AFM tip impulse response in attractive and repulsive regimes

ECE 499 Senior Capstone Presentation

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UNION COLLEGE | ENGINEERING
FOUNDED 1795

Project Goal

➢ To design and implement a software module which will allow for user defined functions to be performed on Union's Asylum MFP-3D Atomic Force Microscope (AFM).

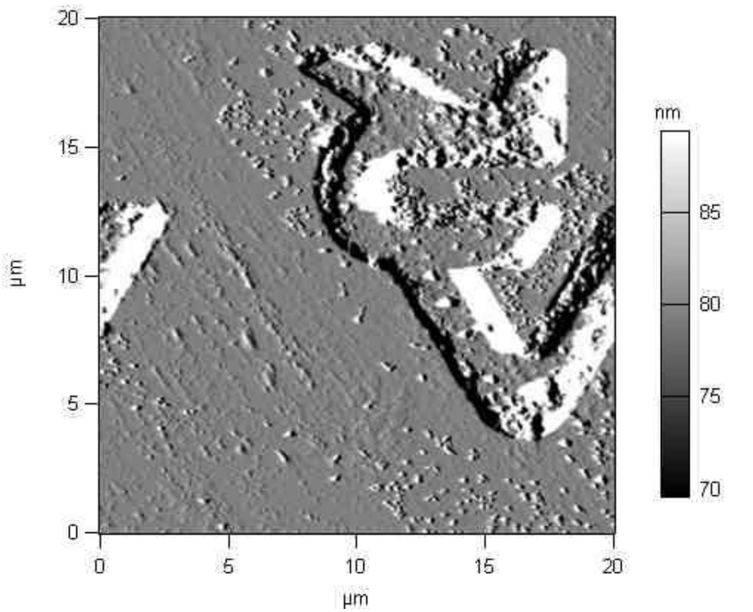
Project Definition

➢ What: A reusable and robust software module which will output AFM tip excitations and record the impulse response of the system.

➢ Why: To gain a deeper understanding of the potential non-linear response which may occur in attractive and repulsive regimes.

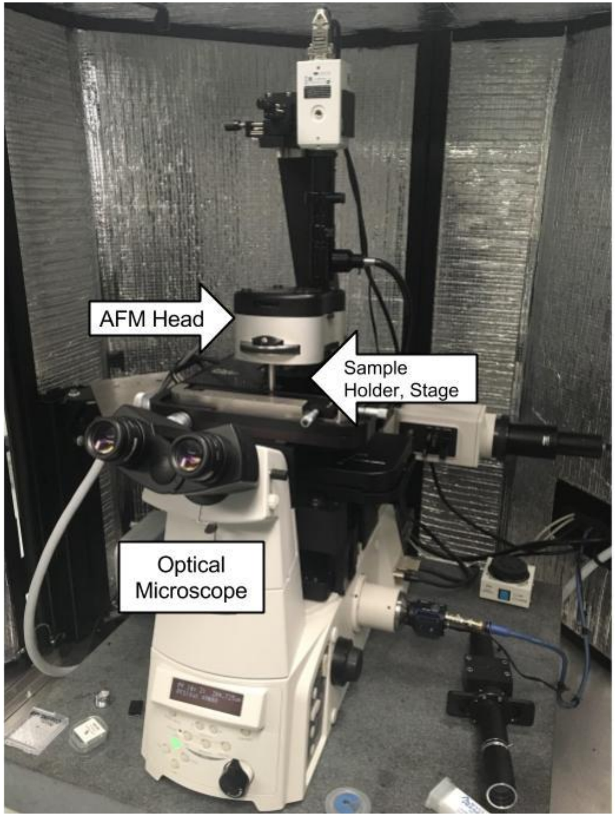
Overview

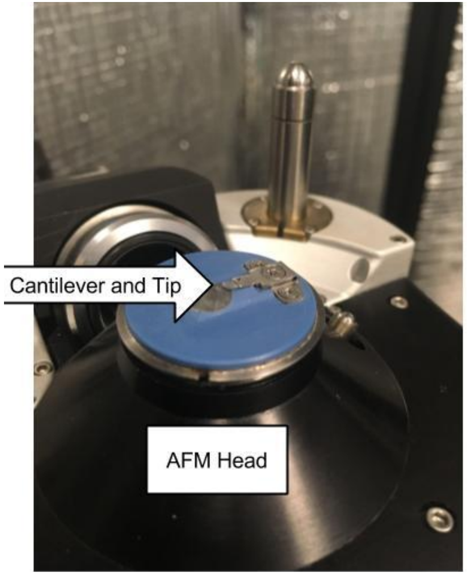
- ➢ Introduction and Background
  - Atomic Force Microscopy
  - Asylum Research software
- ➢ Goals and performance criteria
  - System signal delivery
  - System performance criteria
  - Software design
- ➢ Implementation method
  - Completed software modules
- ➢ Results and comparison to performance criteria
  - Performance criteria review
  - Confirmation of appropriate component reaction
  - Preliminary impulse response data
- ➢ Conclusions and future work



AFM Image of Asylum Research sample surface.
ARlogo ~ ¼ diameter of human hair

Introduction and Background: Atomic force microscopy





Union College's
Asylum Research MFP-3D
AFM

-AFM Functionality
-Important components:

- Tip & Cantilever
- Z-piezo
- Laser & Quadrant detector
- AFM Controller
- AFM Software

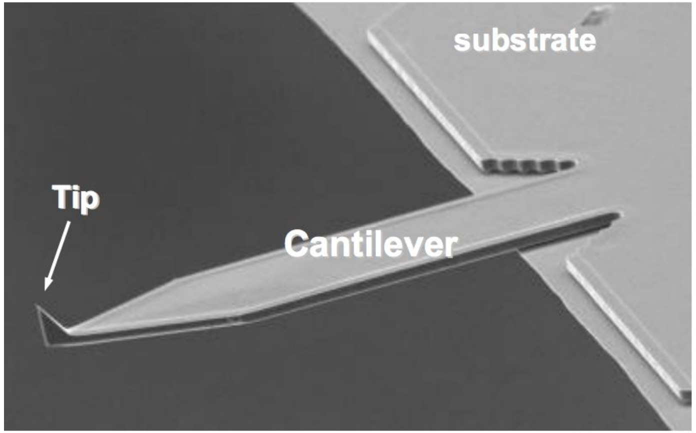


Photo courtesy of Asylum Research

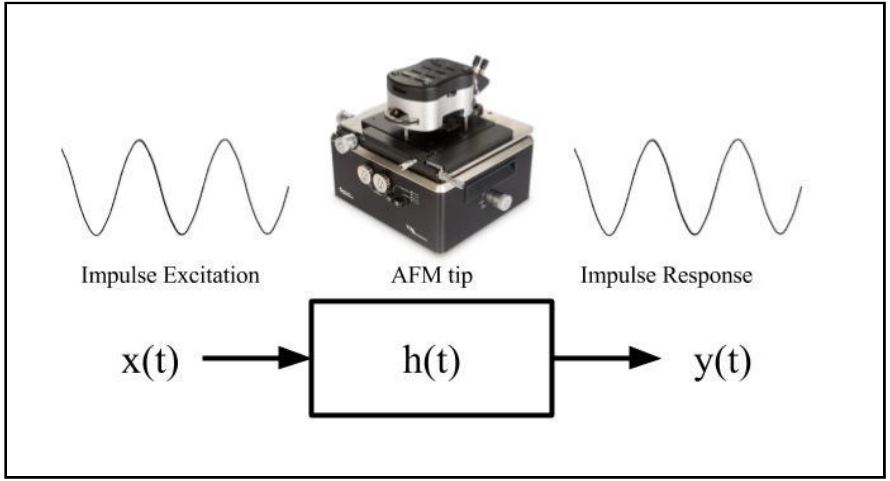
Introduction and background: Asylum research software

Low Level Code:	High Level Code:
• Interfaces directly with AFM controller, which directs I/O of AFM components. • Written by Asylum research, some documentation in software. User defined functions possible.	• IGOR Pro- Scientific data analysis software. • Handles variables, definition of waveforms, control flow of system.

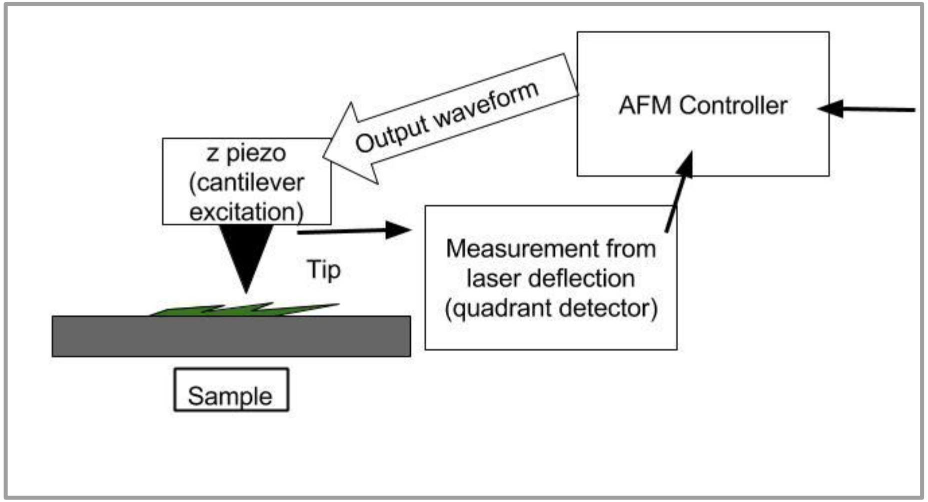
Project Goals

System signal delivery outline

➔ User should be able to define output waveform for cantilever excitation and record the impulse response of the tip.



General system



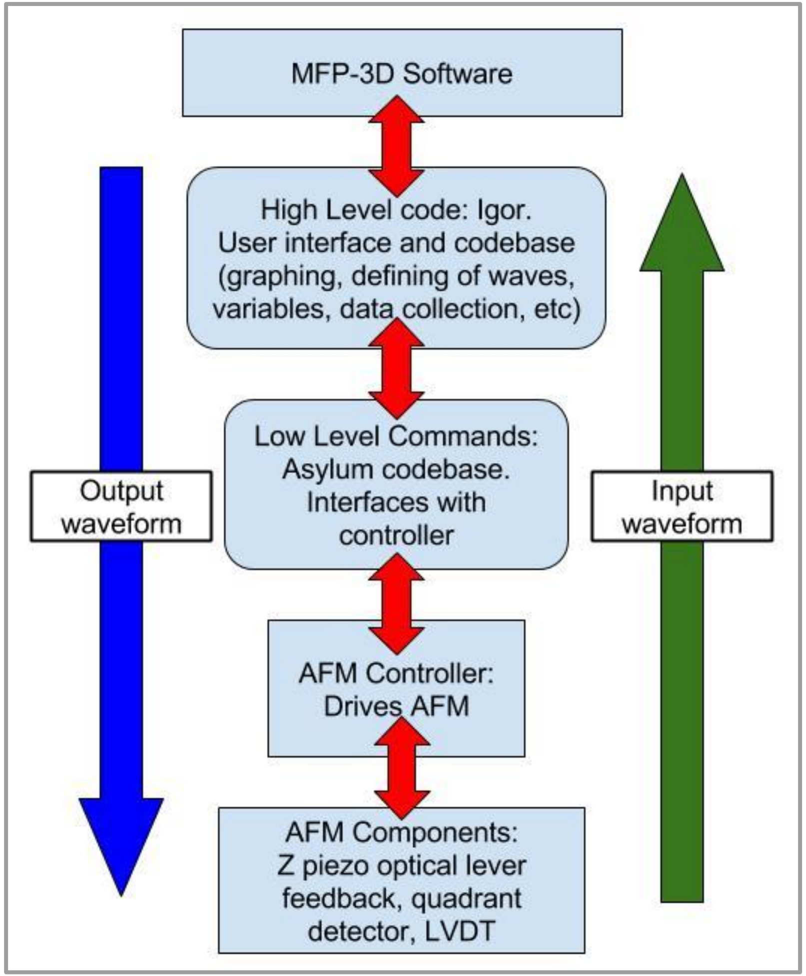
Major components involved

Performance criteria (from 498)

	Description
1	User defined output excitation functions which run in parallel with system
1a	Access low level Asylum functions on AFM controller
1b	Use IGOR code to define and output user defined waveforms to AFM z piezo
2	Record impulse response of system using user defined functions
2a	Z piezo sensor reading from AFM
2b	Deflection measured on PSD quadrant detector of AFM
3	Systematic study of impulse response performed with different samples
3a	Compare results in attractive and repulsive regimes as well as in free air
4	Experiment easily reproducible, complete with programming guide

Goals and performance: software design

- ➢ Must be run from the MFP-3D AFM's main operation software
- ➢ Custom programs written in IGOR
- ➢ Programs will be modular, allowing for easy systematic study of impulse response with different conditions
- ➢ IGOR programs interact with low level Asylum controller functions
- ➢ Asylum functions control AFM components



Block diagram for system I/O

Implementation method: pseudocode

1. Stop all current controller activity which may harm the system.
2. Define variables such as number of data points to be output and amplitude of excitation.
3. Create waveform data variables
4. Read current Z piezo voltage. This is the current height of the Z piezo.
5. Define the impulse drive wave for use in cantilever excitation.
6. Send Output wave to controller
7. Define the input impulse wave to be recorded
8. Trigger the output and input waves to the same event.
9. Display wavedata (output excitation and impulse response)

This magically compiles into......

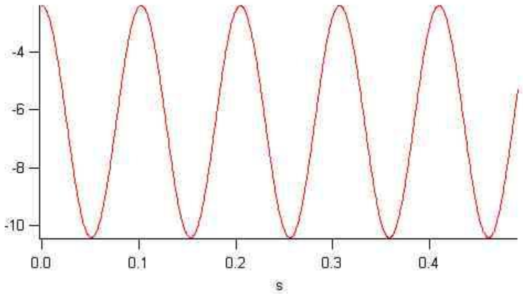
```
#pragma rtGlobals=1             // Use modern global access method.

function Z_Out_IR()
        print td_stopThermal()
        print td_stop()

        Variable ScanRate = 20 //Hz
        Variable startZVoltage  // will store current Z voltage as baseline for impulse
        Variable A //Amplitude of impulse (volts, not peak to peak)
        Variable tot_Time //will store the total amount of time for the impulse
        Variable dataPoints

        dataPoints = 1024 //must be multiple of 32
        A = 16

        Make/O/N = 1024 DataWave, DriveWave
        display DataWave
        display DriveWave


        print td_xSetOutWave(0,"Event.14", "ARC.Output.Z", DriveWave, round(cMasterSampleRate/ (Scan
Rate * DimSize(DriveWave,0))))

        startZVoltage = td_ReadValue("ARC.Input.Z")

        print startZVoltage

        DriveWave = startZVoltage + A * cos(2*pi*x/ 0.1024)

        //set the impulse wave
        print td_xSetOutWave(0,"Event.14", "ARC.Output.Z", DriveWave, round(cMasterSampleRate/ (Scan
Rate * DimSize(DriveWave,0))))
        //record impulse response
        print td_xSetInWave(0, "Event.14", "Deflection", DataWave, "",round(cMasterSampleRate/ (Scan
Rate * DimSize(DriveWave,0))))

        print td_WriteString("Event.14", "Once")

end
```

Performance criteria: review

	Description	*Complete?*
1	User defined output excitation functions which run in parallel with system	Yes
1a	Access low level Asylum functions on AFM controller	Yes
1b	Use IGOR code to define and output user defined waveforms to AFM z piezo	Yes
2	Record impulse response of system	Yes
2a	Z piezo sensor	Yes
2b	Deflection measured on PSD quadrant detector	Yes
3	Systematic study of impulse response performed with different samples	NO
3a	Compare results in attractive and repulsive regimes as well as in free air	NO
4	Experiment easily reproducible, complete with programming guide	Yes

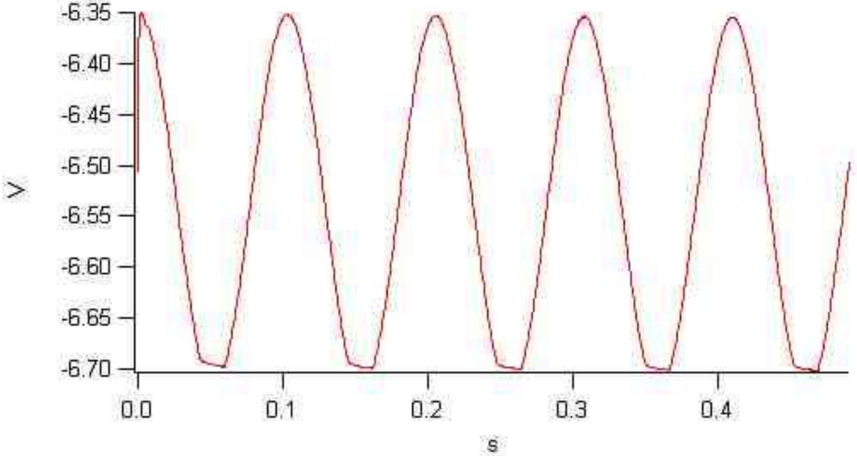
Results: Confirmation of appropriate component reaction

Simple sinusoidal excitation. Graphs of the excitation waveform (a), the Z-piezo sensor reading (b), and the deflection sensor reading (c)

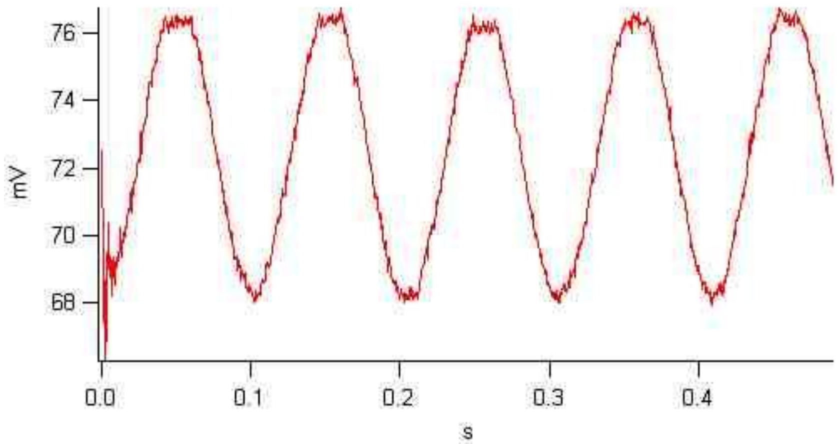


A: 4V output z piezo drive wave

Note that the input waveforms which record the system response to the sinusoidal output are concurrent with the expected results from components.

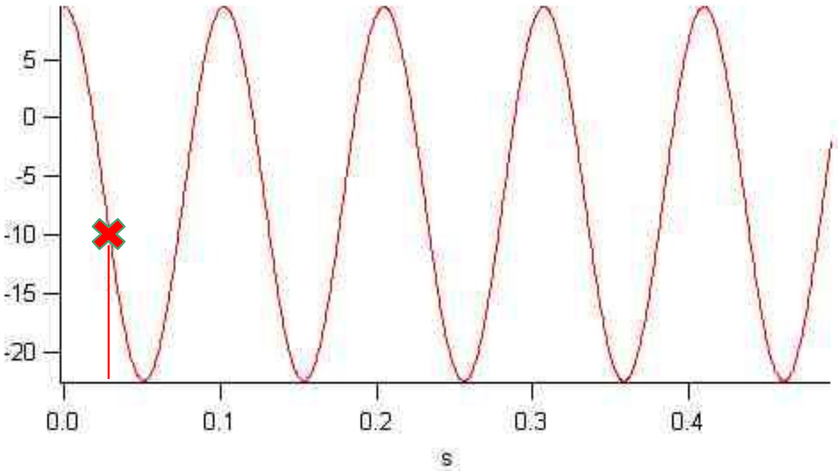


B: Z-piezo sensor input from AFM

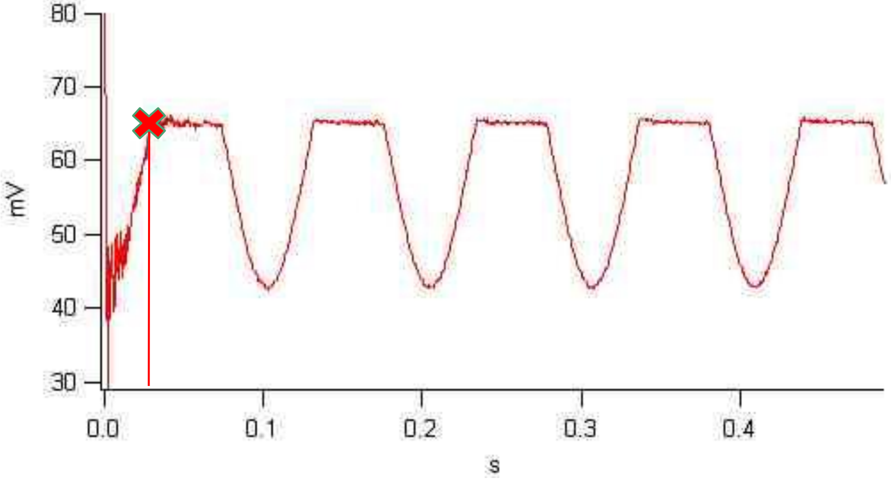


C: Deflection sensor input from AFM

Results: Confirmation of appropriate component reaction



A: 16V output z piezo drive wave

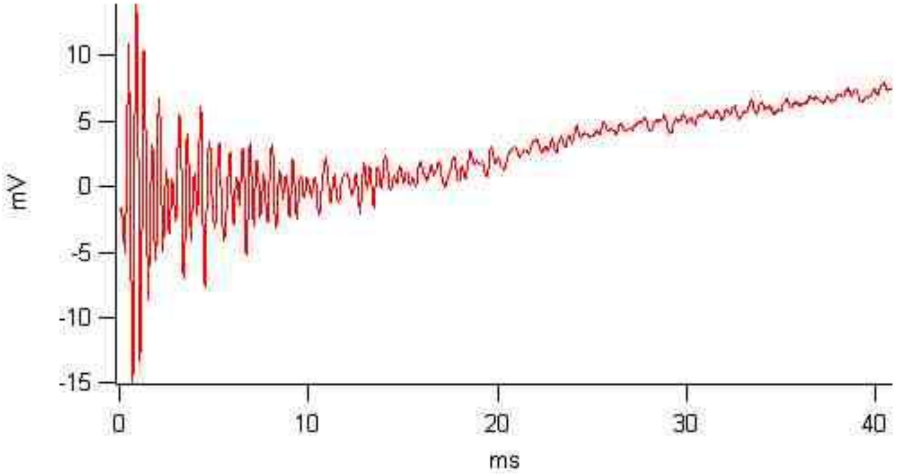


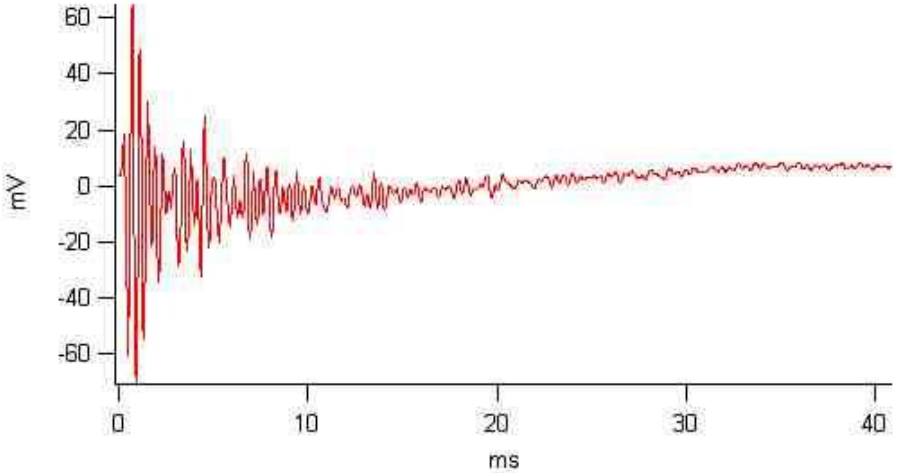
B: Z-piezo sensor input from AFM

Conditions:
-Starting z voltage ~5v
-16 V cos wave impulse

Note that the Z-piezo has drive voltage limits of -10V to 120V. This is why we see the clipping- when the drive voltage is pushed beneath -10V, the Z piezo has reached its limit and there should be no recorded further movement.

Results: Preliminary impulse response data





Shown (left): deflection impulse response to a 4V discrete voltage change to z piezo

Shown (right): deflection impulse response to a 8V discrete voltage change to z piezo

Conclusions and future work

System success

Data collection possibilities

Study impulse response in attractive and repulsive regimes

Last slide- acknowledgements

-My co-advisors

-Maxwell Stwertka

-Union College ECE dept

-Union College Physics & Astronomy dept

-Asylum Research

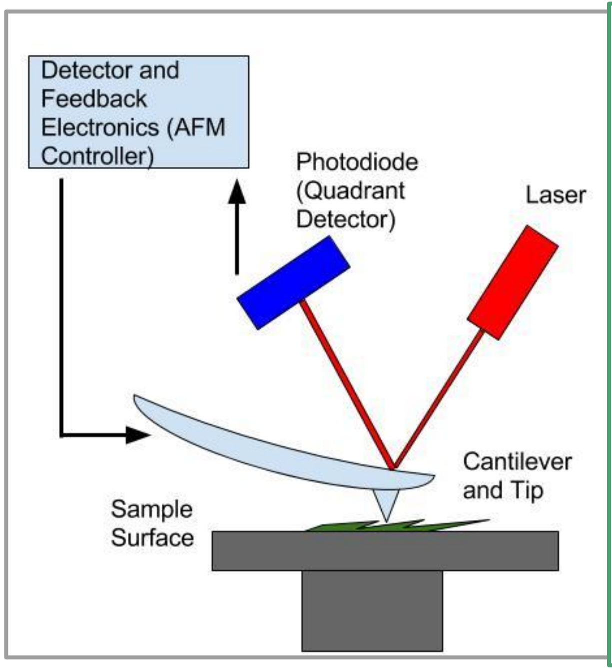
-Scholars work study

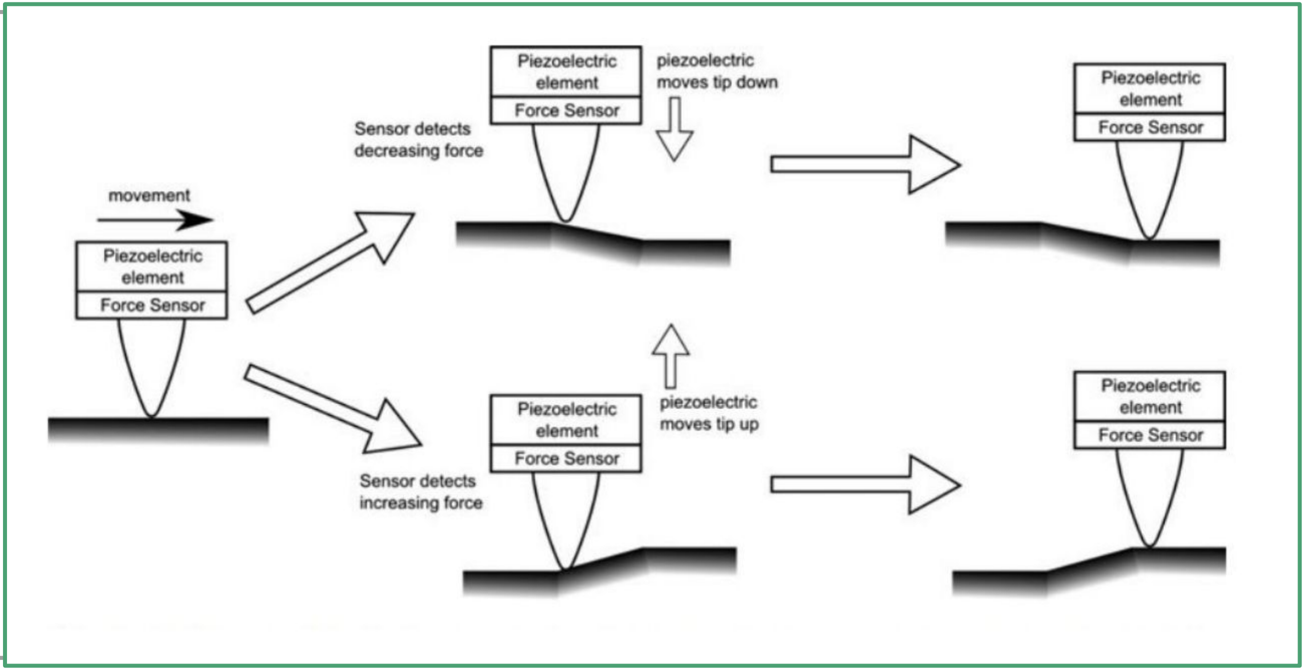
Questions?

Introduction and Background- Atomic force microscopy

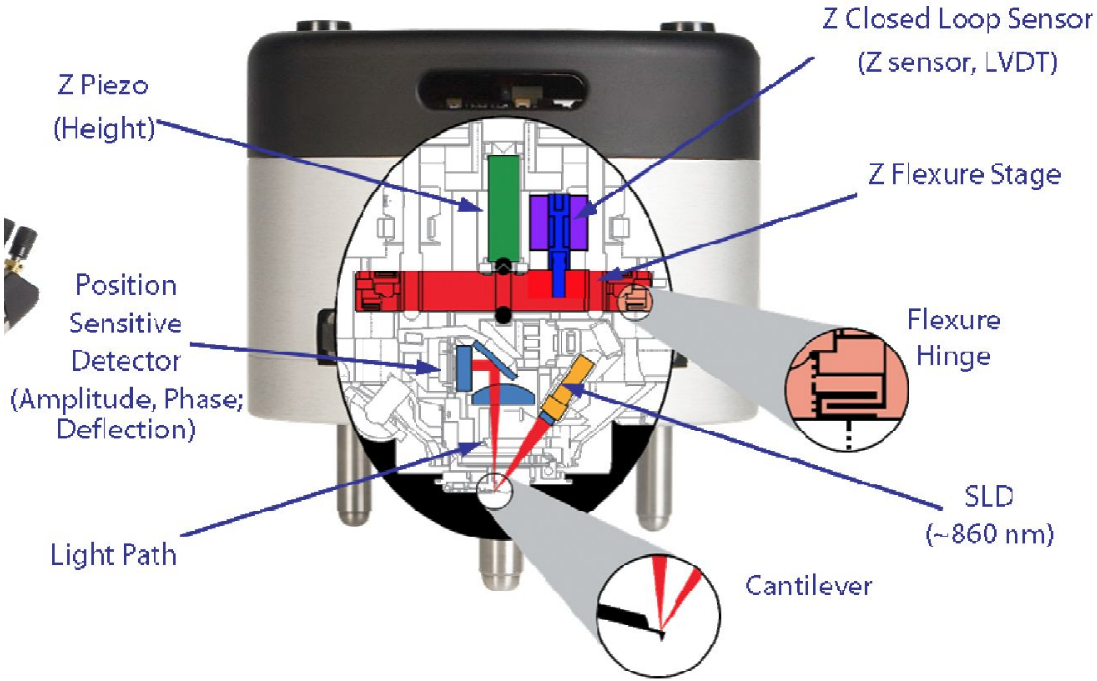
-Force sensor on z piezo measures height from surface. Feedback loop controls tip.

-Laser/ photoelectric diode measurements monitors cantilever movement.





Introduction and Background- Atomic force microscopy



Introduction and Background- attractive & repulsive regimes

1. Attractive:
   a. Up to 10 nm from surface
   b. Van der Waals forces
2. Repulsive
   a. ~ 0.1 nm from surface
   b. Atomic forces between tip and sample

-To image in either attractive or repulsive regimes, change drive frequency offset. Increase 5% for repulsive mode, decrease ~10% for attractive mode. Monitor phase.

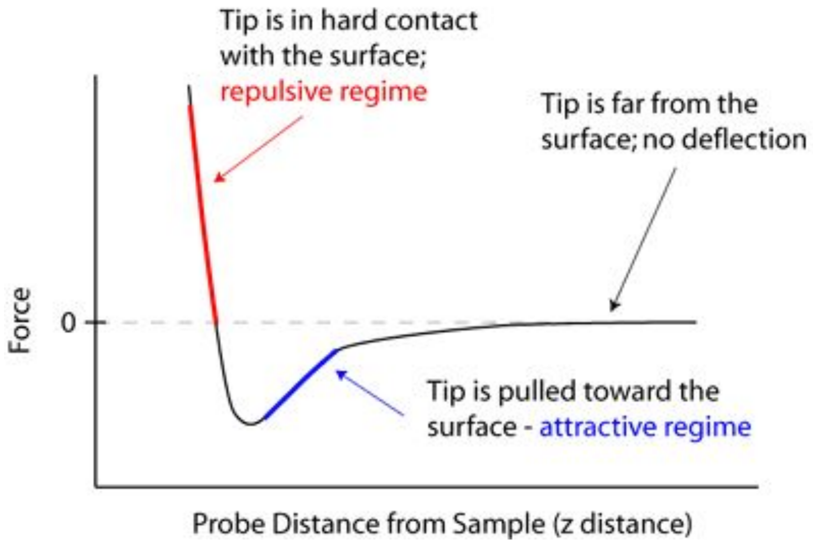


Figure of force curve from Eaton, Peter, and Paul West. "Atomic Force Microscopy." (2010)