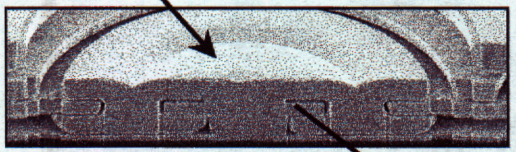
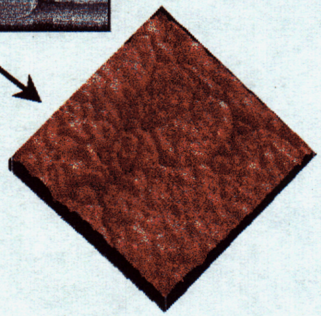
SAND2002-2097P

High Fidelity Friction Models for MEMS

Microengine hub cross section





Problem Description:

A comprehensive and validated model for MEMS-level friction in polysilicon micromachines is needed to enable the accurate analysis of DP MEMS components with moving parts and to assure predictable behavior under STS conditions.

Technical Approach:

Measure friction on the asperity, MEMS, and wafer-scale over a broad range of pressure and velocities to guide and validate the development of a MEMS-scale friction model. Perform simulations that explicitly model asperity interactions using increasingly realistic geometric, material , and cross-gap surface forces, as well as develop a complementary homogenized, multi-scale interface model for grid-scale calculations.

Applications:

•DP MEMS components with moving parts such as microengines, gear trains,pop-up mirrors

Funds: FY02 $400K, FY03 $428K, FY04 $455K

Team Members: B. R. Antoun, 8725
R. W. Carpick, U. of Wisc.
M. P. de Boer, 1762
R. E. Jones, 8726
O. B. Ozdoganlar 1924
E. D. Reedy, 1923

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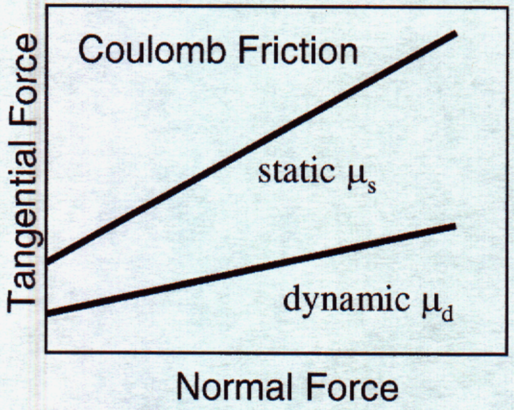
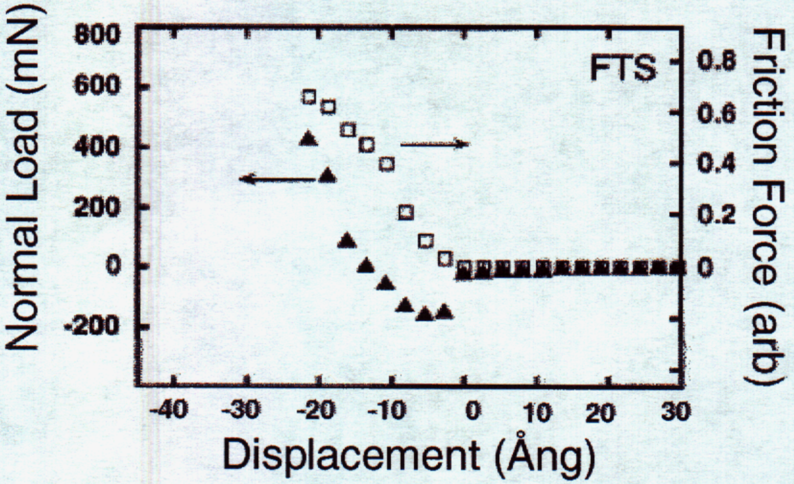
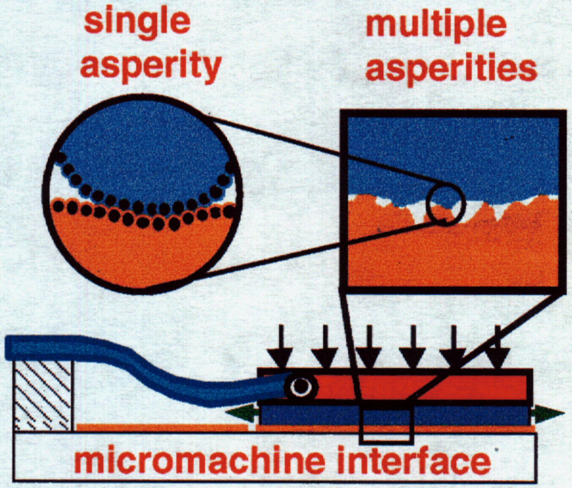
Motivation

MEMS scale friction falls between macro and single asperity models.







- Number of contacting asperities on the order of ~ tens or lower, suggesting expansion of single asperity model.
- Noncontacting surface effects may play an important role in frictional dissipation in microsystems as a consequence of the low real to apparent contact area ratio (A_r/A_o)

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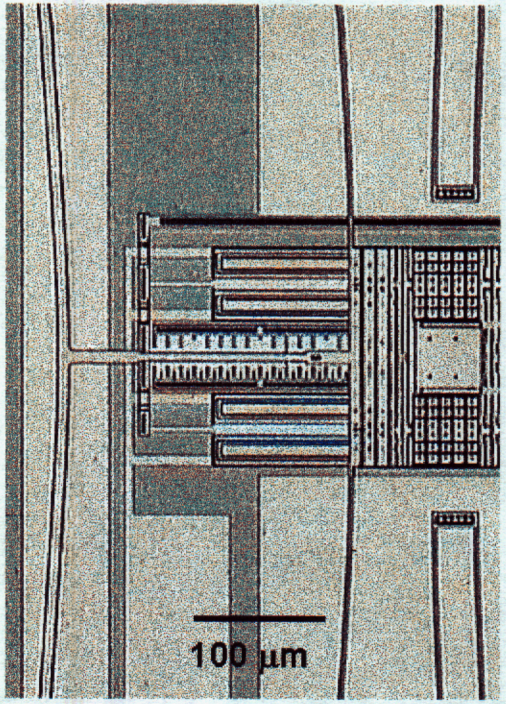
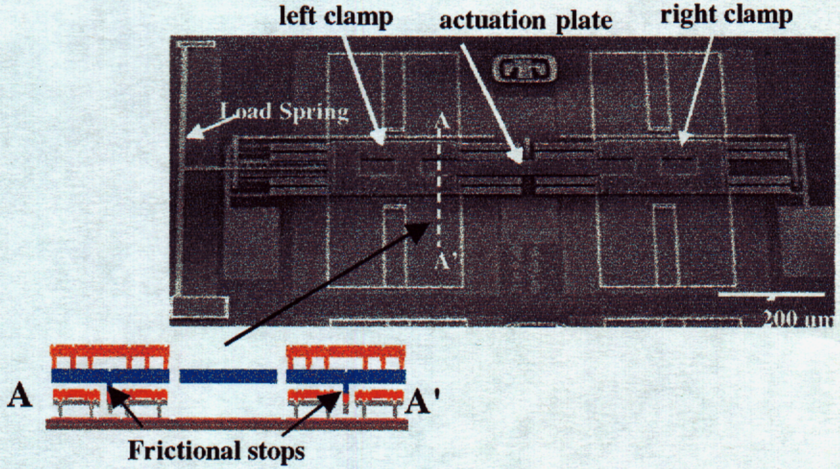
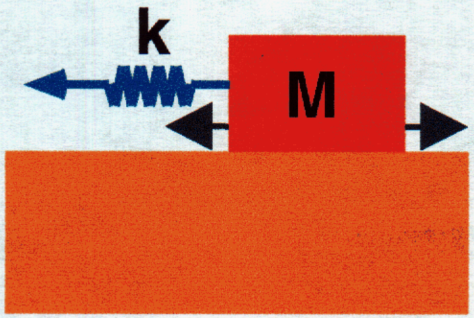
MEMS-scale friction test with inchworm actuator







- Friction forces are purely normal and purely tangential.
- Pressure is uniform.
- First "clean" MEMS friction test

(1) Walk inchworm out against loading spring
(2) Release voltages except on leading clamp
(3) Lower voltage on clamp until slip

Milestone 1: Moiré Metrology

Progress

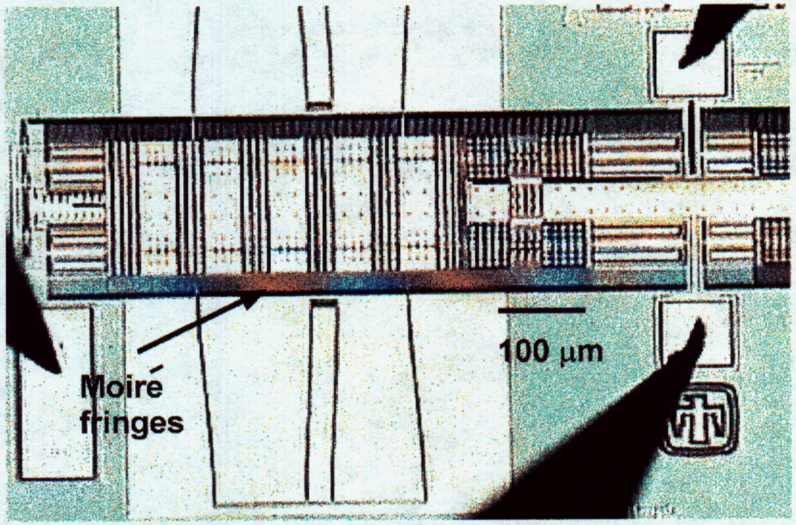
•First implementation of digital Moiré in MEMS

•Important to friction forces to <10% accuracy

•Without Moiré , uncertainty up to 100%

•Moiré magnifies in-plane displacement by 20 to 100X
50 nm in-plane resolution

•Automation implemented for real time displacement readout

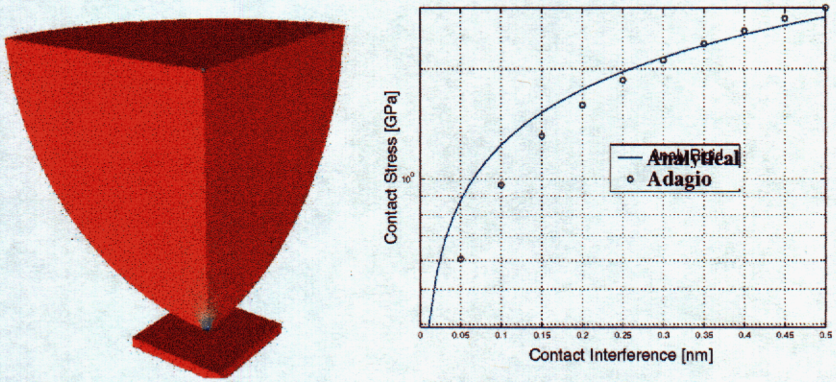


Movie – inchworm3b

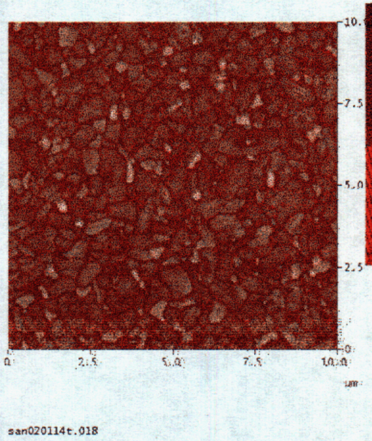
Milestone 2: Preliminary Interface Model

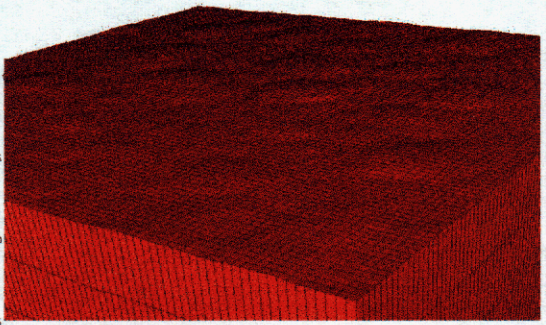
Progress

- Adagio and Presto simulations of two interacting asperities.
- Developing procedure uses CUBIT to create finite element models from AFM topography measurements to enable the simulation of actual polysilicon surfaces with multiple asperity interactions.
- Began implementation of adhesion model in PRESTO/ACME.
- Began development of multi-scale finite element interface model for grid-scale calculations.



ADAGIO simulation of Hertzian contact.





Finite element mesh generated from AFM surface profile data (0-100 nm asperity heights).

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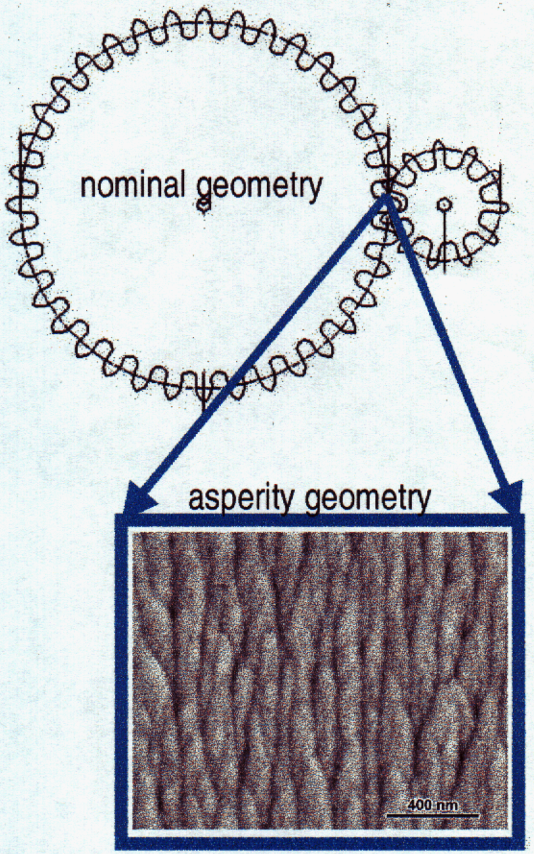
Multi-scale Contact Model

- To directly model surface details is prohibitively expensive for system-sized simulation of MEMS components.
- Consequently, a homogenized model, based on Greenwood-Williamson (1966), is being developed in the SIERRA framework.
- It employs only a mesh of the nominal geometry which is coupled to an analytical micro-mechanical model of the actual contacting surfaces for accuracy and efficiency.
- Will compare homogenized model predictions with finite element solutions for actual polysilicon surfaces.



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Milestone 3: Quantify PV Space

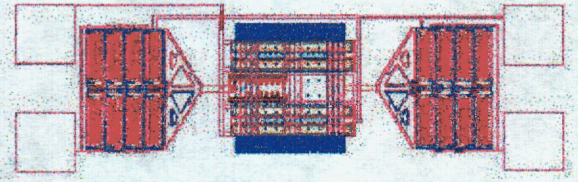
Table I – PV space comparison of friction instruments
Note: each instrument measures static friction

	AFM	Inchworm (friction) (mode)	Comb drive	Torsion-Master
P_n range (MPa)	0.1 - 500	0.01 to 50	0.01 to 50	.05 to 50
V range (μm/sec)	0.001-30	~10^6	0 to 10^6	100 to 50,000

P_n – normal pressure
V – velocity

- **Pressure range exhibits good overlap**
- **Velocity range exhibits reasonable overlap**

Comb drive actuator with same friction sensor has also been designed:



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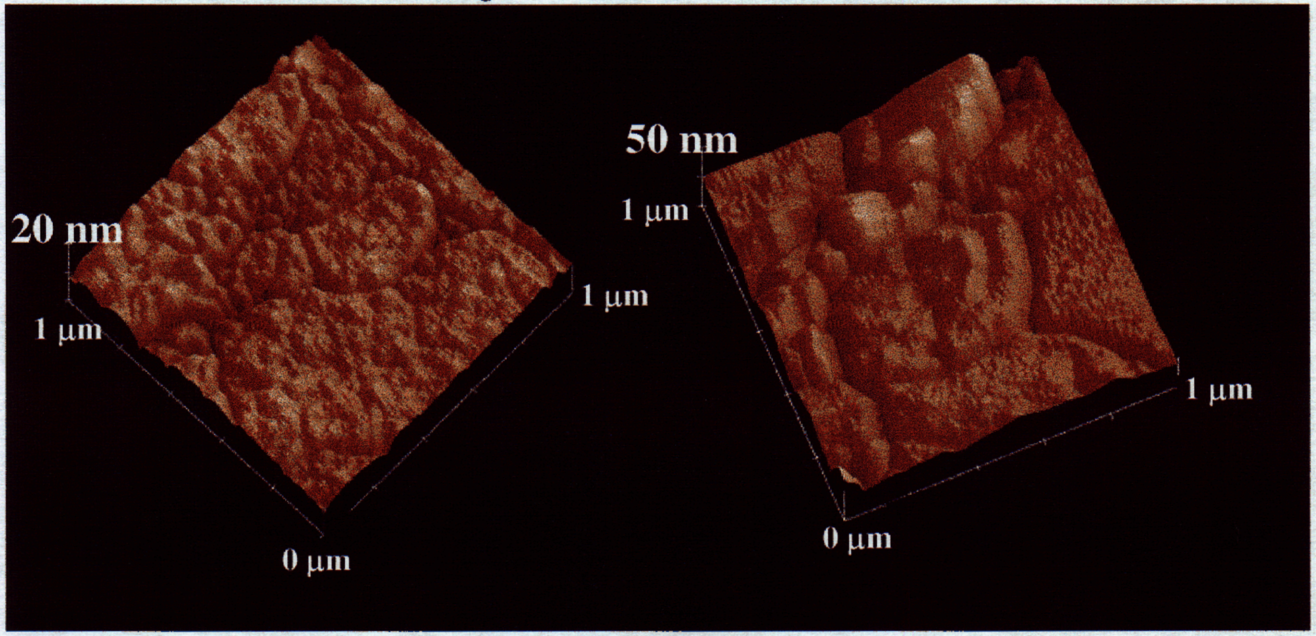
Milestone 4: Evaluate Asperity Geometry

No oxidation: 2.7 nm rms roughness 600 Å oxidation : 11.3 nm rms roughness)



<u>Progress</u>

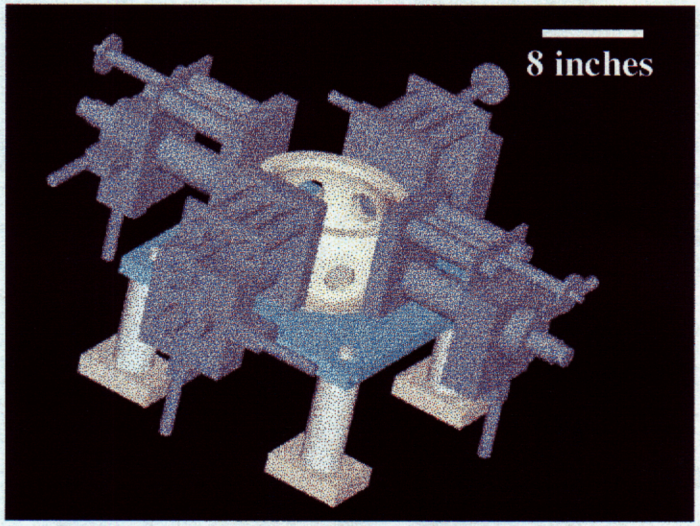
- surface topography quantified by AFM
- single asperity friction law measurements to begin in summer '02
- Robert Carpick, Univ. Wisconsin

Milestone 5: Assemble Test Chamber

•UHV vacuum chamber for MEMS-scale friction tests

•To be used with a long working distance interferometer

Need for FY03 dynamic friction measurements (eliminates air damping)

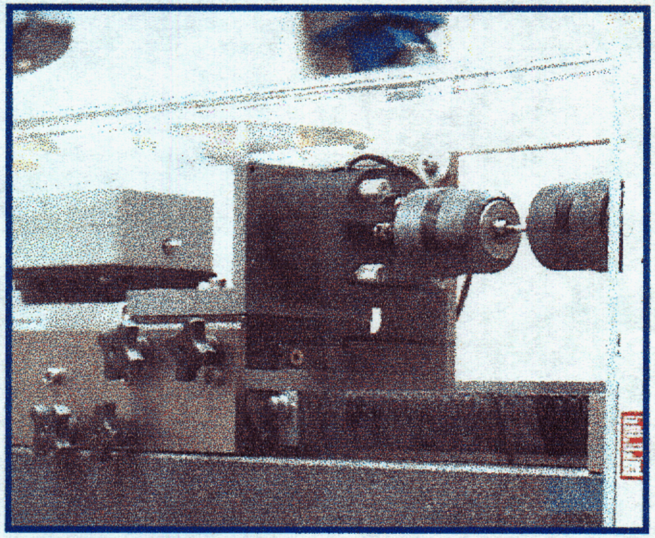


Progress
• Chamber parts received
• Construction underway

Milestone 6: Evaluate Friction of Polysilicon Samples

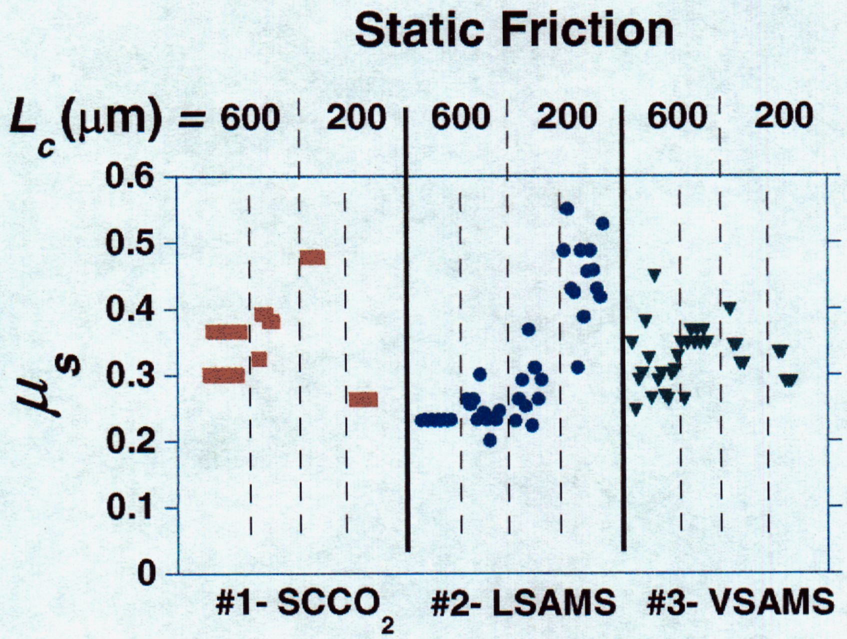
Progress

- Sample fabrication complete: Vary size (5 x 5 mm and 10x10 mm) and roughness
- Initial Torsion-Master setup complete
- Testing to begin in June (FY02)



- **TorsionMaster Testing system**
  - -Rotation rate up to 120 rpm
  - -Torque resolution is better than 100 $\mu N \bullet m$
  - -Angular resolution of 0.005°
  - -Continuous rotations
  - -Axial preloading

Preliminary MEMS inchworm friction results



- Reasonable μ_s values
- No effect of coating observed (unexpected)
- Will examine effect of coatings more <u>*carefully*</u> in FY04