# Quantitative Nanomechanical Measurements: Surfaces and Thin Films


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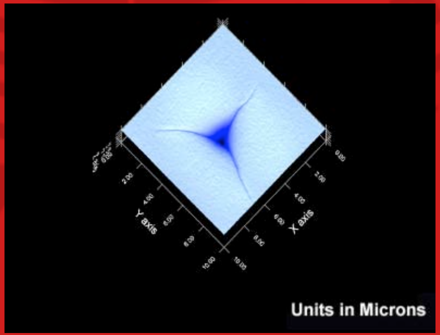
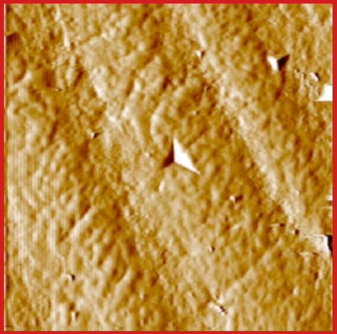


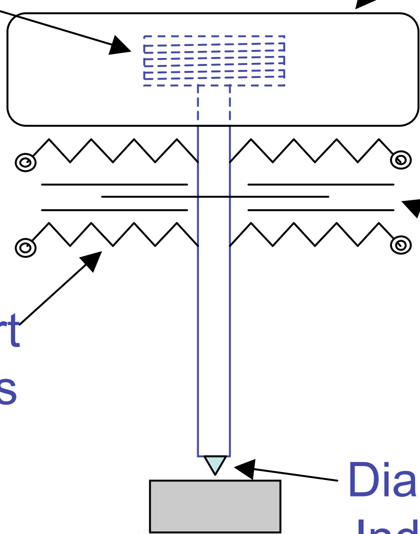

Cracking of an oxidized low-k dielectric



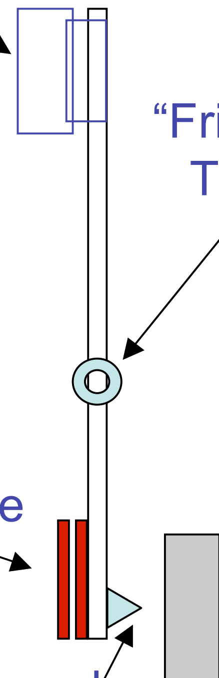
Apatite-collagen lamellae of trabecular bone

## First "nanoindenters" in *Ion Implantation into Metals* (1982):

### Pethica

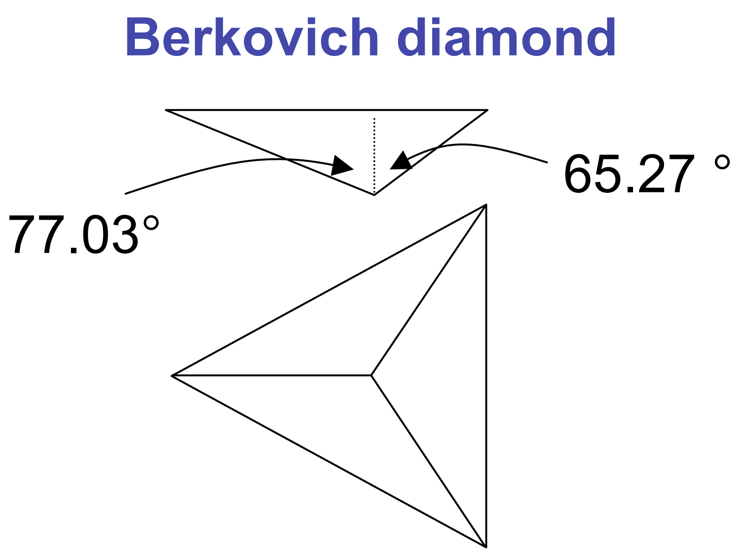


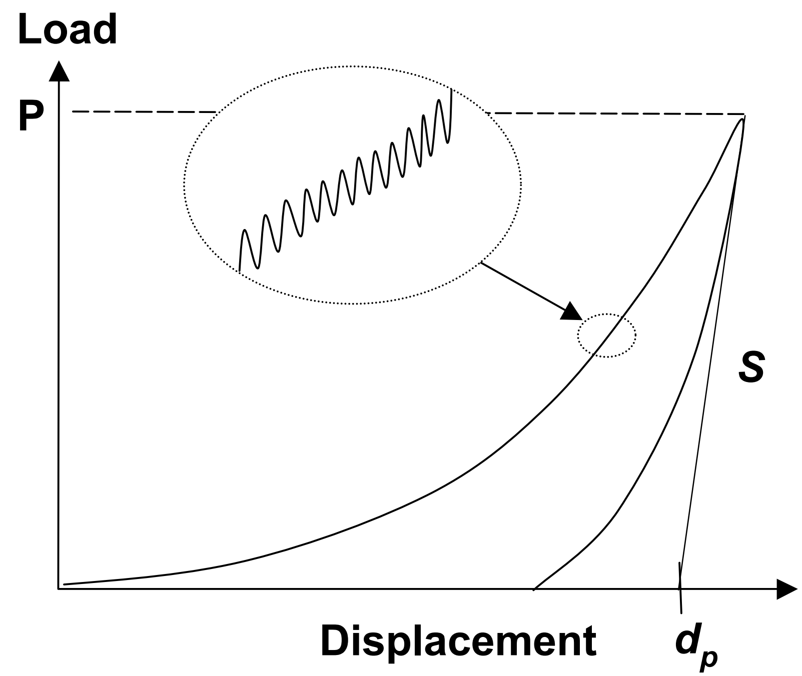

### Newey, Pollock & Wilkins




Optical imaging is not feasible on the nanoscale, so depth/load sensing instruments are vital.

# Measuring Hardness and Elastic Modulus



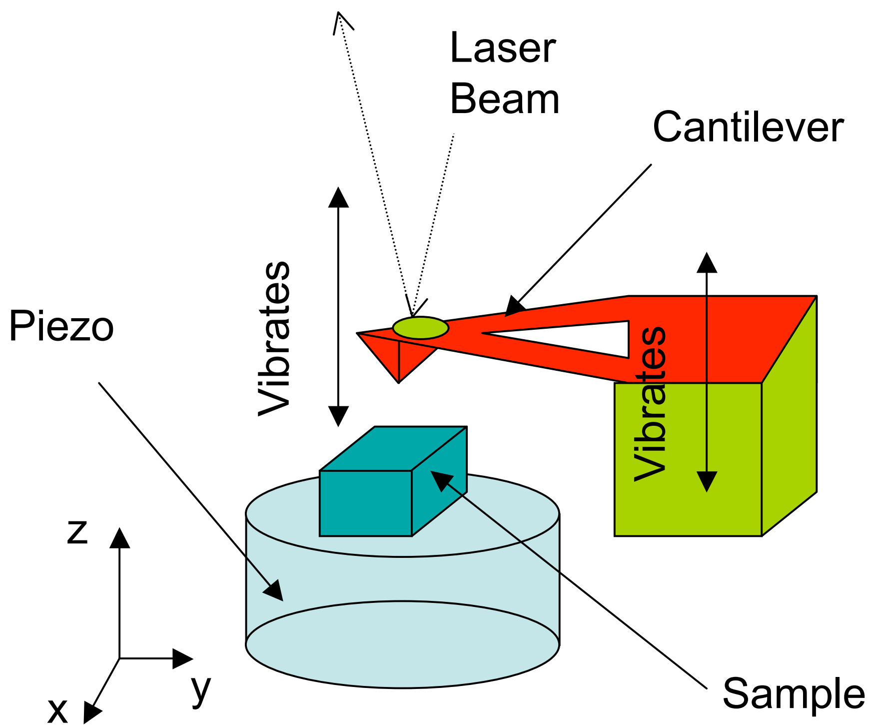

$$H = \frac{P}{A(d_p)}$$

$$S = \frac{2}{\sqrt{\pi}} E^* \sqrt{A}$$

$$\frac{1}{E^*} = \frac{1-\nu_T^2}{E_T} + \frac{1-\nu_S^2}{E_S}$$

# Atomic Force Microscopes

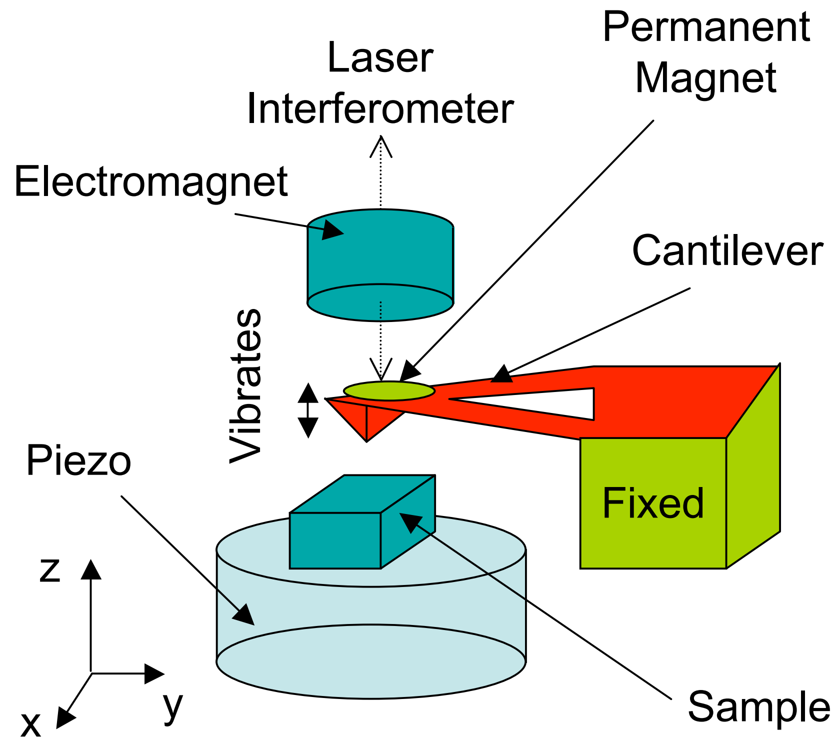
**NORMAL OPERATION- DISPLACEMENT CONTROLLED**




[Advantages:]
Easy to use, commercial instruments.

[Disadvantages:]
Forces are inferred from knowledge of the instruments compliances.

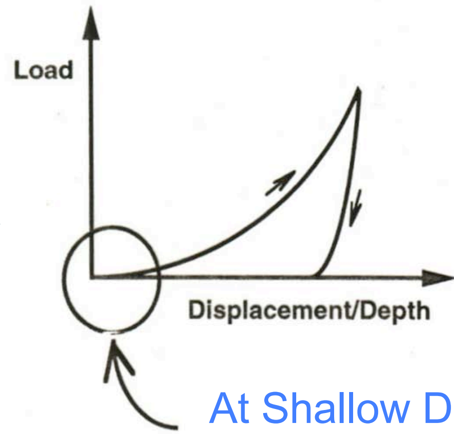
**FORCE CONTROLLED OPERATION**

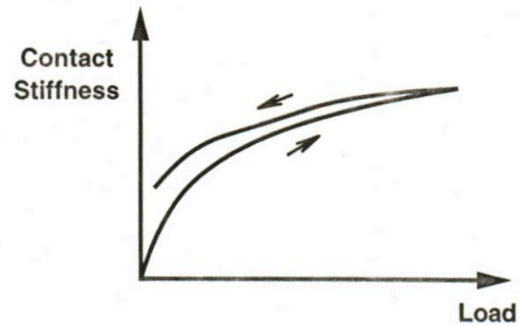



Advantages:
Can measure forces directly.

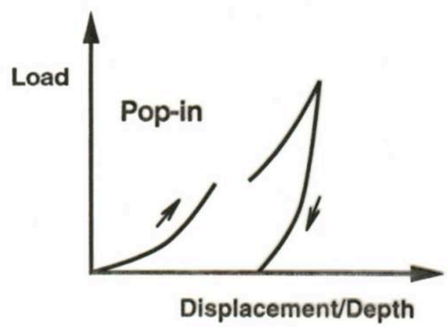
Disadvantages:
Hard to use and even harder to make.

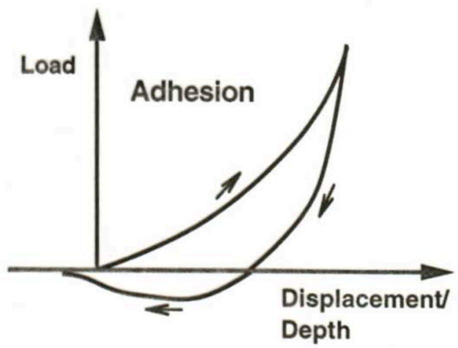
# Ideal Load and Contact Stiffness Data

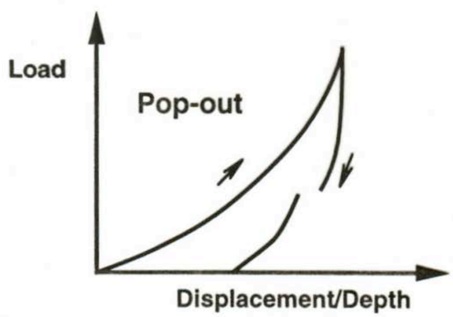



At Shallow Depths (100 nm or less) the Curves can look very different



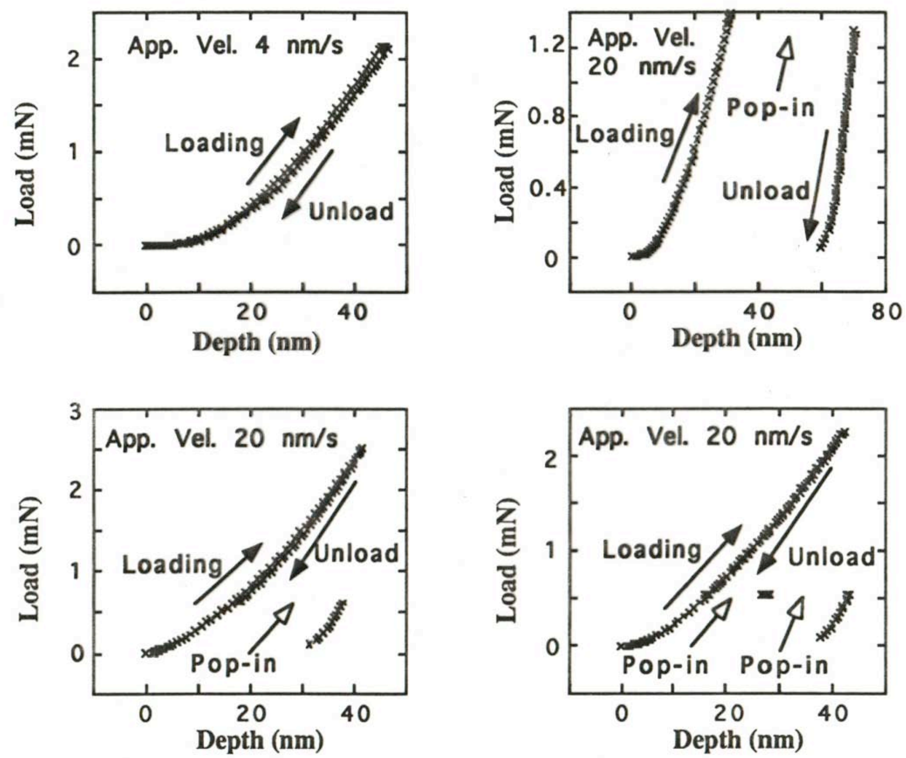




3 Key stage in indentation cycle

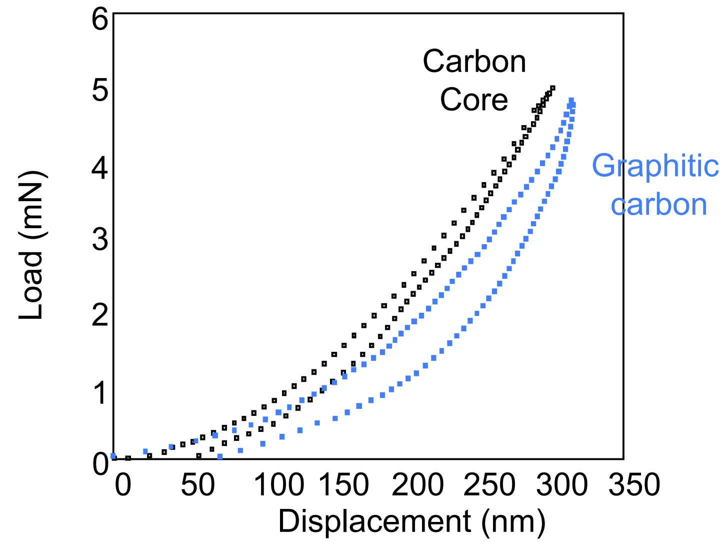
- Initial contact
- Loading/Unloading
- Breaking of contact

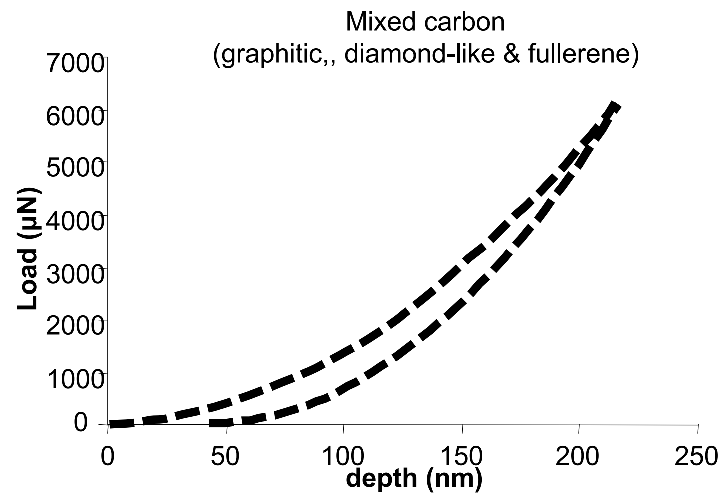
# Real Data Can Show Discontinuities and Adhesion

## In metals like W(100) impact energy a
## surface oxide affects nanomechanics




## Nanomechanics of carbon – depends greatly on structure and bonding



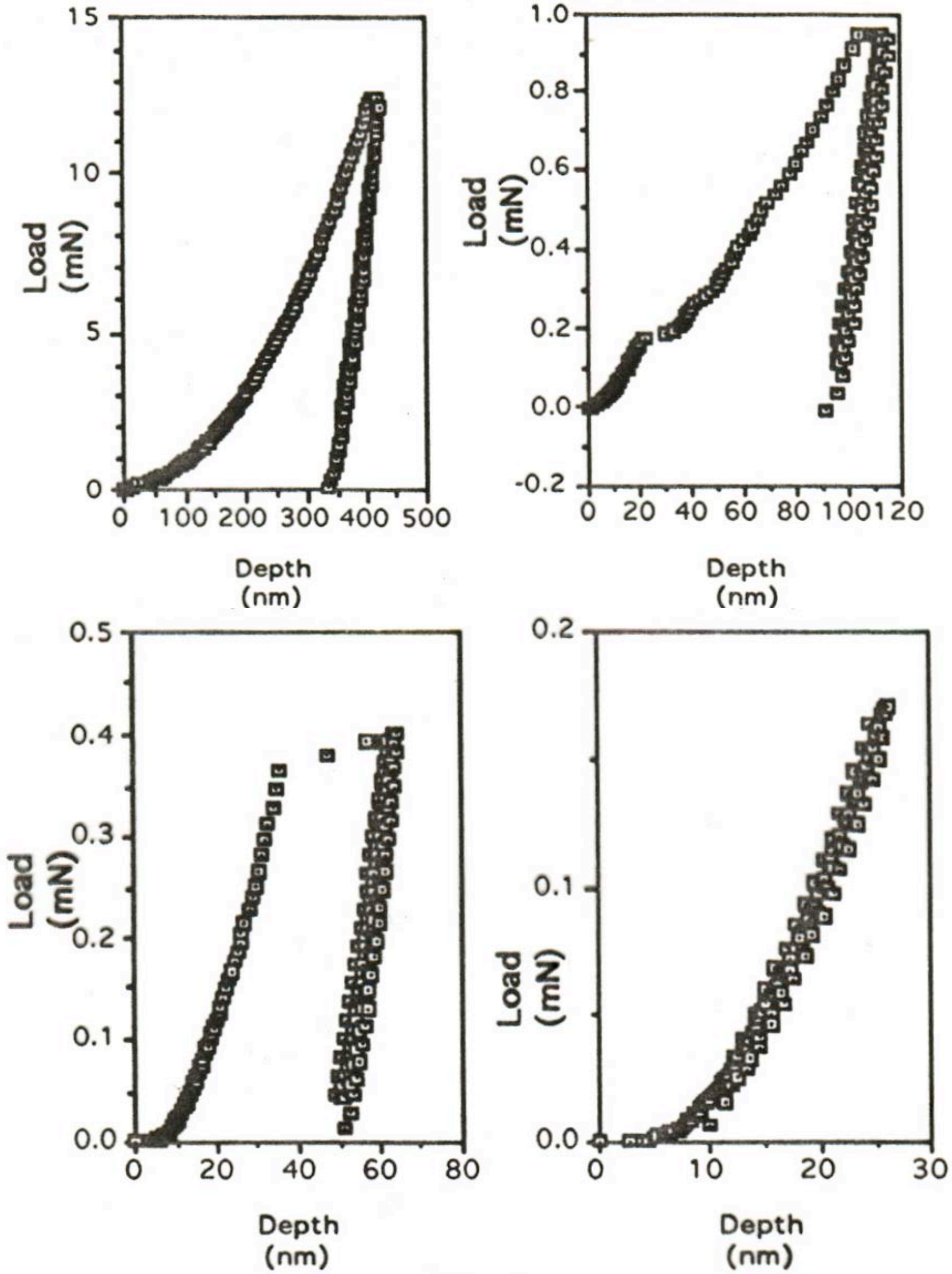
# Residual strains in epitaxial II-VI Semiconductor Films on GaAs Substrates

| Sample Description | Film Thickness | Lattice Mismatch | Comments |
|---|---|---|---|
| GaAs | Not a film | Not relevant | Control Sample |
| ZnMgSSe-A | Nearly 1 μm | Negligible | Medium Mg content |
| ZnMgSSe-B | Nearly 1 μm | Negligible | High Mg content |
| ZnMgSSe-C | Nearly 1 μm | Negligible | Low Mg content |
| ZnSSe | 0.74 μm | da/a = 0.11% | In compression |
| ZnMgSSe-D | 1 μm | da/a = -0.05% | In tension |
| ZnSe | 1.1 μm | da/a = 0.25% | In compression |

Due to the lattice mismatch between substrate and film some of these are in tension or compression.

**ZnSSe (compressive strains)**

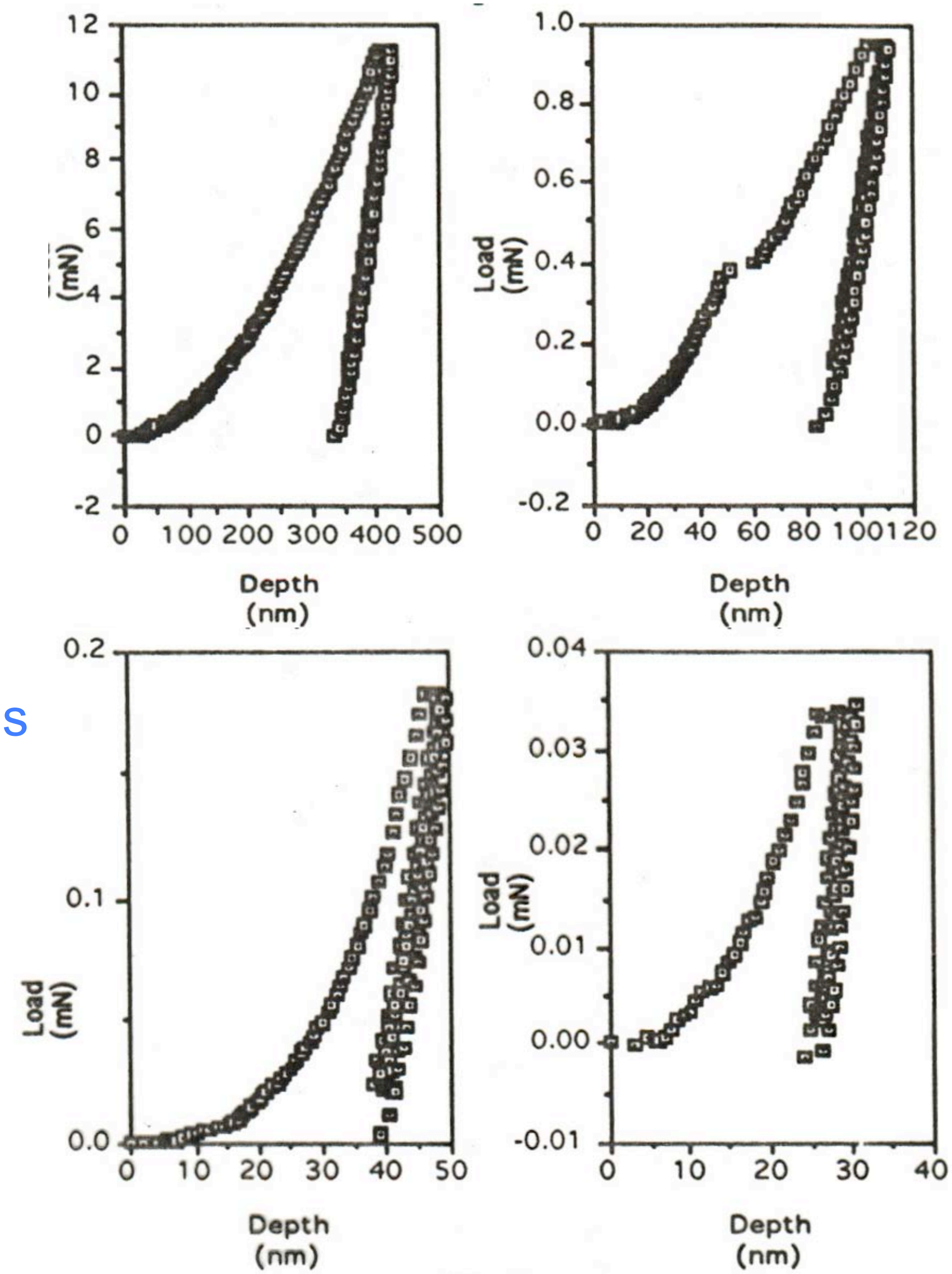
At very shallow depths the film is elastic, but then give a highly reproducible discontinuity.



**ZnMgSSe-D (tensile strain)**

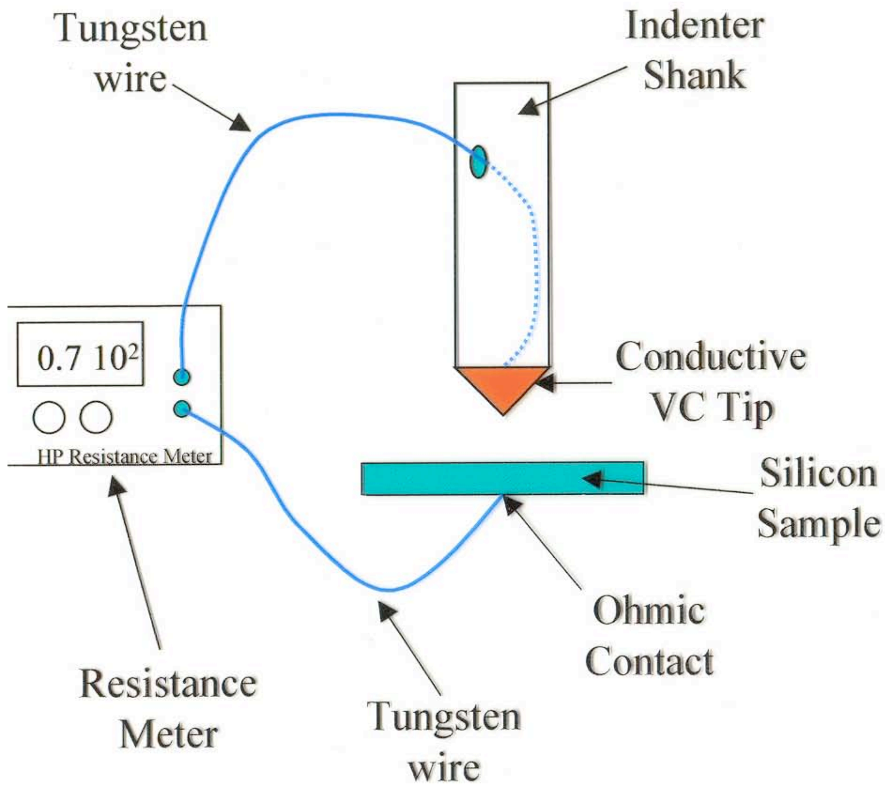
At shallow depths the film
is very soft, but then still gives a
highly reproducible discontinuity
at higher loads.

In this case discontinuity occurs
when plastic deformation commences
in the substrate.

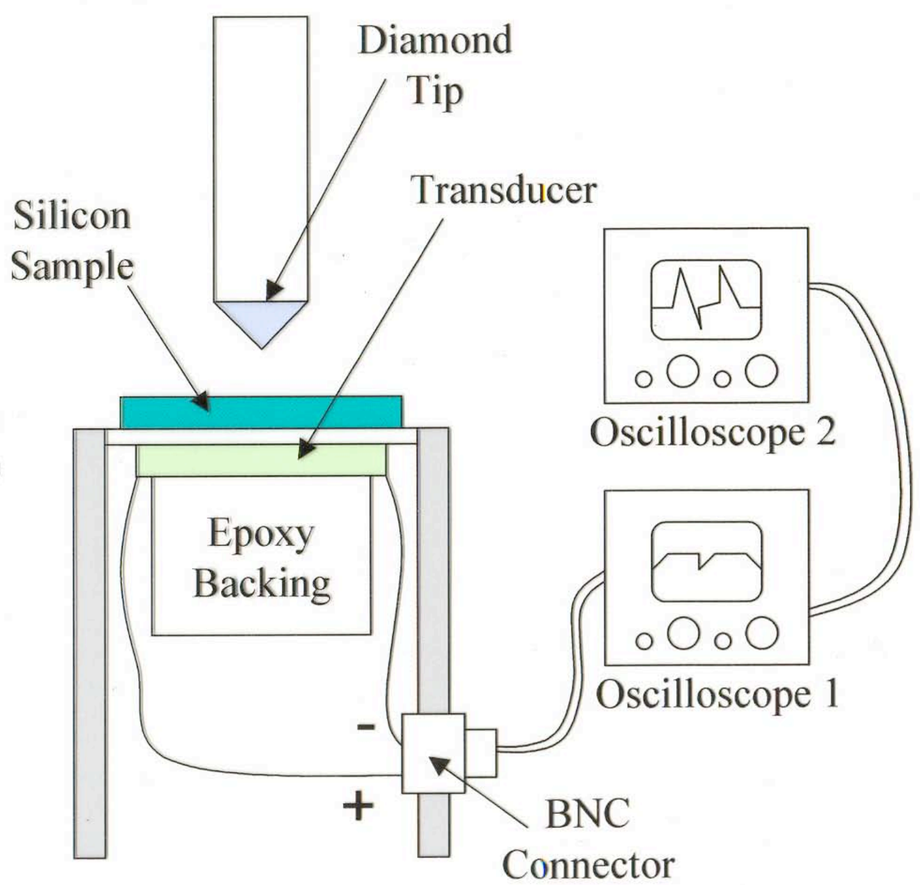


# Nanomechanics combined with other measurements

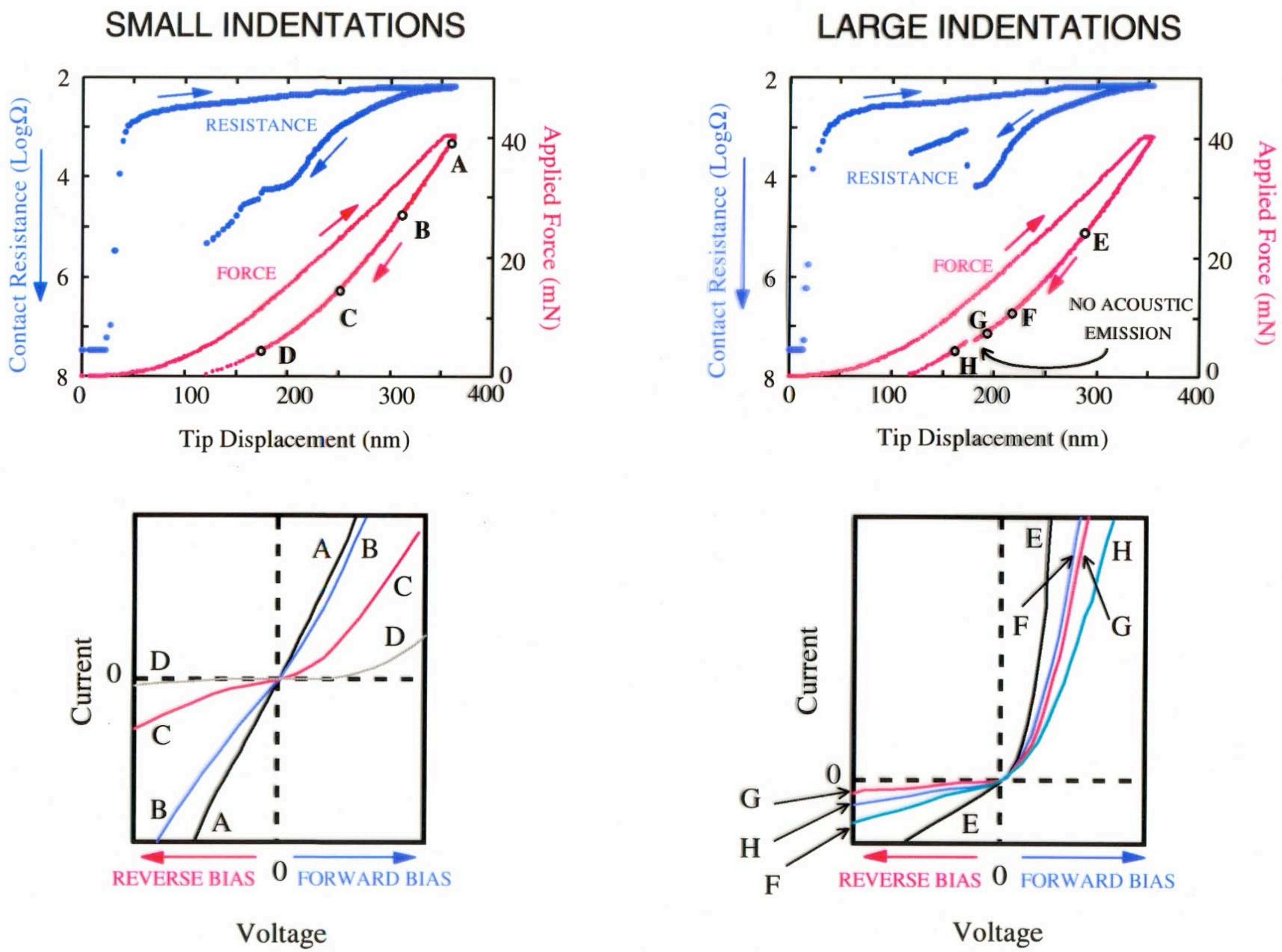
## Electrical Set-Up




## Acoustic Set-Up



## FORCE/DISPLACEMENT, CONTACT RESISTANCE AND RECTIFICATION DATA



## Summary

•Can quantify elastic modulus and hardness, also viscoelastic properties on the sub-micron scale.

•Quantify surface mechanical effects due to ion implantation, oxides, residual strains, work-hardening, surface energy/stresses,…etc.

•Nanomechanical measurements combined with other tools provides additional information (e.g. electric, acoustic or spectroscopic measurements).

•Combining techniques enables different effects to be distinguished – for instance residual strains and work hardening.

•Can be used to verify materials modeling of mechanical behavior using finite element, molecular dynamic or quasi-continuum models.