MEMS Deformable Mirror Development

NASA Phase SBIRs: NNX14CG06C, NNX16CD58P
SAT/TDEM

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Approved for public release; unlimited distribution
Iris AO Segmented DM

Background
Iris AO MEMS Segmented Deformable Mirrors

PTT111 DM
- 111 Actuators
- 37 PTT Segments
- 3.5 mm inscribed aperture
- Factory calibrated

PTT111L DM (Not Shown)
- 111 Large Format Actuators
- 37 PTT Segments
- 7.0 mm inscribed aperture
- Factory calibrated

PTT489 DM
- 489 Actuators
- 163 PTT Segments
- 7.7 mm inscribed aperture
- Factory calibrated
Iris AO Segmented DM Background

- 3 DOF: Piston/tip/tilt electrostatic actuation
  - no hysteresis
- Hybrid fabrication process
  - 3-layer polysilicon surface micromachining
  - Single-crystal-silicon assembled mirror
- Unit cell easily tiled to create large arrays
- Hybrid technology
  - Thick mirror segments
  - <1 nm PV/°C segment bow
  - Enables back-side stress-compensation coatings

Recent Update: > 48 months and calibrations hold!
PTT111L Used for JWST Simulation

James Webb Space Telescope optical simulation testbed IV: linear control alignment of the primary segmented mirror

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Higher contrast ever demonstrated with a MEMS DM!


10⁹ Contrast @ IWA 1 – 4 λ/D Results
GSFC VNC Instrument on 06/09/12
SAT/TDEM Environmental Testing
TDEM Progress

• Prior Results
  – Developed FEM models of the MEMS actuators and mirror segments
    • Models match platform heights to within 6% and capture manufacturing non-idealities
  – In-house vibration, shock, and acoustic testing
    •DMs pass levels required by TDEM program
  – Issues with fabricating test devices: large process variations due to process immaturity
    • Issues from multiple lots identified and processes improved

• Current Effort
  – Manufacturing samples for testing
    • Materials appear to be the best to date

• Remaining Effort
  – Complete characterization at Iris AO and GSFC
  – Environmental testing
  – Post-test characterization
  – Final report
Additional Environmental Testing

- PTT489 DMs passed radiation testing
- PTT111 DM operation tested at -50°C
- PTT111 DM operation tested at 160 K and high vacuum (10⁻⁵ Torr)
- PTT111-5 will be incorporated into a coronagraph on the High-Contrast Imaging Balloon System (HiCIBaS)
  - U Laval, U Leiden, U Montreal, U Victoria, CSA, ABB, Iris AO, JPL, Nüvü
  - Operation at 30-42 km elevation
  - Launch date: September 2018
Phase II SBIR Development
NNX14CG06C
Increasing Phase Resolution
High-Resolution Electronics Development

- Existing Iris AO drive electronics are 14-bit resolution with integrated DAC / HV Amp

NNX14CG06C Development
- 16-bit resolution HV driver card
  - ADI 16-bit DAC + SuperTex HV Amp

- USB2.0 High-Speed interface
  - Microcontroller
  - FPGA to implement timing critical modulation
  - Windows *and* Linux compatible
    - ~4 kHz updates under Linux
Super-Resolution Drive Electronics

- Iris AO electronics are 14 bit (native) resolution
- Super-resolution technique has demonstrated 18-bit resolution
  - Grid spacing is for 1 LSB on 18-bit resolution
  - Software driven control using a PCI interface card
  - Impractical for actual use
- Phase II Development
  - Modulation schemes implemented in FPGA on USB interface card

Software-Driven 14-Bit Super-Resolution Results 2013

14 Bit Native Resolution
2017 Firmware vs 2013 Software

Super-Resolution Step Data at 14+0,+2,+3,+4 bits (Basic Modulation)

SmartDriver II, s/n 03160009, date: 07/18/2017
Output chan 36, nominal 5Vdc output
14+0 (blue), 14+2 (magenta), 14+3 (green), 14+4 (red)
Analog filtering: 2 poles at 19 Hz
DMM: Agilent 34401A, Auto range, ~3 Hz samp

14 Bit Native Resolution

Firmware controlled super-resolution is better than PCIe computer interface hardware using software/DMA writes
Super Resolution: 14 vs 16 Bit Electronics

Iris AO Integrated 14 bit Electronics

Iris AO 14-bit electronics with integrated DAC/HV Amp greatly outperform the ADI DAC + SuperTex HV Amp two-chip solution!

ADI + SuperTex 16 bit Electronics
Super Resolution: 14 vs 16 Bit Electronics

Iris AO 14-bit electronics with integrated DAC/HV Amp greatly outperform the ADI DAC + SuperTex HV Amp two-chip solution!
Iris AO Integrated 14 bit Electronics
• std dev = 0.253 mV
• 200 V max output
• 19.6 bit stability over 30 minutes

ADI + SuperTex 16 bit Electronics
• std dev = 0.959 mV
• 200 V max output
• 17.7 bit stability over 30 minutes
Phase II SBIR Development

NNX14CG06C

Increasing Spatial Resolution
(Increasing Yield)
PTT939: 1000-Actuator DM Fabrication

- Wafer-scale assembly developed
  - Multiple bondsite material stacks tested
  - Process complexity increased over multiple runs
- PTT939 Actuator and mirror wafer fabrication complete
- PTT939 wafer-scale assembly and etch to access mirror array completed
- 2nd wafer-scale assembly run to be completed Q1 2018
  - Reduce delamination
- Yield Increases
  - Projection lithography
    - Better uniformity
    - Excellent overlay error (layer-layer alignment)
    - 0 mask defects
  - Incorporate process improvements from PTT489 fabrication
    - Release development
    - Seed-layer etch improvements

November 16, 2017
Mirror Technology Days 2017
Phase I SBIR Development
NNX16CD58P
Increasing Spatial Resolution Even More

November 16, 2017
Scaling to 3045 Actuators

• Design study of a 3045 actuator (1015 segment) DM
  – DM
  – Packaging
  – Electrical probe-testing hardware

• Results
  – All hardware is feasible using readily available technology
  – DM chip size: 35.6 mm x 27.4 mm
  – Field-stitching required for large arrays
    • Lithography system field size: 22mm x 27.4 mm

• Preliminary PTT3045 design and field-stitching completed in Phase I

• Yield study determined key source of defects in wiring layers
  – Process improvements resulted in 15X reduction in defects
PTT3045 Field-Stitched Wiring Layer

- PTT3045 arrays are exposed in two halves: left and right
- Left/right field misalignment
  - 0.1 µm typical
  - 0.2 µm maximum
- Minimum feature size: 3.5 µm
  - 0.2 µm misalignment is inconsequential
- Phase I Conclusions
  - PTT3045 DM can be fabricated with proven/existing fabrication technologies
  - Scaling to larger arrays will require higher-density interconnect
Summary

• Super-resolution drive electronics demonstrated
  – Super-resolution technique shows clear increase in resolution: nearly 6+ bits
  – 30 minute stability
    • 19.6 bit stability with integrated 14 bit DAC/HV Amp chips
    • 17.7 bit stability with separate 16 bit DAC/HV Amp chips

• Wafer-scale assembly demonstrated
  – PTT939 (1000 actuator DM) fabrication nearly complete
  – Process improvements identified that will be implemented for 2\textsuperscript{nd} assembly run

• 4\textsuperscript{th} generation 3045 actuator DM technology assessment and preliminary design complete
  – Fabrication possible using existing technologies combined with field-stitching
  – Yield study reduced defects 15X