Extreme-Precision MEMS Segmented Deformable Mirror (NASA Phase II SBIR)

Michael A. Helmbrecht, Ph.D.
Iris AO, Inc.

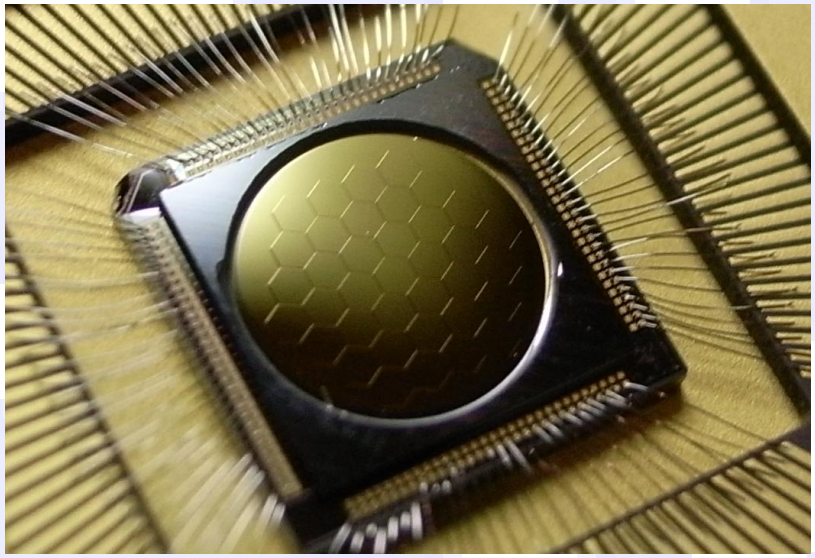
www.irisao.com
michael.helmbrecht@irisao.com
info@irisao.com

Mirror Technology Days

August 25th – 27th, 2008

Precision DMs & Electronics

Compact



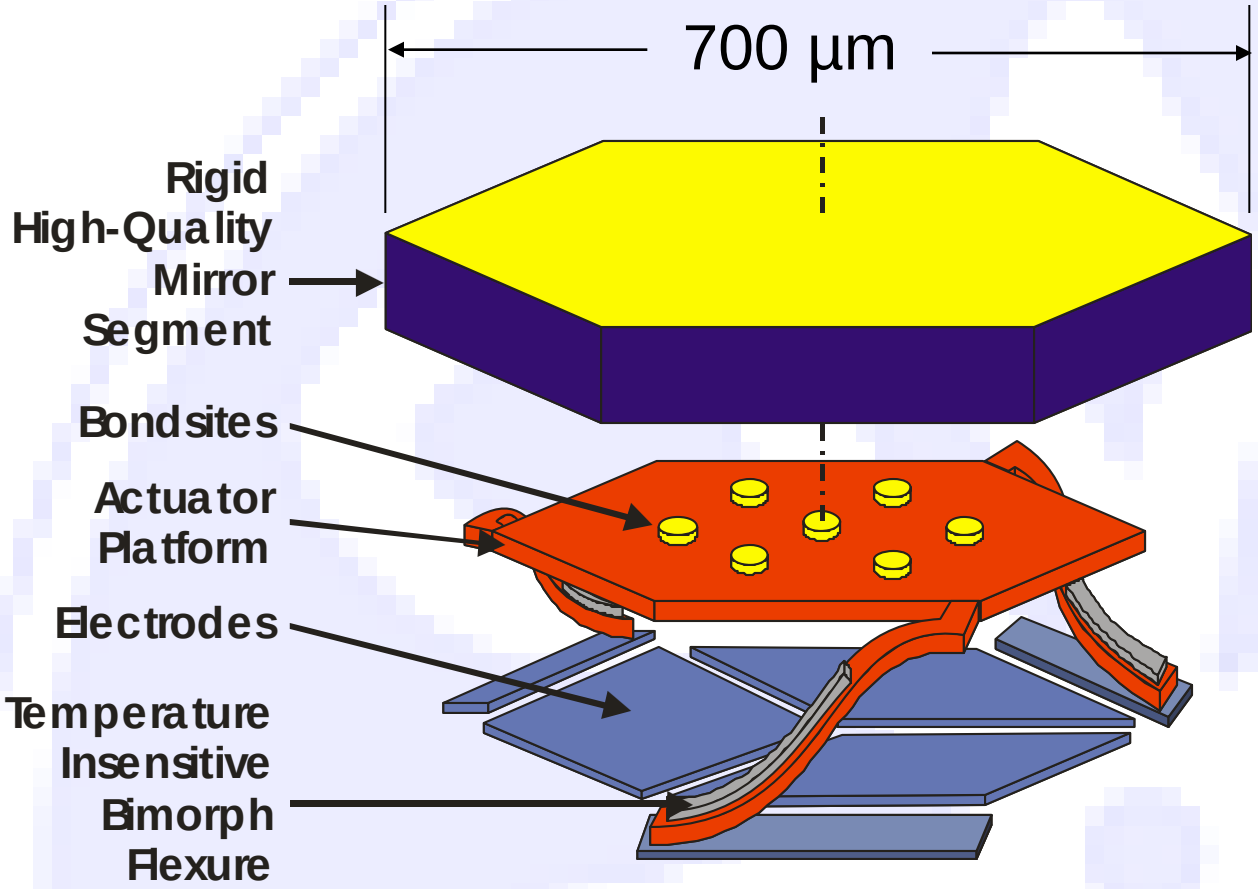
Robust

Easy to Use

Outline

- Iris AO DM Segment
- NASA Phase II SBIR Progress
  - Precision MEMS DM
  - Precision drive electronics
- DM Scaling
  - NIH Phase II SBIR Progress
    - 163 segment DM
  - 10^3 segment scaling demonstration

Segmented MEMS DM Schematic



- Robust single-crystal-silicon assembled mirror surface stays flat (0.56 nm/°C PV)
- Temperature-insensitive bimorphs elevate mirror above substrate (14 nm/°C, σ=0.8 nm/°C)
- Piston/tip/tilt electrostatic actuation
- 2.3 kHz frequency response
  - 170/200 µs rise/fall times, 10-90%

Phase II SBIR Goals

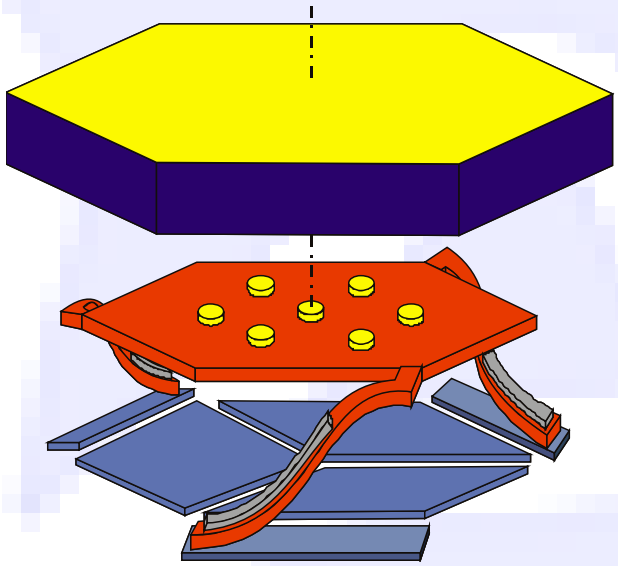
Performance Period: Jan 29 2007 – Jan 28, 2009

Specification	Start of Phase II	Phase II Demo Goal*	Phase II Study Goal	Today (8/2008)
Surface Figure Errors (nm *rms*)	6-20	1-3	0.1	5-11
Open-loop positioning accuracy *(rms)*	20-30 nm	10 nm	Not Specified	8 nm (flattened)
Positioning resolution *(nm rms)*	5 (elect noise limited)	0.14	0.04	0.45 (0.11 PWM)
Stability *(nm rms)* • over 15-60 min	0.2-1.2 (5 elect. noise)	0.2	0.04	TBD
Failure Testing: Continue testing and determine techniques to eliminate potential snap-in failures				

*** Independent verification by the Lab for AO at UC Santa Cruz**

Surface Figure Errors

- Current designs: 5-11 nm *rms*
  - Single-crystal-silicon segments
  - Segment thickness = 25 µm
- Thicker ⇝ Flatter
  - Surface figure errors 🔔 $1/t^{2\text{-}3}$
  - DMs with 50 µm-thick mirrors will be fabricated by end of contract
    - Expect 4-8X improvement in *rms* figure errors



Closed-Loop Flattened DM

Veeco

Mag: 1.4 X
Mode: PSI

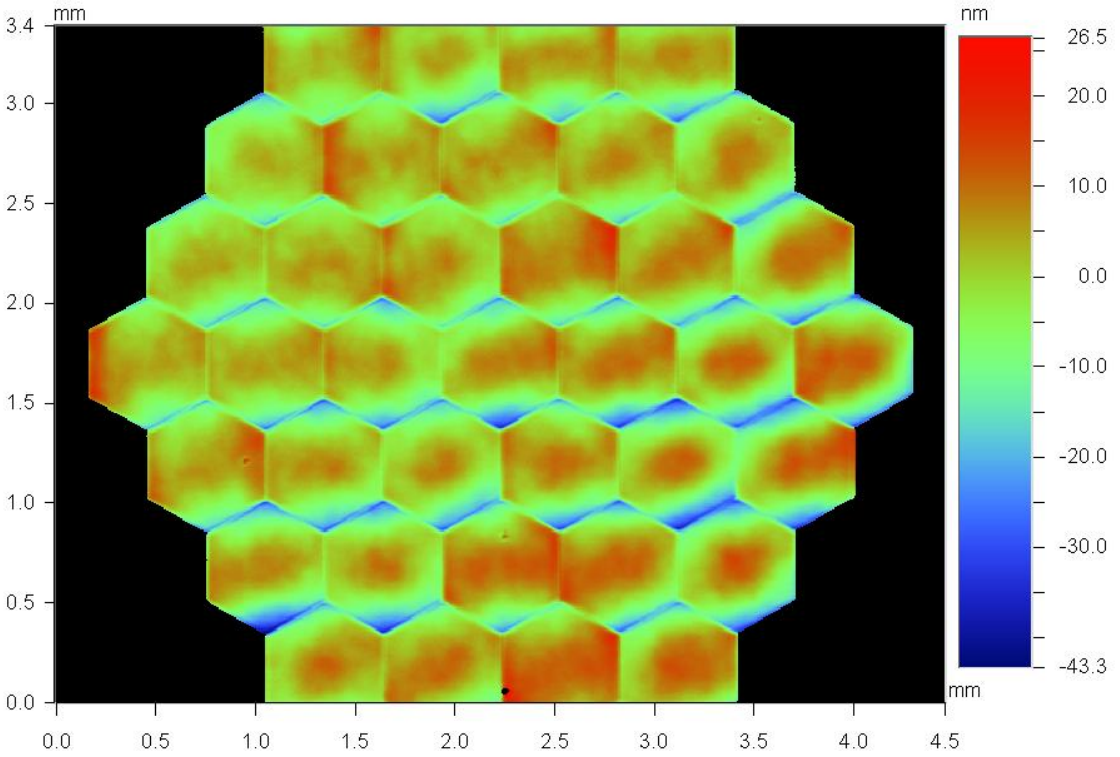
Surface Data

Date: 06/20/2008
Time: 16:19:29

Surface Statistics:
Ra: 6.04 nm
Rq: 7.74 nm
Rz: 55.73 nm
Rt: 69.79 nm

Set-up Parameters:
Size: 736 X 480
Sampling: 6.06 um

Processed Options:
Terms Removed:
Tilt
Filtering:
None



Title: FSC37-01-07-0614
Note: Closed-Loop Flattened

Open-Loop Flattened DM

Veeco

Mag: 1.4 X
Mode: PSI

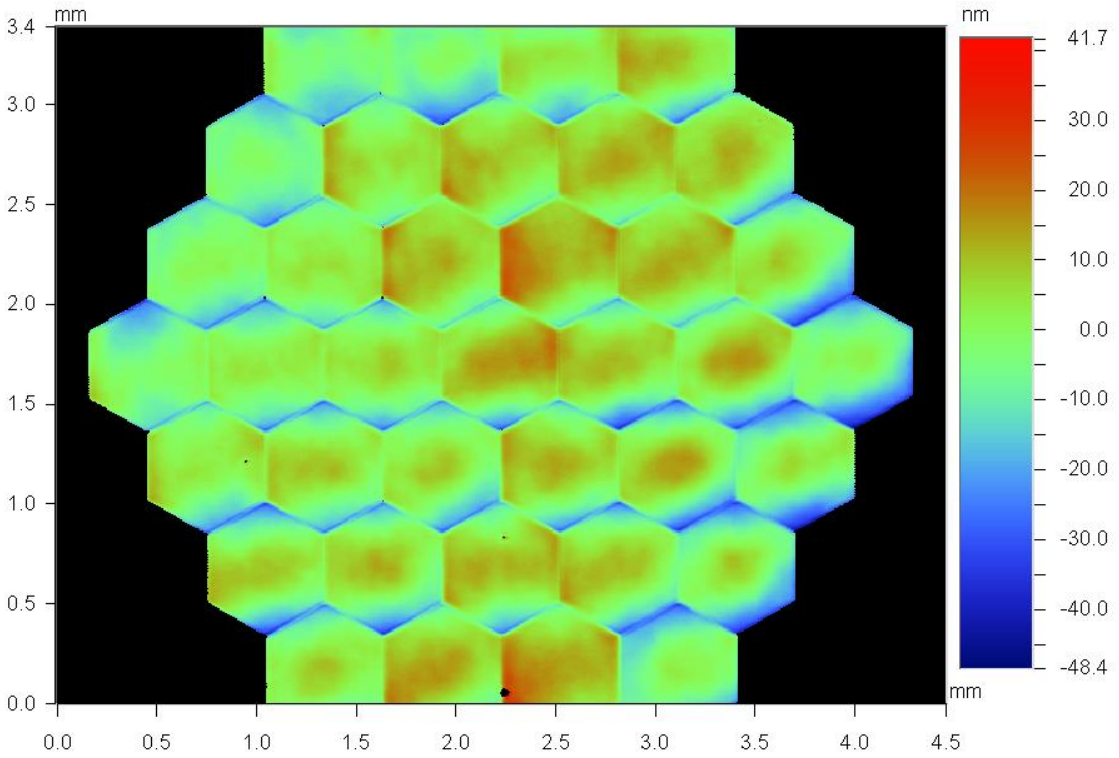
Surface Data

Date: 06/19/2008
Time: 16:02:01

Surface Statistics:
Ra: 7.28 nm
Rq: 9.21 nm
Rz: 67.65 nm
Rt: 90.05 nm

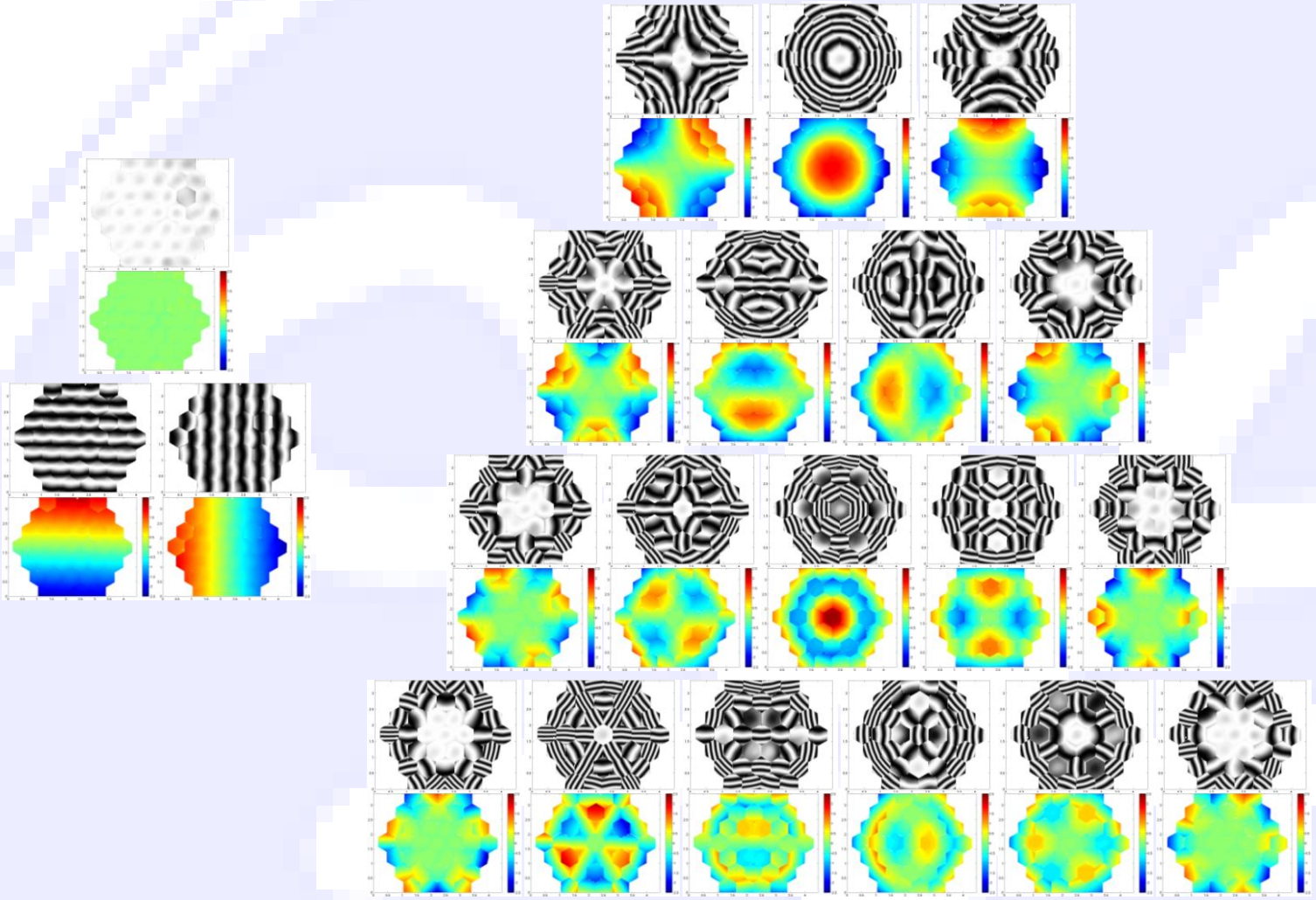
Set-up Parameters:
Size: 736 X 480
Sampling: 6.06 um

Processed Options:
Terms Removed:
Tilt
Filtering:
None



Title: FSC37-01-07-0614
Note: Open-Loop Flattened

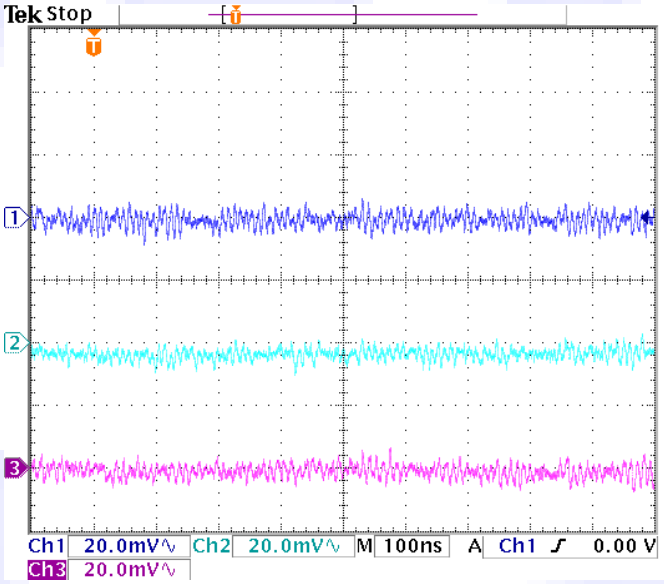
Open-Loop Positioning Example



Extreme Positioning Resolution

1. DM design that uses full scale voltage
   - Actuator fabrication complete
2. Compact, low noise, high resolution electronics

- 14 bit, 200 V
- Factory calibrated with on-board calibration values
- USB interface - (Low speed 150 Hz)
- Scales to > 10k channels
- High speed interface options will be available
  - Digital input supports 35 kHz frame rate
  - Analog Output f_{-3db} > 5 kHz

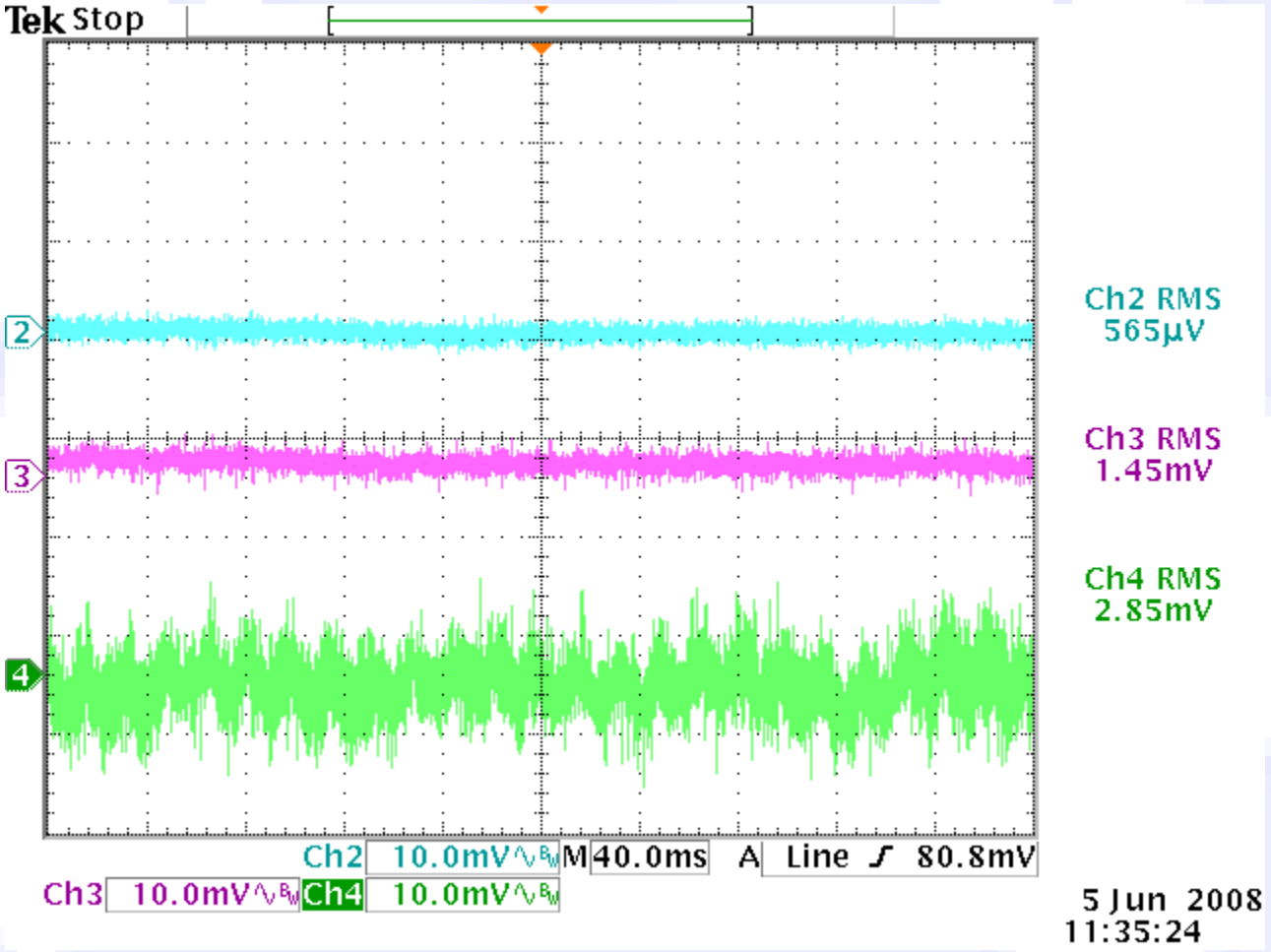


Unfiltered Noise: 3.3 mV rms

Iris AO, Inc.

Noise Filtering

- Noise is mostly high frequency
- Low-speed applications can take advantage of filtering



2nd Filter Output (15.9 Hz F_{-3dB})

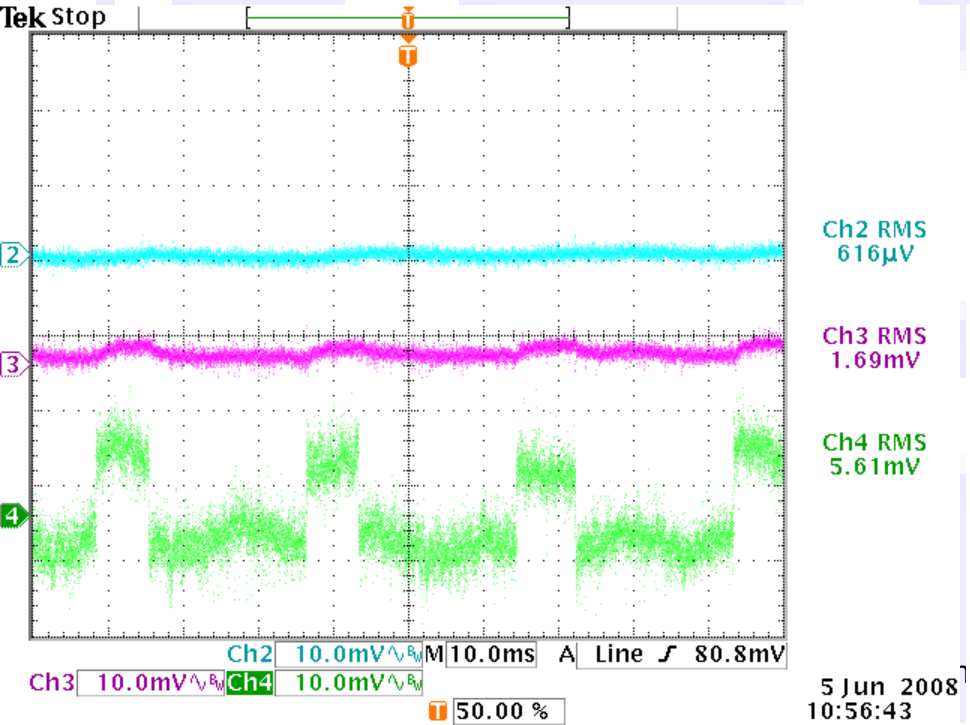
1st Filter Output (15.1 Hz F_{-3dB})

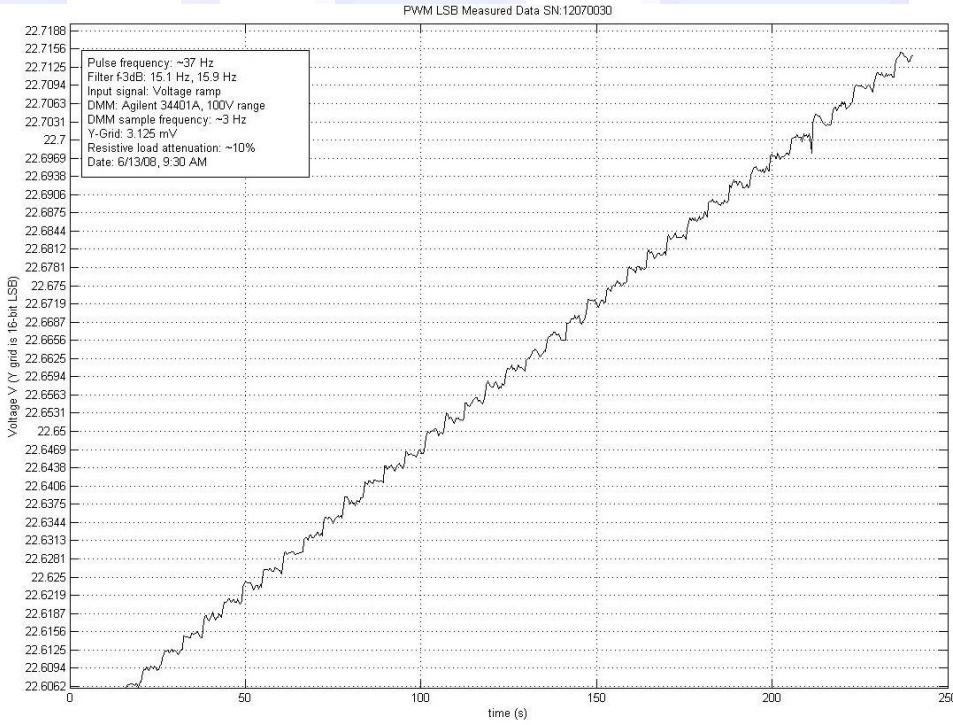
Unfiltered Output

Iris AO, Inc.

Modulation + Filtering = Super Resolution

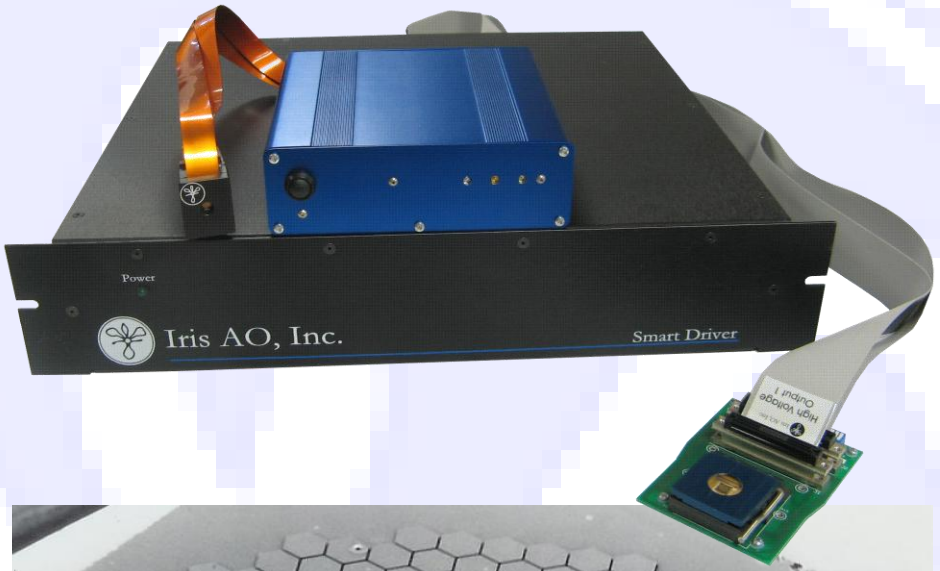
- LSB modulation with low-pass filtering
  - 16+ bits resolution
- First demonstration modulated at ~35 Hz shows 16-bit resolution
- >5 kHz modulation when implemented in firmware

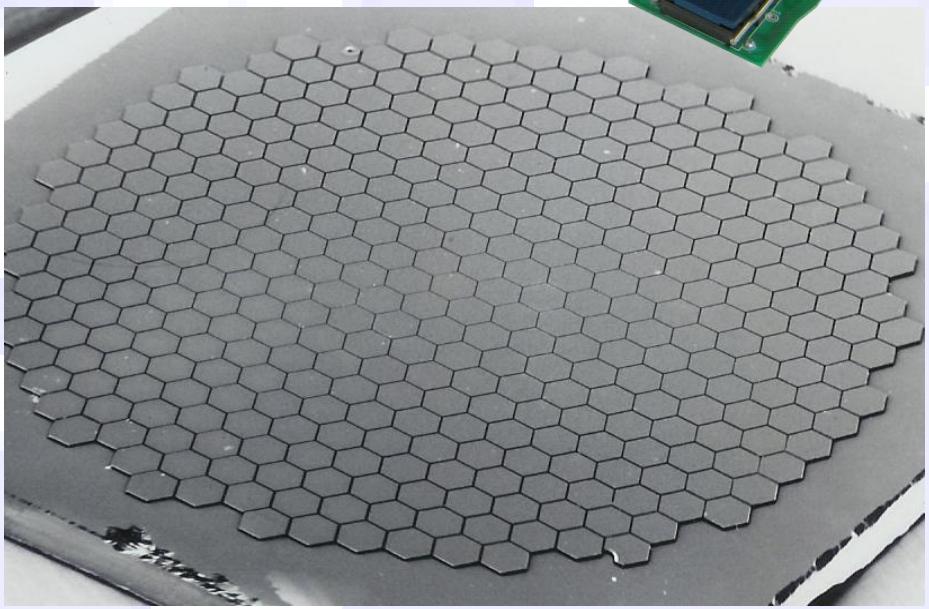




Scalability

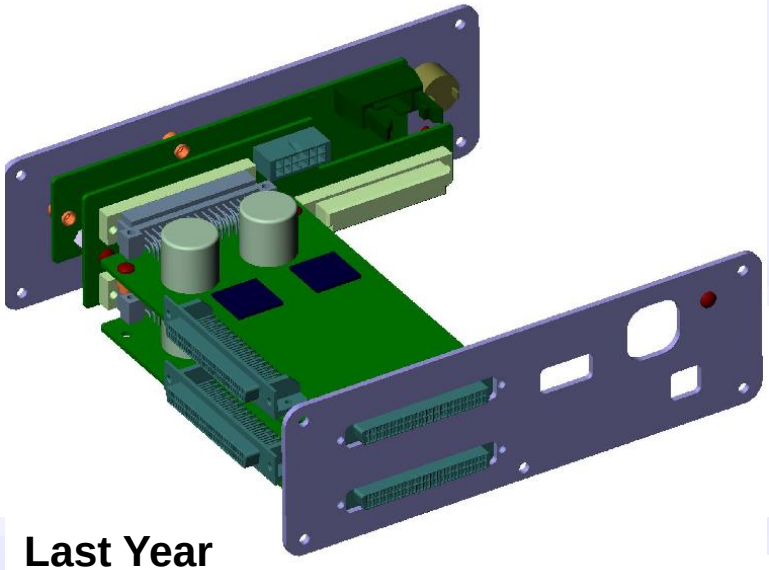
- Scalable drive electronics
  - NASA Phase II SBIR
- 163-segment DM
  - NIH Phase II SBIR
- 10^3 segment DM
  - Funding TBD
  - Preliminary experiments where possible



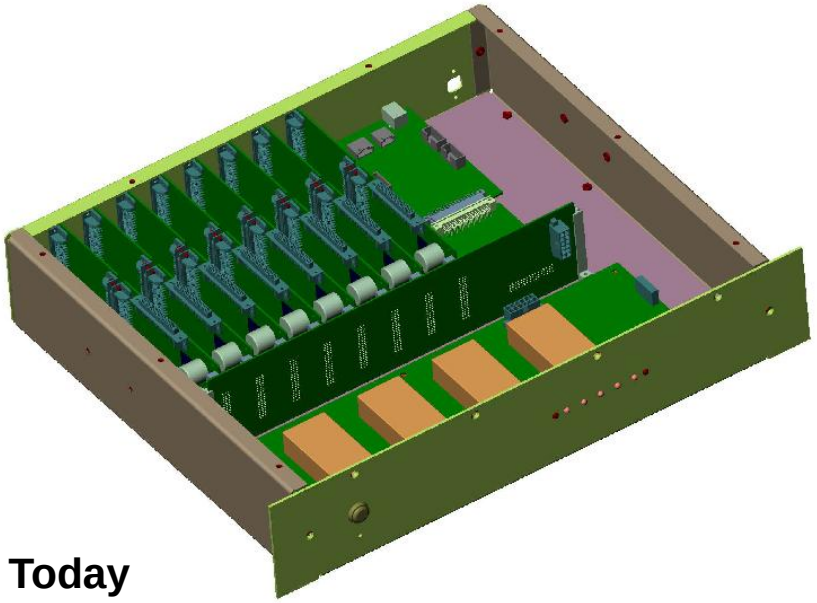


Iris AO, Inc.

Smart Driver II Electronics – 512 Channels

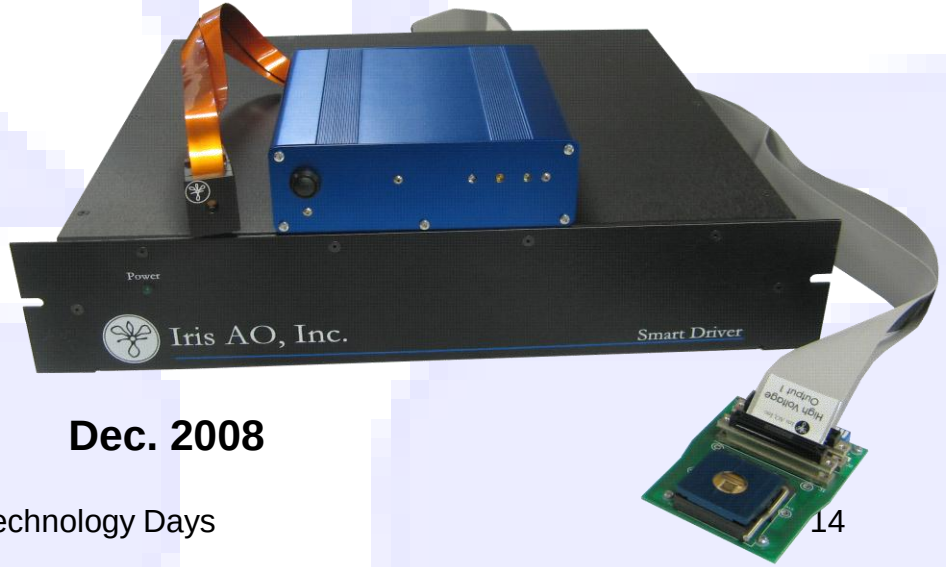


Last Year



Today

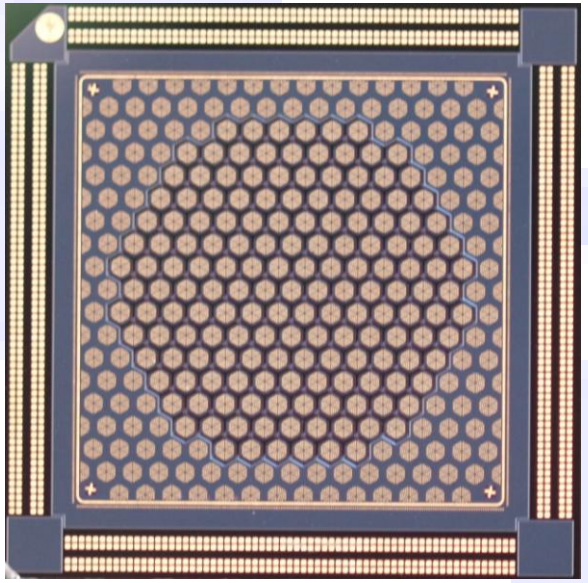
Today



Dec. 2008

163 Segment (S163-X) DM Development

- Funded by NIH Phase II SBIR
  - Sept 2007 – August 2009
- Actuator wafer process development underway
  - 1st Run: Electrode and mechanical layer only
  - 2nd Run: Includes wiring layer
    - Fabrication begins 9/2/08
- Mirror-wafer fabrication to begin 10/2008
  - Mirror-wafer process already developed

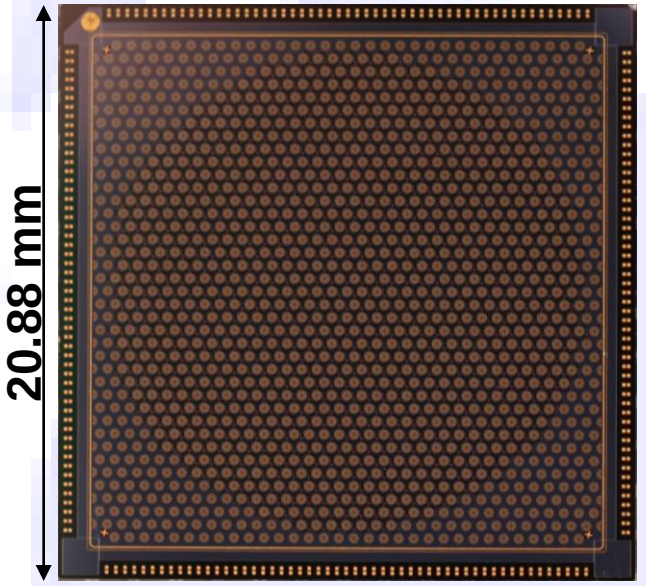


13.4 mm

Iris AO, Inc.

10^3 Segment DM

- Path-finding research into 10^3 segment class DMs
- Developing along with S163-X
  - Multi-project wafer
  - 1st and 2nd fabrication runs
- 925 actuators w/ganged electrodes to reduce wiring
- Segment pitch matches EPIC point design
  - Extrasolar Planetary Imaging Coronagraph (EPIC) - Discovery Mission Concept
  - Clampin/Lyon GSFC
- Additional funding TBD
  - Proposing Phase I SBIR to NASA GSFC



Summary

- On our way to meeting Phase II SBIR goals
  - Low-noise electronics
  - Super-resolution technique
  - DM flatness improving (2X since start of contract)
    - Expect to reach 1-3 nm rms surface figure error goal
- Developing larger mirrors
  - S163-X prototype development
  - 10^3 segment DM proof-of-concept development
    - Needs additional funding to wire and package

Acknowledgements

Funding Sources

- NASA – Phase II SBIR, (Extreme Precision DM Testing and Development)
  - NNG07CA06C
- Center for Adaptive Optics (DM Process Development)
  - National Science Foundation Science and Technology: No. AST – 9876783
- National Eye Institute – Phase II SBIR (DM Process Development)
  - 2 R44 EY015381-02A1
- US Air Force – Phase II SBIR (DM Control)
  - FA8650-04-M-6518
- National Science Foundation – Phase II SBIR (Ancillary Process Development)
  - DMI-0522321

R&D Fabrication Facility

- Berkeley Microfabrication Laboratory

Research Collaboration

- Berkeley Sensor & Actuator Center