Multimodal Microscopy Using "Half and Half" Contact Mode and Ultrasonic Force Microscopy

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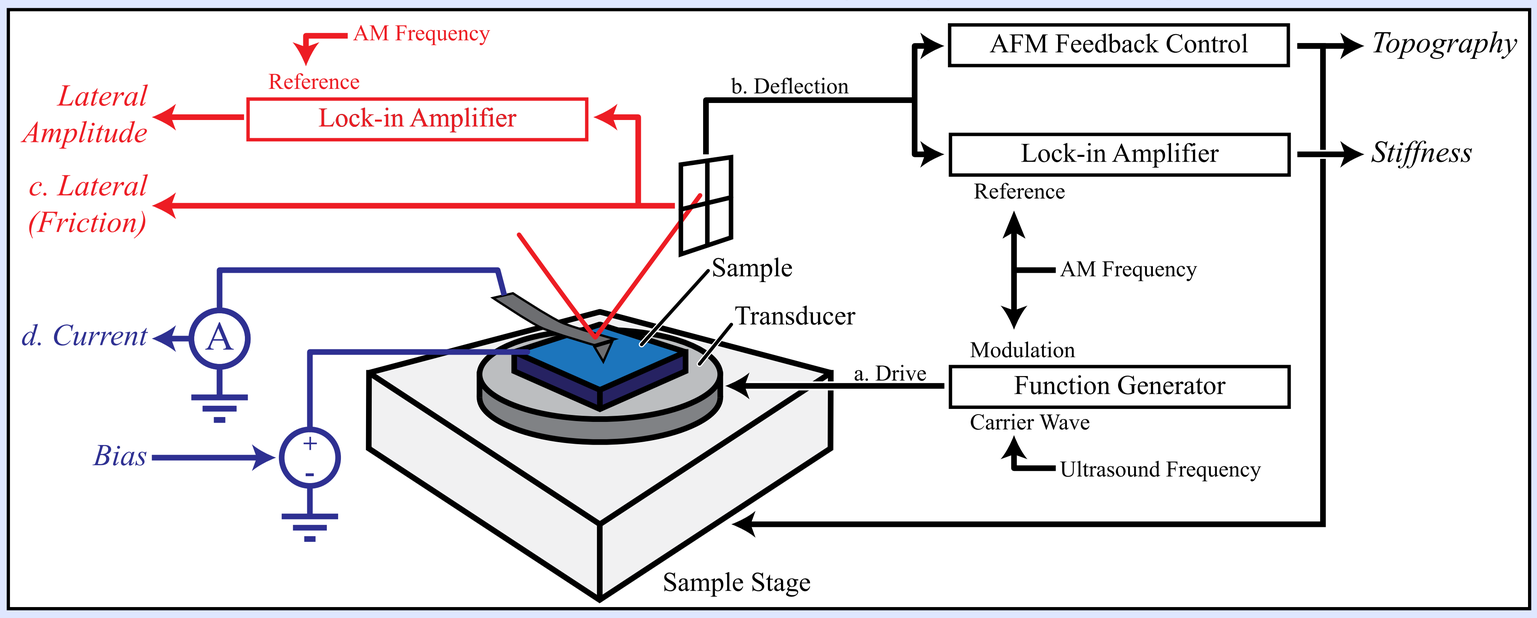
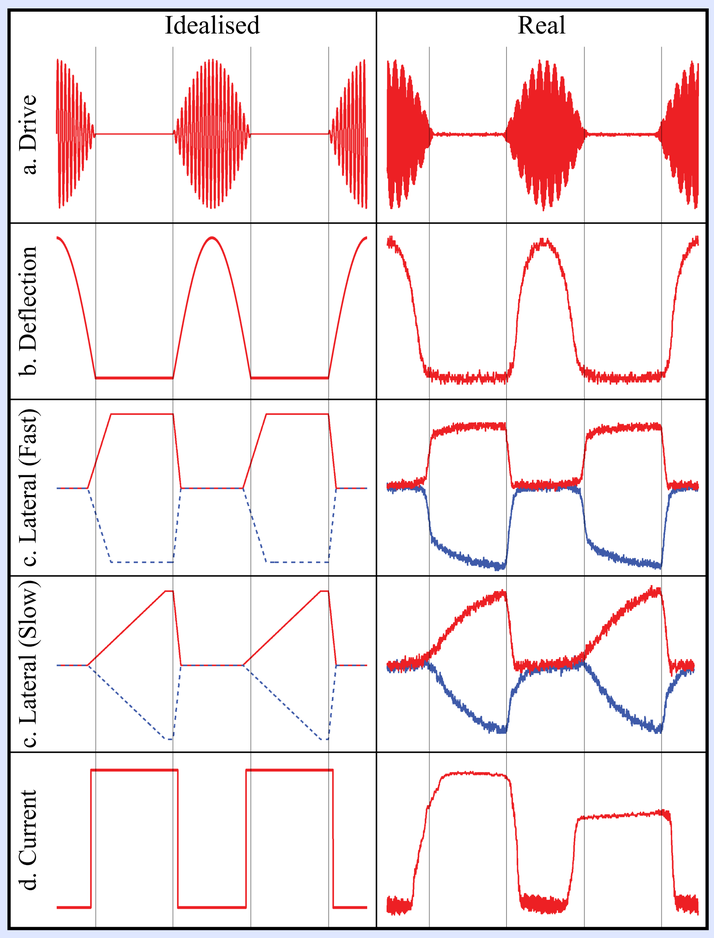
Summary

- Ultrasonic Force Microscopy (UFM) is used to investigate relative stiffness of a sample surface.
- Application of ultrasound is modulated at much lower frequencies, resulting in a "half and half" static and dynamic imaging mode.
- Contact mode techniques can be applied using the static portion.
- Multimodal scanning demonstrated using friction and conductive AFM combined with UFM.
- UFM also reduces damage to samples that is typical of contact mode, allowing use of these techniques on delicate samples.

Theory

- Sample is mounted on piezoelectric transducer and oscillated at frequencies well above the cantilever resonance.
- Cantilever is stationary over oscillation period, with the deflection determined by average force, which depends on the shape of the force curve (i.e. the sample stiffness).[1]
- Stiffer samples cause greater deflection.
- Ultrasound is modulated at lower (<10kHz) frequencies to be off for half a modulation period, decoupling topography and stiffness.
- During the off period, the tip is in contact with the sample, allowing contact mode techniques, such as friction force microscopy (FFM) and conductive AFM (cAFM) to be used in conjunction with UFM.



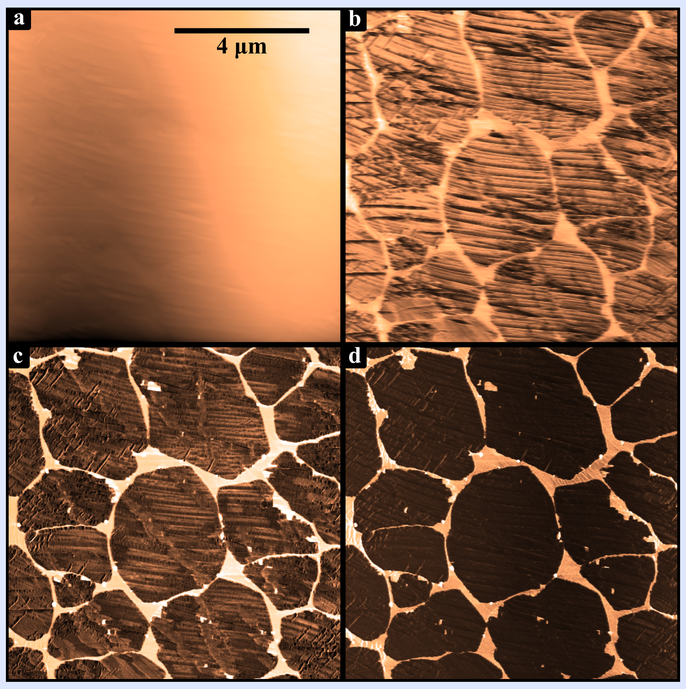


Figures

- Left - Schematic of the UFM setup with the additional contact mode channels also shown.
- Above - signals seen in the labelled channels of the schematic.
  - » "Fast" and "slow" refer to the relative tip velocity.
  - » Blue lines are for the retrace signals.

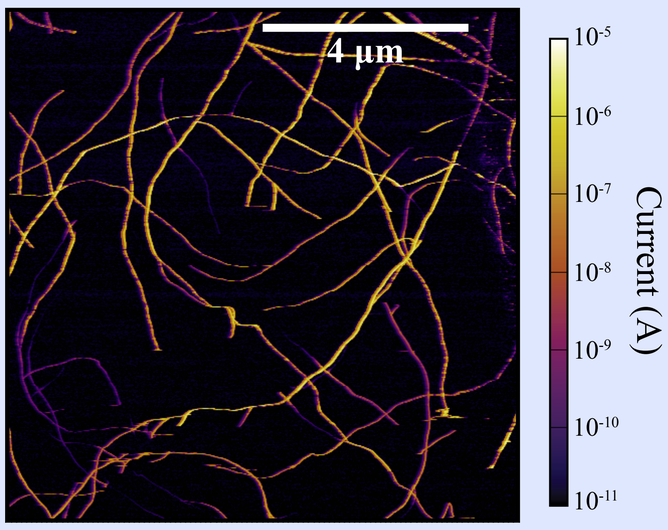
Friction

- No friction during ultrasound period, friction during contact period.
- Measure lateral deflection of cantilever.
- Affected by topography, remove first order influence by subtracting the retrace from the trace.[2]
- Can also measure the lateral amplitude using a lock-in amplifier, which gives friction and is independent of topography, allowing single direction scans.
- Example (below) - partial coverage graphene on copper, all images are acquired simultaneously.
  a. Topography (600 nm full data scale) - sample is too rough to clearly resolve graphene flakes.
  b. UFM - graphene appears slightly softer than copper (out of plane stiffness).
  c. Friction (later trace minus retrace) - Clear contrast between graphene and copper.
  d. Lateral amplitude (retrace only) - clear contrast, same as the standard friction image.



Conductivity and Fragile Samples

- Conductive contact is broken when ultrasound is on.
- Current still flows during contact period.
- Lack of friction during ultrasound prevents dragging of surface material - reducing damage to delicate samples.[3]
- Example (below) - conductivity map of single walled carbon nanotubes taken with UFM active.
  - » Nanotube network attached to gold contact held at a bias of 2 V.
  - » Repeated scanning was possible while UFM was active, whilst scanning in contact mode swept nanotubes away.



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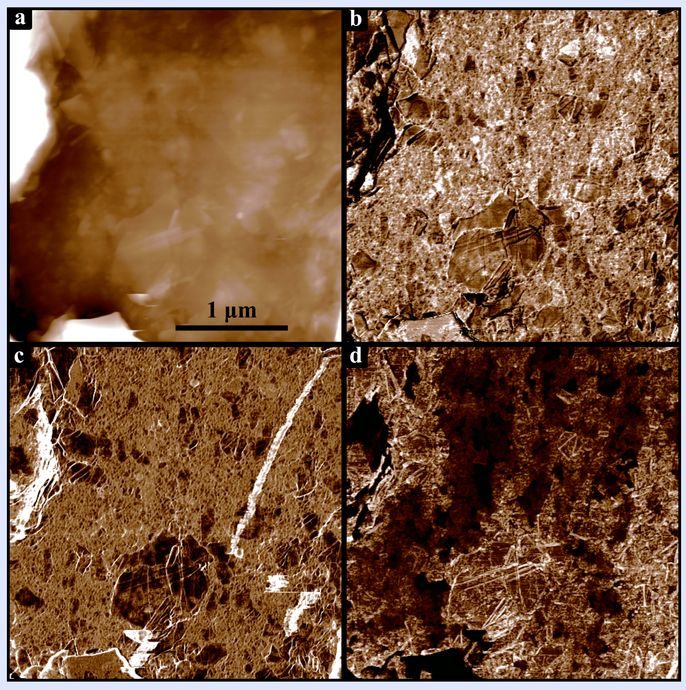
References

1. Yamanaka, K., Ogiso, H., & Kolosov, O., *Applied Physics Letters*, **64**, 178 (1994).
2. Marsden, A. J., Phillips, M., & Wilson, N. R., *Nanotechnology*, **24**, 255704 (2013).
3. Dinelli, F., Castell, M., & Ritchie, D., *Philosophical Magazine A*, **80**, 2299 (2000).

Multiple Channels

- Can combine many contact mode techniques with UFM as required.
- Example (below) - UFM, friction and conductivity of a graphene in epoxy composite.
  a. Topography (150 nm full scale) - sample surface is very rough, though some surface flakes can be distinguished.
  b. UFM - surface flakes are visible as softer (darker) regions.
  c. Friction (lateral trace minus retrace) - surface flakes have lower coefficient of friction than the surrounding epoxy.
  d. Current (2 µA full scale), with a 0.5 V bias applied to top of sample - surface flakes have a high conductivity. Further detail is also present, showing the extended subsurface conductivity network formed by the flakes.
  - » Strong correlation between all property channels.



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