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MEASUREMENT COMPARISONS BETWEEN OPTICAL AND MECHANICAL EDGES FOR A SILICON MICROMACHINED DIMENSIONAL CALIBRATION STANDARD

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1. Sandia National Laboratories
2. Micro Encoder Inc
3. Mitutoyo America Corporation

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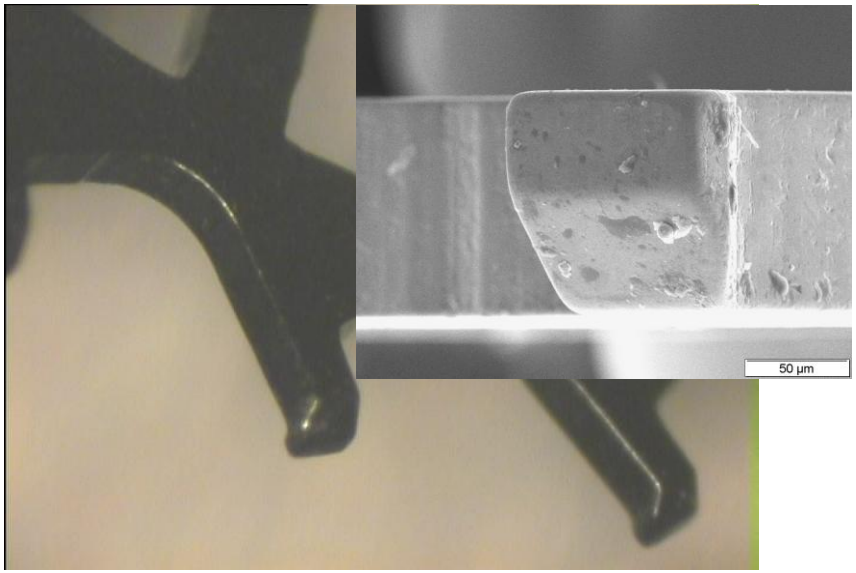
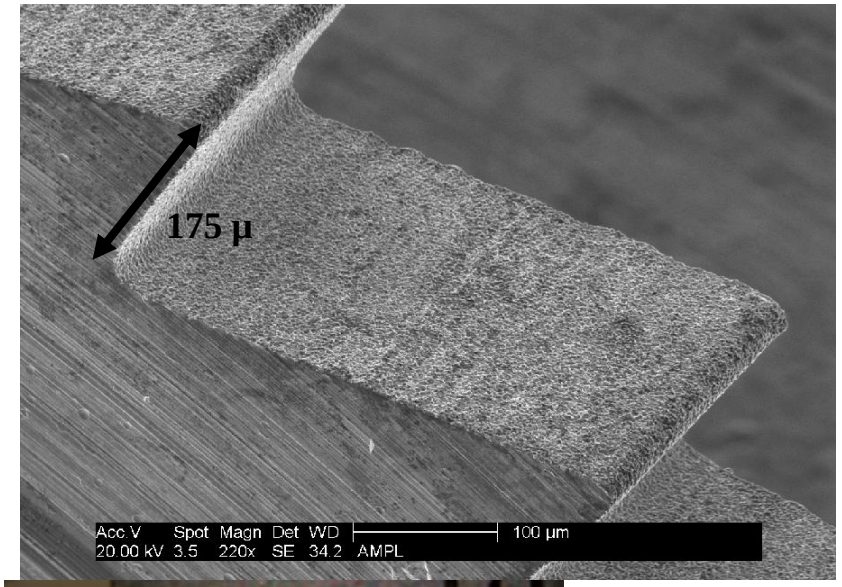
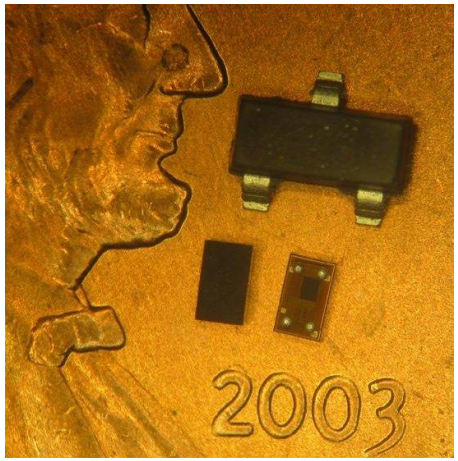
Outline of Presentation

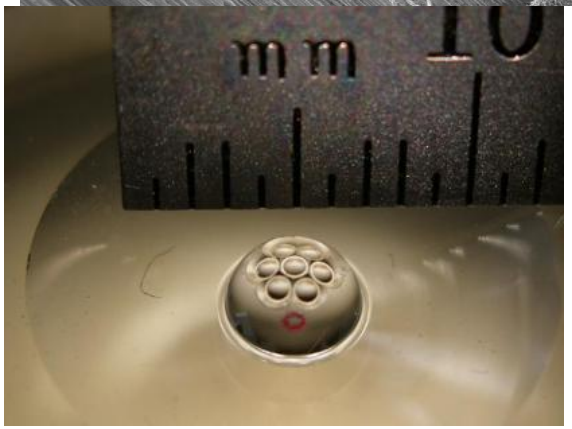
- Motivation for work: Inspection of mm-scale parts with μm to sub-μm measurement uncertainty
- Development of bulk-micromachined silicon calibration standard, with a common mechanical (touch probe) and optical (vision) edge
- Experimental Results
- Conclusions

Examples of Mesoscale Components









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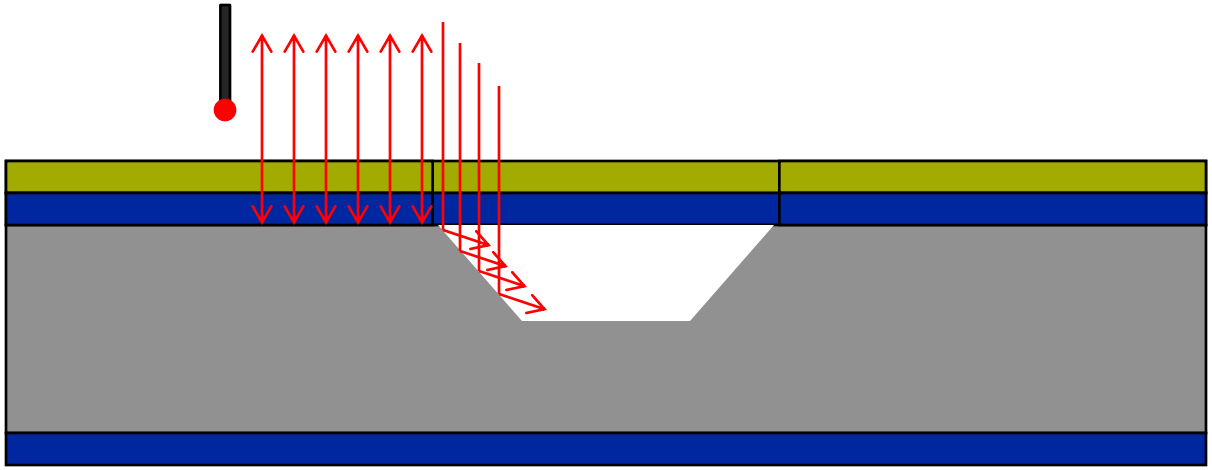
Typical Capabilities for Existing Systems

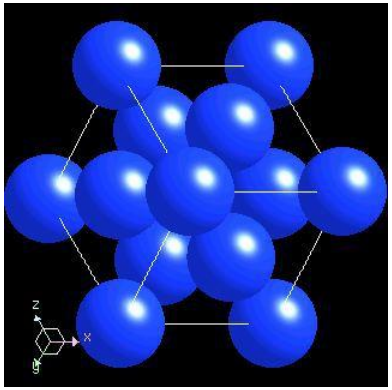
- Vision system repeatability typically order of 0.1μm (using averaging)
- Typical measurement uncertainties from various manufacturers and models (vision):
  - 1.5 + 4L/1000 μm
  - 0.5 + 2L/1000 μm
  - 1.0 + 2L/1000 μm
- Typical measurement uncertainties for Micro CMM's:
  - 0.3 + L/1000 μm
  - 0.25 + 1.5L/1000 μm
- Hybrid, or multi-sensor systems with both stylus & non-contact (vision) sensor

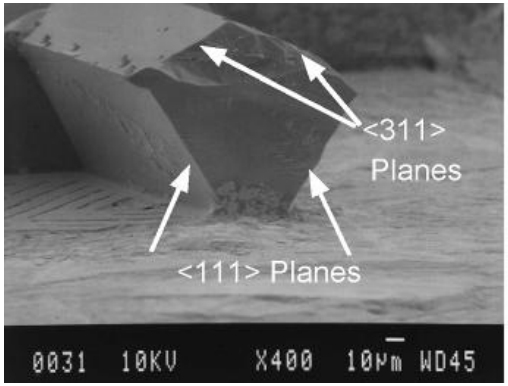
How Do We Improve Calibration?

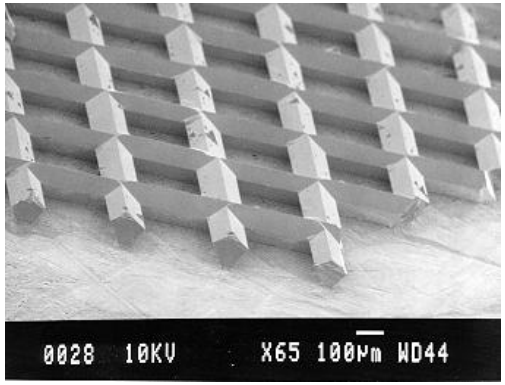
- The accuracy of vision systems is typically limited by calibration artifact, not resolution:
  - Calibration artifact accuracy ~1μm
  - System repeatability ~0.1μm
- Can we design a better calibration tool?
- Can we make a calibration artifact that satisfies the needs for vision systems, micro CMM's, and multisensor systems?

Si Bulk Micromachining









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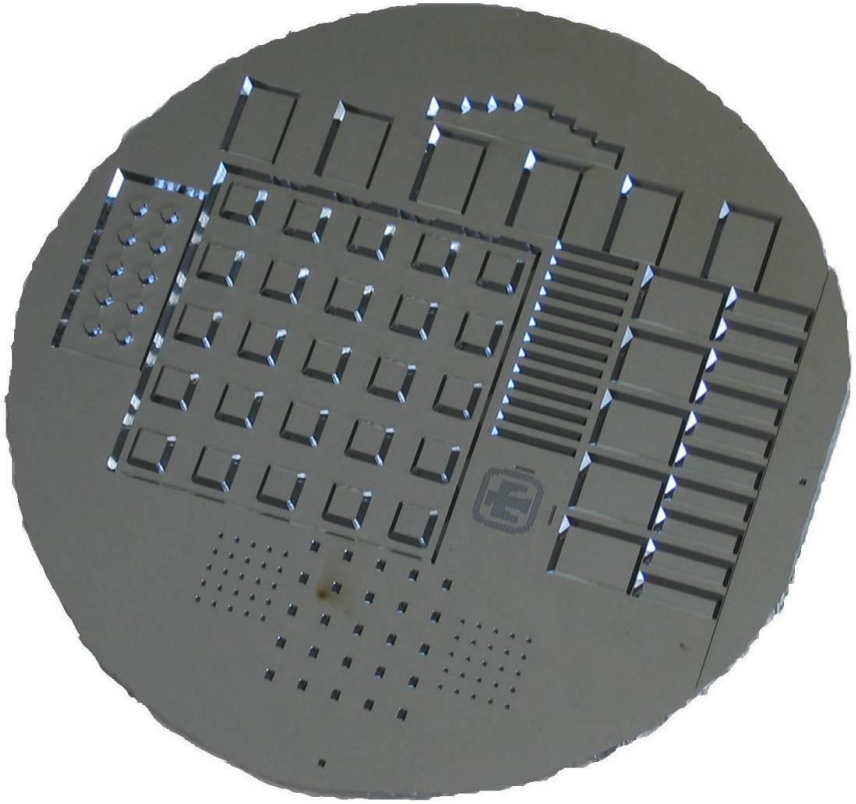
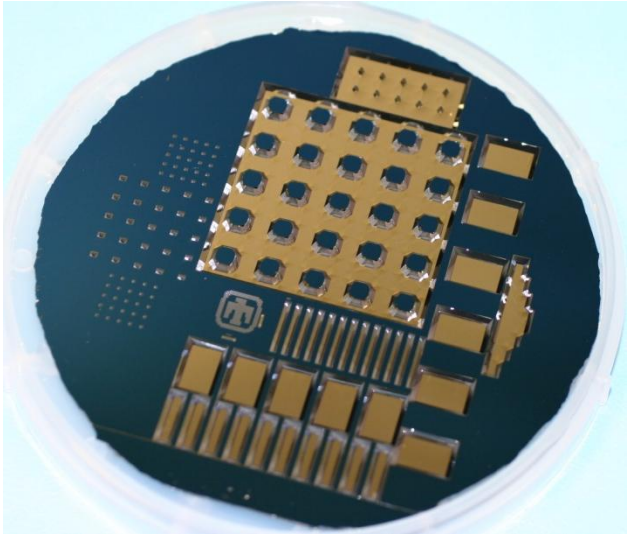
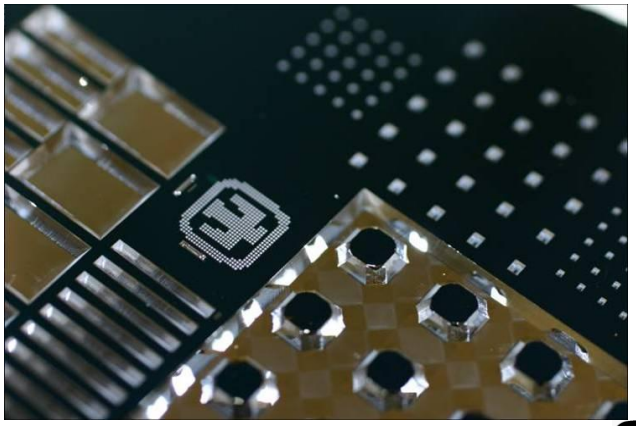
Initial Test Structures







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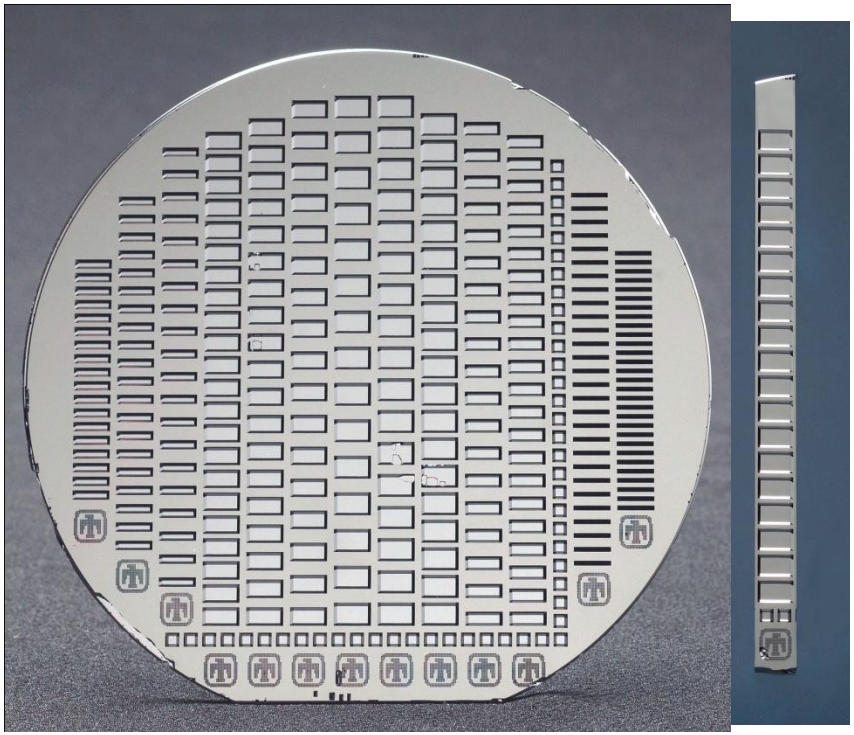
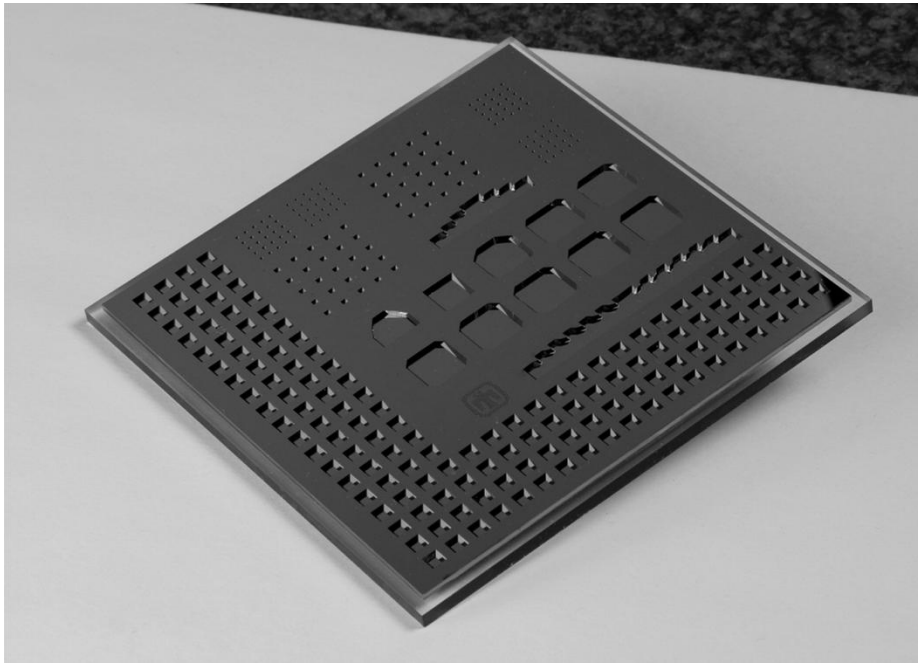
Second Design Iteration

- **Process improvement studies (etch optimization; mask alignment improvements)**
- **Two designs, based on user feedback (using 150 mm wafers)**





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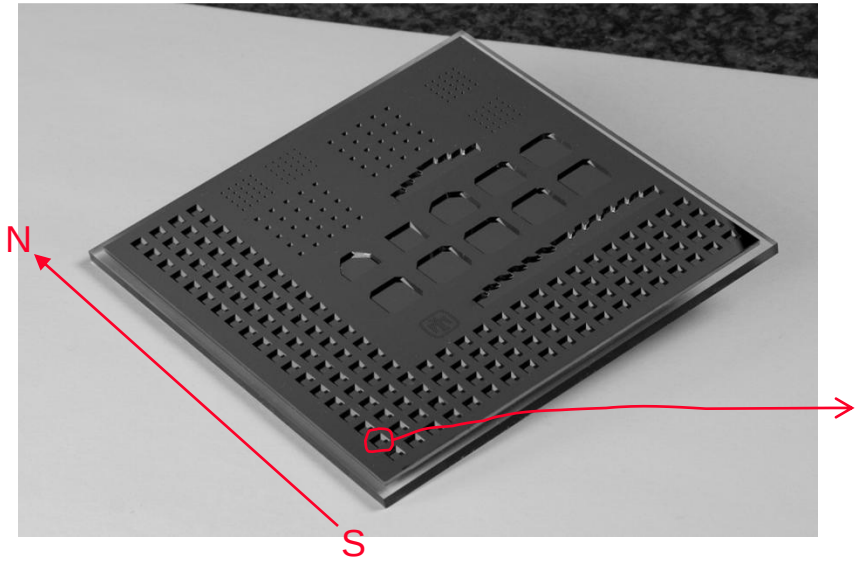
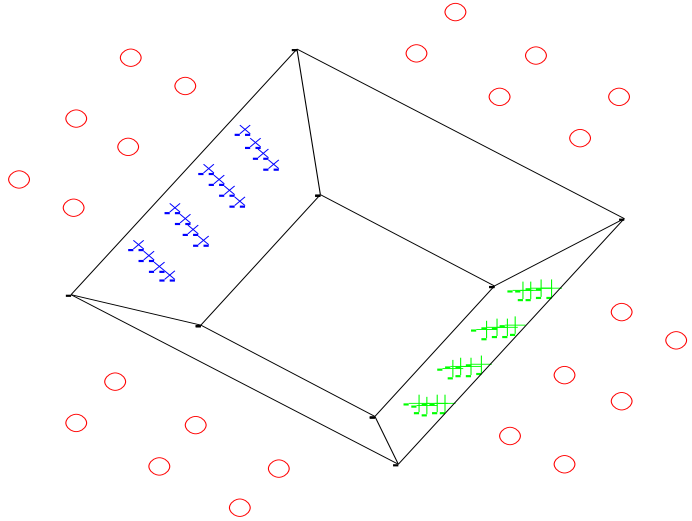
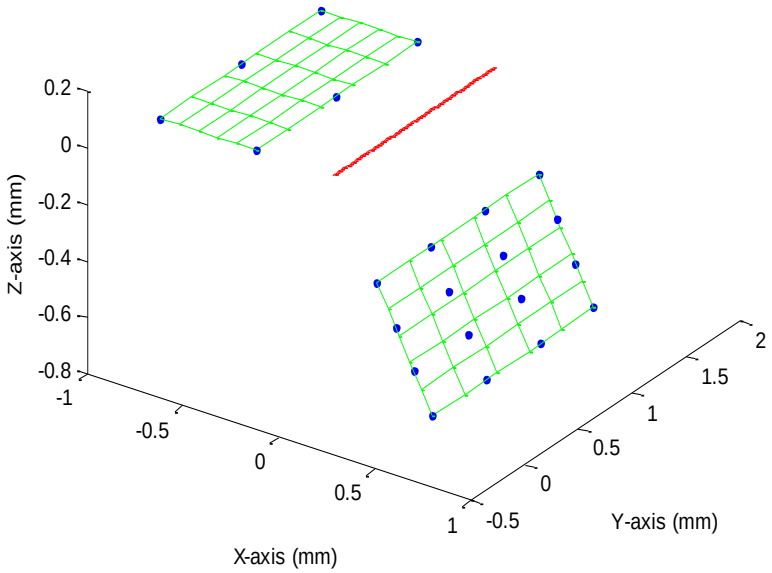
Probing on CMM





Surface Roughness of Silicon Artifact

- **Process optimization in alignment and etch parameters performed, but sidewalls are still not as smooth as top surfaces.**
  - **Top surfaces have combined form/roughness deviations ±100 nm over 5 mm span**
  - **Etched sidewalls have combined form/roughness deviations ±600 nm over a 5 mm span**
- **Form and roughness deviations may lead to greater uncertainty in the location of the plane or the projected intersection line (edge)**
- **Form and roughness deviations have minor effects on the location of the midpoint between two edges!**



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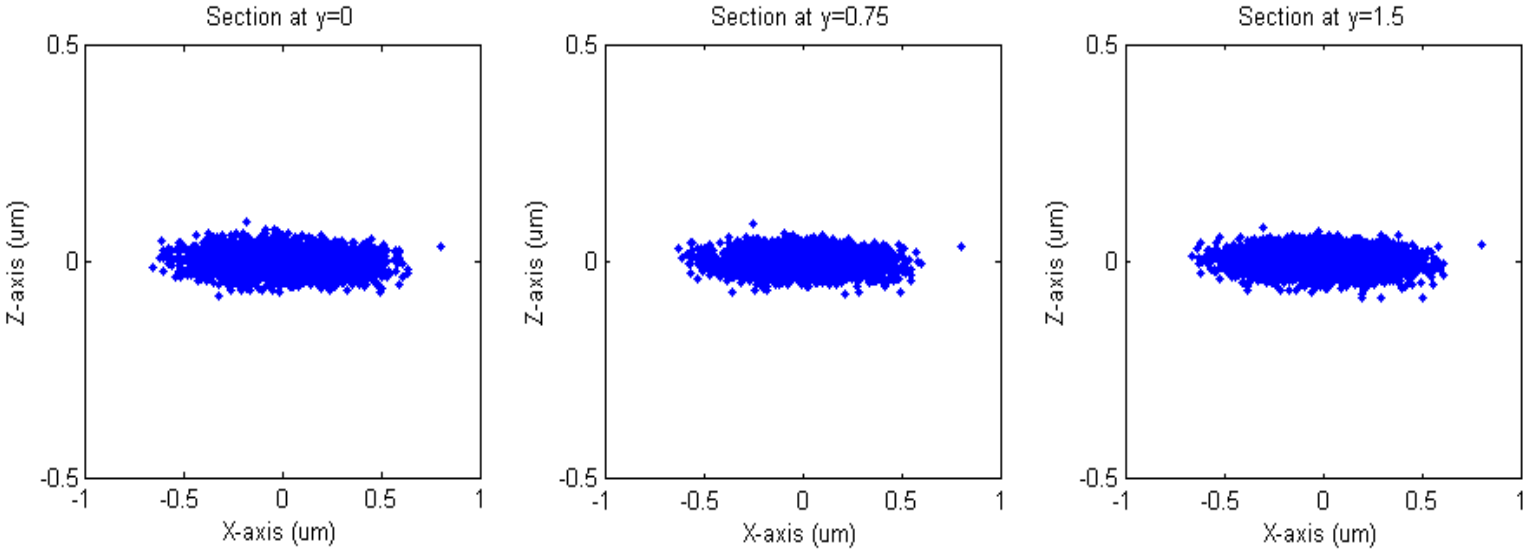
Monte Carlo Simulations for Effects of Roughness



- **Plots from 5000 simulated data sets, using statistics from actual CMM data→0.4 μm uncertainty at k=2 for location of a single edge**
- **Note that roughness should not have an effect on the distance of the pitch between adjacent cavities**

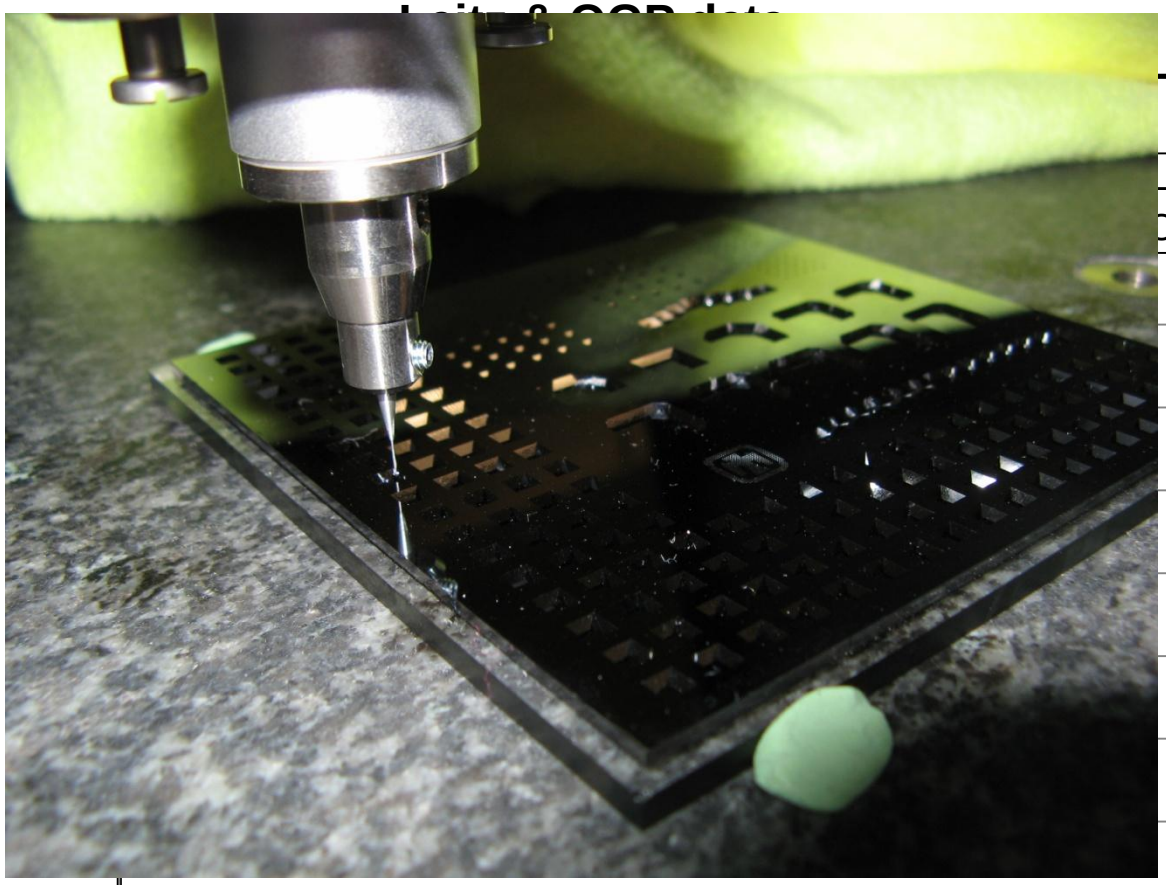
Measurement Comparisons

- Leitz PMM-C-Infinity 12.10.6 at Sandia National Laboratories
- OGP Smartscope Apex at Sandia National Laboratories
- Mitutoyo QV Ultra at Micro Encoder Inc with a 25 X objective
- 2 Mitutoyo M-Nanocoord; one with UMAP and vision probing; other with long range ultralow scanning probe (LNP)
- Mitutoyo Formtracer CS-3100 at Mitutoyo America Corp, Aurora, IL

Estimates of measurement uncertainty

- Mainly type B, based on:
  - Simulation of roughness→0.4 μm
  - MPE of equipment→rectangular distribution
- Repeatability of measurements significantly smaller than type B evaluation
- We estimate: Larger of either 0.4 μm or MPE converted from rectangular to normal at k=2

Leitz & OGP measurement results



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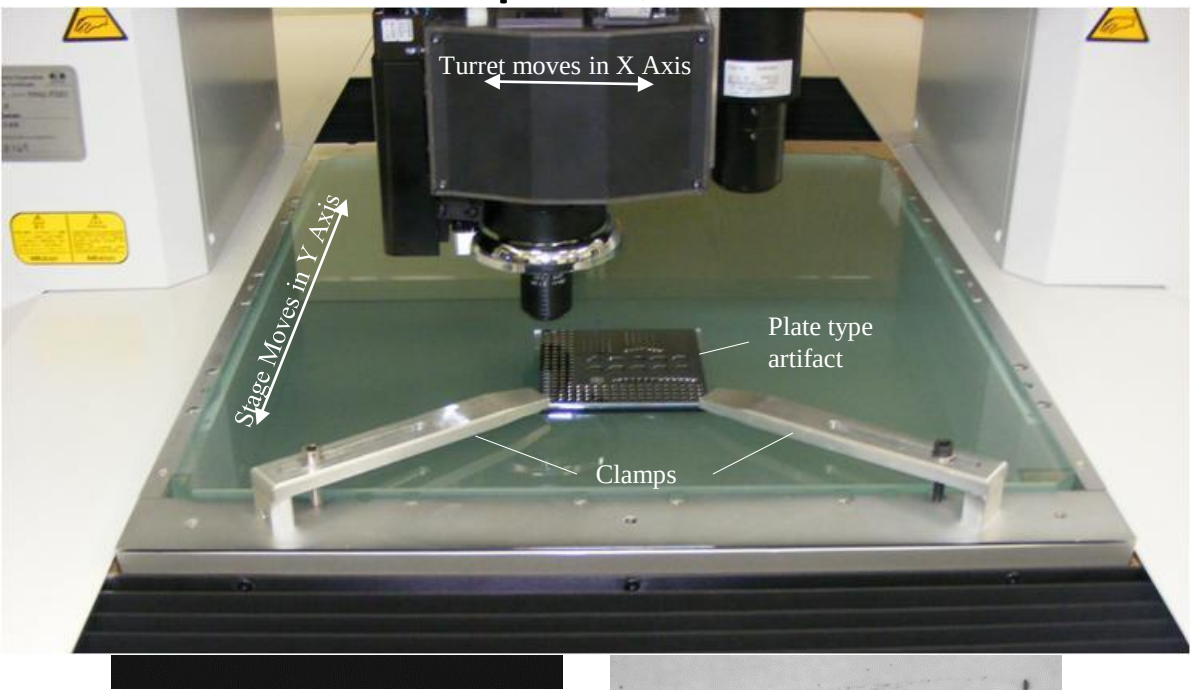
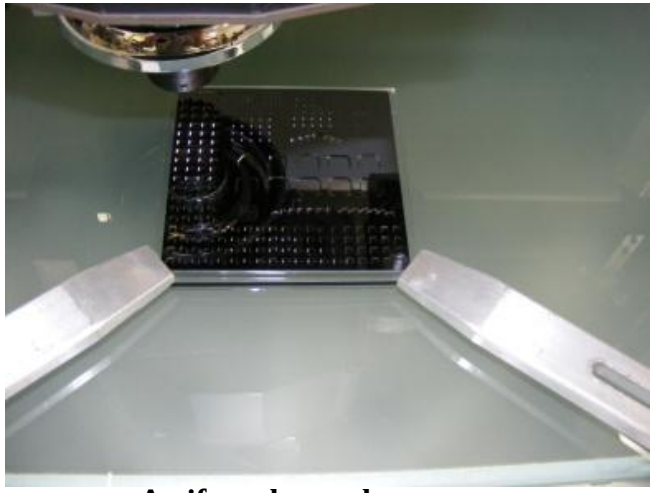
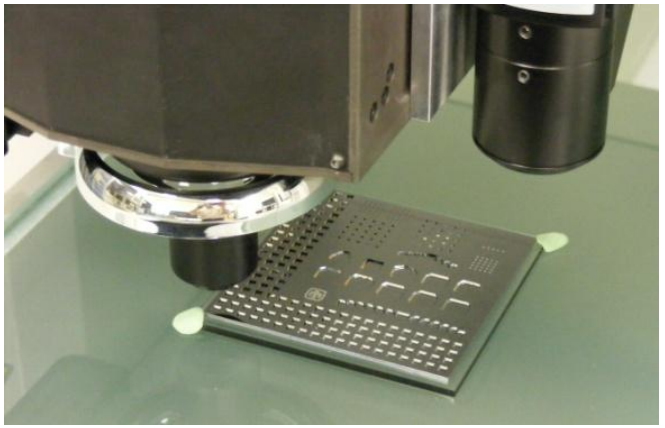
MEI measured the plate type artifact with QV Ultra

Measurement setup on QV Ultra





Artifact clamped to stage



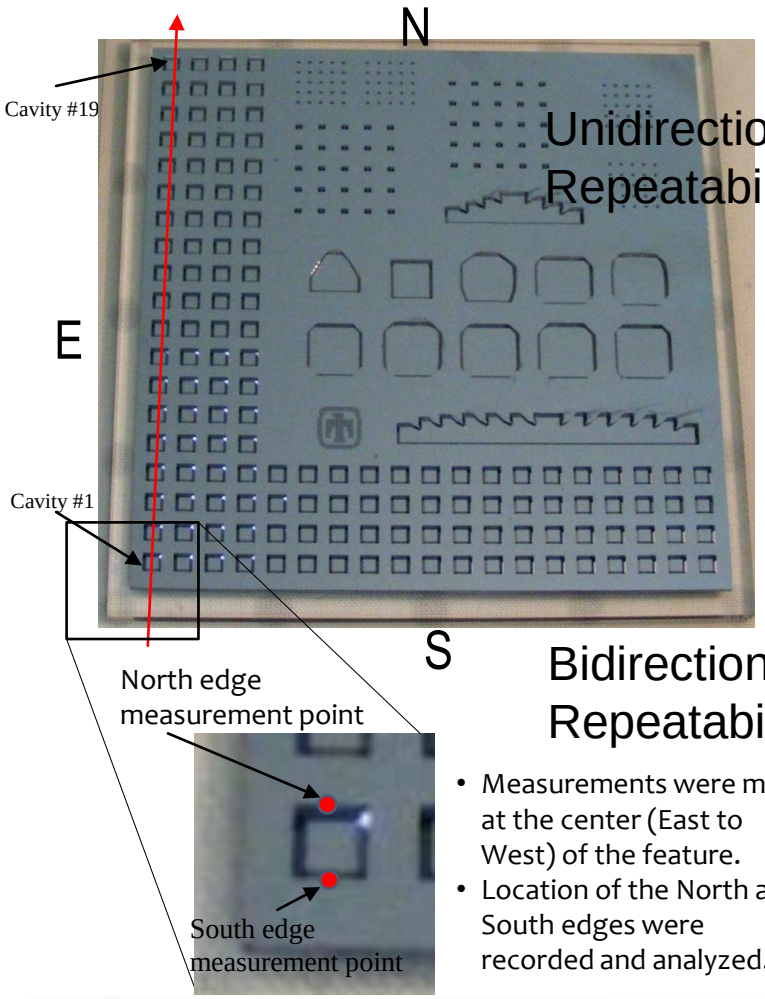
Artifact held with clay

- 25 X objective, calibrated before measurements
- QV box tool used. Both rising edge and falling edge algorithm were tested
- QV Ultra machine was recently calibrated
- The artifact was attached to the QV stage in three different ways: Clamp, clay, resting (just placed on stage)

QV Ultra measurements at Micro Encoder Inc

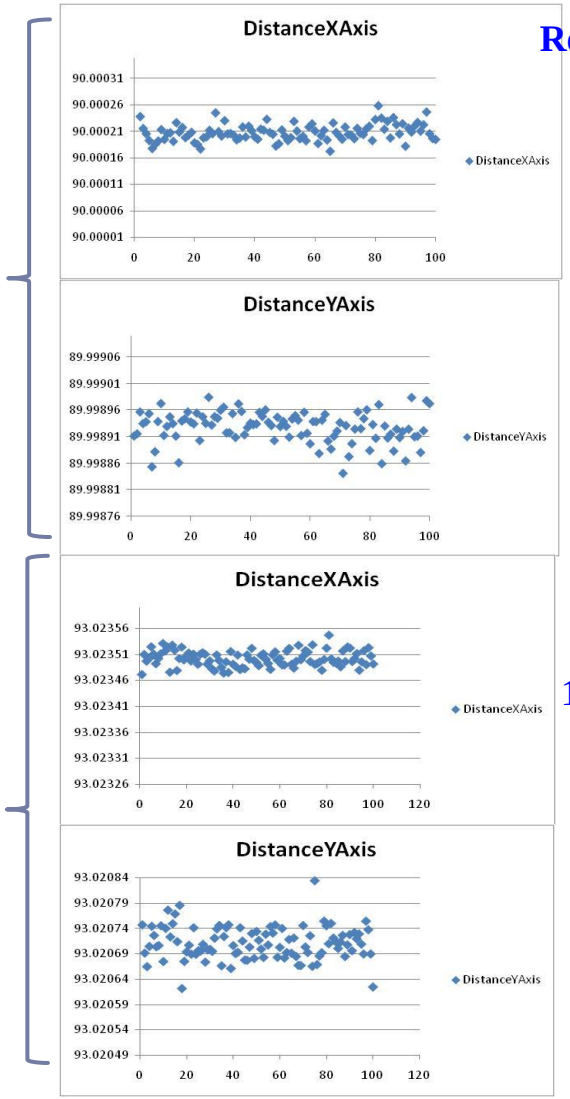
- Measurements were made using MEI's QV Ultra system (recently calibrated). Two sets of QV measurements were made using different measurement algorithms (rising edge and falling edge) with a 25 X objective.
- MEI measurements were made at the same nominal locations as Sandia measurements.

Measurements were made at the each cavity (1 ~ 19) along of the East most column, in the direction indicated.

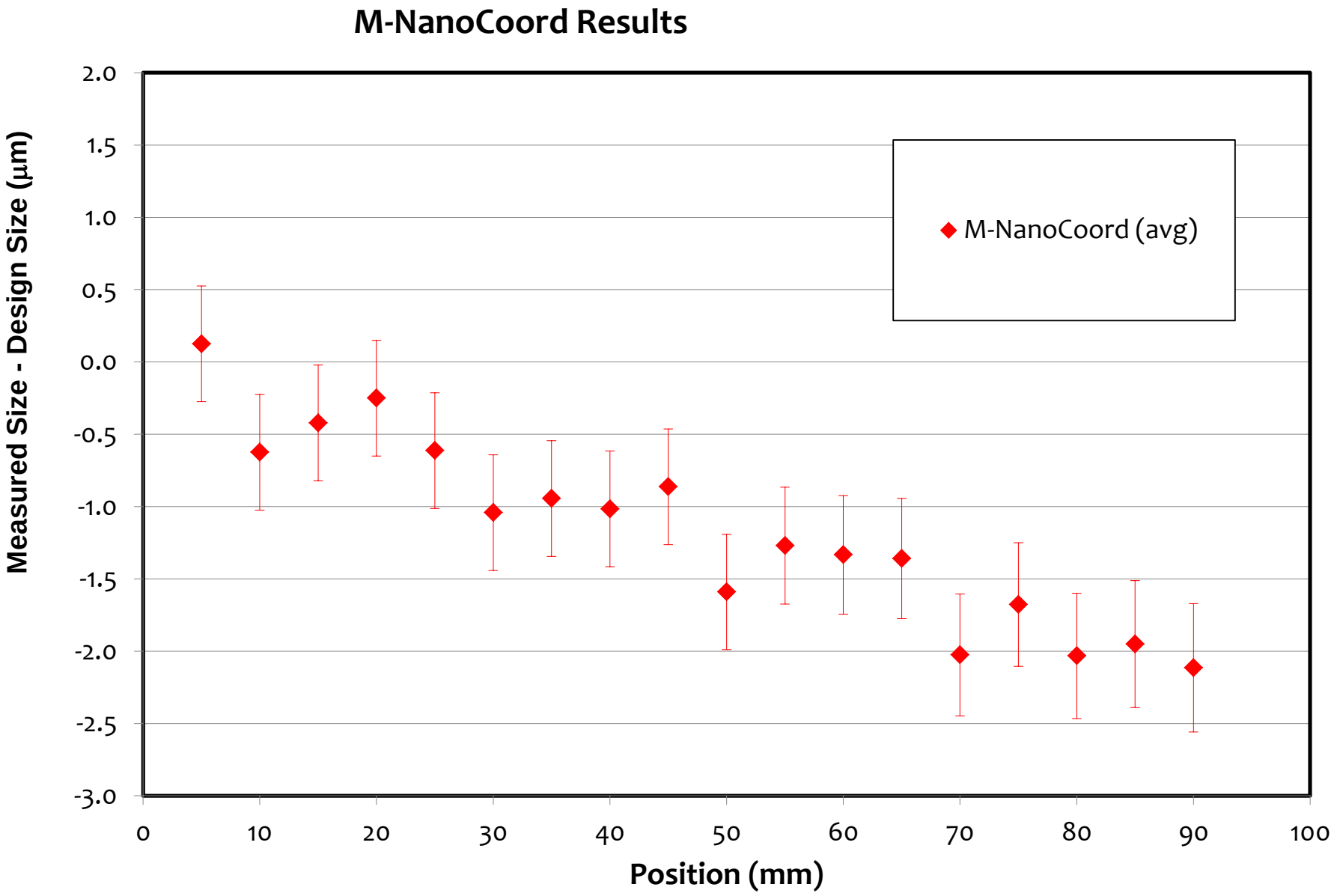


- Measurements were made at the center (East to West) of the feature.
- Location of the North and South edges were recorded and analyzed.

Repeatability

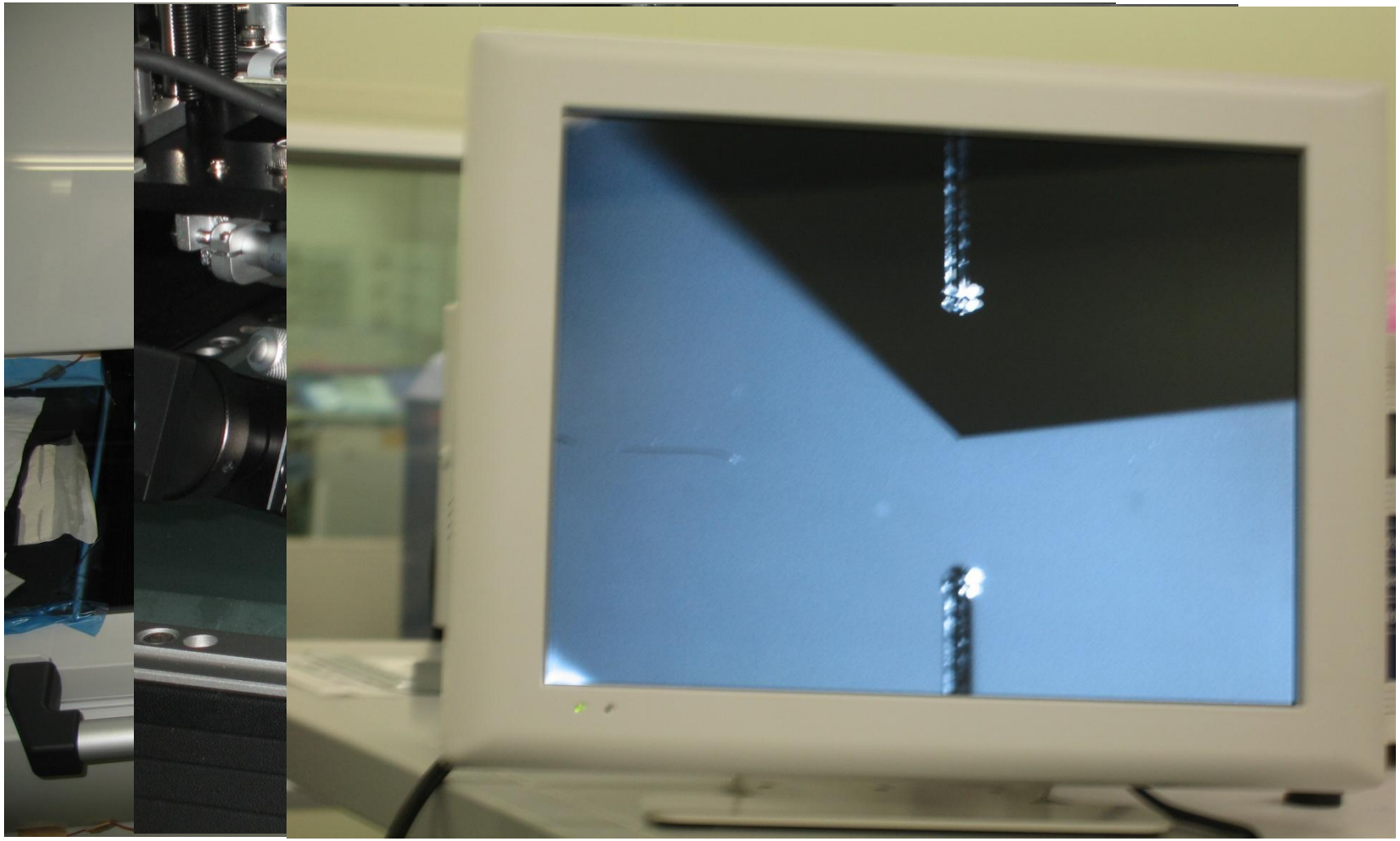


QV Ultra measurement results

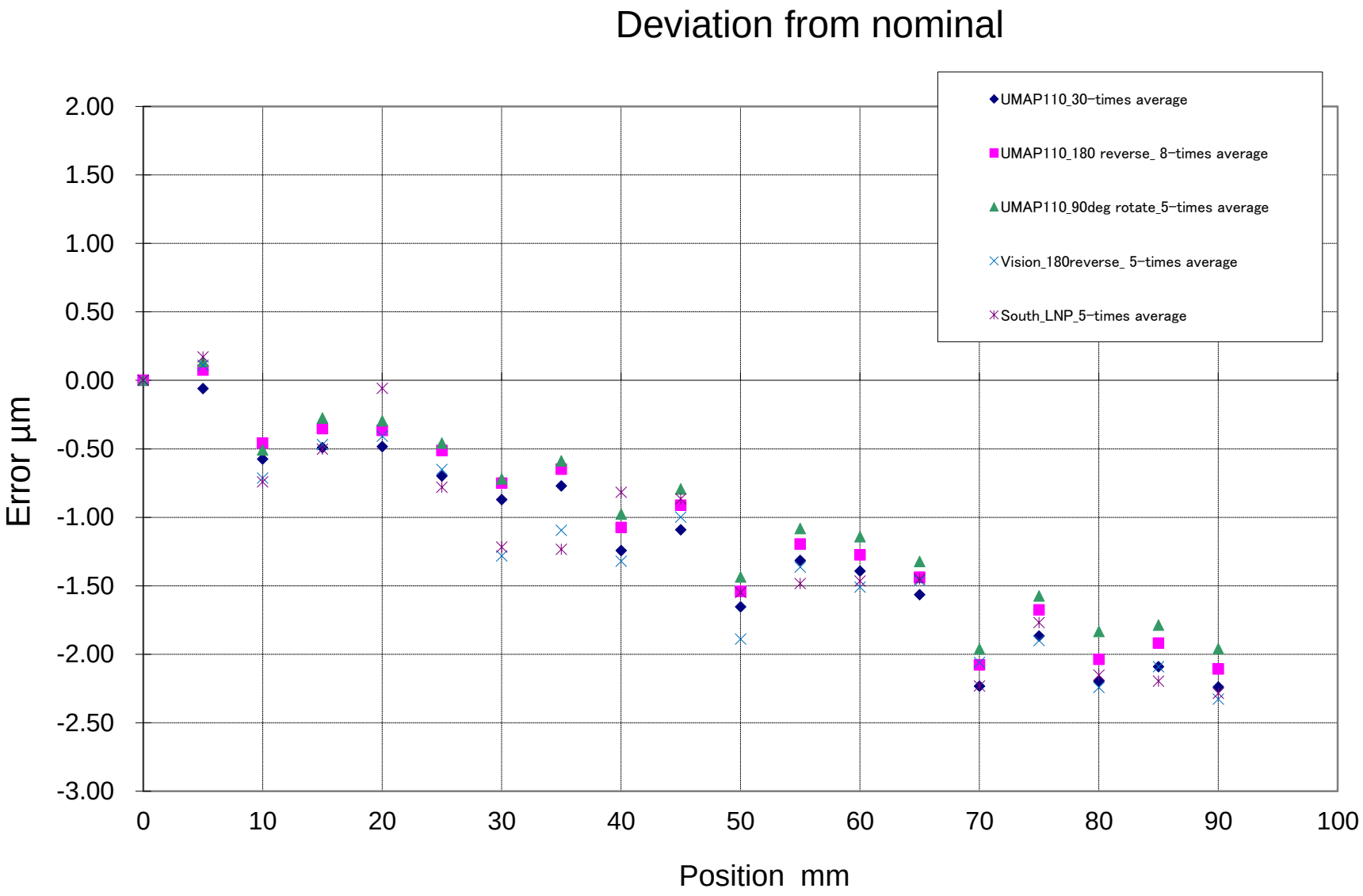


Mitutoyo M-Nanocoord measurements

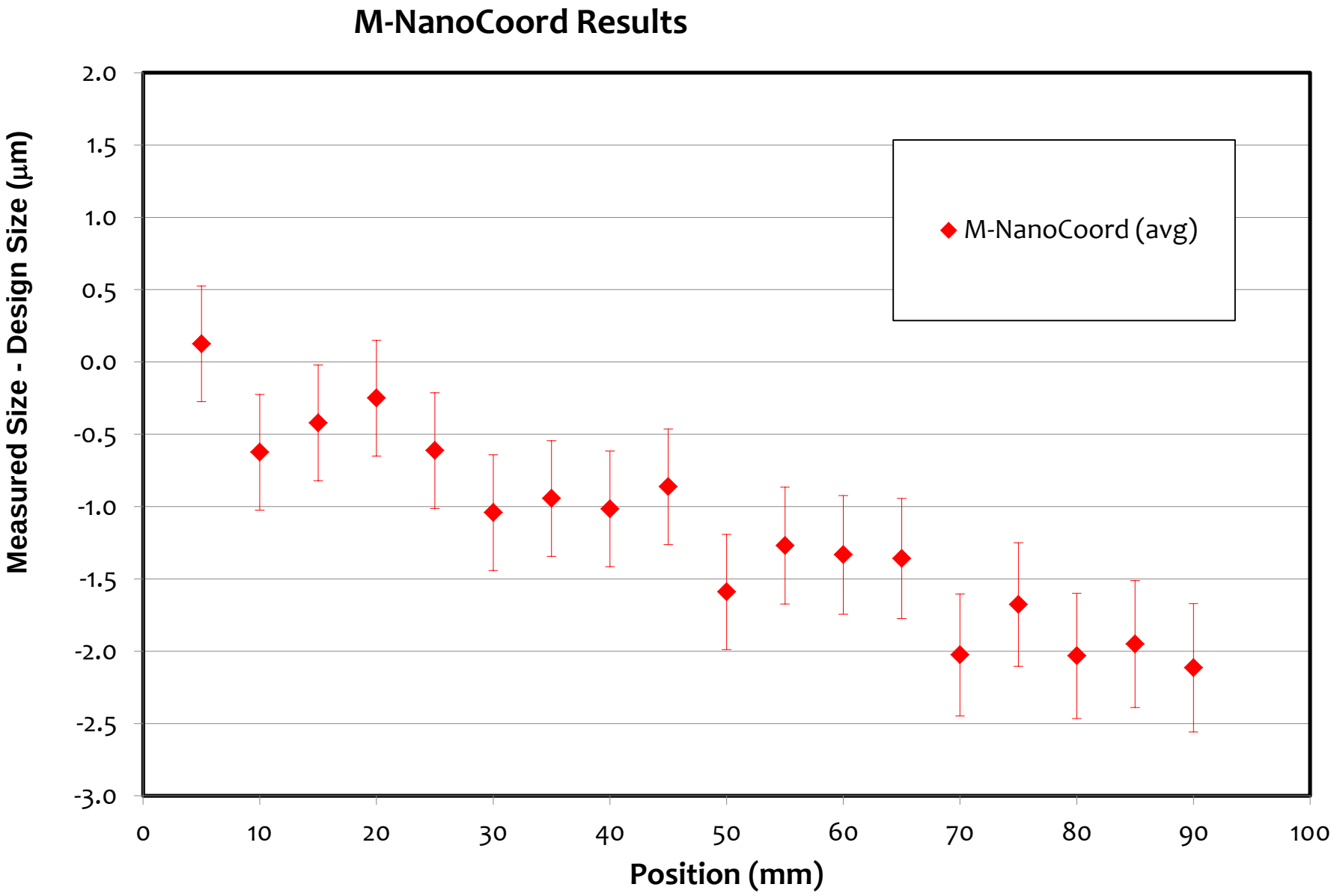
- Two different M-Nanocoords used
  - One uses both UMAP ultrasonic touch probe and optical vision probe
  - Other uses long-range ultralow force scanning probe (LNP probe)



M-Nanocoord intercomparison of probe systems

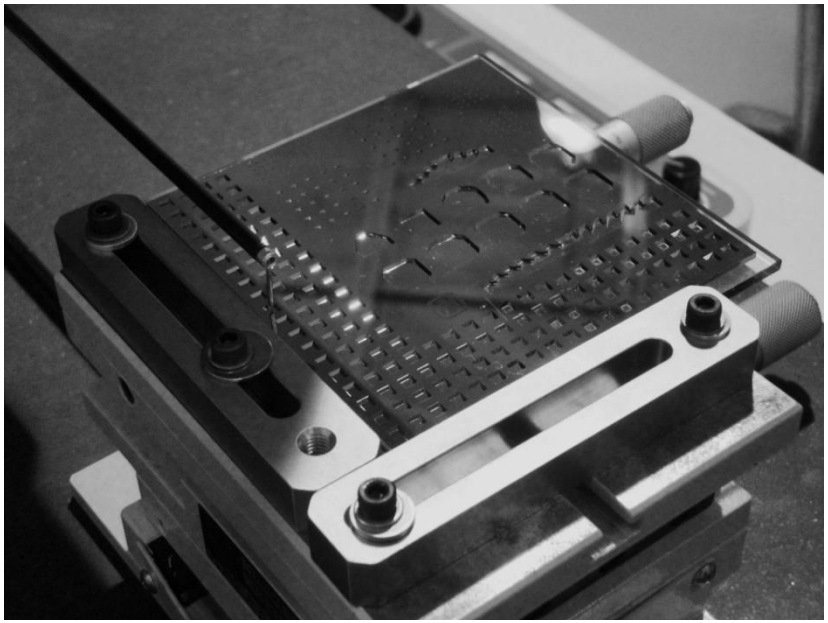


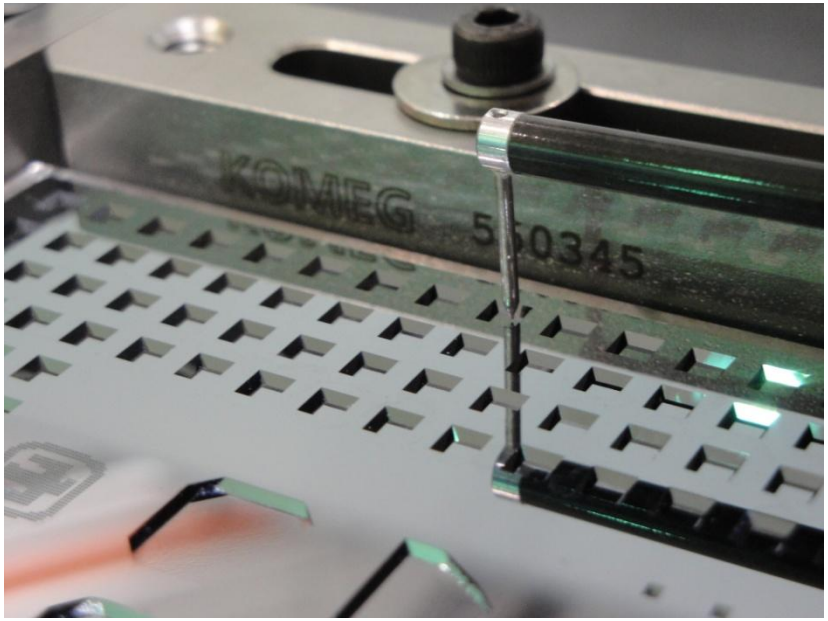
M-Nanocoord results



Setup

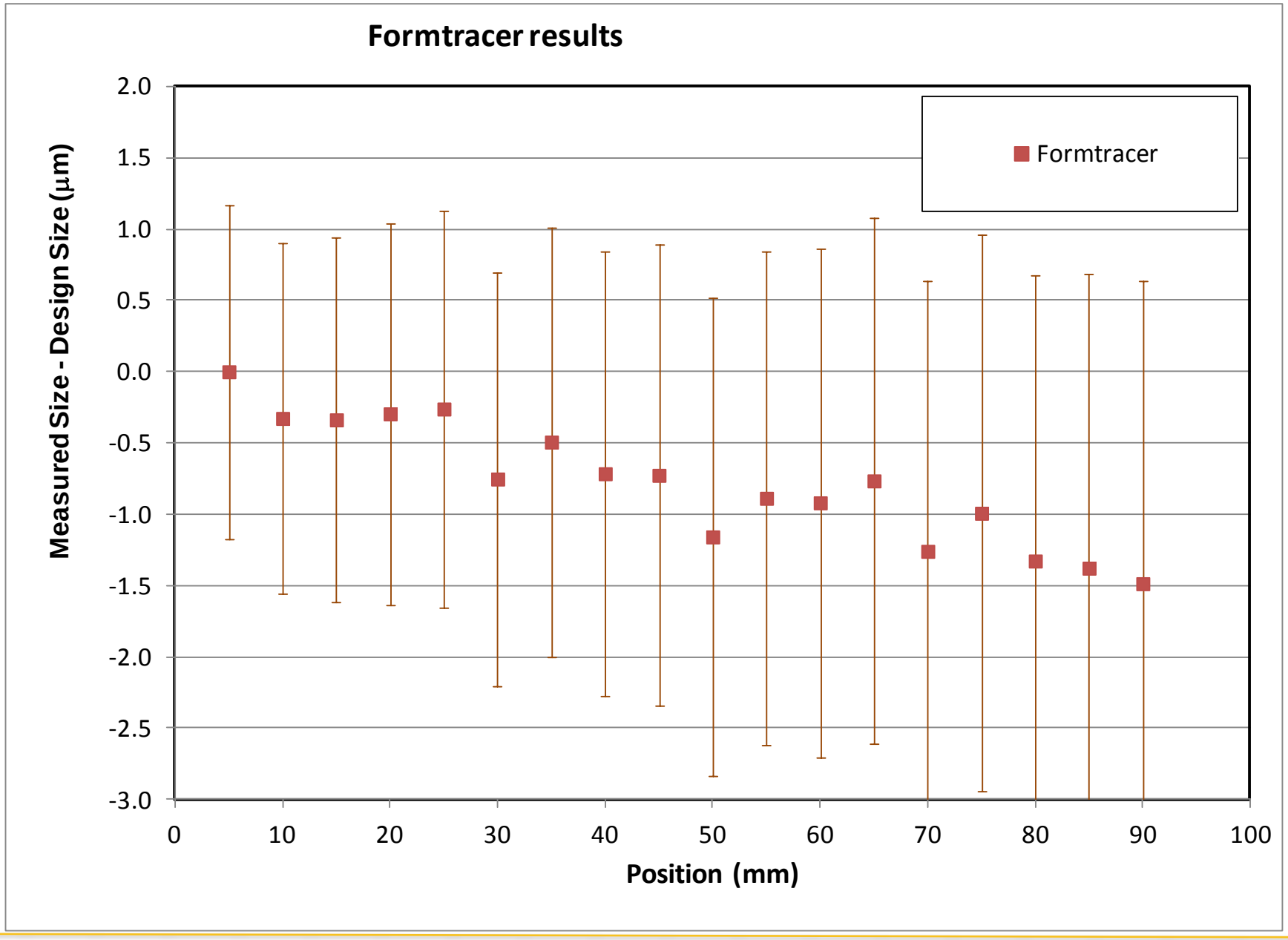
- A precision leveling table was used
  - Leveled to ½ micron manually
- Two brackets were mounted to the precision leveling table in an “L” shape to manually align the artifact into a fixed position
  - Further alignment would be done via software



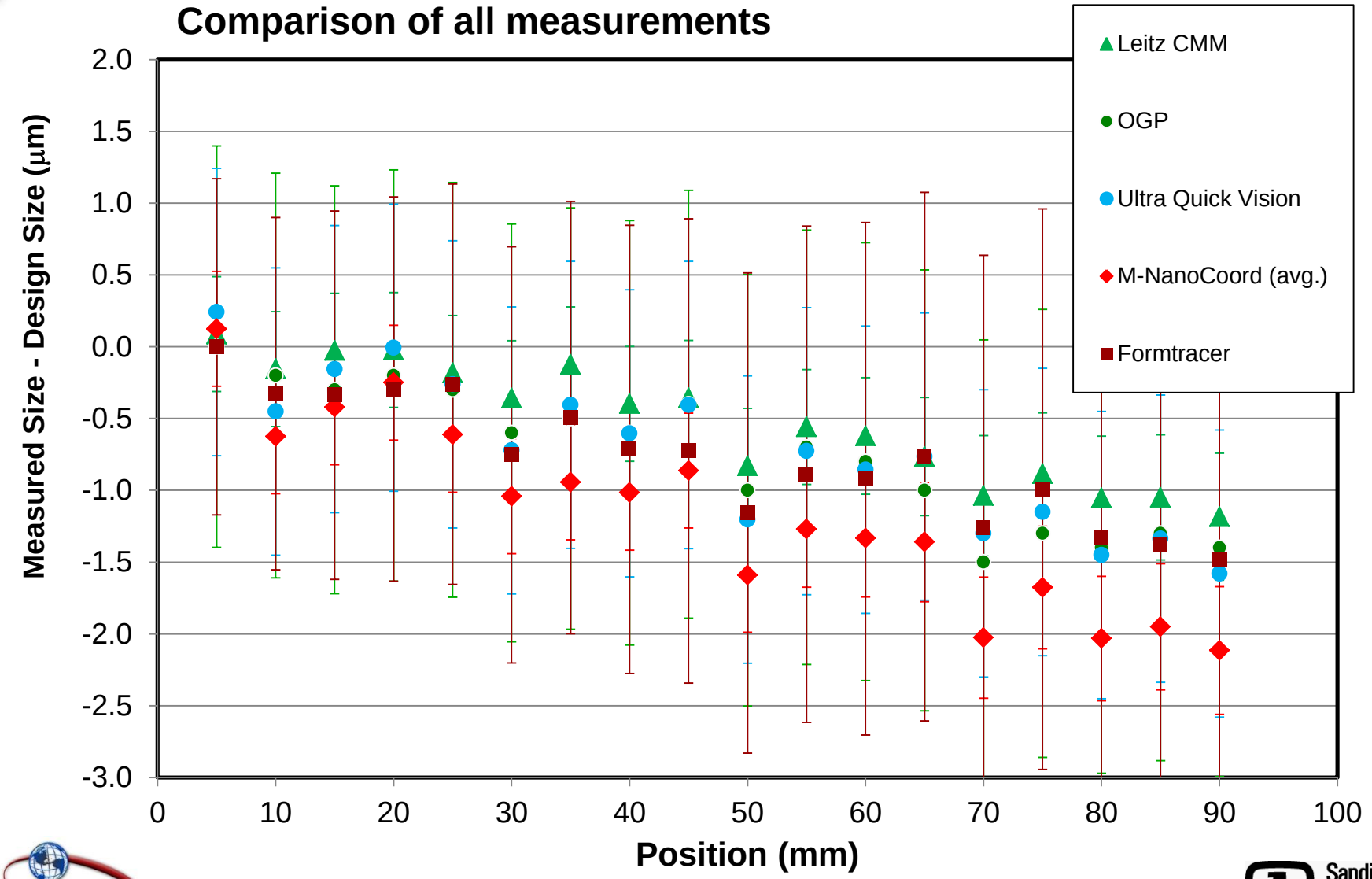


- Stylus used:
  - Number: 12AAD560
  - Stylus Tip Radius: 2µm
  - Stylus Tip Angle: 60°
  - Stylus Tip Material: Diamond
- Stylus Measuring Speed: 0.1 mm/sec
- Measurement Force of Stylus: 0.75 mN

Formtracer CS-3100 measurements



Intercomparison of all results



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Discussion & Conclusions

- Manufacturing process still needs improvement
- Monte Carlo simulations show that even with rough sidewalls, expected measurement uncertainty of silicon artifact still > 2x better than for chrome-on-glass grid plates
- Common mechanical edge/optical edge verified with M-Nanocoord measurements
- Light level change has little effect on pitch measurement (very good contrast and sharp lines)

Acknowledgments

- This research was funded by the Laboratory Directed Research & Development (LDRD) program at Sandia National Laboratories.
- Thanks for many technical contributions from: Todd Bauer, Margie Baca, Tony Bryce, Roger Burton, Andre Claudet, Ted Doiron, Orlando Espinosa, Harlan Gant, David Luck, Andy Oliver, Meghan Shilling, John Stoup, among others.

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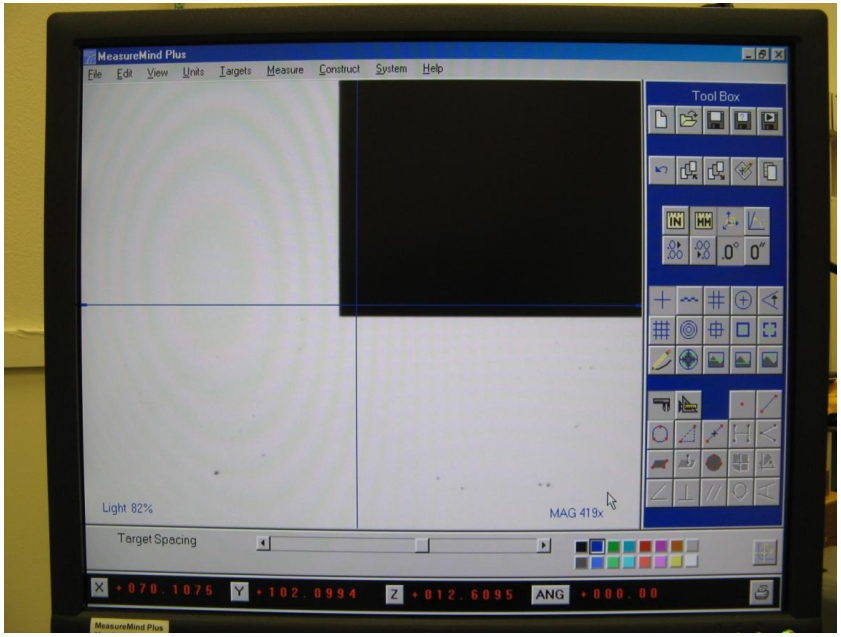
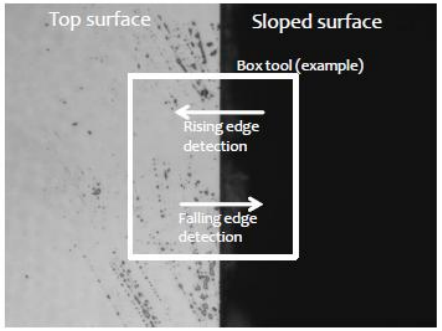
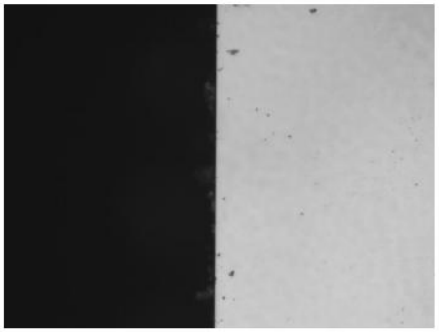
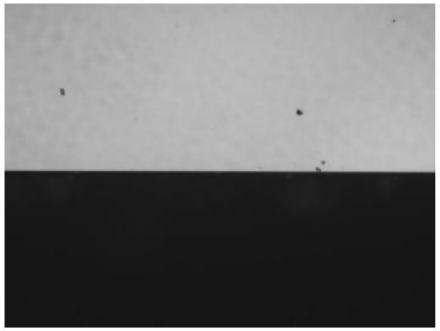
Backup slides

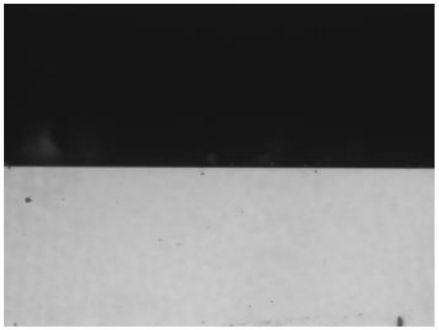
Effects of Roughness on Vision System











- **Edges are very well defined with very good contrast, in spite of roughness on sidewalls**

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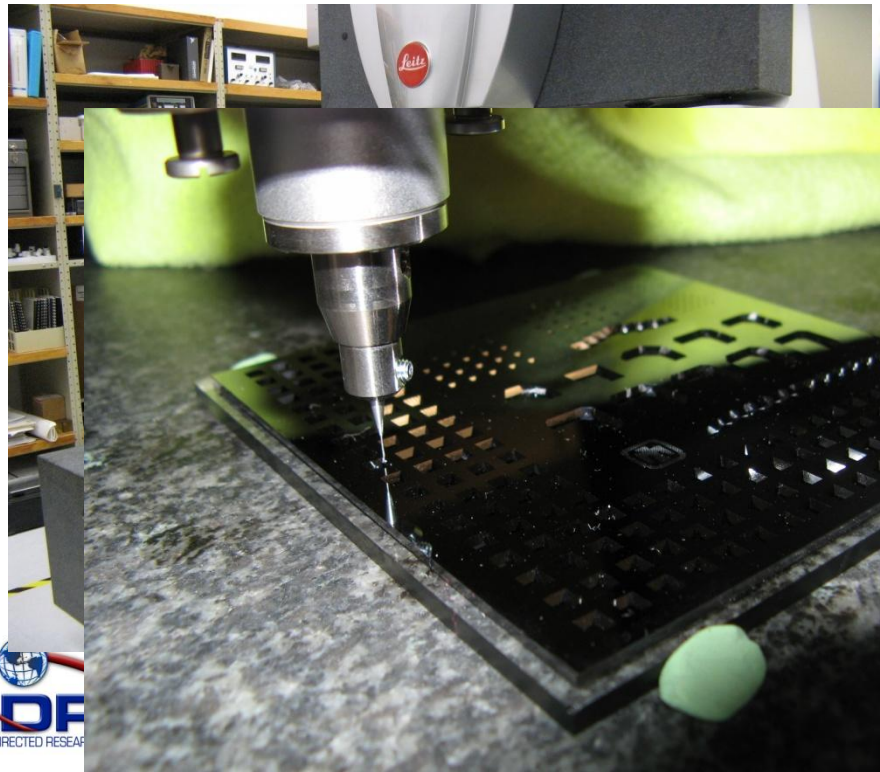
Initial CMM & optical CMM measurements

- CMM is Leitz PMM-C-Infinity 12.10.6
- MPE_e=(0.3+L/1000) μm

- OGP Smartscope APEX
- XY Accuracy

  (1.2 + 2L/1000) μm



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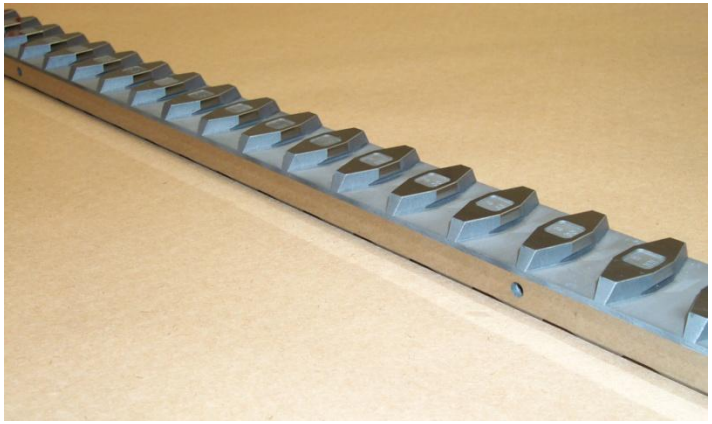
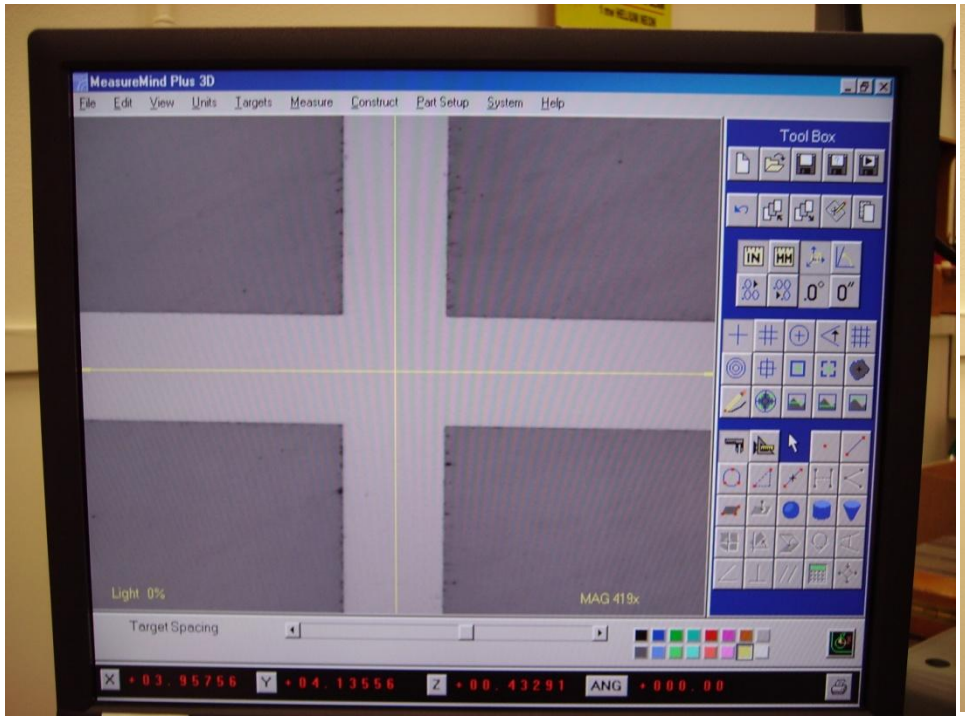
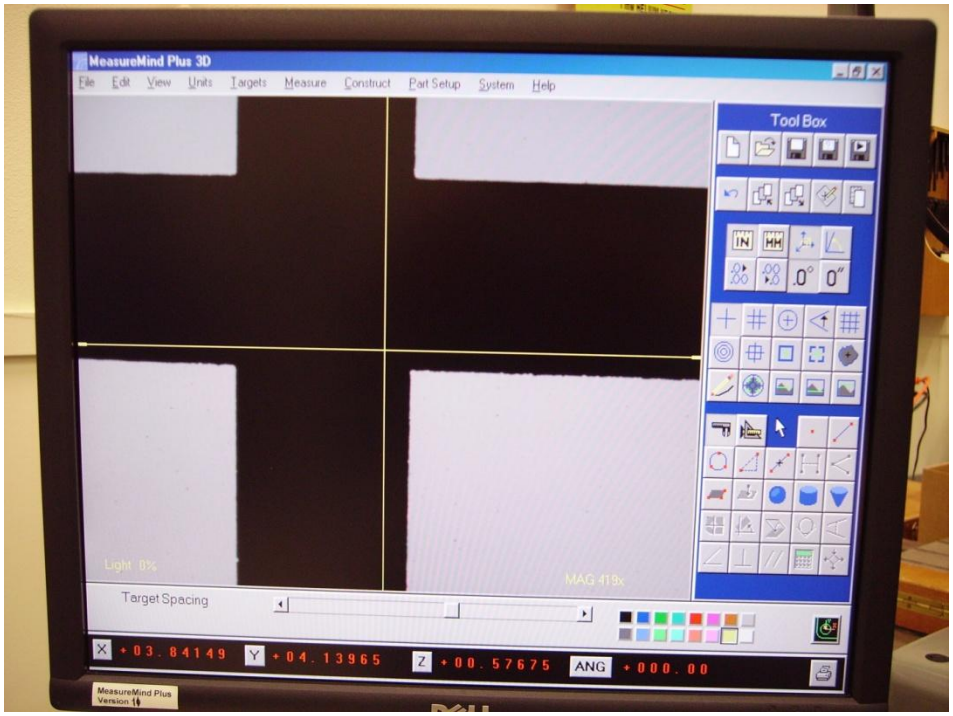
Design Ideas for Calibration Artifact

- Fabricate artifact which contains miniature versions of “macro” metrology
- Step gage
  - 1D performance evaluation, 2/3D with repositioning
- Ball plate
  - 2D performance evaluation, 3D with repositioning
- Other objects for investigation



Typical grid plates





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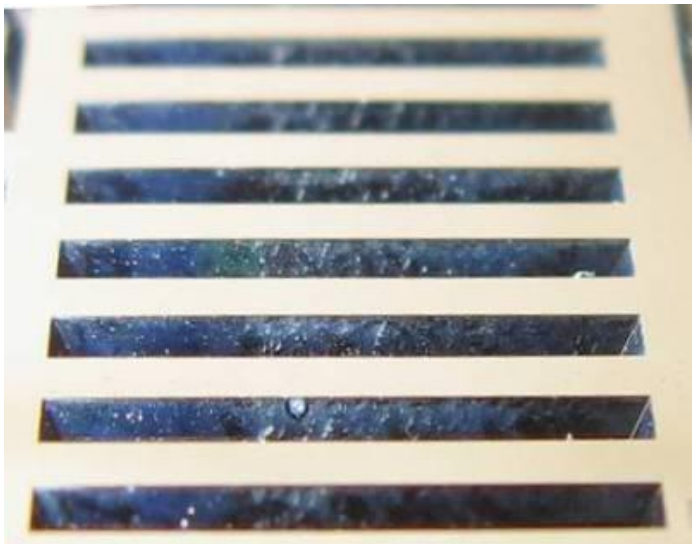
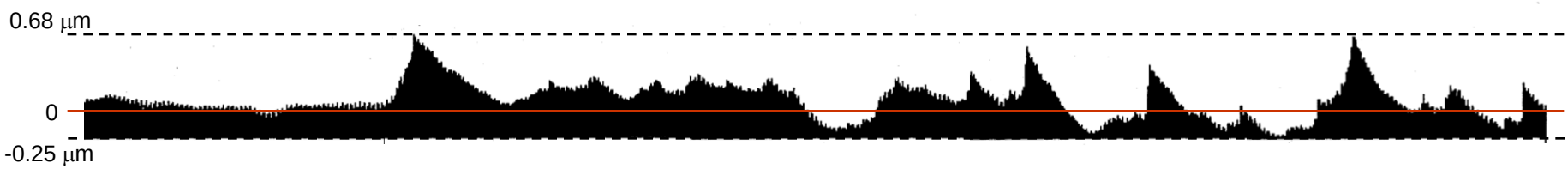
Manufacturing Issues

- Sidewalls are not smooth
- Appears that multiple crystal planes are being etched (misalignment?)
- Sidewalls may also be attacked by nitride removal process
- Effects of alternative removal processes studied





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Edge Measurement with UMAP

- Mitutoyo UMAP Ultra
- Contact measurements with probe
  - 30 μm diameter
  - 2 mm stylus length
- Accuracy

  (1.2 + 3L/1000) μm
- Repeatability

  s < 0.1 μm

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UMAP Edge Measurement