Dynamic Mode, Probe Based High Density Data Storage

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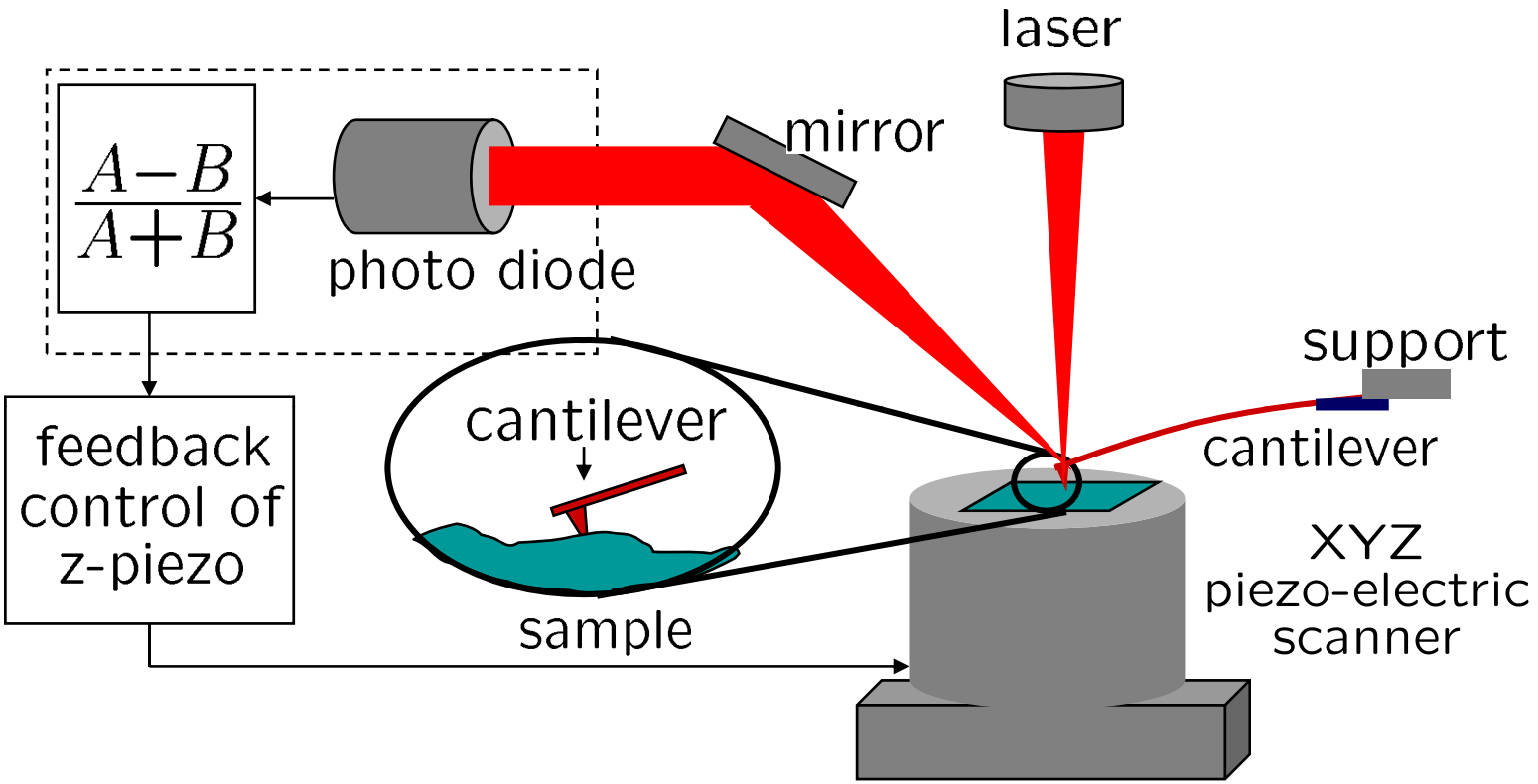
Systems Based Nano-interrogation

"These instruments, including scanning tunneling microscopes, atomic force microscopes, and near-field microscopes, provide the eyes and fingers required for nanostructure measurement and manipulation"

NanoDynamics

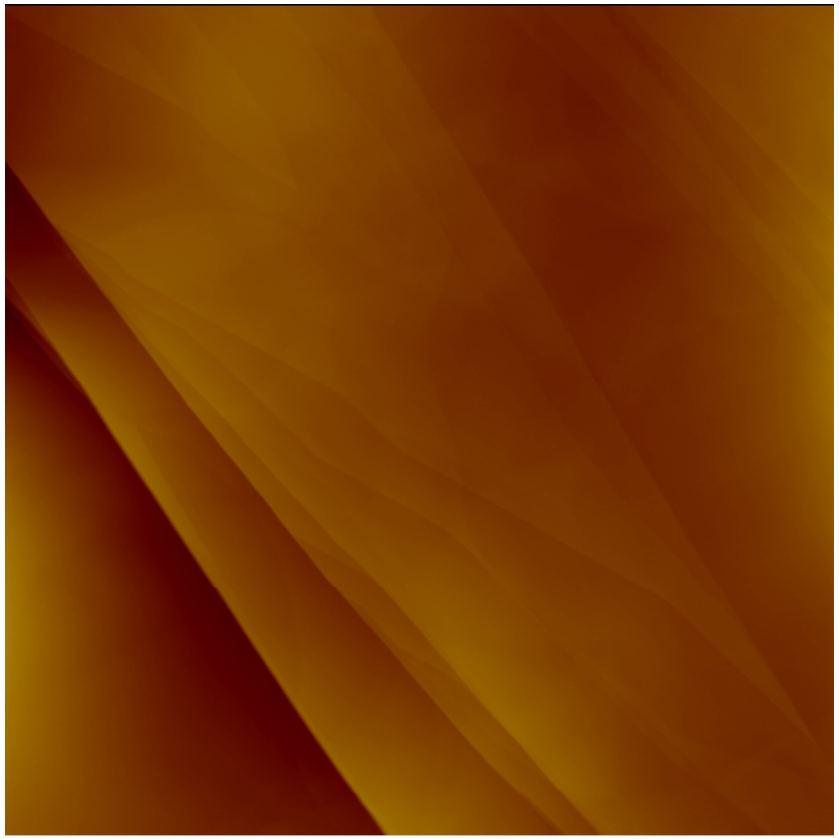
Systems Laboratory

Atomic Force Microscope

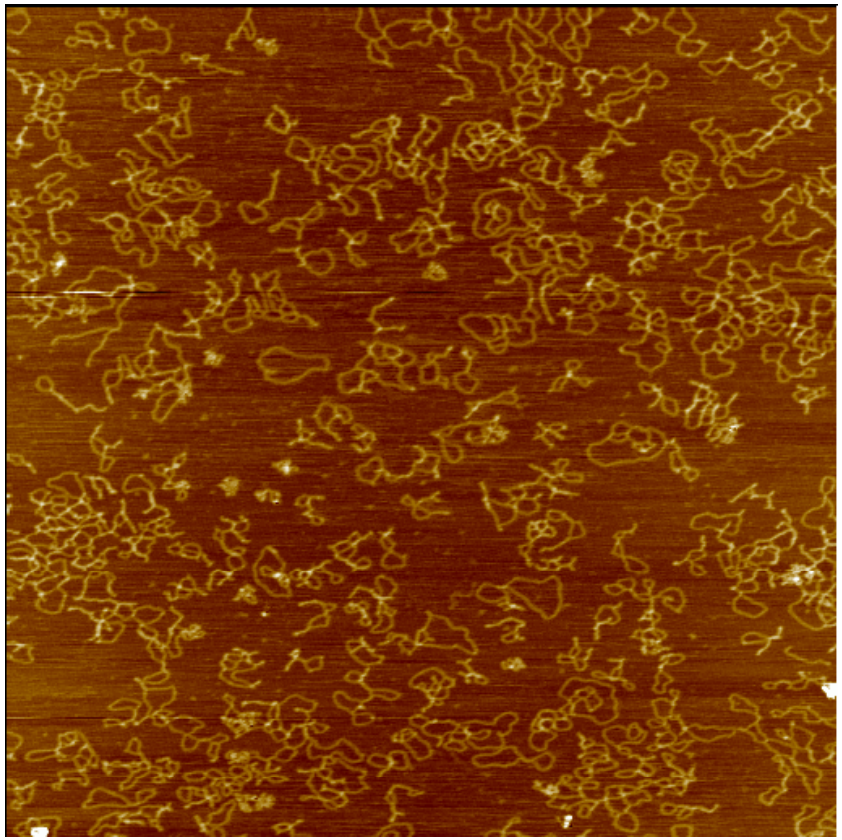


- One of the inventors
  - ⋆ Dr. Gerd Binnig; 1987 Nobel Prize winner; IBM, ZRL

Graphite and DNA

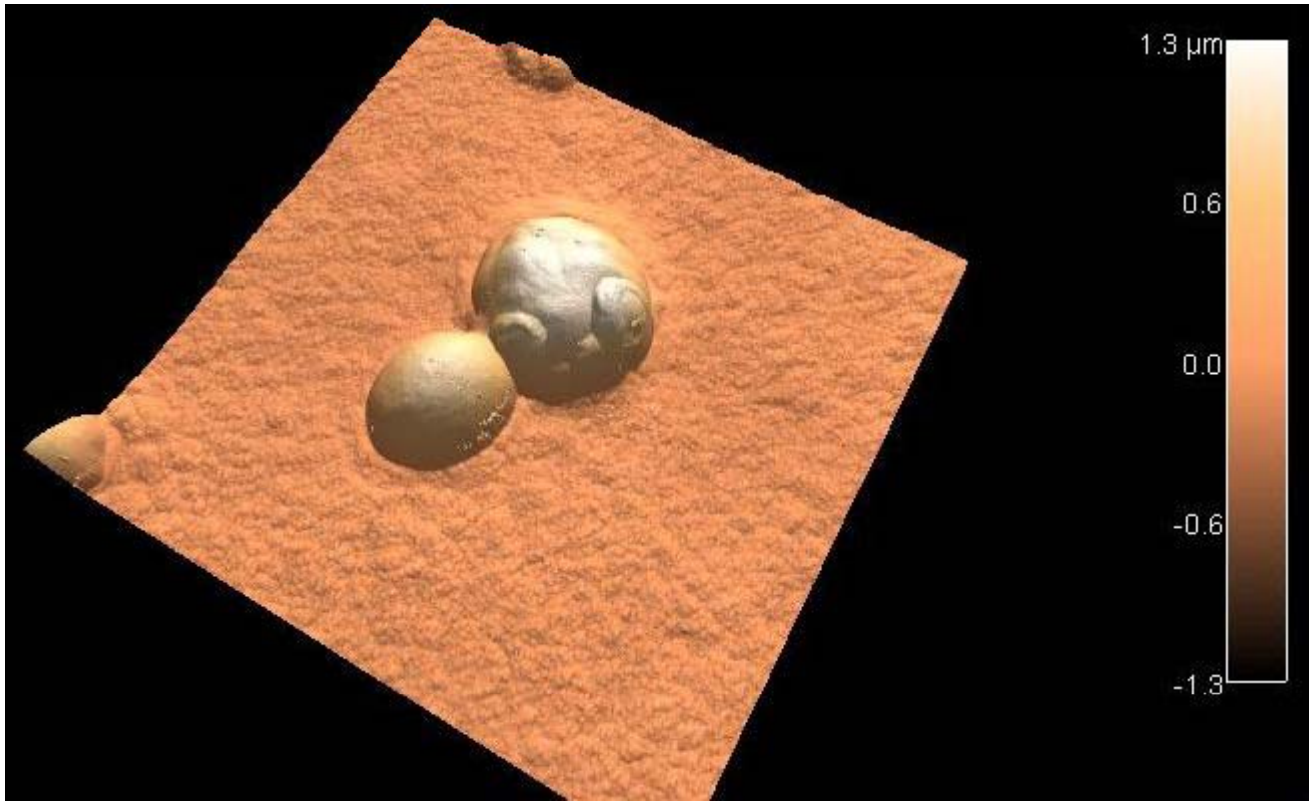


- Atomic Terraces on graphite surface
- Step heights: Multiples of 3.4 Angstrom

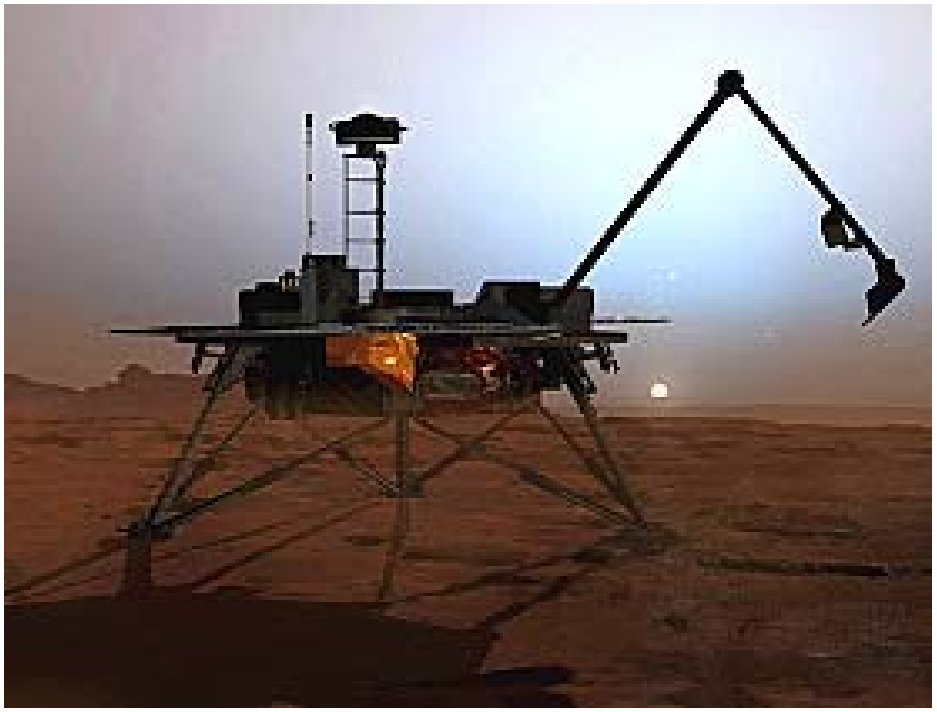


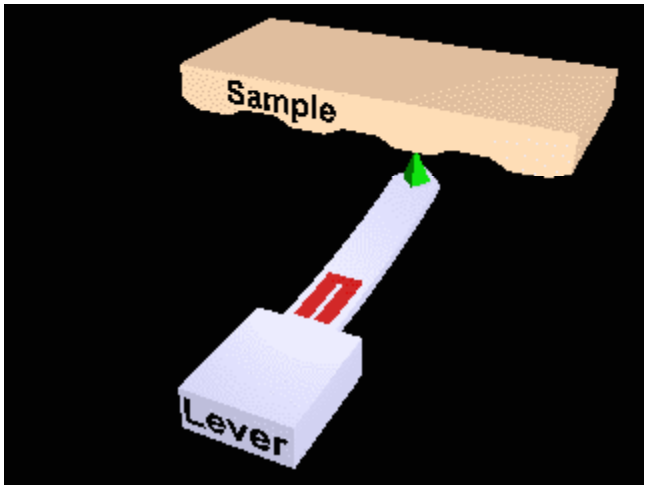
- Scan size 4 μ x 4 μ
- DNA height 1.2nm

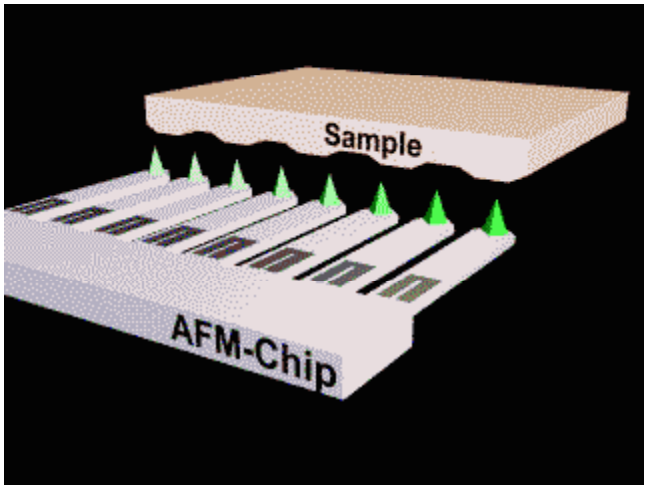
Budding Yeast With Scar



AFM on Mars Rover, Phoenix







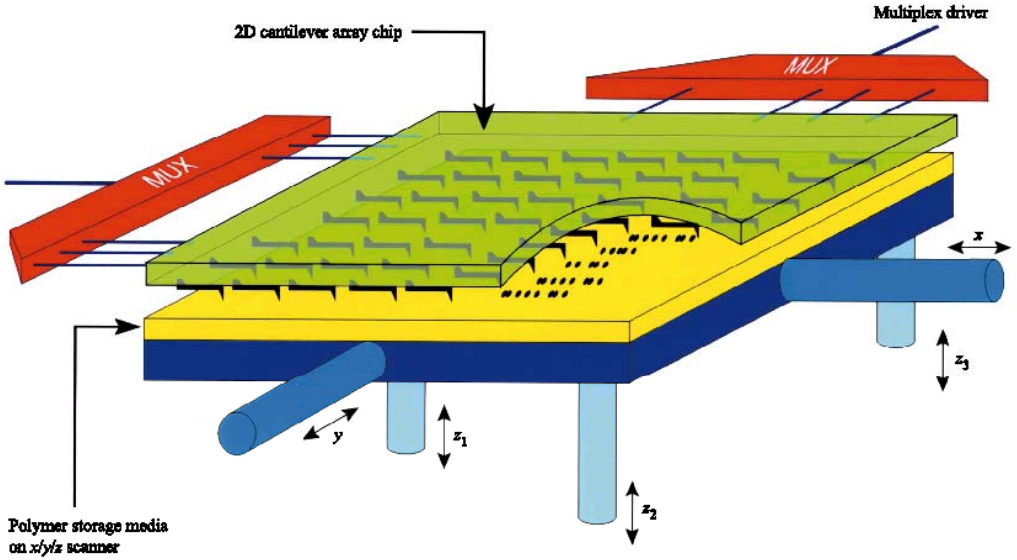
Taken from UNI BASIL, Switzerland

Collaborative Efforts With Industry

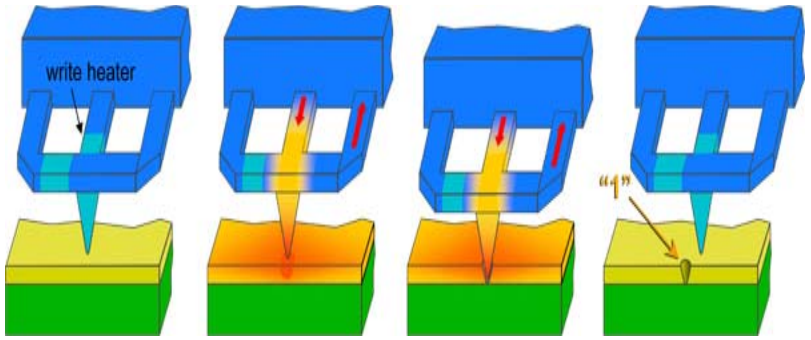
Conventional Means of Data Storage

- Magnetic
  - ⋆ Close to 300 Gb per square inch, 80 Mb/sec speeds, at 2.5 dollars per GB
  - ⋆ Fundamental limitation caused by supermagnetic effect that limits size of magnetic domains
  - ⋆ Systems Approaches
- Optical
  - ⋆ 5 GB in a single disk, low cost, tens of Gb per inch square densities
  - ⋆ Fundamentally limited by the wavelength of the laser
- Solid state based storage devices
  - ⋆ Competetive; life is a concern (10^5 write erase cycles)

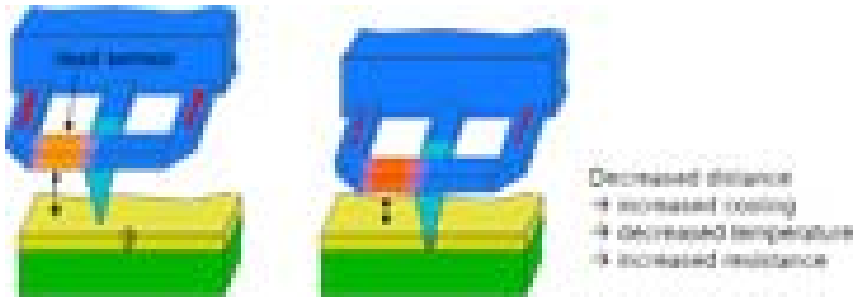
IBM: High Density Data Storage Millipede project



- Prototype demonstrating 1Gb per inch square acheived
  - ⋆ Abu Sebastian a previous PhD student pivotal to the success
    - – Pioneered breakthrough nanopositioning work with Prof. Srinivasa Salapaka
  - ⋆ Collborative agreement in place between NDSL and IBM, Zurich



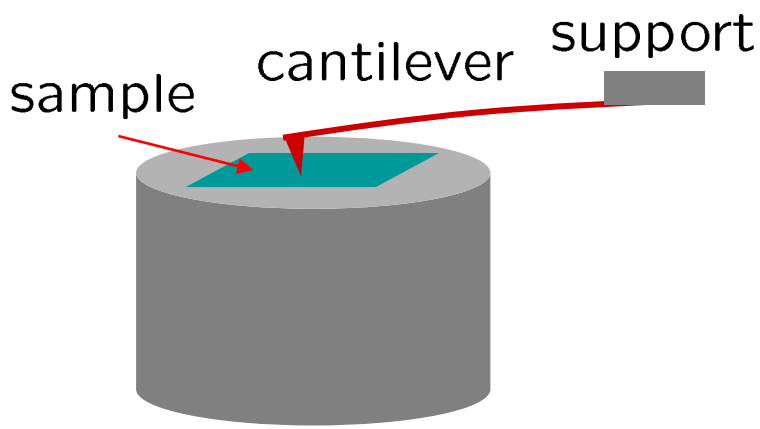
- Write Mechanism

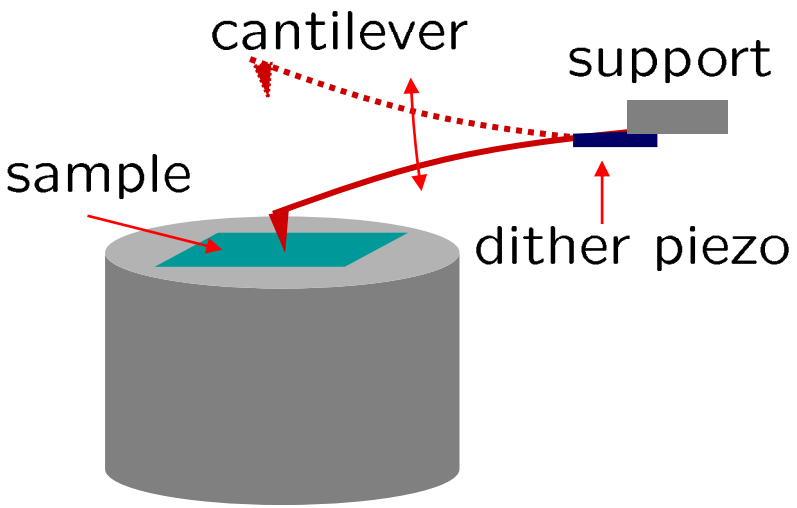


- Read Mechanism

Sponsor: (a) NSF under the title "Dynamic Mode High density Probe based data storage" (b) IBM Zurich Research Labs

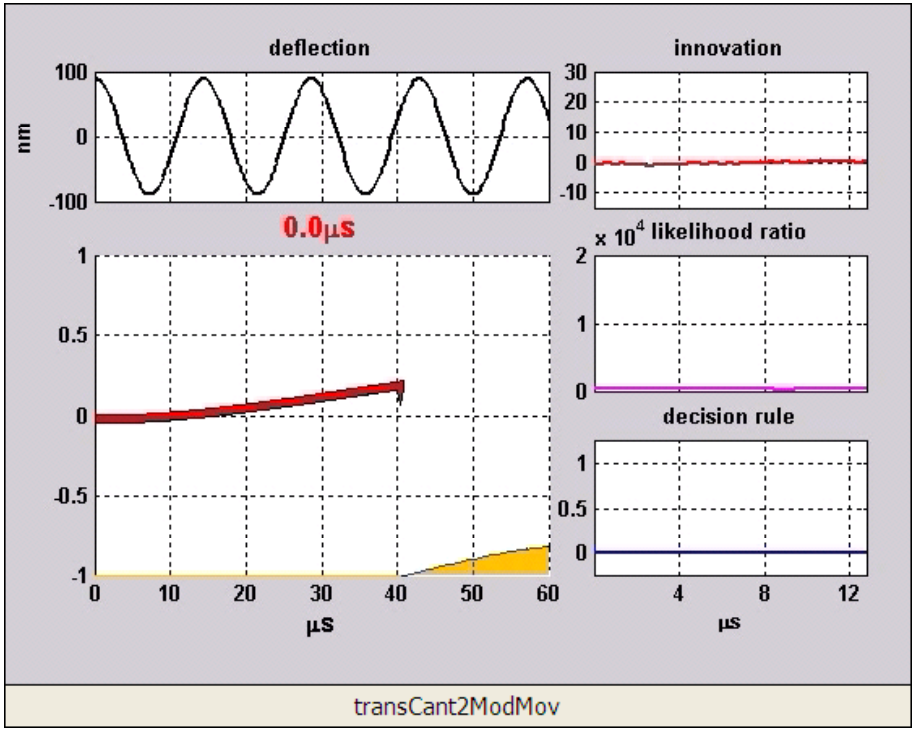
Operational Modes





- Contact mode:
  - ⋆ Cantilever not forced externally
  - ⋆ Deflection primarily due to tip-sample interaction forces
- Dynamic mode:
  - ⋆ Cantilever support is oscillated sinusoidally at or near first resonant frequency
  - ⋆ Amplitude and phase of the first harmonic of resulting orbit is interpreted to obtain sample properties
- Primary advantages of Dynamic(AM-AFM)-mode operation:
  - ⋆ Less harsh on the sample and tip
  - ⋆ High signal to noise ratio

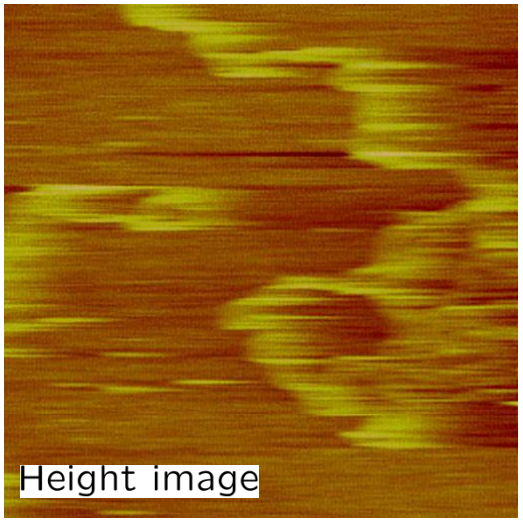
Systems Approach for faster read

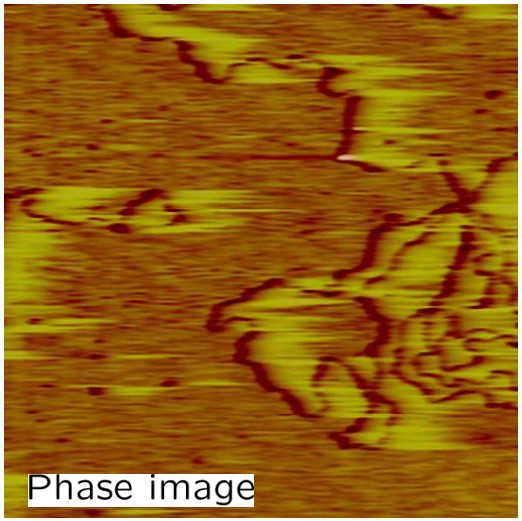


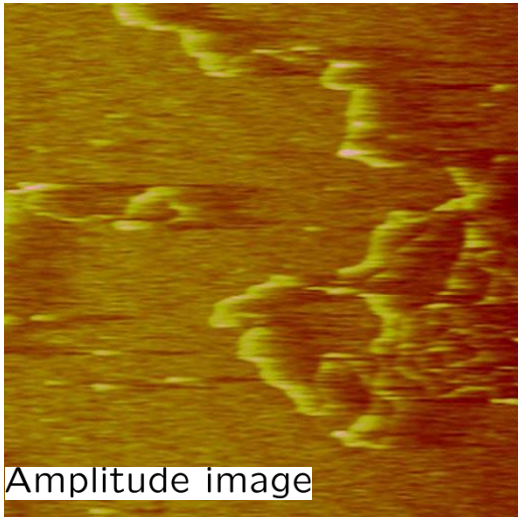
- Challenges of Dynamic Mode
  - ⋆ Conventional methods too slow for the read operation
- Transient Force AFM
  - ⋆ Invented at NDSL
  - ⋆ Utilizes Systems tools that are not familiar to Physicists
  - ⋆ Relaxes some fundamental limitations of previous techniques
  - ⋆ Upto teo orders increase in detection speeds

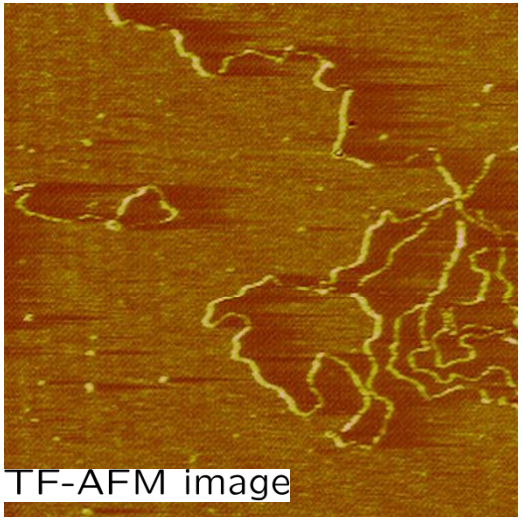
D. R. Sahoo(s), A. Sebastian, M.V. Salapaka, Transient Signal based sample-detection in Atomic Force Microscopy, *Applied Physics Letters*, 83(26), pp. 5521-5523, December (2003)

TF-AFM: Illustrative Results


Height image


Phase image


Amplitude image


TF-AFM image

- Sample
  - ⋆ Lambda DNA is approx 2 nm in height. The lateral scan size is 2 μ m.
  - ⋆ Scan speed is 12 line scans per second

Sponsor: NSF under the title "High Bandwidth and Minimally Invasive micro-cantilever Sensing Based on Transient Dynamics and Thermal Noise Effects"

University Research Goals

- Research to extend the boundaries of science and technology
  - ⋆ Publish or perish
    - – Basic science component is critical for NSF funding
  - ⋆ Funding for bringing ideas to fruition
- Education
- Outreach
- Intellectual property
  - ⋆ Universities becoming increasingly aggresive at IP protection
  - ⋆ Startup companies

Public Company Goals

- Increasing value to share holders
  - ⋆ Publications not directly beneficial
  - ⋆ Patenting is one possible means of facilitating publications but the information becoems public
  - ⋆ Most companies keep information proprietary particulalrly information that has immediate practial use
- Competing objectives often not compatible

Benefits

- Pull for university researchers
  - ⋆ Seeing some of the results translated into practice is of immense satisfaction
  - ⋆ Possible source of funding
  - ⋆ Keeping research relevant
  - ⋆ Key for graduate students career
- Pull for industry researchers
  - ⋆ Obtain information on the state-of-the art
  - ⋆ Obain a competetive edge over the rivals
  - ⋆ Demonstrate feasibility of the technology
  - ⋆ Common research curioisty where the objectives not directly economical get pursued.
  - ⋆ Suitable source of funding that incentiveizes the common effort

Making it work

- A mutual area of research that is of considerable interest to both parties
  - ⋆ A previous PhD student helped in presenting the expertise at NDSL
  - ⋆ A workshop held at Denver sponsored by NSF brought the two parties together
    - – It is important to involve speakers from other disciplines more frequenctly
- Complimentary set of skills

Making it work

- The research divisons of industry and academic partners understand what drives the research for their counterpart.
- IP protection through patents
  - ⋆ Usually difficult for the university to provide the right to refuse publications
    - – Iowa State objected to these clauses vigorously
    - – Agreed for a limited one year grant
  - ⋆ The restrictive publication clauses are not present with the UMN contract
- Patience! The lawyers take their time