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Technology Development Status of Adjustable Grazing Incidence X-ray Optics

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Summary Status: Refresher from Aug. '12

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- Demonstrated good agreement between modeled and measured influence functions on flat test optics
- Improved yield on test flats to > 95 per cent (good piezo cells)
- Modeling with representative figure errors from mounted mirrors consistent with half arc sec HPD post correction.
- Claimed TRL 2
- Just started work on curved segments
  - Uniform deposition
  - Printing electrode pattern
- Incorporating optical profilometer

Summary Status: New Since Aug. ’12

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- Improved yield on flat mirrors to routinely 100 per cent
  - I.e., all piezo cells good
- PZT deposition development essentially complete
- Incorporated new metrology
  - Lower noise than before and faster, but not meeting our expectation
- Response uniformity meets requirements (+/- 30 per cent)
- Repeatability within metrology noise (20 nm, rms)
- Fabrication and testing of cylindrical test mirrors
  - Influence functions match models to within metrology noise
  - Piezo coefficient same (within errors) to flat pieces
- Believe now at TRL3

Flat sample repeatability and uniformity

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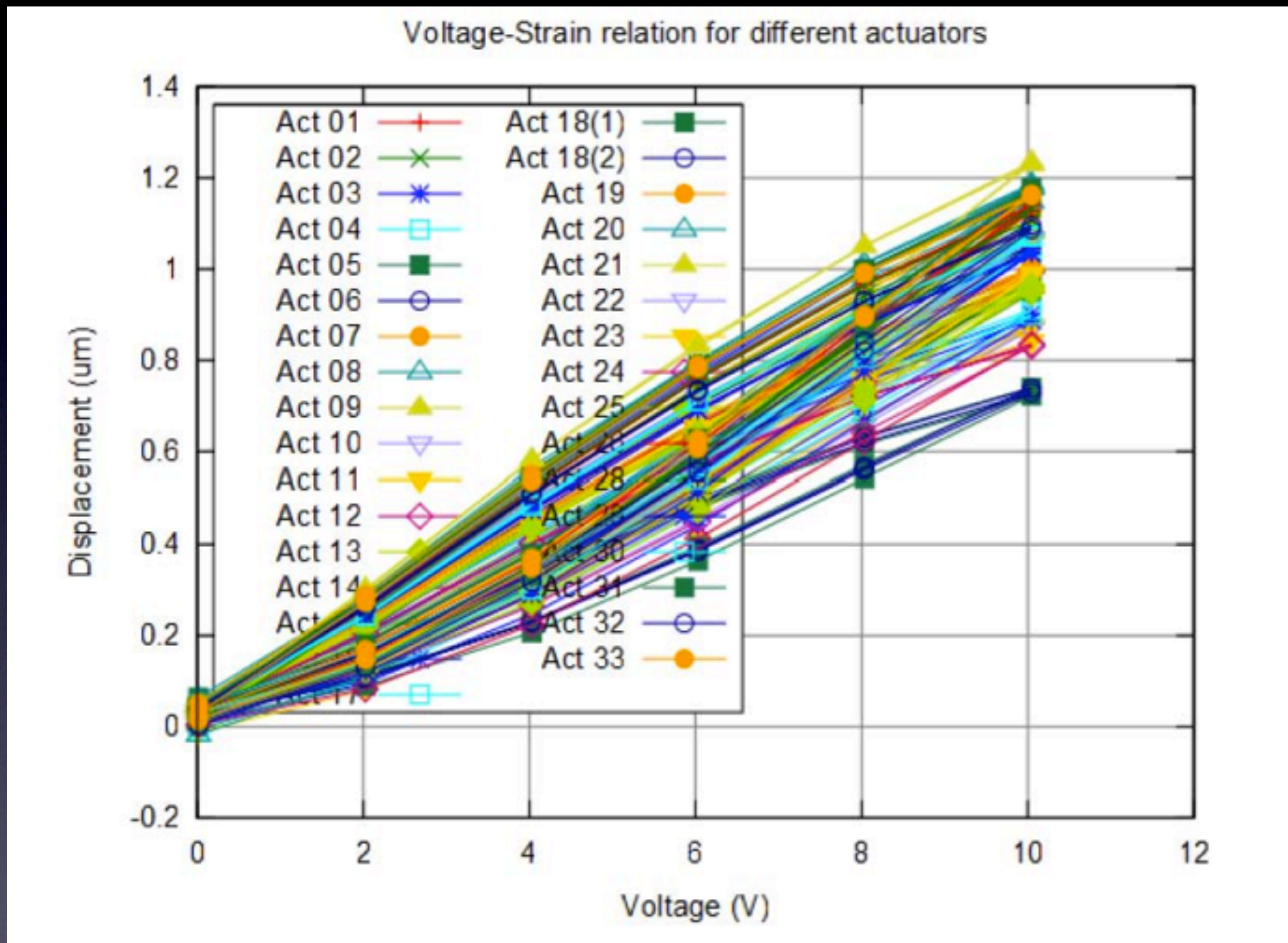

Hysteresis curves for all 33 actuators on 10 cm diameter flat test sample.

Flat sample: multiple piezo cells

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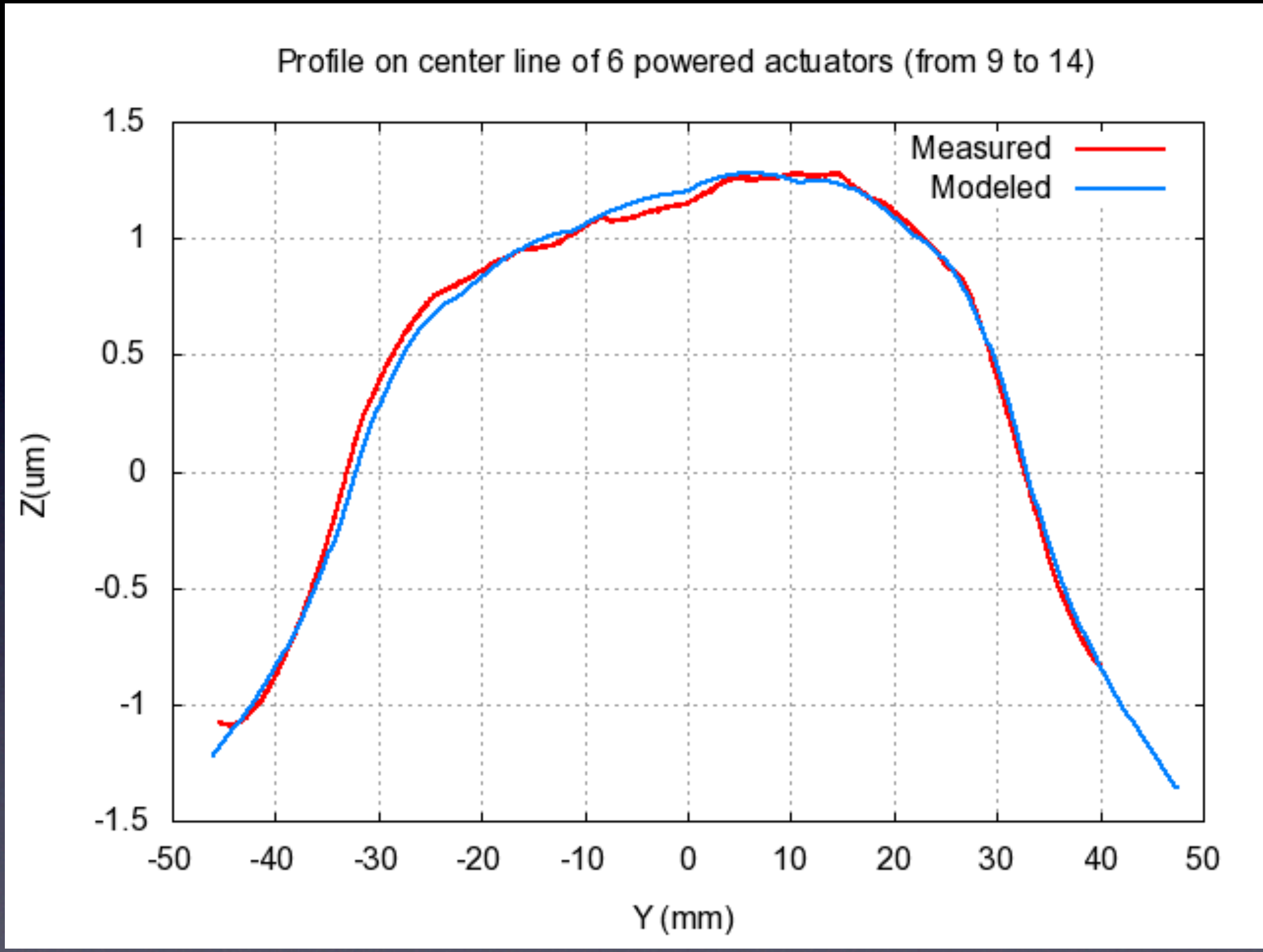

Energized 6 piezo cells in a row – all at same 10V. Measured profile matches modeled profile to within 40 nm, rms.

Cylindrical sample

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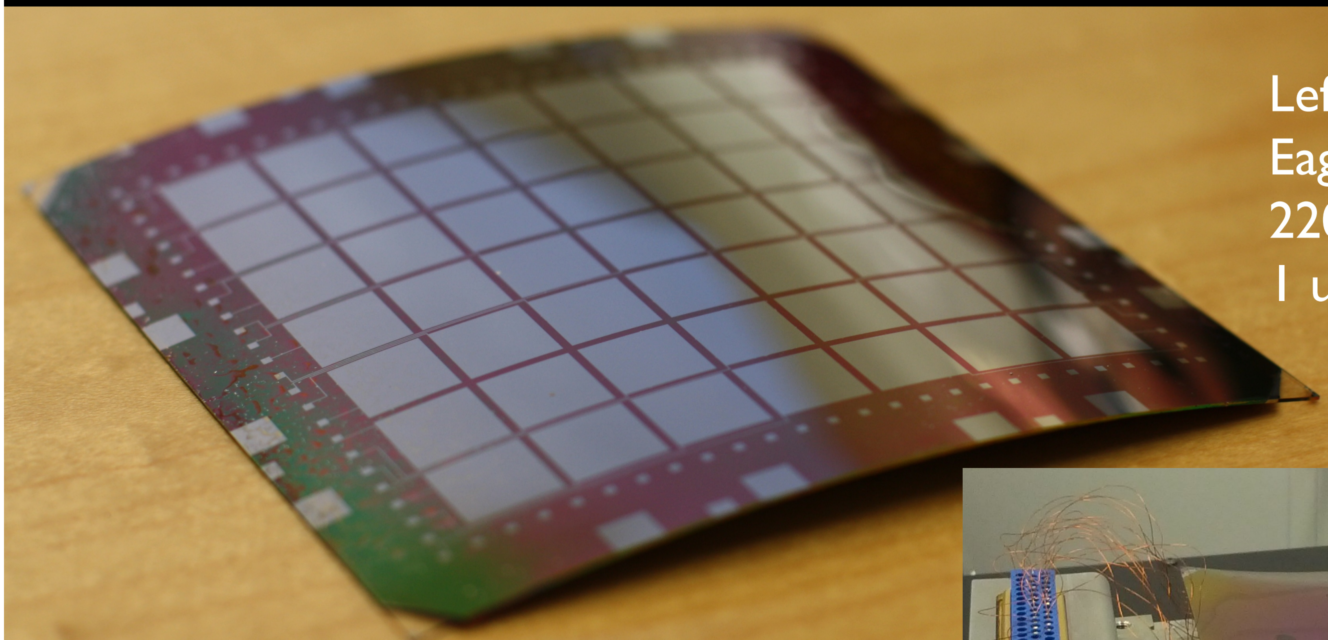
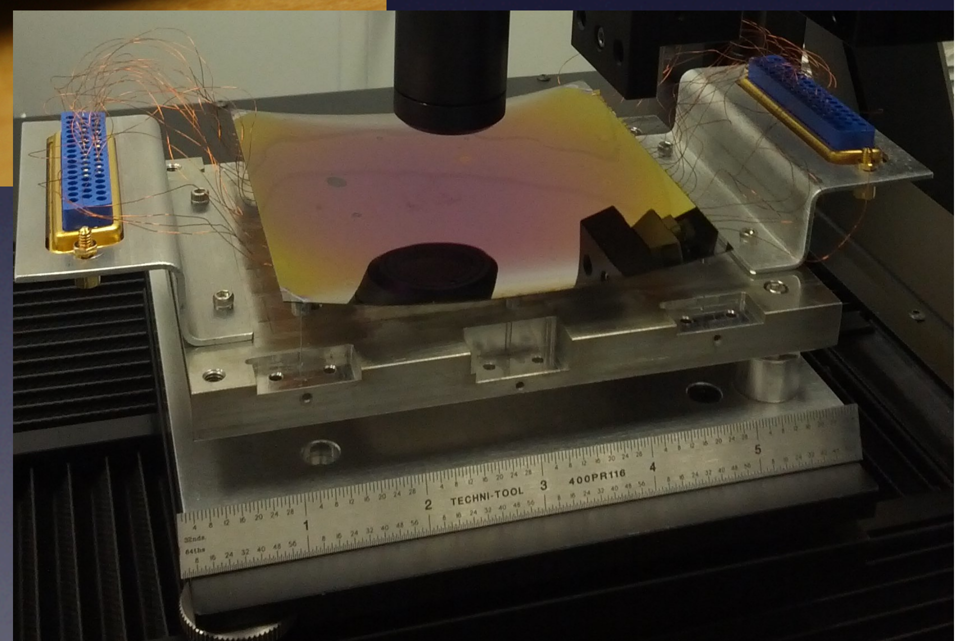


Left: 10 x 10 cm^2 Corning Eagle piece, 0.4 mm thick, 220 mm radius of curvature. 1 um thick PZT layer



Right: same sample as above, mounted to cylindrical optic metrology mount, on scanning optical profilometer

Repeatability and gain on cylindrical test piece

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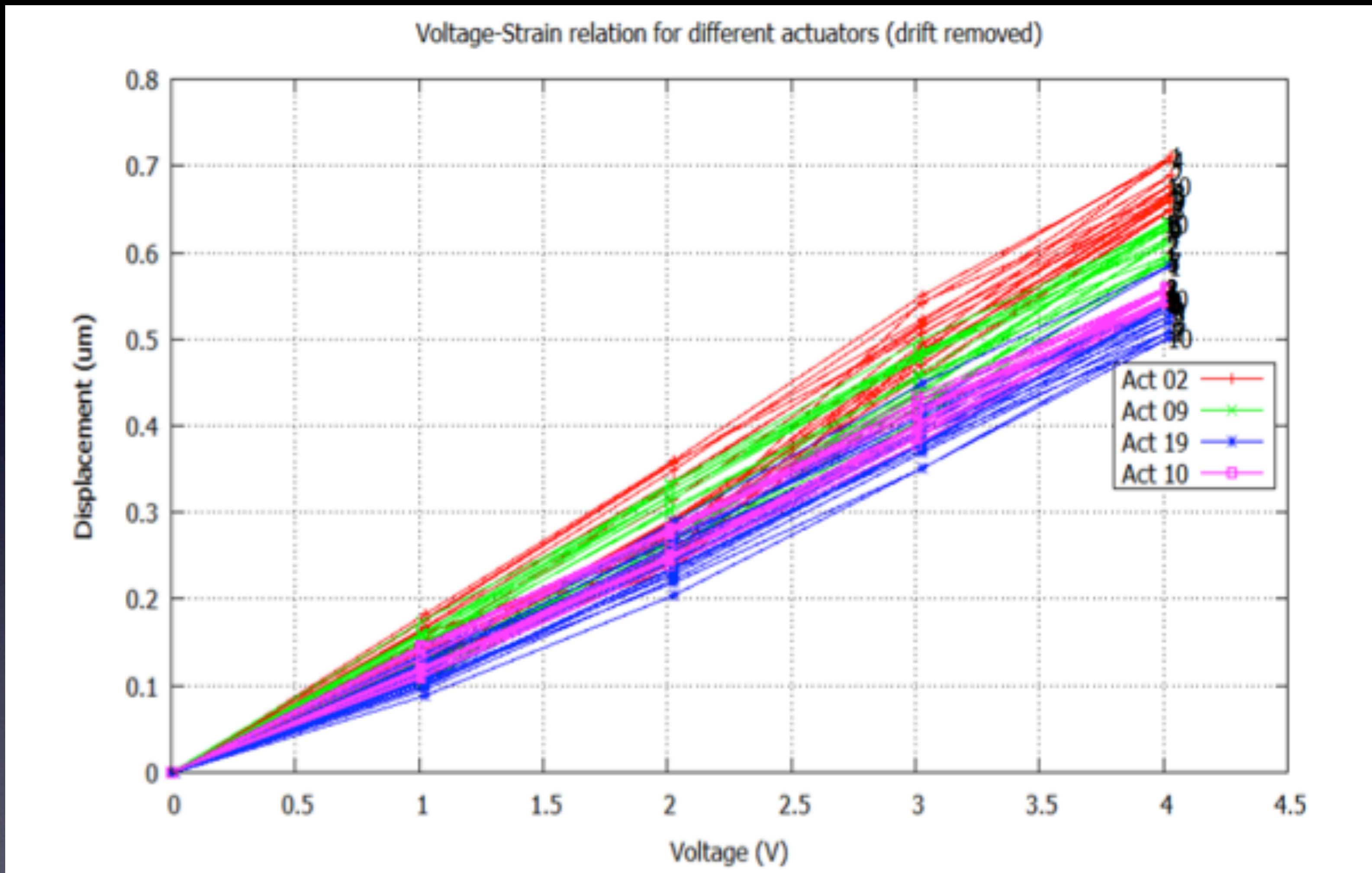

Hysteresis curves.

Cylindrical segment: repeatability

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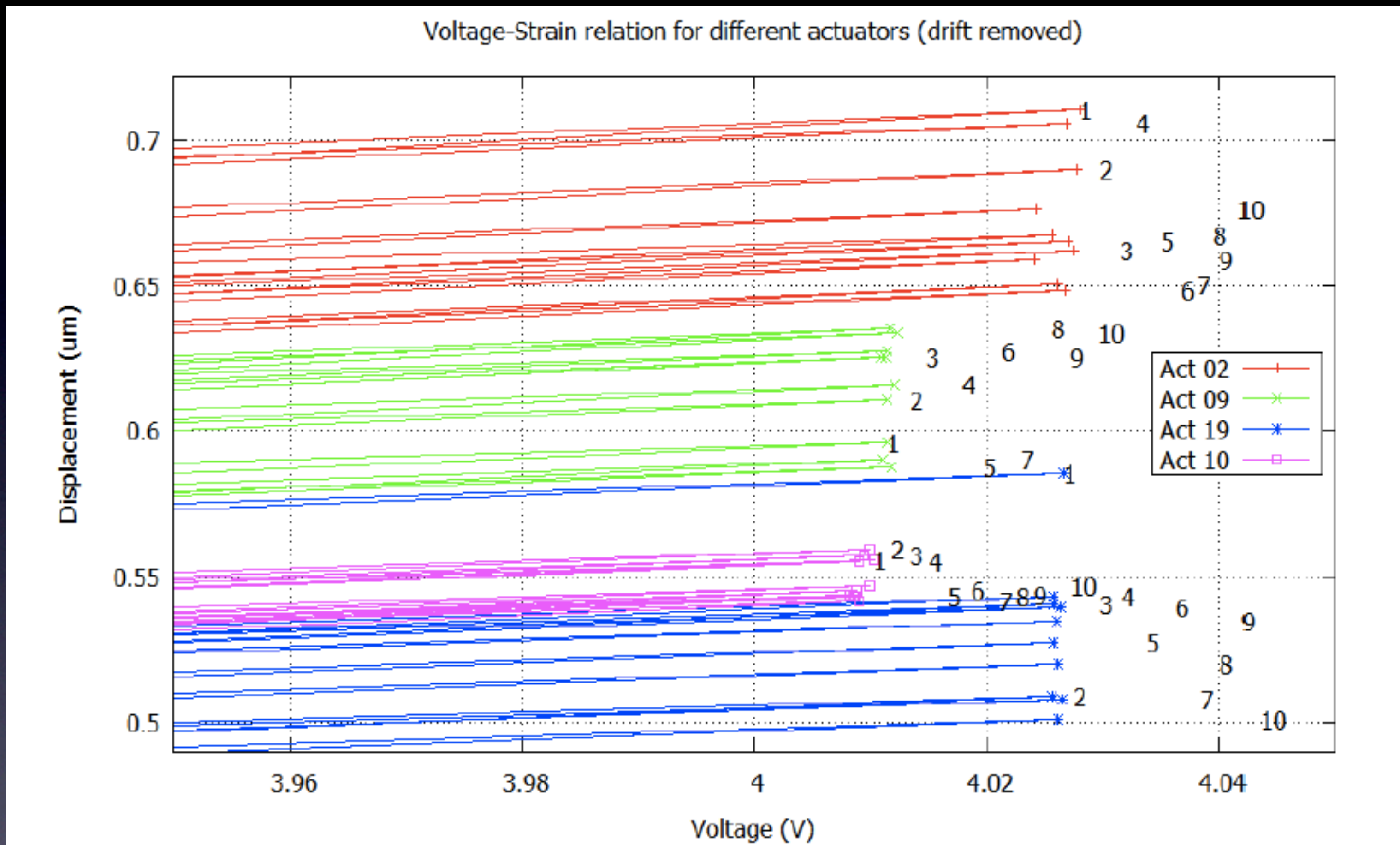

Expanded plot of hysteresis curves for cylindrical test mirror. Numbers on right represent order in which the hysteresis curves were measured.

Repeatability = 20 nm, rms, equal to metrology noise for test,

Cylindrical test mirror: influence functions

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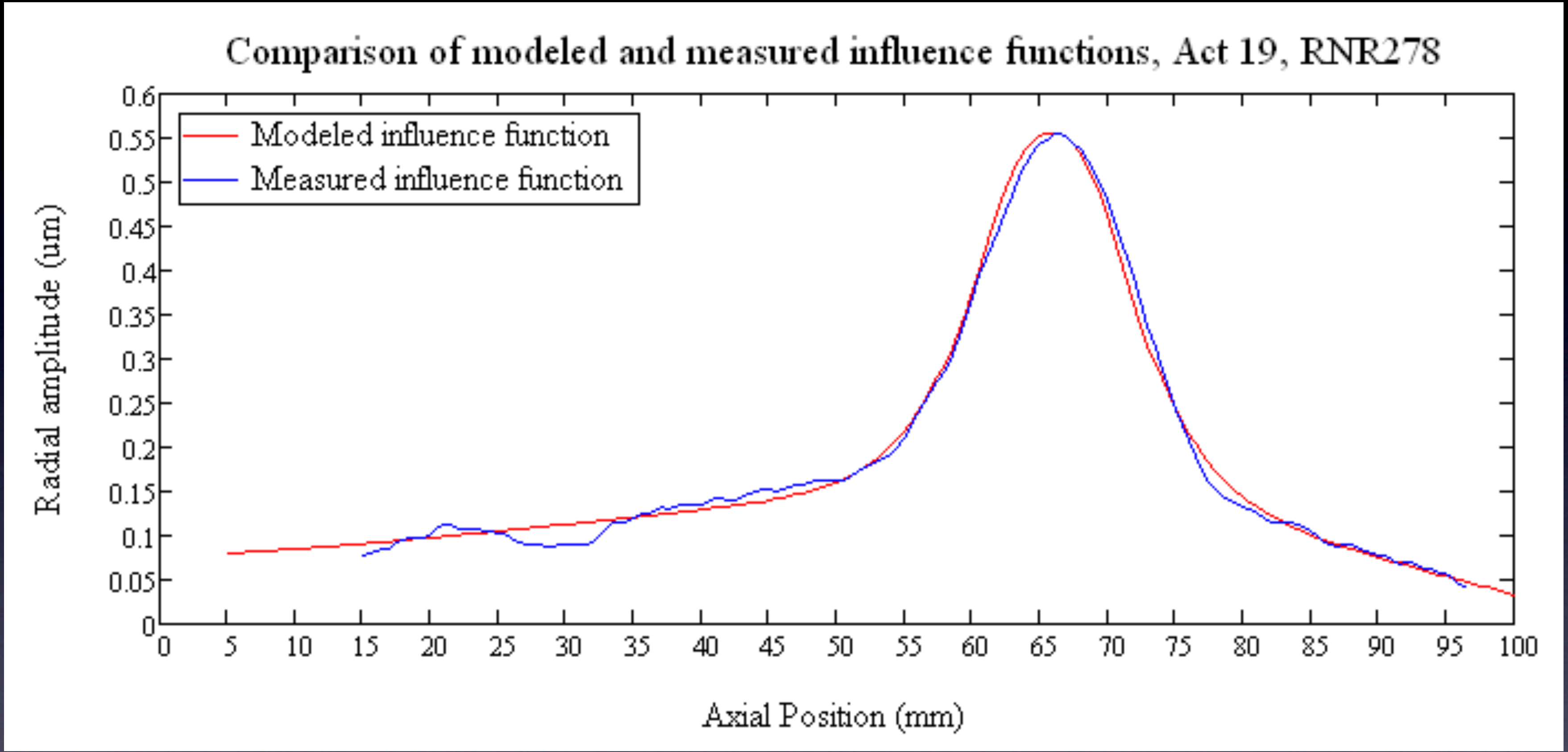

Comparison of modeled and measured influence functions for cylindrical test mirror (4V). Difference between model and measurement is 11.4 nm, rms – metrology repeatability ~ 20 nm rms

Other activities

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- Accelerated lifetime testing
  - Examining effects of Nb dopants
  - Refining parameters for accelerated lifetime testing scaling with voltage and temperature
  - Current estimates, not including area scaling, ridiculously long (thousand of years)
- Modeling/optimization
  - Simulation of different size and shape piezo cell layouts
    - Interleaved layout yields best result
    - Ellipsoidal shaped cells and 5 mm electrodes on 10 mm spacing give poorer result than nominal square array
  - Piezo voltage optimization with bounds and constraints
    - Bounded constrained least squares
    - Non-negative least squares

Small piezo cell modeling (ZnO program)

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- Nominal piezo cell sizes (1 mm gaps between cells)
  - 10 mm x 10 mm for development optics
  - 10 mm x 20 mm (L × W) for SMART-X simulations

- New, small size piezo cell modeling
  - For SMART-X simulations
  - 4.8 mm x 9.8 mm with 0.2 mm gaps
  - 0.9 mm x 0.9 mm with 0.1 mm gaps
    - Also looking at:
      - Error correction bandwidth
      - Potential for redundant sets of adjusters
      - Error correction amplitude range

Simulation Results – I

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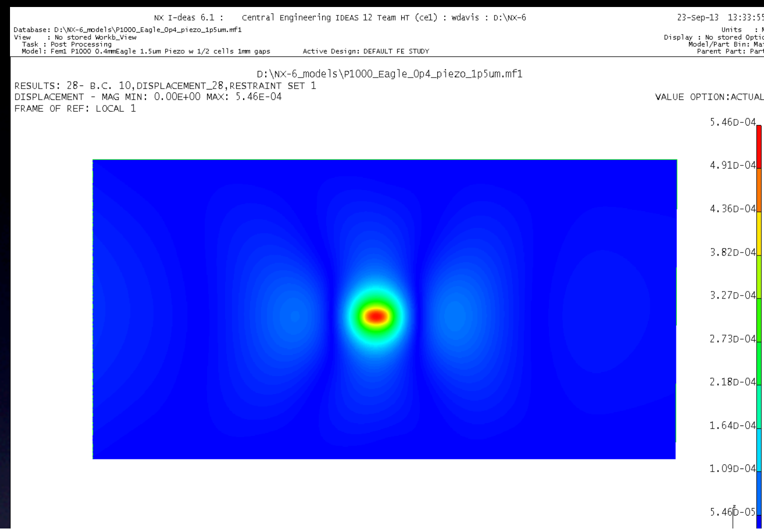
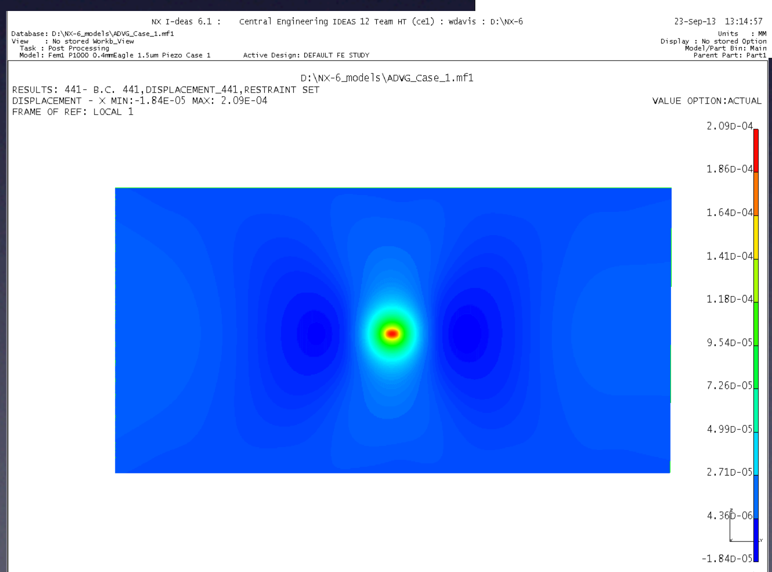
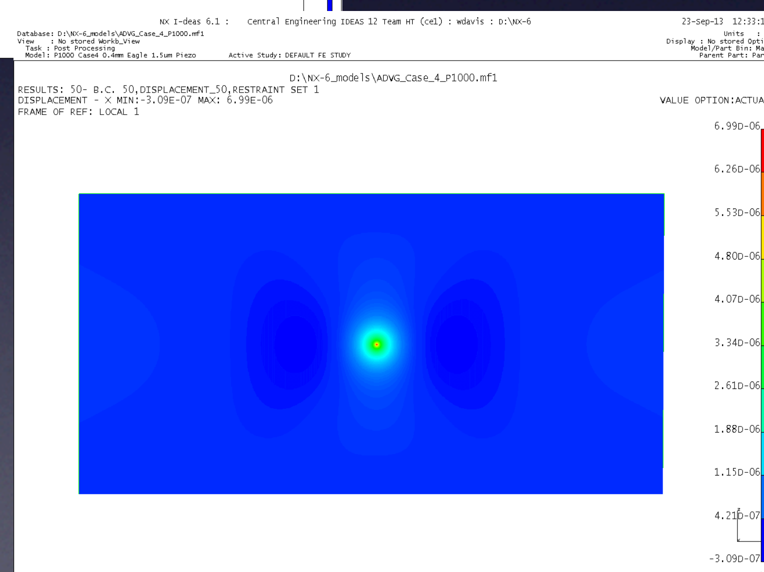
0.56 um/100 ppm





0.21 um/100 ppm



0.007 um/100 ppm

Simulation Results – II

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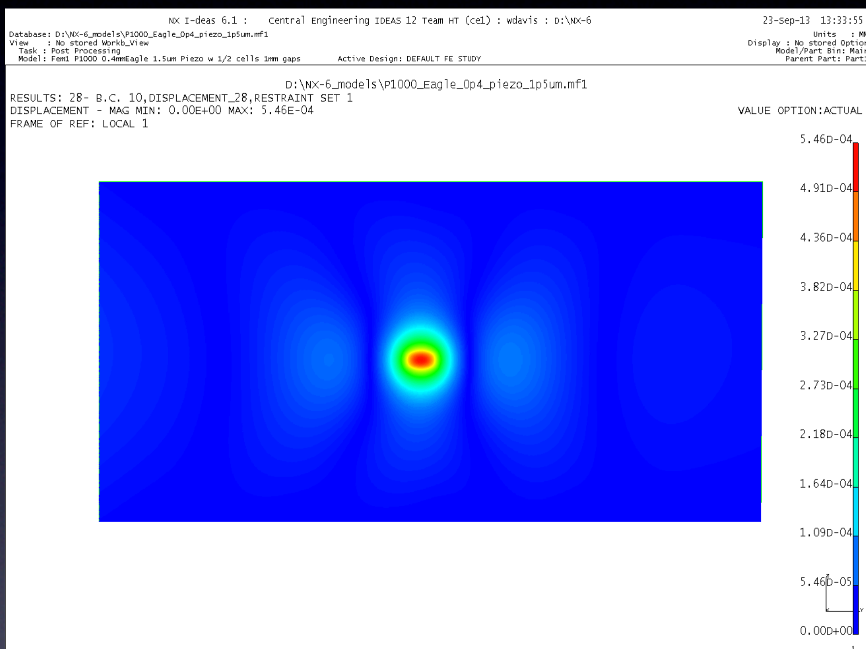

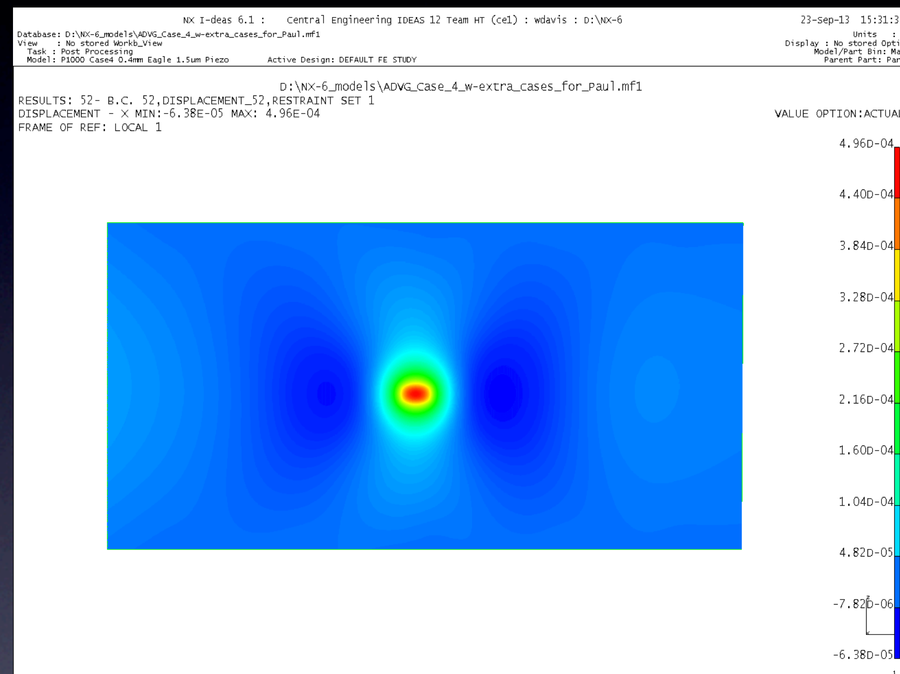

1 cell x {10 x 20}
0.56 um/100 ppm

10 x 20 cells x {1 x 1}
0.5 um/100 ppm

Simulation Results – III

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- 5 x 10 mm^2 cells give slightly better (few percent) corrected residual than 10 x 20 mm^2 cells, using exemplar data
  - Relatively low spatial frequency errors
  - Will compute an effective piezo cell correction 'filter efficiency'
    - Error correction as a function of spatial error frequency

- 5 x 10 mm^2 cells have slightly lower amplitude correction range than 10 x 20 mm^2 cells
  - Larger strain required to correct exemplar data

Simulation Results – IV

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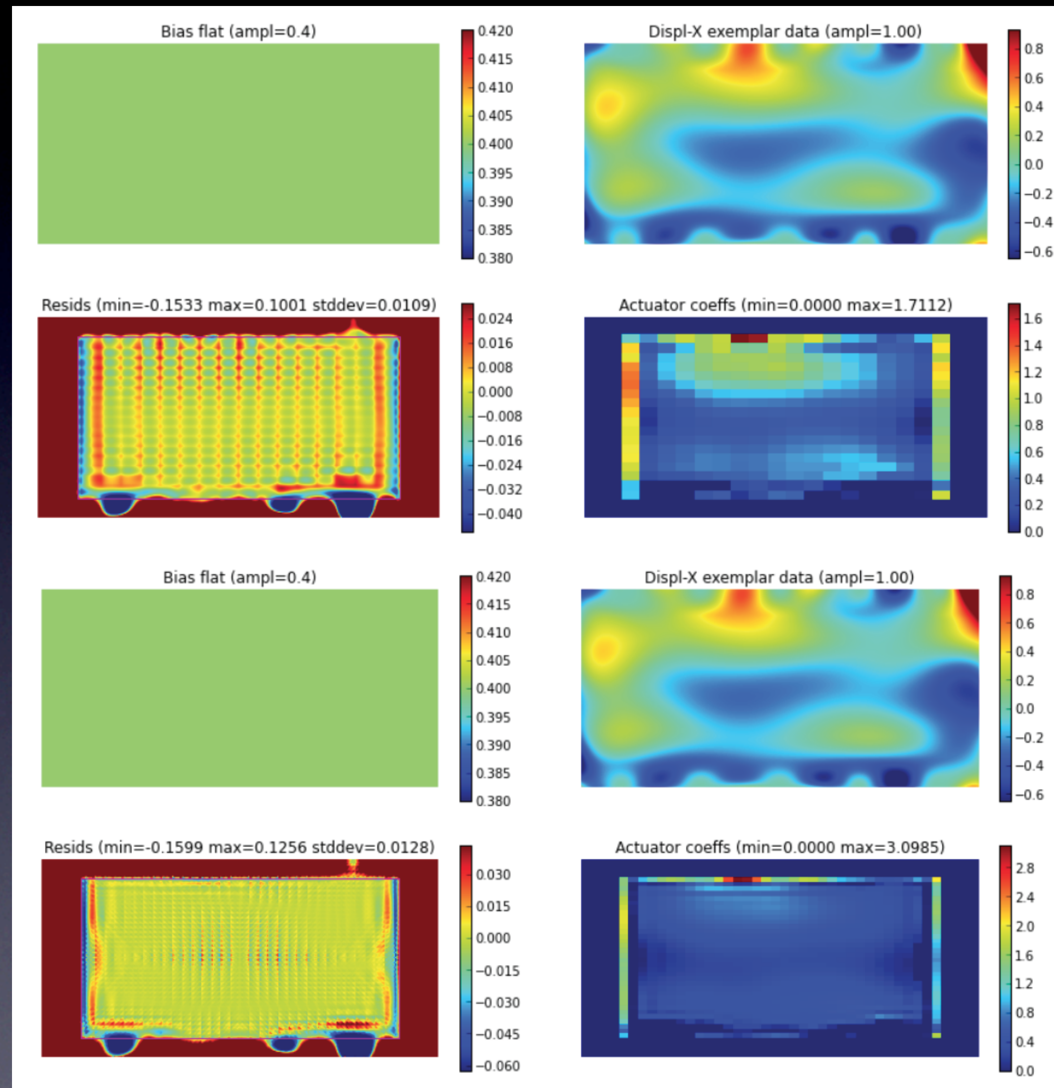
10 x 20 mm^2 cells

5 x 10 mm^2 cells



Strain gauges for on-orbit feedback/correction

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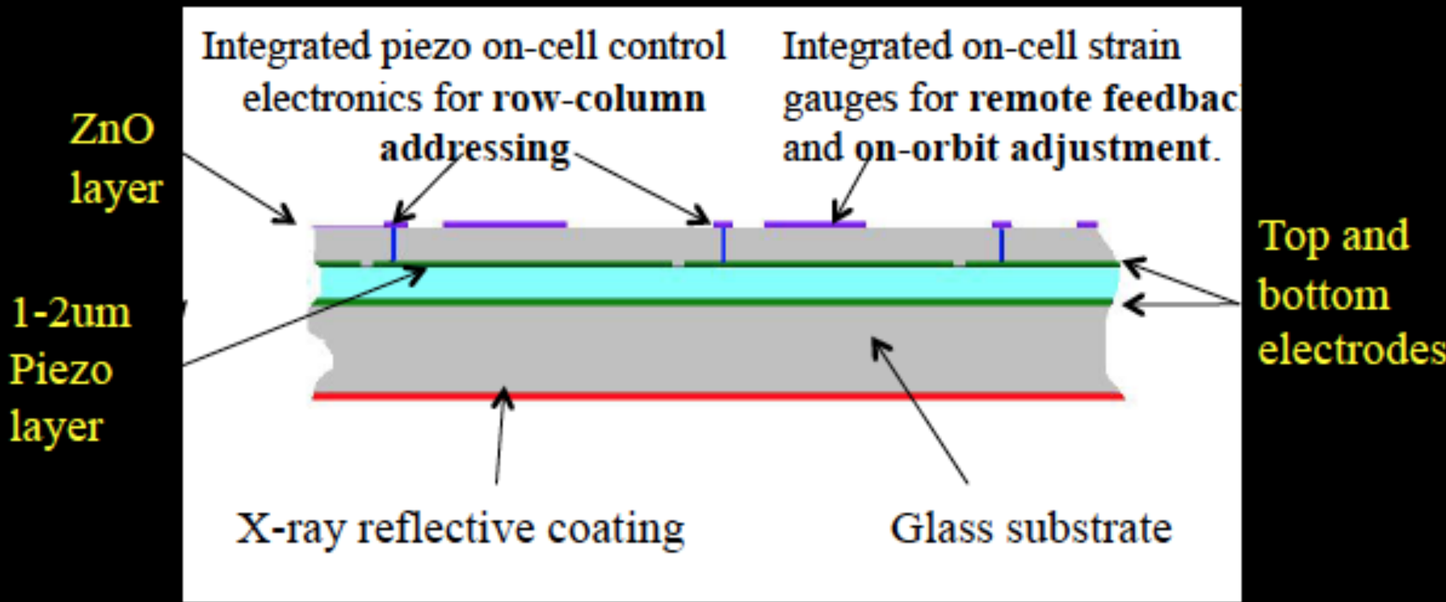

- Independently addressable piezo cells.
- Voltage across top electrode and bottom electrode produces strain in piezo in plane of mirror surface, resulting in localized bending.
- **Optimizing the piezo voltages *after* mirror mounting enables correction of fabrication errors *and* mounting-induced deformations.**
- Calibrated on-cell strain gauges provide feedback on cell strain/deformation, enable mirror figure corrections to be made on-orbit.

Other activities

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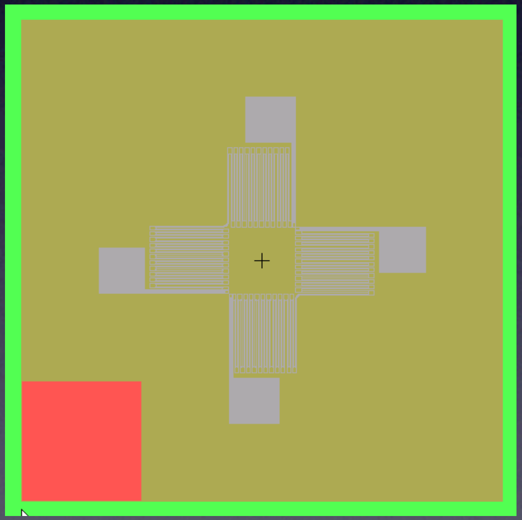
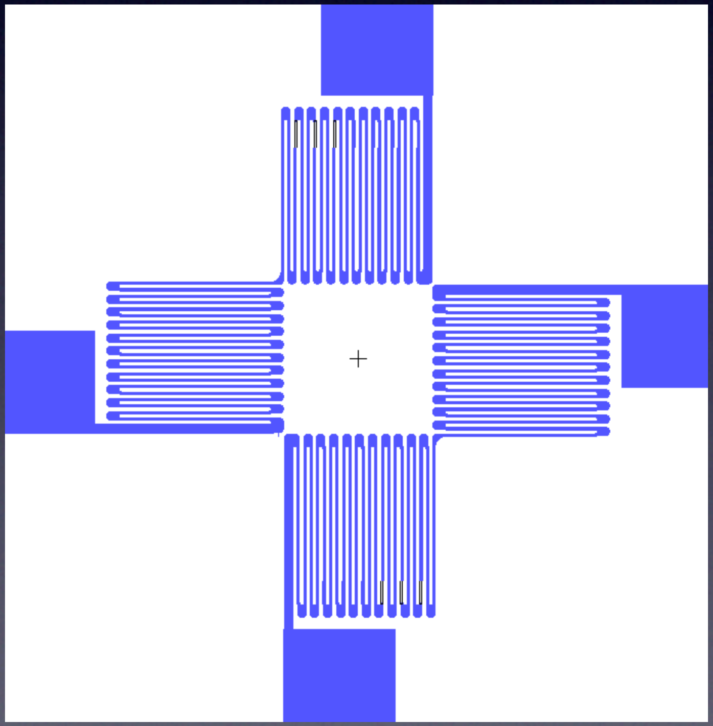
- Real time lifetime testing
  - mask and fixturing designed, being fabricated
  - Incorporate strain gauges directly on piezo cell
    - Need to test/calibrate, but estimated strain accuracy is +/- 1 part per million (ppm), compared to nominal strains of ~ 500 ppm





Flat test mirror with strain guages

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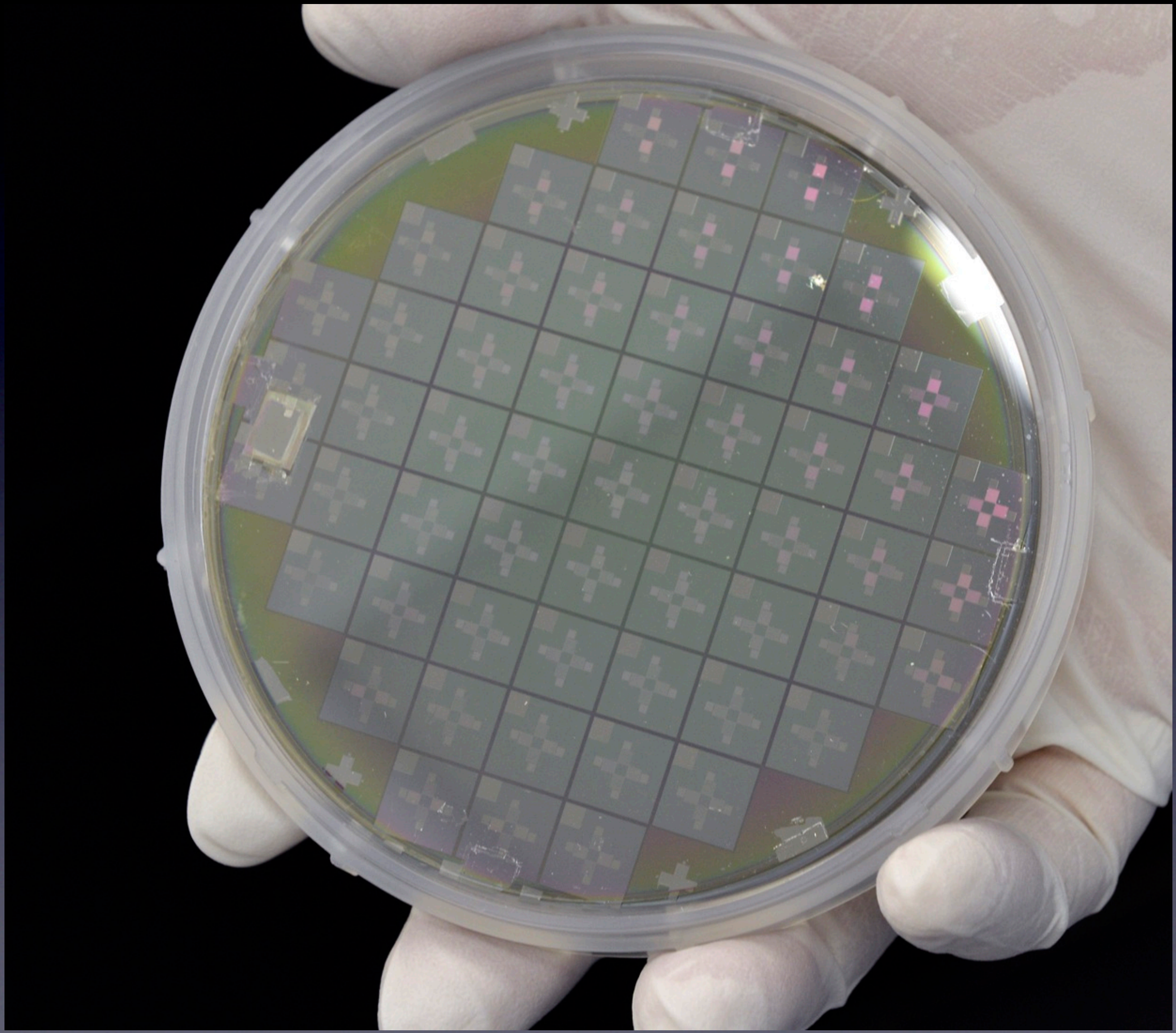

Summary

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- We continue to make progress.
- Claim current TRL = 3
  - Measurements match models on curved mirror segments
  - Measurements repeatable to metrology noise levels
  - Models suggest correction of 7 – 10 arc sec mounted mirrors to sub-arc sec level
  - PZT deposition process developed
- Plan for full aperture X-ray test of mounted, aligned, corrected conical pair in late FY15
  - TRL 4
- Separate development contract (PSU PI, SAO Co-I) for ZnO integrated electronics