DTR Summary: Workshop on Reliability Issues in Nanomaterials

Barriers:

- Standards
- Fabrication tools
- Measurement tools
- Data
- Understanding
- Modeling tools

DTR Summary: Plenary talks

Workshop on Reliability Issues in Nanomaterials

Susanne Arney Materials Requirements and Measurements in Design and Manufacture of Micro- and Nano- Electromechanical Systems for Performance and Reliability

Review and application of classical reliability

Required: specified, excellent performance over 20 year lifetime

Analysis tools used in process optimization:

SEM, TEM, SIMS, Auger, AFM, EDX, RBS, etc.

Special characteristics of active MEMS devices:

Measure displacements accurately

Optics in environmental chambers lacking

Key performance metric: reflectivity

John Randall Materials Requirements and Measurements in Nanoscale Manufacturing and Assembly

Assembly manufacturing is currently in a sad state

No assembly solution for parts, tolerances smaller than 0.5 mm

For their devices, would like excellent position accuracy in 6 degrees of freedom

Trying to understand fiber-matrix effects for carbon nanotubes

How perfect are nanotubes? How about a particular one?

CNT diameter: TEM, AFM; length: no good approach

Accuracy of scanning probe systems is known to be bad (without active feedback)

Surfaces, subsurfaces in 3D?

How do you design in reliability?

Modeling and lots of it

Ken Rodbell, IBM Materials Requirements and Measurements in Design and Manufacture of Advanced Electronic Interconnect for Performance and Reliability

Adaptation of a laboratory instrument to a production-line metrology tool: X-ray Diffraction

Measure thickness by comparing diffracted intensity from test film to reference film—NIST supply reference or standard films 200 nm thick, with specified texture and phase?

Measures texture by a new theory relating area-detected X-ray intensity to ODF (orientation distribution function)

Next problem: measure stress

Rachel Goldman Materials Requirements and Measurements in Design and Fabrication of Semiconductor Nanostructures for Performance and Reliability

Reviewed principles and materials for quantum dots

Key functional parameters: quantum dot size, shape, density, uniformity, positions

Cross-sectional scanning tunneling microscope (XSTM)

- Limitation: vacuum
- Need: reproducible sharp STM tips

Reliability issue: stability of various defects

Wish list:

Control of quantum dots: size, shape, densities, uniformity, positions

Need: reproducible sharp STM tips

Substrate temperature uniformity

Low noise 1-D and 2-D wafer curvature measurement,
compatible with MBE, MOCVD

Fast UHV nano-jet probe compatible with MBE, MOCVD

Gas-source UHV focussed ion beam (FIB) compatible with a variety of MBE and MOCVD systems

William Gerberich Significance of Mechanical Behavior in Small Volumes to Design of Reliable Nanomaterials and Nanoscale Devices

Characterize nanomaterials by:

Young's modulus, E

σ_{ys} , yield strength

σ_f , flow or fracture strength

K_{Ic} , fracture toughness

da/dt, fatigue crack growth rate

Strain controlled fatigue?

Most or all of these can be measured by careful application of a nanoindenter

However there are barriers to simplistic measurements of these quantities:

Size Effect
Yield Points
Adhesion
Work Hardening

“Hot topics” as indicated by the program for the coming MRS meeting:

- S: Size Effects
- T: Temp. or Viscoelasticity
- M: Multiscale Modeling
- A: Adhesion or Surface Energy

Challenges of small length scales:

- Importance (establishing?)
- Indentation size effect
  - Polymers
  - Metals
- Film fracture
- Nanoparticles

Discussion of some experiments, pointing length scales as deduced from continuum mechanics modeling, adhesion effects (can be large)

Error sources in nanoindentation measurements of E or H:

Work-hardening; strain-gradient plasticity
Pressure effects
Image forces, reverse plasticity
Adhesion and pile-up
Interface energy
Roughness or porosity

Tantalizing possibility:
Atomistic modeling of actual experiments

Martin Dunn Necessary Reinterpretations of Continuum Mechanics Concepts for Applicability to Nanomaterials

Thermomechanics of thin film structures

Issues:

- Deformation
- Stresses
- Stability
- Creep
- Stress relaxation

Surprising phenomena fully explainable using conventional mechanics considerations, and handbook property values

Nancy Burnham Role of Atomic Force Microscopy in Conception, Design, and Characterization of High-Performance and Reliable Nanomaterials

“How can nanomaterials be reliable if the tests and models we apply to them are inaccurate and unproven?”

Use AFM to measure

- Modulus
- Damping
- Adhesion
- Friction
- Wear

Examples and problems were given

Wish list:

- Good metrology for position and force
- Force sensor normal to surface with high resonant frequency, with very sharp durable tip
- Selectable cantilever stiffness for mechanical properties and topography
- Easy switching between force and displacement control
- Choice of relative, absolute, or direct deflection measurement
- Wide range of frequencies, temperatures
- High-bandwidth, low-noise preamp

Neville Moody Significance of Adhesion and Interfacial Fracture in Design of Reliable Nanomaterials and Nanoscale Devices

In many applications, interfaces control performance and reliability

Many different test methods for adhesion have been reported:

- Stressed overlayer
- Nanoindent
- Nanoscratch

Continuum mechanics models are needed to reduce the observations to fracture toughness values

Enough complementary observations are possible to give some confidence in the measured interfacial toughness

Measurements and modeling are interdependent

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Materials Science and Engineering Laboratory (and NIST) Activities

Standards

Measurements

Data

Modeling

What did we hear?

Standards

- Force calibration (something available from NIST but poorly marketed?)
- Reflectivity
- Film on substrate, for thickness, texture

Measurement steps to characterizing a nanomaterial:

1. Imaging

    Atom positions in 2 and 3 D

    Sharp, durable, reproducible STM tips

    Sharp, durable, reproducible AFM tips

    Crystal structure, grain size, texture

2. Mechanical properties

    AFM

    Nanoindentation

    FIBbed columns

    microtensile

3. Interfaces

    Adhesion or fracture toughness

4. Coupled measurements

    e. g. mechanical-optical

Data

Bulk property data for which accepted measurement methods exist should be available for all relevant compositions

Modeling

Desired: predictive and informative modeling
Pervasive part of all nanoscale measurements

What are the priorities?

- Atom imager?
- AFM, indent in TEM? How many places?
- Quantitative improvements in AFM, nanoindentation?
    - x, y position
    - z position
    - force
    - tip shape
    - Better STM, AFM tips
- Nano-jet
- Standard MD software?