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Silicon Micromachined Artifact for Hybrid Dimensional Measurement

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Research Objective

- Mesoscale metrology commonly uses video probing
- Accuracy of video systems are typically limited by calibration artifact, not resolution
  - Calibration artifact accuracy ~1μm
  - System resolution ~0.1μm

Objective: To create a calibration artifact for a video-based measurement system which can be certified to better than 0.1μm accuracy.

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Outline

- Introduction
- Artifact Design
  - Micromachining
  - Design Details
- Fabrication
- Certification
  - Equipment
  - Uncertainty analysis
- Implementation

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Introduction

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Design Requirements

- Need artifact with dimensional features
  - Length calibration requires distance measurements
- Location of features known to sub-μm accuracy
  - By intrinsic characteristics
  - By measurement with high-accuracy system
- Measurement area of at least 100 mm

Manufacturing Options

- LIGA
  - Lithography, electroforming, and molding
  - Produces orthogonal sidewalls, good surface finish
  - Sidewalls not necessarily parallel to each other
- Bulk Silicon Micromachining
  - Anisotropically etched (400:1 ratio)
  - Produces smooth etch planes at intrinsic angles
    - Angles repeatable throughout wafer
  - Good mechanical properties

Certification

- Intrinsic lengths not created by silicon bulk micromachining
- Must certify artifact on high-accuracy measurement system
  - Coordinate Measurement Machine (CMM)
  - 10 nm resolution, 100 nm accuracy achievable
- Features must be measurable on both CMM and vision system

Artifact Design and Fabrication

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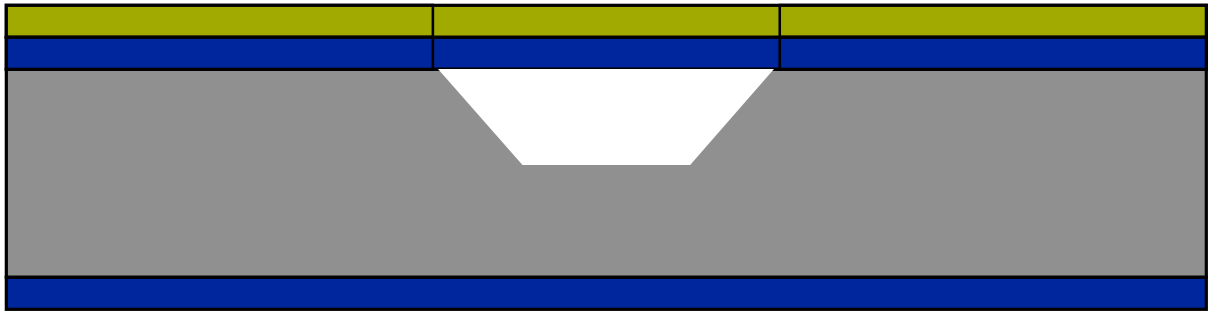
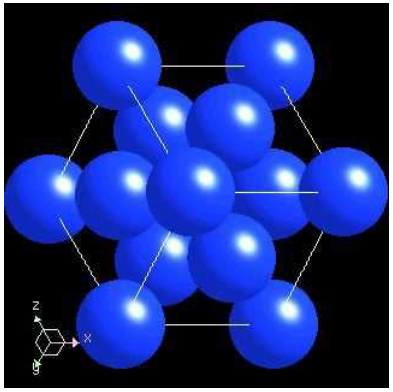
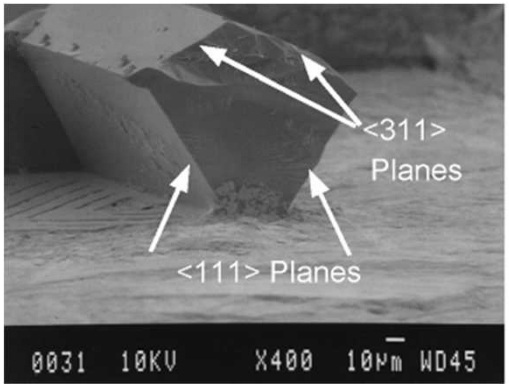
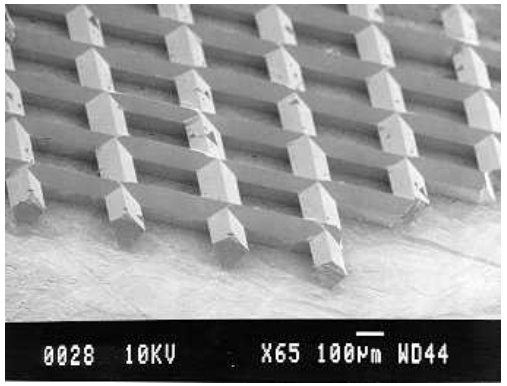
Si Bulk Micromachining









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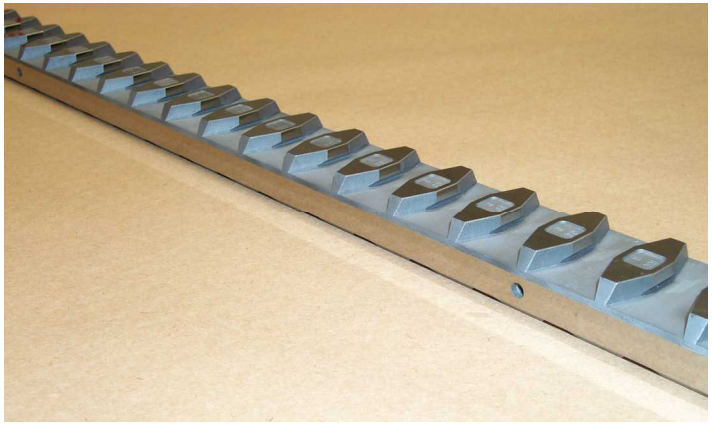
Manufacturing Design Details

- <100> silicon with KOH etchant
  - Gives sidewalls at 54.74 degrees
  - Yields etch planes flat to 50 nm
  - Edges are sharp and straight to nm level
  - Bottom of trenches not perfectly flat
- 1.5 mm thick wafer, polished on both sides
  - Flat to 50-70 nm over 20-30 mm
  - Etch depth can be varied

Geometric Design

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



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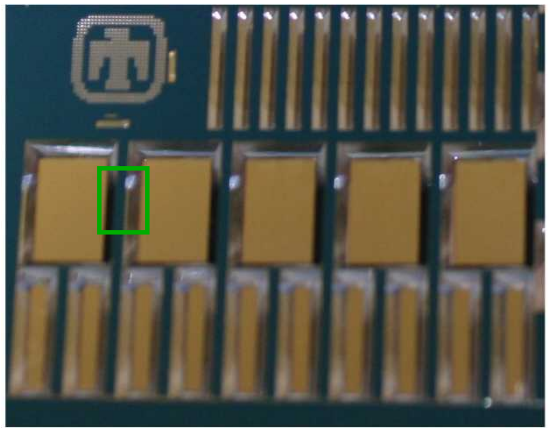
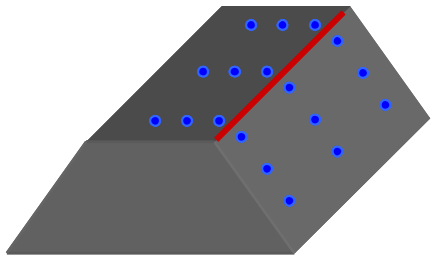
Geometric Design Details: Step Bar

- 4 “Step Bars”
- Various pitches (2 to 12 mm)
- Various widths (1 to 7 mm)

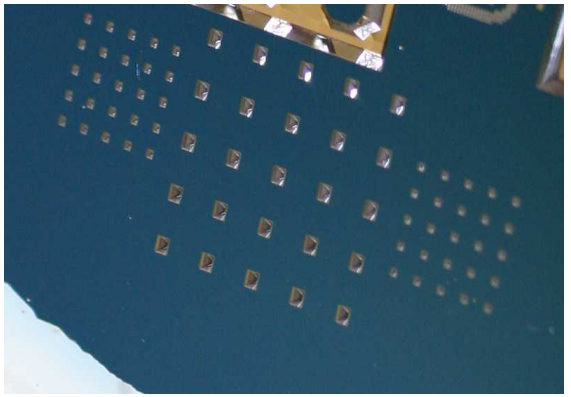


- Vision system will locate edge formed by intersection of top and etch planes
- CMM will probe top and etch planes and calculate intersection line

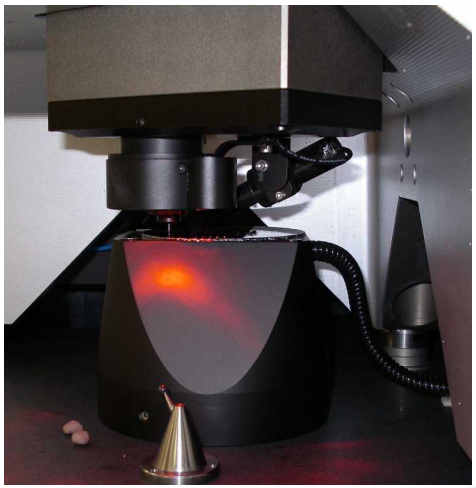


Geometric Design Details: Ball Plates

- 3 Ball plates
  - 5 x 5 grids
  - 1 mm or 0.5 mm balls
- Rectangular design for kinematic mounting



- For 3D performance evaluation
- Can be used with micro-CMM (Zeiss F25)



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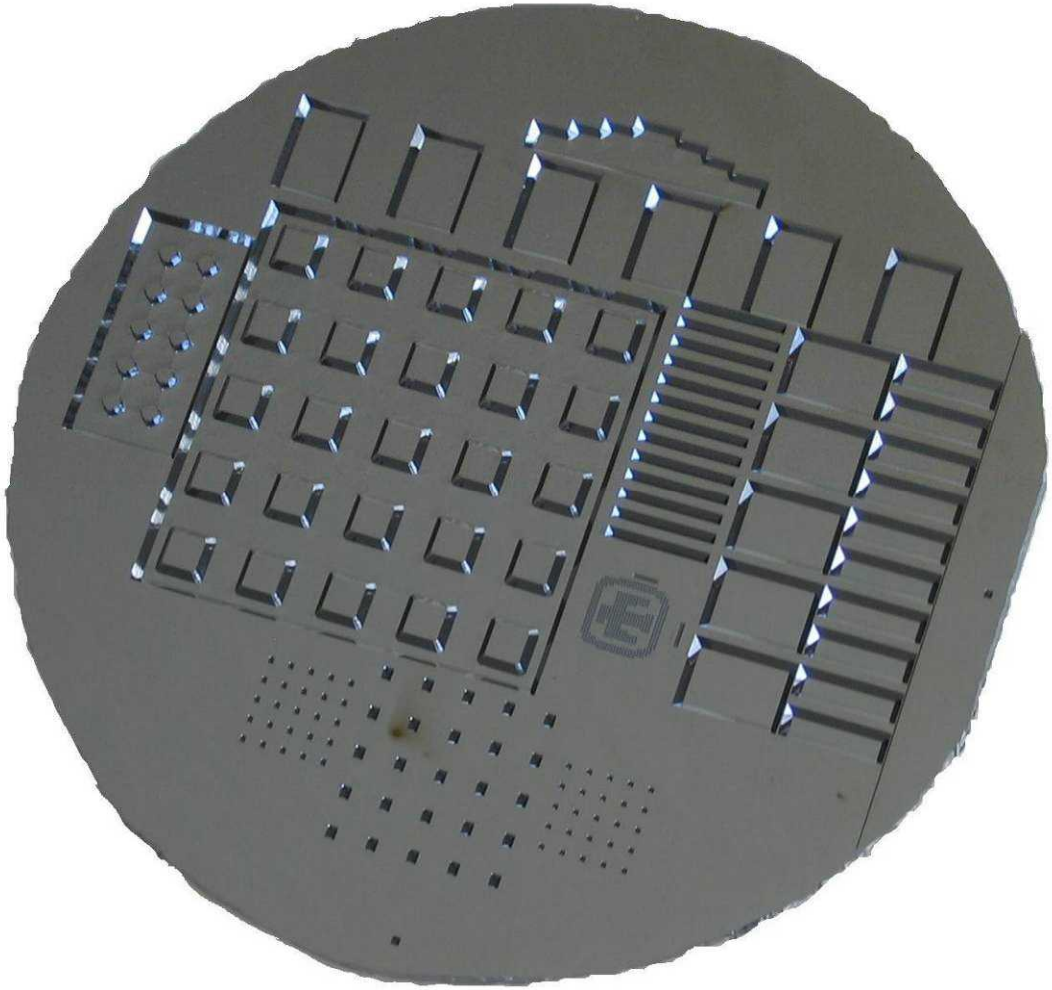
Fabrication Details

- 1.5 mm single crystal Si wafers are purchased with thin silicon nitride layer
- Silicon nitride layer is patterned with mask and selectively etched
- Wafer is etched in 6M 85^{o} KOH solution to depth of 1.0 - 1.3 mm
- Silicon nitride layer is removed

Artifact



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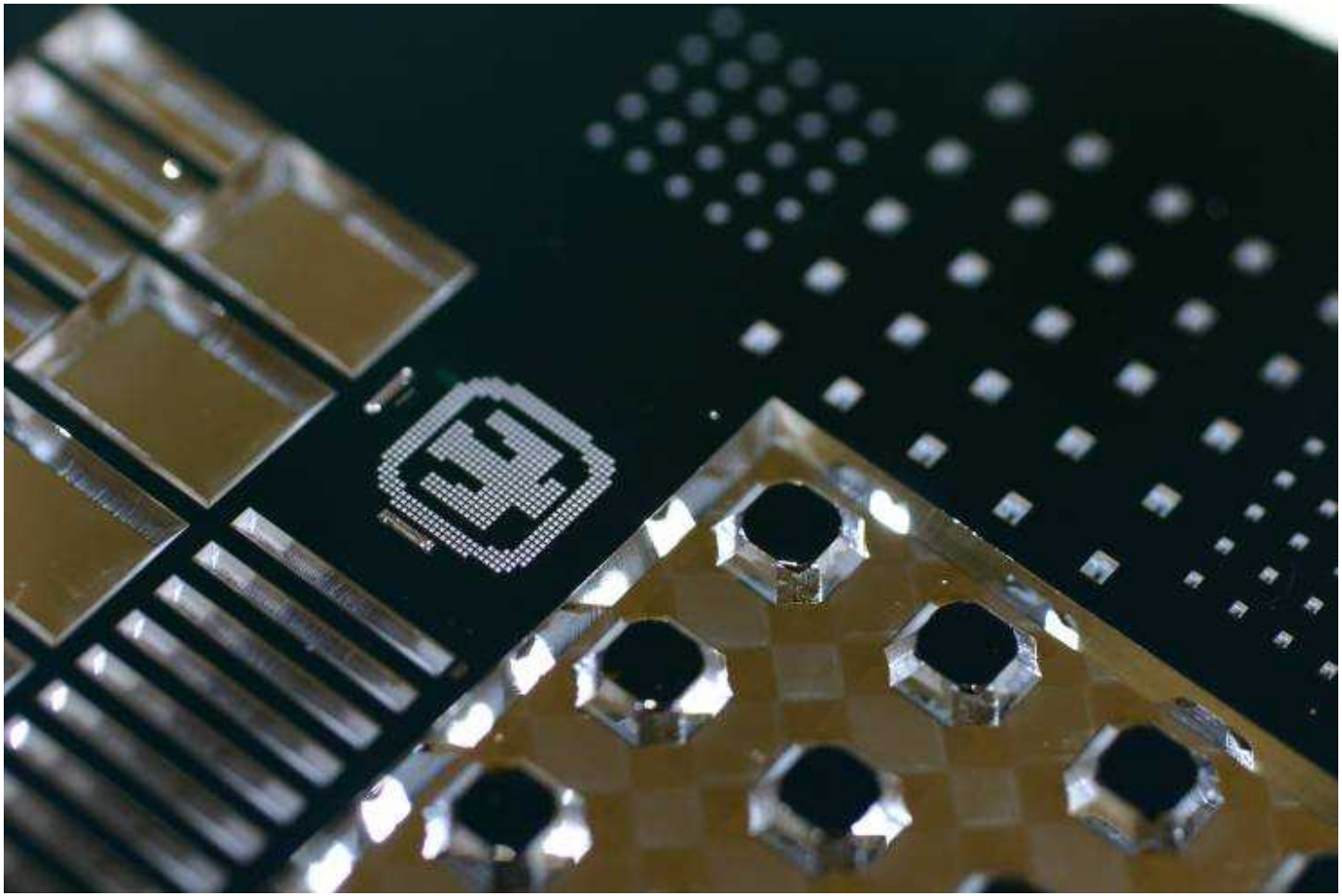
Artifact



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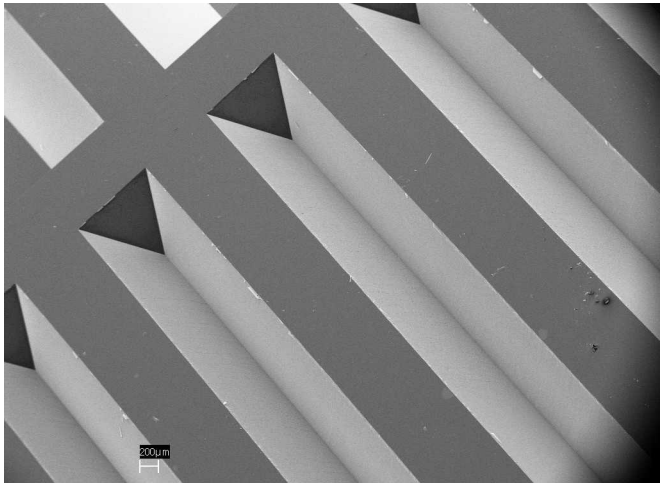
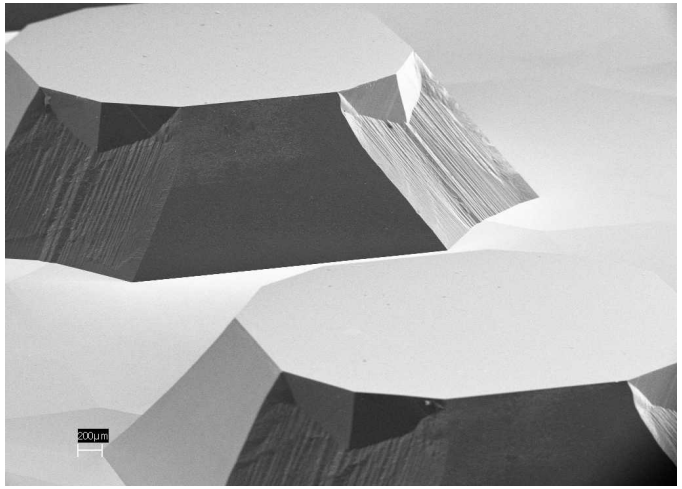
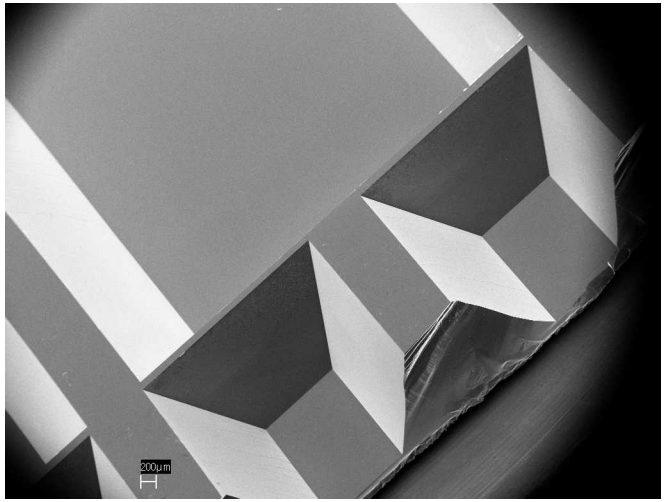
Artifact







Certification

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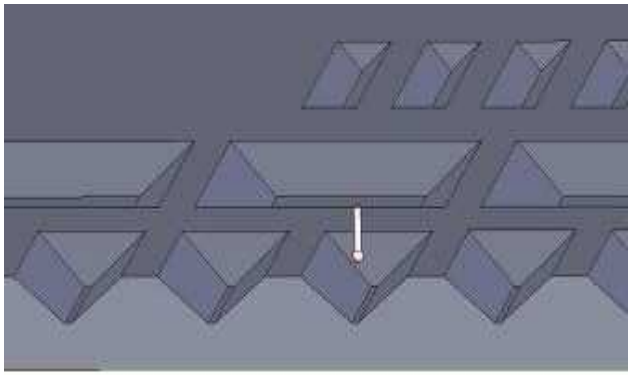
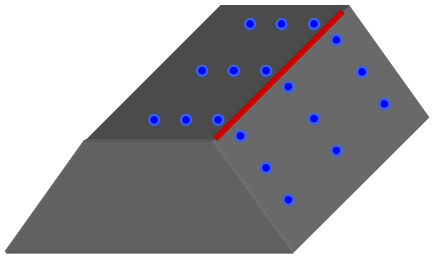
Certification Plan

- Vision system can image points the edges
  - Line extracted from points
- Need to certify line location
- CMM probes two intersecting planes
  - Line extracted from intersection
  - Uncertainty of line location is important



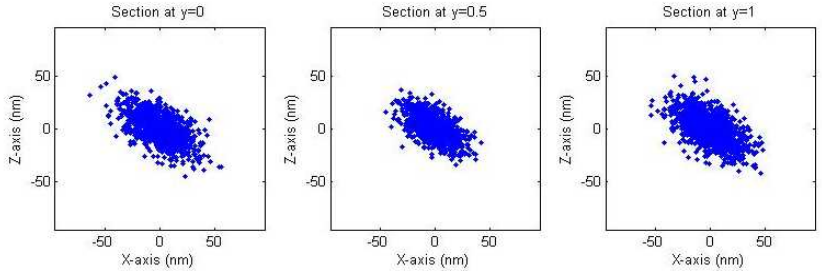


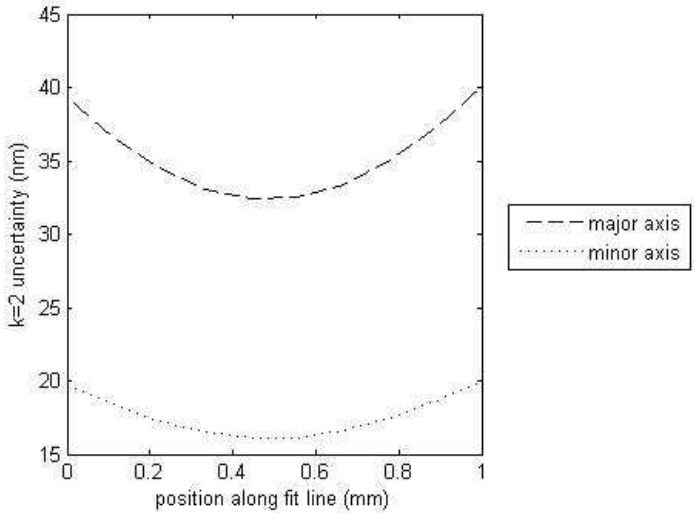
Line Uncertainty Analysis

- Conventional method is to use GUM
- GUM exceedingly complex for the calculations involved
- Monte Carlo analysis offers an alternative
  - Need understanding of input probability density functions (PDF) and system model
  - Run many times with inputs according to PDFs
  - Estimate uncertainty based on spread of output values

Intersection Line Uncertainty

- Input uncertainty
  - Touch probe
  - Surface imperfections (roughness and planarity)
- Line uncertainty estimate
  - Elliptical shape
  - Varies along intersection line
- Major Axis - 33 to 40 nm
- Minor Axis - 16 to 20 nm





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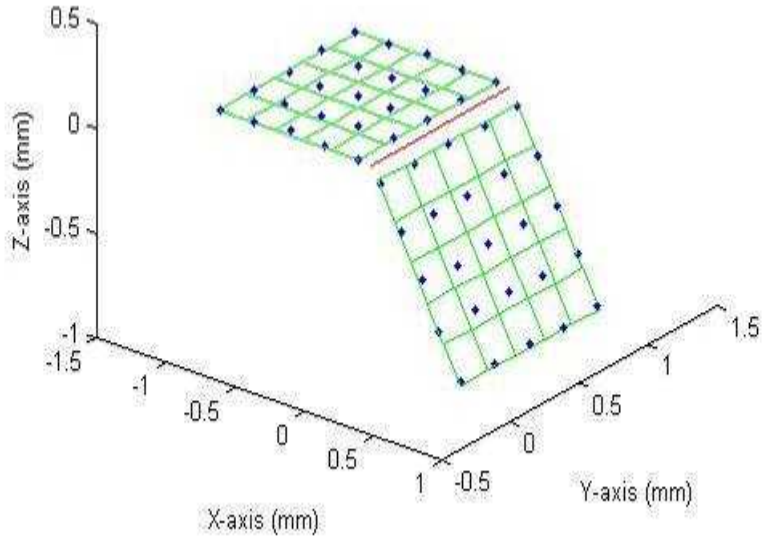
Uncertainty of line locations

- Intersection of etched and top plane is critical
  - Touch-probe calculates line based on points from both planes
  - OGP measures directly
- Use Monte-Carlo to estimate uncertainty of intersection line from CMM measurements
- Line uncertainty estimate
  - Elliptical shape
  - Varies along intersection line (k=2, less than 50nm)



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Implementation

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Implementation Details

- Measure artifact using CMM to certify geometry
  - Moore M48 CMM
    - 0.01 μm resolution
    - 0.1 μm accuracy (1 to 2-D, depending on machine, range of motion, & map)
- Measure artifact using vision system
  - OGP
    - 0.1 μm resolution or better
    - ~1 μm accuracy
- Compare measurements in order to error map the vision system
- Apply error map to vision system to improve accuracy

Measurement Details

- Artifact will be permanently mounted
  - Needed to fixture on CMM
  - Retains consistent geometry between CMM and vision system
- Vision system will operate with coaxial lighting
  - Clear transition from top surface to etch plane is critical
  - Tests show 10x increase in reflected light from etched plane to top surface

2-D mapping of an OGP

- Use a 25pt grid square
- Enter maps into OGP
- OGP maps stage errors in its software
- OGP software does not generate the uncertainty statement or the MPE_{xy}.
- We then evaluate the system uncertainty based on either ANSI B89.4.18 (draft) or ISO10360:7 (draft)

Future Work

1. Design family of micromachinable artifacts; obtain Si substrates
2. Fabricate artifacts (1st round)
3. Measure using M48 CMM; evaluate on production equipment in 2-D
4. Assess results; 3-D artifact development
5. Fabricate 3-D artifacts; evaluate on M48
6. Evaluate on production equipment in 2D; improve production calibration
7. Evaluate 3-D results for artifacts
8. Assess results; Final report

Extra Slides

Results to date

- We investigated possibly generating an intrinsic length standard
- We decided on silicon bulk micromachining of the calibration artifact(s); and using a high accuracy machine (Moore CMM) to establish artifact geometry for optical gage calibration
- We have designed and built the first set of artifacts
- We have submitted two conference papers & one TA
- We have talked with KCP & LLNL; they both would like to evaluate our calibration artifact & method for their optical dimensional measurements
- Org 02455 is getting a Zeiss F-25 microCMM; our work complements the F-25's combined vision/contact probing