

Development of a Deformable Mirror for High-Power Lasers

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Mirror Technology Days
August 1, 2007

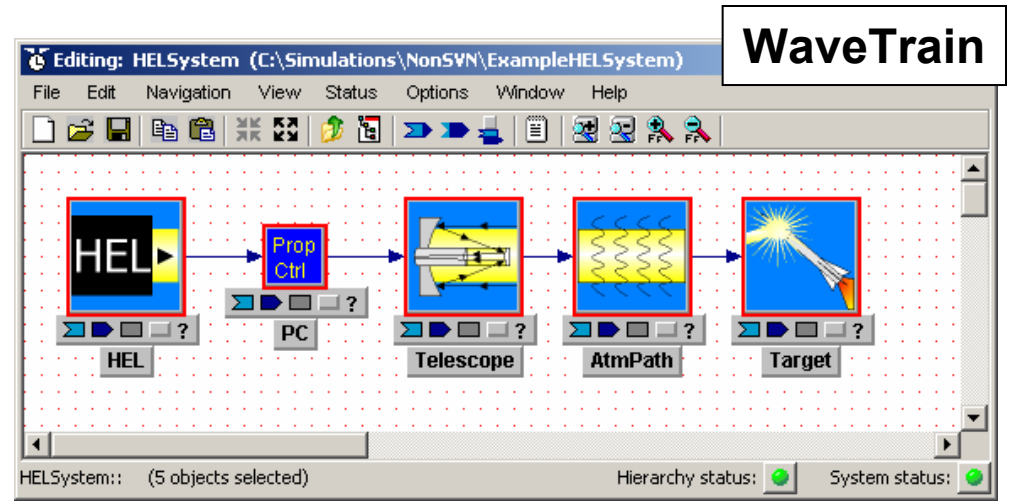


Outline

- Introduction & Project Goal
- Deformable Mirror Modeling
- Drive Electronics, Packaging, and Coatings
- Device Demonstrations
 - Prototype Demonstration
 - Full-Scale Device
- Conclusions and Future Work

Introduction to MZA & AOS

- MZA was founded in 1991 to support the government directed energy community.
 - WaveTrain – Connect the blocks wave-optics and AO modeling software
- Active Optical Systems, LLC, was founded in 2005 to commercialize adaptive optics hardware.



**1" Diameter DM
Before Packaging**



HV Drive Electronics

Project Goal

- Develop two deformable mirrors capable of being used in high power laser applications.
- Devices should be
 - 2” in diameter
 - sufficient to compensate an example laser gain medium aberration
 - Capable of being addressed from a PC
 - Completed in ~6-8 weeks
 - \$78k

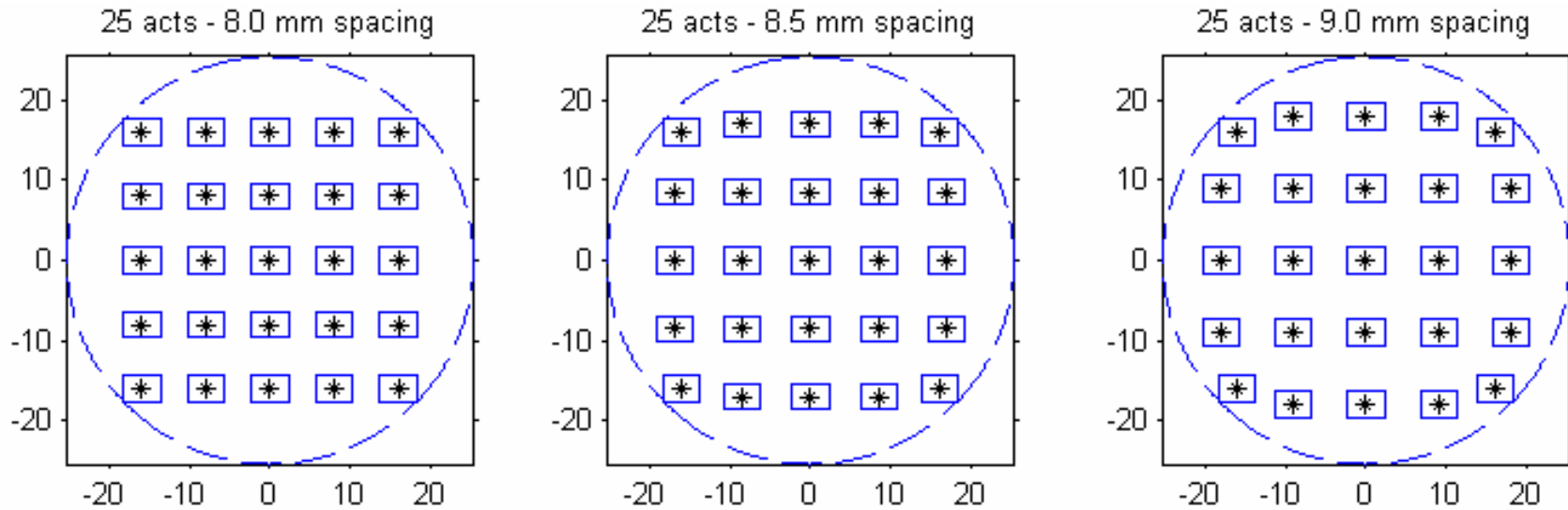
DM Aberration Compensation Modeling

Modeling Question:

How many actuators? What spacing?

- Procedure
 - Influence functions (IFs) were determined from an analytical expression for a small area force on a clamped plate model.
 - Use the IFs to fit the aberration and determine Strehl ratio using the integral form assuming a flat intensity.
- Developed a program to determine the optimum actuator spacing based on the aberration measured from a slab solid-state laser gain medium.
- Decided to not clip the corner actuators, but instead move them in.

Actuator Configurations

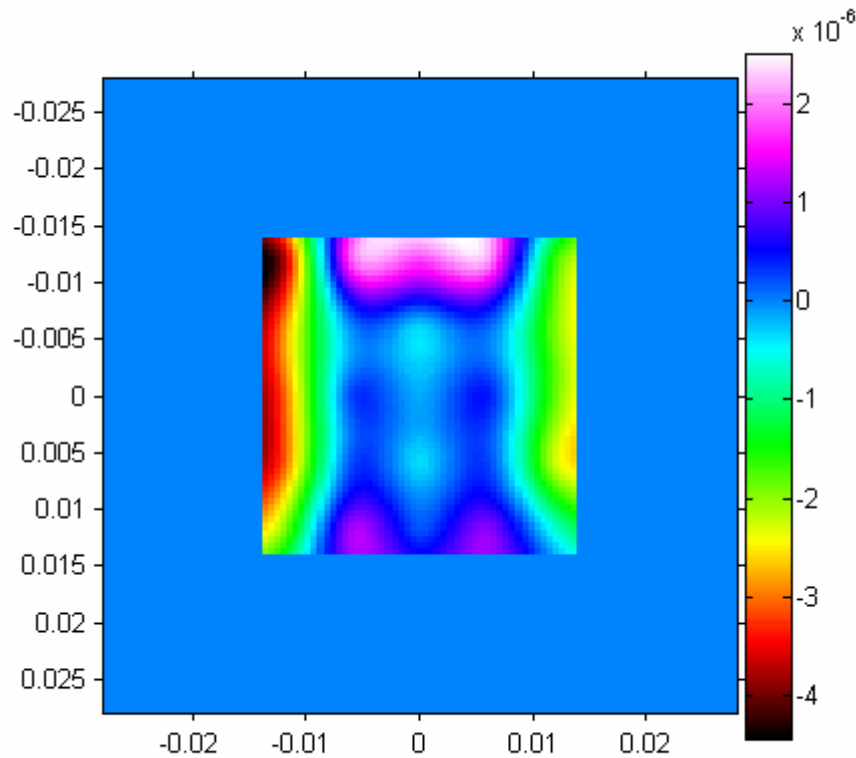


Select Actuator Configurations

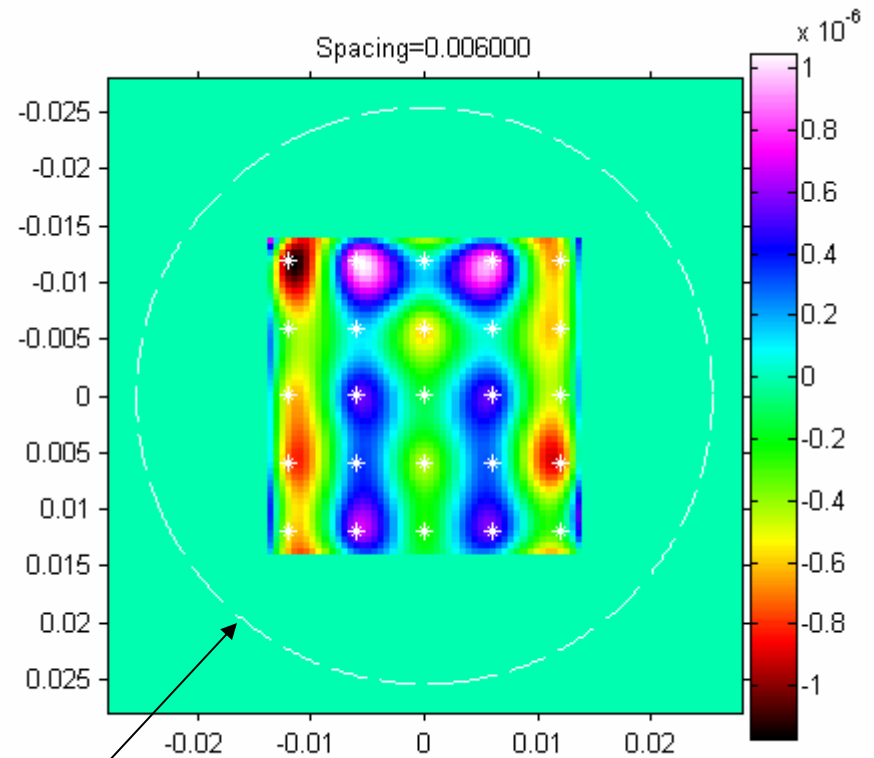
- 25 Actuators
- Actuator Spacing from 6 to 11.25 mm

Example 1 - 6.00 mm spacing, 25 acts

DM Surface



Difference

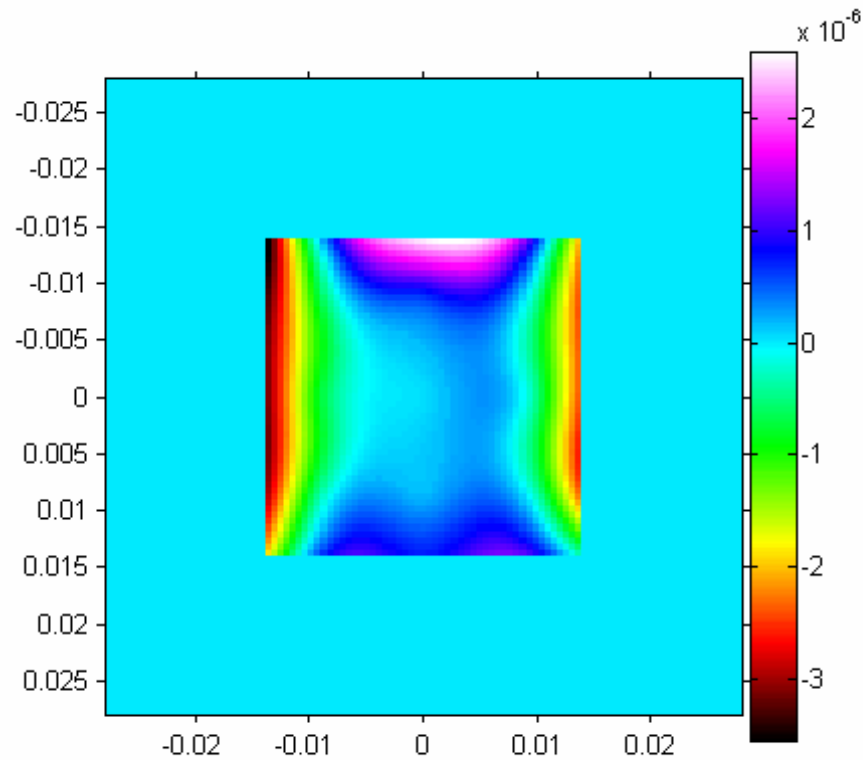


2" DM Aperture

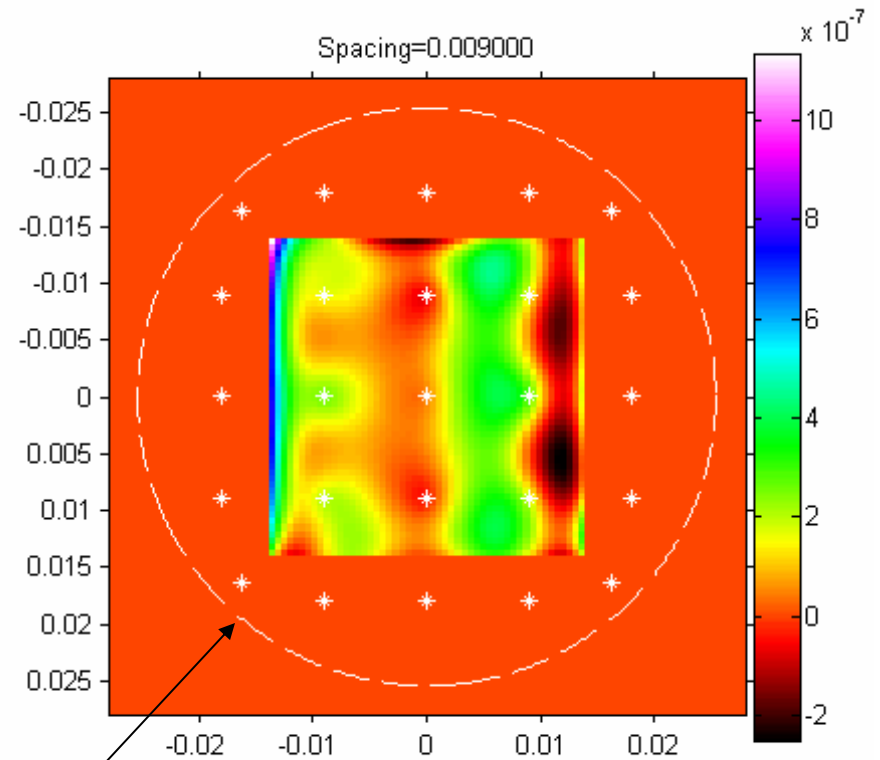


Example 2 - 9.00 mm spacing, 25 acts

DM Surface



Difference

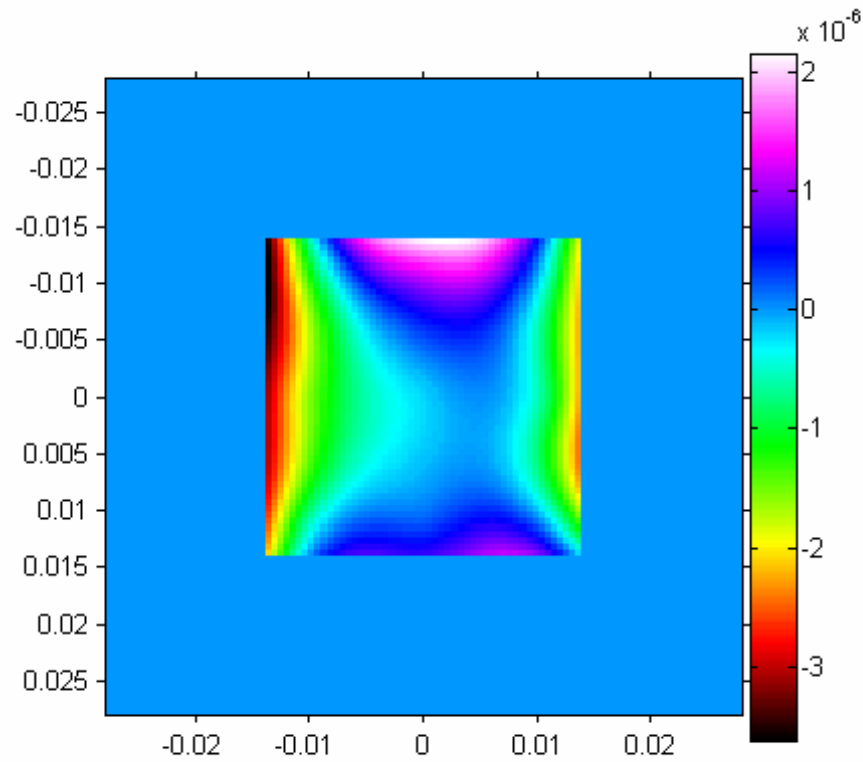


2'' DM Aperture

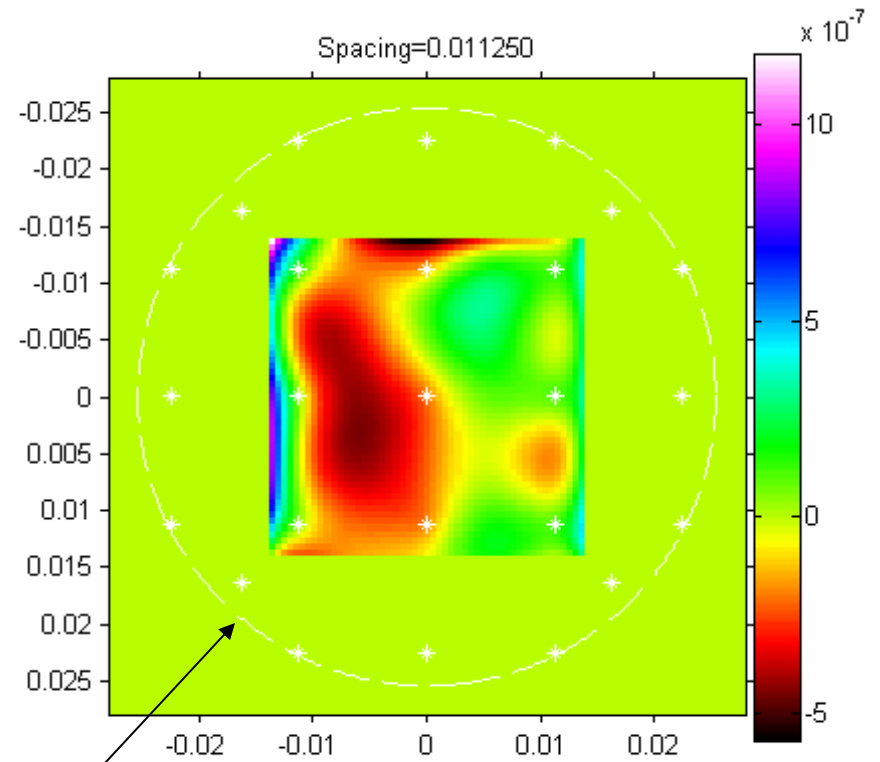


Example 3 - 11.25 mm spacing, 25 acts

DM Surface

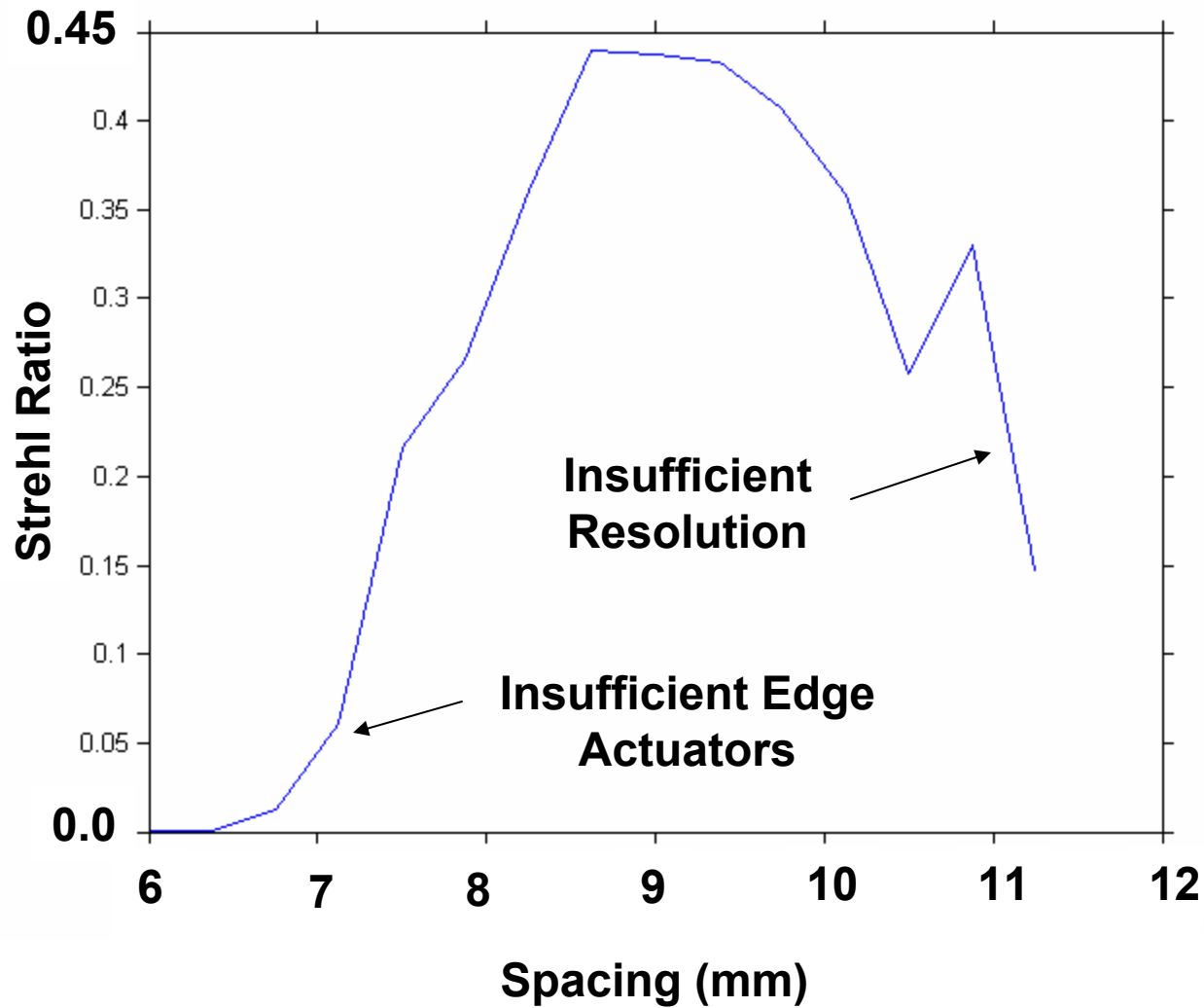


Difference

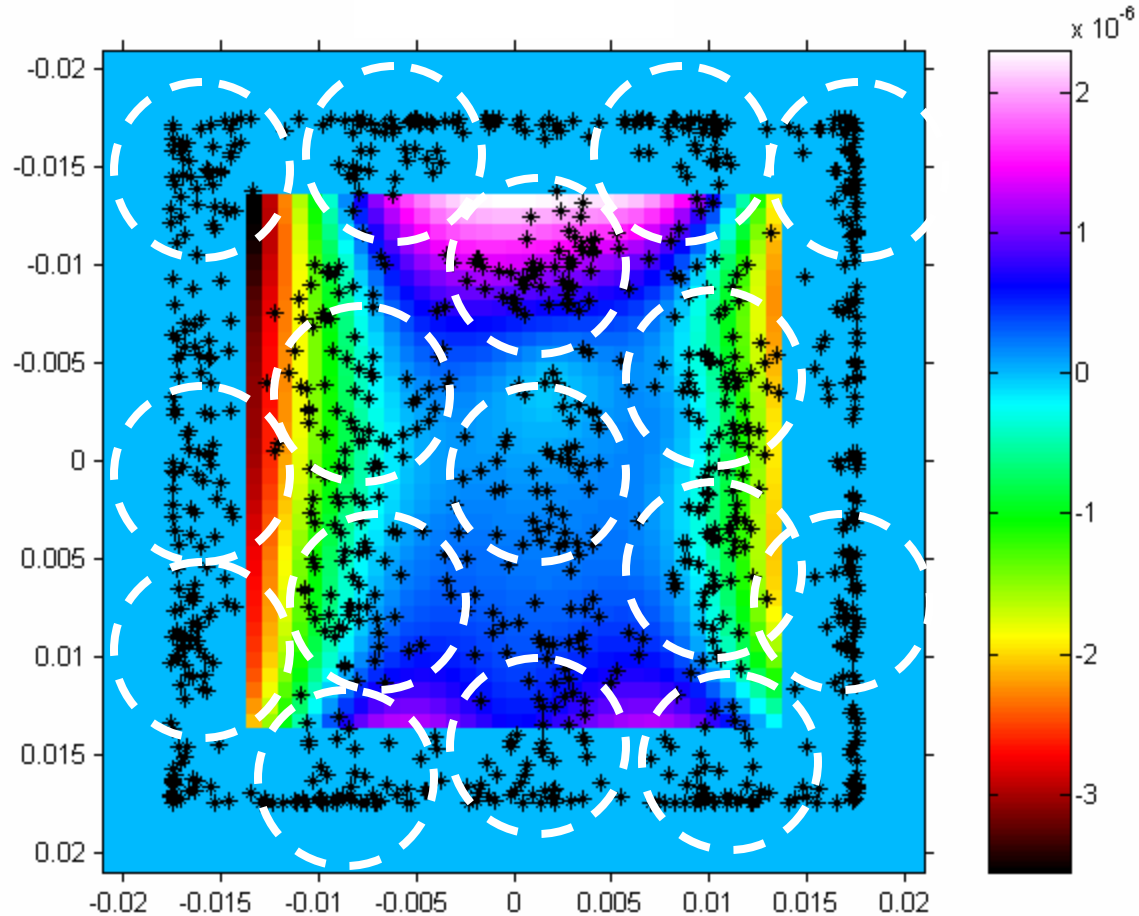


2" DM Aperture
10

Strehl Ratio for 25 Actuators



Clusters in Non-Grid Positioning



~15 Actuators

Modeling Conclusions

- We decided to maintain a square grid instead of an arbitrary positioning to maximize potential for use for varying aberration shapes.
- We found that for the aberrations seen typically in this laser development, the best spacing was around 9 mm.



Drive Electronics, Packaging, and HR Coatings

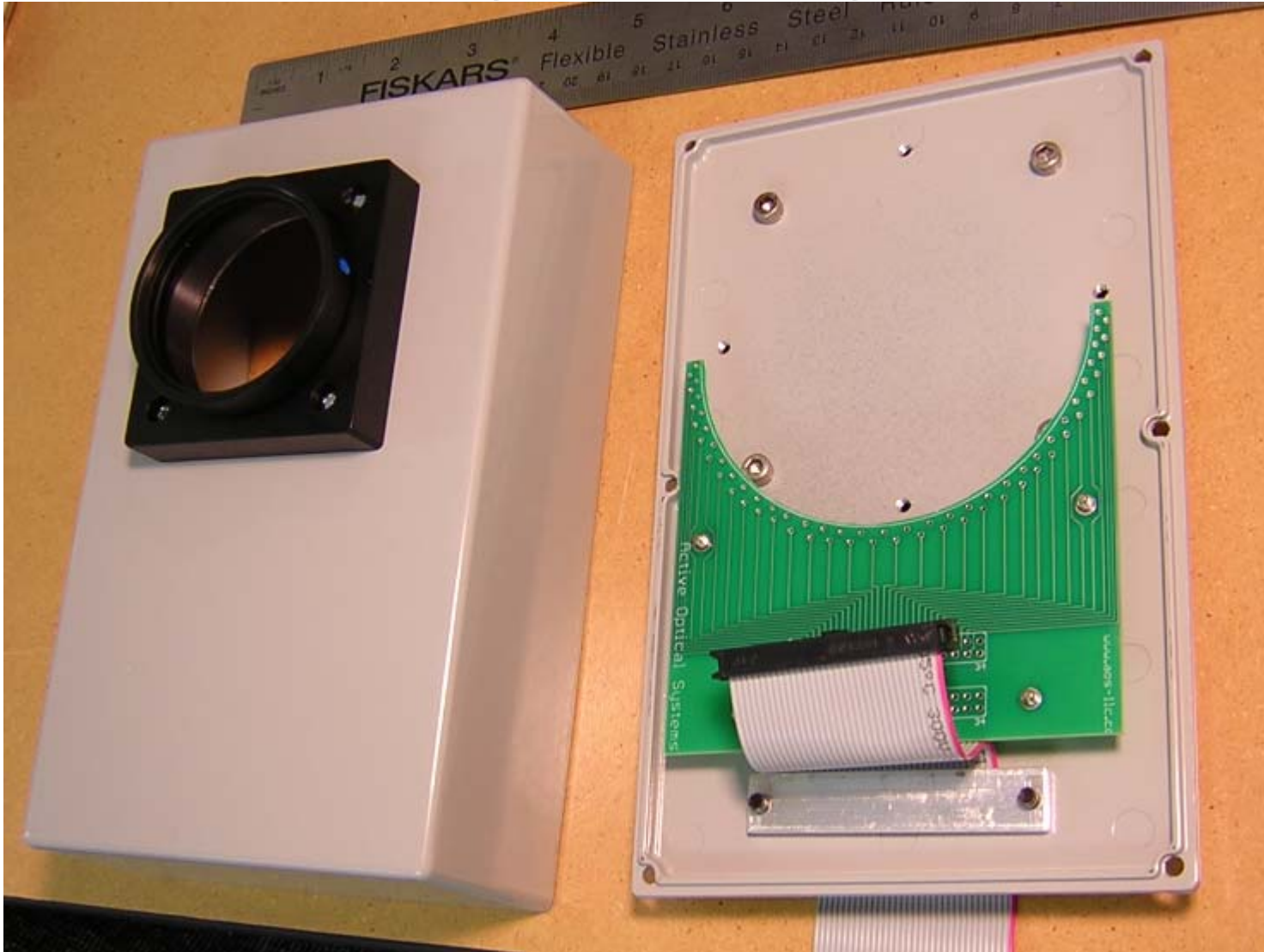


Drive Electronics

- We found that we could use the existing MEMS / membrane electrostatic deformable mirror drive electronics for the PZT DMs.
- The drive electronics uses a simple USB interface via the virtual COM port.
- The 10% to 90% rise time was ~ 35 ms for 70V potential difference across the ~ 200 nF capacitive load of the actuator.
 - Can be augmented to increase the speed.



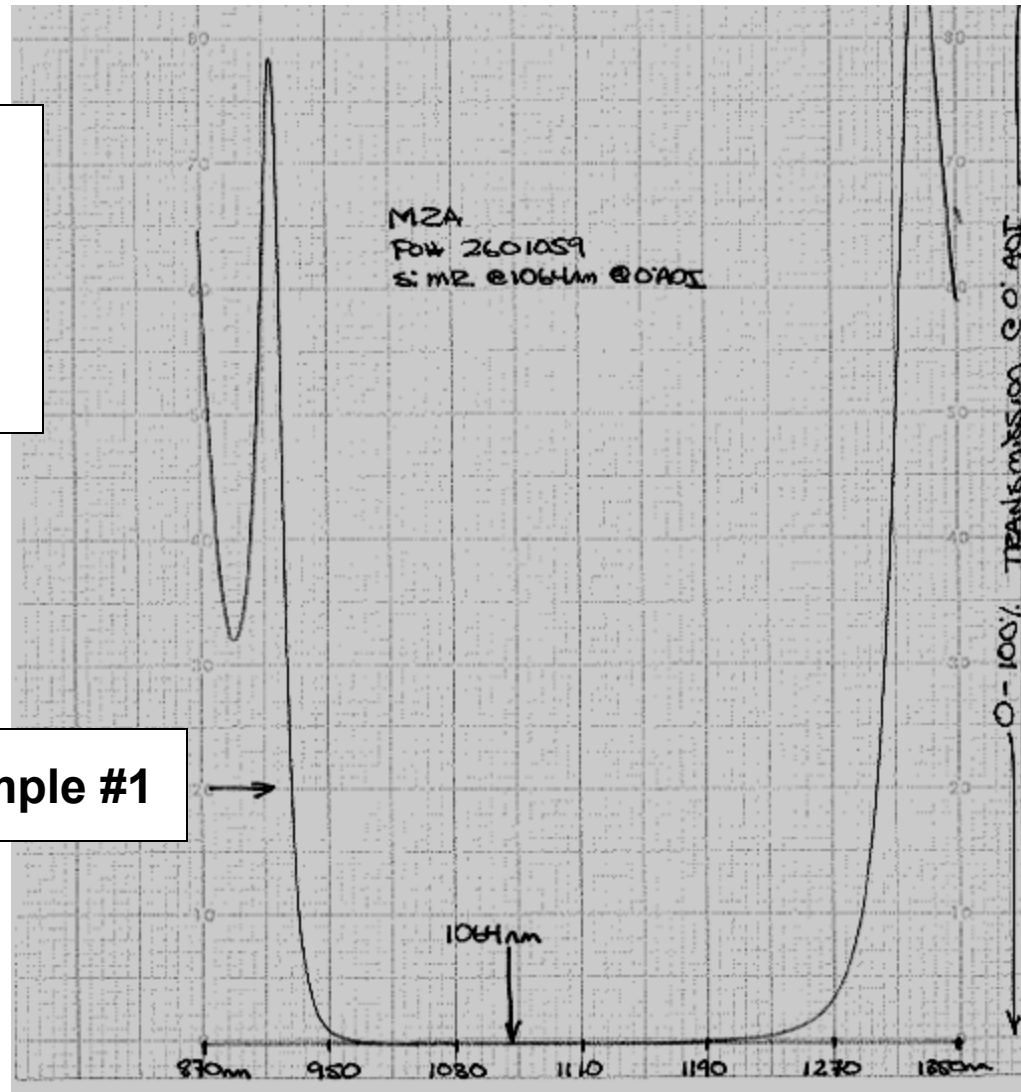
Package Photograph



HR Coating Measured Transmission

18 pair high
reflectivity stack
(99.98%
calculated)

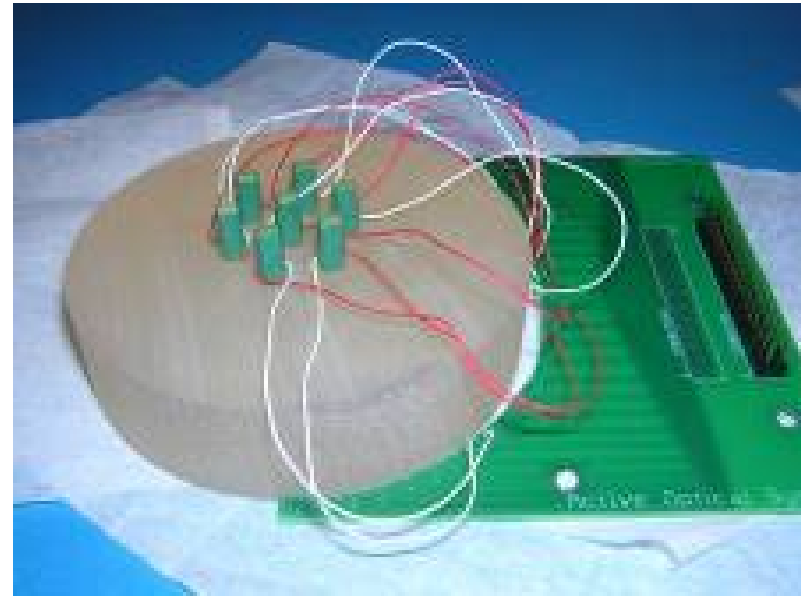
Sample #1



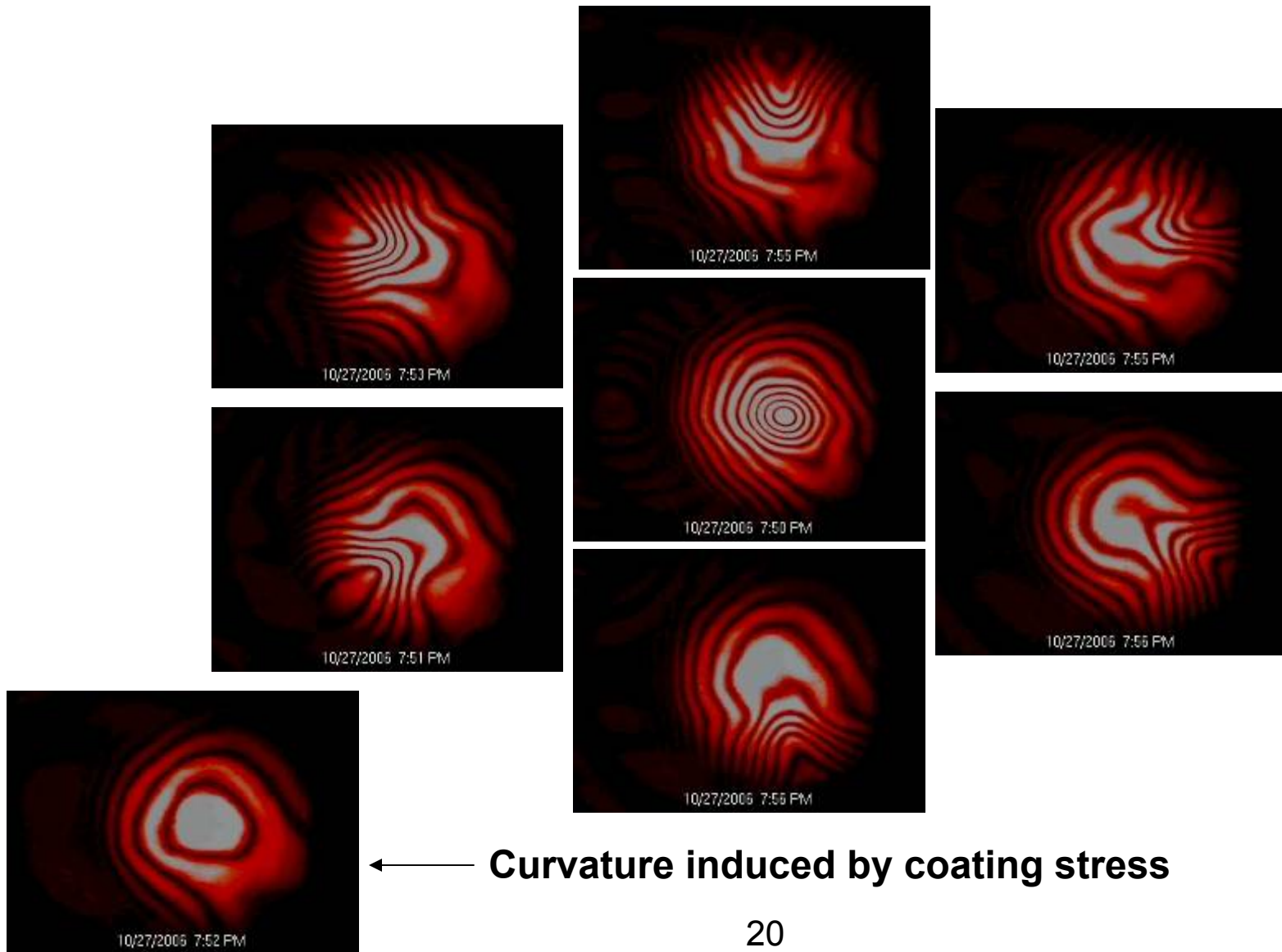
Scaled-Down Prototype Demonstration

Prototype Device

- 1-mm thick silicon faceplate with a high reflectivity multi-layer dielectric stack at 1064nm without a backside coating
- 7 PZT actuators on a 12 mm pitch



30-V Influence Functions

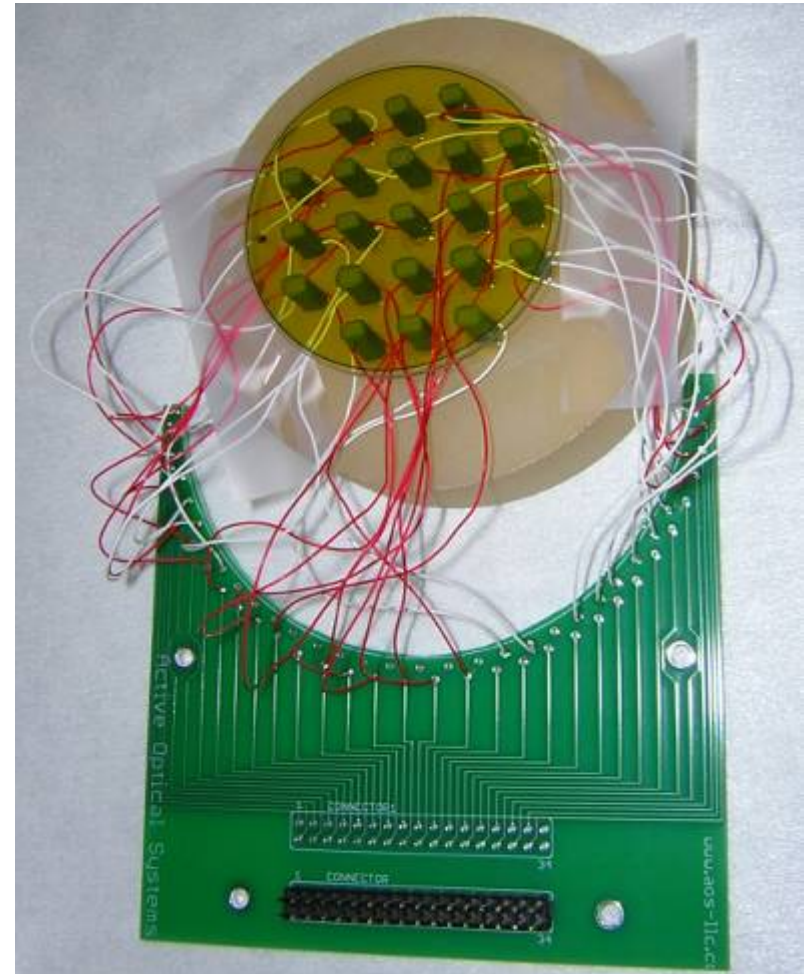


Full-Scale Deformable Mirror Demonstration



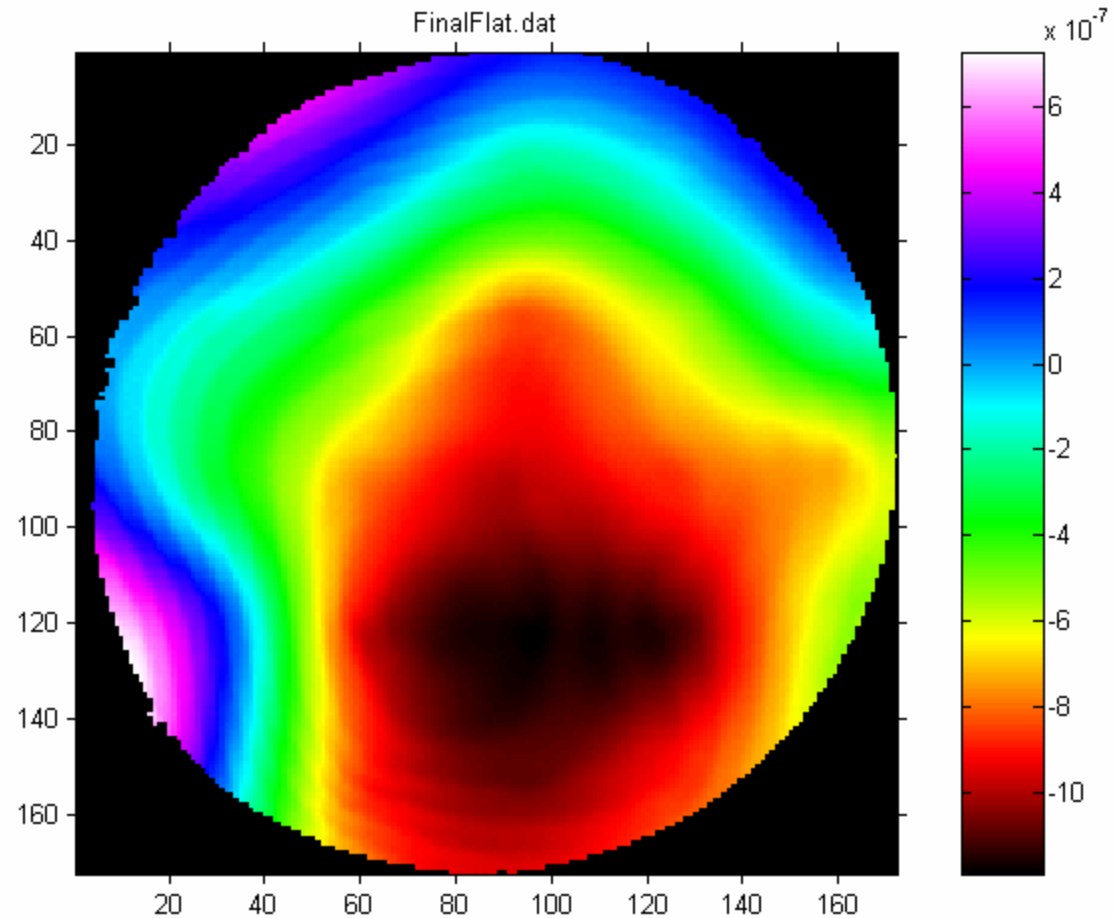
Full-Scale DM Development

- 21 PZT actuators on a 9 mm pitch
- Face plate was changed to 1.4mm thick Zerodur



Static DM Surface

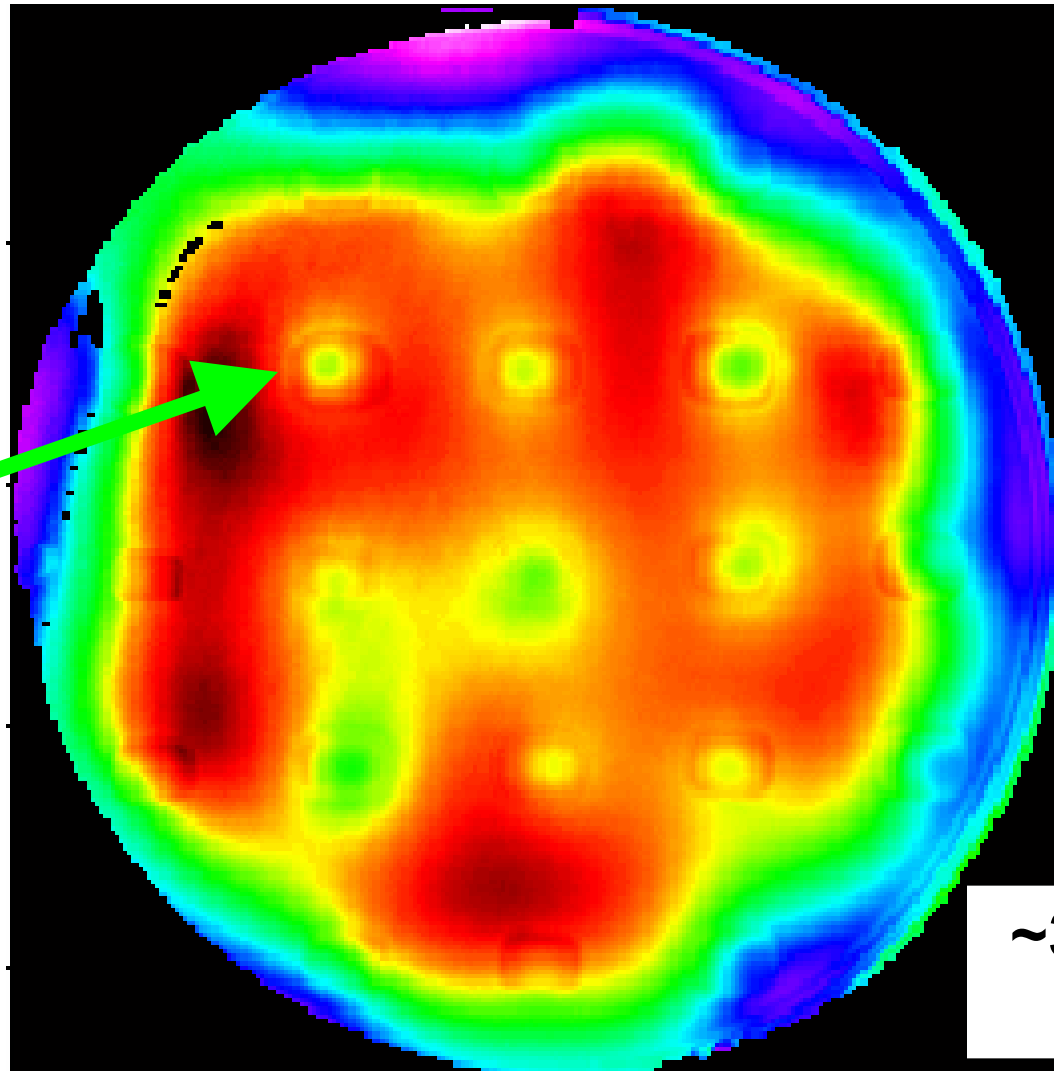
RMS = 447 nm, but there are low-order terms that could be removed actively...



23

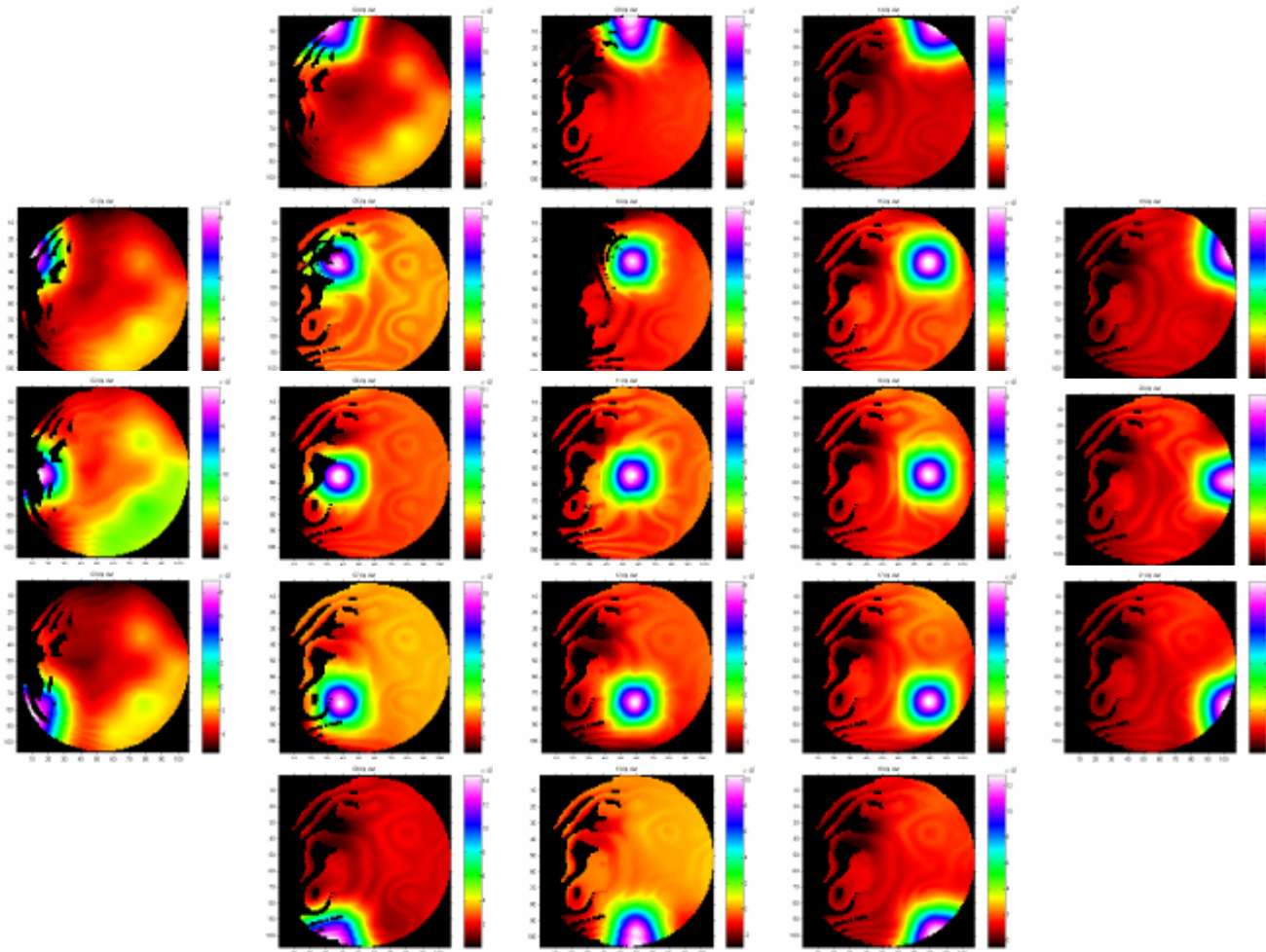
Manually Actively Flattened

Small Static
Distortion at
Actuators

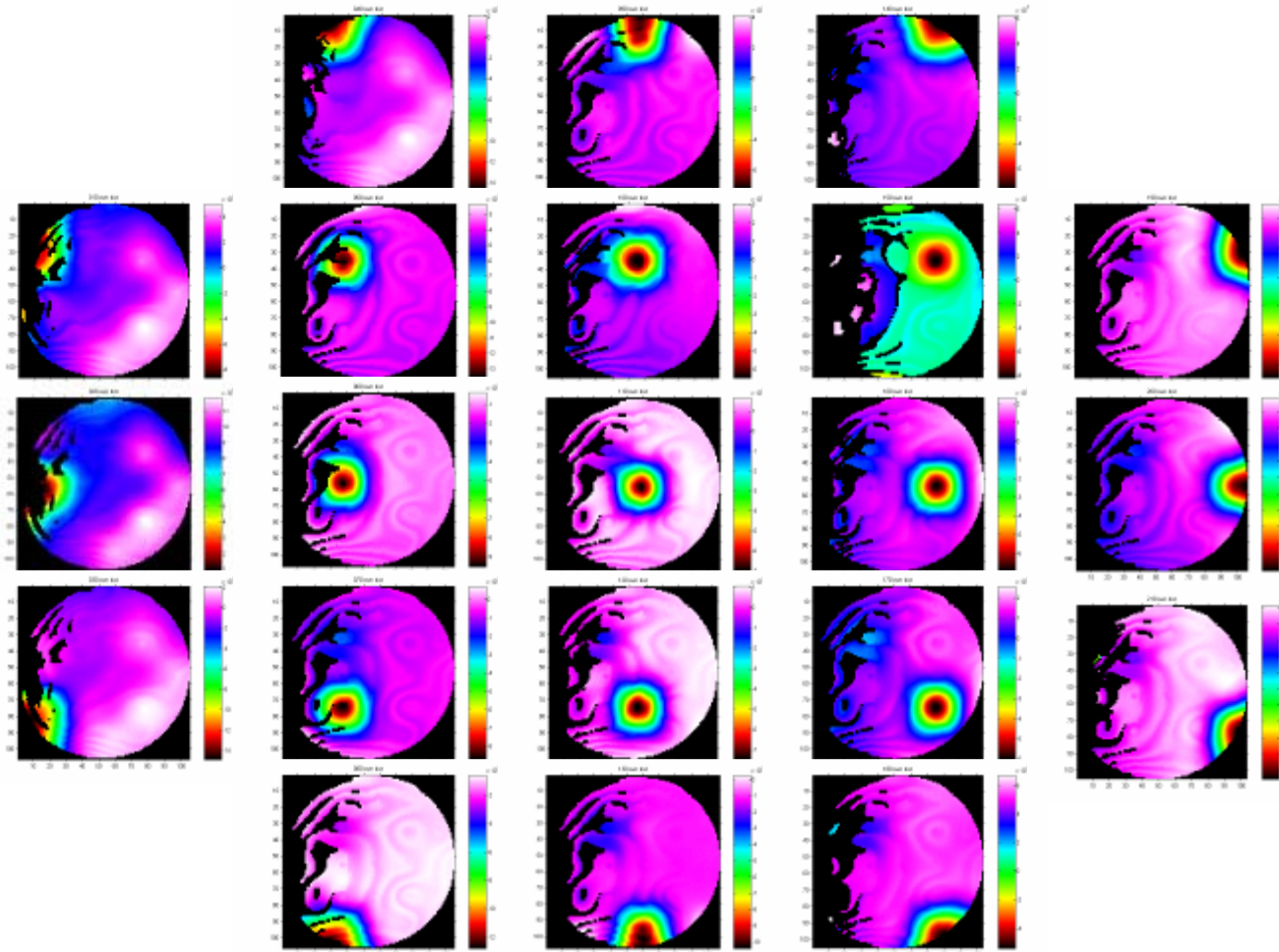


~31 nm RMS
= $\lambda/30$

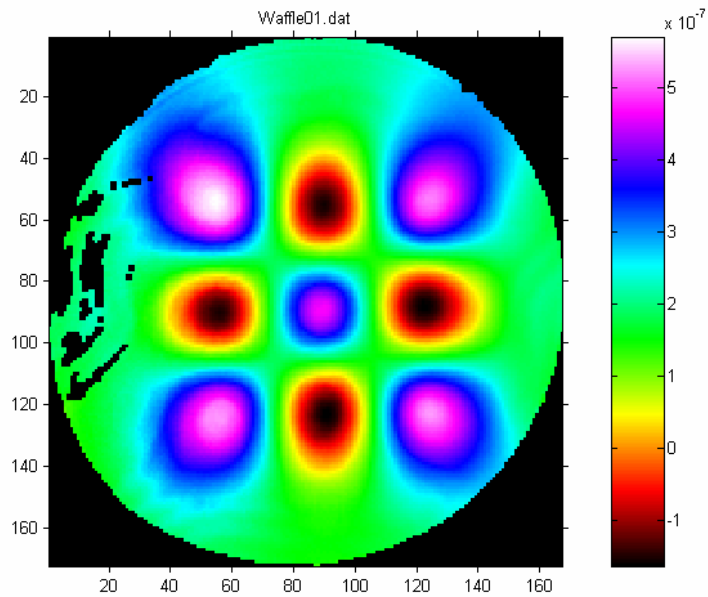
DM 1 Up Influence Functions



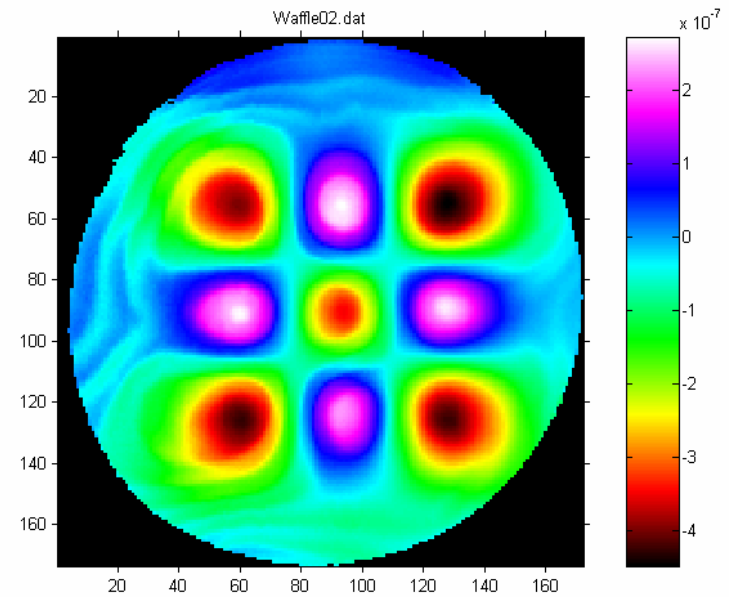
DM 1 Down Influence Functions



Central 3x3 in Waffle

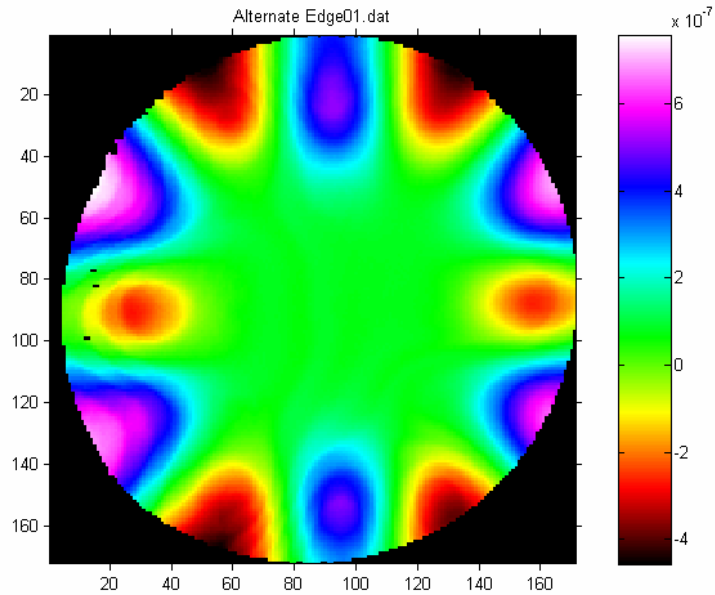


~0.8 wave PV

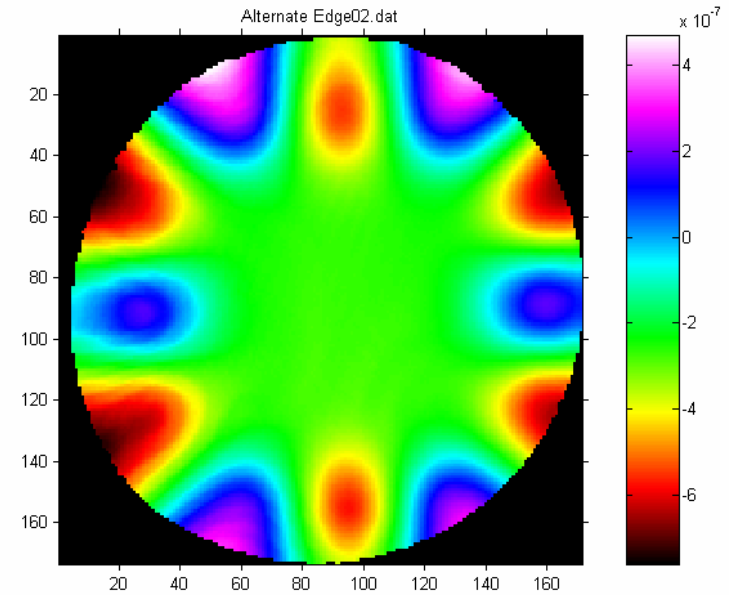


~0.8 wave PV

Alternating Edge Waffle



~1 wave PV



~1 wave PV

Comparable Product Comparison

Vendor	Price with HR Coating	Lead (months)	Custom Device	Other Analysis
Xinetics	\$45k + \$30k coating	12+	Adds time and cost	
OKO	\$25k	~3	Probably	Almost unusable surface quality
MZA	~\$35k	~2	Yes!	Capable of creating a full system

OKO 109-ch DM*

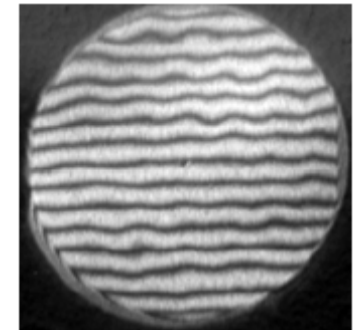


Fig.3. Corrected

RMS=0.04 μm

P-V=0.32 μm

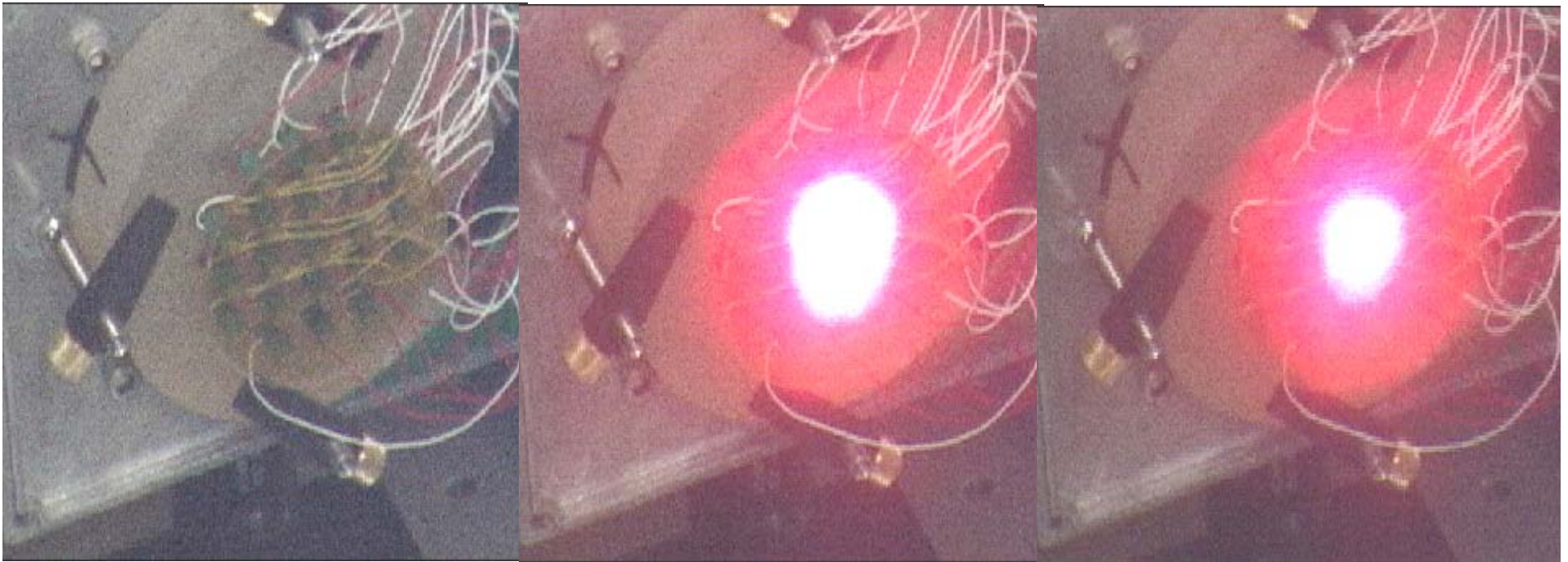
0.64 μm PV WFE

**Taken from OKO advertisement*

High Power Testing

- Tests were done using a cw 6 cm² 1064 nm laser beam at nearly normal incidence with power levels of ~6 and ~12 kW
- The mirror surface was monitored with an interferometer at 860nm.

High Power Testing of DM1 – Double Side Coated



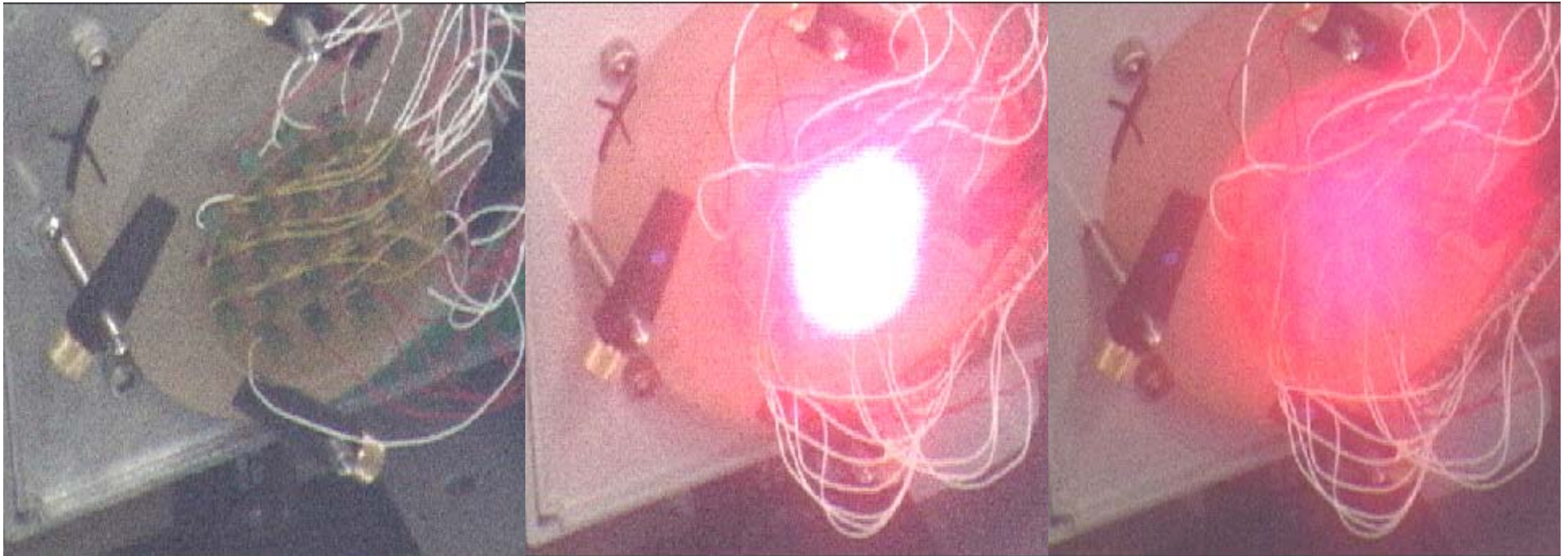
**Before Laser
Illumination**

**Early Laser
Illumination**

**After ~5.0s of Laser
Illumination**

Saw no thermally induced distortions on the interferometer.

High Power Testing of DM2 – Single Side Coated



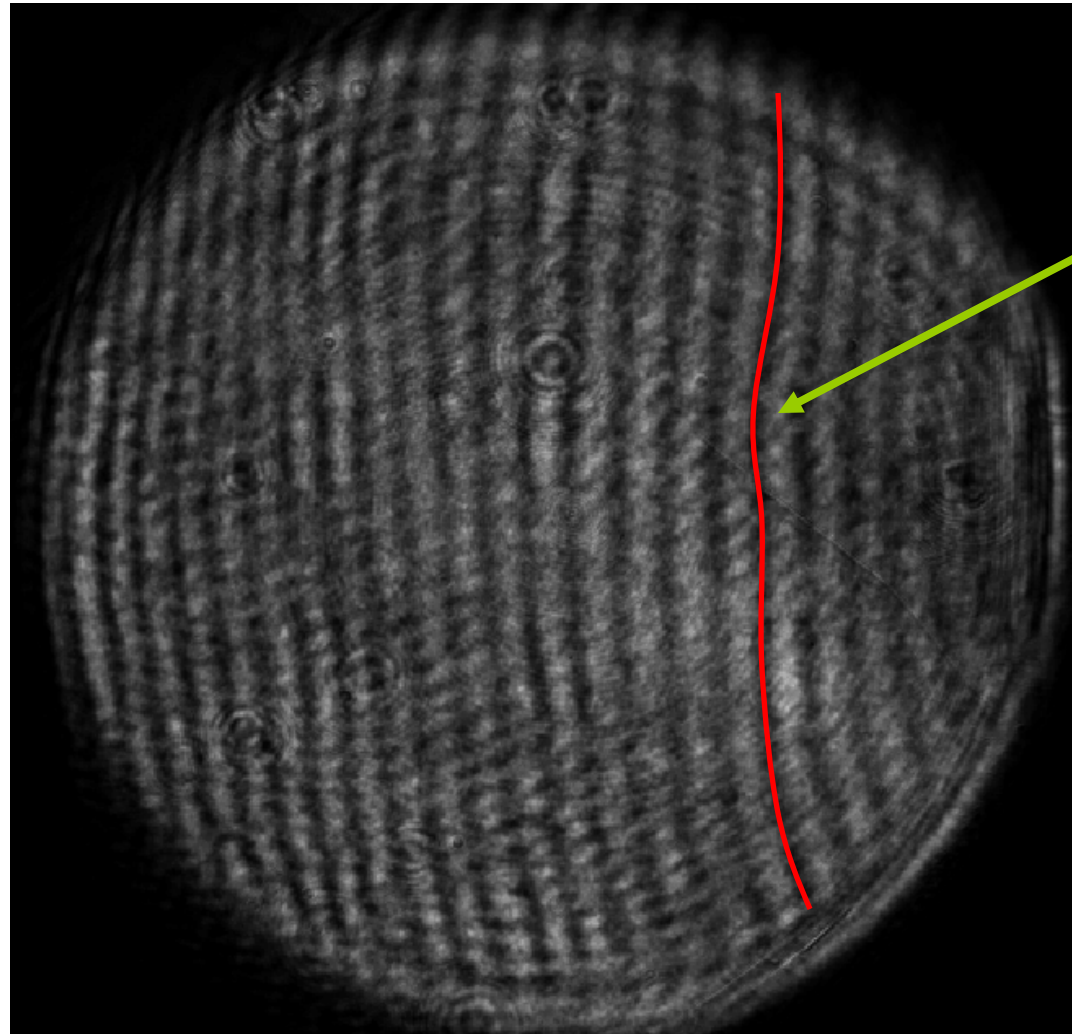
**Before Laser
Illumination**

**Early Laser
Illumination**

**After ~5.0s of Laser
Illumination**

Saw only minor thermally induced distortions on the interferometer.

Interference Fringes from 860nm Probe during the 12 kW Testing of the Single-Side Coated DM



Slight bowing due to thermally induced distortions

High Power Testing

- No visible thermally induced distortions on an 860-nm interferometer at 12 kW CW 1064nm power for double-side coated DM.
- $\sim\lambda/8$ PV wavefront distortion for a single-side coated DM ($\sim\lambda/20$ RMS) at the actuator locations.

High Reflectivity Coated Pellicle Deformable Mirrors



Pellicle Deformable Mirrors

- AOS has productized polymer membrane deformable mirrors for low power operation.
- We added 2” and 3” pellicles to the HR coating runs.
- The resulting membranes were showing obvious warp due to the compressive stress of the coating, but the center of the membranes was still reasonably flat, so we tested a pellicle at high power.

High Power Testing of Pellicles



**Before Laser
Illumination**



**Early Laser
Illumination**



**After ~1.0s of 12 kW
Laser Illumination**

***The pellicle survived the laser illumination with no permanent damage,
but saw obvious and large magnitude thermally induced distortion.***

Conclusions

- We demonstrated a piezoelectric actuator high-reflectivity DM capable of withstanding 12 kW of CW 1064 nm laser radiation (2 kW/cm²).
- In the future we would like to investigate the cause of the warping at the actuator connection sites and higher quality coatings.

Acknowledgements

We thank the High Energy Laser Joint Technology Office for their support of this effort.

Questions?

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