Interfacial Force Microscopy Group

Lead Scientist:
Jack Houston

IFM Instrumentation Lead:
Bill Smith

Team Members:
Nathan Moore, Doug Crowson

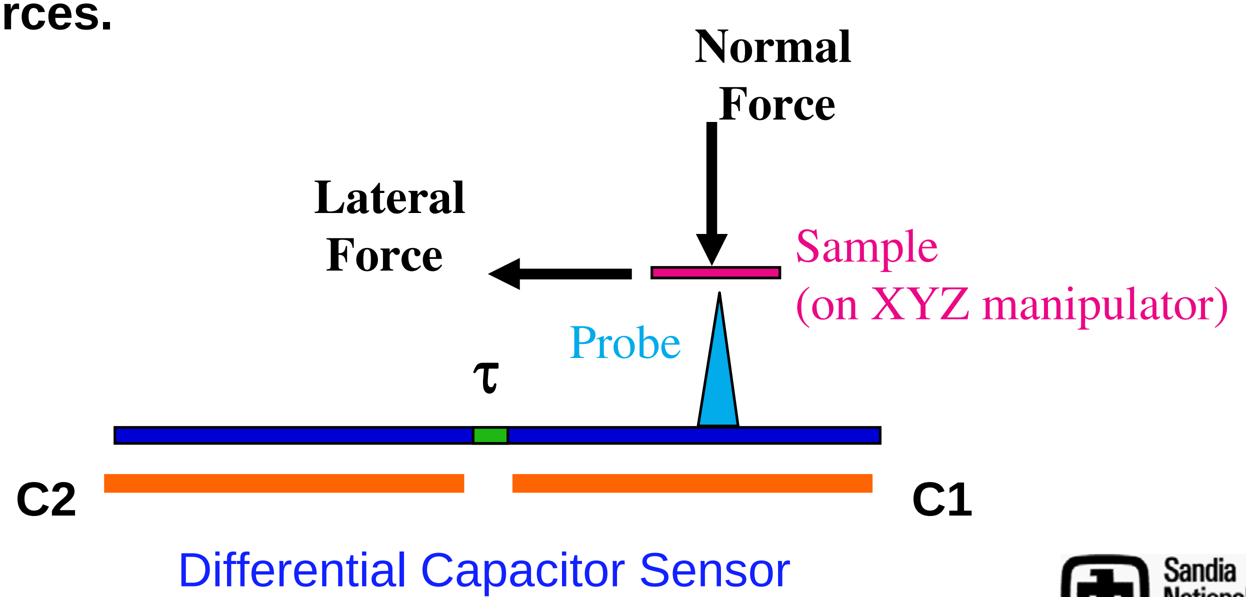
Sandia National Laboratories

The Interfacial Force Microscope (IFM)

• Initially developed at Sandia (JE Houston) with BES support for fundamental surface and interface science investigations, has been recently highlighted in water, self-assembled monolayer and superhydrophobic research activities.

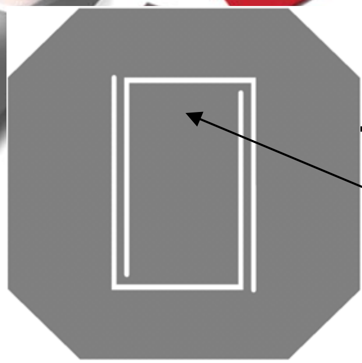
• The research instrument is patented, and earned an R&D 100 Award (1994)

• Unlike other compliant scanning probe techniques (like STM, AFM), the non-compliant IFM offers a differential feedback mechanism that offers superior stability and also allows the direct measurement of vertical (normal) and lateral forces.



Sandia National Laboratories

2D Laser-Interferometer IFM Sensor



100 µm Si(001) top plate with etch pattern defining flexible elements

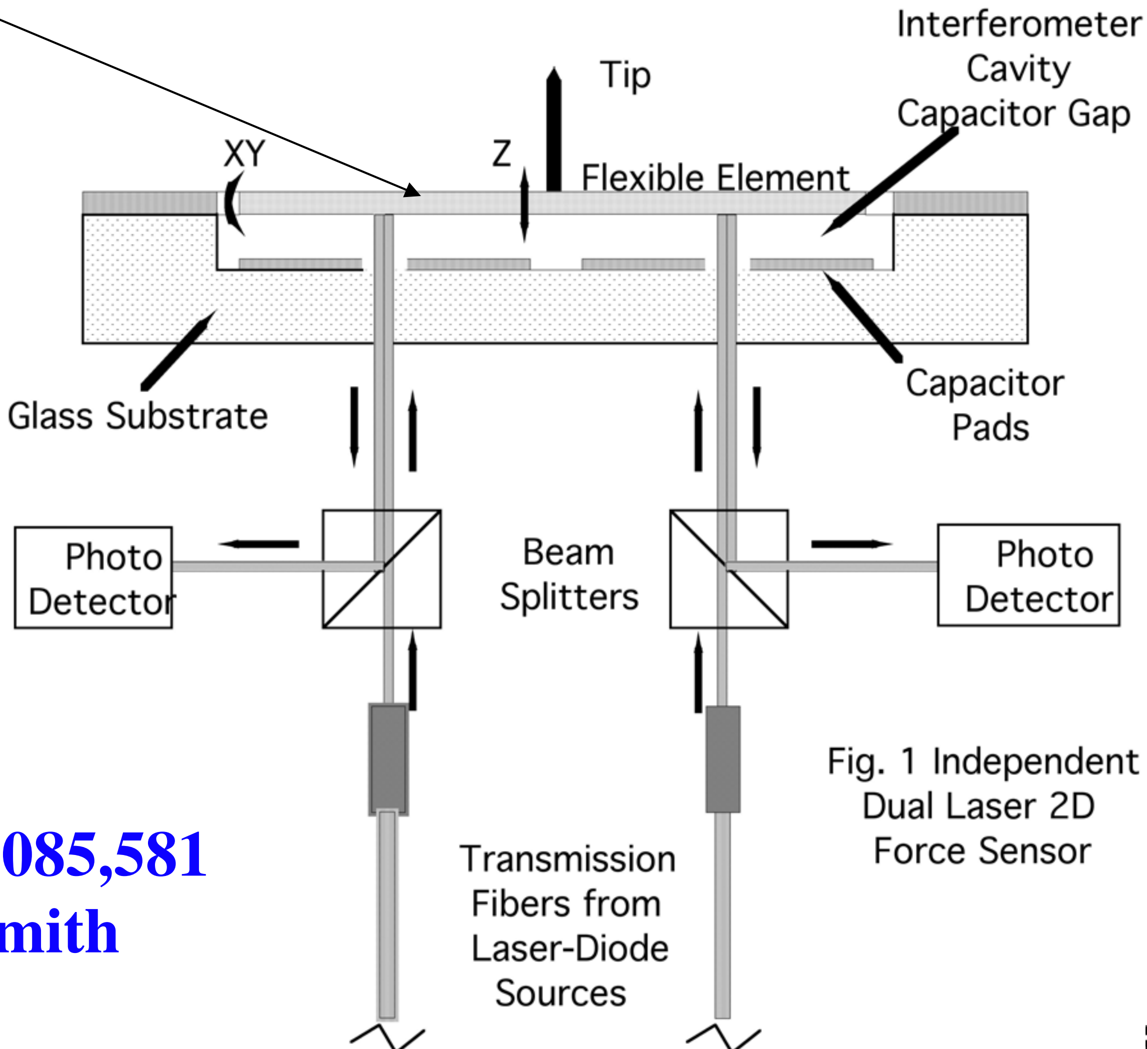


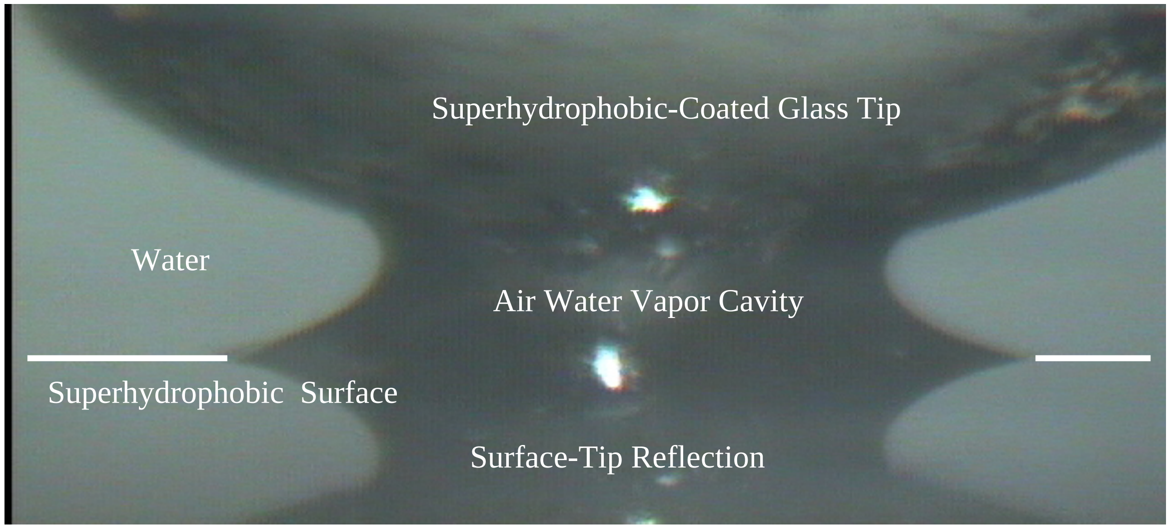
Fig. 1 Independent Dual Laser 2D Force Sensor

US Patent No. 6,085,581
Houston & Smith

IFM Characterization of Interfacial Water I-a

Cavity Nucleation Between Superhydrophobic Surfaces

(1) Interfacial Force Microscopy (IFM) investigations of superhydrophobic (SH) surfaces in water SH surfaces nucleate a air/water-vapor cavity when brought very close to contact, giving rise to considerable interfacial attraction (see: Singh, Houston, Van Swol and Brinker, Nature 442, 526, Aug 2006)



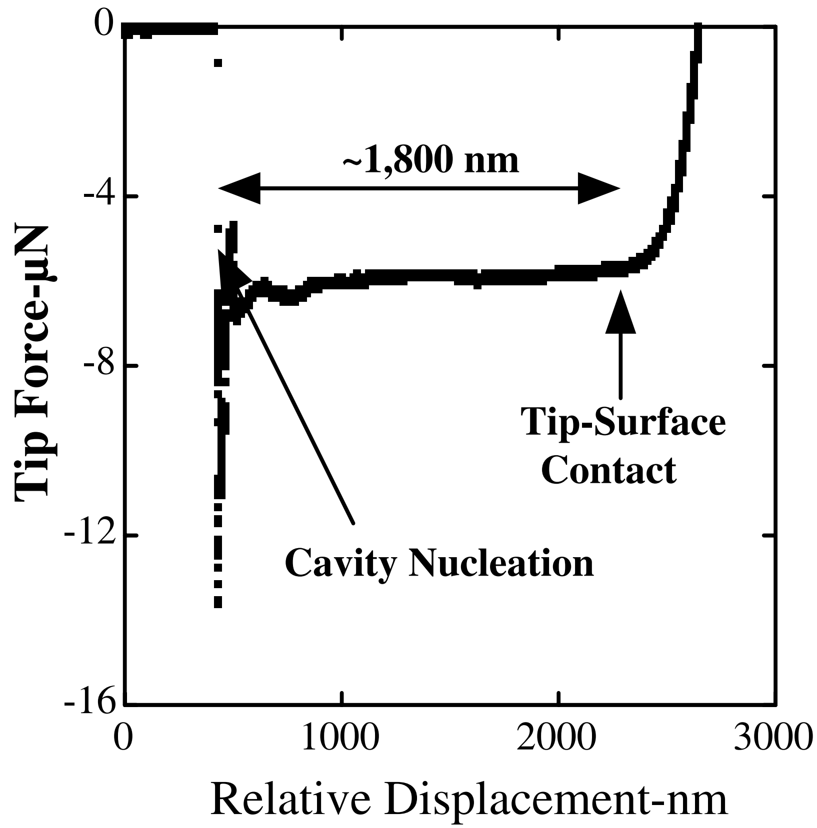
The photo shows a glass tip coated with a superhydrophobic film approaching a similar surface submerged in water. The substrate surface is indicated by the white lines and the bottom section is the reflection of the tip and cavity off the substrate surface. The meniscus looking area between the tip and substrate is an air/water-vapor cavity or bubble.

Sandia National Laboratories

IFM Characterization of Interfacial Water I-b

IFM Force v. Displacement curve of a Superhydrophobic surface brought to near contact in water, nucleating an air/water-vapor cavity that creates a large attractive force between the tip and substrate.

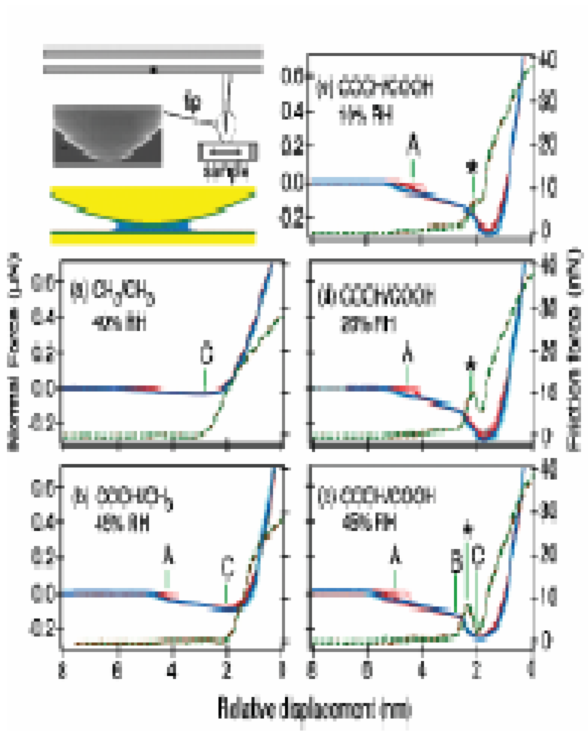
The plot shows the force on the tip (negative forces are attractive) as a function of the relative interfacial separation. The sudden increase in attractive force signals the nucleation of the air/water-vapor cavity shown in the previous photo. As the tip continues its approach, the contact between the tip and substrate surfaces is signaled by the rapid rise of the force toward repulsive values. The nucleation, thus, occurs at a separation of about 1,800 nm.



Sandia National Laboratories

IFM Characterization of Interfacial Water II

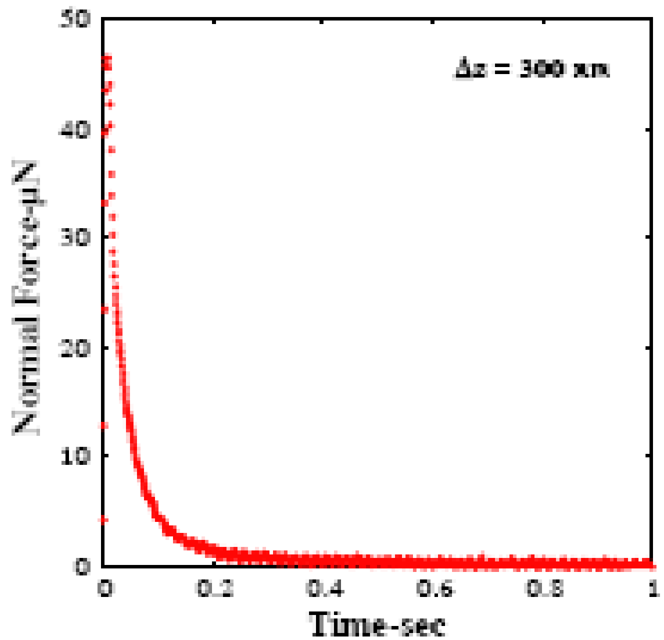
(2) IFM observes that nano-confined water exhibits high viscosity (see: R. C. Major, J.E. Houston, M. J. McGrath, J. I. Siepmann & X.-Y. Zhu, PRL 96, 177803, 2006)



The SEM image shows the parabolic Au IFM tip with radius of curvature of 500 nm. (a)–(e) shows the normal force and friction force profiles as a function of relative displacement between the tip and the sample for Au surfaces made hydrophilic or hydrophobic by the chemisorption of a COOH or CH3 terminated alkanethiol SAM.

Dynamic - Nanoindentation IFM Analysis of Viscoelastic Materials

The unique feedback-based stability of the IFM was applied to the microlevel transient analysis of the time-dependent properties of an extreme example of a "solid liquid" viscoelastic material with challenging adhesive creep properties (Silly Putty™). See: Journal of Polymer Science: Part B, Vol. 43, 2993–2999 (2005)



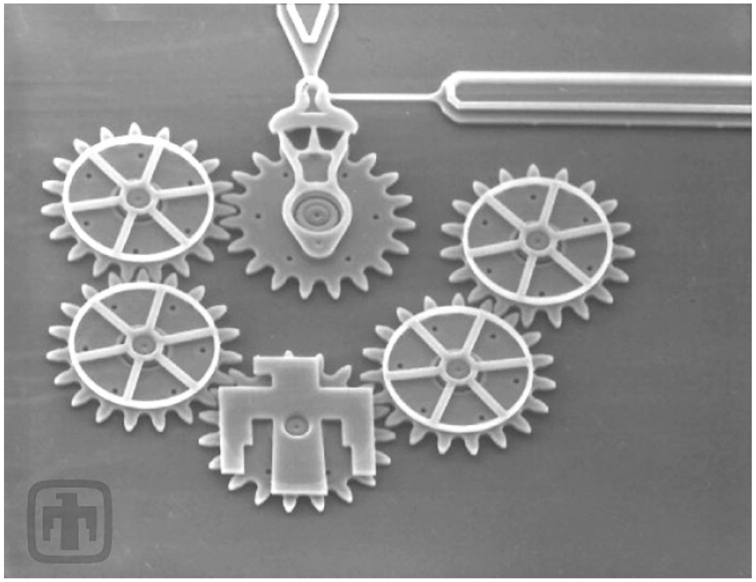
IFM relaxation measurements shows that "silly putty" is very stiff for very short times but will not support long-term load

This demonstrates that IFM has the potential to investigate challenging matrix aging degradation mechanisms in polymer composites and fiber reinforced composites.

The Microsystems Qualification Challenge

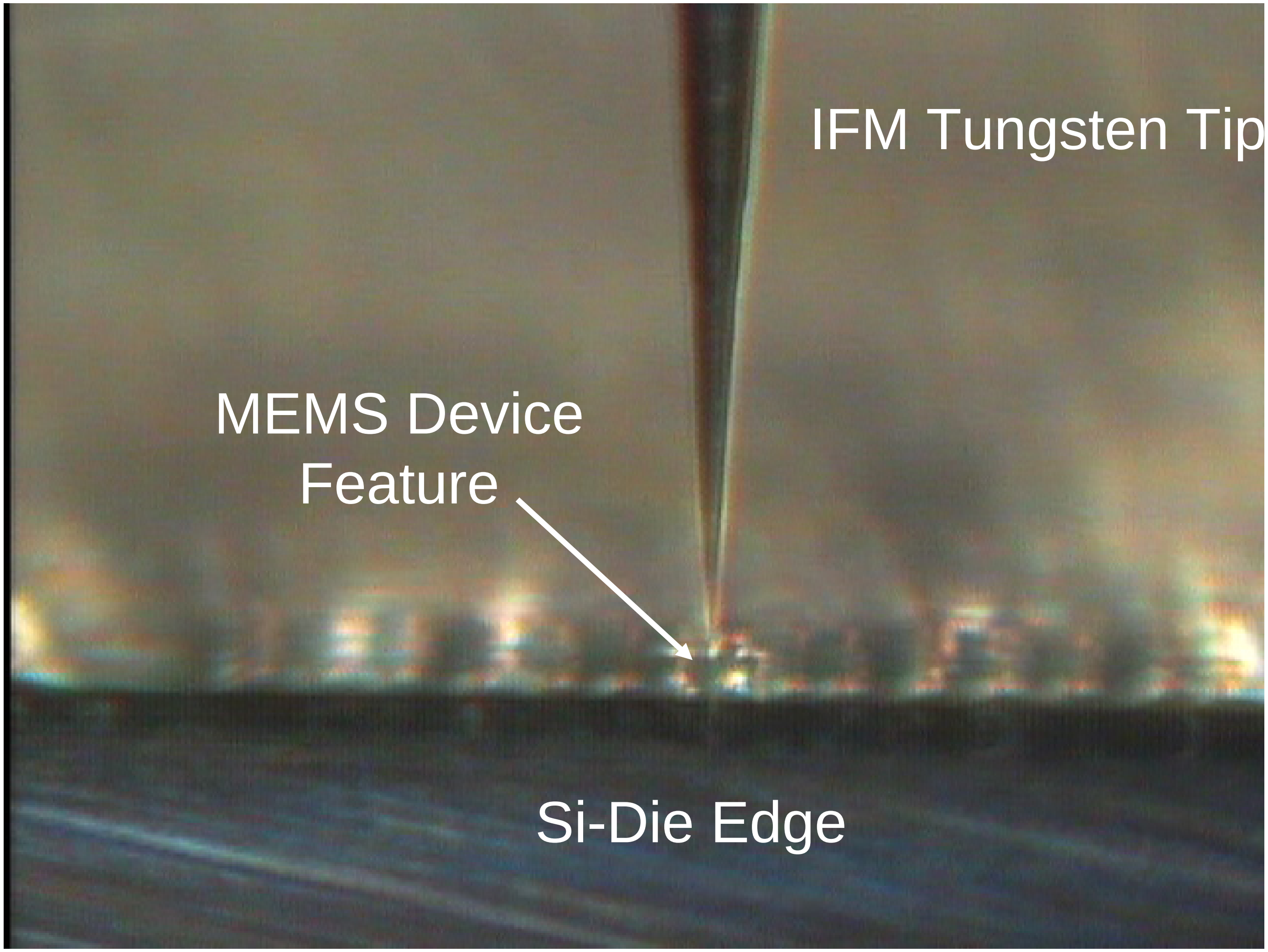
SNL is adapting instrumentation developed to support its fundamental BES science activities to directly and quantitatively characterize the in-plane forces and displacements involved in active elements within an integrated microsystems device and its passively coupled components. This will impact nanomechanics, validate microsystem design, enable microsystem failure analysis, and address stringent MEMS component qualification needs.

For acceptance of microsystems in critical applications, new instruments must be developed that can guide design efforts and enable failure analysis studies that can improve device reliability. The IFM has the potential for adaptation to meet this critical requirement.



Sandia National Laboratories

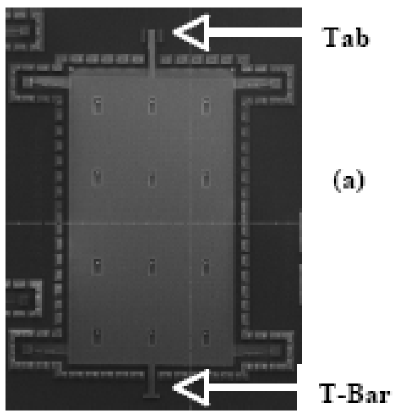
Lateral-Force IFM Sensitivity Permits MEMS Rheology and Mechanical Measurements

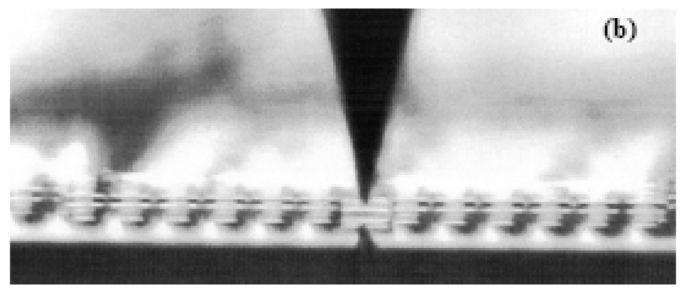


Sandia National Laboratories

Direct IFM Measurements of MEMS Structures I

The IFM can directly the normal and lateral forces generated by the active elements in MEMS, and also how these forces progress through a chain of coupling components. At present, no other technique is available for making such measurements.



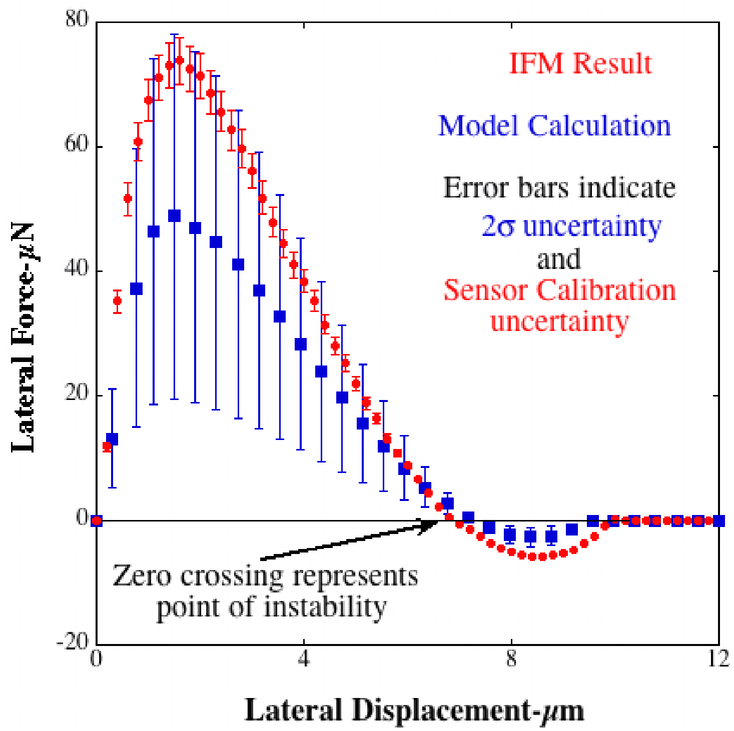


(a) A SEM image of a bistable MEMS component. The central shuttle is supported by nonlinear springs on each corner and is mechanically accessed by a "T-Bar" on the bottom and a "Tab" on the top. (b) is a micrograph of the device viewed edge on from the bottom showing the IFM tip located in the center of the T-Bar in preparation for the displacement of the device downward to make contact with the tip.

Sandia National Laboratories

Direct IFM Measurements of MEMS Structures II

Simulated and IFM-Measured Force-Displacement Curve of a bistable MEMS Component



The figure shows the IFM results shown in red along with the model predictions in blue. The error bars indicate the confidence level of the modeling and the calibration of the IFM sensor. The IFM results are within the error bars for model but differ in scaling. However, even if the scaling is compensated, there still remains a significant discrepancy between the measured and predicted values for the instability point, i.e., where the slope of the two curves changes sign. This value represents the critical parameter in qualifying device performance.

IFM can be used to efficiently guide MEMS design & fabrication!

Sandia National Laboratories

Potential IFM Collaboration Opportunities

Staff contact: Jack Houston (SNL)

CINT User Call at cint.sandia.gov

- **Collaboration using the IFM for developing novel SAMs coatings (i.e., for microsystems)**
- **Collaboration using IFM towards obtaining state-of-the-art nanotribological data of novel nanostructures and nanocomposites**
- **Developing IFM capability using newest SNL instrument developments**
- **Fundamental science of nanoscale properties of the fluid/solid interface**