This project presents a home brewed solution to high resolution Microscopy

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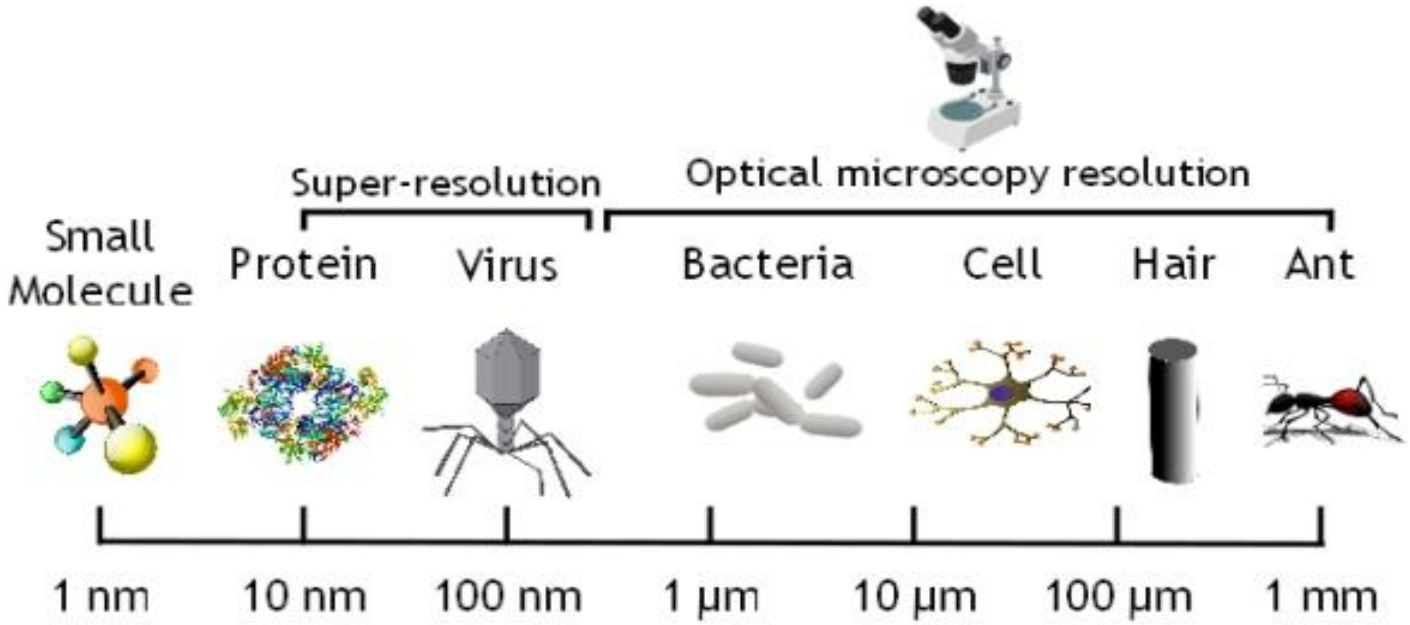
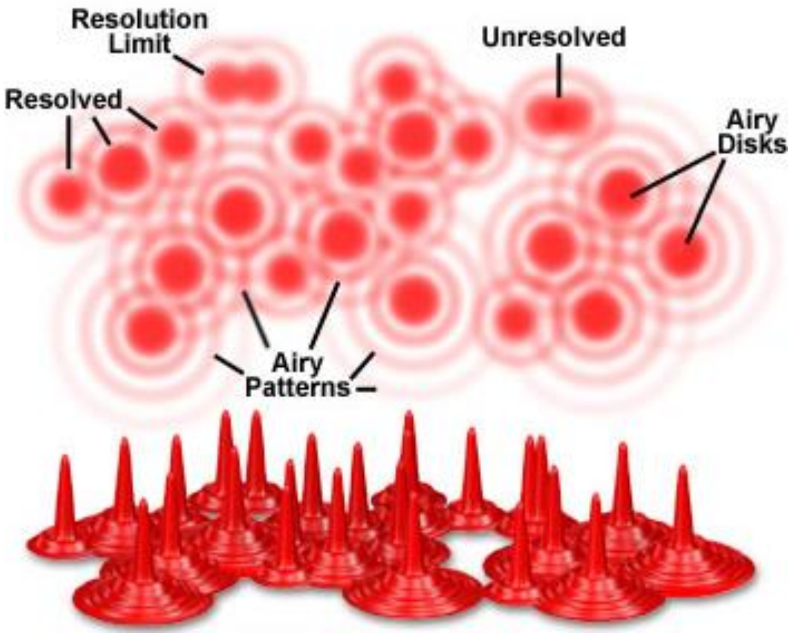
The most common microscopic technique is Optical Microscopy in which an object is viewed directly by magnifying light coming from it

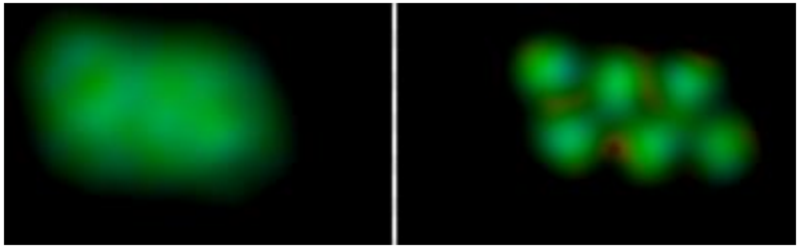
Optical Microscopy is limited due to a fundamental property of light: Diffraction

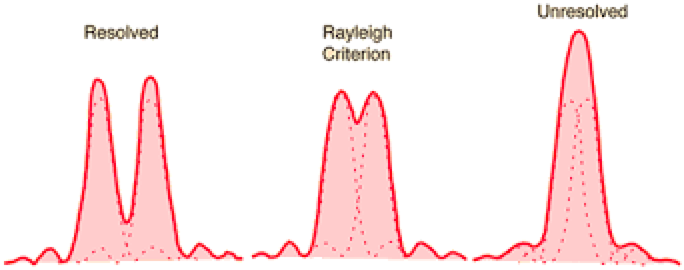


Optical Limit

- Optical Microscopes can not resolve objects of size smaller than λ/2 (~ 250 nm for white light)



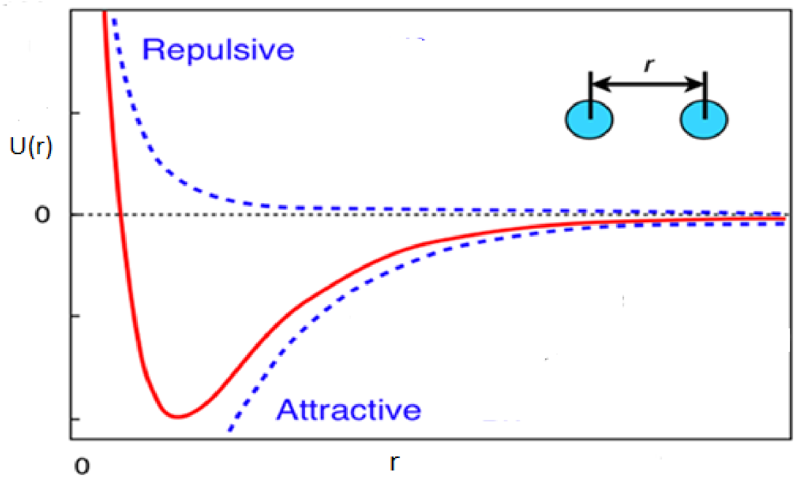




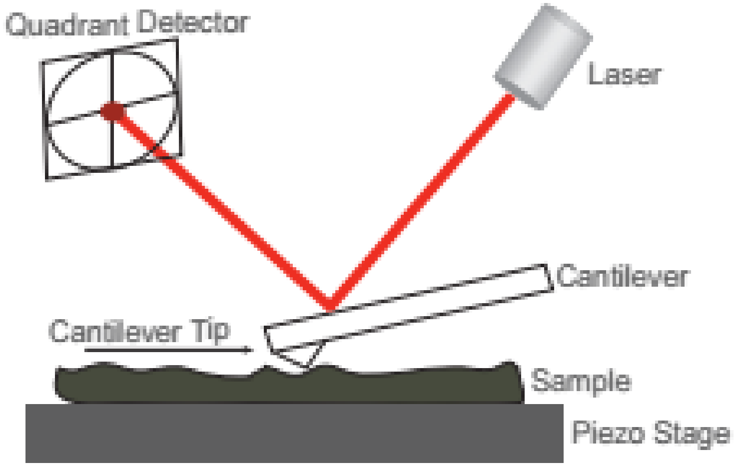
A new Microscopic Technique that goes beyond optical limit (introduced in late 80's)

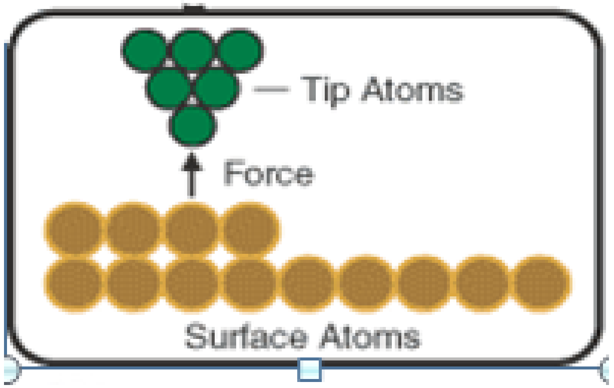
Atomic Force Microscopy (AFM) is a technique in which a sample is imaged indirectly using the **atomic forces** between its atoms and a very small probe

The atomic force between two atoms is a function of distance given by **Lennard-Jones** function



So instead of observing the object directly, we map its contours by corresponding atomic forces with **Lennard-Jones** function



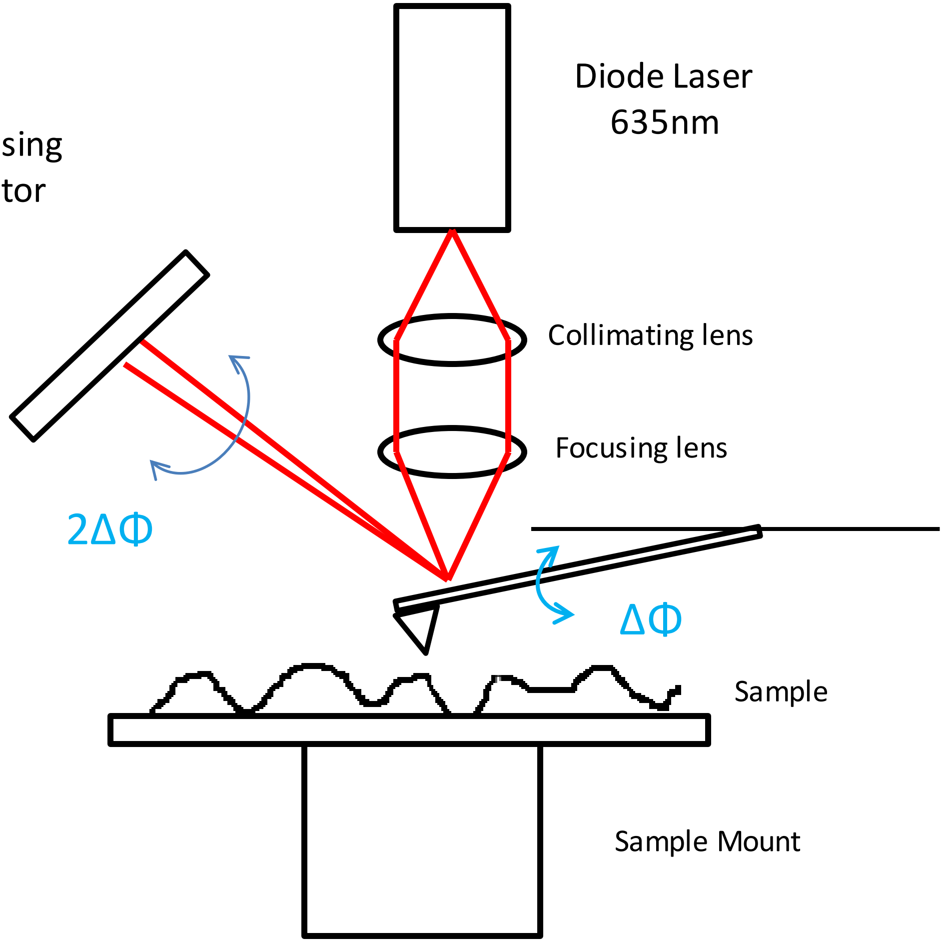


Requirements for AFM

- Measurements of small changes in laser reflection angle
- Controlled Nano-scale motion in all axes to move probe pixel by pixel
- Electronics and data acquisition system capable of detecting and amplifying variations in millivolts

Laser Reflection Angle Detection

Optical Setup

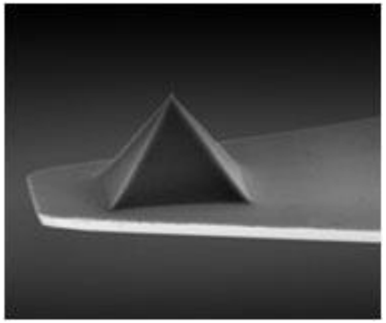


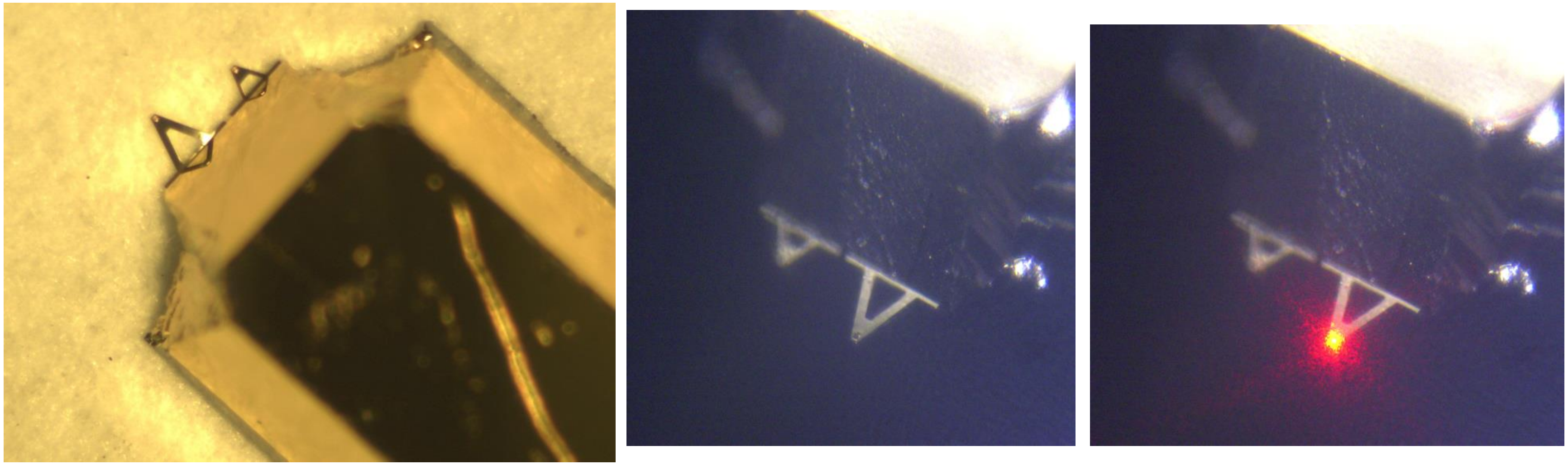
Laser Reflection Angle Detection

AFM Probe

Silicon Nitride Probe

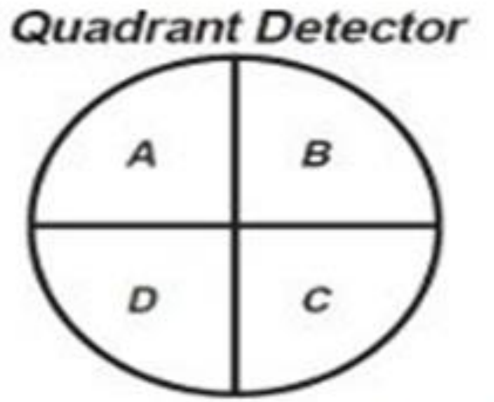
- Tip size: 32nm
- Top area 50x50 um approx.





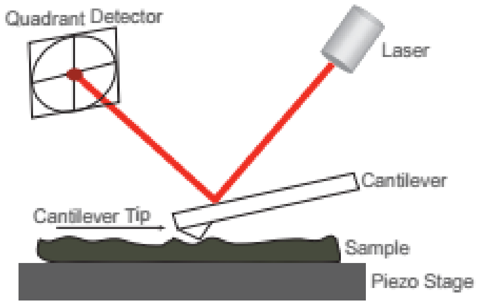
Laser Reflection Angle Detection

Position sensing Photodetector



$$X\ \text{Position} = \frac{(A+D)-(B+C)}{A+B+C+D}$$

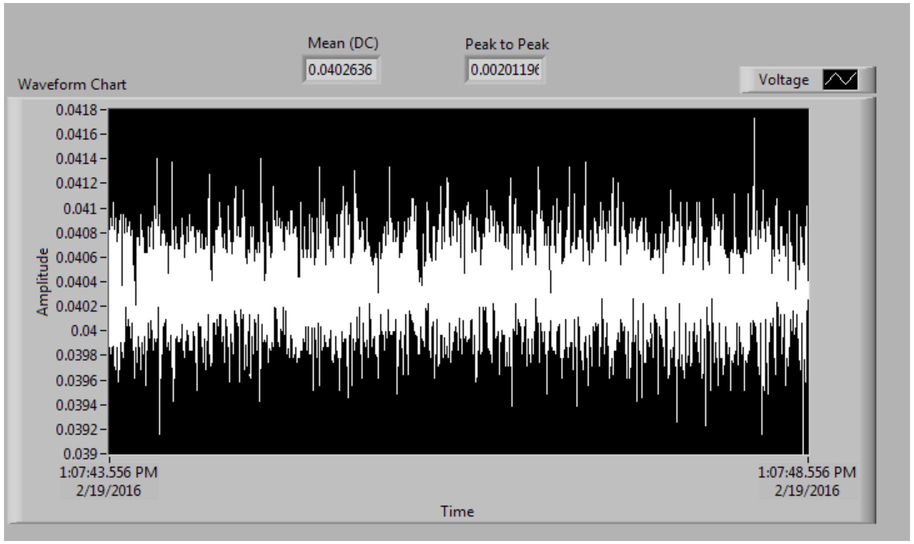
$$Y\ \text{Position} = \frac{(A+B)-(D+C)}{A+B+C+D}$$



Position sensing Photodetector

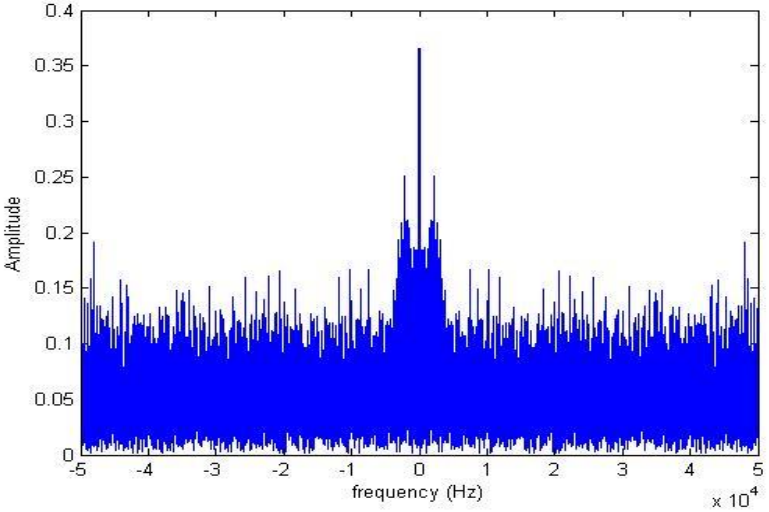
Response of Photodetector to 34.8mW laser beam. Signal shows Shot Noise of the detector

$$SNR = \frac{\mu^2}{\sigma^2} = 2530.8$$



Mean (DC): 0.0402636

Peak to Peak: 0.0020119



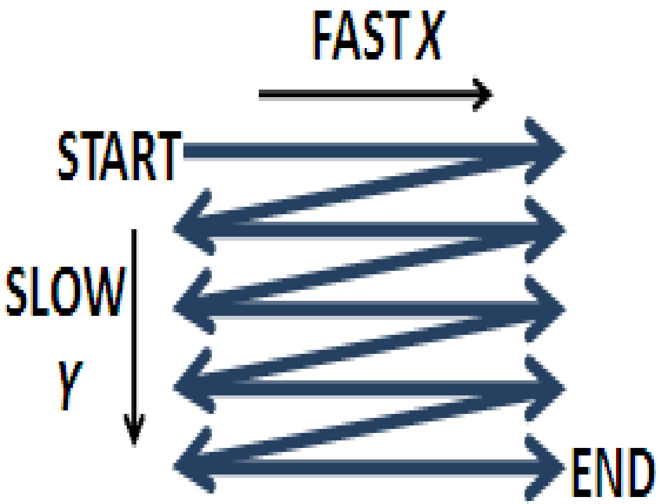
Controlled Nano-scale Motion

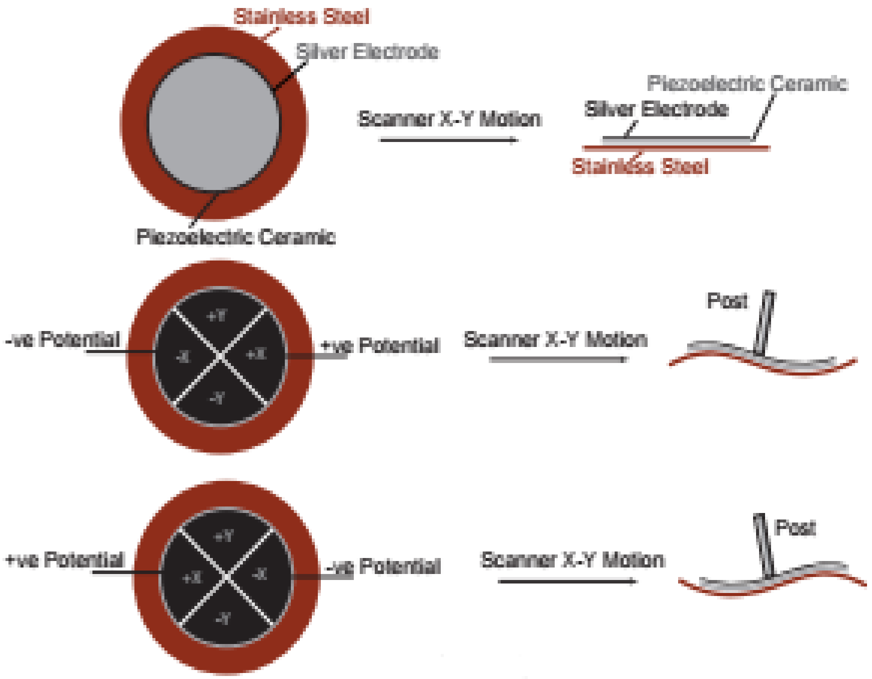
X-Y Axis

Piezoelectric Discs (PZT) produce motion in nanometer precision when acted upon by large voltages

Required voltages go as high as 80V

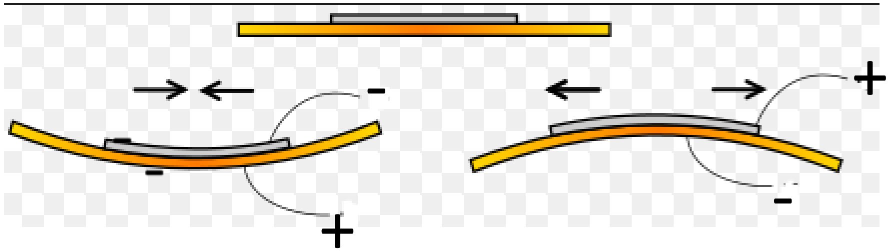
Raster scan

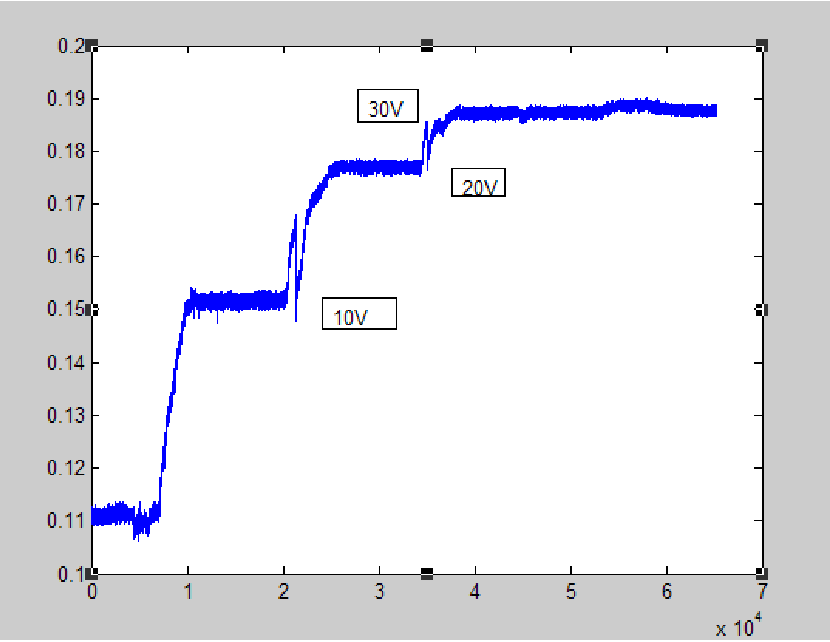




Controlled Nano-scale Motion

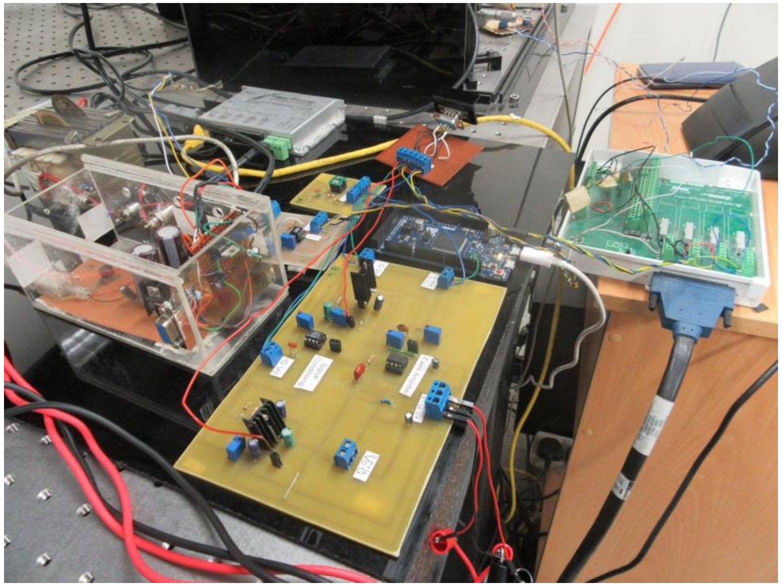
Z Axis





Electronics

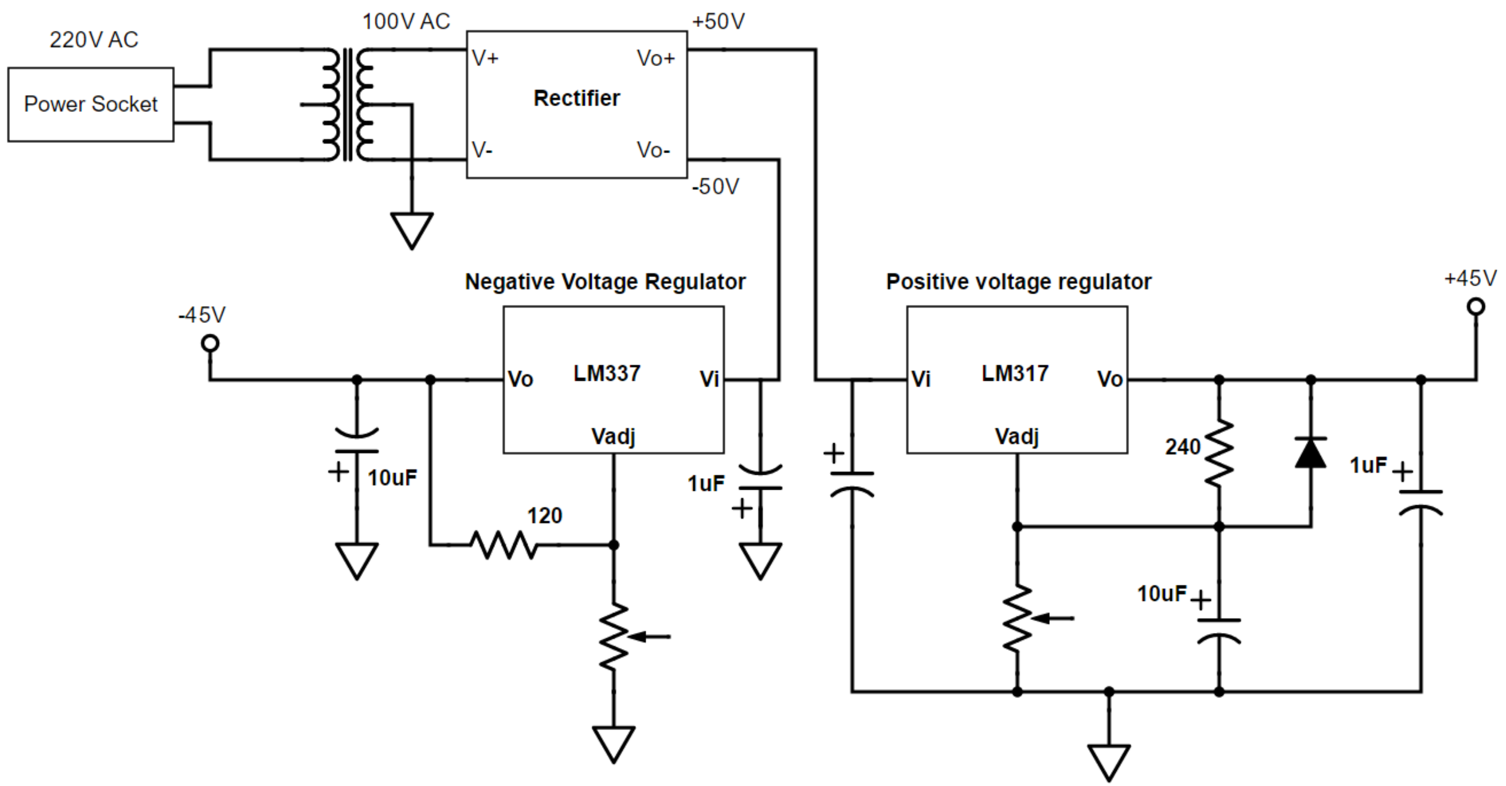
- Bipolar high voltage power supply (100V)
- XYZ Piezo disc Drivers
- Signal Conditioning and feedback electronics
- Data Acquisition and processing with **LabVIEW**



Electronics

100V (±50V) Bipolar supply

- Additional voltage regulator circuit to cancel ripples



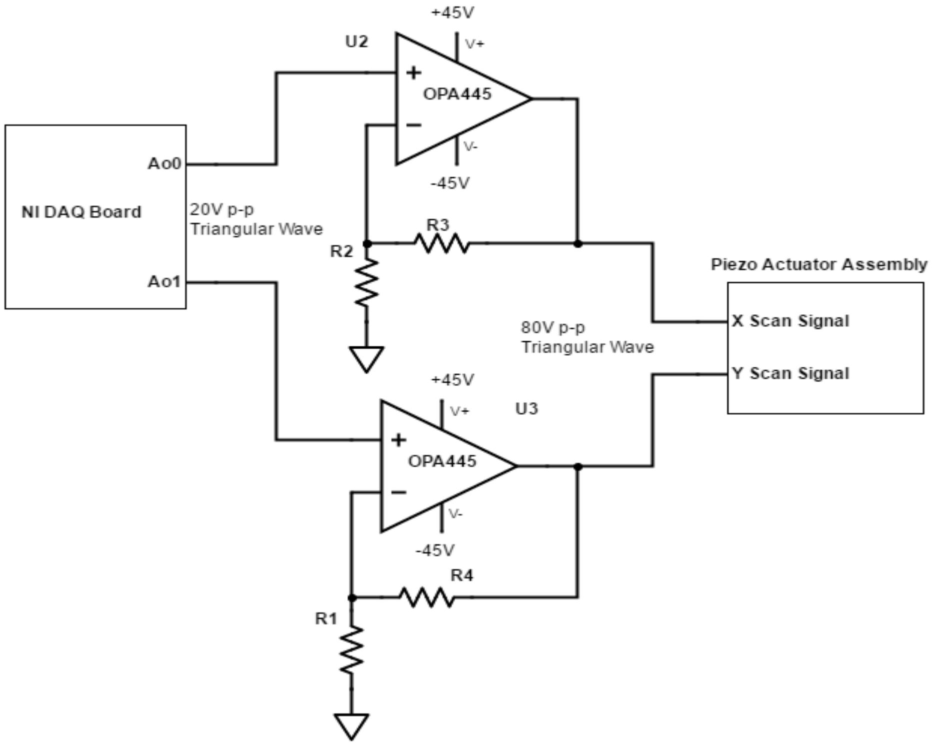
Electronics

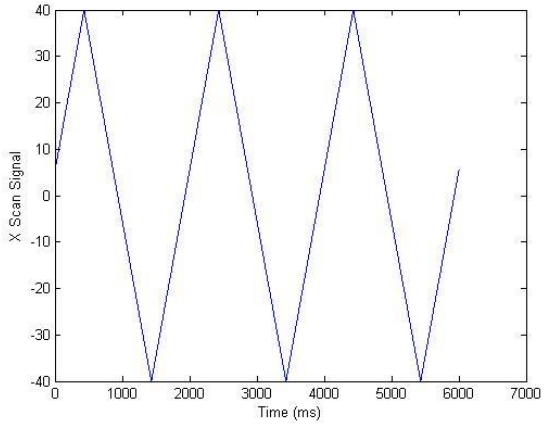
X-Y axis Piezo Amplifier

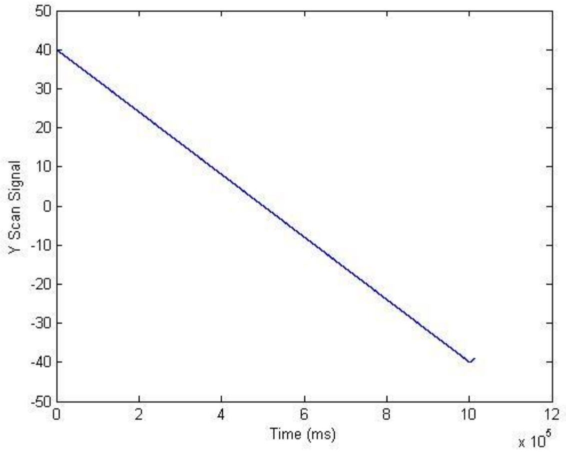
Amplifier Stage

OPA445: High Voltage Op Amp

Maximum Output swing: 90V



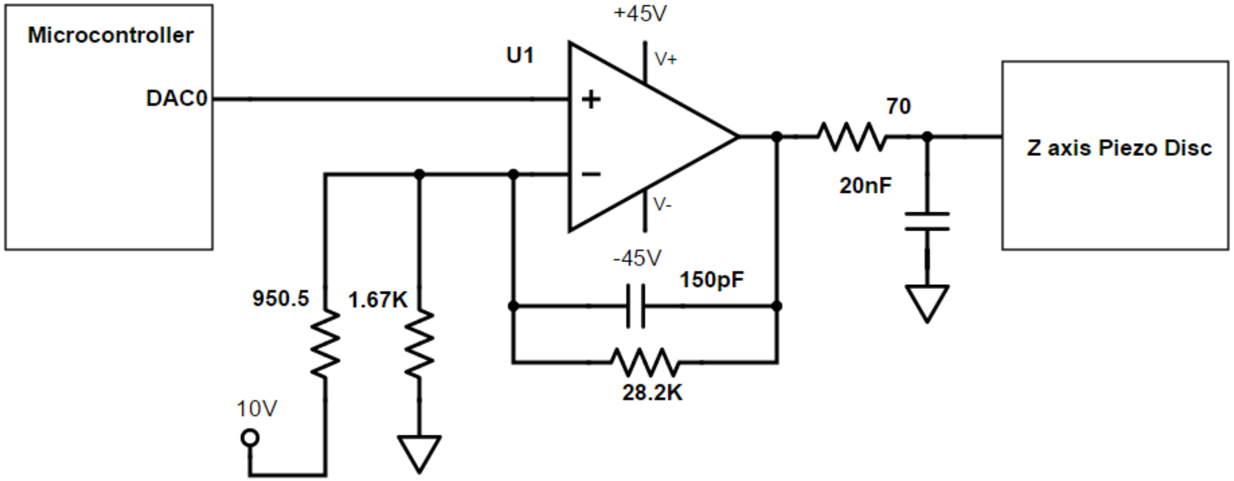




Electronics

Z axis Piezo Driver

Z axis motion signal is generated by feedback Control from an Arduino board



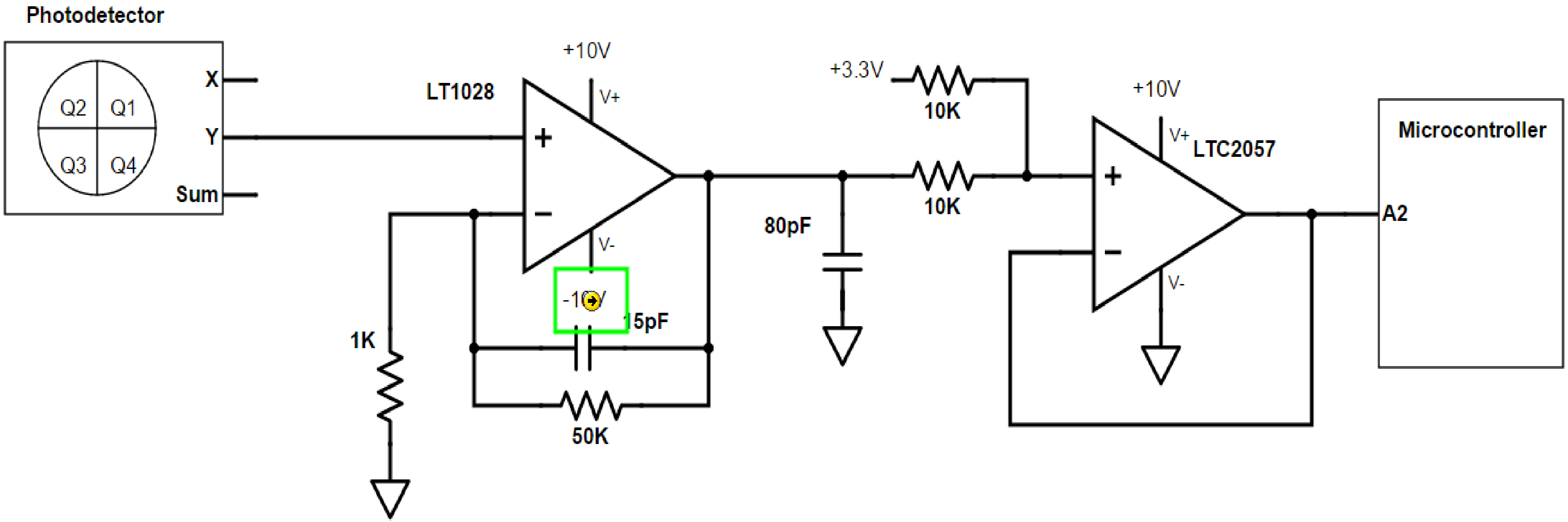
Electronics

Signal Conditioning for feedback

LT1028, LTC2057: Ultra-low noise high speed Precision Op Amps

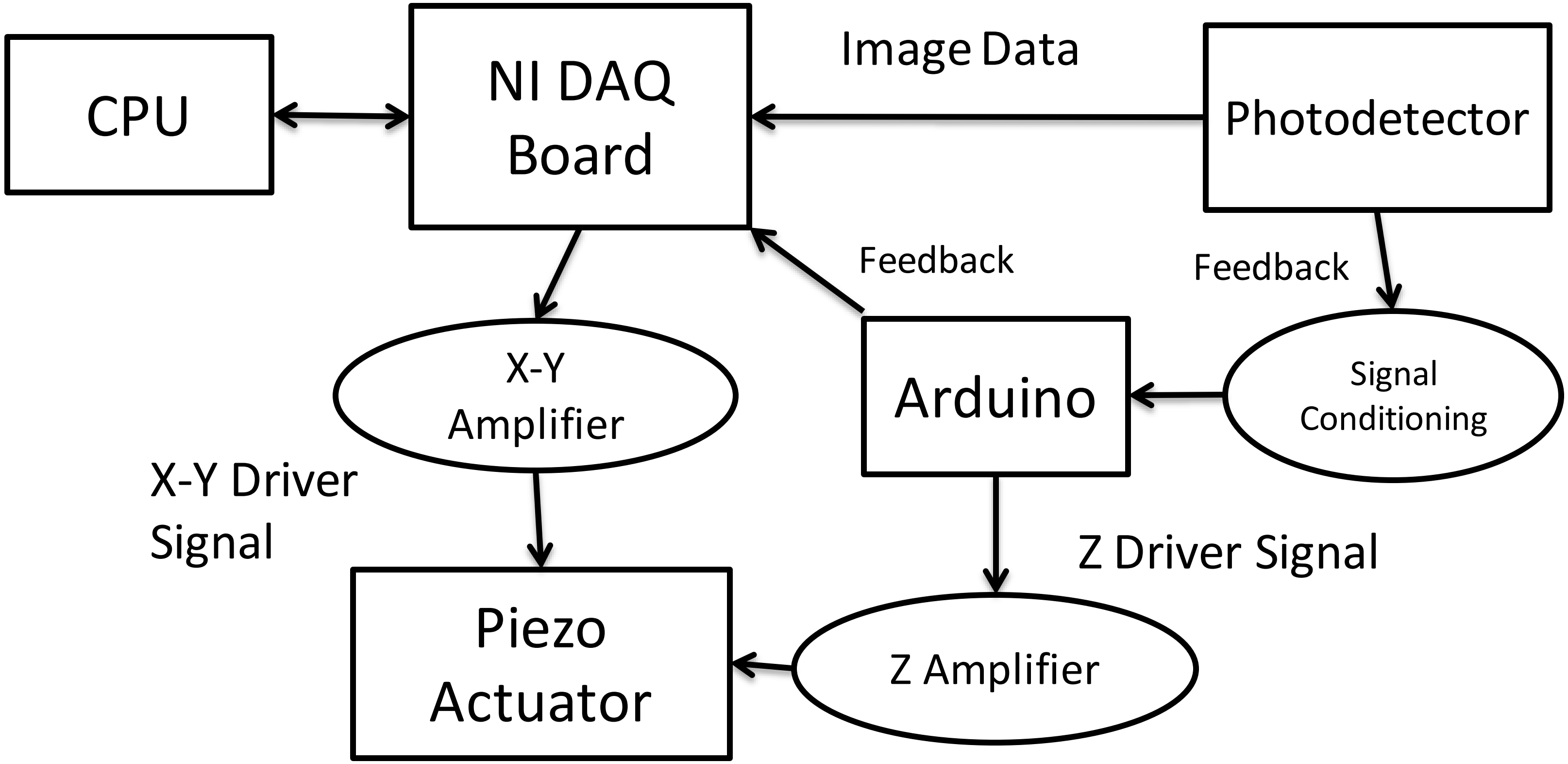
P-P noise = 3.5 nV

Slew Rate: 11V/us



Electronics

Data Flow



CPU

NI DAQ Board

Image Data

Photodetector

Feedback

Feedback

X-Y Amplifier

Arduino

Signal Conditioning

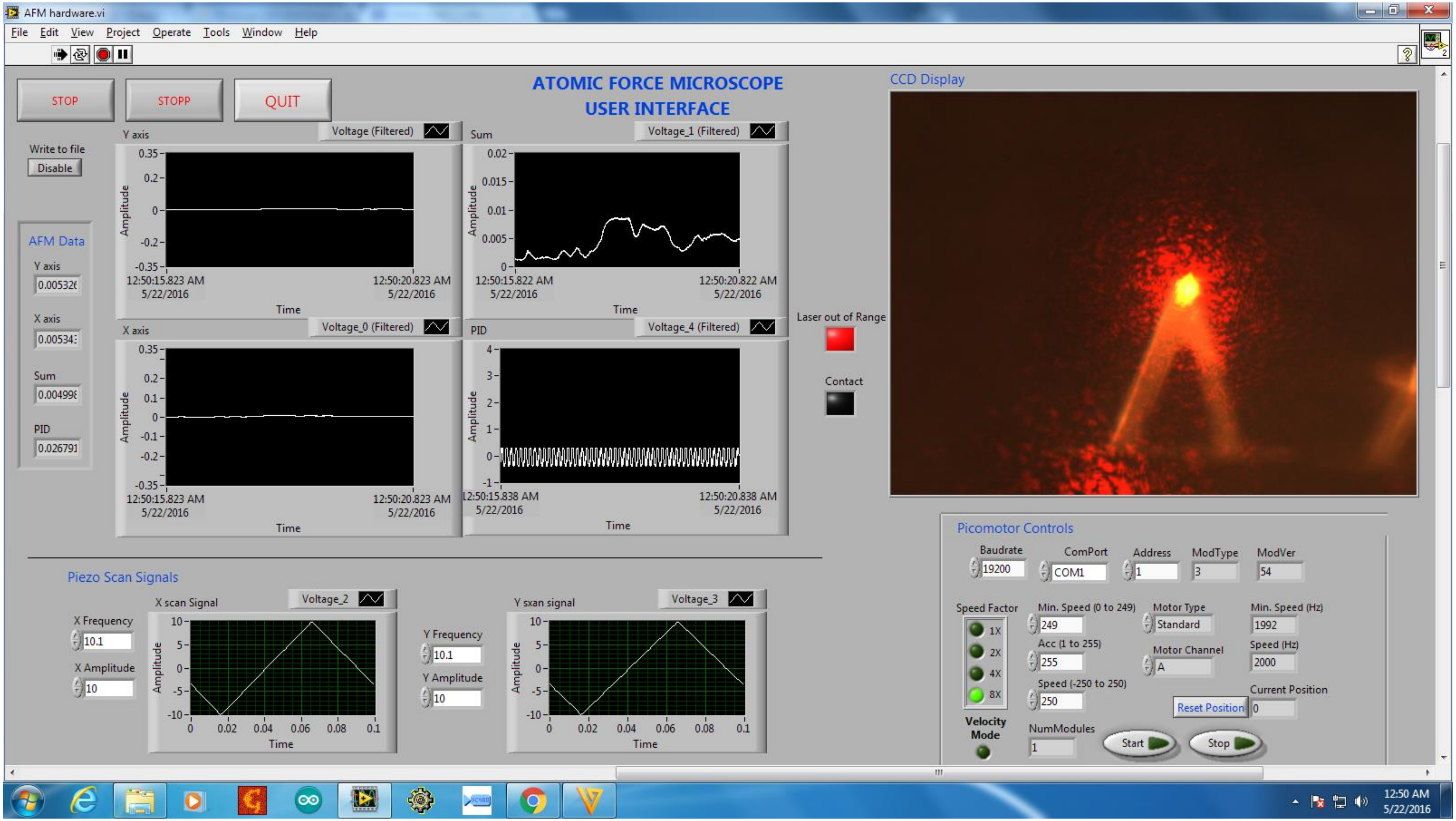
X-Y Driver Signal

Z Driver Signal

Piezo Actuator

Z Amplifier

User Interface



Write to file: Disable

AFM Data

- Y axis: 0.00532
- X axis: 0.00534
- Sum: 0.00499
- PID: 0.026791

Piezo Scan Signals

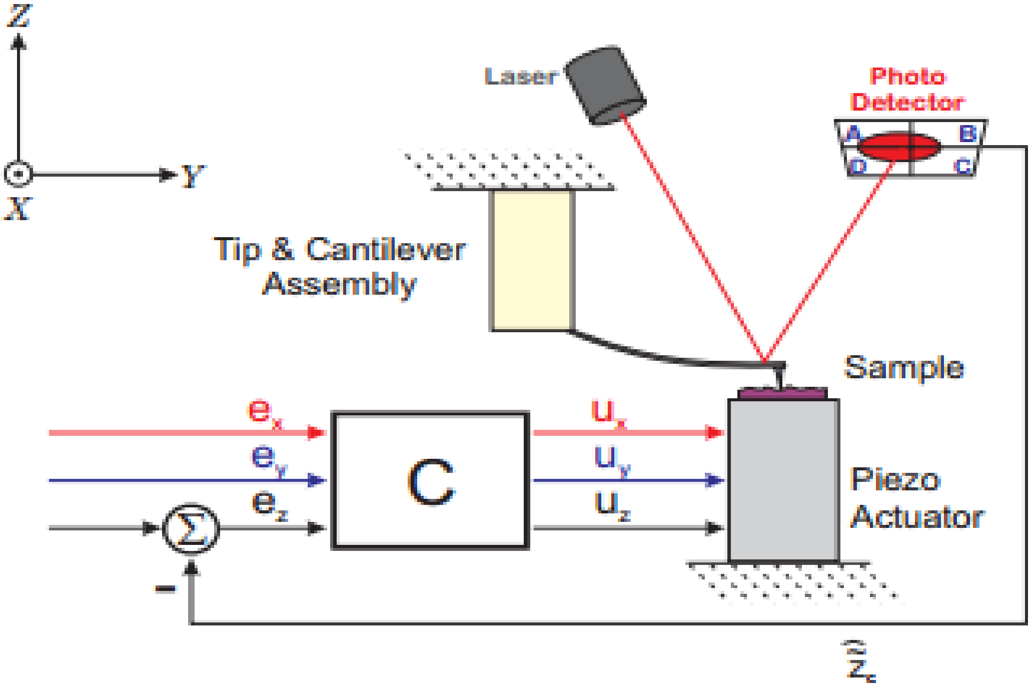
- X Frequency: 10.1
- X Amplitude: 10
- Y Frequency: 10.1
- Y Amplitude: 10

Picomotor Controls

- Baudrate: 19200
- ComPort: COM1
- Address: 1
- ModType: 3
- ModVer: 54
- Min. Speed (0 to 249): 249
- Acc (1 to 255): 255
- Speed (-250 to 250): 250
- NumModules: 1
- Motor Type: Standard
- Motor Channel: A
- Min. Speed (Hz): 1992
- Speed (Hz): 2000
- Current Position: 0

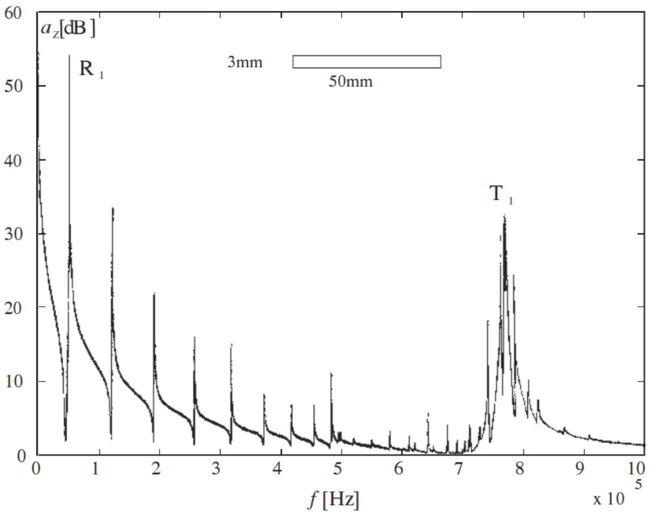
Feedback Control of AFM

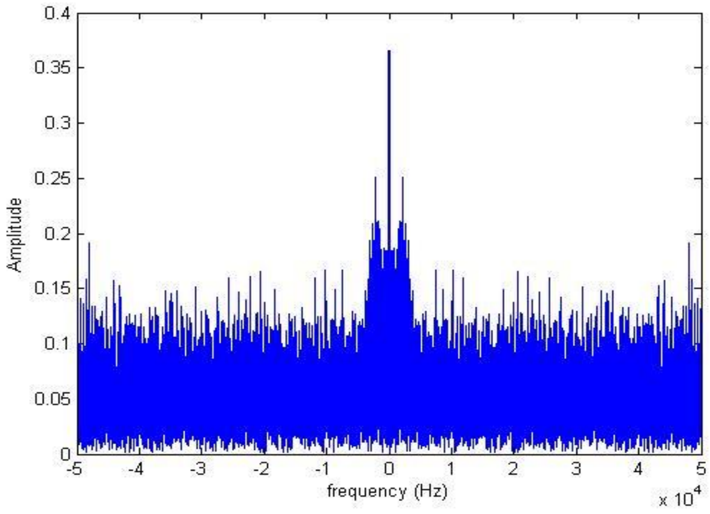
Essential for scanning large samples (>500nm)



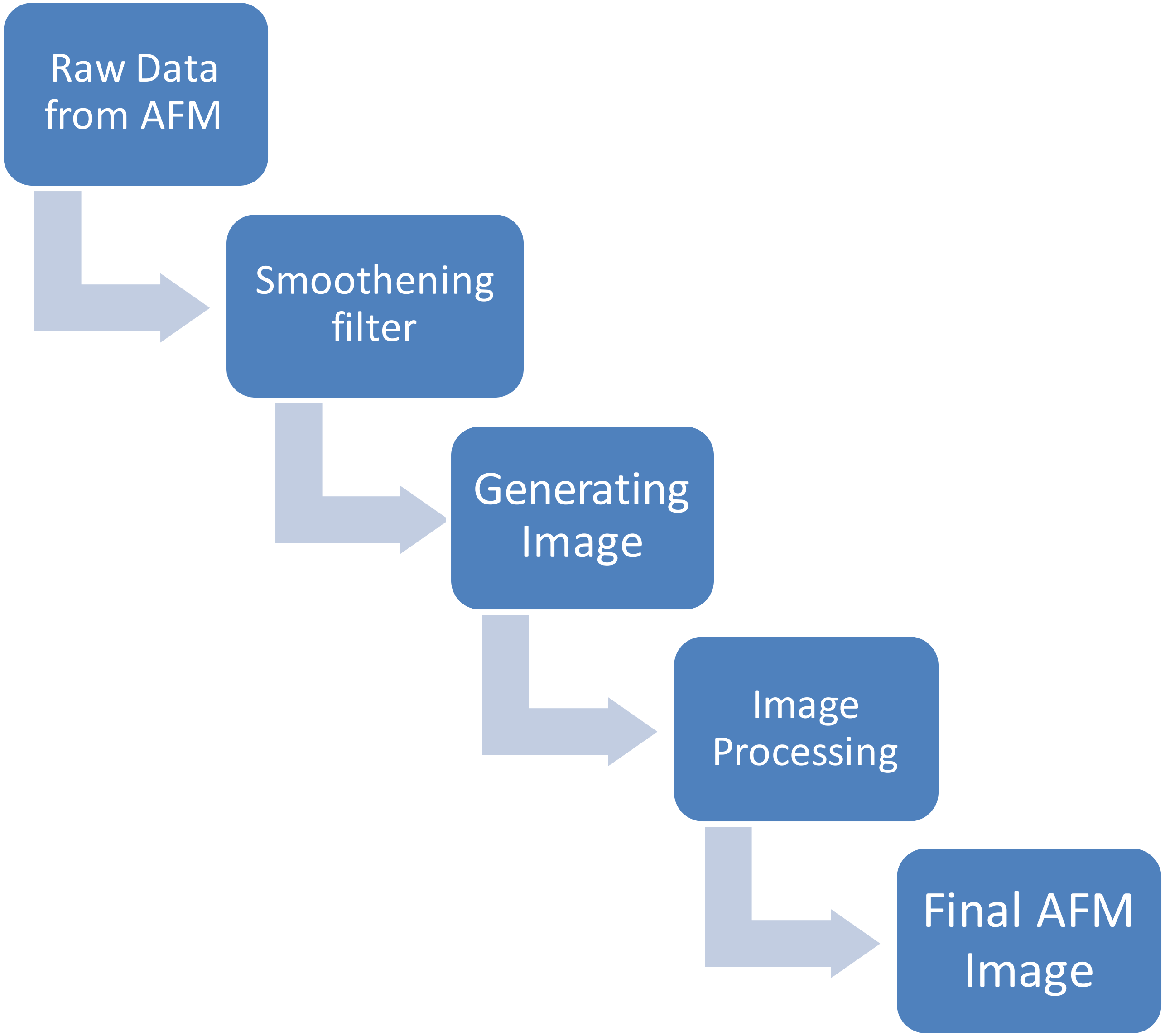
Feedback Control of AFM

- Controller designed by Zeigler Nichols Method
- Noisy control loop: Kd=0
- PI controller will suit the AFM feedback
- Noise present at resonance frequencies of Piezoelectric actuator
- Control loop running at 1kHz sampling rate to avoid noise at resonance (50, 120 KHz)





AFM Imaging



Raw Data from AFM

Smoothening filter

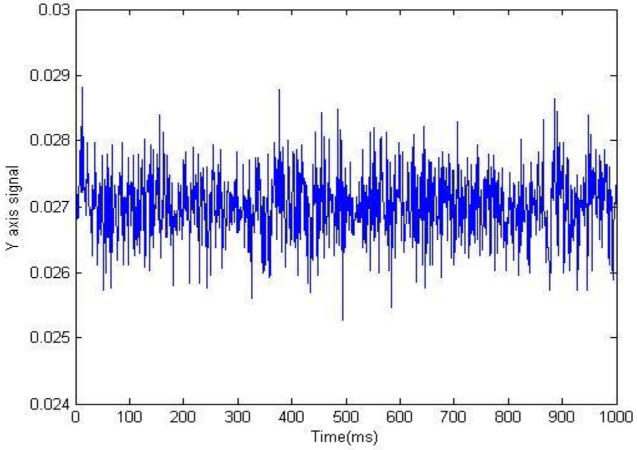
Generating Image

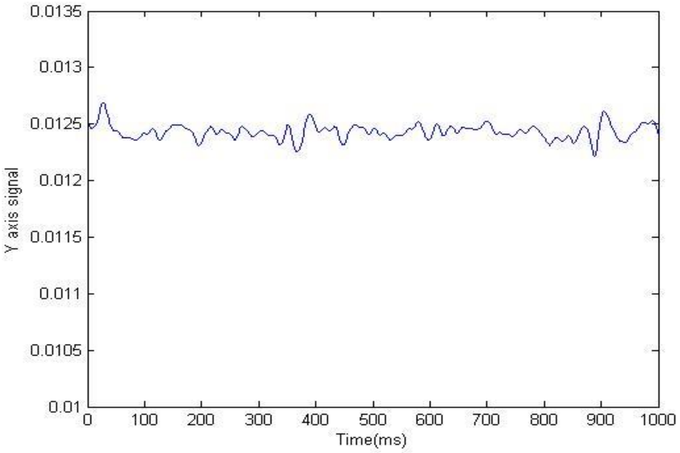
Image Processing

Final AFM Image

AFM Imaging

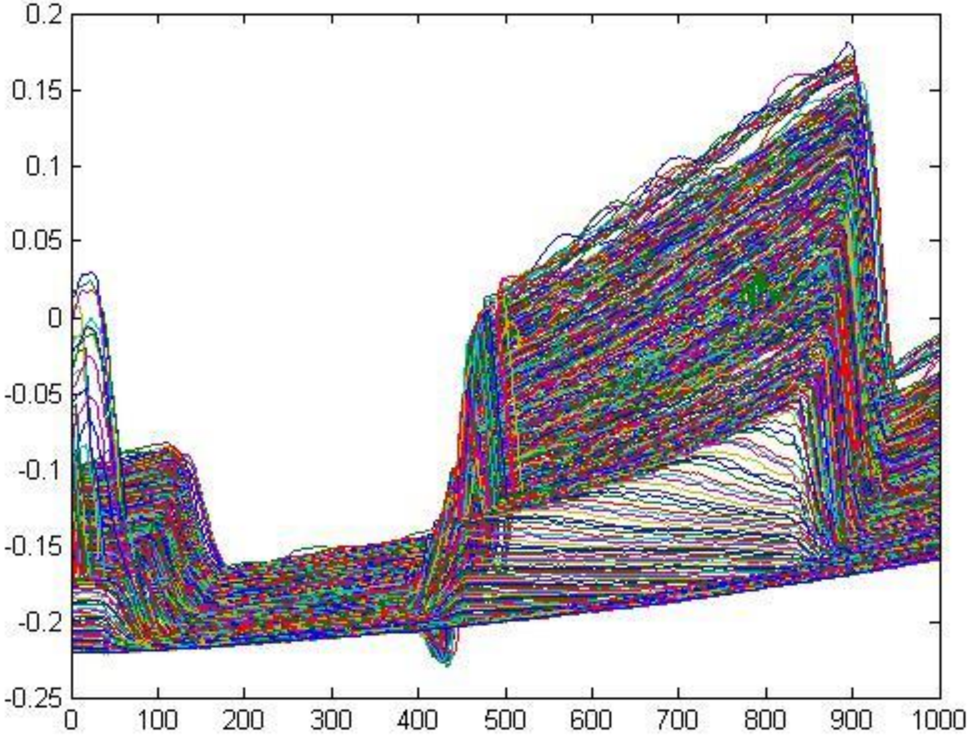
Moving average filtering to reduce noise





AFM Imaging

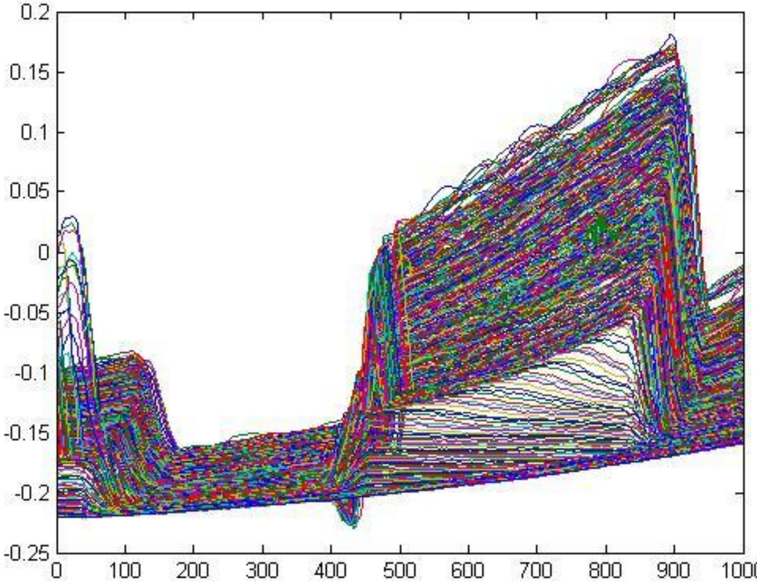
Generating Images

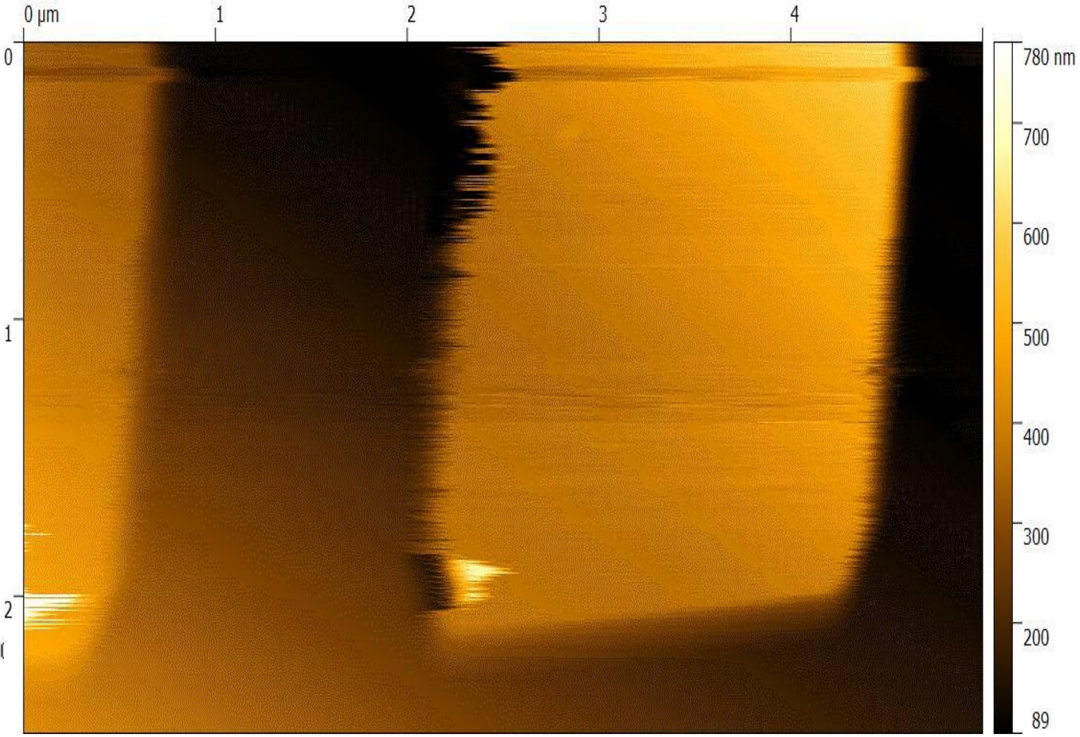


AFM Imaging

Generating Images

500nm

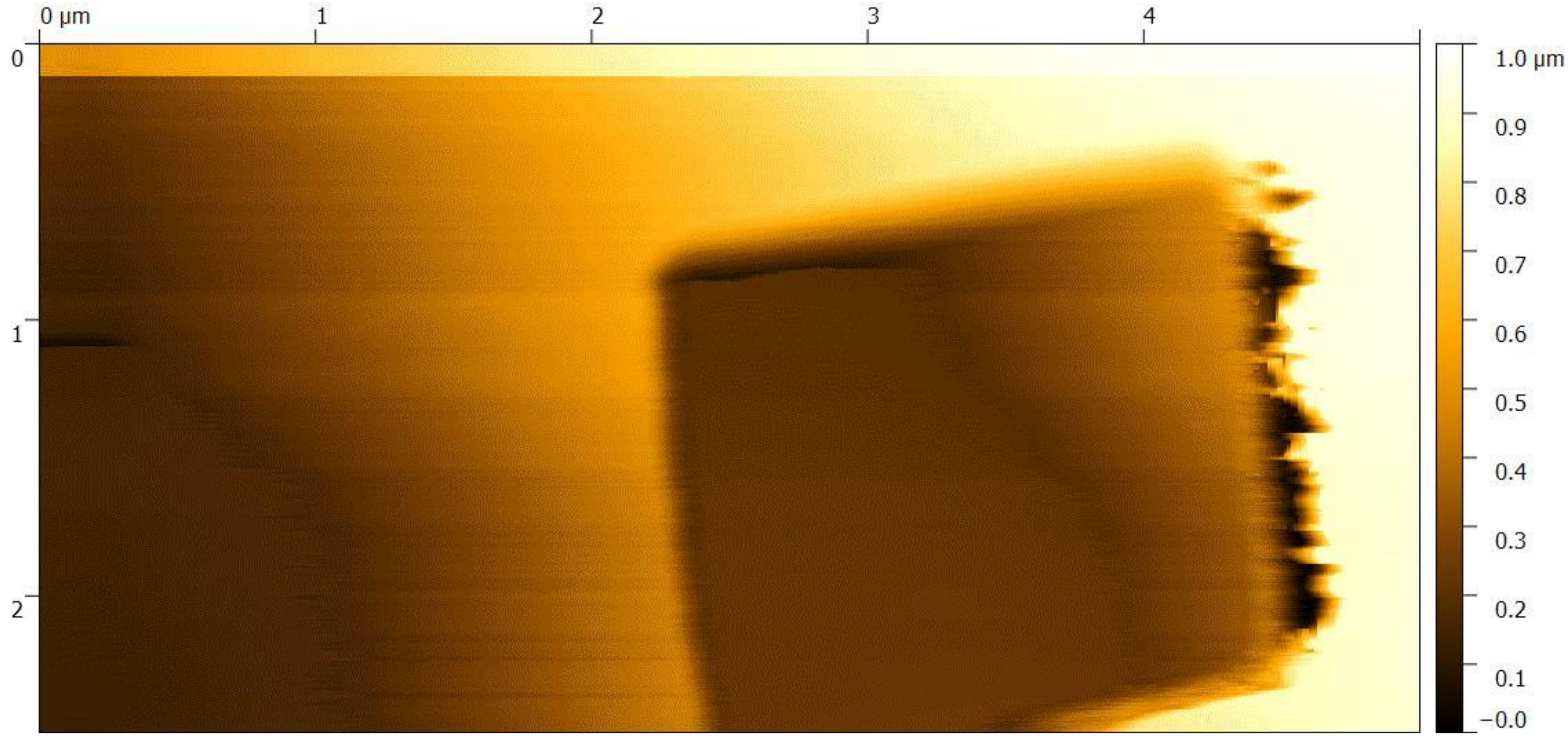




AFM Imaging

Generating Images

500nm



AFM Imaging

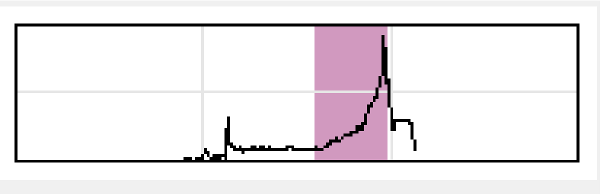
Raw Data

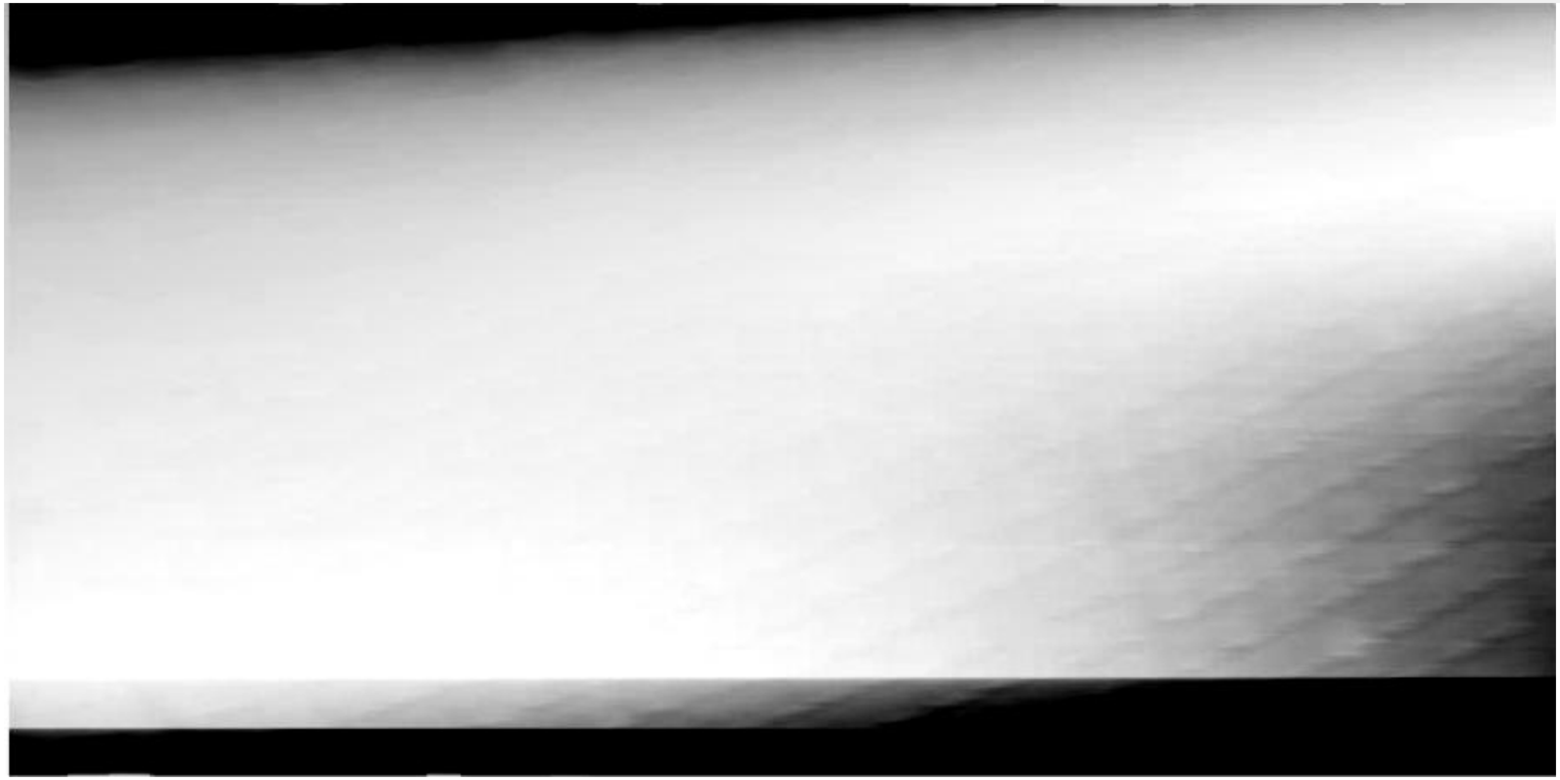
AFM Imaging

3rd order polynomial background subtraction

AFM Imaging

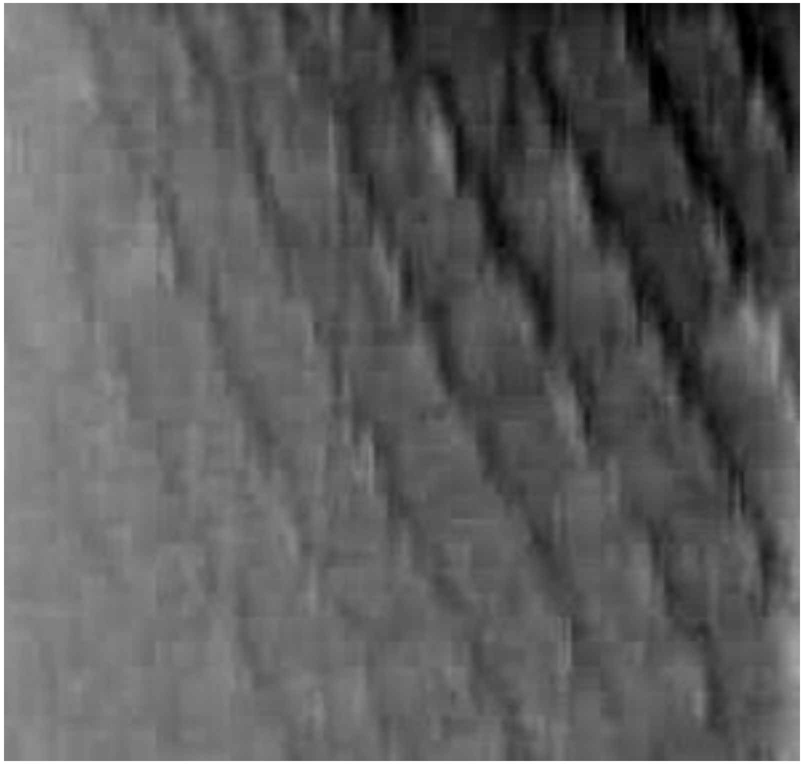
Histogram Specification





AFM Imaging

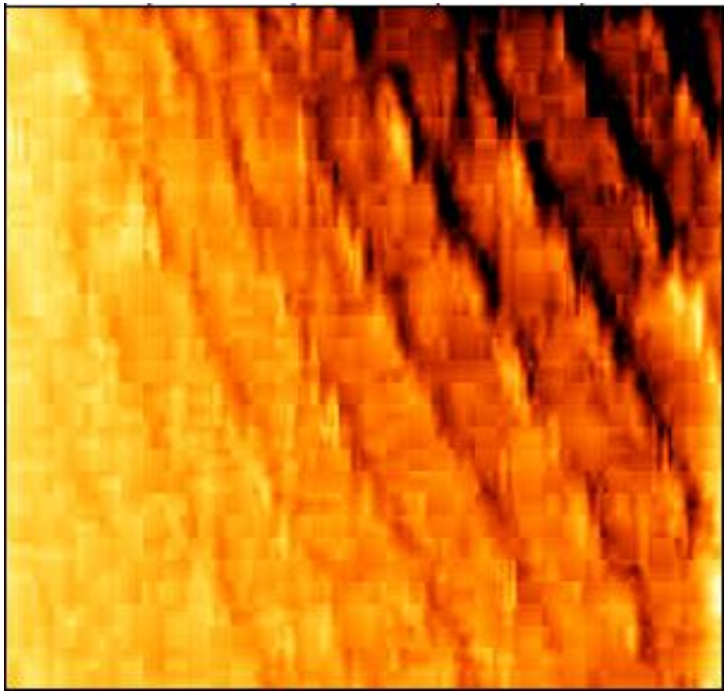
Cropping useful portion, high pass filtering



AFM Imaging

Assigning color and scale

It is a 30nm grid!



Achievements

- Microscope is able to scan samples at “**Super Resolution**”
- Detection sensitivity for small objects is beyond any Optical or Electron Microscope with a fraction of the cost
  Approx. cost: PKR 200,000

Achievements

- Scan area = 12um x 10um
- Approx. Scan time = 16 minutes

- Height Resolution: up to 30nm
- Horizontal Resolution: 1.25nm Approx.
- Magnification: 600,000x (Calculated for grid sample)