Friction Models for Microelectromechanical Systems (MEMS)

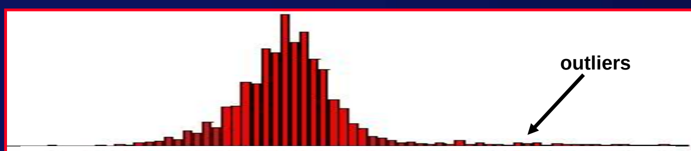
SAND2007-5389P

Goals

- Determine how MEMS-scale friction differs from friction on the macro-scale.
- Develop a capability to perform finite element simulations of MEMS components that accurately predicts response in the presence of adhesion and friction.

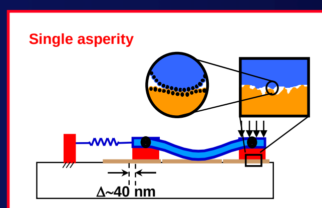
Polysilicon Surface Topography

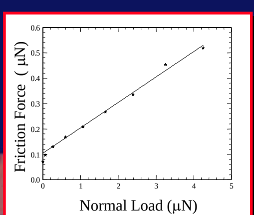
- Atomic Force Microscope images suggest that a few summit height outliers may dominate response.
- Use AFM to also measure friction on a single asperity --- the AFM tip is the asperity (Professor Carpick, U of Wisc).



Inchworm MEMS Friction Tester

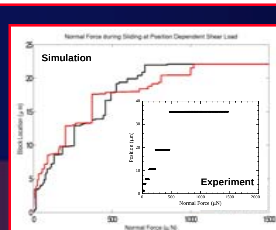
- Actuation plate and two frictional clamps
- Step size is only 40 nm
- Operates at up to 80,000 cycles per second
- 100s of times more force than more common comb drives

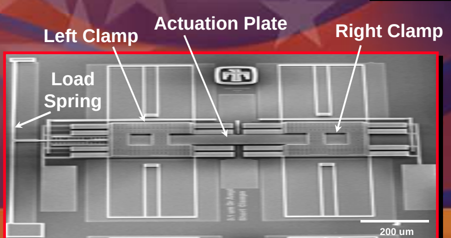




At low loads, adhesion is important

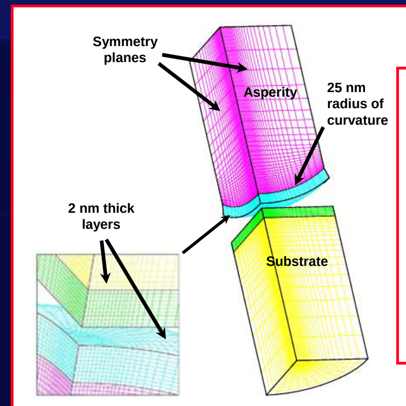
Discovered gross slip prior to sliding

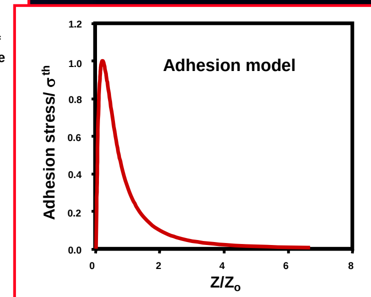




Asperity-scale Finite Element Contact Simulations

- An adhesion model has been implemented into Sandia's three-dimensional, transient dynamics finite element code

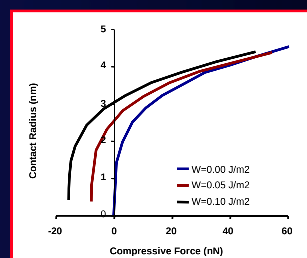




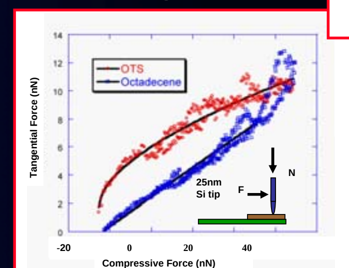
Mesh and adhesion model used in PRESTO calculation

Simulation Results

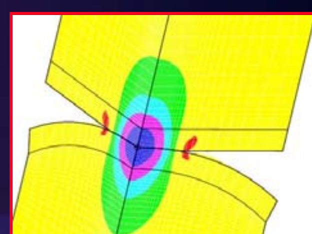
- Adhesion energy has a strong influence on the calculated contact radius and pressure.
- The AFM single asperity friction data also shows that frictional force can occur under a tensile load and that there is a nonlinear relation between normal and tangential force



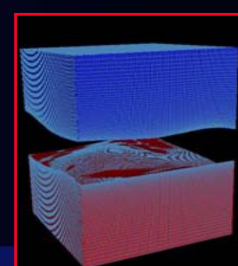
Variation of calculated contact radius with adhesion energy



AFM single-asperity friction data



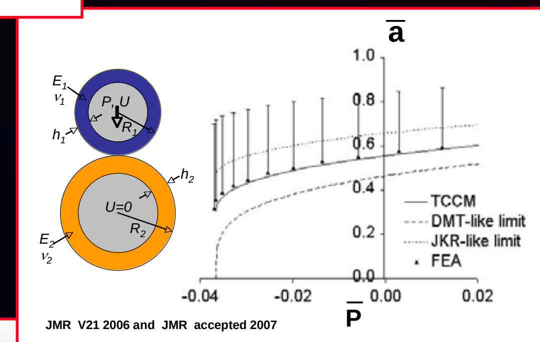
SAM coating has a drastic effect on calculating contact radius and pressure



Finite element meshed created directly from an AFM image

Thin Coating Contact Mechanics – TCCM

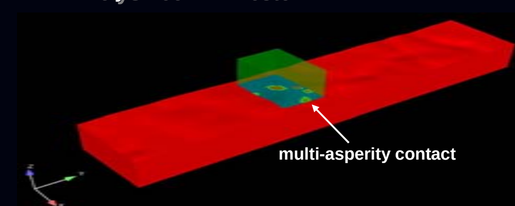
- A new analytic contact mechanics theory for spheres with a thin, relatively compliant coating that includes adhesion.
- Motivated by need for a contact mechanics applicable to PolySilicon asperities coated with a molecular monolayer.
- Verified analytic results by performing finite element simulations using Presto's new adhesion model.



JMR V21 2006 and JMR accepted 2007

Multi-Asperity Contact

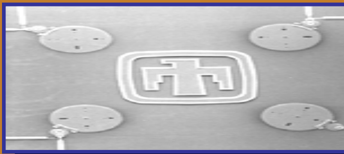
- Used Thin Coating Contact Mechanics to perform discrete asperity contact simulations of the response of coated PolySilicon nano-positioning device.
- Performing dynamic finite element simulations of multi-asperity contact of PolySilicon in Presto.



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.

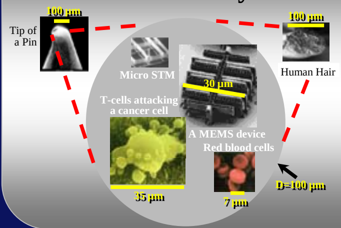
Thermal Phenomena in Microelectromechanical Systems (MEMS)

Microscale Sciences and Technology Department, 01513
Sandia National Laboratories, Albuquerque, New Mexico

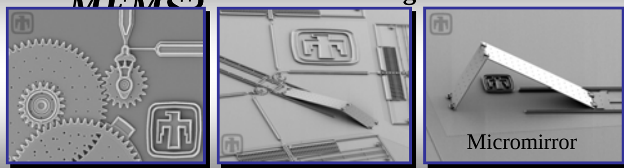


What are MEMS?

MEMS are very small



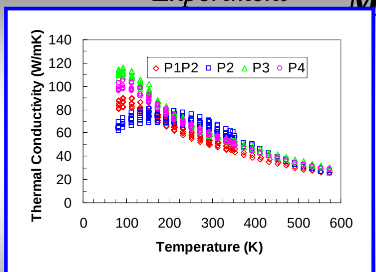
Surface Micromachining at Sandia



http://mems.sandia.gov

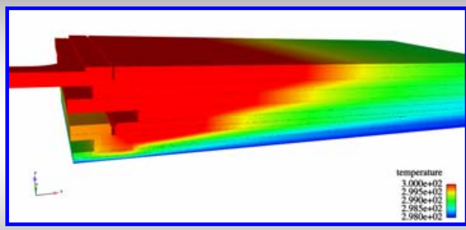
Thermal Properties of MEMS Materials

Experiment



Thermal Conductivity of SNL SUMMIT V Polycrystalline Silicon Layers

Simulation



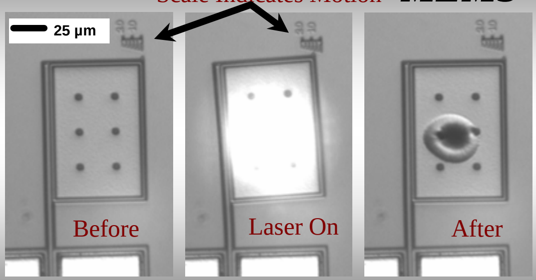
Predicted Temperatures in a Bond Pad Showing Heating During Thermal Conductivity Measurement

MEMS Properties May Differ from Bulk Values

Laser Interactions with MEMS

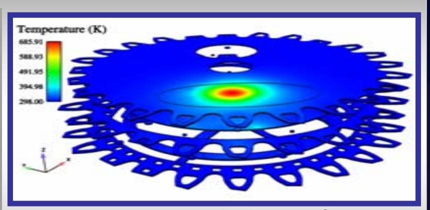
Experiment

Scale Indicates Motion



Laser Powered Flexure Thermal Actuator

Simulation

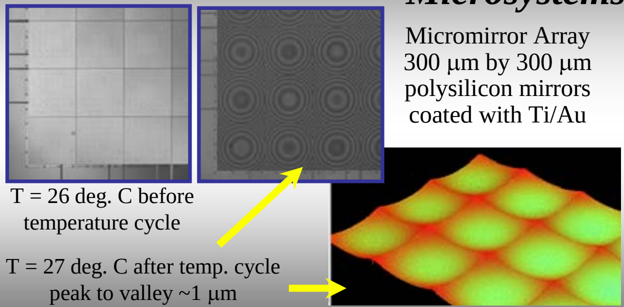


Laser-Heated Shutter for Optical Switching
Initial Investigation of Temperature

Small Volume ➤ Low Thermal Capacity ➤ Good Heat Dissipation is Essential

Thermomechanical Coupling in Microsystems

Experiment

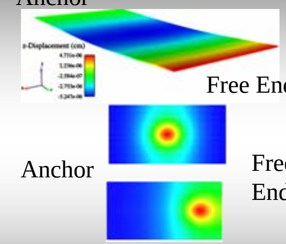


Micromirror Array
300 µm by 300 µm polysilicon mirrors coated with Ti/Au

T = 26 deg. C before temperature cycle

T = 27 deg. C after temp. cycle peak to valley ~1 µm

Simulation

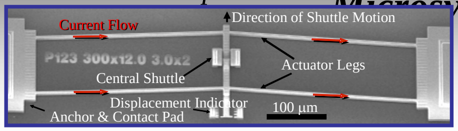


Contours of Predicted Deformation on a Laser Heated Cantilever

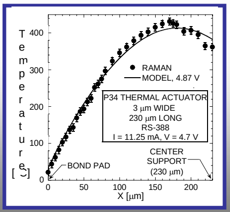
Interaction between Multiple Physical Phenomena

Noncontact Surface Thermometry for Microsystems

Experiment

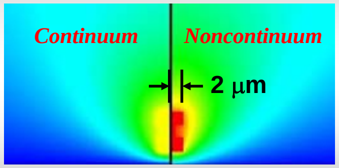


Raman Thermometry of a Thermal Microactuator
Spatial resolution ~1 µm for temperature profile along an actuator leg



Simulation

Ambient air, Joule-heated beam
Substrate and far-field gas at room temperature



Beam Temperature Predictions
Continuum = 750 K, Noncontinuum = 900 K

Importance of Noncontinuum Transport

Contributors

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Digital Image Correlation (DIC)—a Full-Field Metrology Spanning from Meters to Nanometers

DIC Provides to Sandia:

1. *Full-field* shape, displacement, velocity, rotation, and pose;
2. Scales from meters to nanometers;
3. Rates from static to MHz;
4. *Full-field* experimental results for *full-field* model validation.

DIC Goals at Sandia:

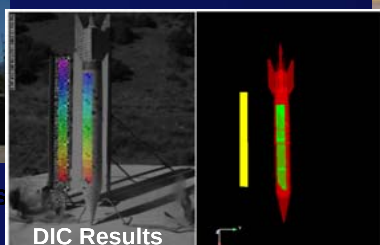
1. Use DIC to conduct high-fidelity model validation experiments
2. LEMUR—Integrating full-field experimental results with model results
3. Cutting edge experiments using DIC
4. Advance DIC state-of-the-art

DIC Research Connections:

1. UQ at University of South Carolina
2. Work with Correlated Solutions, Inc.
3. Intra-lab DIC users-support group
4. 1 International presentation
5. 9 Conference proceedings
6. 2 Journal Articles

Large-Scale Testing—Meters

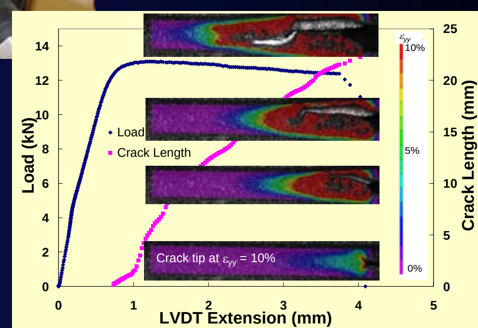
***System qualification** at full-scale and full-field*



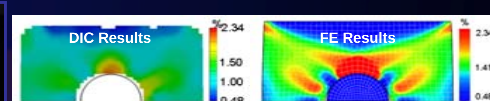
Linking Experiments to Models

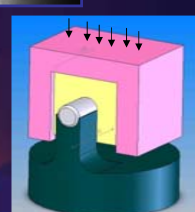
Lab-Scale Testing—Centimeters

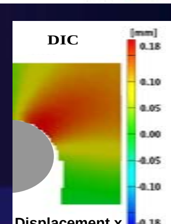
***Model development** by providing crack-length measurements*

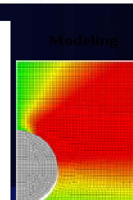


***Model validation** of foam crush*



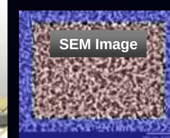


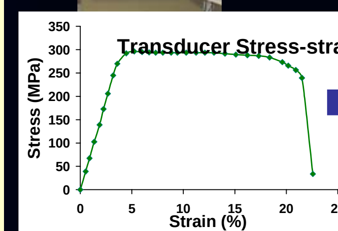


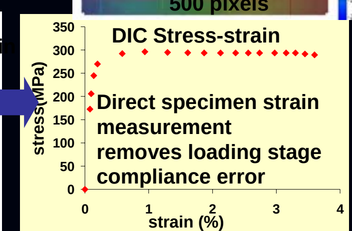


Micro-Scale Testing—μm

***Material testing** at μm lengths*

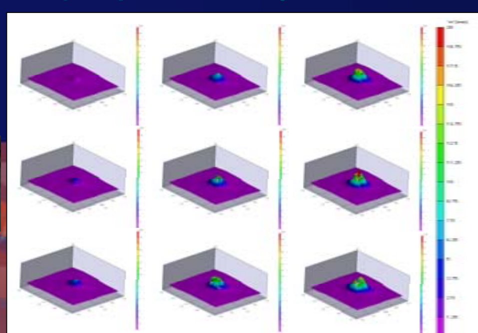






High-Rate Testing—MHz

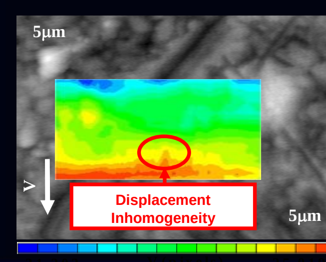
***Ultrahigh speed** testing*



First-in-the-world demonstration of new Shimadzu cameras doing ultrahigh speed DIC (500kfps)

Nano-Scale Testing—nm

***Atomistic scale** materials research*



Future work:
Nanoscale Displacement Measurement DIC using AFM Imaging (Atomic Force Microscope)

POC: Phillip Reu, plreu@sandia.gov

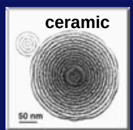
Nanoparticle Suspension Modeling for Material Design

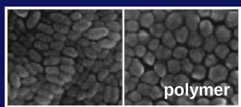
Randall Schunk, Gary Grest and Jeremy Lechman

Motivation

- A promising aspect of nanotechnology is to distribute nanoparticles in or on materials to engineer functionally tailored nanocomposites
- An efficient method of accomplishing this is fluidization in a carrier liquid followed by traditional processing techniques (coating, casting, spinning), which allows control of nano building blocks at the macroscale
- To facilitate design and analysis of such processes, a mesoscale modeling and simulation capability for dense suspensions of arbitrary shaped nanoparticles is necessary in order to build system understanding and control

Technical Horizon: Suspension-based Nanocomposite Manufacturing





Nanoparticle Manufacture
- Solution, HighT, etc.

Size/shape →

Nanoparticle batch characterization
- Microscopy…

Distribution →

Dispersion Chemistry
- Polymer functionalization

Rheology, stability →

Fluidization/Processing - e.g. coating, casting…
- Rheology, Microstructure, self-assembly

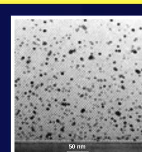
µstruct →

Solidification
- Drying, curing, sintering

(other means of processing into product do exist)

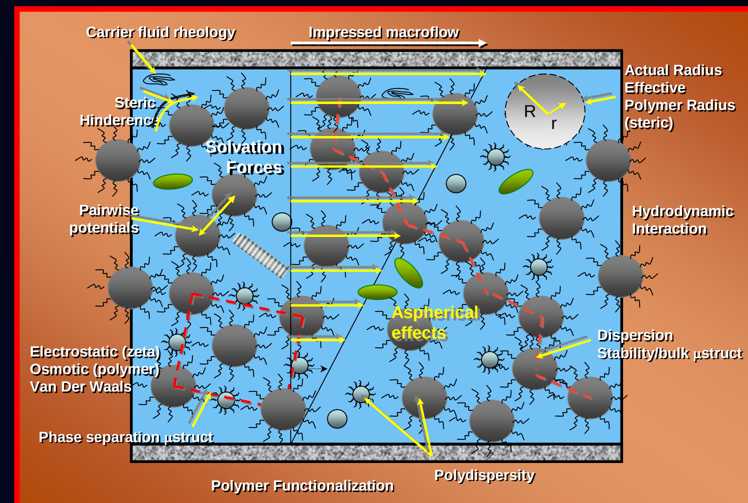
µstruct/residual stress →

Product properties
- Thermophysical, mechanical characterization/prediction



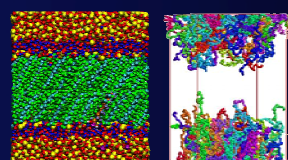
Ag-Silica nanocomposite

Technical Challenges: Rich Physical Phenomena

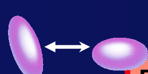


Technical Approach: Integrated Capability

Molecular scale — nanoseconds, 0.1 to 10 nm

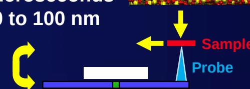


MD, DFT



Effective potentials

Particle Scale — microseconds, 10 to 100 nm

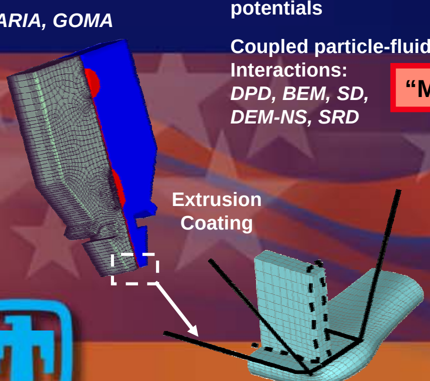


Experimental Validation:
Optical Tweezers, GSAXS, Interfacial Force Microscopy, Acoustic Spectroscopy, Suspension Rheology, …

Coupled particle-fluid Interactions:
DPD, BEM, SD, DEM-NS, SRD

"Mesoscale" — milliseconds, 100 nm-10 µm

FEM, ASC SIERRA APPS:
ARIA, GOMA



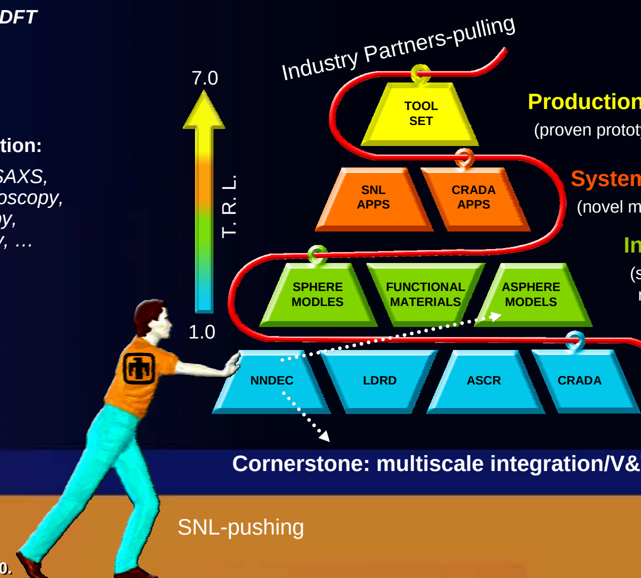
Constitutive Relations
Micro-structure

Integrated Modeling and Simulation Tool
CRADA/SNL Applications
Experimental Knowledge Base
Tools at smaller scales
Academic Research
(Materials/Numerical methods)

seconds

Engineering Scale

Goal: Predictive Manufacturing Capability



Production Design and Analysis
(proven prototype in operational environment)

System Integration & Validation
(novel materials applications and processing)

Invention & Characterization
(subsystem: functionalized particles, novel materials & modeling)

Fundamental
(includes numerical methods and some basic science directed to rheology, dispersion stability, surface self-assembly of dense nano-suspensions)

Cornerstone: multiscale integration/V&V

ENGINEERING SCIENCES CENTER

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