LECTURE 3: ADDITIONAL NANOMECHANICS INSTRUMENTATION COMPONENTS

Outline :

Objectives: To describe the function of other instrumentation components necessary for nanomechanical experiments; lasers and piezos.

Readings: Course Reader Document 9

Multimedia : Listen to *Lipid Bilayers* podcast : *http://web.mit.edu/cortiz/www/Nanonewton.html*

NANOMECHANICS ART FROM HOLLAND

Jacob Kerssemakers Ph.D. Thesis U. Groningen (NL)

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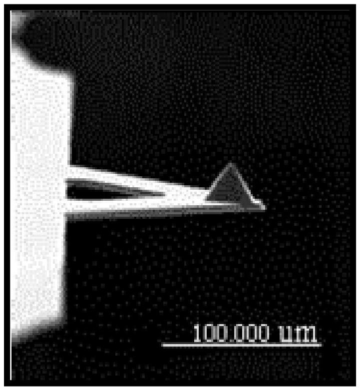
LAST TIME : THE FORCE TRANSDUCER- HOW CAN WE MEASURE SUCH TINY FORCES?

i.e. nN (=1•10^{-9} N), even pN (=1•10^{-12} N) ! → typical engineering structures are Newtons

microfabricated cantilever beams



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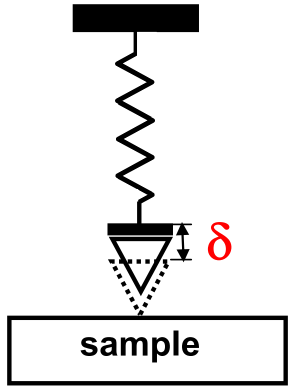
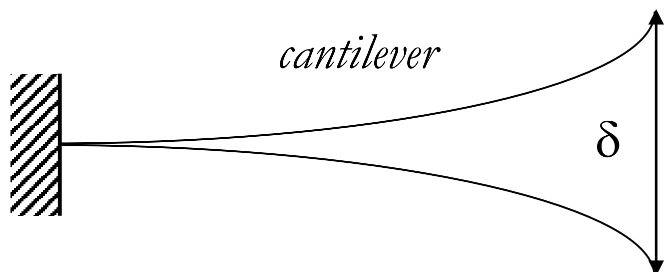


force transducer- sensor device that responds to an external force where you can output and record that response

- **continuum beam theory** : reduces to Hooke's Law

$$F = \left[\frac{3EI}{L^3}\right]\delta \rightarrow F = k\delta$$



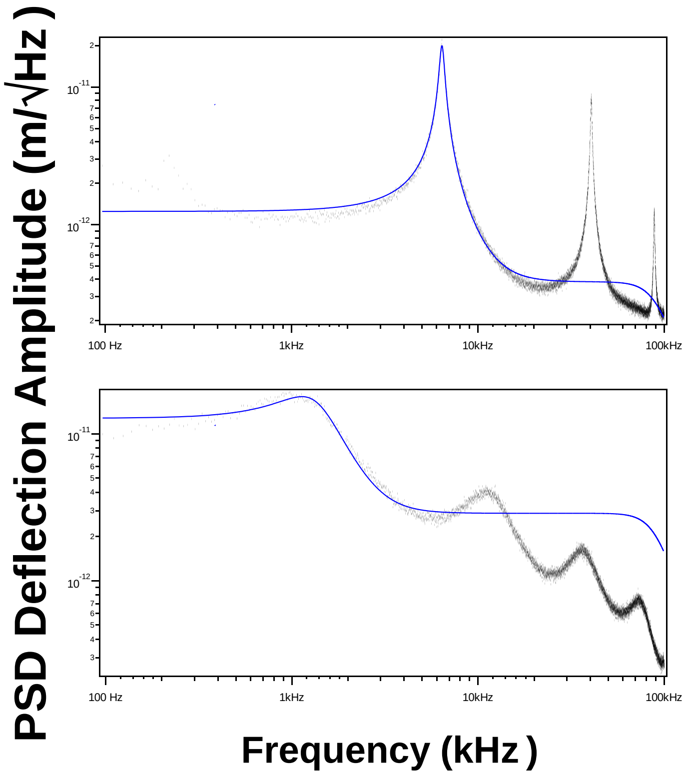
E= elastic modulus
I = moment of inertia of cross section
L= length of beam
k= cantilever spring constant

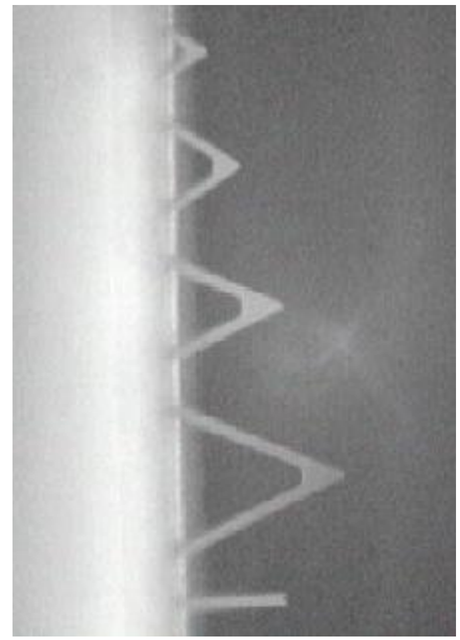
-**attachments** to nanosized probe tips at the ends of microfabricated cantilevers

-**limit of force detection given by thermal oscillations**→ can represent cantilever as driven, damped simple harmonic oscillator

TRANSDUCER (SPRING CONSTANT) CALIBRATION

- determine the relationship between the externally applied force and output signal to automatically convert to a force

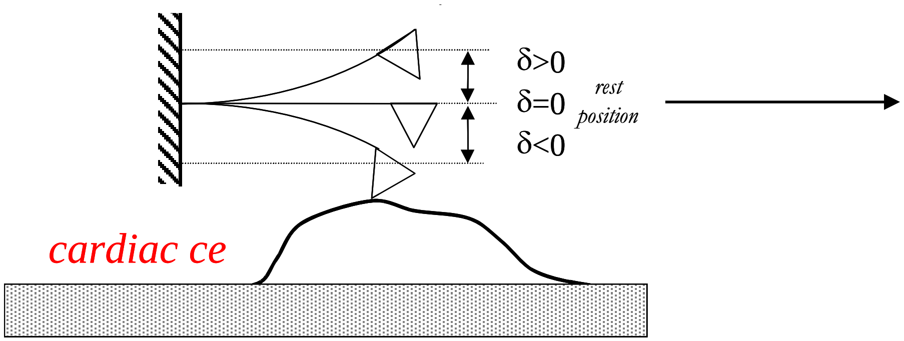




$$A(\omega) = \text{amplitude of oscillations} = \frac{F/m}{\left[\left(\frac{k}{m}-\omega^2\right)^2+\left(\frac{\omega\beta}{m}\right)^2\right]^{1/2}}$$

Derivation : Vibrations and Waves A.P. French, W. W. Norton and Company, NY 1971 eq. 4-13 and for more info see Shusteff, et al. Am. J. Phys. 74 (10) 2006 (Posted on the MIT Server, Optional Supplementary Resources)

MAPPING THE MECHANICAL PULSE OF SINGLE CARDIOMYOCYTES



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Domke, et al. Eur. Biophys. J. (1999) 28, 179

I. **Individual cell** : sequences of high mechanical activity alternate with times of quietness, irregular beating which often last for minutes, active sequences were irregular in frequency and amplitude

II. **Group of cells**: “pulse mapping”

III. **Confluent layer of cells** : beat regularly in terms of frequency and amplitude, enormous stability of pulsing, cell are synchronized and coupled together : diverse pulse shapes due to macroscopic moving centers of contraction and relaxation

INTRACELLULAR CALCIUM WAVES IN 2D BONE CELL NETWORKS AS A SINGLE CELL IS LOADED *Guo, et al. MCB 3(3) 95-107 (2006)*

-Bone cells were cultured on micropatterned network with dimensions close to *in vivo*

-A force of ~ 61 nN was applied to an individual cell in the center with a microfabricated cantilever

-Fluorescence time-lapsed images of intracellular calcium [Ca^{2+}] waves signaling molecule)

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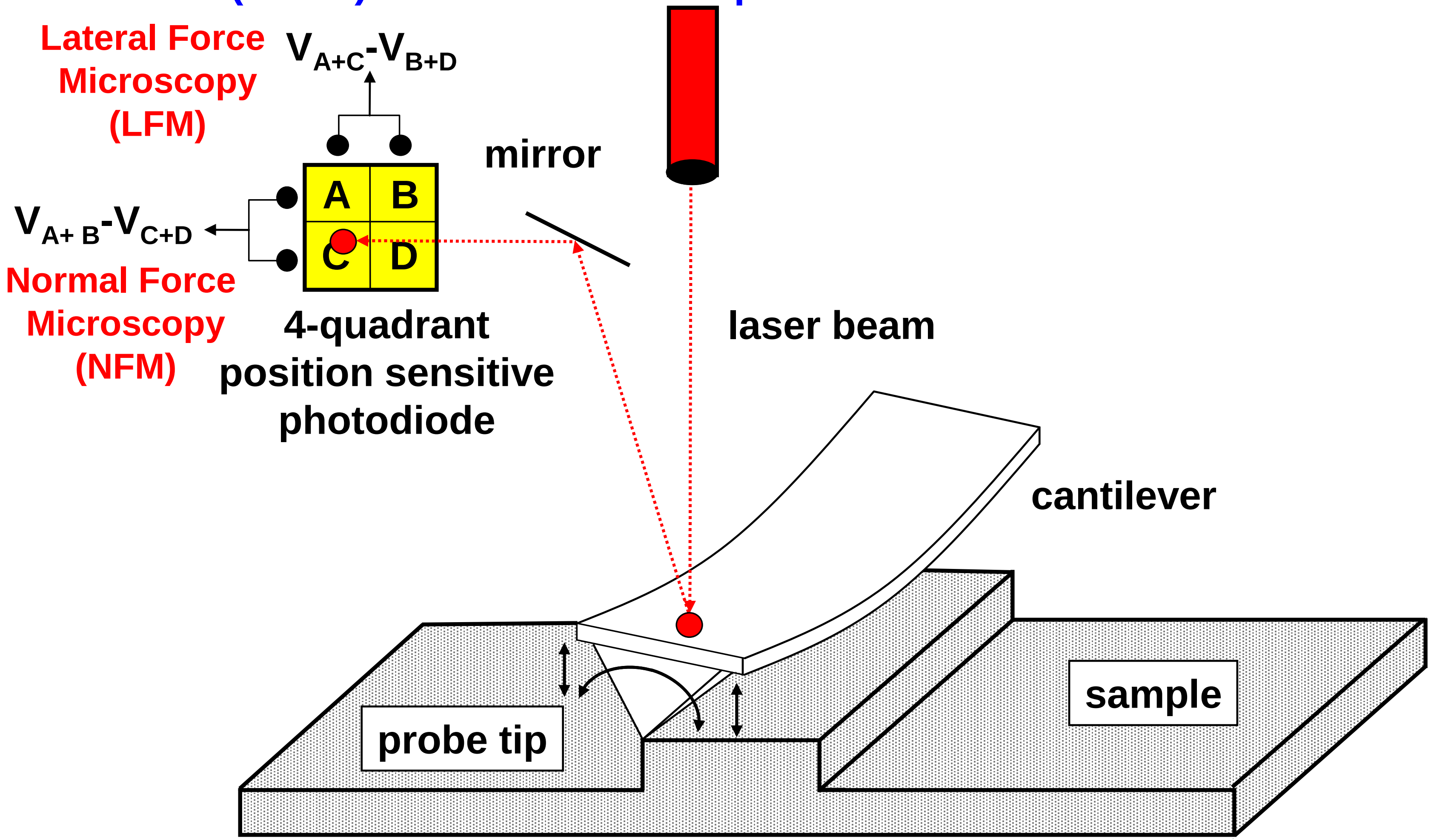
-Some bone cells exhibit double response through signal propagation via different cell pathways, the ability to respond multiple times without a decrease in magnitude may play a role in memory of previous loading history

Mechanotransduction - mechanism by which cells convert mechanical stimulus into chemical activity.

HIGH RESOLUTION DISPLACEMENT DETECTION : Optical Lever (Beam) Deflection Technique



HIGH RESOLUTION DISPLACEMENT CONTROL : How can we move an object one nanometer at a time?

"piezoelectric materials" : material which exibits a change in dimensions in response to an applied voltage and conversely, the material develops an electric potential in response to an applied mechanical pressure
-generally made by sintering ceramic powder to yield polycrystalline material where each crystal has its own electrical dipole (randomly aligned)

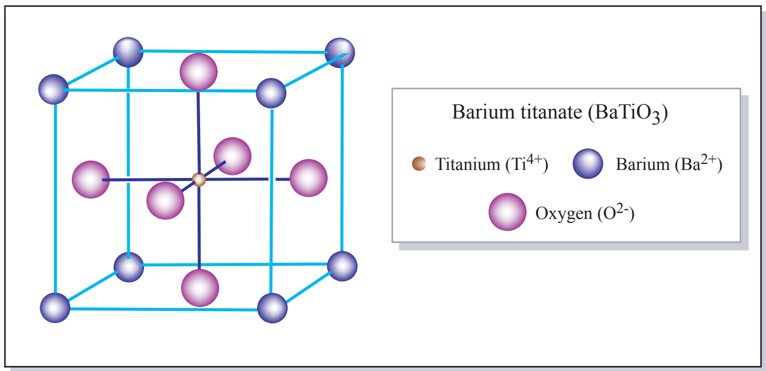
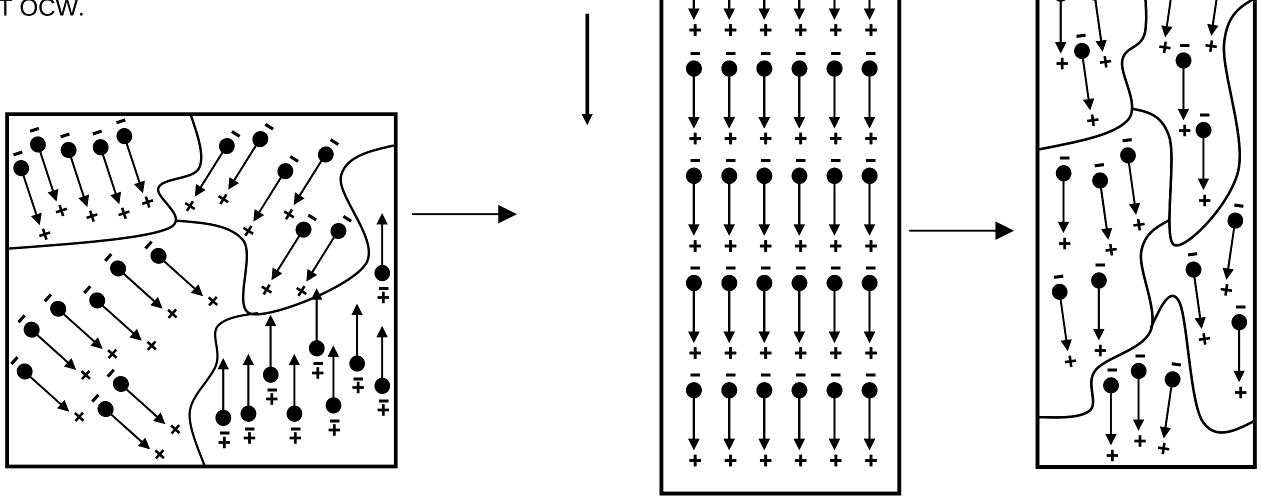


Figure by MIT OCW.

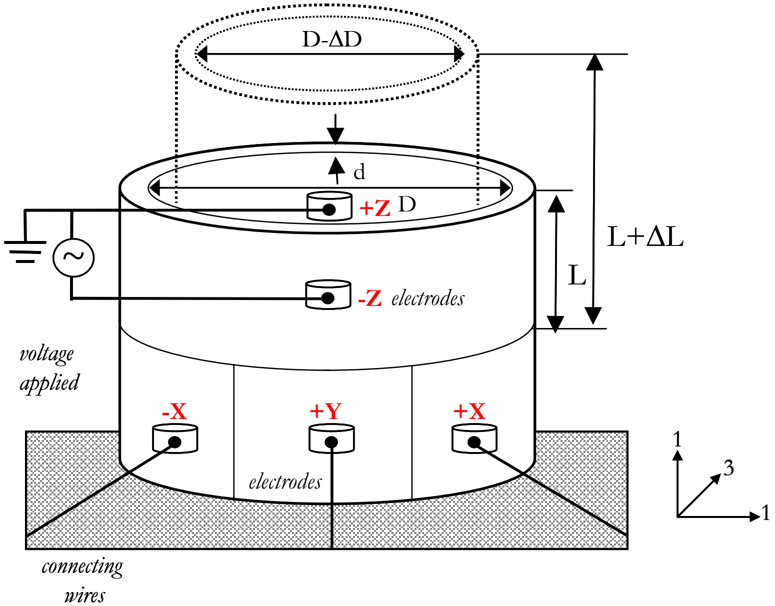


"Poling" : apply high electric field at high temperatures for a few hours to align the dipoles→remnant polarization after removal of electric field/cooling

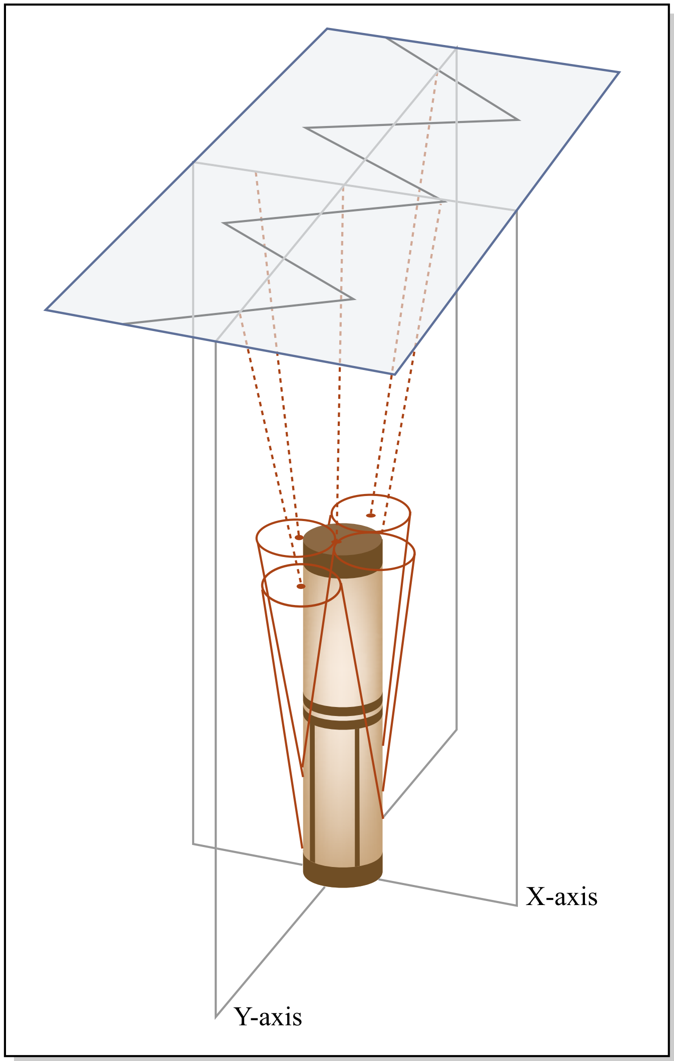
PIEZOELECTRICITY

*(*Digital Instruments "JV" PZT scanner)*

Courtesy of Veeco Instruments. Used with permission.



PIEZO TUBE SCANNERS



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