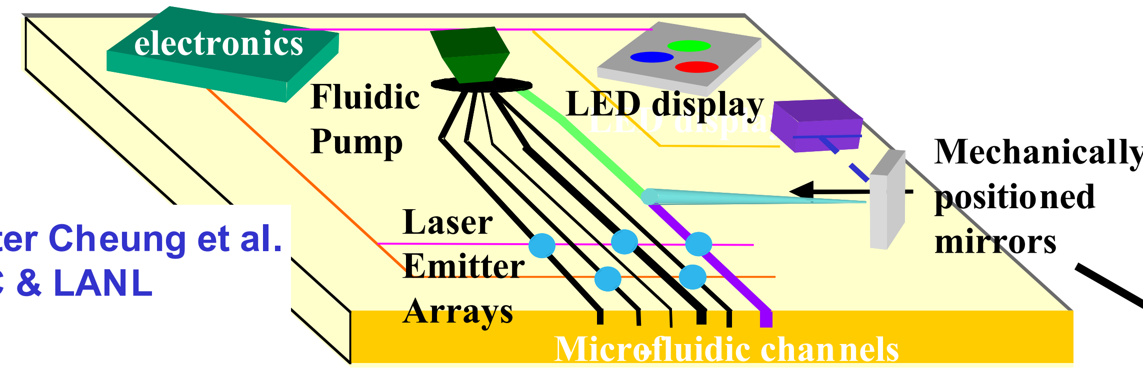
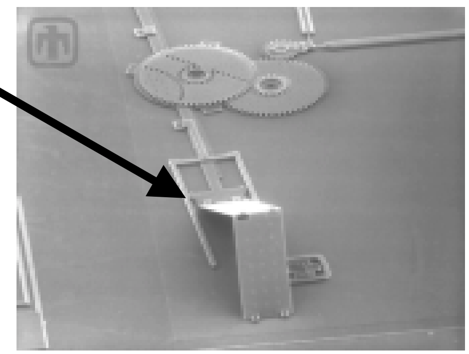
Nanomechanics

The production of mechanical work at the nanoscale and the transduction of energy from nano- to microscale systems



After Cheung et al.
UC & LANL



SNL	LANL
Charles Barbour	Mike Nastasi
Jack Houston	Harriet Kung
Sam Myers	Amit Misra
Liz Holm	Richard Hoagland
David Follstaedt	Brad Holian

Advances in nanomechanics will lead to new integrated systems

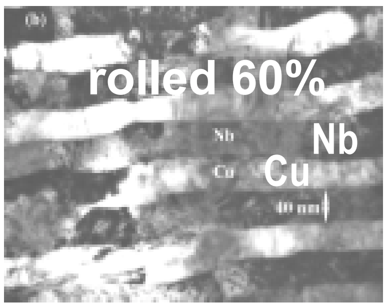
- **couple mechanical response with electrical, optical, magnetic, and chemical stimuli between micro- and nano-length scales.**

Nanomechanics: Key Scientific Issues

Understand the mechanisms and limits of mechanical deformation and stability of materials, and the transfer of energy to and from materials.

Nanostructured Materials ⟷ Unique mechanical properties

Nanoscale Architectures ⟷ Tools to perform work and probe material properties.



Kung, Misra - LANL

Friedmann, Sullivan, Dugger, LaVan - SNL

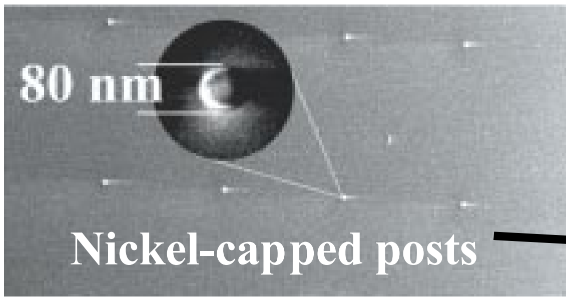
Discover what unique mechanical properties occur because of size scale:

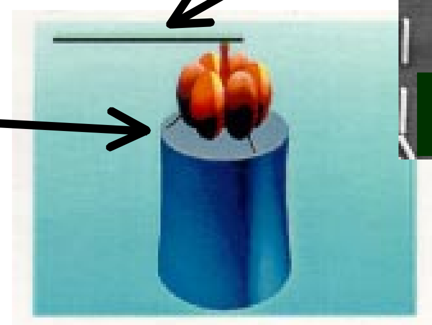
- ☆ **change in deformation processes - continuum to discrete**
- ☆ **increased surface area to volume ratio - increased stored energy**

How can we learn from nature to better fabricate and utilize nanoscale mechanical systems - better integrate dissimilar materials?

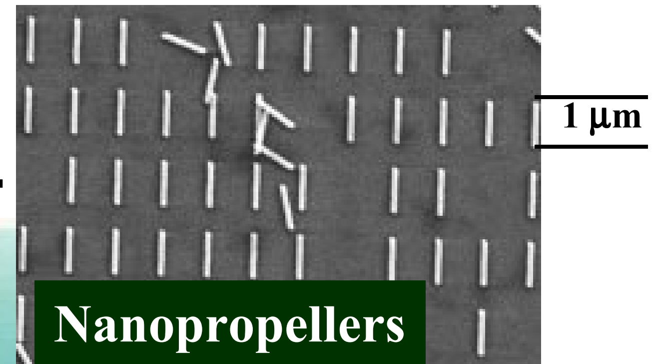
Nanomechanics Integrated with Bio-Functions

F_1-ATPase-powered
Bio Motor





Ni Nanopropellers



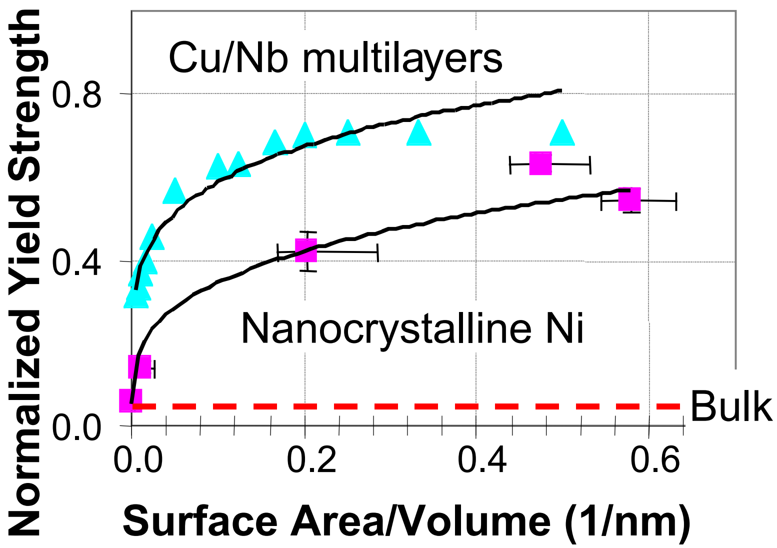
Bachand (SNL)
Montemagno (Cornell)

- Angular velocity:
  Mean = ~4.4 Hz Max = 8.5 Hz
- Rotary torque* = ~120 pN·nm
- Efficiency = 50% (-7.3 kcal/mol ATP)

Materials Issues: Adhesion, Yield Strength, Cyclic Fatigue, Frictional Losses ...

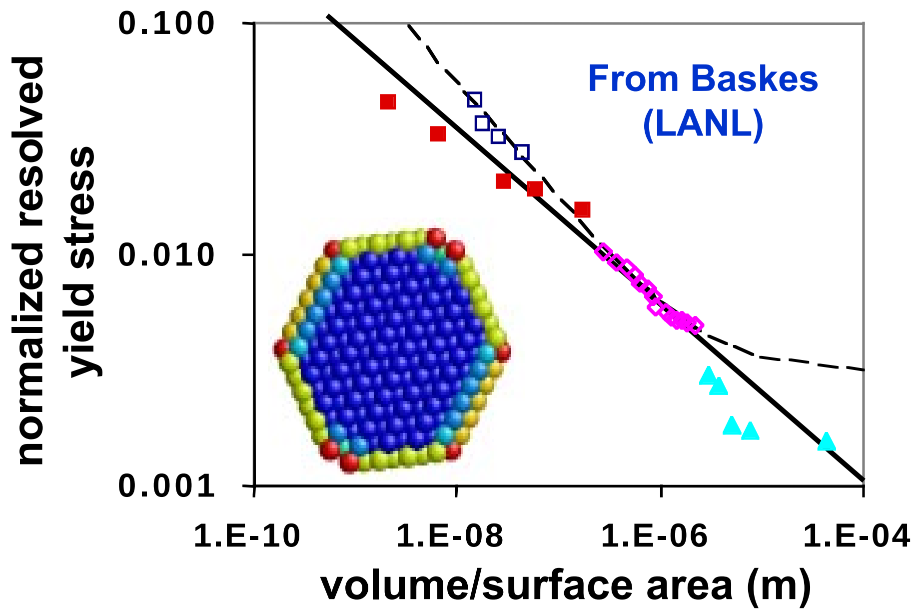
Nanomechanics: Nanoscale Deformation Physics

New mechanical behavior for high interface/volume ratio



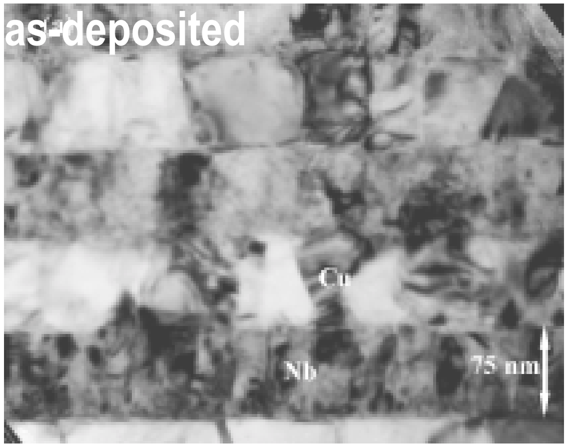
Misra, Kung (LANL)
Knapp, Follstaedt (SNL)

Modeling: large fraction of interface atoms increases strength

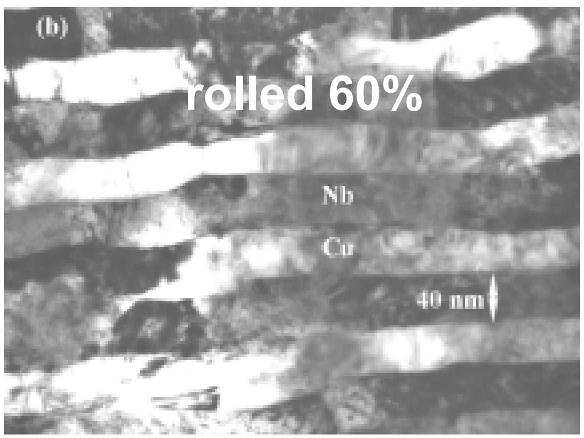


Science: Understand Deformation Mechanisms for High Interface/ Volume Ratio - predict transition from continuum to discrete behavior

Unique Strain Energy Storage and Dissipation at Nanoscale



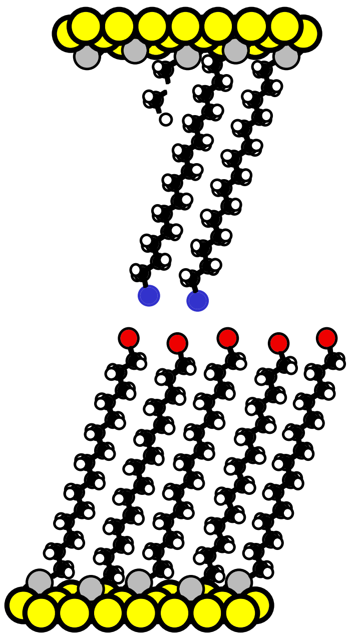
LANL has studied dislocation storage and annihilation mechanisms in materials with large fraction of atoms at surfaces and interfaces



No accumulation of dislocation damage within the layers; In fact, lower defect density after cold rolling

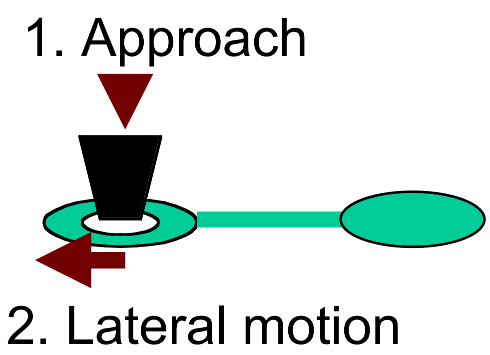
Unique properties obtained from nanostructuring - allows control over strain energy storage

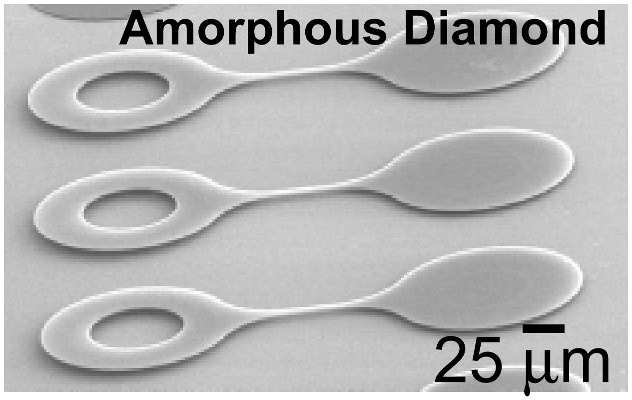
Nastasi, Kung, Misra - LANL

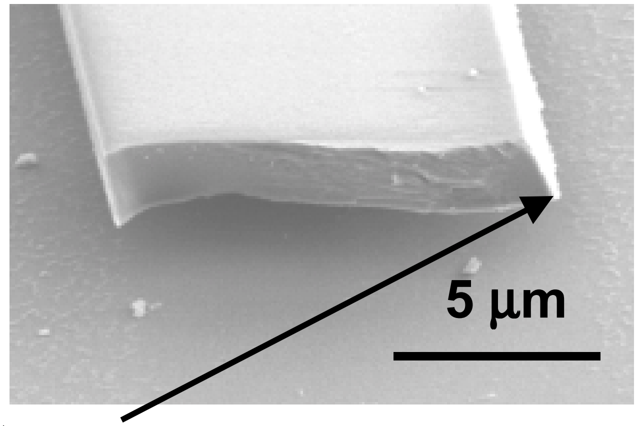


Probe the Properties of Nanostructured Materials

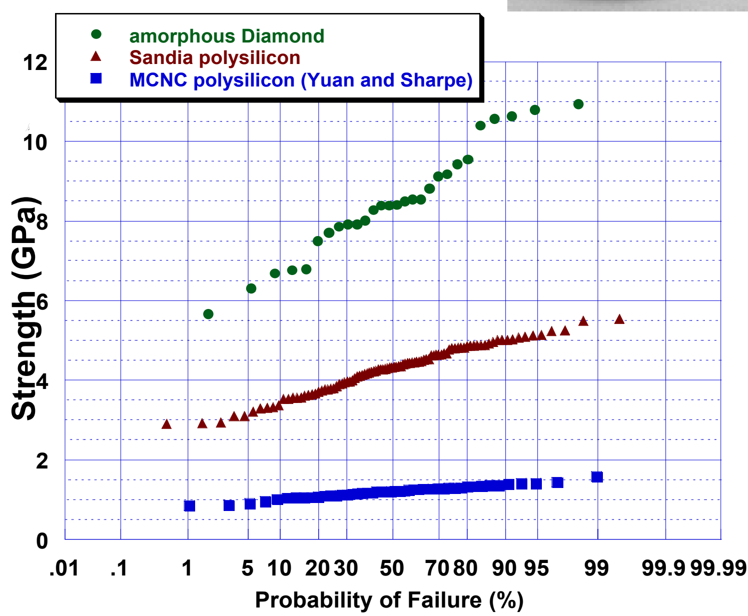
Tensile Testing using Nanoindentor







flaw initiates near corner



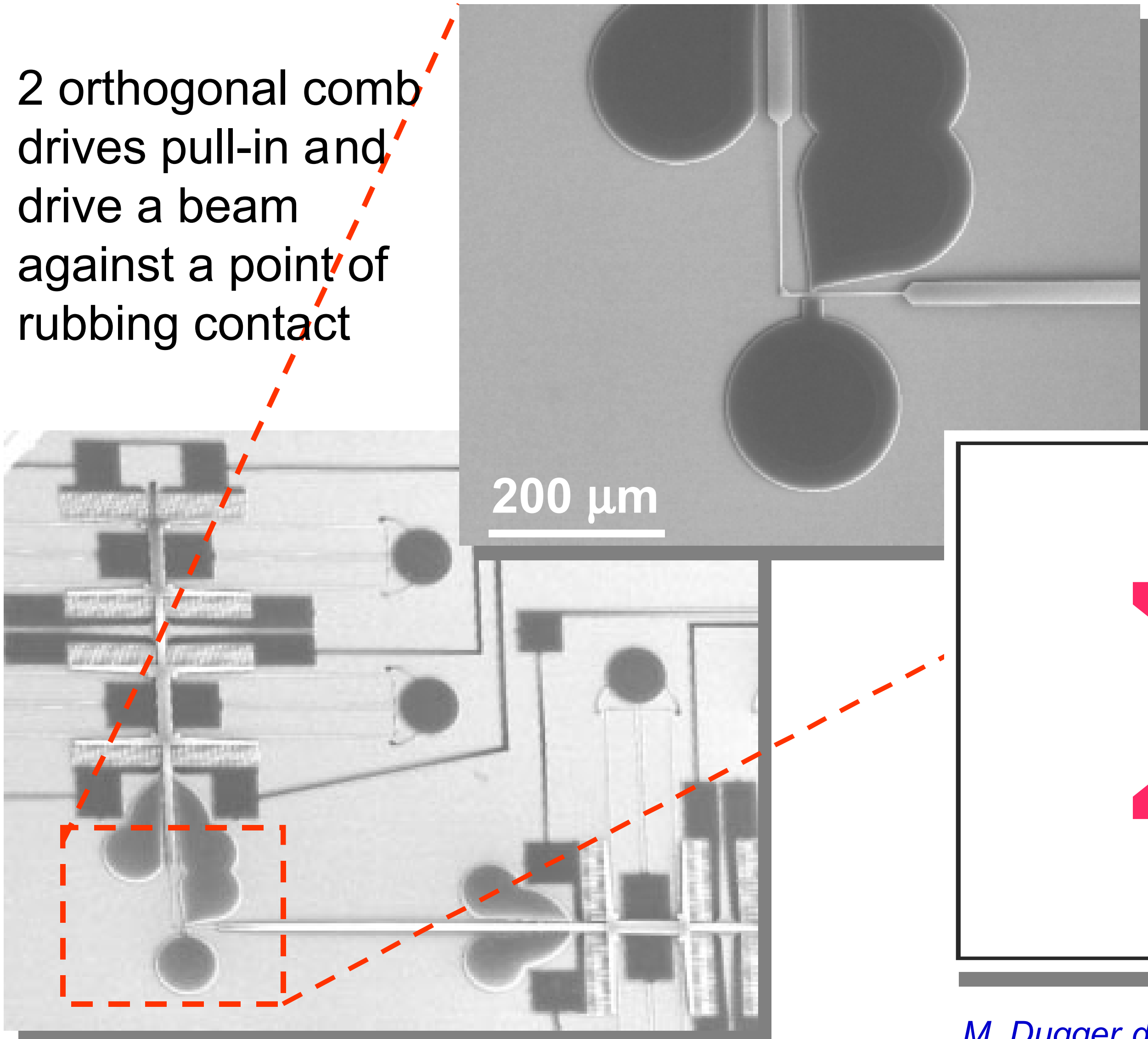
- **Measure a-D fracture toughness and strength**
- **Fracture Strength 8.5 ± 1.4 GPa**
- **Toughness K_{IC} = 8 MPa•m$^{1/2}$**

What happens when test piece is nanoscale - what do these terms mean then?

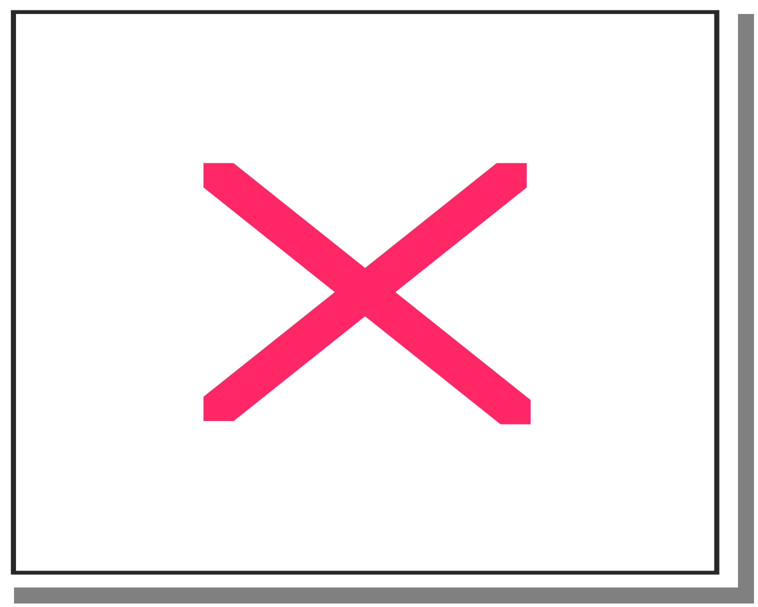
Friedmann & Buchheit - SNL

Probe Properties and Link Nano to Micro Scale

2 orthogonal comb drives pull-in and drive a beam against a point of rubbing contact



Friction and Wear Using MEMS Structures



M. Dugger design, modified by D. LaVan

Future Nano-Machines:
Test Materials & Perform Work

university U
industry I

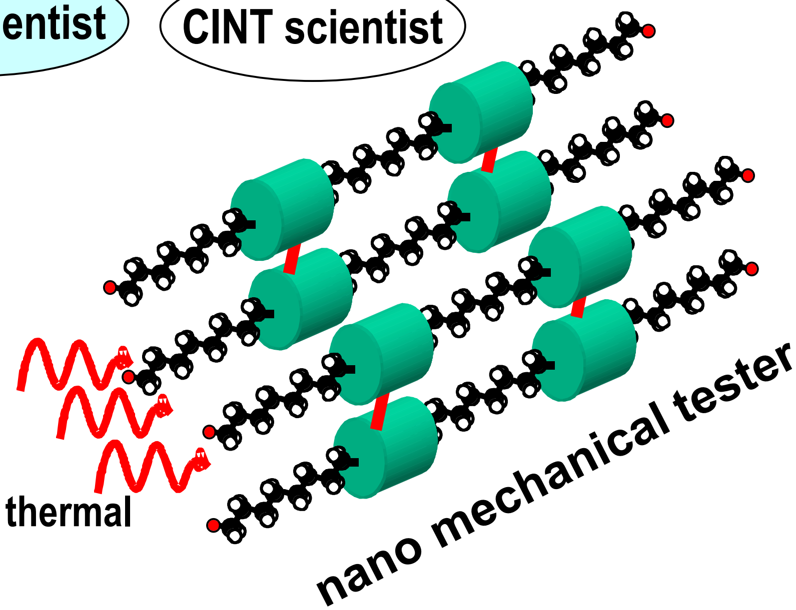
CINT scientist
nano-e/p

Quantum Dots collaborative proposal

CINT scientist

CINT scientist

Mechanically tunable photonic lattice



CINT nanomechanics → new tool for performing mechanical tests

CINT Capabilities: Nanomechanics

Experimental Equipment: VIBRATION SENSITIVE

NanoFab facility: including e-beam lithography, deposition tools (PVD, PLD, electrodeposition)
Optical microscope & optical profilometry
X-Ray w/ in-situ mech. testing: diffractometer, reflectometer, SAXS
SEM-high resolution
FIB cutting/materials modification
SEM- environmental for high Pressure and bio work
Nanoindenter
SPM- IFM, etc.
AFM-general purpose
TEM w/ in-situ mechanical testing
Nano tensile-test room (the manufactured device is the test)
Nano fracture-test room (the manufactured device is the test)

university U / industry I respond to website → Walk away with new tool for nanomechanical tests

Nanomechanics: Opportunities for novel and exciting research

Your opportunity to discuss the exciting collaborations in nanomechanics:

First opportunity is after this presentation and in the **breakout sessions** tomorrow

Also, you can give your views in the questionnaire - registration packet

CINT Capabilities Probe Mechanical Properties at the Nanoscale and Link Nano to Micro World

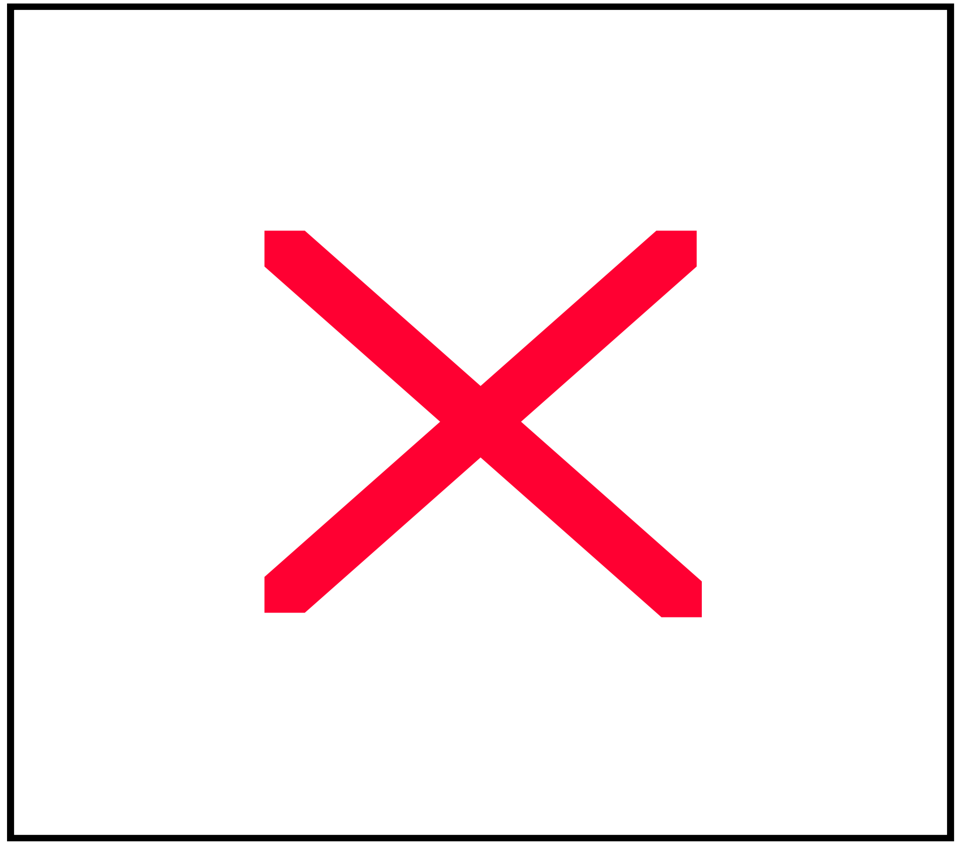
Experimental Areas:

Measurement of Nano-Materials Mechanical Strength and ability to do Work

.stress-strain measurements: tensile tests and compression test
.high strain-rate measurements: fracture mechanics
.tribological properties at the molecular level
.adhesion strength
.cyclic fatigue strength

F_1-ATPase-powered Nanopropeller System

- Mean angular velocity = ~4.4 Hz
- Maximum angular velocity = 8.5 Hz
- Functional Duration = >2 hrs
- Rotary torque* = ~120 pN·nm
- Efficiency = 50% (-7.3 kcal/mol ATP)

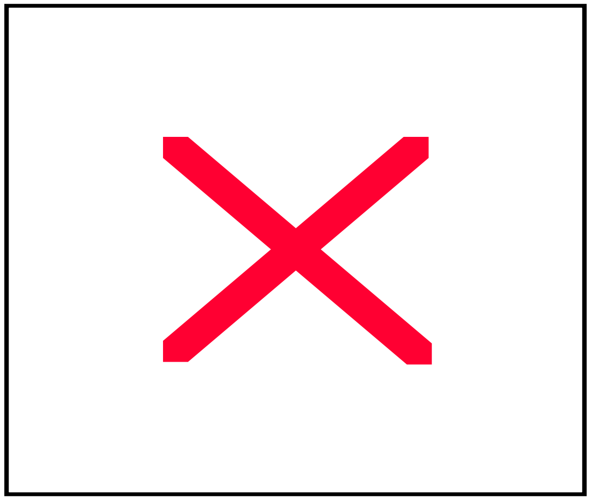


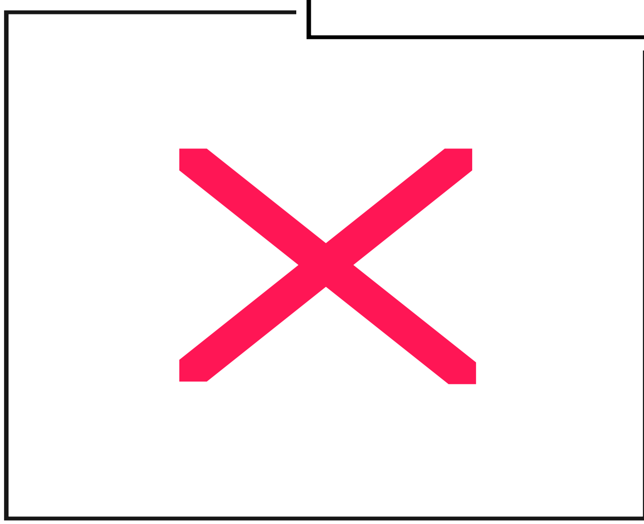
$$^{*}\tau = \frac{4}{3}\frac{\pi\mu\omega(L_1^{\,3}+L_2^{\,3})}{\cosh^{-1}(h/r)}$$

where:
μ = viscosity of medium (10^{-3} N·m·s^{-2})
L_1 *and* L_2 = length of the propellers extending from the rotational axis
r = radius of propeller (150 nm)
h = height relative to the surface (200 nm)

Nano-electromechanical Oscillators (NEMOs)

Yasumura et al., J. of MEMS ***9****, 117, ‘00*

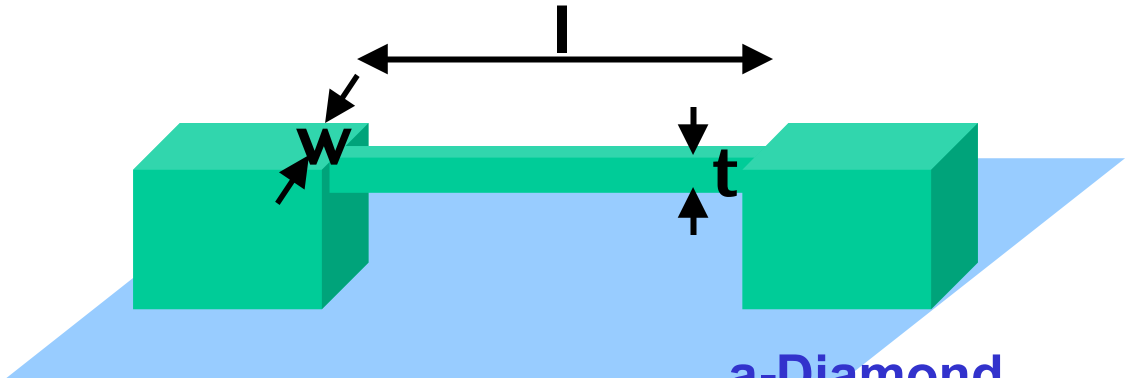




Cleland & Roukes, APL ***69****, 2653, ‘96*

High Elastic-Modulus Amorphous Diamond for High-Resonant Frequency Structures

For a doubly-clamped beam:



	$l \times w \times t$ (μm)	ω_0 (Si*) (silicon)	ω_0 (a-D) (a-Diamond)
contact lithography	100 x 3 x 0.1	77 kHz	150 kHz
optical lithography	10 x 0.2 x 0.1	7.7 MHz	15 MHz
nano-lithography	1 x 0.05 x 0.05	380 MHz	0.8 GHz
nano-lithography	0.1 x 0.01 x 0.01	7.7 GHz	15 GHz

**Roukes, Sol. State Sensors & Actuators (2000).*

These high-resonant frequency structures are potentially useful for RF signal processing or ultra-low force sensors, but need high Q.

NOTE: $\omega_0 \sim (E/\rho)^{1/2}$