Recent Progress in MEMS Deformable Mirrors

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Outline

- BMC DM Technology
- NASA funded mirror technology programs
- Astronomy Applications
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• BMC DM Technology
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MEMS DM Architecture

- Actuator Array
- Mirror Facesheet
- Actuator Electrode

- Continuous mirror (smooth phase control)
- Segmented mirror (uncoupled control)
- Hex Tip-Tilt-Piston
BMC Mirror Family

Small Cartesian Arrays
- Square arrays from 32 to 140 actuators
- Strokes: 1.5µm, 3.5µm or 5.5µm

Medium Cartesian Arrays
- Square and circular arrays from 492 to 1020
- 1.5µm & 3.5µm stroke

Large Cartesian Arrays
- Square and circular arrays from 2040 to 4092
- 1.5µm and 3.5µm stroke

Hex Tip-Tilt-Piston
- 37, 331- and 1021-Segment Devices

Developed through NASA funding
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MEMS Deformable Mirror Technology Development for Space-Based Exoplanet Detection

Contract#: NNH12CQ27CSAT/TDEM

Objective: Demonstrate survivability of the BMC MEMS Deformable Mirror after exposure to dynamic mechanical environments close to those expected in space based coronagraph launch.
Testing at JPL VSG

**Repeatability**
- Initial
- Final
- 1.4nm RMS difference

**Stability**
- Initial
- Final
- 0.9nm RMS difference

**Flattened**
- 6.6nm PV focus,
- 2.9nm PV 45 deg astig, 0.3nm
- PV 90 deg astig, 7.6nm RMS
- higher order terms

Average Bias

Average Bias

Time

Time
High Contrast Imaging Laboratory (HCIL)
Kasdin Lab, Princeton University

- Batch process estimator with two pairs of probes
- Stroke minimization controller
- Two BMC DMs with 952 actuators on each
- Achieved $2 \times 10^{-7}$ contrast within $6-11 \lambda/D$ and $9 \times 10^{-7}$ contrast $5-14 \lambda/D$
Vibration Testing for TDEM

- Levels defined by WFIRST
- 9 DMs were tested
  - 3 Low Level
  - 3 Medium Level
  - 3 High Level
- 1 DM traveled to Goddard and back but was not exposed to vibration
- 1 DM stayed at BMC
- All DMs were characterized at BMC before going to Goddard
Example Results

Pre Vibe Flattening

Post Vibe Flattening

Difference

5nm RMS

5nm RMS

4nm RMS
Project Flow

- MEMS Mirror Fabrication
  12 Devices

- BMC Characterization

- Coronagraph Test
  Bed Component Insertion and Baseline Null Testing

- Launch Environmental Testing
Improved Yield, Performance and Reliability of High-Actuator-Count Deformable Mirrors

Contract Number: NNX16CP14C Phase II SBIR

Mirror architecture
- 2040 actuators
- Active Aperture Diameter: 19.6mm
- # Actuators across active diameter: 50
- Actuator Pitch: 400µm
- Actuator Stroke: 1.5µm
- Operating Voltage: 0 – 100V
- Mirror Surface Figure: <5nm RMS

2K DM Die Layout

Single element of 2040 array
Phase II 2K DM Status

Actively Flattened

- 5 nm RMS

Voltage vs. Deflection Test

Low Voltage Design
Phase II 2K DM Status

Actively Flattened
- 5 nm RMS
- Delivered to JPL in July
- Characterization ongoing
- Insertion into HCIT early in 2019

Voltage vs. Deflection Test

Low Voltage Design

Voltage map for flattening DM
Phase II-X Program

Goal
• Deliver two 2040 actuator DMs with 100% functioning actuators
• Extensions from Phase II
  • Change substrate thickness to reduce unpowered figure error
  • Use new design developed in Phase II

Current Status
• First fabricated part arriving
• Probe station developed to test yield of devices before packaging
• Starting testing of devices from Phase II
Technology Development for High-Actuator-Count MEMS DM Systems

NASA Contract #NNX17CP76P

- Flip chip bonding process where DM is attached directly to flex PCB with high density interconnect
- Packaging and interface design development ongoing
- Proposed for space applications
- Transferable for ground-based applications

<table>
<thead>
<tr>
<th>Mirror architecture</th>
<th>7860 actuators</th>
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<tbody>
<tr>
<td>Active Aperture Diameter</td>
<td>29.7 mm</td>
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<tr>
<td># Actuators across active diameter</td>
<td>100</td>
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<tr>
<td>Actuator Pitch</td>
<td>300 µm</td>
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<tr>
<td>Actuation architecture</td>
<td>Electrostatic</td>
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<tr>
<td>Actuator Stroke</td>
<td>1.5 µm</td>
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</table>
“Primary Tweeters: Segmented micro-mirrors for picometer-scale wavefront compensation in space-based observatories”

NASA Phase I SBIR

- Fabrication of hex deformable mirror that can model segmented primary
- Hex DM segments with range of actuators underneath segment (3,5,8,13...)
- Phase I will evaluate control of varying actuator count
- Phase II will make a DM matching known primary (e.g. JWST, HabEx, LUVIOR)
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Space Applications

THE PICTURE PROGRAM
PLANETARY IMAGING CONCEPT TESTBED USING A ROCKET EXPERIMENT

PICTURE
Launched 2011

PICTURE-B
Launched 2015
Kilo-DM Completed Successful Flight Survivability Test

PICTURE-C
DM Delivered 2017

DEFORMABLE MIRROR DEMONSTRATION MISSION (DeMi)

Program Goal:
Validate and demonstrate the capabilities of high actuator count MEMS deformable mirrors for high contrast astronomical imaging.
Future Space Missions

Need for higher actuator count DMs

Habitable Exoplanet Imaging Mission (HabEx)  Large UV/Optical/IR Surveyor (LUVOIR)
Ground Based Astronomy with BMC Mirrors

- Kitt Peak 2.1m Robo-AO
- Lick Observatory Shane-AO
- Subaru telescope SCExAO
- Gemini South Gemini Planet
- Keck Telescope Keck Planet Imager and Characterizer
- Magellan Telescope MagAO-X
- UH 2.2-m telescope Robo-AO 2
Conclusion

• TDEM program is progressing with conclusion early 2019
• Phase II-X program continued for WFIRST deliverable
• Results from our Phase I and II program show good promise for next generation MEMS DMs.

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  • Contract#:  NNX17CP76P NASA Phase II  SBIR
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Thank You

Questions?

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