Role of Atomic-Force Microscopy in the Characterization of High-Performance and Reliable Nanomaterials

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Workshop on Reliability Issues in Nanomaterials
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PH 2510, Atomic Force Microscopy

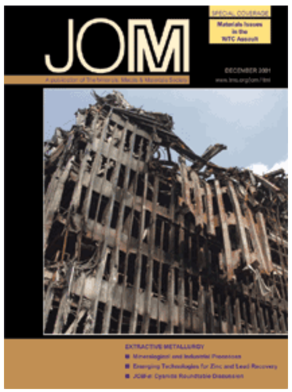
- Students learn:
  - ✓ Laboratory procedures
  - ✓ How to acquire and optimize an image
  - ✓ Tip, cantilever, and scanner calibration
  - ✓ Force curve acquisition and interpretation
- I emphasize:
  - ✓ Introductory physics (e.g. Newton’s, Hooke’s Laws)
  - ✓ Current research
  - ✓ Scientific practice

Do we expect nanomaterials to be reliable if the tests and models we apply to them are *inaccurate* and *unproven*?

- Perspective on models
- Perspective on instrumentation
- Accuracy of models and methods (participate!)
- Wish list, status and future

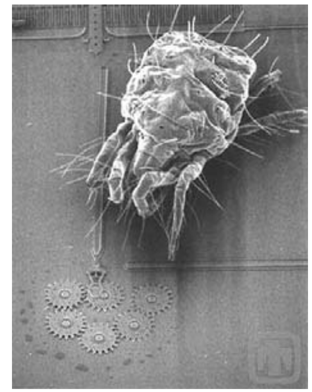
Large size range of mechanical systems

skyscrapers → transport → microsystems → molecules

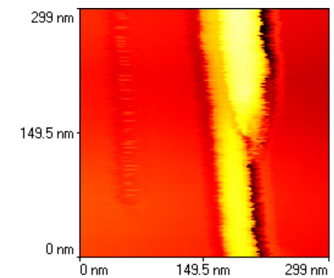


Journal of Materials

Dean Kamen



Sandia National Lab

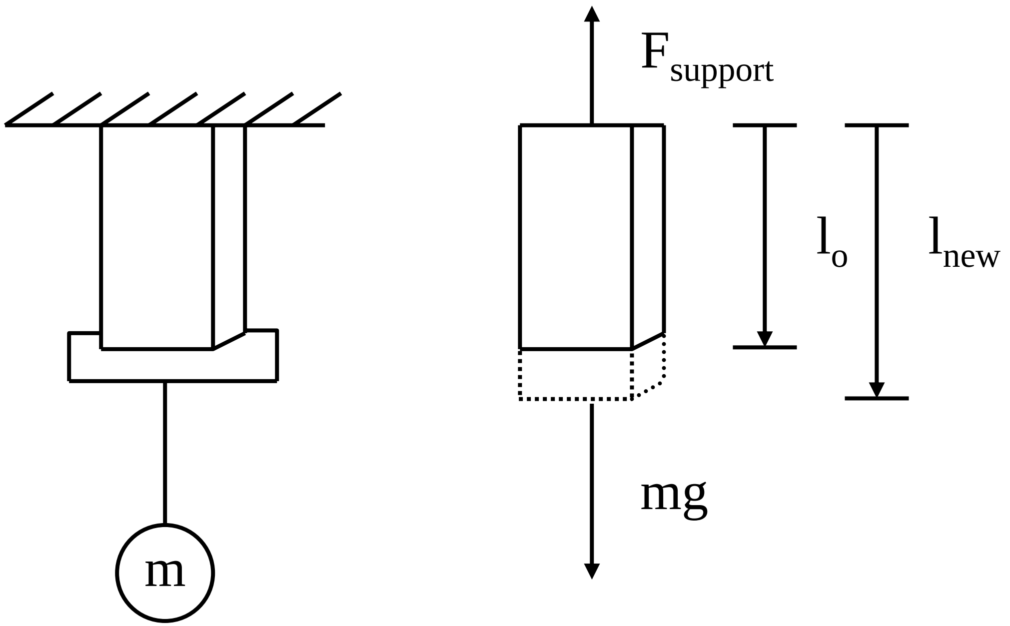


NP Thompson, WPI ‘02

Need to have numbers for mechanical properties, for example:

modulus
damping
adhesion
friction
wear

Quite often, mechanical properties are determined by some relationship between *force* and *deformation*.

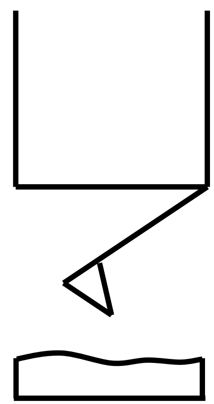


Can find force-deformation relationships at the submicron scale with a device called an atomic force microscope (AFM). An AFM is usually used for imaging features in the size range 10 nm → 10 μm.

Scanner

Cantilever

Sample



Stiffness ~ 1N/m

Tip radius ~ 100 nm

Control position of base of cantilever

⇩

Observe cantilever response, F = -kd

⇩

Deduce materials properties

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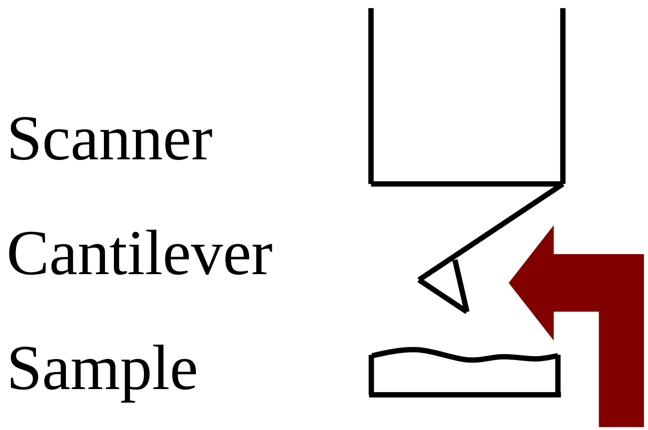


Stiffness ~ 1N/m
Tip radius ~ 100 nm

Note that cantilever is at an angle!

Control position of base of cantilever

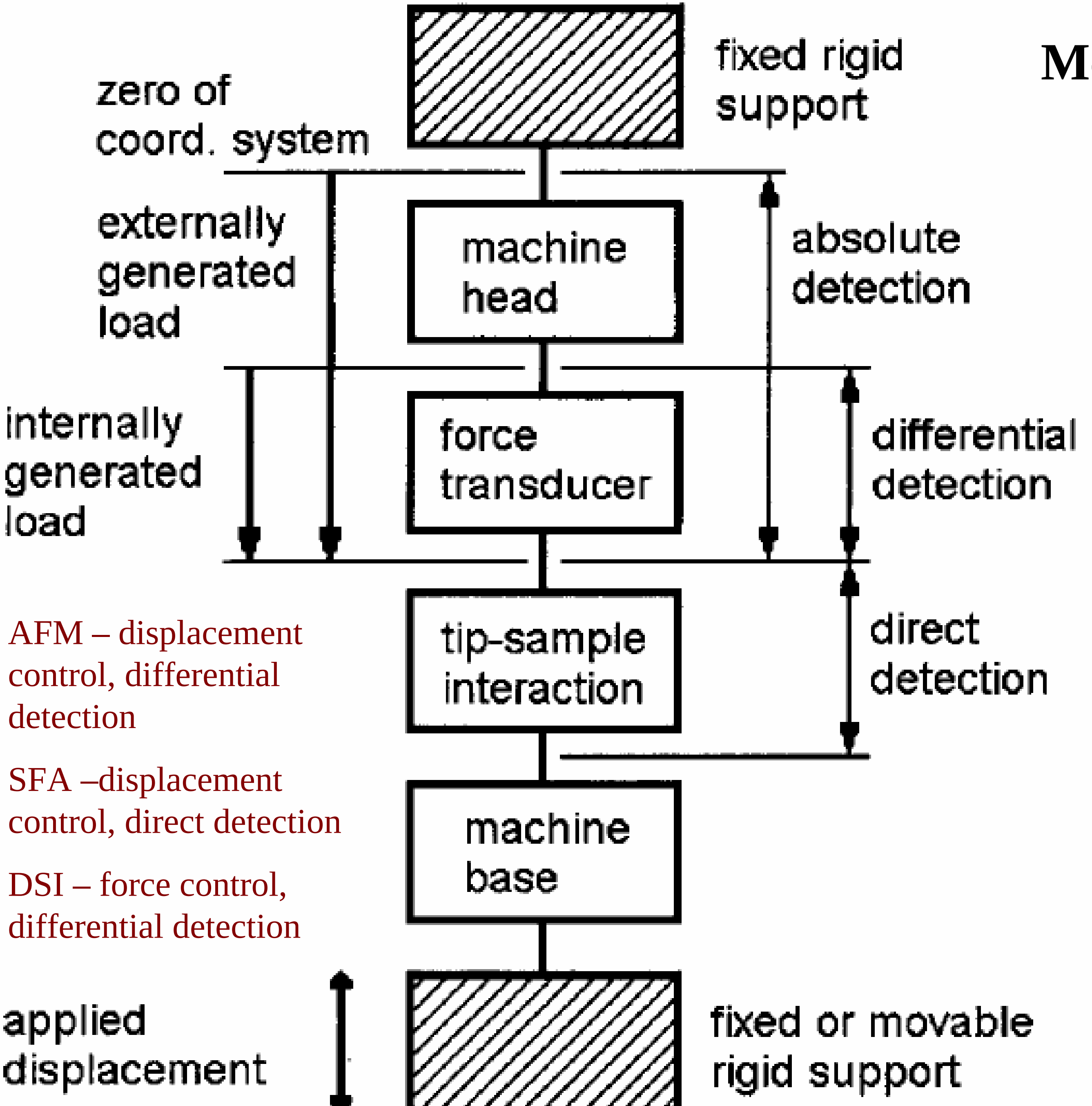
⇩

Observe cantilever response, F = -kd

⇩

Deduce materials properties

Mechanical Properties Nanoprobes



AFM – displacement control, differential detection

SFA –displacement control, direct detection

DSI – force control, differential detection

Surface-forces apparatus (SFA), depth-sensing indentor (DSI), and atomic-force microscope (AFM) form an instrument class in which force or displacement is applied to a sample or force transducer, and resulting displacement or force is measured.

Burnham, Baker, Pollock, JMR **15**, 2006 (2000)

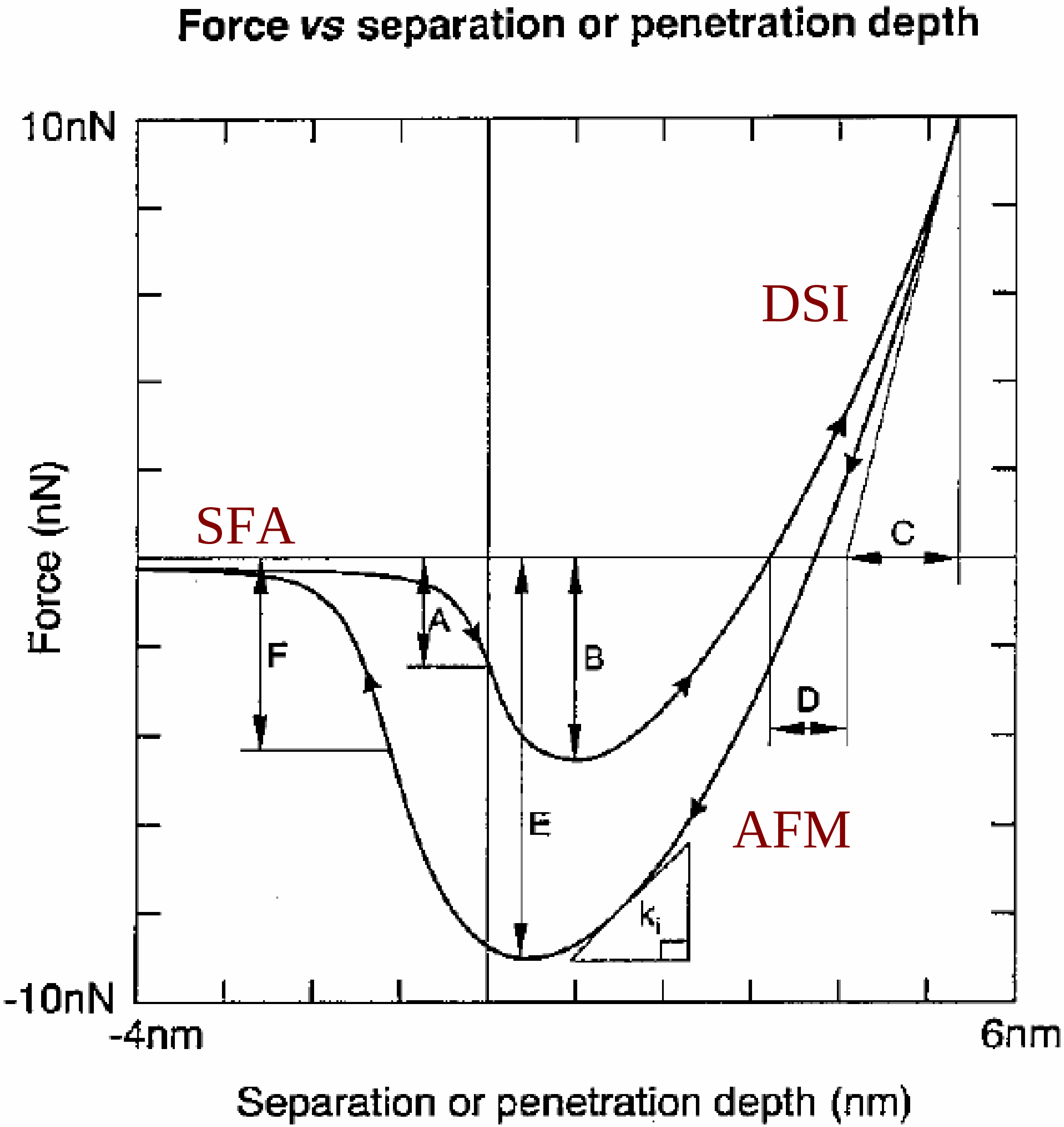
Accuracy

Models – simple, yet descriptive

- SFA, DSI cover different depth regimes than AFM
- Surprise for compliant materials at low loads
- Few-asperity contacts

Methods – systematic and random errors, calibration

- Radius calibration of spherical tips
- Normal stiffness of AFM cantilevers 10%!
- Lateral force calibration for AFM



Different separation or depth regimes

Theory well developed for SFA and DSI regimes, where one need consider only attractive and repulsive forces, respectively. AFM gives us the opportunity to explore the very first stages of contact, but necessitates models that incorporate both attractive and repulsive forces, *and their interaction.*

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The perfect instrument for nanomechanics?

- Good metrology for position *and* force
- Force sensor normal to surface with high resonant frequency *and* with very sharp, durable tip.
- Choice of stiffness of force sensor for both good measurements of mechanical properties *and* topography
- Easy switch between force *and* displacement control
- Choice of relative *or* absolute *or* direct detection
- Wide range of operational frequencies, temperatures
- High-bandwidth, low-noise preamplifier

Status and future

Currently, AFM force metrology is poor and models for tip-sample interactions are just beginning to be quantitatively compared with experiment.

Short term, AFM spring-constant calibration methods should be verified and improved. Five percent accuracy might be possible.

Medium term, robust small tips of well-defined geometry should be developed. Carbon nanotubes are a possibility. Can an AFM tip move perpendicularly to surface?

Long term, models need to be quantitatively checked against experiment.