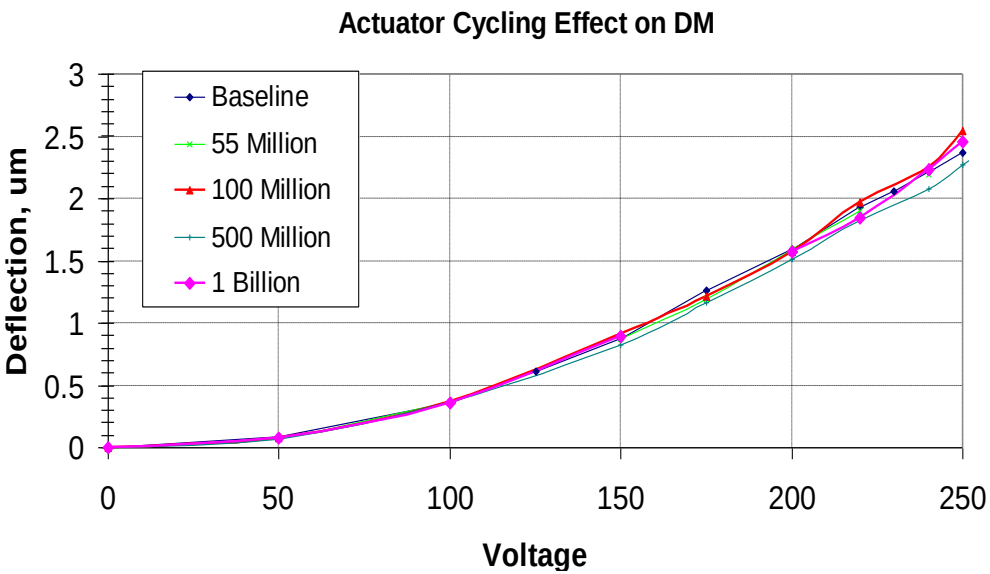


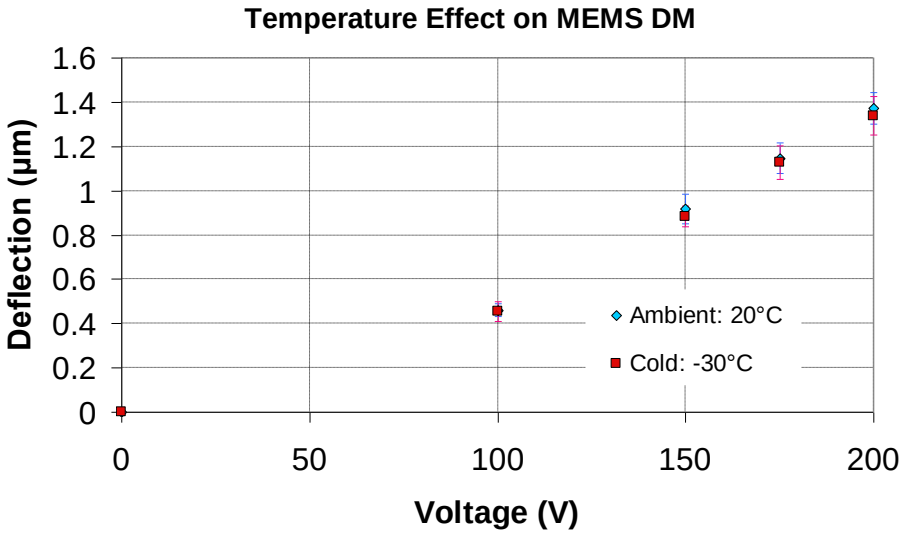


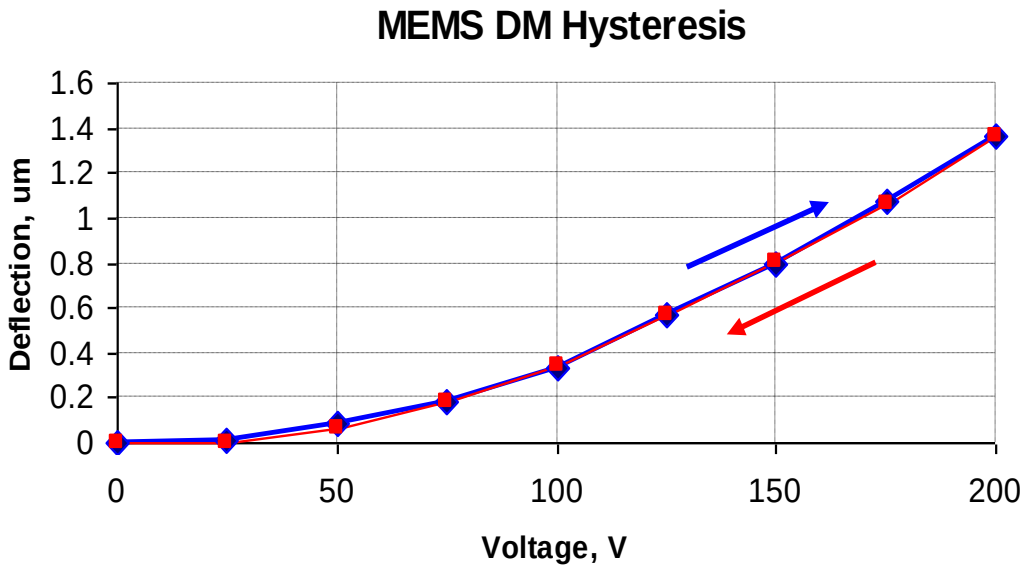


- Array/Aperture Sizes:
  - 12x12 (3.3-4.95mm)
  - 32x32 (9.3-10.5mm)
- Influence Function: 23-35%
- Surface Figure: 10-35nm RMS
- Fill Factor: 98.6-99.8%

Life Cycling, Temperature, & Hysteresis Effects







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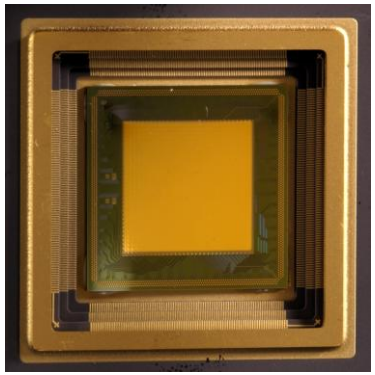
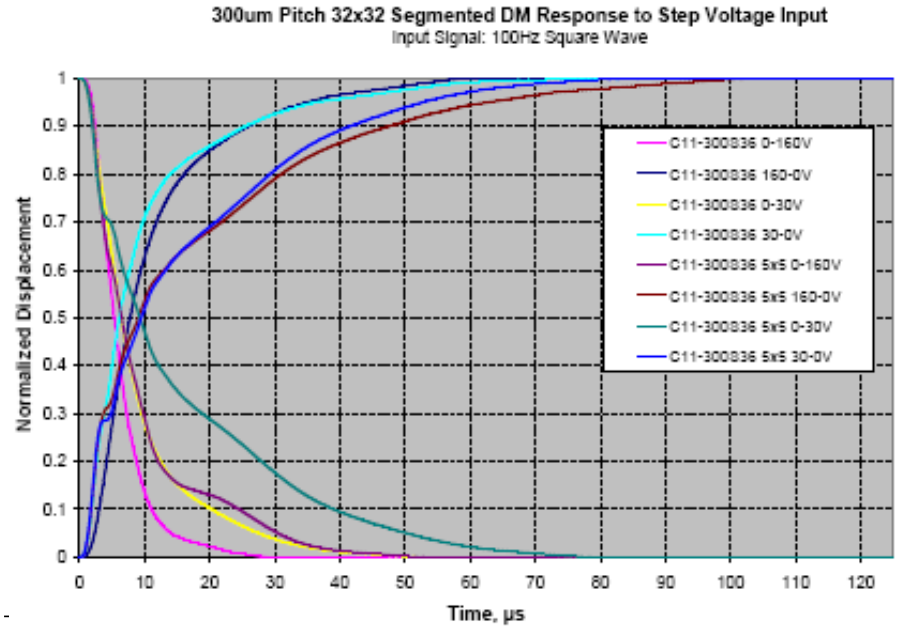
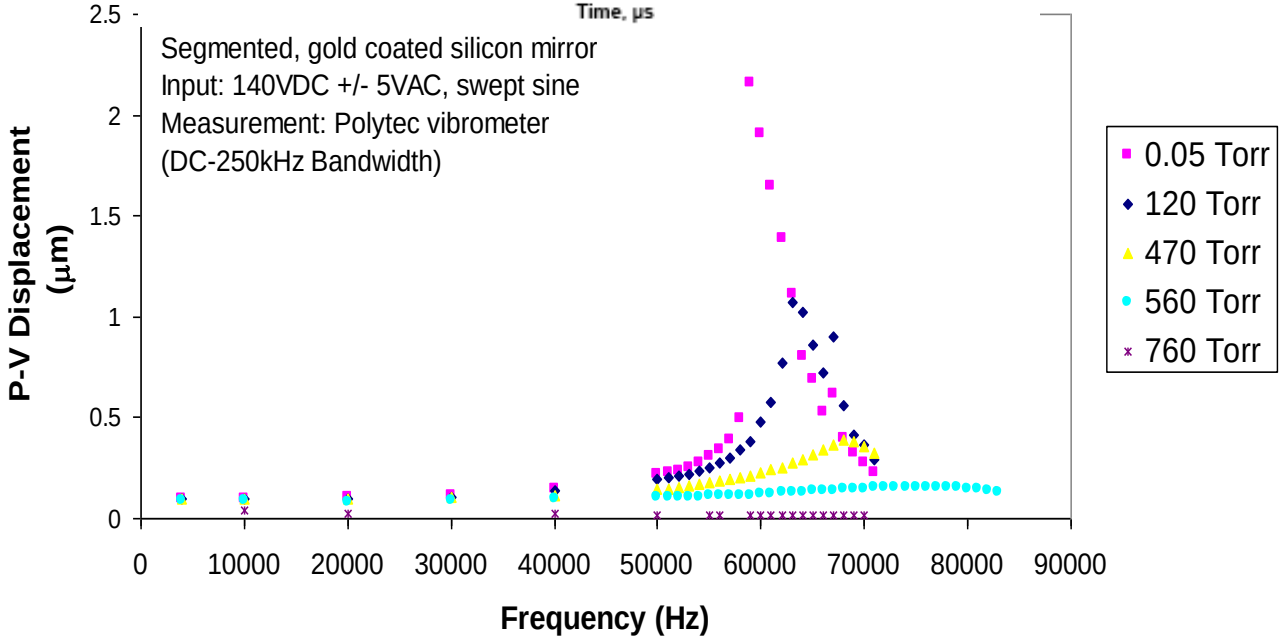
DM Dynamic Response Characteristics







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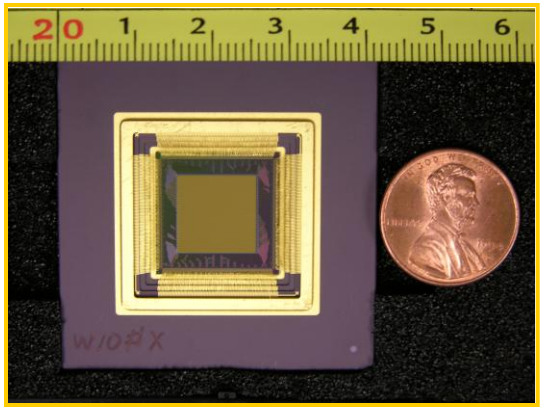
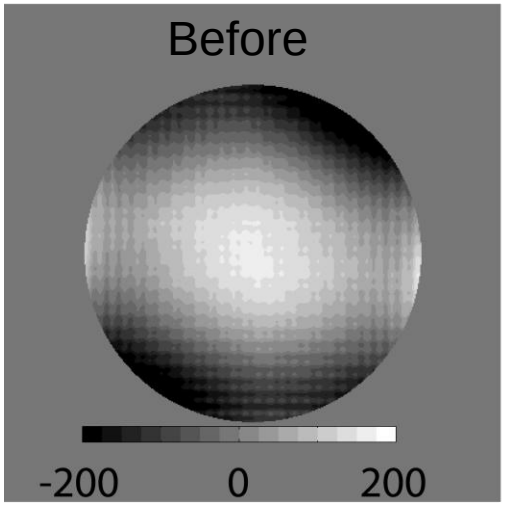
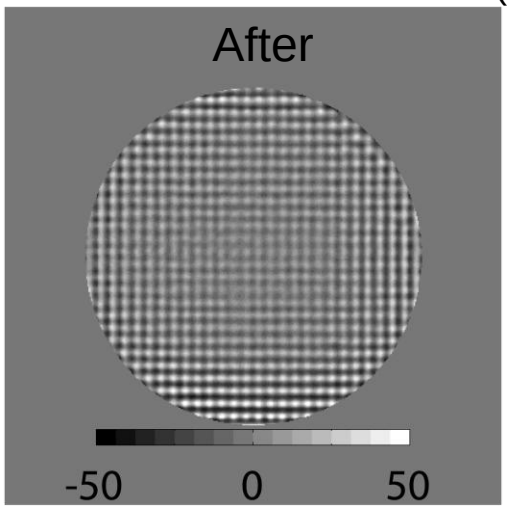
1024 MEMS DM Validated in ExAO Testbed

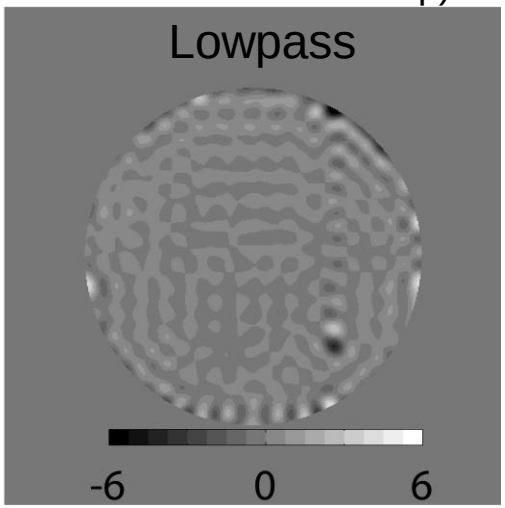
- DM Actively Flattened to 0.54nm RMS WFE inc control band.
- Long term Stability: 0.08nm RMS



1024 element (32x32) MEMS DM (Boston Micromachines Corp)







RMS WFE 148.1 nm 12.8 nm 0.54 nm

Don Gavel, Julia Evans, LLNL, LAO

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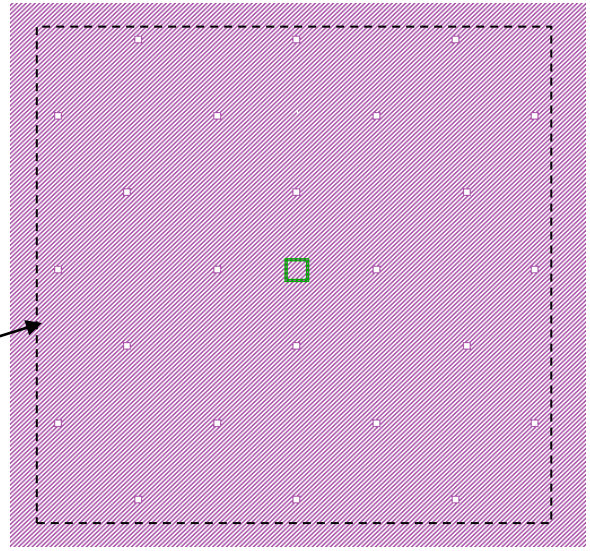
64x64 DM Device Design Description

- Die Size: 49mm
- Array Size: 68x68
  - Active: 64x64
  - 2 inactive rows around periphery
- Actuator Pitch: 400µm
- Active Aperture: 25.2mm
- Fill Factor: > 99.5%
- 3µm stroke
- 1µm interactuator stroke
- <10 nm RMS surface figure

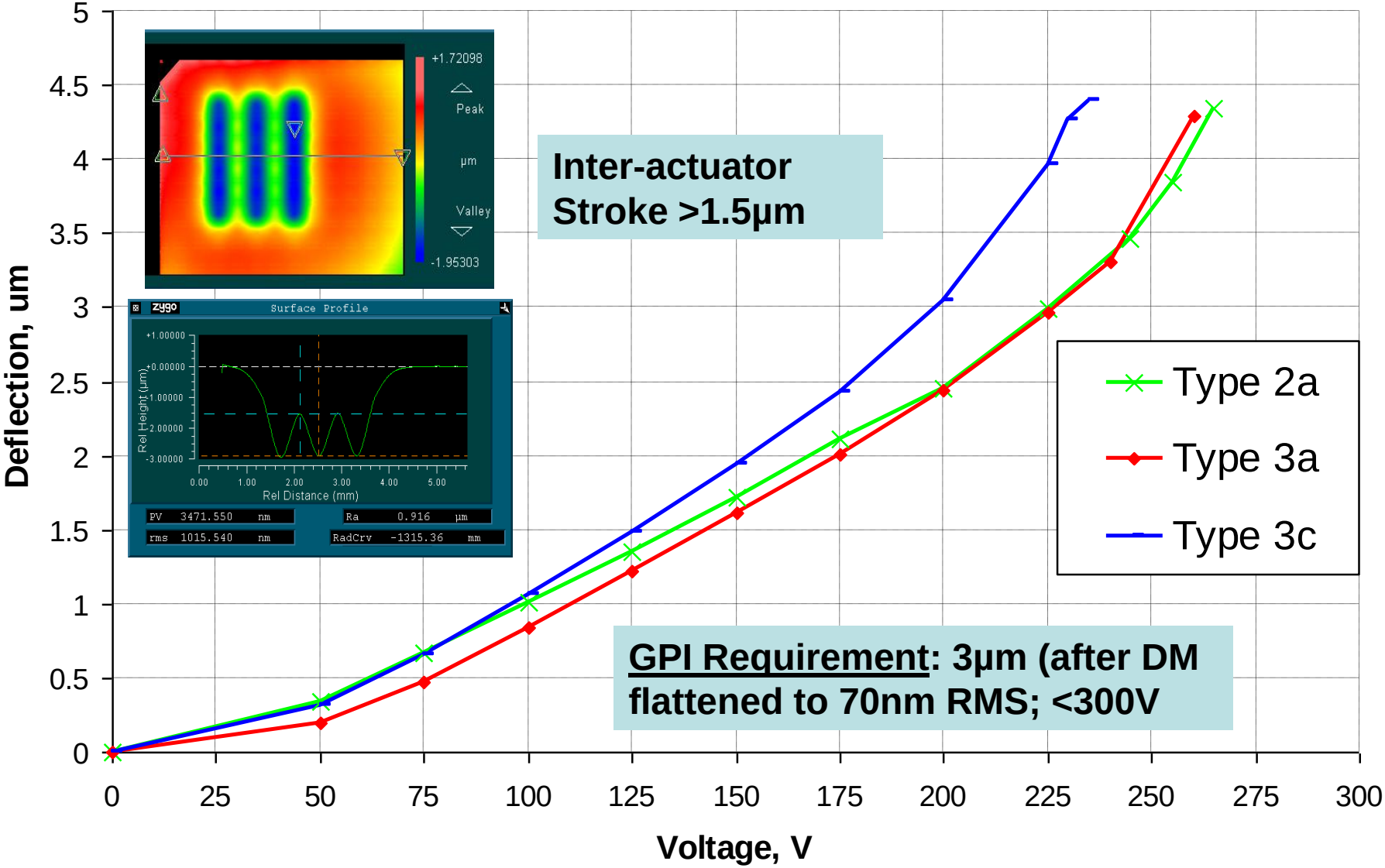


Single Element
Mirror surface

Phase I Results – Stroke

Phase 1 DM Electromechanical Performance

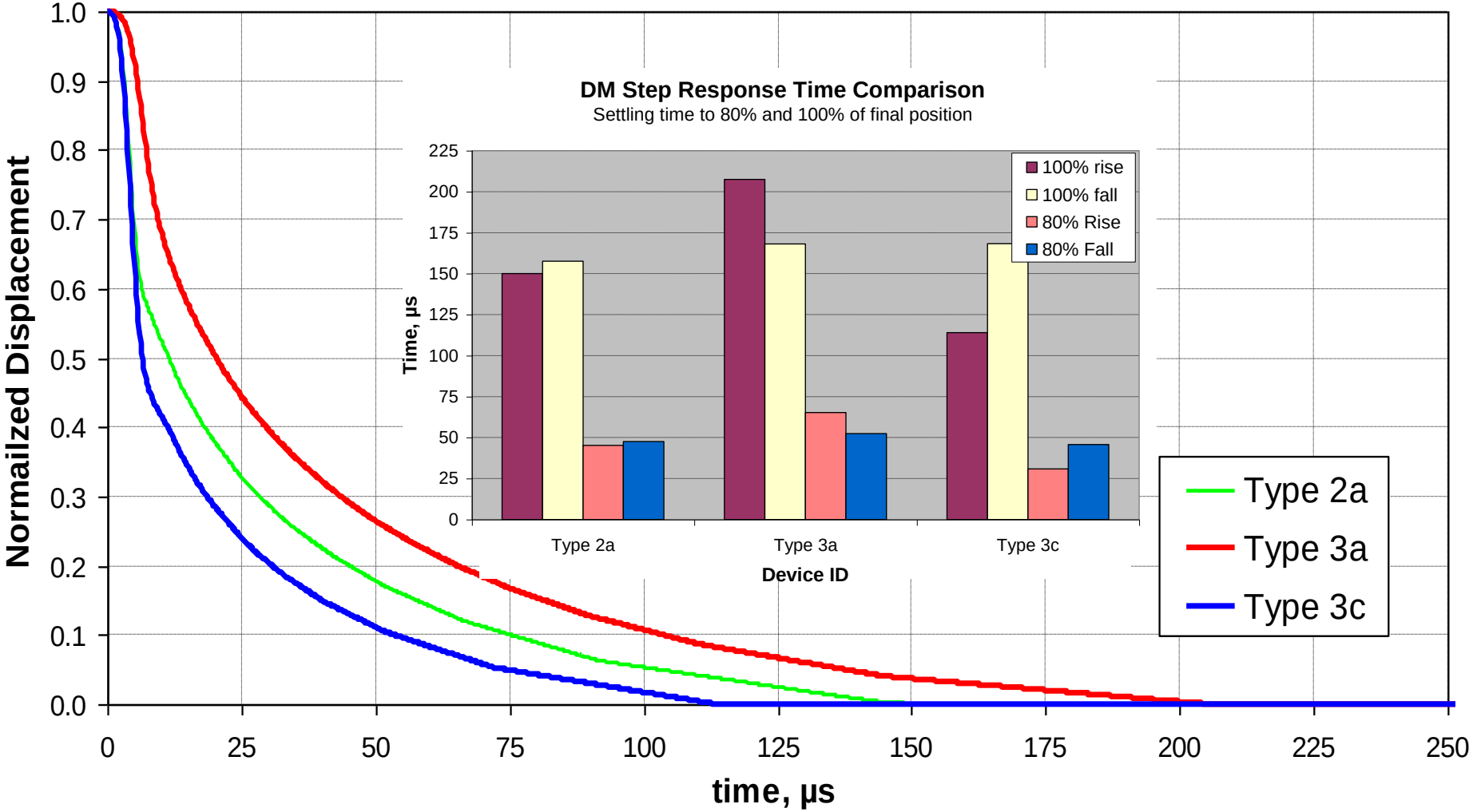
measured by actuating a 3x3 array of elements



Phase I Results – Settling Time

Phase 1 DM Step Response

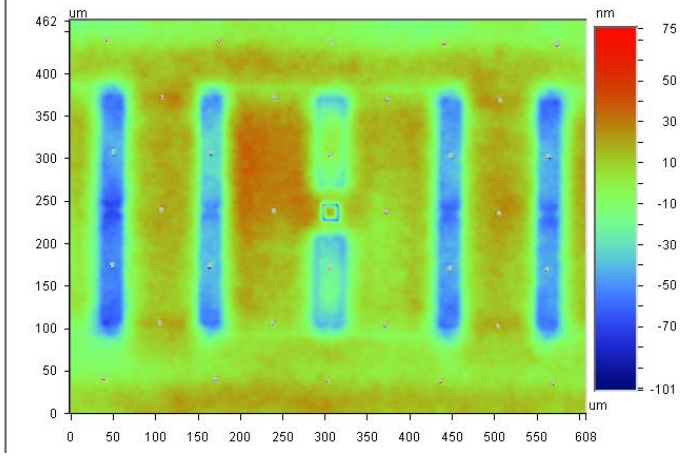
Square Wave Voltage Input ~40-70V (~150nm displacement)



GPI Requirement: <200 microseconds to 80%

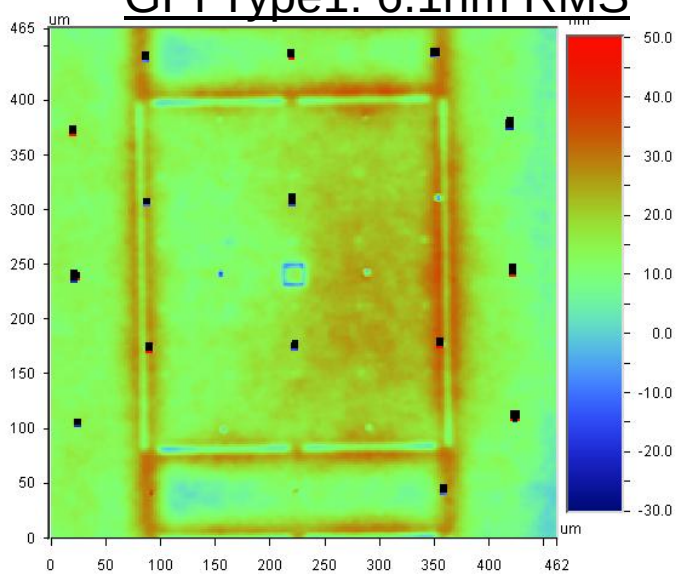
Phase I Results – DM Surface Quality

Baseline Device: 20.5nm RMS

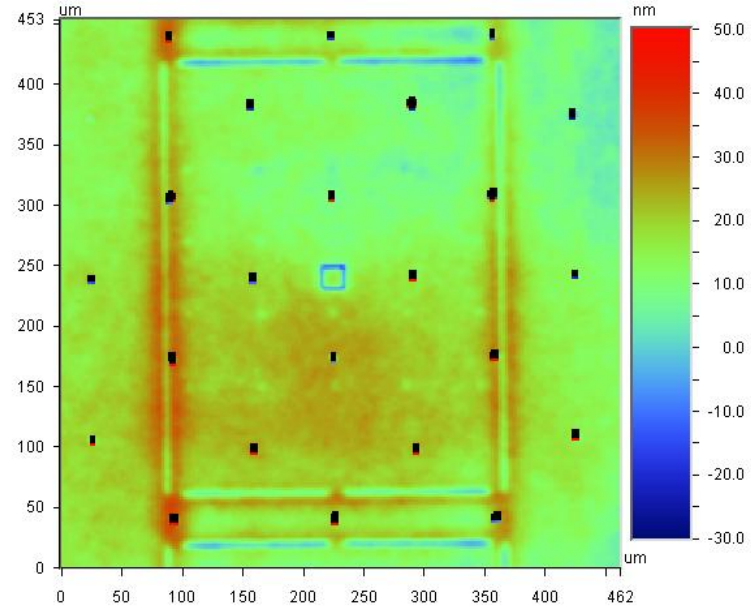


- Surface figure improved from 20nm RMS to <6nm RMS by reducing print-thru

GPI Type1: 6.1nm RMS



GPI Type 2: 5.0nm RMS



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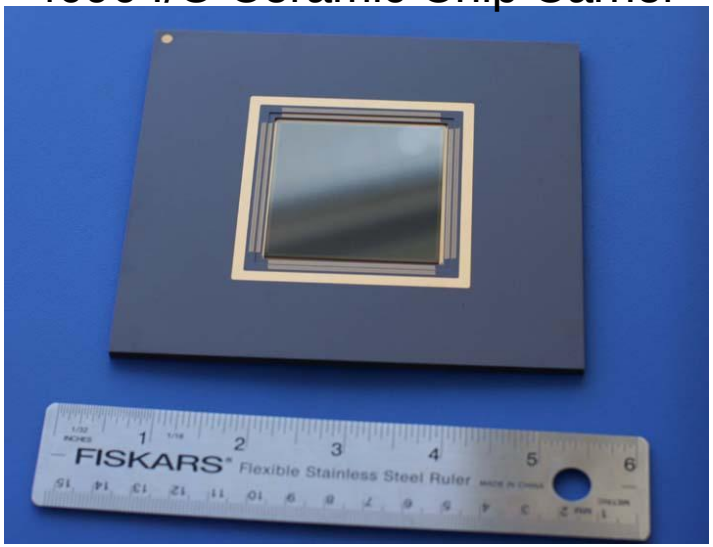
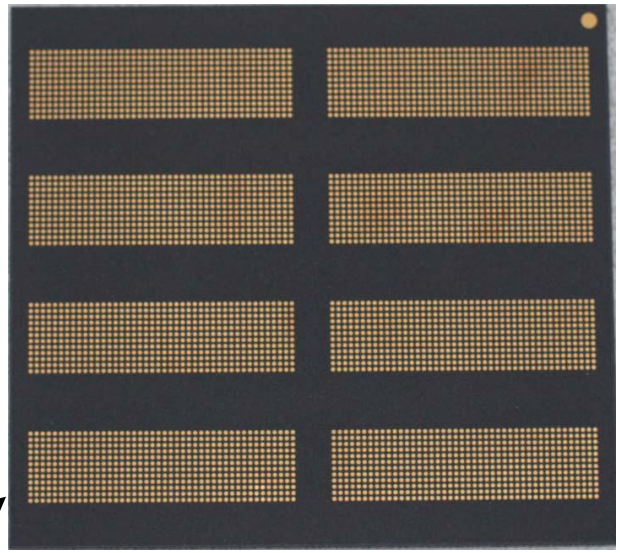
DM Packaging & Driver

4096 I/O Ceramic Chip Carrier





3.3mm thick

127mm

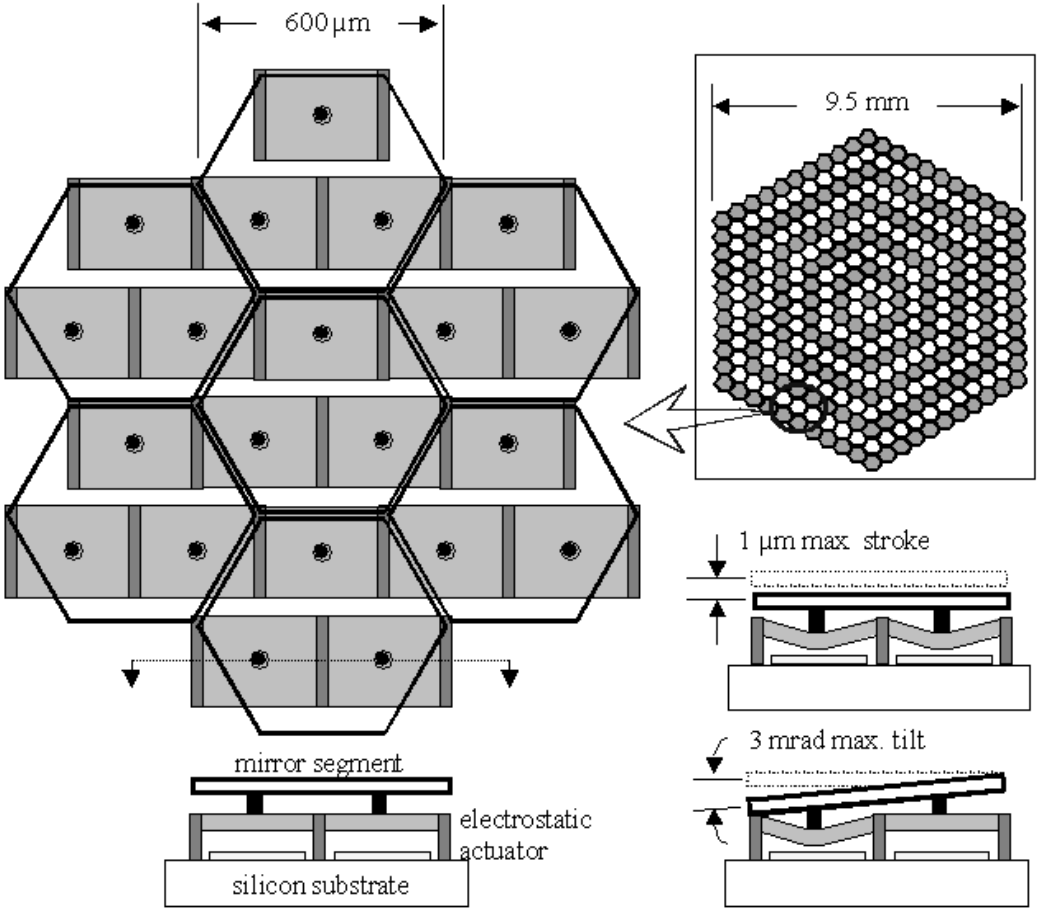
116mm

8x 528 Pos MegArray Connector locations

- Driver in Development (9/15/07):
  - 3U Chassis, 16X 256 Channel Output boards
  - Latency:
    - 15/30µs (1024 ch)
    - 45µs (4096 ch)
- 1st 4096 DMs are in house

Tip/Tilt Piston DM for TPF-C

- 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
  - 1μm of stroke
  - 3mrad tip/tilt
- <10nm RMS Mirror segment Flatness through range of motion
  - Epi-Poly fabrication process developed fro Mirror segments



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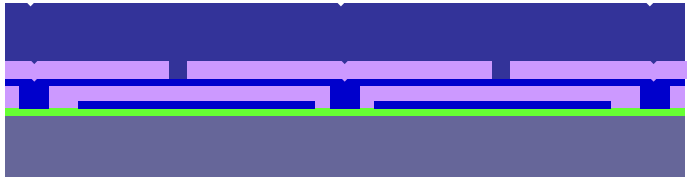
Device Fabrication Process

Start with silicon wafer coated with Nitride dielectric layer

Deposit & pattern polysilicon actuator electrodes

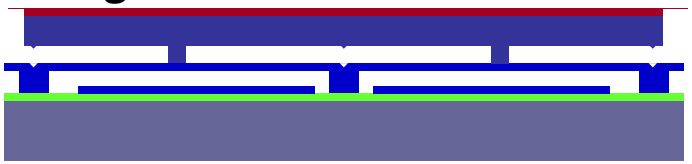
Deposit sacrificial PSG layer and pattern actuator anchors

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

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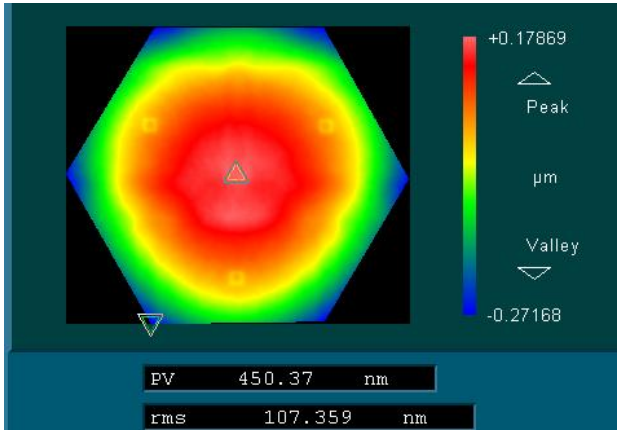
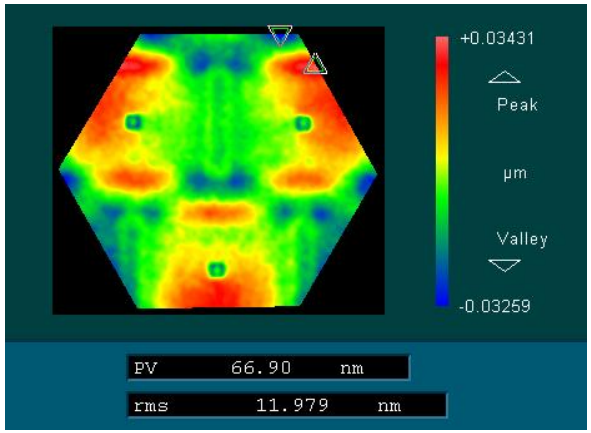
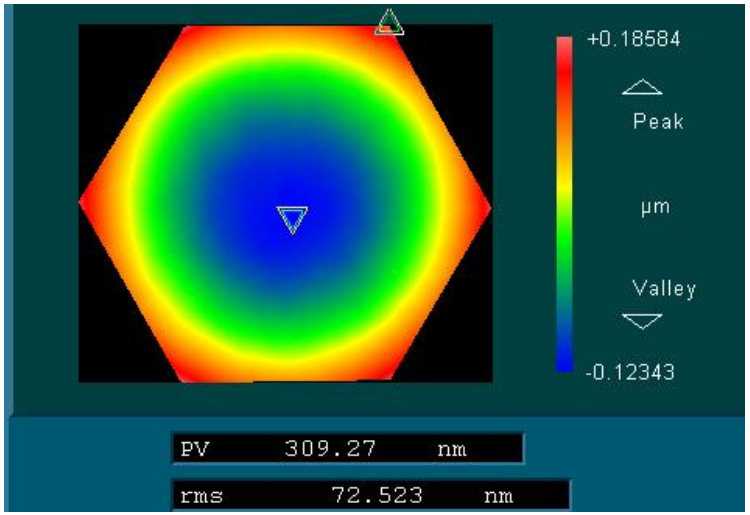
Mirror Segment Surface Figure



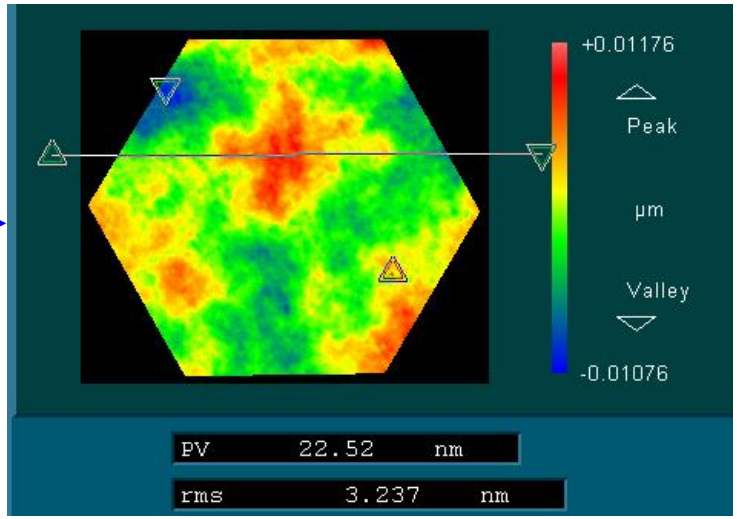
Hex segment : Poly-Si



Hex segment : Poly-Si
(curvature removed)



Hex segment : Epi- Poly



Hex segment : Epi-Poly
(curvature removed)

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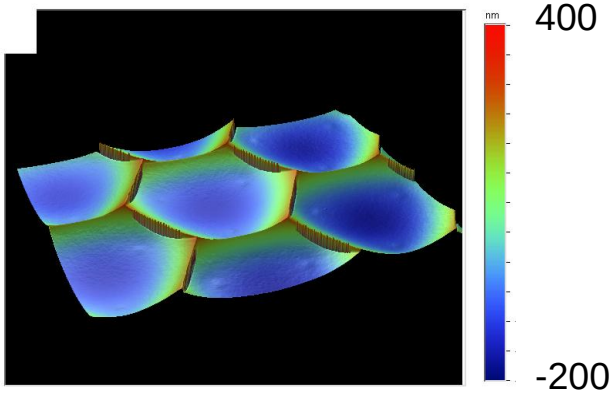
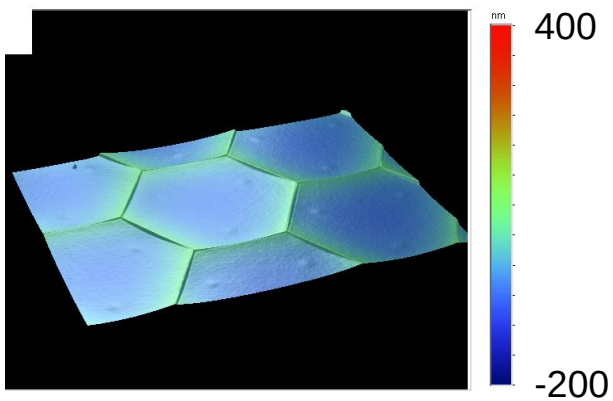
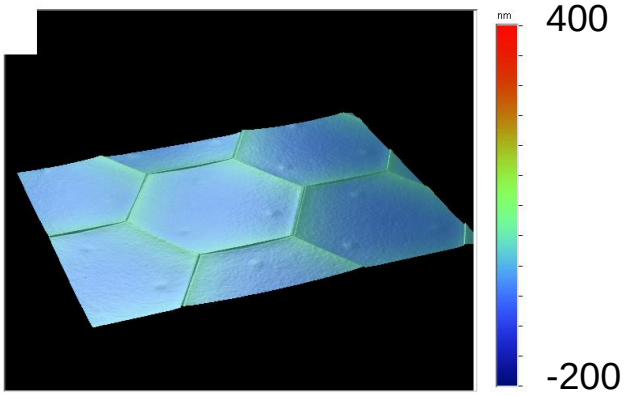
Mirror Curvature Control with Anneal



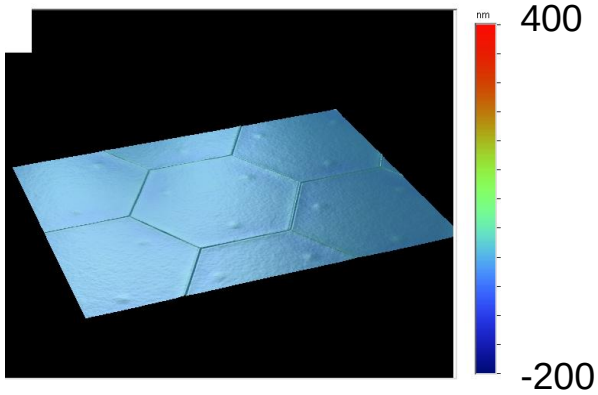
Condition I



Condition II

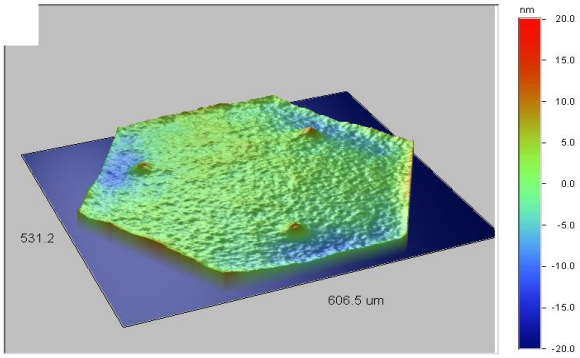


Condition III

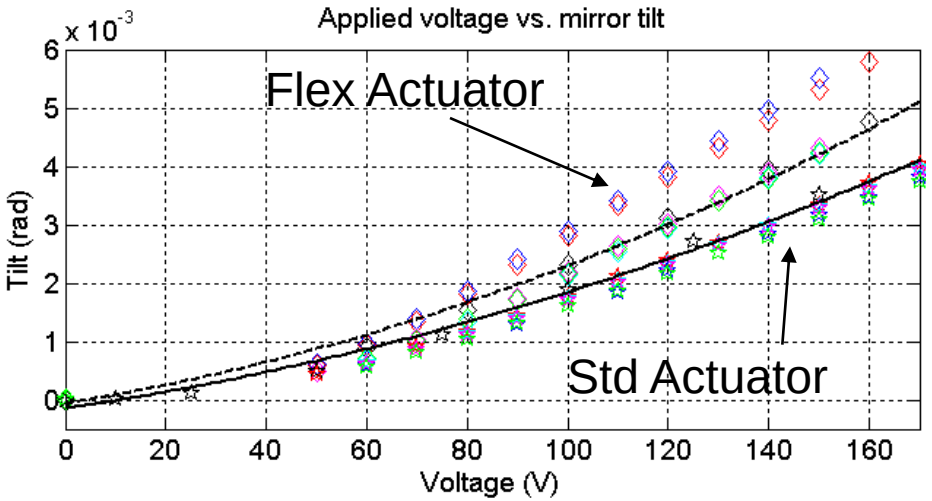


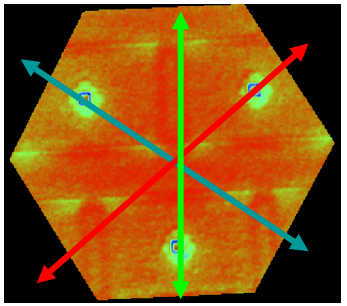
Condition IV

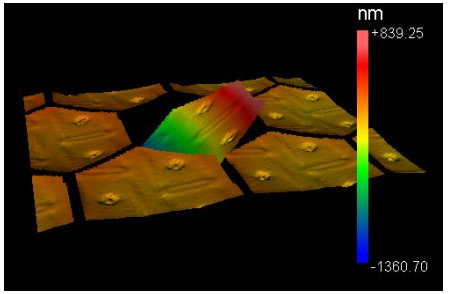
Mirror segments with 2.2 nm RMS surface flatness have been achieved



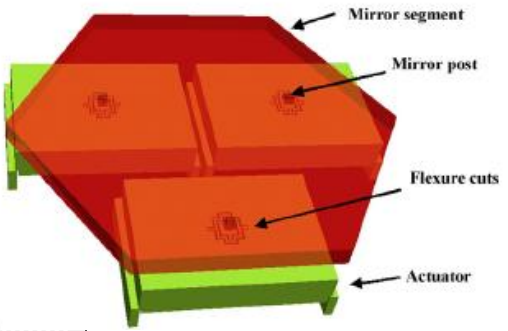
Tip/Tilt/Piston DM Development Results

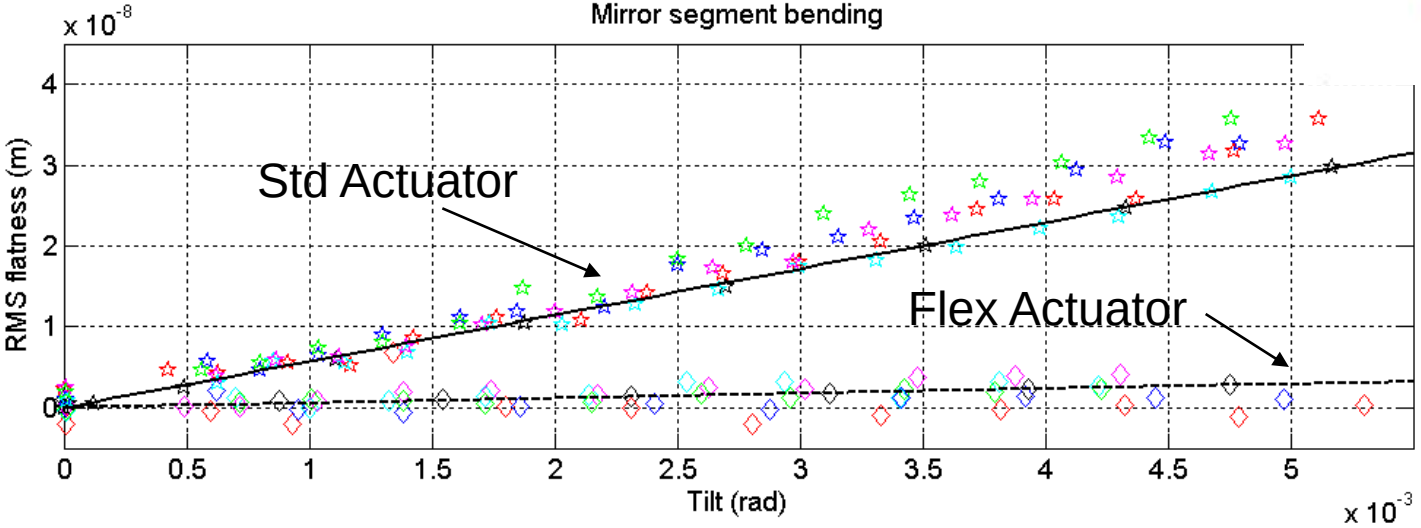






Axis 1 = blue
Axis 2 = green
Axis 3 = red

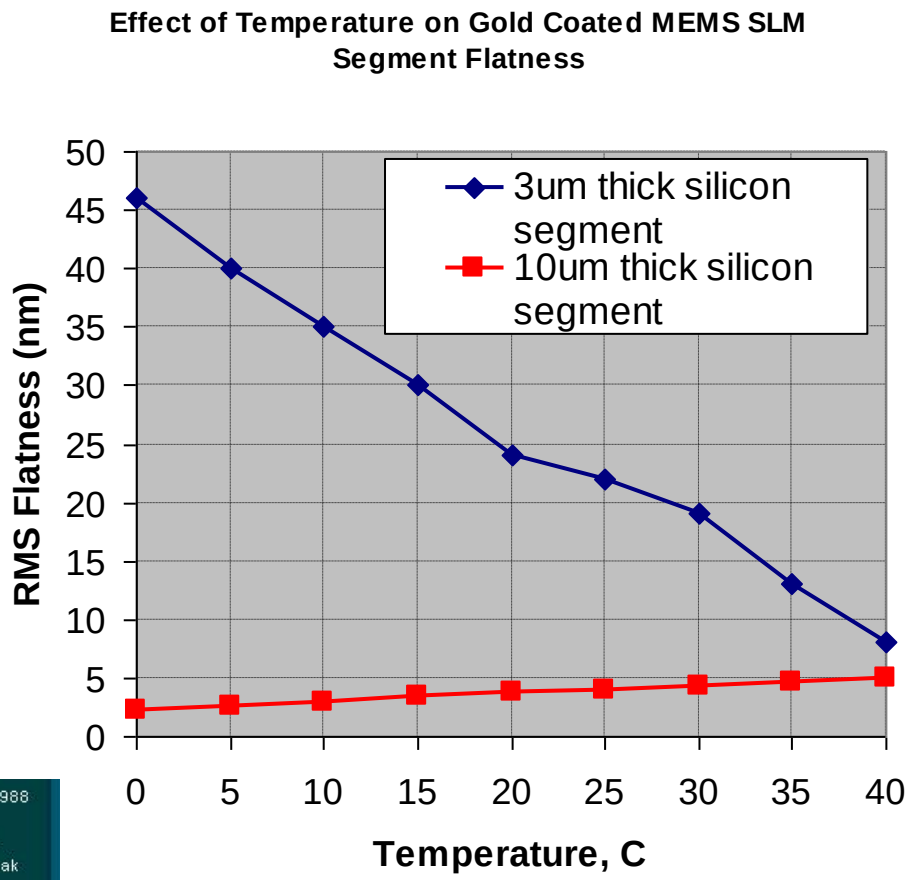


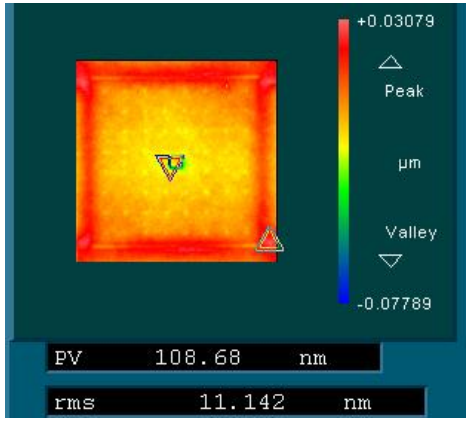


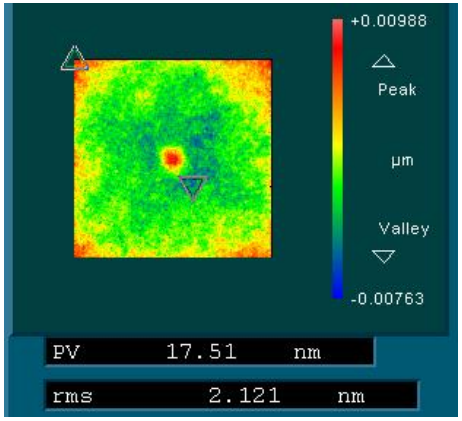
Flexured actuator design reduces mirror bending to<0.5nm RMS

Tip/Tilt/Piston DM Development Results

- Epi-Poly process results in:
  - Wider operational temperature range
  - Less sensitive to stresses of reflective films
    - Allows for protected Ag and dielectric coatings
- Improved surface figure by removing print-thru







Fabrication processed developed in this effort to be integrated into commercial DMs

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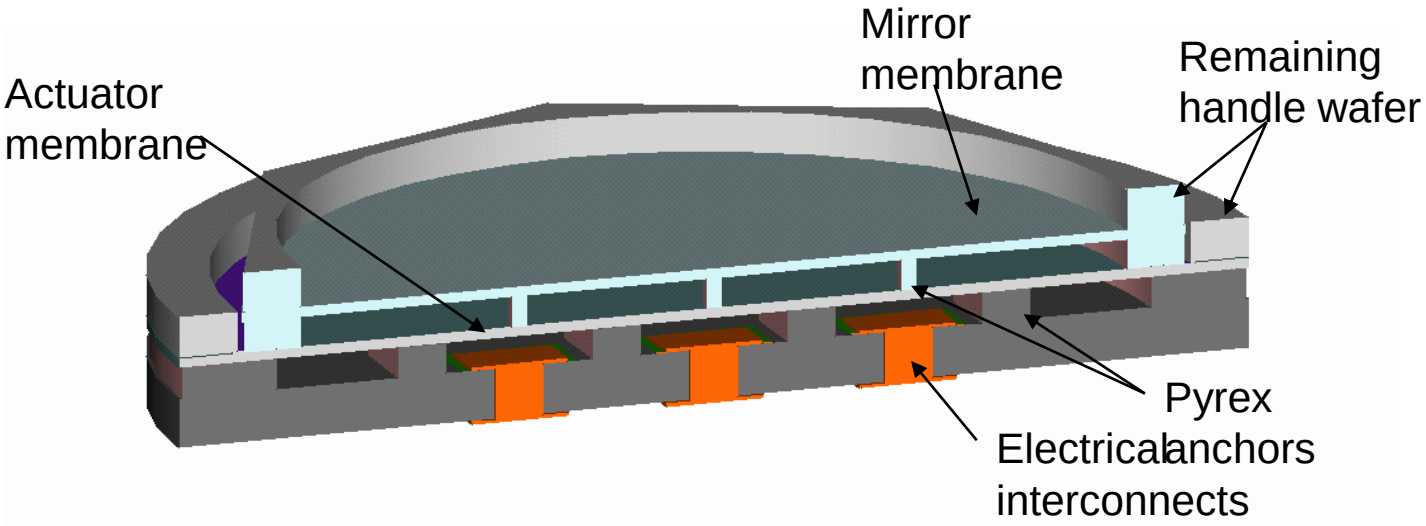
Large Aperture MEMS Deformable Mirrors



DM Characteristics:

- 60mm Aperture
- 1000 control points
- 5nm RMS surface figure

Technology Developments:

- Anodic bonding process of MEMS mirror structure
- Thru-Wafer Interconnects

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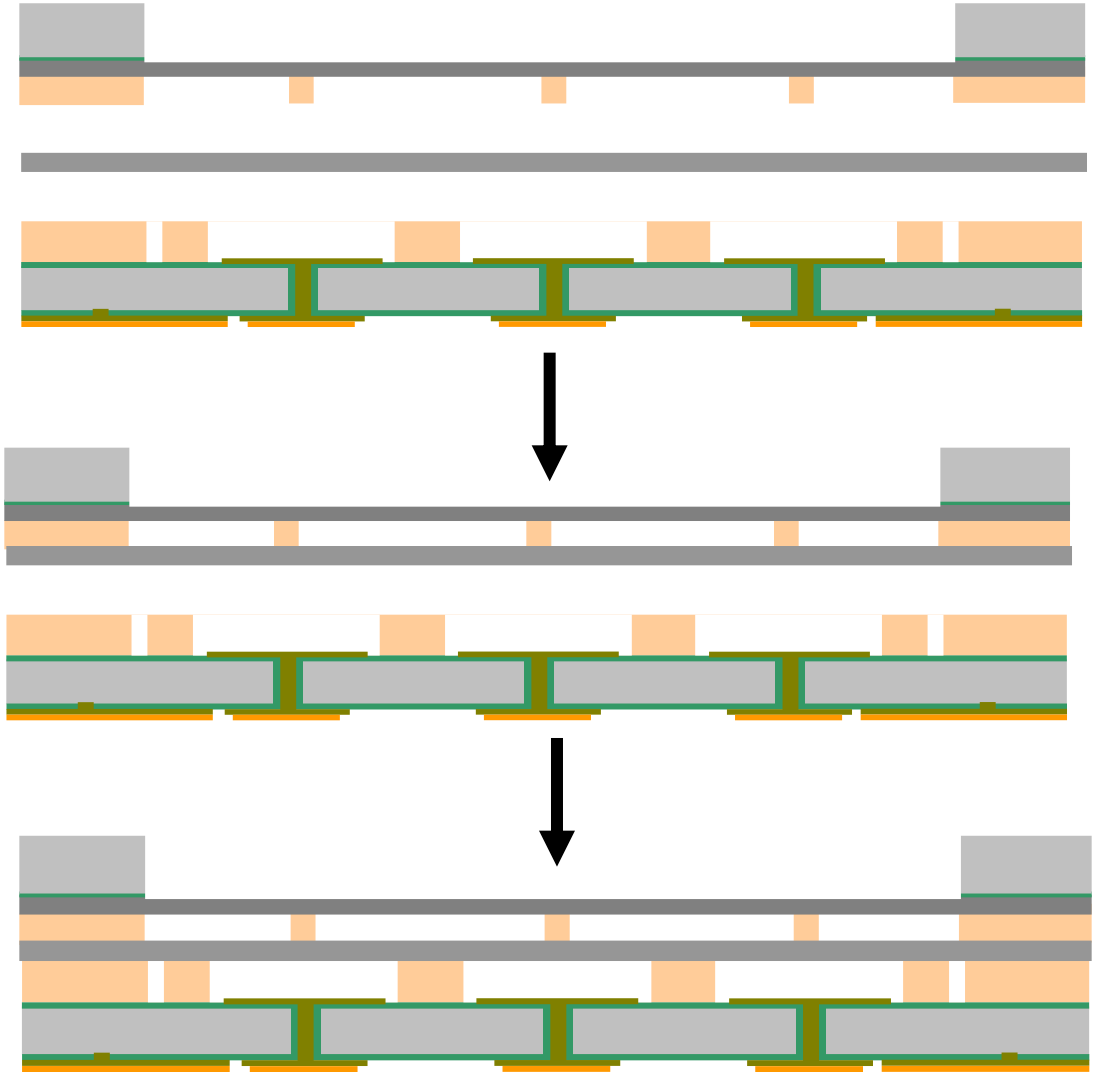
DM Fabrication Process Flow

- Same architecture as BMC Surface-micromachines polysilicon DMs
- Three 100mm wafers bonded together
  - One Si wafer with thru-wafer contacts
  - 2 SOI wafers
- 5µm thick patterned Pyrex film used for bonding
- Pyrex Actuator anchors and mirror posts



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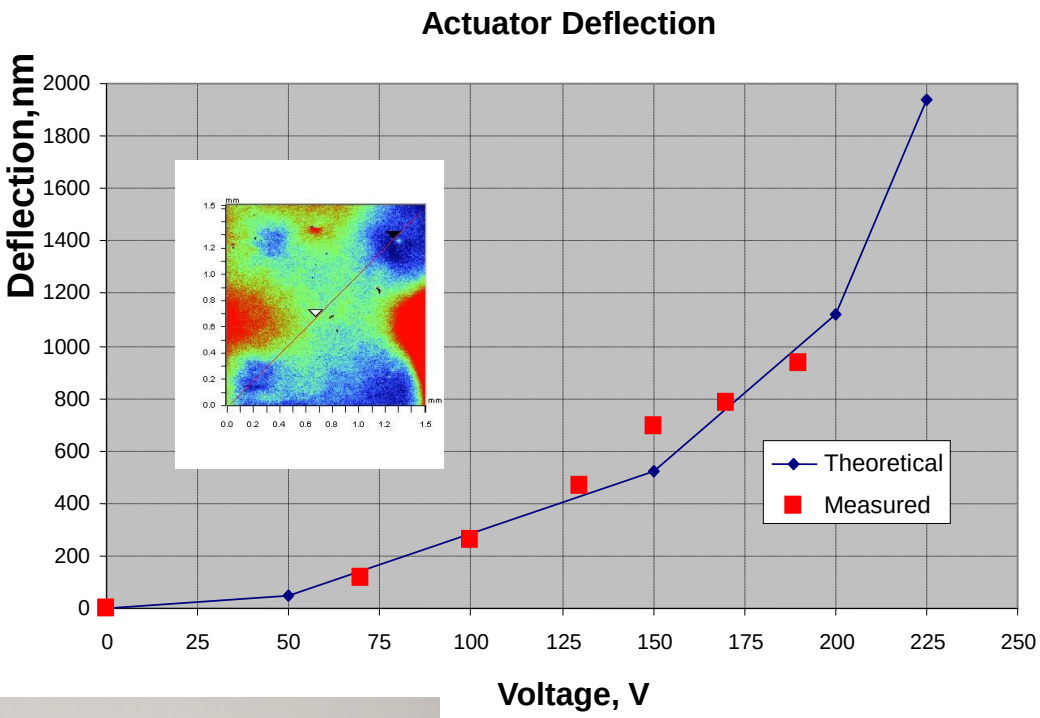
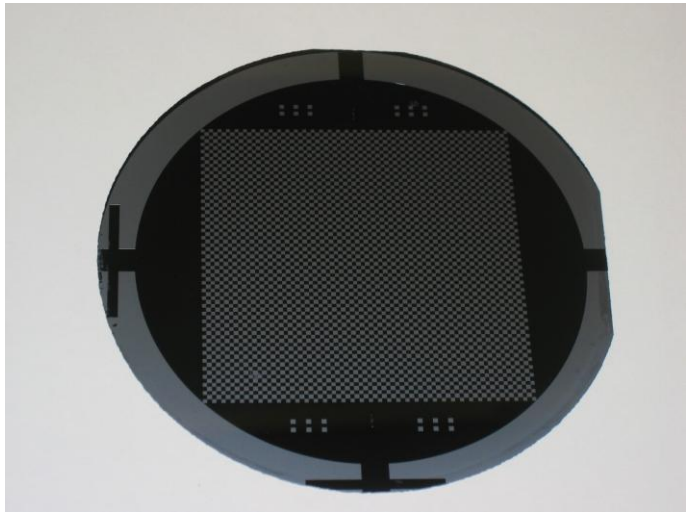
Large Aperture MEMS Deformable Mirrors

- Fabrication Process demonstrated in Phase I
- Main DM fabrication challenges:
  - Deposition of anodically bondable film
- Thru-wafer via array fabricated





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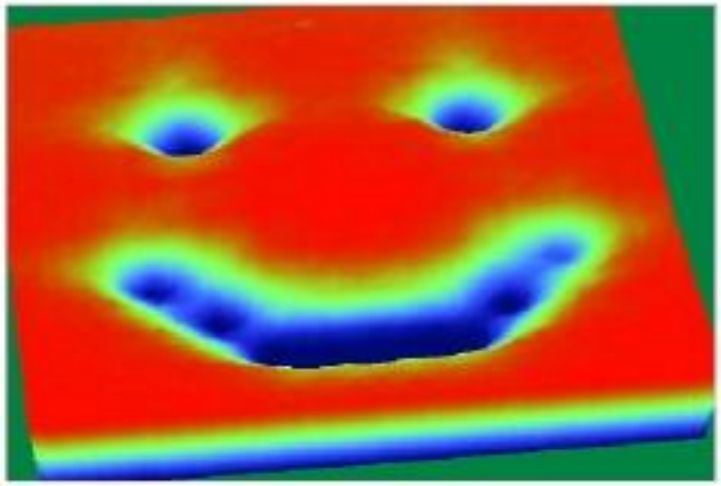
Summary

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



Thank you

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