Simultaneous Electrical and Mechanical Property Mapping at the Nanoscale with PeakForce TUNA

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"Begin with the End in Mind"

Sample courtesy of Dr. Battaglia, LBL

- Simultaneous Topography
  + Mechanical Property Mapping
  + Electrical Property Mapping
- Sample
  Soft / Delicate
Tunneling AFM (TUNA)  
= AFM-based Conductivity Measurement
Atomic Force Microscope Modes

AFM evolution centers around force control.

- 1986 Contact Mode, Binnig (IBM), Quate, and Gerber
- 1993 Tapping mode, Digital Instruments
- 2009 PeakForce Tapping Mode, Veeco/Bruker
PeakForce Tapping Mode

A force-distance curve is obtained in each tapping cycle with controlled peak force.
High Resolution Imaging on Liquid Crystal

Star-shaped mesogen (liquid crystal) Courtesy of Domitri Ivanov @ ICSI
Simultaneously obtain quantitative data:

- Topography
- DMT Modulus: \(~1\text{MPa} \text{–} 100\text{GPa}\)
- Adhesion
- Energy Dissipation
- Deformation
QNM - Approach to Material Assignments

Multi-component polymer blend (7 µm scan)
Which mode will you use to image the conductivity of an conducting polymer?
Integrating PeakForce Tapping with TUNA

- PeakForce Tapping + TUNA

Bandwidth Matching:
- PeakForce Tapping Frequency: 1 kHz - 2 kHz
- TUNA: >10x faster
PF-TUNA Module
-why a new current amplifier design

- High Bandwidth
  - ~15 kHz

- High Gain
  - 6 gain settings from 100nA/V to 20pA/V
PF-TUNA Quantities

1) Peak Current  
2) Contact-Averaged Current  
3) Cycle-Averaged Current

C  
B<--->D  
A<------->E
Lithium Ion Battery Composite Cathode

Gao Liu, LBL
Simultaneous Morphology, Mechanical and Electrical Mapping (L333-Glue)

Li[Ni$_{1/3}$Mn$_{1/3}$Co$_{1/3}$]O$_2$
Two distinct conductivity peaks can be assigned to the less conductive Li[Ni$_{1/3}$Mn$_{1/3}$Co$_{1/3}$]O$_2$ and the more conductive PVDF+AB blend. A conductive network is formed within the PVDF+AB region; with a overall coverage of 56%.
The higher conductivity peak increases as more (AB+PVDF) is added, conductive network approaches full coverage with 12.8% additives. More additives (24%) likely just increase the thickness of PVDF+AB coating.
Young’s modulus decreases as more (AB+PVDF) is added, offering more tolerance for volume change during cycling. The trend change agrees with expectation.

Organic Solar Cell
Donor/Acceptor Pair and Bulk Heterojunction (BHJ)

A common donor/acceptor pair used in organic solar cells: P3HT:PCBM).

The stacking of an organic bulk heterojunction solar cell
P3HT on PEDOT/ITO/Glass

2μm scan, Peakforce 1nN, Bias 3V. Au-coated ScanAsyst-Air.
P3HT spin coated on PEDOT/ITO/Glass, annealed at 120° C. Sample courtesy: Dr. Ngyuen of UCSB.
P3HT:PCBM on PEDOT/ITO/Glass

2um scan, Peakforce -1.5nN, Bias 2.5V. Au-coated ScanAsyst-Air. Sample courtesy: Dr. Nguyen of UCSB.
“Perhaps one of the most significant practical challenges to using pcAFM is obtaining a good electrical image without causing significant damage to the sample. Patience and a willingness to sacrifice many AFM cantilevers in the name of science, are often necessary.”

Carbon Nanotubes

Current map clearly identifies electrical connectivity of individual carbon nanotubes.

Sample courtesy of Prof. Hague, Rice University
Vertical Carbon Nanotube Mat

Topography (left) and current maps (right) of carbon nanotube pillar array. Image size 1μm.
Point&Shoot I-V Curves on V-CNT
PF-TUNA vs TR-TUNA

Current: PF TUNA shows more consistent conductivity across individual nanotubes
Bruker AFM + MBraun Glovebox
-Integrated, Turnkey

Vibration Isolation Table

<1ppm O₂/H₂O

Sturdy Support
New turnkey environmental control
Comparison of AFM-based conductivity measurement techniques

<table>
<thead>
<tr>
<th></th>
<th>PF-TUNA</th>
<th>Contact-TUNA</th>
<th>Tapping-TUNA</th>
<th>TR-TUNA</th>
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</thead>
<tbody>
<tr>
<td>Conductivity mapping</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Minimum peak force</td>
<td>&lt;100 pN</td>
<td>&lt;10 nN</td>
<td>&lt;3 nN</td>
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<td>Quantitative Mechanical Property Mapping</td>
<td>Yes</td>
<td>No</td>
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<td>Ease of use</td>
<td>Yes</td>
<td>Yes</td>
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</table>
Concluding Remarks

- Enable reliable nano-electrical imaging on soft delicate samples such as loosely bound nanostructures, conductive polymers
- Improve imaging resolution and tip lifetime while making conductive AFM measurements easier
- Enhance material assignments on the nanoscale by making use of both quantitative nano-mechanical and nano-electrical properties
- ppm environmental control
  Preserve sample and measurement integrity in lithium battery and organic optoelectronic applications (solar, LED)
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Application Note #132

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