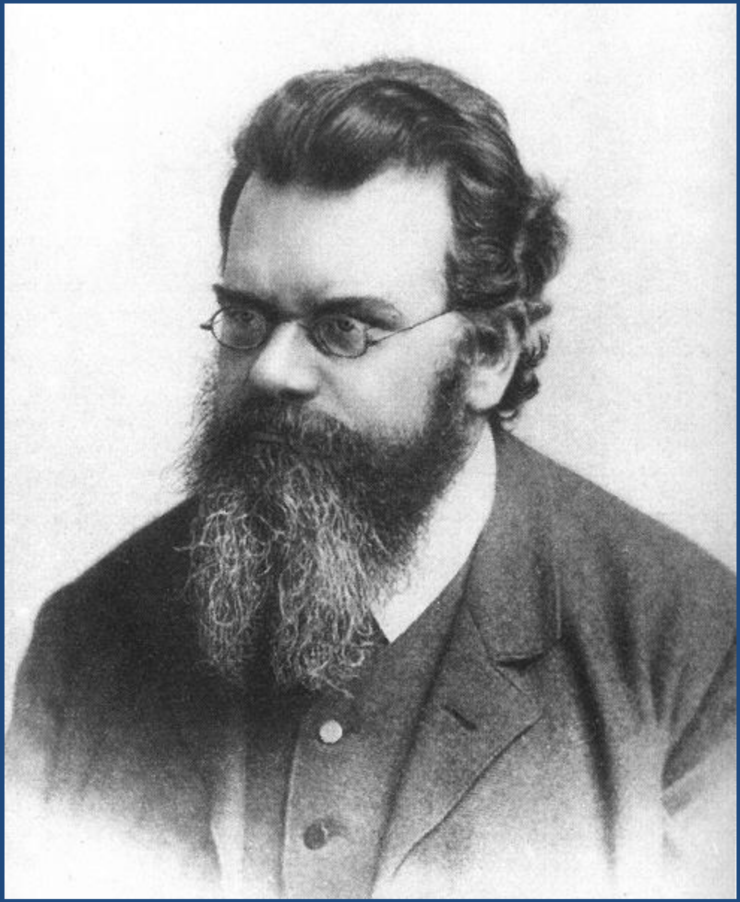
How to do the Thermal Noise Lab



And also your DNA melting lab report

Agenda for our Theory Free Day

- How to put away your DNA melting apparatus
- DNA melting lab report
- The teaching AFM
- Tips for the thermal noise lab

Logistics

- Four thermal noise lab stations will be available on Monday
  - Six stations available for finalizing work on DNA melting
  - Thermal noise stations will be added throughout the week as needed
- You need a new lab partner
  - Email me by Monday if you do not have one
- DNA melting report is due 10/10
  - Hand in to me in lab by 7:00 PM
  - Submit electronically (PDF or MS Word document)
  - If you do not get a confirmation email within 1.5 hours, assume I have not received your report
  - Late work not accepted without prior arrangement
  - Come by the lab with data analysis questions
- Thermal noise lab ends 10/17
  - Report due 10/24

FINISHING UP DNA MELTING

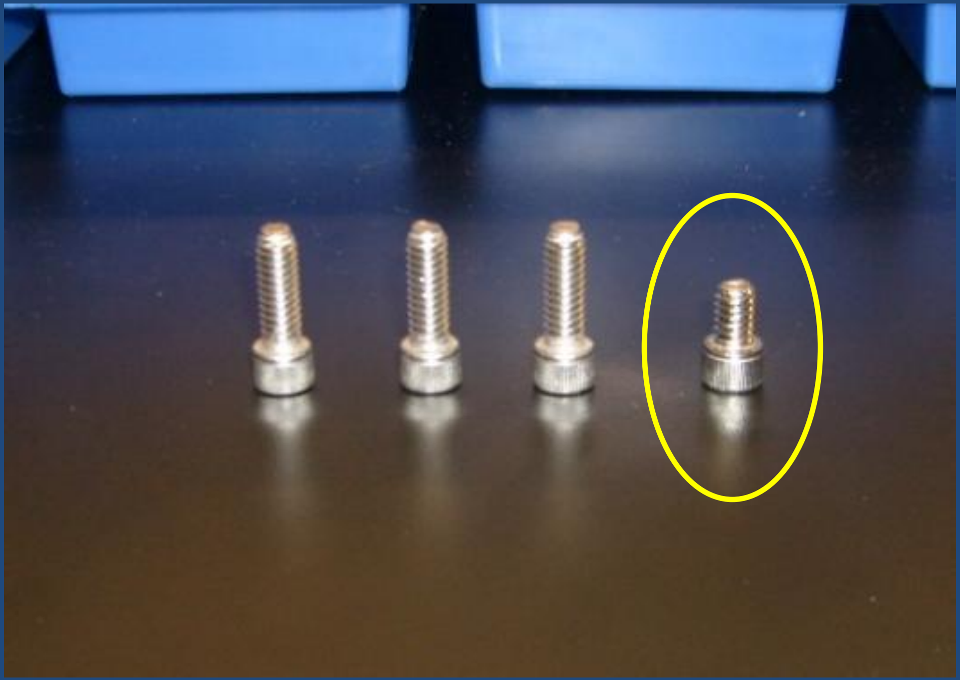
How to Put Your DNA Melting Apparatus Away

- Everything taken apart, returned its correct location
  - It may help to sing the *One of These Things* song while you work
- Do not put anything back broken
- Strip your electronic breadboard
  - Return large caps, op amps
  - Resistors, broken components in dead components box

Susan, introducing *One of These Things* in the very first episode of *Sesame Street.*
(Image reproduced from *The Muppet Wiki*)

20.309 version of *One of These Things*

It’s Time to Play Our Game



How to Put a Lens Away

- Properly identify lens
  - Lens measuring demo
- Clean, if necessary
- Wrap like a piece of candy
- In the right box
  - If you didn’t keep the original box, find one
- Wrap filters similarly and replace gently in storage bin
  - Do not clean them
  - If very dirty or damaged, return to an instructor

Report (and life) Ethics

- You may discuss the report with your partner and other students; however:

The report you submit must be entirely your own work

- Give credit to your lab partner
- You may share data with other groups; however:

You must clearly state the source of anything that was not a direct result of your own efforts in the lab

- You must produce one set of charts using *only the data you gathered in the lab*
  - You may provide additional analysis based on other people's data
- You must submit your raw data and the scripts you used
  - Email detailing format coming

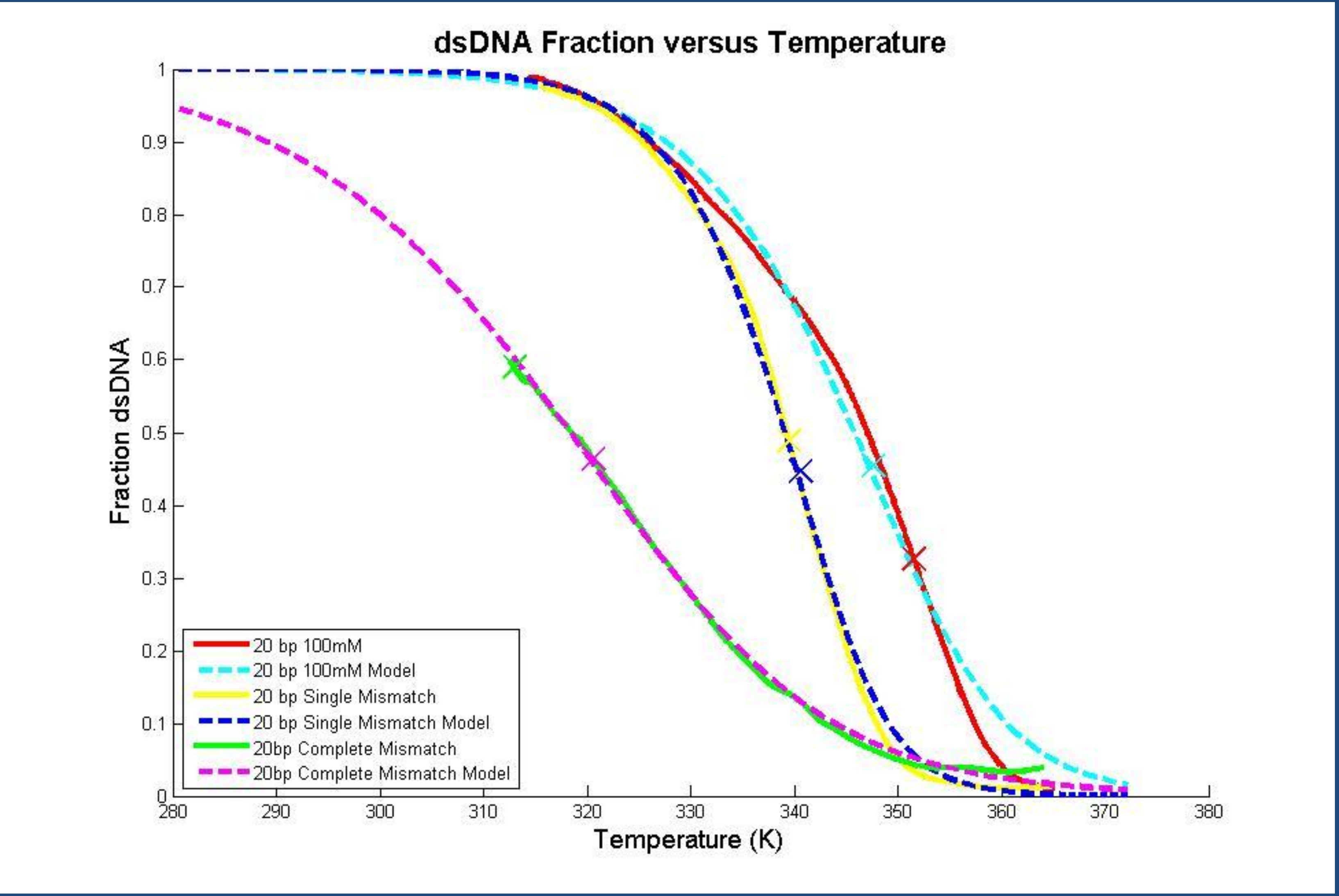
If you used any code that you did not write yourself, you must credit the author

I have no sense of humor about plagiarized work. Please be diligent with your citations.

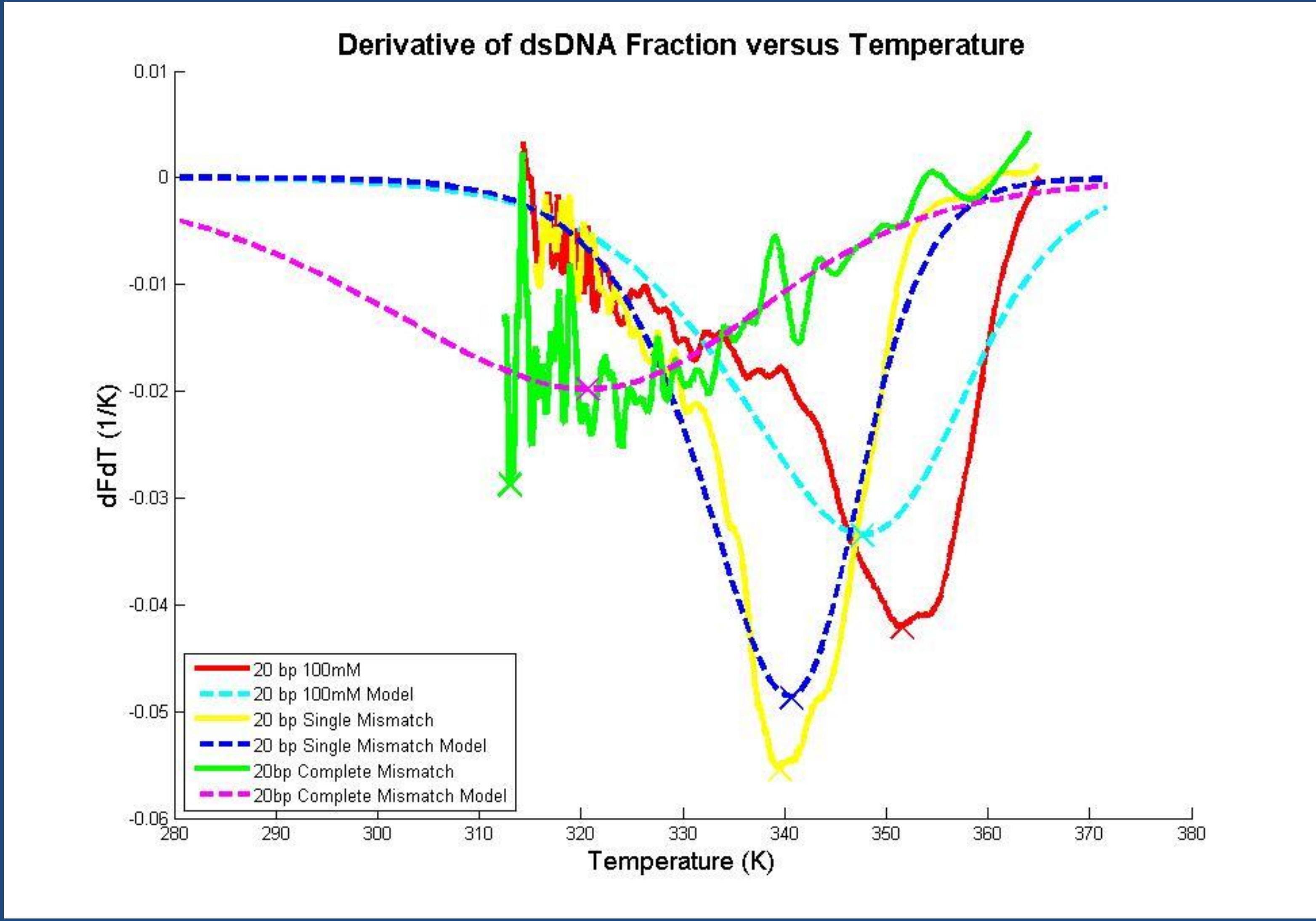
DNA Melting Report

- Report should be around 5 and certainly < 10 pages, with charts, not including code listings
- Suggested format: bullet points
- Section 1A: *Your* results
  - List of samples you ran
  - Four exquisitely presented and labeled plots
    - 20 match; single mismatch; and complete mismatch f vs. T with curve fits, melting points, and estimated thermodynamic parameters
    - Derivative plots with curve fit and melting temperature by various methods
    - Similar plot with length or strength investigation on single set of axes
    - Derivative plot of strength/length
  - Table with all estimated thermodynamic parameters
    - T_m (by various methods)
    - $\Delta S°$, $\Delta H°$
  - Presentation counts!
    - All plots titled, axes labeled, legend, units specified, readable fonts, etc…
  - Bullet points explaining anything about your data that needs explaining
- Section 1B: Complete results
  - Plots, tables including data you may have obtained from other people
  - I can provide data for comparison/additional analysis

Example Data Plot



Example Derivative Plot



DNA Melting Report, Continued

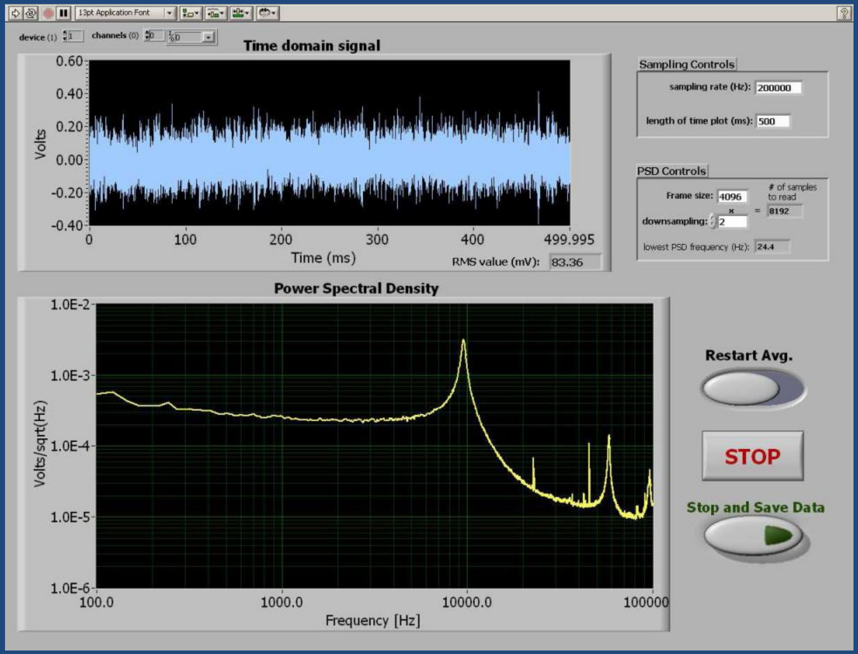
- Section 2A: Document your instrument
  - Gains/component values/cutoff frequencies, etc…
  - Optical layout (simple block diagram including component values)
  - Did you do anything differently than the lab manual suggested?
- Section 2B: How did your design change?
  - What problems did you have in the lab?
  - How did you modify your original design to address the problems?
- Section 2C:Characterize your instrument
  - Signal to noise (power ratio, dB): compute the standard deviation of your signal and divide by the range. Take 20 $\log_{10}$ of this value.
- Section 3: Analysis and discussion
  - Outline data analysis algorithm. Include relevant parameters: filter kernel lengths, window shape, etc…
  - How do various methods of estimating T_m compare?
  - How do the thermodynamic properties compare with models?
  - Discuss sources of systematic and random error
- Section 4: Raw data and code
  - Each group should *electronically* submit .m files (or other language), raw data (.txt) files
  - Do not submit any code or data that your group did not create
  - You will receive an email this weekend detailing the format for your submission
  - I will compile class-wide results from raw data

THERMAL NOISE LAB

Thermal Noise Lab Procedure

- Only experiment 3 in the lab manual is required
  - If you are interested in imaging, you can give it a try
  - You can also do a final project on the AFM

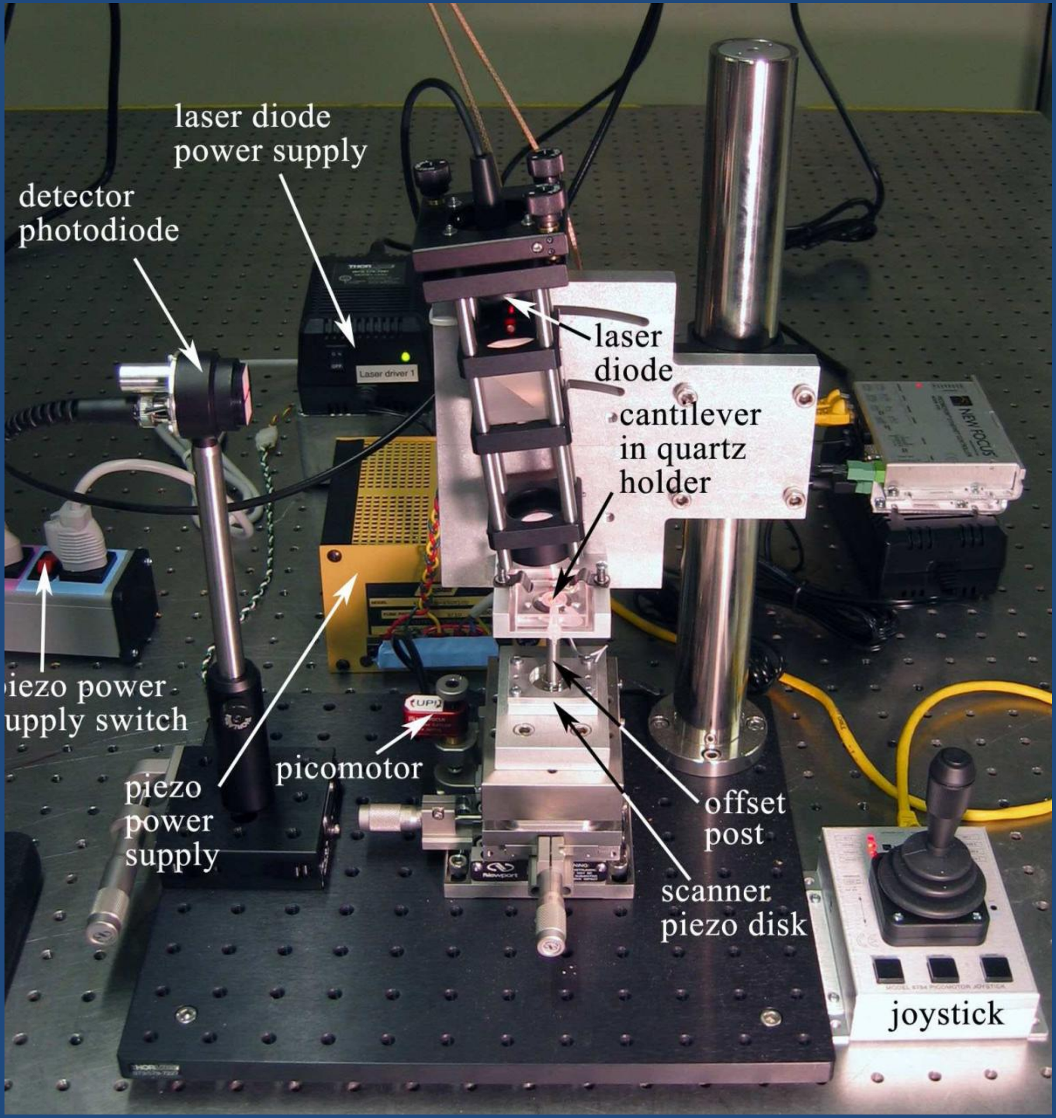
1. Calibration
   - Determine the sensitivity of the detector (distance/Volt)
2. Set system gain
   - Remember to record your amplifier settings
   - Very common mistake last year
3. Measure PSD of cantilever excited by thermal noise
4. Analysis
   - Model cantilever as a mass/spring system
   - Fit curve to determine resonant frequency, Q, and thermal noise limit



Example PSD

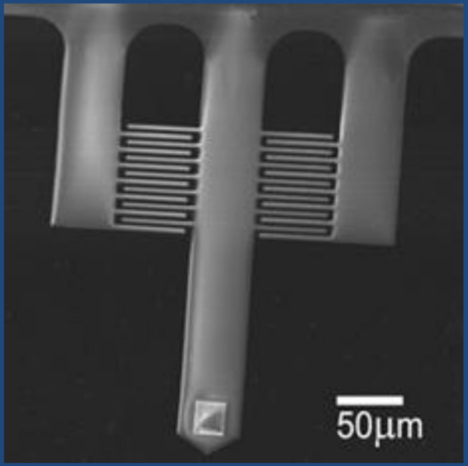
Practical Introduction to the Teaching AFM

- Interdigitated probes
- Optical system
- Sample positioning system



Interdigitated Probes

- ID fingers act like a diffraction grating
- Deflection of tip changes intensity of diffraction spots
  - Fingers travel through a distance of $\lambda/4$ from maximum to minimum intensity
- 3 sizes of imaging probes (shown above)
  - Two probes on each device (L&M or M&S)
  - Long: 400um long; grating starts 117um and ends 200um from the base
  - Medium: 325um long; grating starts 77um and ends 160um from the base
  - Short: 250um long; grating starts 43um and ends 125um from the base
- Noise probe (below) gives a cleaner curve
  - Two probes on each device
  - 350um long [NOTE: ID fingers have 4um spacing, not 2um as usual]; grating starts 140um and ends 250um from the base
  - 275um long; grating starts 93um and ends 175um from the base
- Correction factor must be applied to account for placement of fingers versus tip

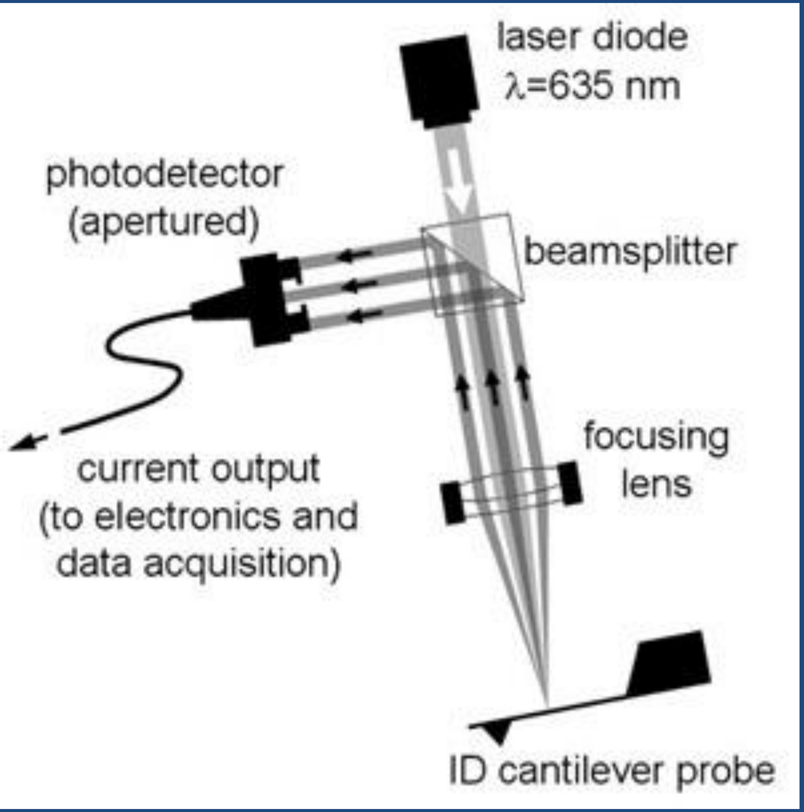


Imaging Probe

Thermal Noise Probe

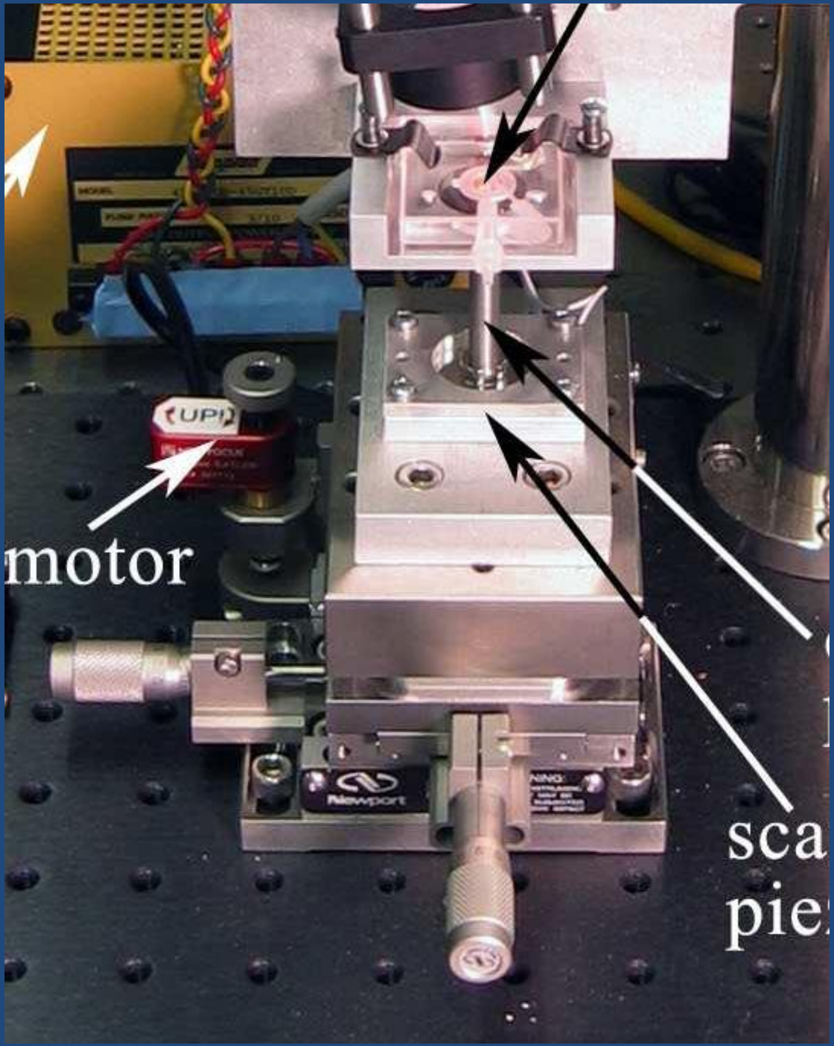
AFM Optical System

- Beamsplitter reflects 50% of the light at 90 degrees
  - Beam to the right is stopped
- Lens focuses spot on cantilever and re-colimates reflected light
- Fundamental diffraction spot falls on photodiode



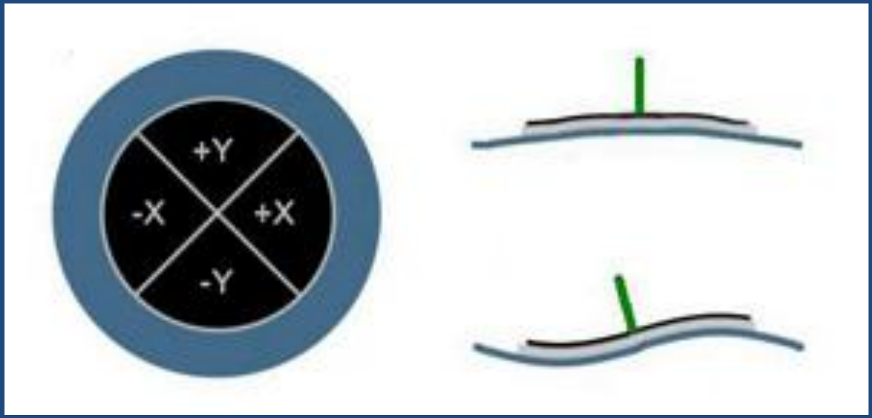
Sample Positioning System

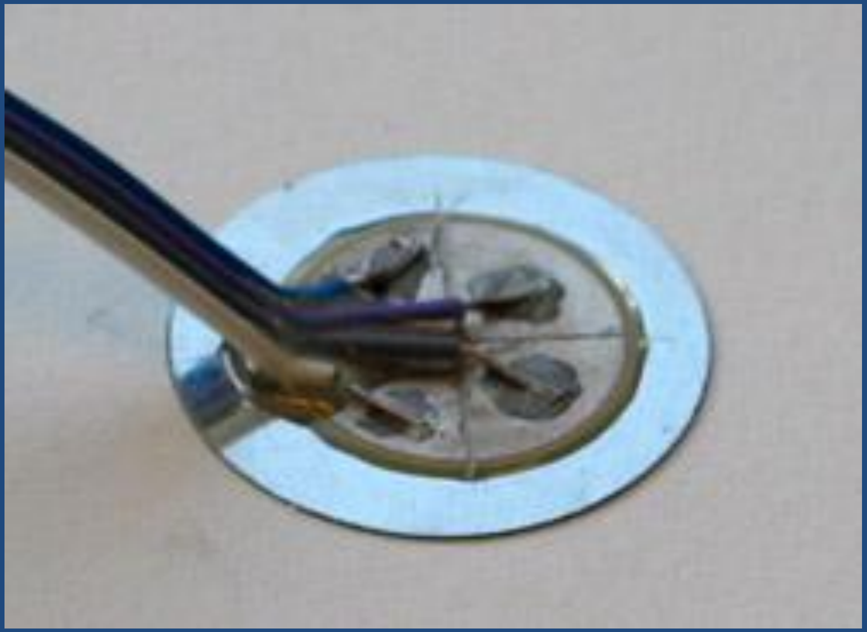
- X-Y-Z stage for coarse movement
  - Micrometer driven X-Y
  - Motorized Z
    - Motor is *very* slow. Move large distances (such as when loading samples) by hand
- Piezo movement for scanning



Piezo Scanning Stage

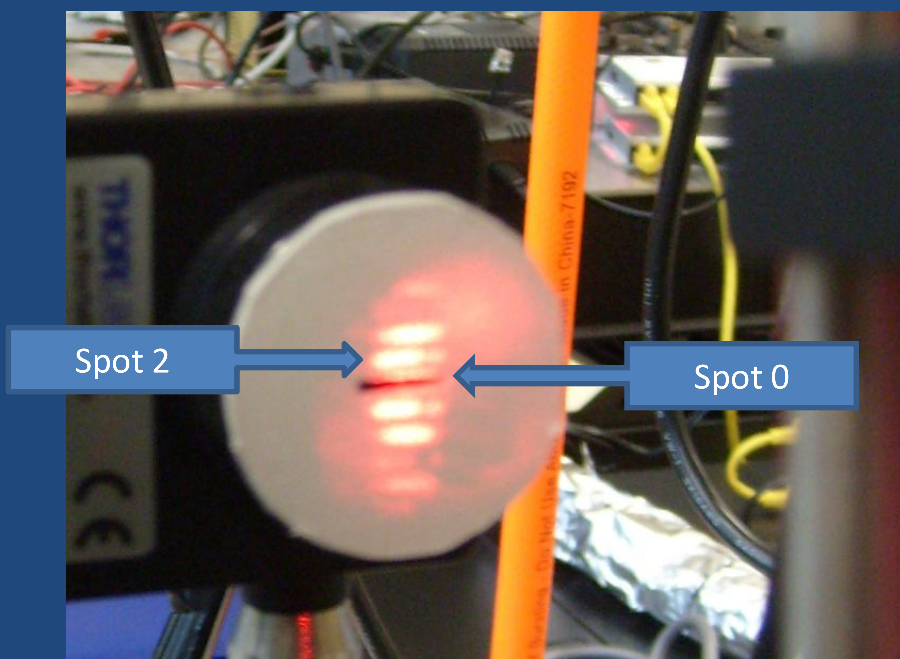
- Piezo material changes dimension in response to electric field
- Disc divided into quadrants
- Equal voltage on quadrants induces up/down (fundamental mode) movement
- Opposite voltages induces 2nd mode motion
- Magnet/steel rod amplifies motion

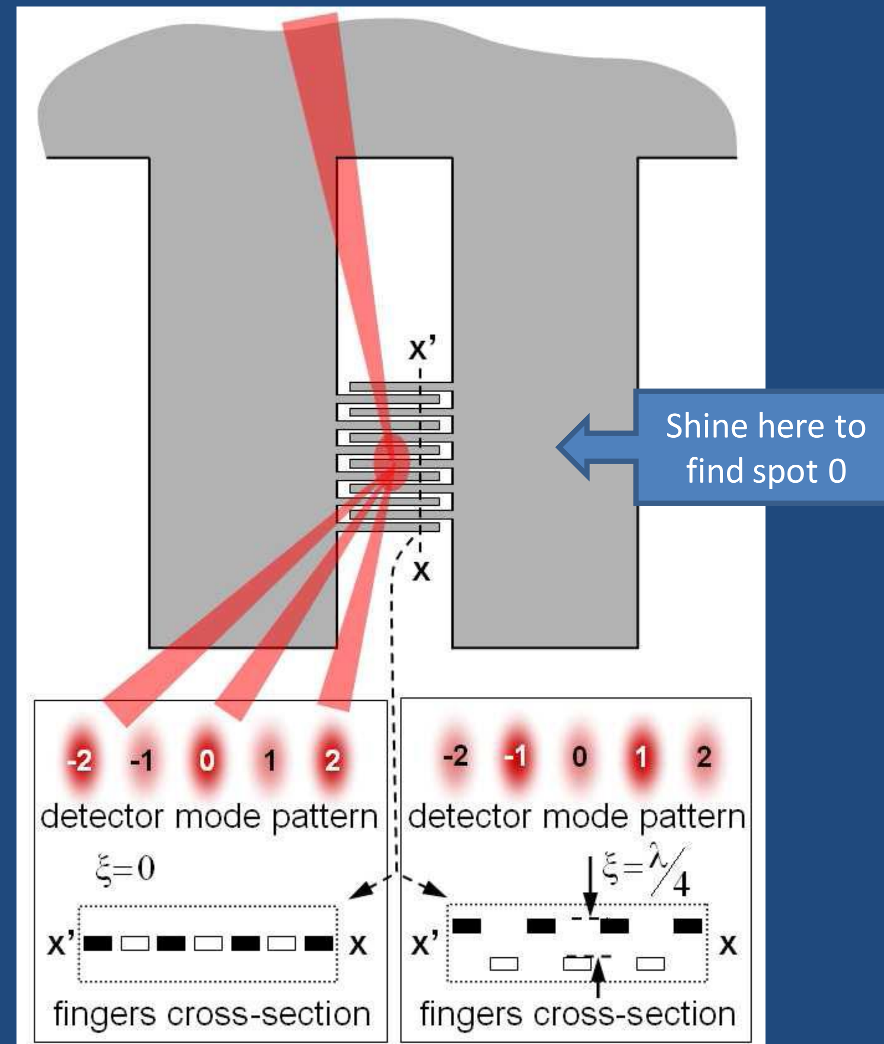




Adjusting the Laser

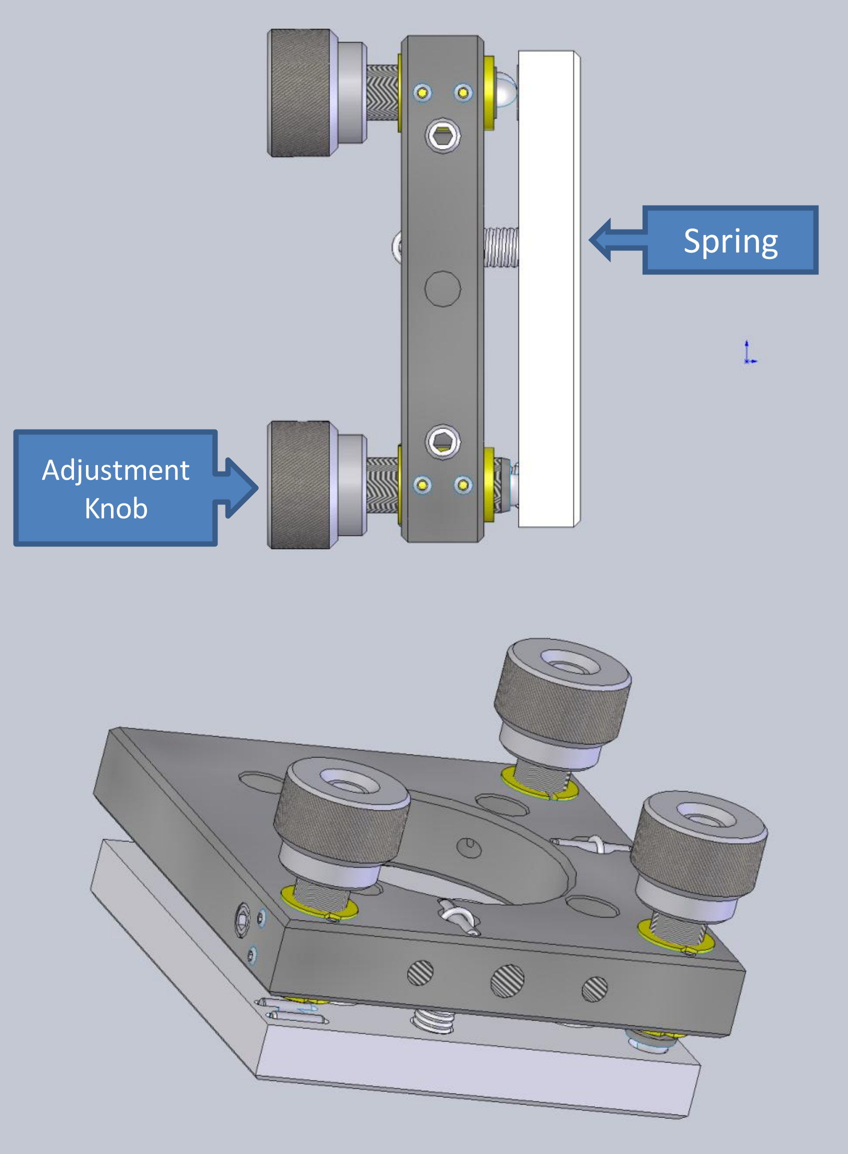
- Adjust the laser to shine on the ID fingers
- Position photodiode
  - Fundamental spot should pass through opening and fall on photodiode
  - Aim at cantilever to find fundamental





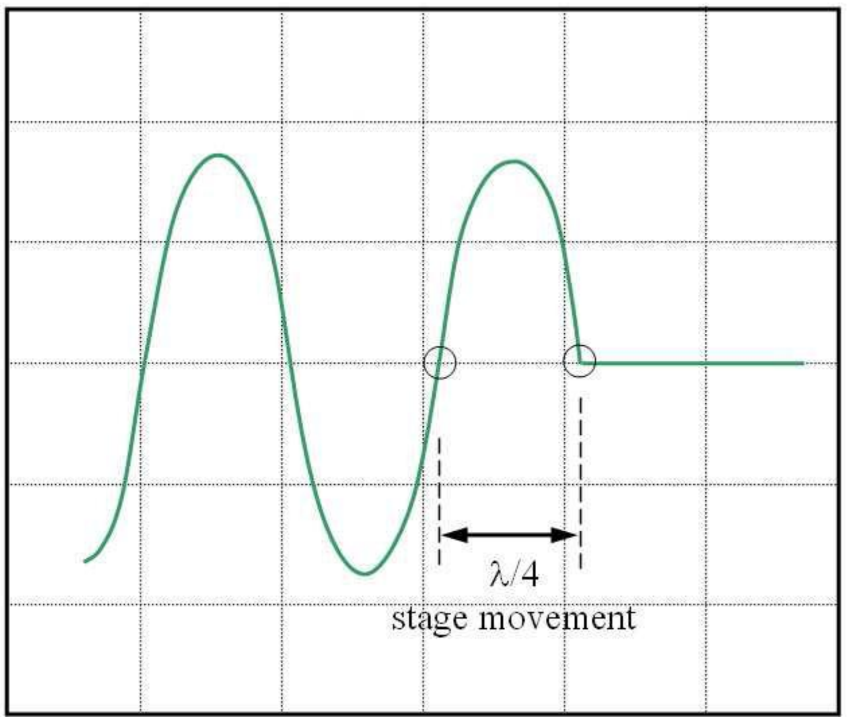
Laser Kinematic Mount

- ThorLabs KC1 Kinematic mount
  - 3 thumbscrews allow fine setting of laser beam direction
- Easiest to use X- and Y-directions and walk beam out to the ID fingers



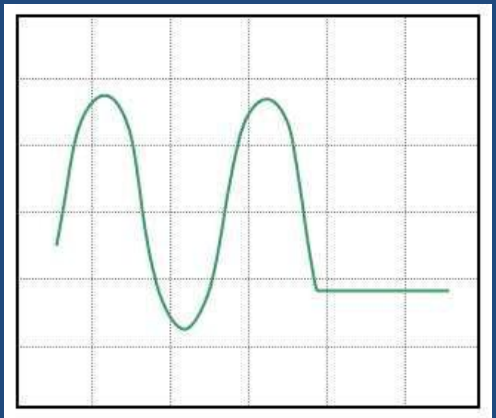
Calibration

- Output is nonlinear
- Sensitivity (Δout/ Δin) is equal to the derivative of the response curve
  - Greatest sensitivity is in the middle of the curve
  - Sensitivity is zero at the peaks and valleys
- You will measure sensitivity by bringing a hard sample into contact with the probe and scanning it up and down with the piezo stage
  - Z-mod scan software function
  - Use relationship to laser wavelength (λ/4 between zeroes) to determine absolute distance
  - Apply probe geometry correction factor
- Tip: position the spot at one end or the other of the ID fingers

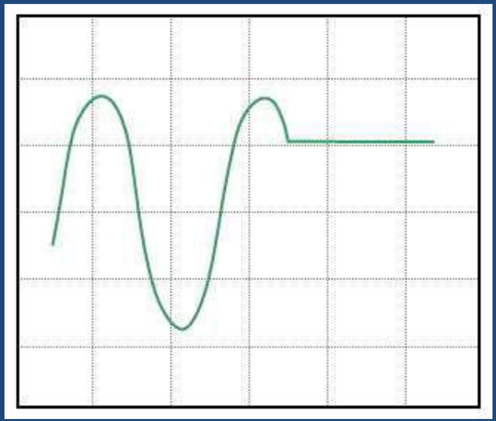


$$I \propto \sin^2\left(\frac{2\pi}{\lambda} z\right)$$

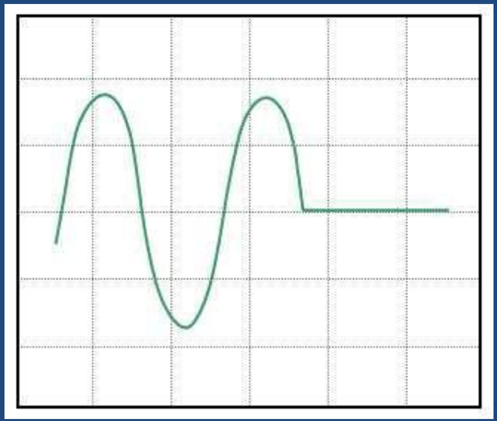
Biasing



Too Low

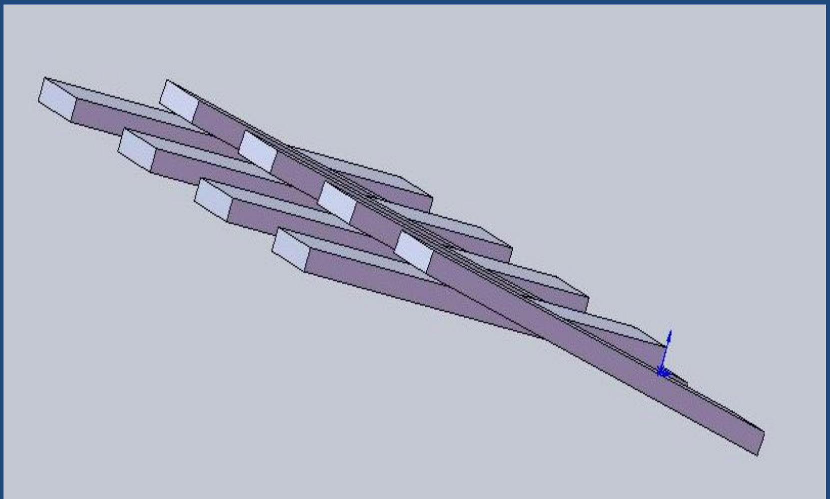


Too High



Highest Sensitivity

- Alignment of fingers varies due to residual stress in the silicon wafer
- Can use this effect to bias sensor at point of highest sensitivity for thermal noise measurement



Procedure

- Crank X-Y-Z stage way down (annoying)
  - Use your fingers, not the motor
- Mount sample disk on top of the post
- Make sure magnet is at the center of the piezo stage
- Bring the sample close to the tip
- Run Z-mod scan in software
  - Make sure switch on back is in Z-mod scan mode
- *Gently* bring the sample into contact
  - Don't crash the sample disk – look underneath
  - You will see the diffraction spots change when the sample makes contact
  - Try not to break a cantilever
  - If you do, ask an instructor to change it
- If you are using thermal noise probe, align sample so it touches only one cantilever
- Record calibration curve
- Back sample away
- Turn up amplifier gain
- Record noise spectrum