The Second Tri-National Workshop on Standards for Nanotechnology - February 6, 2008

NanoElectroMechanical Devices and Metrology

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Outline

- Dimensional Metrology for MicroNanoTechnology (MNT)
- Materials Standards
- Wafer Bond Standards
- Force Measurement (Stiction)
  - NIST-On-A-Chip

Dimensional Metrology for MNT

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Dimensional Metrology for MNT

- Issues:
  - Three-dimensional structures
    - No single metrology tool which can characterize such structures fully
  - Measuring trench dimensions in NanoFluidics devices
- Ongoing work on Critical Dimension (CD) standards
  - RM 8111 for nanoelectronics

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RM 8111 - Fabrication

- Vertical sidewall structures
- Fabricated on (110) SIMOX wafers (silicon wafers with electrically isolated device layer via implanted, buried oxide)
  - SiO2 hard mask
  - Features aligned to <112> lattice directions
  - Etching using anisotropic etch to create features with sidewalls defined by (111) lattice plane
    - TMAH
    - KOH

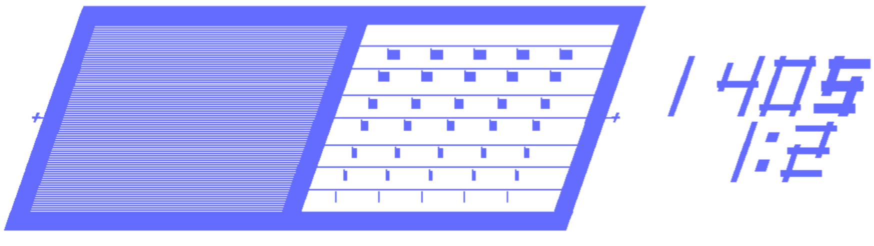
RM 8111 - Calibration Structure

Line	Design Width
1	n nm
2	$n + 30$ nm
3	$n + 60$ nm
4	$n + 90$ nm
5	$n + 120$ nm
6	$n + 150$ nm

Calibration tools:
- Cross-Section HRTEM
- AFM (boot tip)

R. G. Dixson, R. A. Allen, W. F. Guthrie, and M. W. Cresswell, "Traceable Calibration of Critical-Dimension Atomic Force Microscope Linewidth Measurements with Nanometer Uncertainty" J. Vac. Sci. Technol. B Vol. 23, 3028-3032 (2005).

RM 8111 - Scatterometry



Dense Features   Isolated Features

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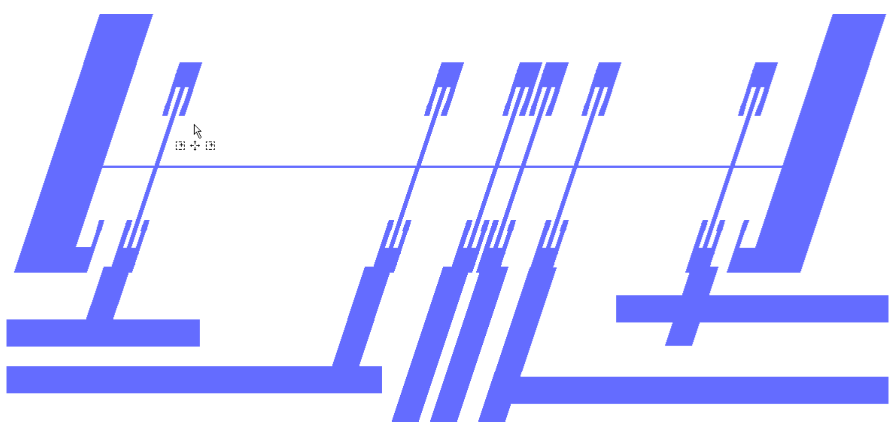
RM 8111 - Electrical CD Structure



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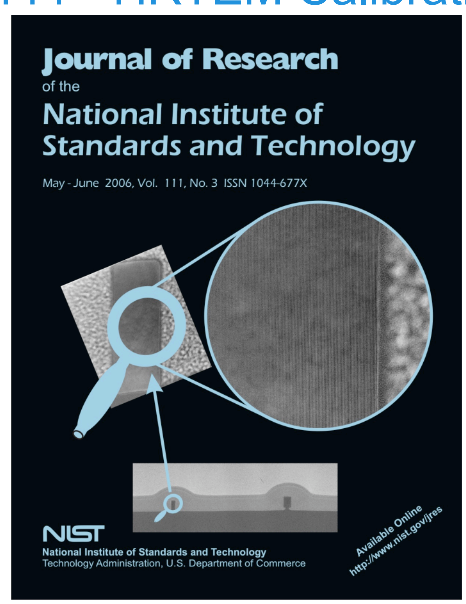
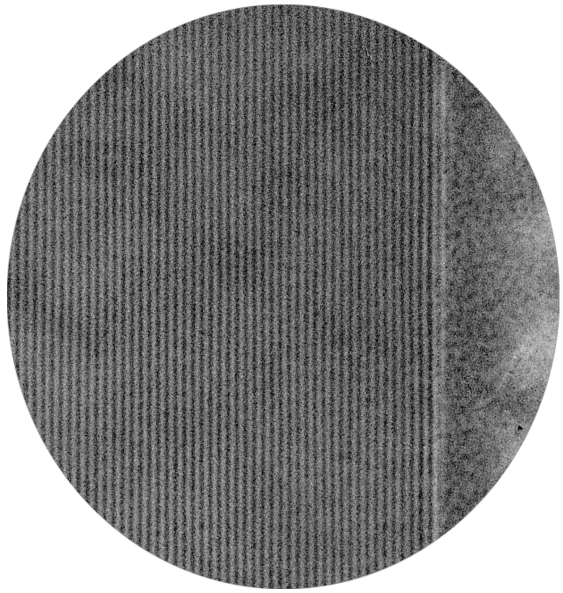
RM 8111 - Application

- Calibration tools
  - AFM
  - HRTEM
  - (optional) Electrical
  - (optional) Scatterometry
- Applications
  - AFM Calibration
  - CD SEM evaluation
  - Optical Critical Dimension tool evaluation
  - Electrical characterization
  - Mechanical strength

RM 8111 - HRTEM Calibration



RM 8111 - HRTEM Calibration



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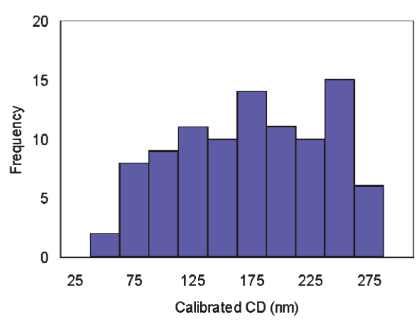
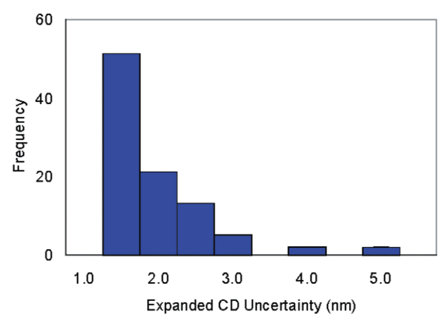
RM 8111 - Calibration Results





R. G. Dixson, R. A. Allen, W. F. Guthrie, and M. W. Cresswell,
"Traceable Calibration of Critical-Dimension Atomic Force Microscope Linewidth Measurements with Nanometer Uncertainty"
J. Vac. Sci. Technol. B Vol. 23, 3028-3032 (2005).

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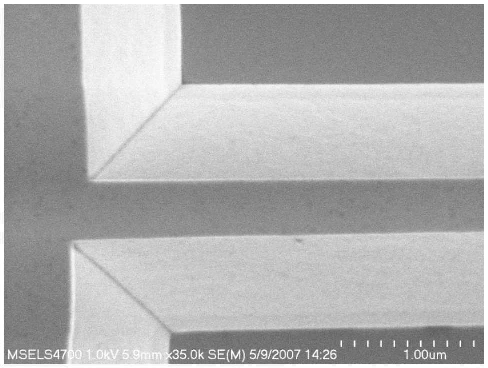
CD Structures with Non-Vertical Sidewalls



SEM View of (100) Silicon Line

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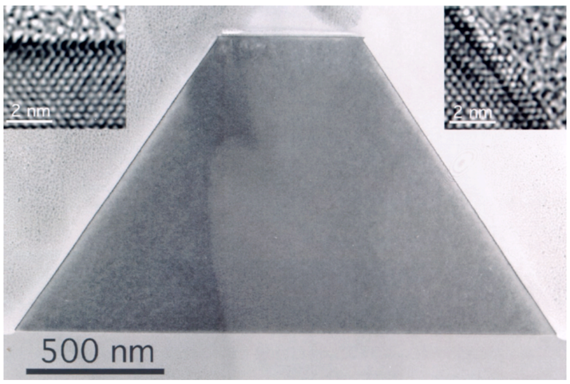
(100) Silicon HRTEM Lattice-Based Calibration



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Materials Metrology

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Materials Metrology

- Strength of Silicon nanowires
- Current MNT Standards
  - Materials properties
  - Wafer bond strength

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Characterization of Silicon Nanowires

- Silicon Nanowire arrays similar to scatterometer structures on RM 8111
  - E-beam lithography to provide uniform, narrow widths and spaces
- Nanoindentation tests of nanowire arrays to test for mechanical properties
  - Deformation
  - Fracture

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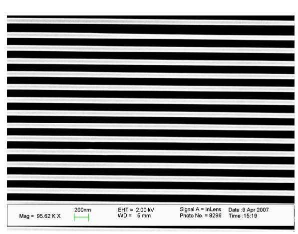
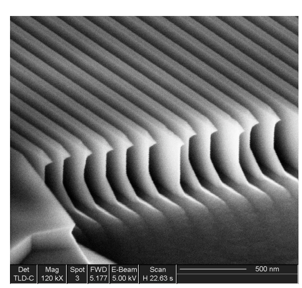
Arrays of Silicon Nanowires





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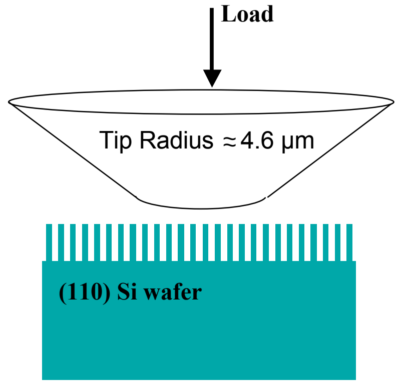
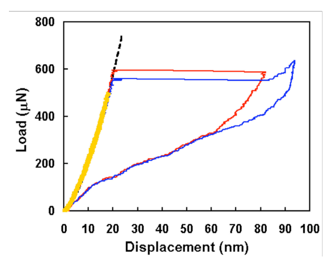
Test Procedure



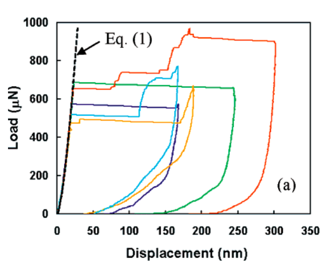
Li, et. al., Nanoletters (online: 6-Dec-2007)

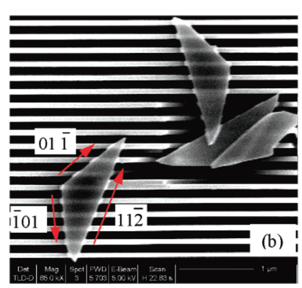
Results for 74 nm SiNL

Elastic Deformation

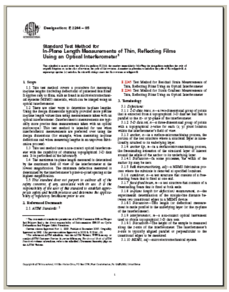


Plastic Deformation

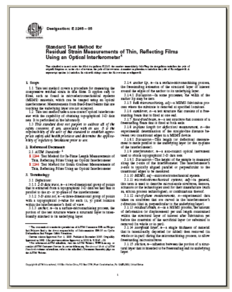




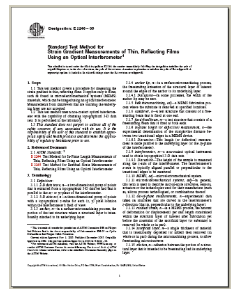
ASTM MNT Test Method Standards



ASTM E 2244–05
in-plane length



ASTM E 2245–05
residual strain



ASTM E 2246–05
strain gradient

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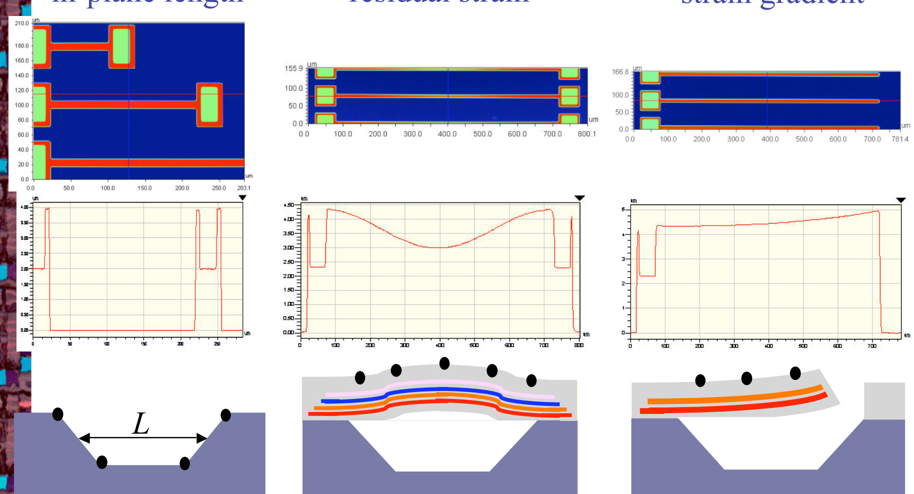
Snapshot of the 3 ASTM MNT Standards

in-plane length | residual strain | strain gradient



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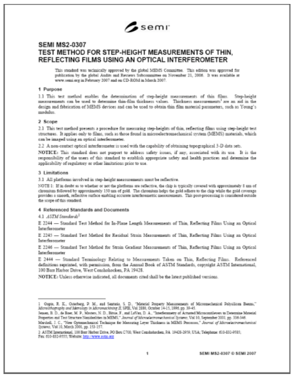
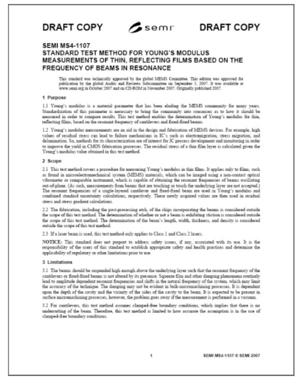
Key measurement tool
All: Optical interferometer

SEMI MNT Test Methods Standards


semi

SEMI MS2-0307
TEST METHOD FOR STEP-HEIGHT MEASUREMENTS OF THIN, REFLECTING FILMS USING AN OPTICAL INTERFEROMETER


DRAFT COPY semi DRAFT COPY

SEMI MS4-1107
STANDARD TEST METHOD FOR YOUNG'S MODULUS MEASUREMENTS OF THIN, REFLECTING FILMS BASED ON THE FREQUENCY OF BEAMS IN RESONANCE

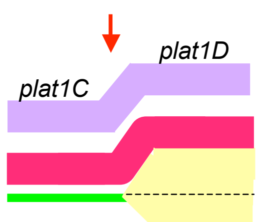
SEMI MS2-0307
step height

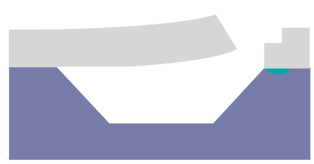
SEMI MS4-1107
Young's modulus

Snapshot of the SEMI Standards

step-height

Young's modulus





$$step1_{CD} = plat1D - plat1C$$

$$E = 38.330\left[\frac{\rho f^2 L^4}{t^2}\right]$$

Key measurement tool

Optical interferometer

Optical vibrometer

5-in-1 SRM

- These five properties
  - Length
  - Residual Strain
  - Strain Gradient
  - Step Height
  - Youngs Modulus
- …are being incorporated into a NIST SRM, which we hope to release in 2009

Wafer Bonding

Wafer Bonding Standardization

- NIST MEMS Standards Development
- Wafer bonding applications
  - CMOS (normally unpatterned wafers)
  - MEMS and Microfluidics Applications
- MEMS Standards Development
  - ASTM
  - SEMI
    - Wafer bond strength
- Standard Reference Materials for MEMS

Wafer Bonding in MNT

- Wafer bonding is used in a number of key MNT devices in current and future production
  - …used to provide hermetic sealing for
    - Vacuum
    - Dry
    - Fluidics
- Issues:
  - Leakage
  - Wafer Bond Strength
  - Reliability…*and most applications have safety implications!*

Leakage

- MNT sensors have internal pressure from
  - <0.01 Pa to 30 000 Pa
- To maintain the desired vacuum, leak rates must be held to below 10^{-15} Pa/m^3/s

Requirements for David project (0.13 mm^3 volume)

SEMI Standard MS5-1107

semi

SEMI MS5-1107
TEST METHOD FOR WAFER BOND STRENGTH MEASUREMENTS USING MICRO-CHEVRON TEST STRUCTURES

This standard was technically approved by the global MEMS Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on September 5, 2007. It was available at www.semi.org in October 2007 and on CD-ROM in November 2007.

1 Purpose

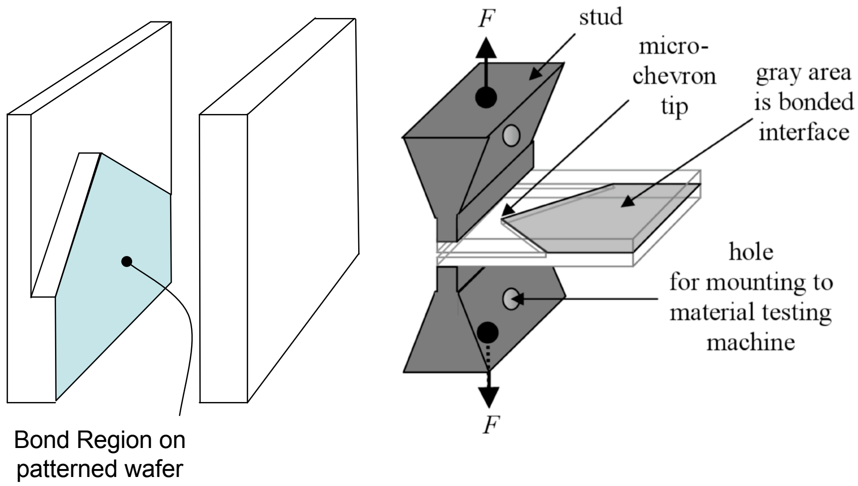
1.1 This test method enables the determination of wafer bond strength using micro-chevron test structures. Wafer-wafer bonding is a mainstay for microelectromechanical system (MEMS) design and fabrication. MEMS components, such as acceleration sensors, gyroscopes, micropumps, or microvalves that are increasingly found in smart automotive and navigation control systems or in medical devices typically use wafer bonding technologies. Due to being subjected to mechanical stresses, the industrial applications of these components require both a high mechanical strength and reliability of the wafer-bonded interface. For a knowledge of the strength determining factors (such as fatigue and stress corrosion) of wafer bonding, for quality control, and for the development of new bonding technologies, a method for determining the strength of such bonds is important to producers and users of MEMS devices, of wafer bonding equipment, and of wafer materials.

2 Scope

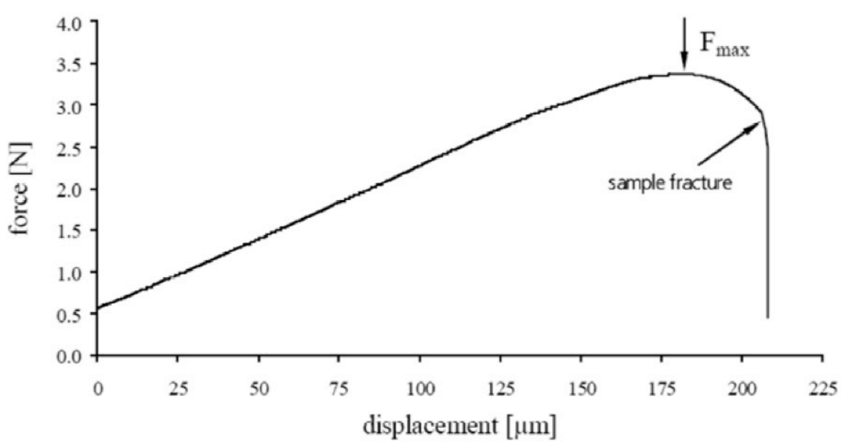
2.1 This test method will define the method[1, 2, 3, 4, 5] to determine the bond-interface strength of bonded wafer materials using micro-chevron test structures. It is restricted to the use of silicon with one geometrical configuration for the micro-chevron test structures.

2.2 The processing of the micro-chevron test structures (e.g., the etching used to create the micro-chevron pattern, the bonding of the wafers, and the sawing of the bonded wafers) is beyond the scope of this test method. In addition, this test method does not recommend etching, bonding, or sawing techniques, rather, it is used to ascertain the bond strength once the wafers are bonded. Therefore, this test method can be used to determine a preferred bonding technique.

Snapshot of the SEMI Wafer Bond Strength Standard



Load Displacement Curve for MicroChevron Structure (MS5)



Note: Units should be considered arbitrary

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NIST-on-a-Chip

- First target:
  - pN Force Standards
- Why?
  - Measurement of stiction forces in MNT devices
- How?
  - Integrated capacitance measurement with microcantilever

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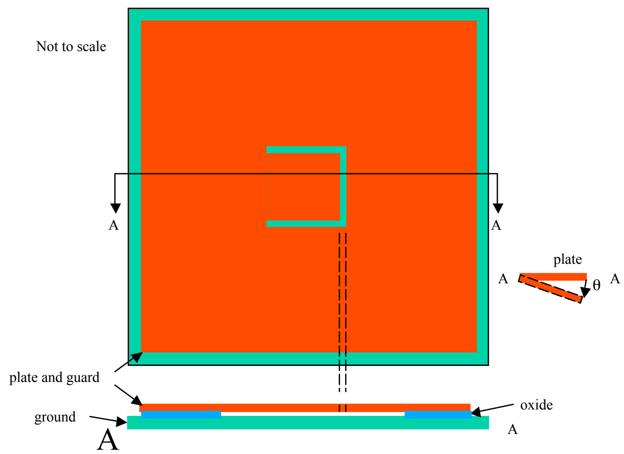
Proposed Design



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Cantilever with 1 nm/pN loaded Deflection

Parameter	Symbol	Value	Unit
Length	L	60	μm
Width	W	40	μm
Thickness	T	50	nm
Gap	H	100	nm
Least resonant frequency	f	20.47	kHz
Force applied to tip	F	1	pN
End-loaded tip deflection	y_l	0.914	nm
Gravity-loaded tip deflection	y_g	0.915	nm
Voltage-loaded tip deflection	y_v	0.932	nm
Voltage applied across gap	v	1.6	mV
Capacitance gradient	dC/dy	2.125	fF/nm

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Calibration

- Using this design, the cantilever can be calibrated against the local gravitational field by comparison of deflections when the chip is rotated
- Complimentary measurements may be performed with
  - Capacitance measurements (on- or off-chip)
  - Point force calibrations at multiple points on the cantilever
  - Addition of on-chip circuits to provide feedback damping of unwanted transducer motion

Summary

- Challenges of MNT metrology include
  - Dimensional
  - Material properties
  - Stiction
- Measurement tools must increasingly be incorporated into the MNT devices
  - Nano scale devices will likely require microscale factories and measurements

Questions?

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Acknowledgements

- Ted Vorburger, Janet Marshall, Ronald Dixson, George Orji, Jon Geist - NIST
- Bin Li, University of Texas, Austin

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