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Micro CMMs
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Define Micro CMM

- Small work volumes
  - Typically 100mm x 100mm x 100mm
- Fine positional accuracy
  - <300nm
- Low contact force
  - <1mN

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Commercial Options

- IBS
  - ISARA
- Mitutoyo
  - UMAP
  - Nanocord
- Zeiss
  - F25

- Non-commercial
  - Many academic and NMI level projects

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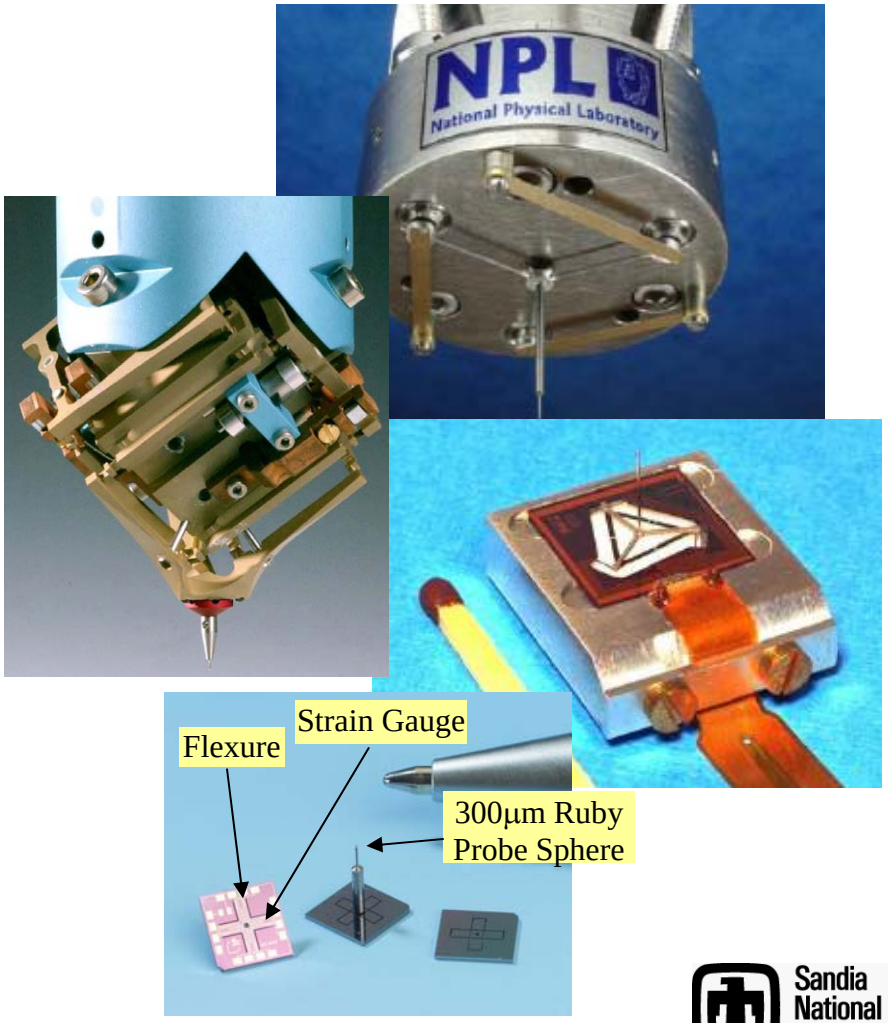
Contact Probing Technology

- **MEMS Based**
- **Flexure / Capacitance**

- **Force gauges**



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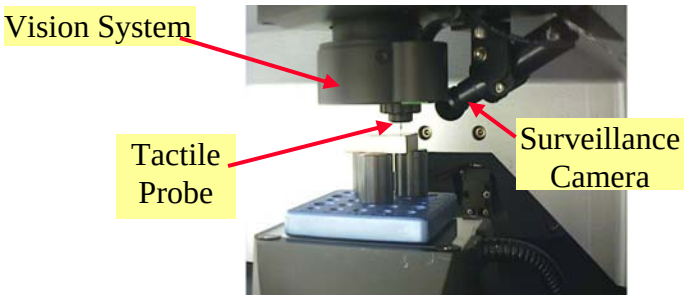
Vision Probes

- **Most systems have both tactile and vision probing options**
- **Increases calibration complexity**
- **Registration of coordinate frames**



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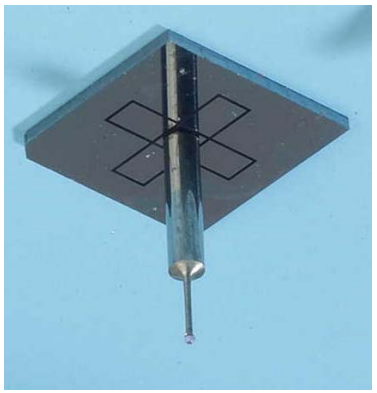
Probe Access

- **Probe access is limited**
- **Gauging point (B89) on a gauge block inaccessible**
- **X-Z and Y-Z angles can be challenging**



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Calibration Concerns

- **Users should at least establish a verification procedure**
- **Optimally, users should be able to calibrate their own equipment**
- **Keep the tests simple (*e.g.*, gauge blocks)**
  - **Wringing skill**

Operator Finesse

- Checklists
- Change in attitude
  - Much more technical
  - “Virtual” operation
- Cleaning
- Heat transfer
- Everything matters

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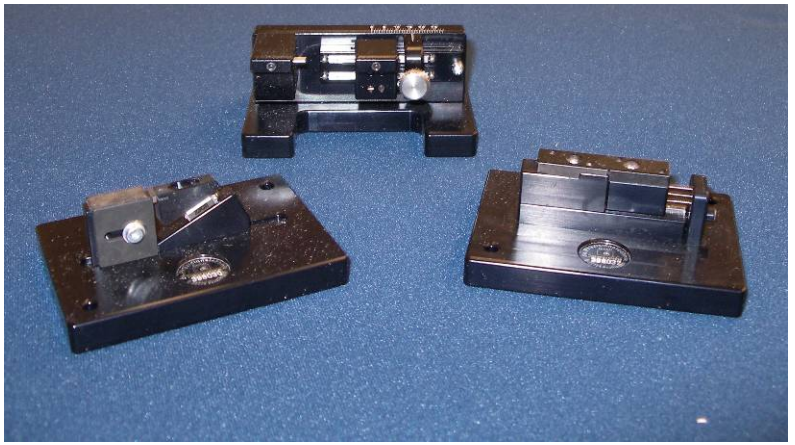
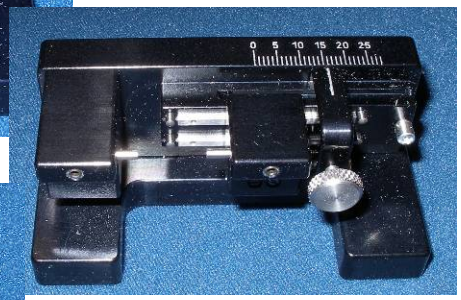
Fixturing

- Low contact forces
- No fixturing required?
- Best practice is to fixture parts
- Fixturing Options
  - Clay – No!
  - Clamps
  - Magnets
  - Cyanoacrylate
    - Low and High Viscosity
  - Hot glue
    - Thermals





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Important considerations for micro-CMMs

- High purity cleaners
  - Spectroscopic grade IPA
  - Spectroscopic grade Acetone
    - Caution
- No canned/compressed air
  - High force
  - Cools parts
- Mechanical cleaning of probes may be done with extreme care
- Characterization of probe
  - Full: Once per installation
  - Fine tune: Daily

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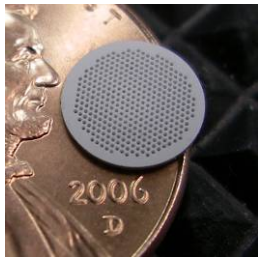
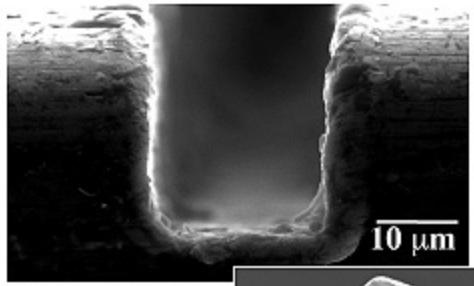
Sandia's Experience

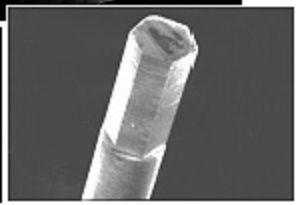
- **Sandia designs and manufactures a range of meso-scale components**

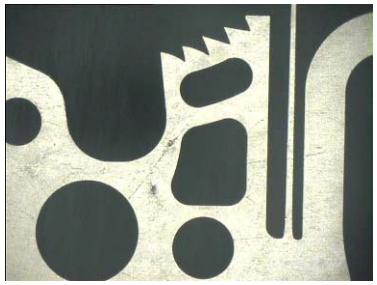




A 25-µm end mill tool (right), with five cutting edges, was fabricated using focused ion beam machining.

The end mill was used to make this 25-µm deep channel (above) in aluminum.





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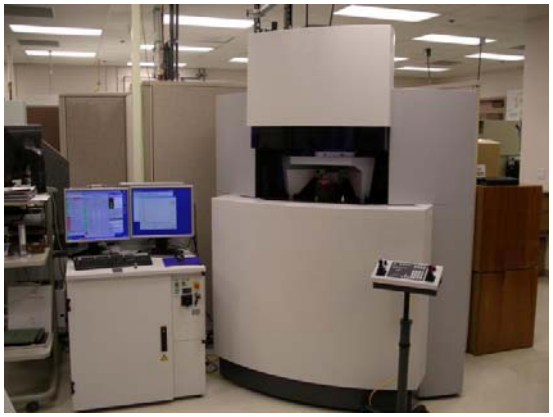
SNL has acquired a micro-CMM.

- **Meso-scale manufacturing and system development area**
  - **10^{1}mm in size**
  - **10^{-1}mm features**
  - **10^{-3}mm tolerances**
- **MPE_E of (0.250+L/666)μm**
- **0.5mN probing force**
- **100mm x 100mm x 100mm work volume**
- **Tactile and vision probes**
- **Surveillance camera for operation**



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Precision design principles support accuracy claims by vendor

- Dual bridge design minimizes Abbe offsets
- Air bearing design modifications increases stiffness
  - >40 air bearings
- Vibration isolation
- Thermal shielding
- Glass scales
- Linear motors
  - Heat generation proportional to load

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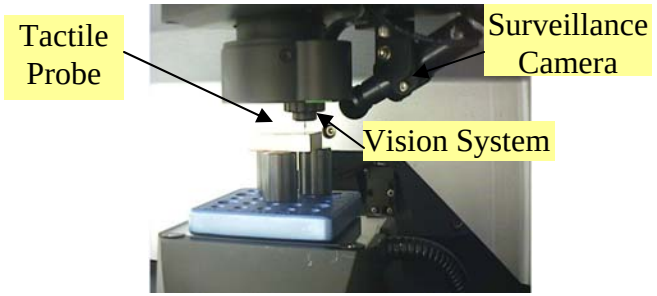
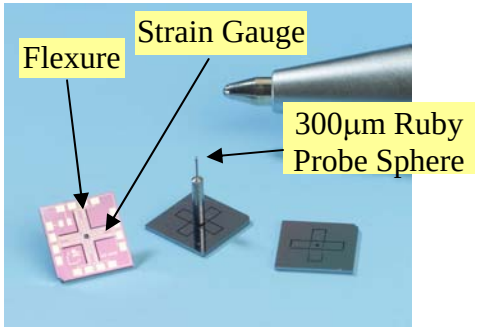
Silicon flexure tactile probe applies low contact force, ~0.5mN

- 120μm and 300μm diameter probes readily available
- Flexure + strain gauge sensing technology
  - Analog nature enables scanning
- Force-deflection response linearized during special calibration
- Max deflection is ~100μm





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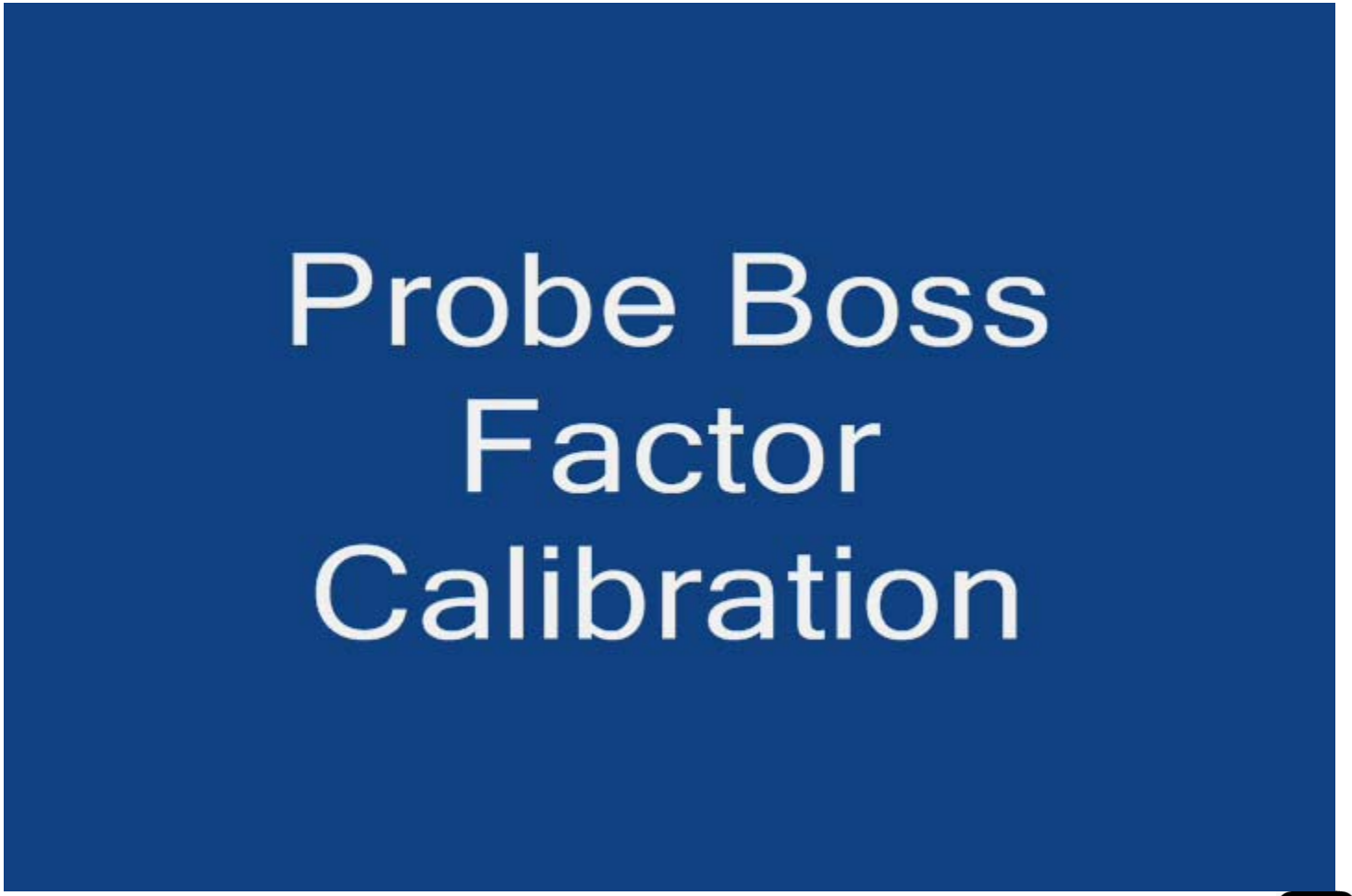
Force-Deflection Linearization Video



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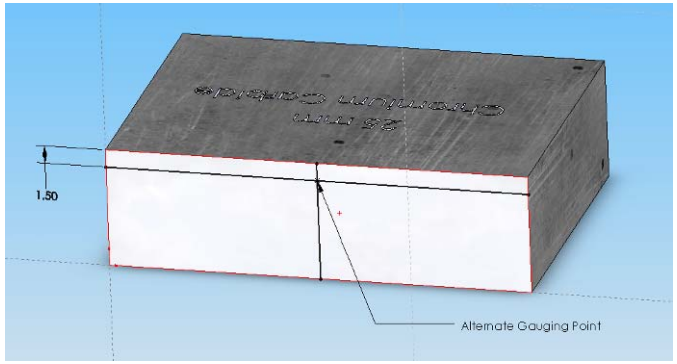
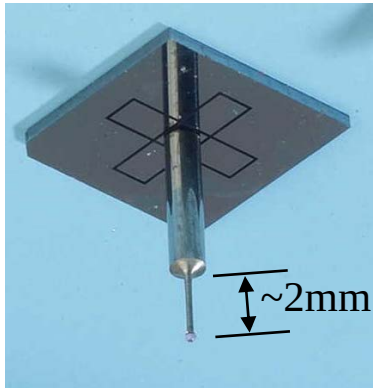
Evaluation requires special calibration of gauge blocks

- Shank length is approximately 2mm
  - 300μm sphere / 200μm shaft
  - 120μm sphere / 50μm shaft
- Unable to reach standard gauging point
- Alternate gauging point as shown (1.5mm down)
- Certification by SNL primary standards laboratory on gauge block interferometer





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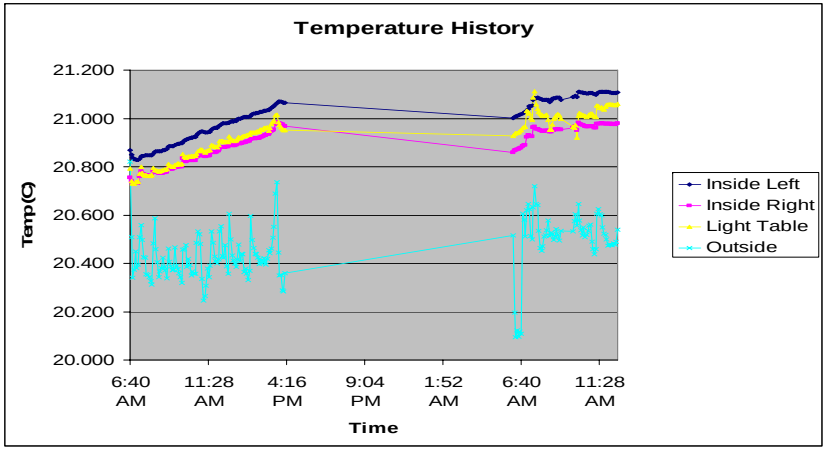
Temperature and cleanliness are important at these levels

- Temperature
  - Absolute and gradient restrictions
  - Manual thermal compensation for this study
  - Minimize handling
- Cleaning
  - Spectroscopic grade IPA and acetone
  - Probe is delicate



Probe Cleaning

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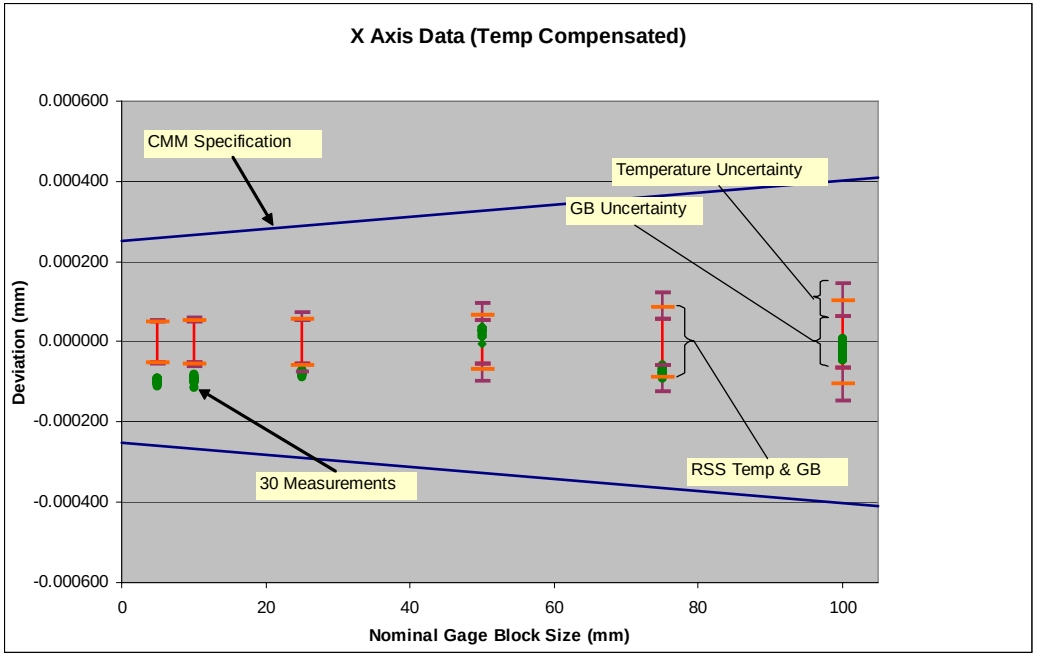
X-Axis Results

- **Excellent repeatability**
- **Well within specification**



Temperature compensated x-axis results.

	5mm	10mm	25mm	50mm	75mm	100mm
Range	21 nm	32	16	45	32	54
Average	-98 nm	-93	-77	25	-74	-17
Std. Dev.	5 nm	6	4	10	7	16
F25 Spec +/-	258 nm	265	288	325	363	400

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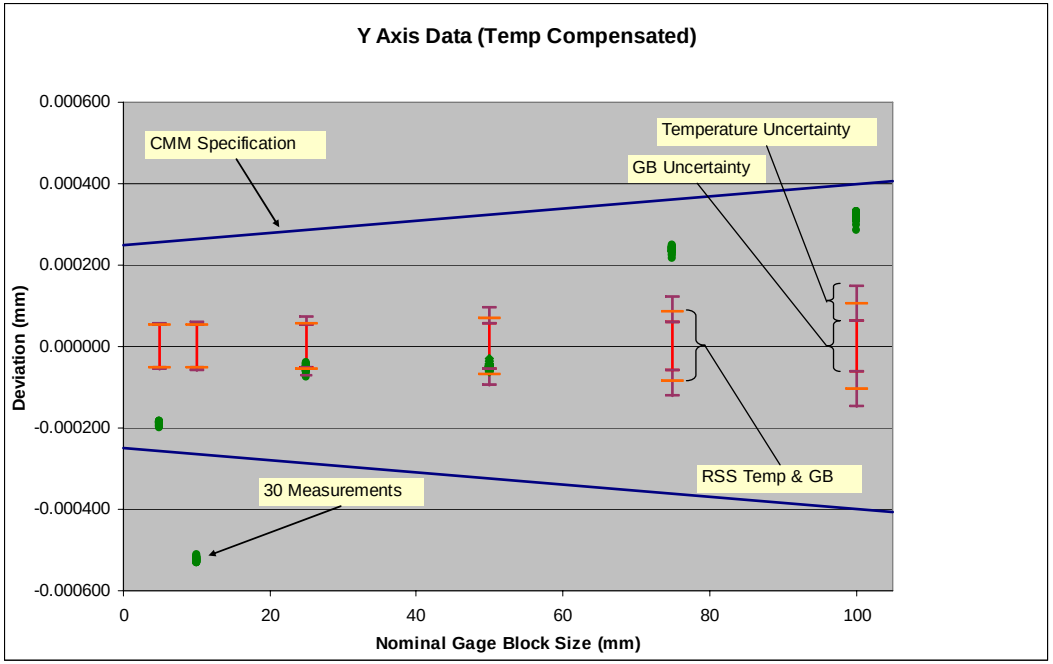
Y-Axis Results

- **Excellent repeatability**
- **One set of outliers**
  - **Dust?**
  - **Not supported by other measurements**
- **Balance within specification**



Temperature Compensated Y-Axis Results.

	5mm	10mm	25mm	50mm	75mm	100mm
Range	17 nm	22	37	33	35	49
Average	191 nm	***-524***	-54	-49	237	320
Std. Dev.	5 nm	5	8	7	7	11
F25 Spec +/-	258 nm	265	288	325	363	400

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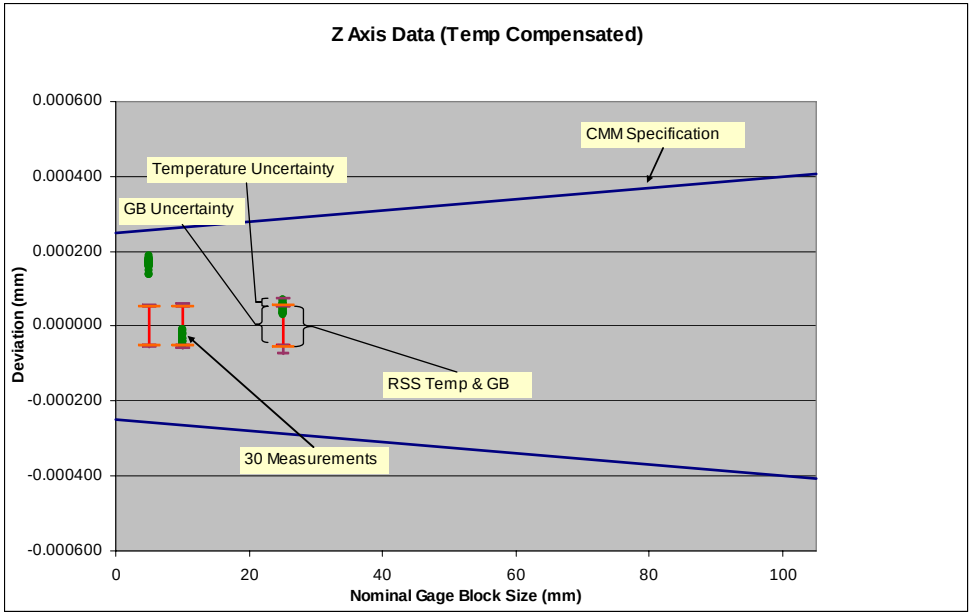
Z-Axis Results

- **Mechanical constraints reduce gauge block set**
- **Sample repeatability as x- and y-axes**
- **Within specification**



Temperature compensated z-axis data.

	5mm	10mm	25mm	50mm	75mm	100mm
Range	50 nm	45	41	NA	NA	NA
Average	168 nm	-31	49	NA	NA	NA
Std. Dev.	11 nm	12	12	NA	NA	NA
F25 Spec +/-	258 nm	265	288	325	363	400

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Squareness Results

- **75mm gauge block in x-y plane**
- **0.675 arcsec out-of square**

Squareness data.

	75mm (+X,+Y)	**75mm (-X,+Y)**
Range	21 nm	63
Average	-205 nm	286
Std. Dev.	5 nm	14

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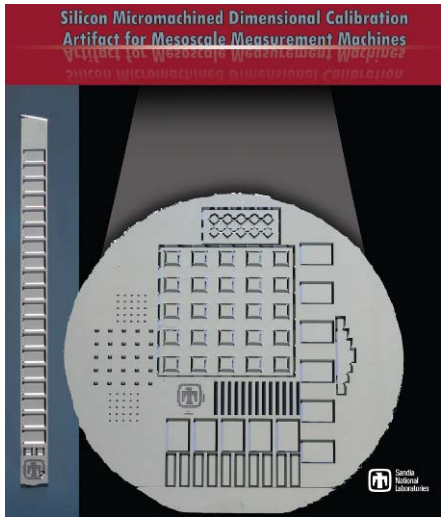
Advanced Calibration and Tactile/Vision Registration

- R&D effort to improve calibration
- Silicon bulk micromachining
- Take advantage of crystal structure intrinsic properties
- 2008 R&D 100 Award Winner



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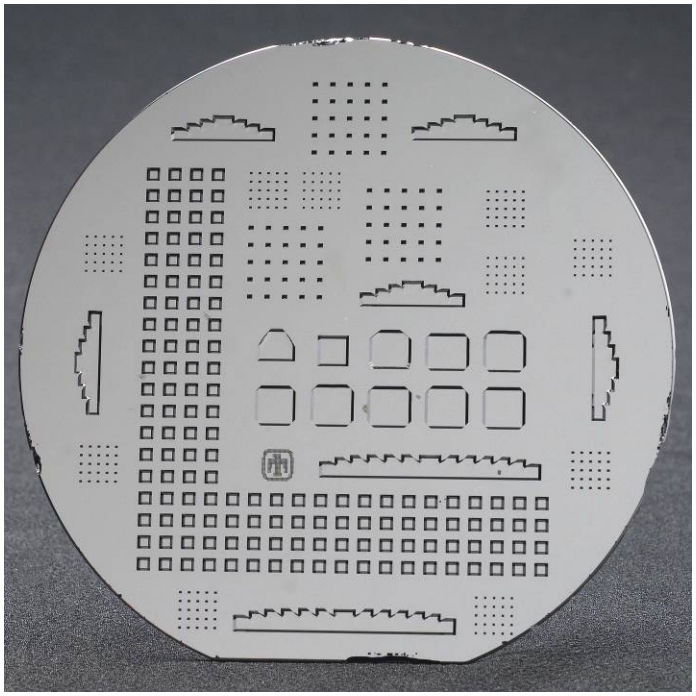
Design Details

- Bulk-etched Si
  - <100>, gives sidewalls 54.74 degrees from horizontal
  - 1.5 mm thick wafer, polished on both sides
  - KOH etchant
- Geometric Features
  - “step gages”
  - “ball plates”
  - Additional shapes



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Final Points

- Jump from traditional to micro CMMs larger than expected
- Probes are expensive
- Opportunity to train a new operator
- Clean, clean, clean
- Checklists
- Video capture for surveillance camera
  - Additional surveillance cameras

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Discussion

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