Measuring Stiffness and Adhesion on the Nanoscale with AFM

Dalia Yablon, Ph.D.
A.B. Chemistry, Harvard University
Ph.D. Physical Chemistry, Columbia University
• Type questions into the question field

• Webinars are being recorded

• Recorded webinars can be found at www.mccrone.com
Measuring Stiffness and Adhesion on the Nanoscale with AFM

Dalia Yablon
dalia.yablon@surfacechar.com
AFM can measure many other useful surface properties

**Mechanical**
- Tapping mode
- lateral force (LFM)
- force modulation (FMM)
- contact resonance (CR-FM)
- torsional resonance (TRM)
- pulsed force (PFM)
- shear force modulation

**Force spectroscopy**

**Electrical**
- Kelvin force (KFM)
- Electrostatic force (EFM)
- Piezo force (also PFM)
- Conducting AFM (C-AFM)
- Scanning capacitance (SCM)

**Magnetic**
- magnetic force (MFM)

**Optical**
- Near field Raman (NSOM-Raman)
- Near field IR

**Other**
- molecular pulling
- lithography
- manipulation
- thermal microscopy (SThm)
- 3-D nanoprinting
Force curves/force spectroscopy: single point measurements

- **Static force spectroscopy**: Single point measurements where the tip goes in and out of the surface
  - Employ contact mechanics models to probe adhesion, capillary force, modulus
  - Can map force curves over the surface as well

- **Dynamic force spectroscopy** – force curves while cantilever is oscillating
  - Plot amplitude, phase as cantilever approaches the surface
**Force curve mapping vs tapping mode**

**Dynamic mode**
- (AC or “tapping mode”)
- → RESONANT (higher freq)

**Nonresonant**
- (lower freq)

**Force Curve Mapping:**
- “Force Volume”
- “Volume spectroscopy”
- “Pulsed Force mode”
- “Peak Force QNM” (quasistatic, reduce shear)

→ NONRESONANT
Force curve/force spectroscopy

- Modulus
- Adhesion
Static force curves contain important mechanical information on your surface

• Static force curve measures the interaction (force) between your tip and sample as a function of distance (z)

• Operates in the elastic regime

• Contact mechanics models used to model interaction between tip and sample to measure:
  • Young’s modulus
  • Adhesion/surface energy

• Hertzian contact mechanics: predict stresses and deformation that occur when two solid objects are brought into contact with each other
  • BUT….these models don’t take into account van der Waals interactions between the tip and sample
  • Resort to DMT, JKR model that do take into account interactions between tip and sample
Hertz analysis – model 2 lenses

Studied interference fringes between 2 glass lenses, pressed together
Derived equations to model the observed behavior

Contact between two spheres → region around contact deforms with center displacing by $\delta$
Circular contact area $A$ is formed with radius $a$
Contact mechanics models with tip-sample interactions
Force curves on impact copolymer
Create force maps...

**Height**

**Adhesion**
Create stiffness maps with different models

- Height map
- JKR modulus map

JKR modulus for rubber: 8 MPa
JKR modulus for PP: 270 MPa
2 Rubbers cured for different amounts of time: fit with JKR model

Rubber #1
Peak fit: 3.8 MPa

Rubber #2
Peak fit: 4.7 MPa

Modulus

Adhesion
Peak fit: 6.9 nN
Peak fit: 5.7 nN

“stiffening”

“less sticky”

Data from Nanosurf

SHOCON lever (0.12 N/m, 155 nm/V sensitivity)
Forcemaps on cells

Adhesion

Elastic modulus

Epithelial cells

Data from nanosurf

Fibroblast cells

Elastic modulus

Data from Asylum Research (online image gallery)
Forcemsaps on polymer brush

Polybutylacrylate

Data from Bruker Nano (AN128)
Force spectroscopy – current state of the art

• Impressive control over all features of force curve:
  • Separating out parameters for approach and retract
  • Customizable parameters: triggers, hold (creep) segments, frequencies, etc.

• Main contact mechanics models are commercially available for fitting
  • DMT, JKR, Sneddon, Hertz are all standard parts of force analysis packages

• Wide range of spring constants for commercial cantilevers

• Speed, speed, speed
  • Force volume now done with real time acquisitions speeds
Challenges of force spectroscopy

• Useful tool to measure stiffness and adhesion force in your sample
• End up with large data sets!
• Analysis can be a real hurdle
  • Real-time analysis with limited set of models
  • Need user-friendly ways to use different models within the same image
    • Heterogeneous materials – all materials may not be suitable for DMT analysis
    • Need to have familiarity with method and analysis for rational analysis
• Truly quantitative measurement with force curves still a challenge because of uncertainties in:
  • Tip shape calibration
  • Spring constant determination
  • Contact mechanics model assumptions
Courses in
Atomic Force Microscopy/
Scanning Probe Microscopy

To register for future webinars or if you missed one of our past webinars, access the recorded presentation and related resources. Our webinars provide insightful information and innovative approaches to microanalysis that apply to a wide range of industries.

www.mccrone.com/webinars

Hooke College of
Applied Sciences

Dalia Yablon, Ph.D.
www.hookecollege.com