MEMS Deformable Mirror Development

Iris AO, Inc.

NASA Phase SBIRs: NNX14CG06C, NNX16CD58P

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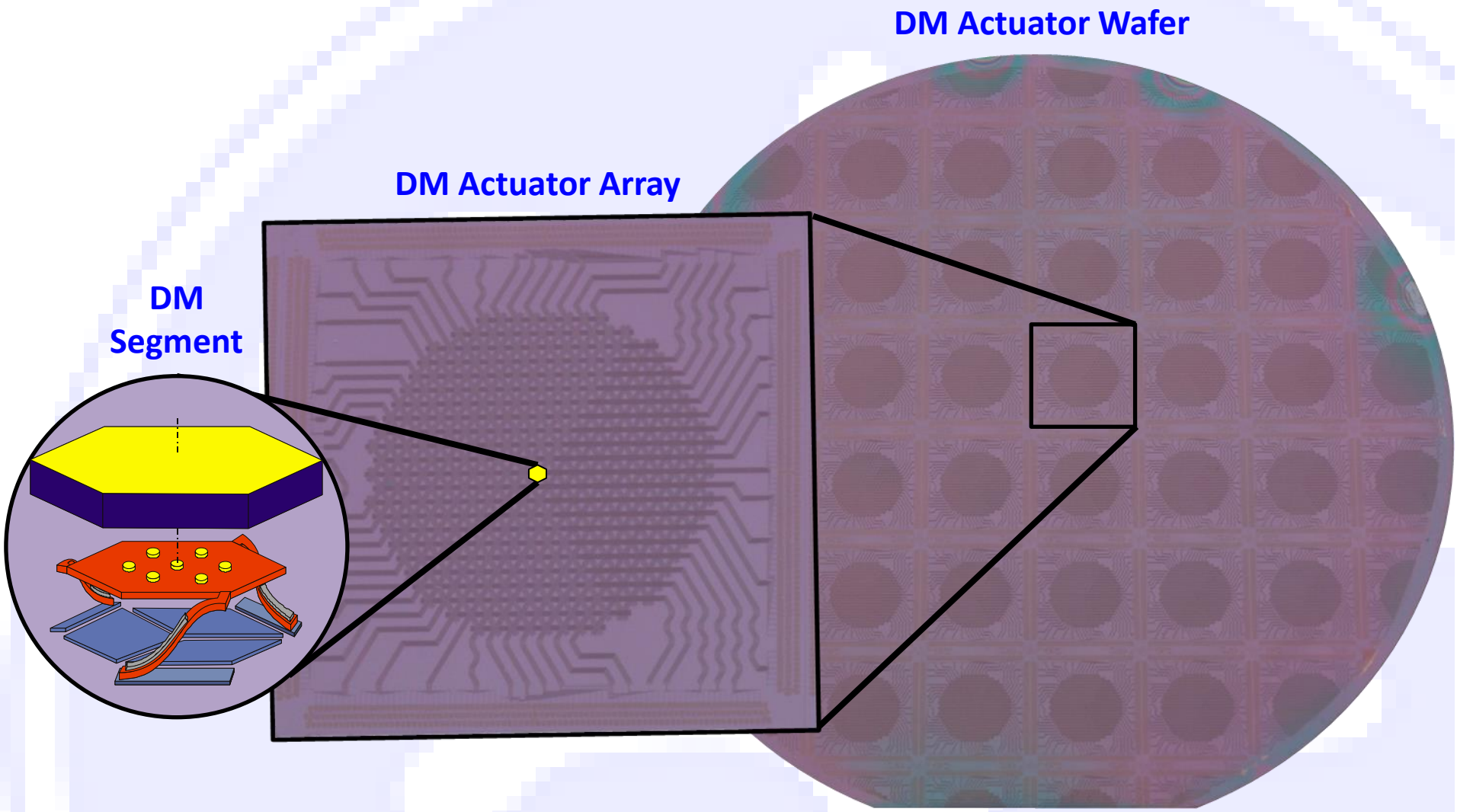
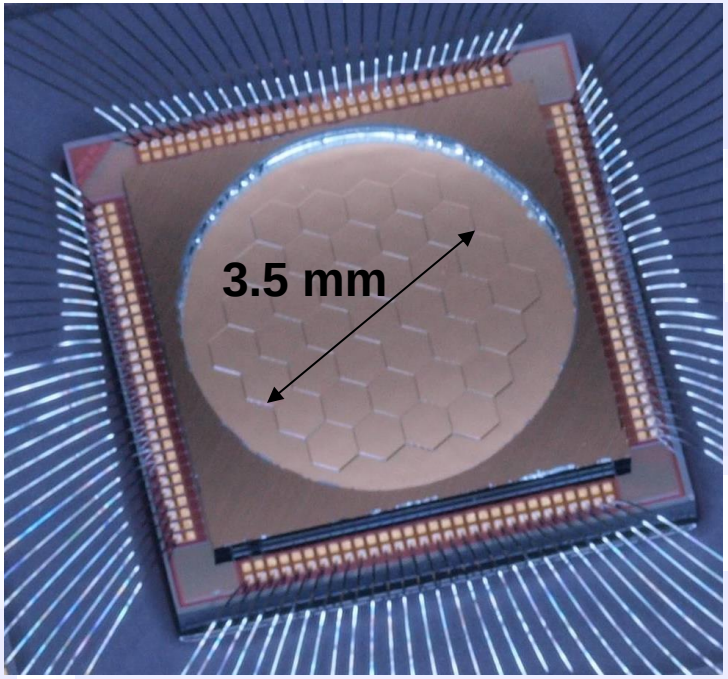
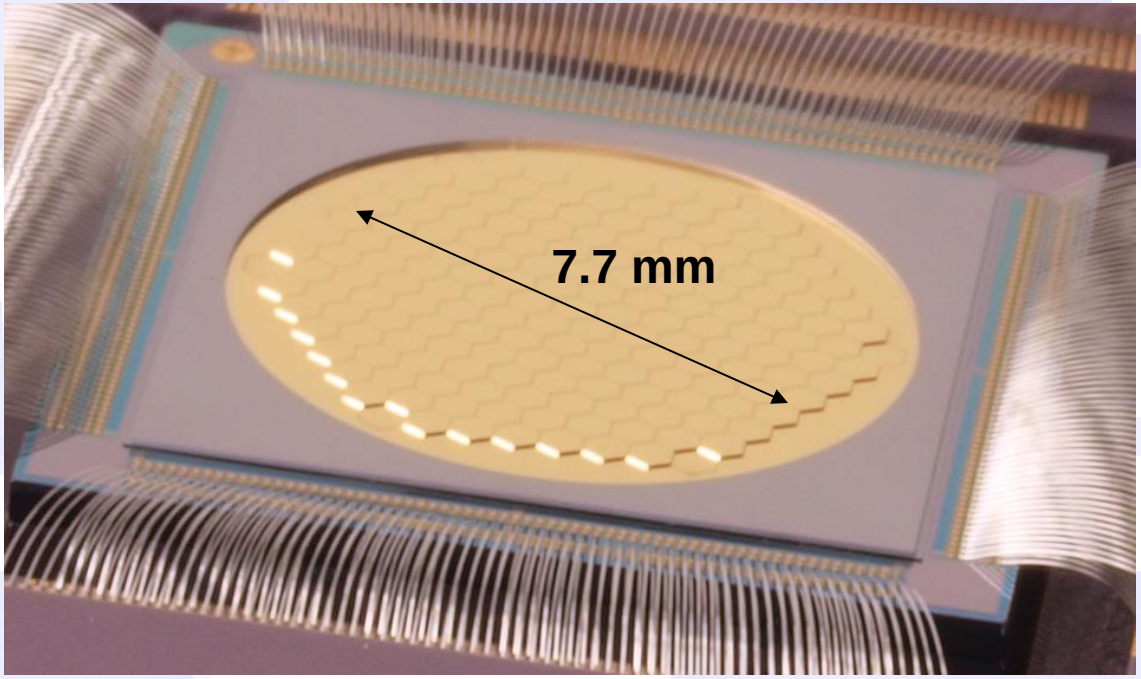
Iris AO Segmented DM Background

Silicon Wafer Processing



Iris AO MEMS Segmented Deformable Mirrors

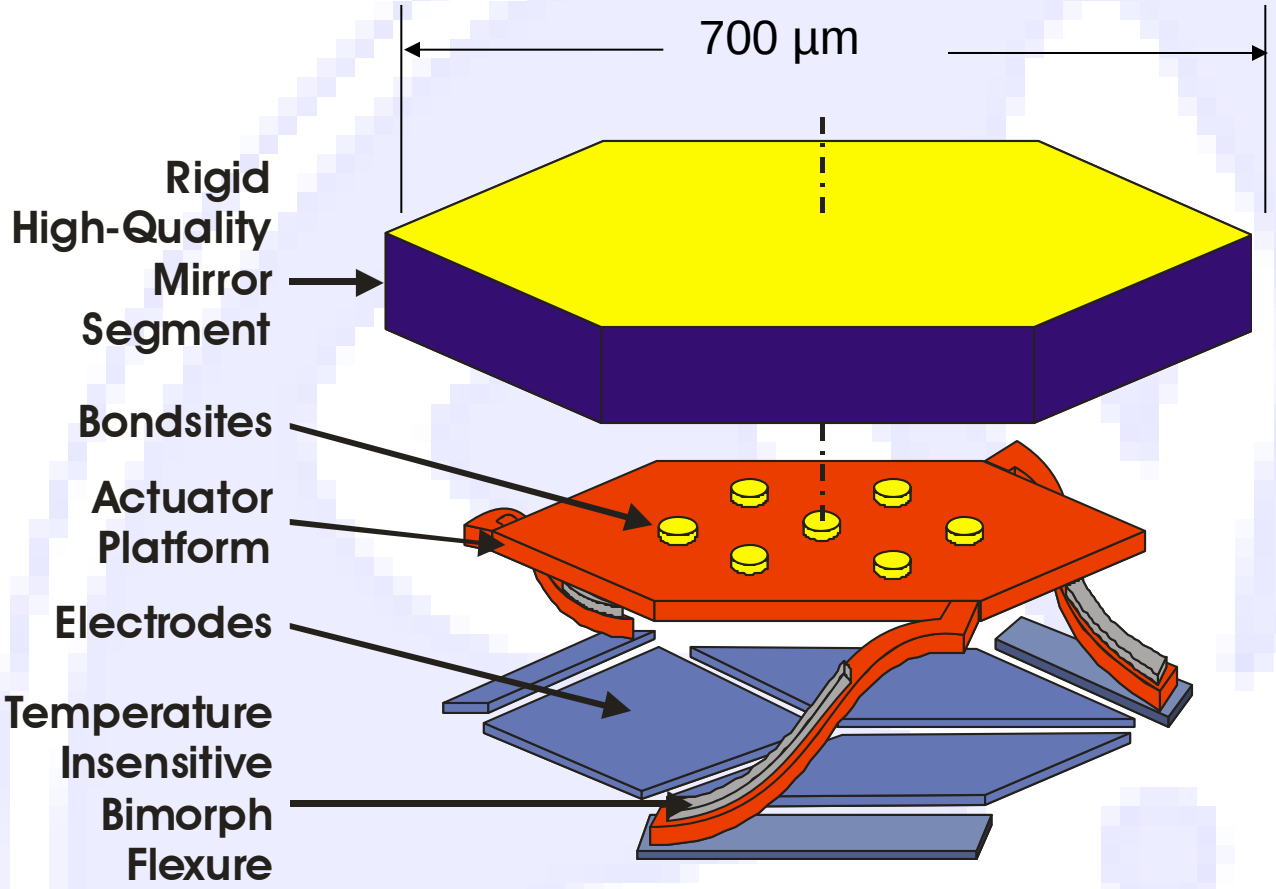




PTT111 DM
- 111 Actuators
- 37 PTT Segments
- 3.5 mm inscribed aperture
- Factory calibrated

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**

DMs calibration holds >30 months, http://arxiv.org/abs/1609.04742

Phase II SBIR Development NNX14CG06C

Increasing Phase Resolution

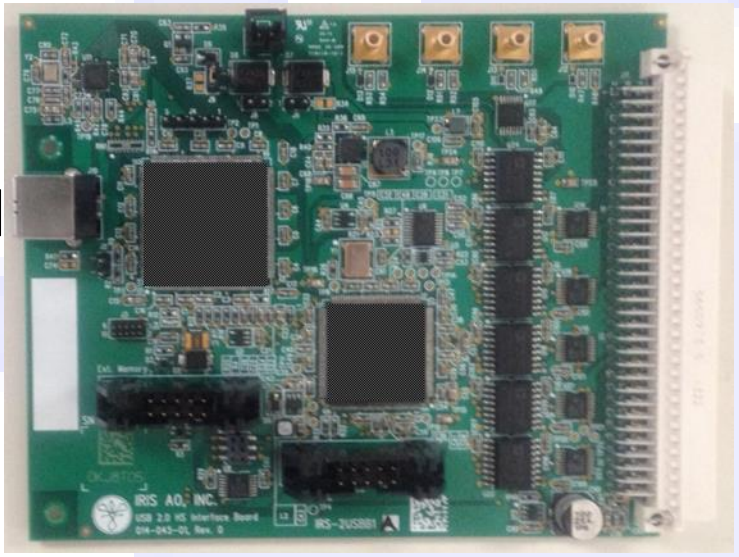
High-Resolution Electronics Development

- Standard Iris AO drive electronics are 14-bit resolution

NNX14CG06C Development

- 16-bit resolution HV driver card

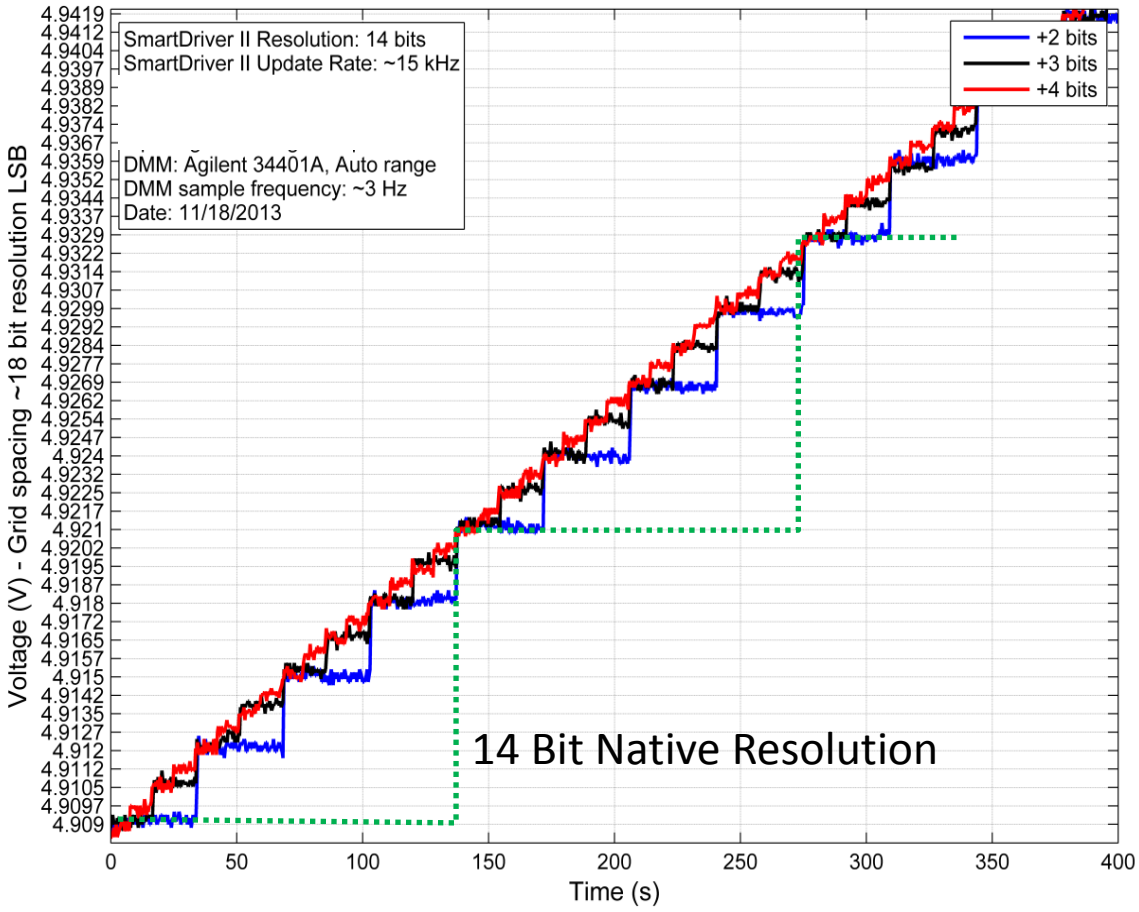
- USB2.0 High-Speed interface
  - Microcontroller
  - FPGA to implement timing critical modulation
  - Windows ***and*** Linux compatible
    - ~4 kHz updates under Linux



Super-Resolution Drive Electronics

- Standard 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
- Modulation schemes implemented in FPGA on USB interface card
  - 16 bit – firmware demonstrated
  - 14 bit – firmware under development
- ***Expect 20+ bits of resolution***
  - ***Limited by electronics noise floor and bandwidth requirements***
- Testing to be complete Q1 2017

Software-Driven 14-Bit Super-Resolution Results

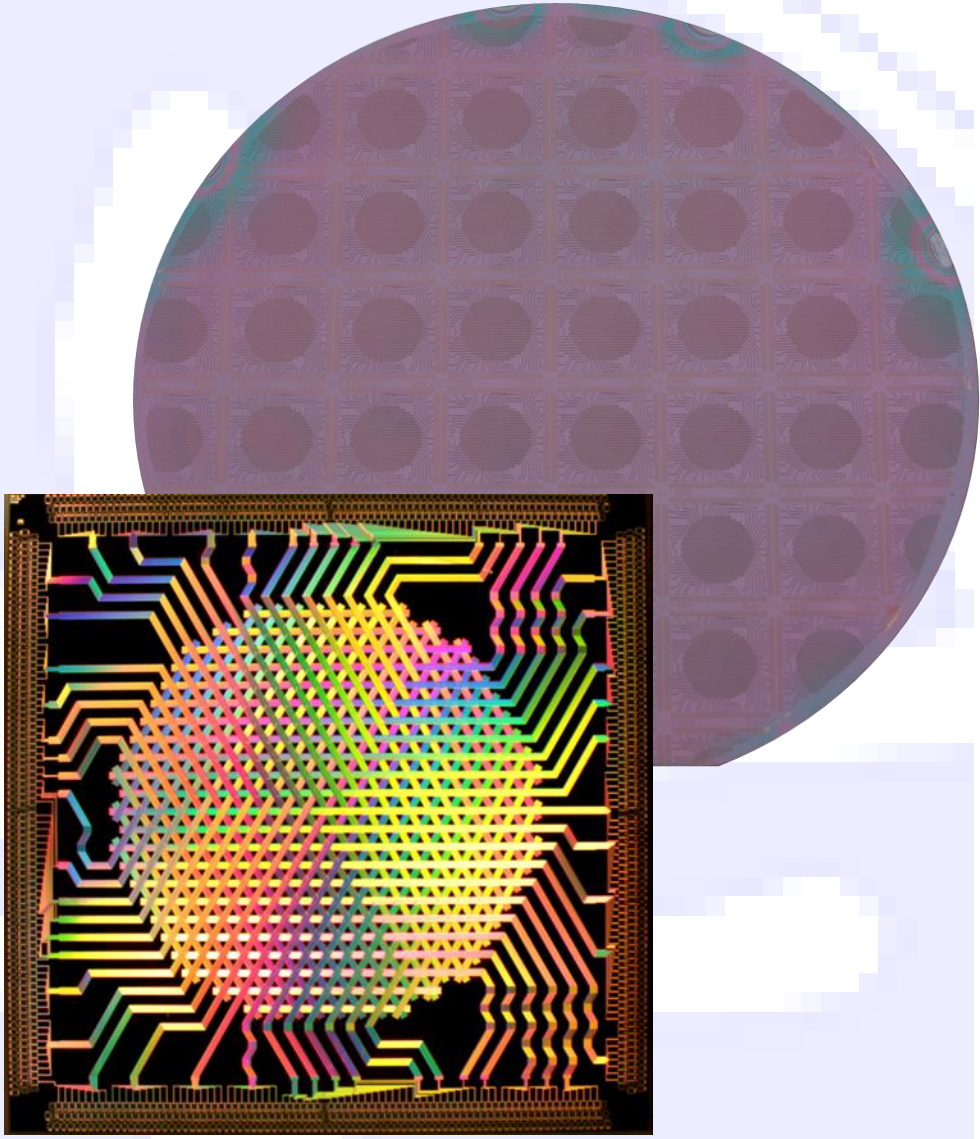


Phase II SBIR Development NNX14CG06C

Increasing Spatial Resolution (Increasing Yield)

PTT939: 1000-Actuator DM Fabrication

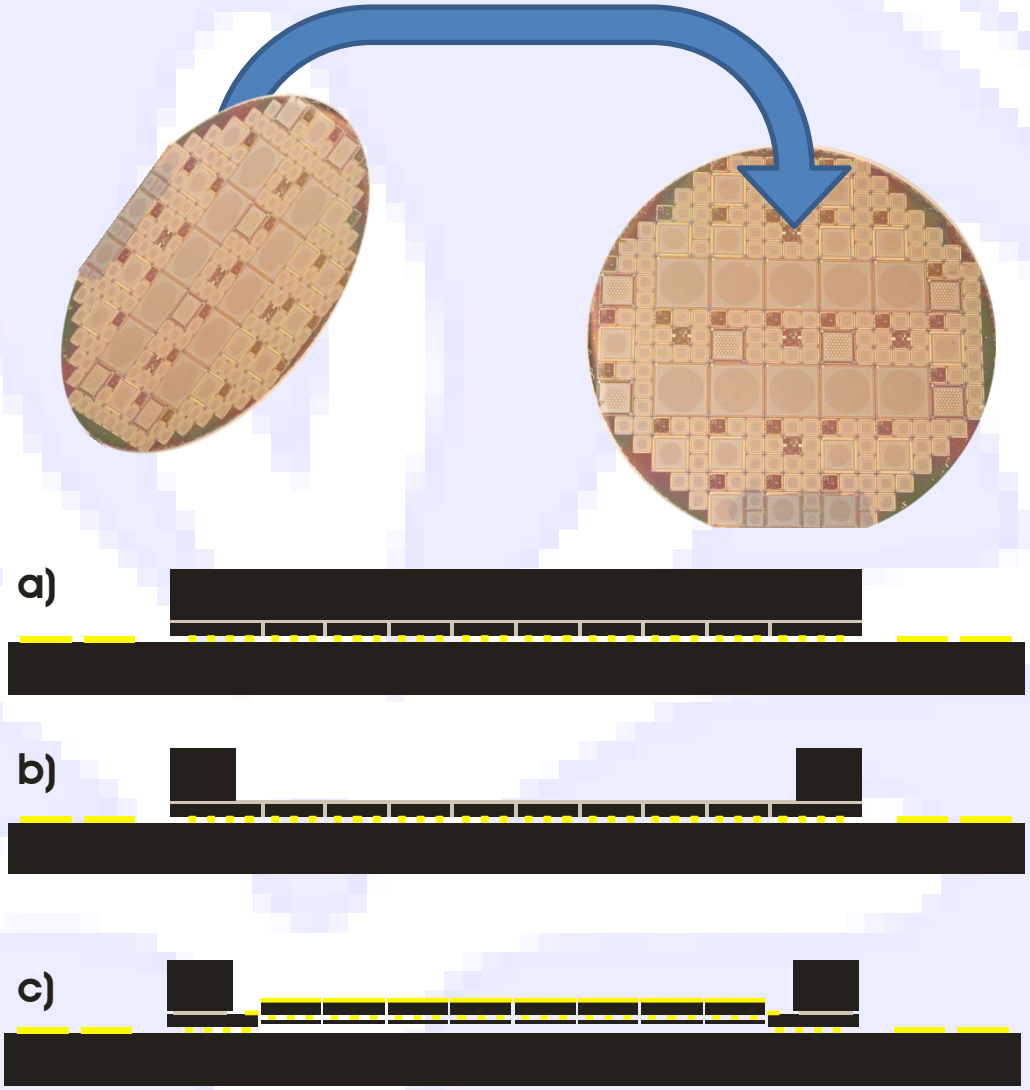
- Actuator and mirror wafer fabrication underway
  - Actuator wafers: ~30% completed
  - Mirror wafers: ~60% completed
- PTT939 process uses projection lithography
  - ASML PAS 5600/300 DUV stepper
  - Better uniformity
  - Excellent overlay error (layer-layer alignment)
    - <0.1 µm observed
  - 0 mask defects
- Iris AO recently hired additional process engineers
  - Fabrication resources tripled
  - Crucial resources now available to focus on increasing yield
  - Initial studies have already resulted in a 15X reduction in defects



PTT939 DM Wiring Layer

Scaling Up: *Wafer-Scale Assembly*

- DMs >1000 actuators require wafer-scaled assembly techniques
- Wafer-scale assembly dramatically reduces effort to fabricate DM arrays
- Uses existing materials/designs Lowest risk path to wafer-scale assembly
- Two bondsite stacks compared
- Future testing will increase test-wafer complexity



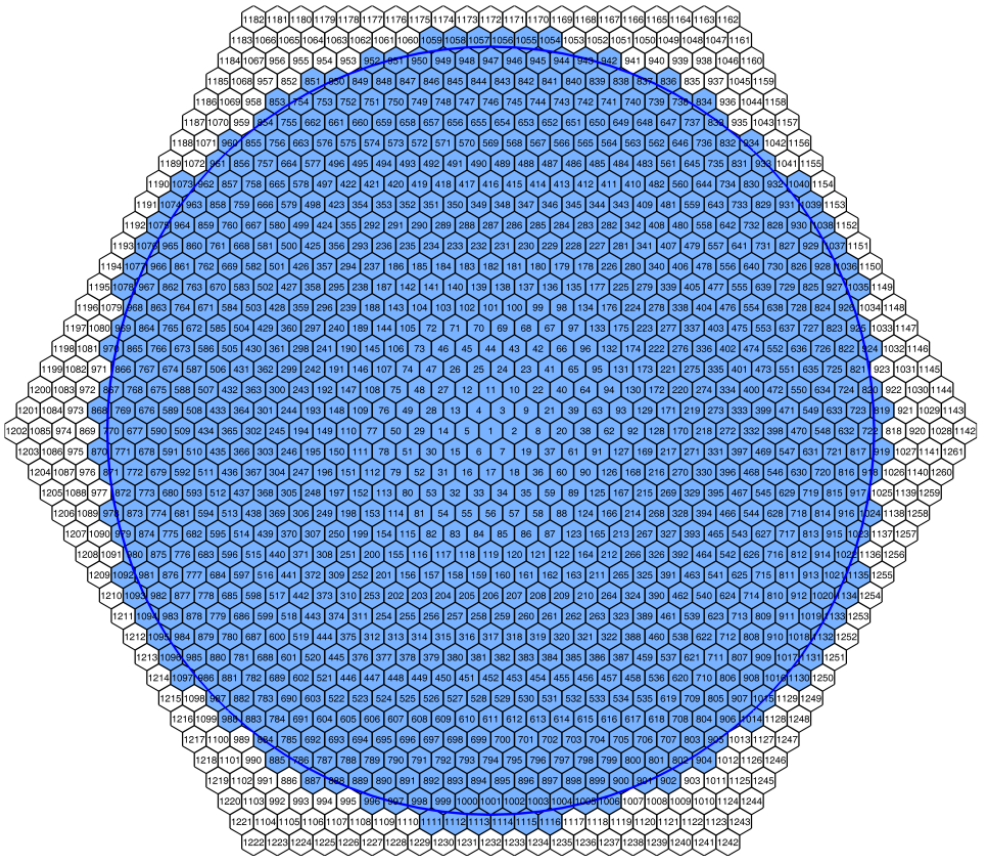
Wafer-Scale-Bonding Destructive-Testing Results

Phase I SBIR Development NNX16CD58P

Increasing Spatial Resolution Even More

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
- Field-stitching demonstration for large arrays
  - Lithography system field size: 22mm x 27.4 mm
  - Excellent field-field alignment:
    - 3σ<30 nm reported
- PTT3045 design to be completed in Phase I
  - Design verification and fabrication in Phase II



PTT3045 DM

- **3045 Actuators**
- **1015 PTT Segments**
- **19.6 mm inscribed aperture**

Summary

- Developing 20+ bit resolution drive electronics
  - Firmware completed, tests underway
  - Ultimate limit will be electronics noise floor and bandwidth requirements
- Fabricating a 1000 actuator DM – PTT939
- Developing wafer-scale assembly
  - Bond yield of early tests shows >90% yield across wafer
  - Enables scaling to 4th generation 1000 segment (3000 actuator) DM
- Designing 4th generation 3045 actuator DM