Measuring Damping, Poisson's Ratio and Residual Stress from Samples with Small Volumes

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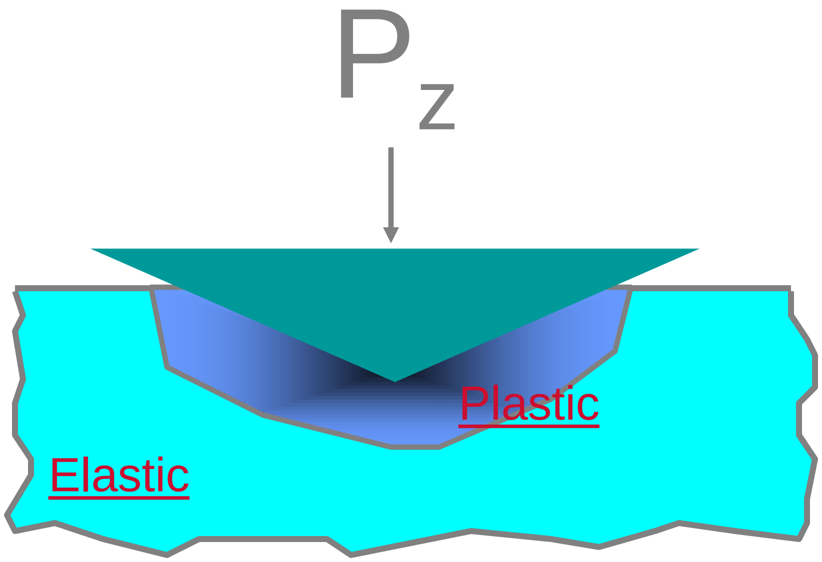
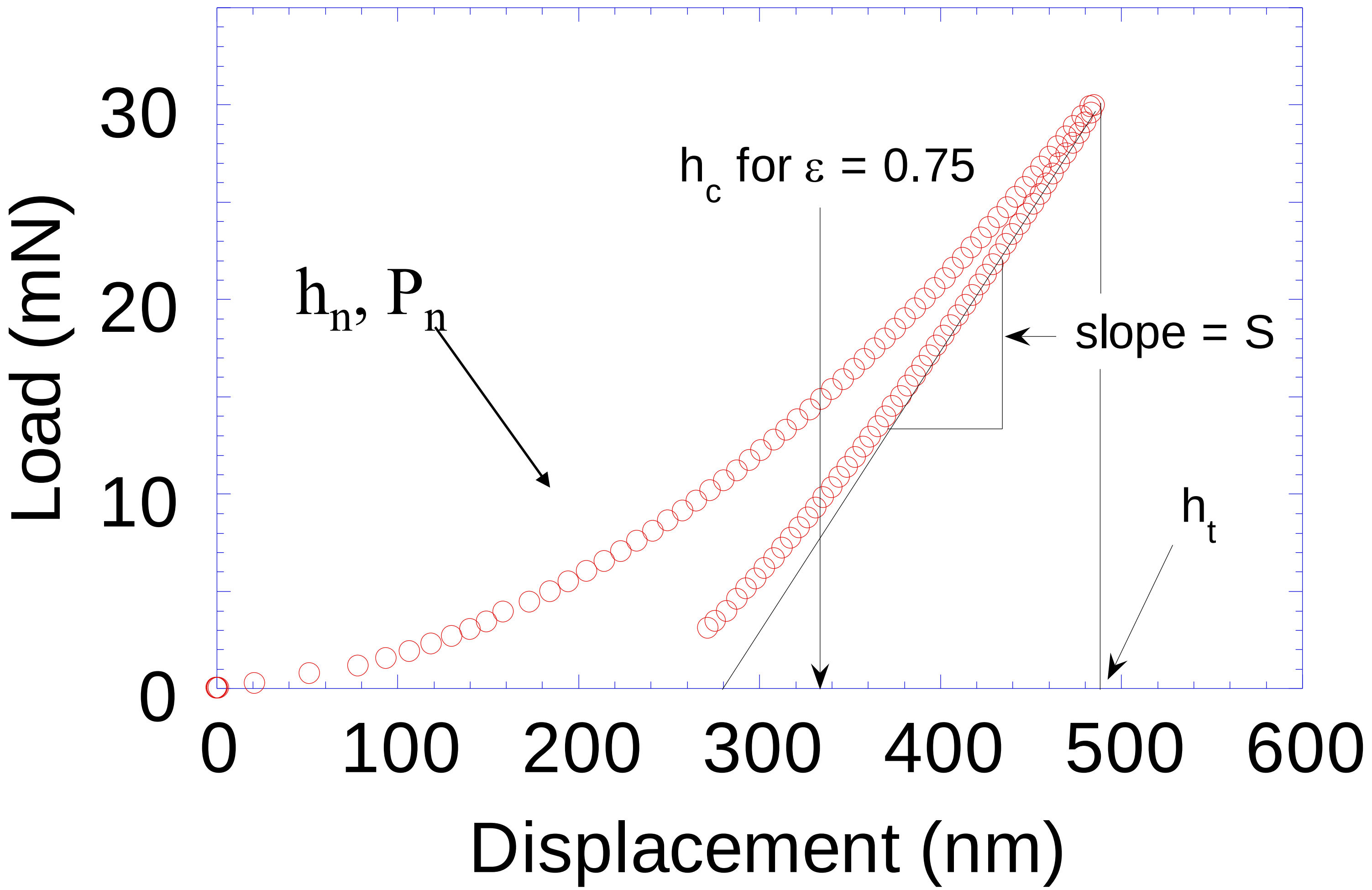
Familiar Territory – Loads in Z-Direction

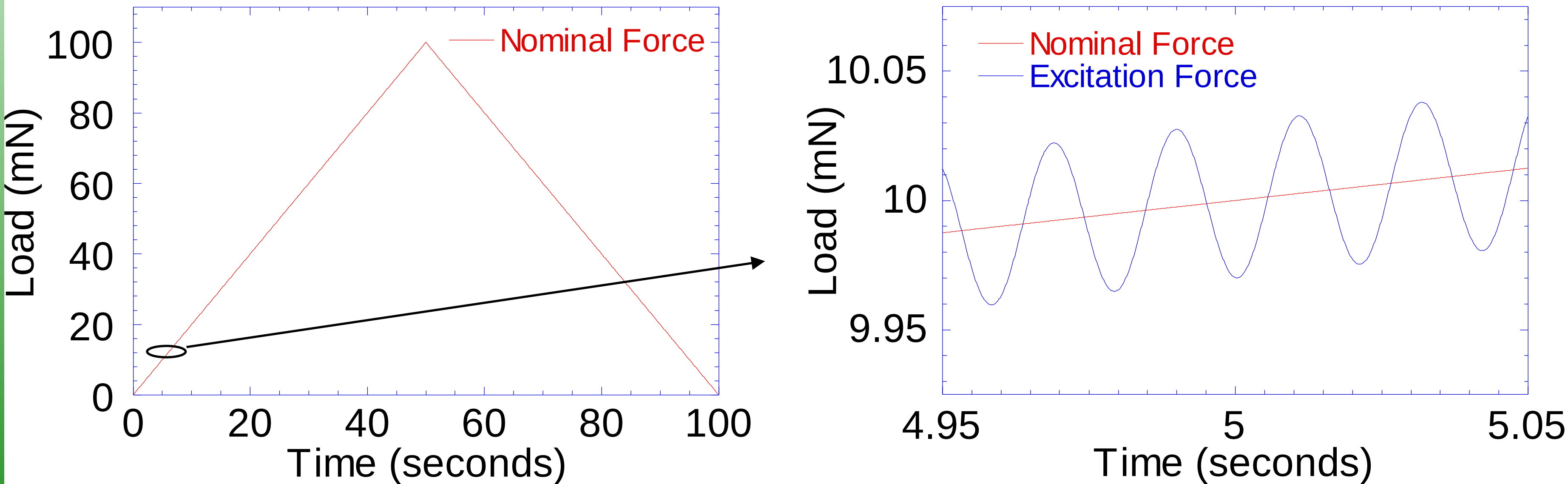
- **Relatively simple stress state (for contact mechanics)**
- **What can we measure?**
  - **Young's Modulus**
  - **Hardness (strength)**
  - **Creep Properties**
  - **Fracture Properties**
  - **Damping**



Instrumented Indentation

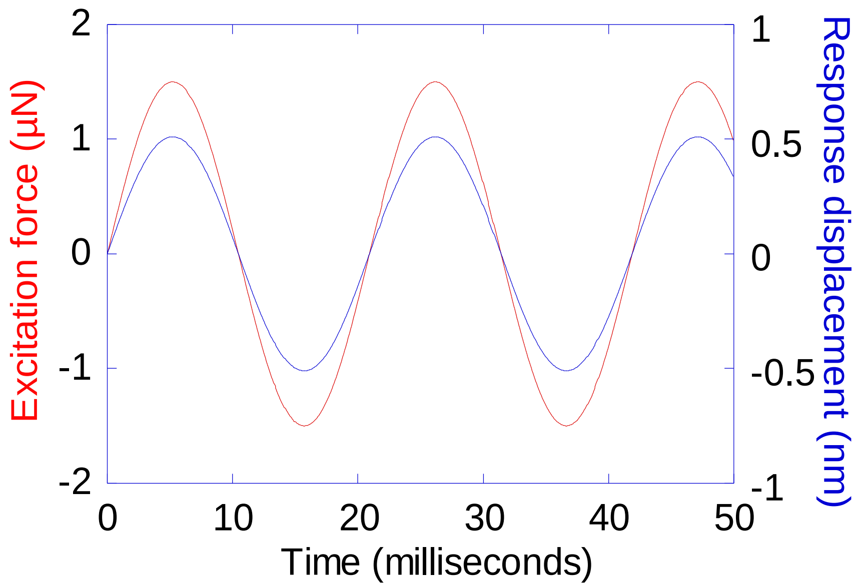


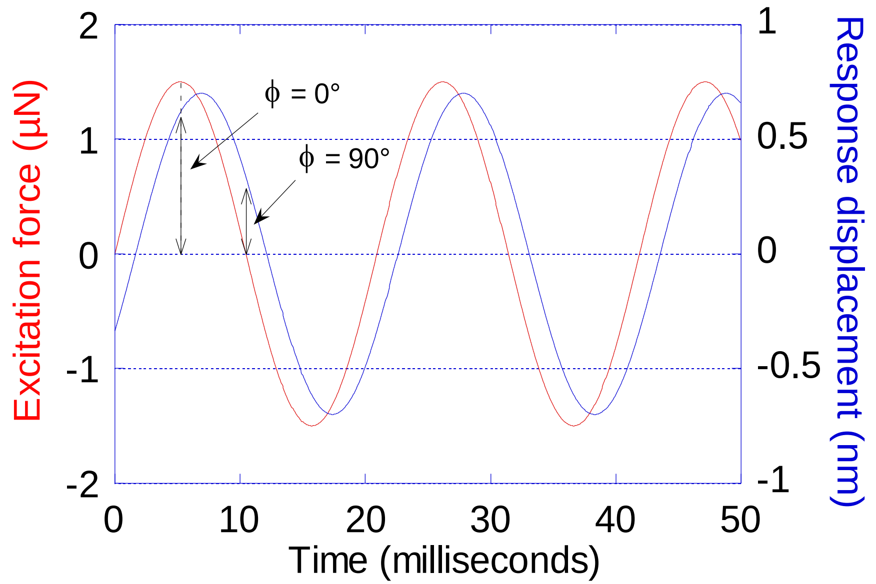
Dynamic Indentation-CSM



Dynamic Indentation-CSM

Use amplitude ratio and phase shift to determine stiffness continuously with indenter penetration

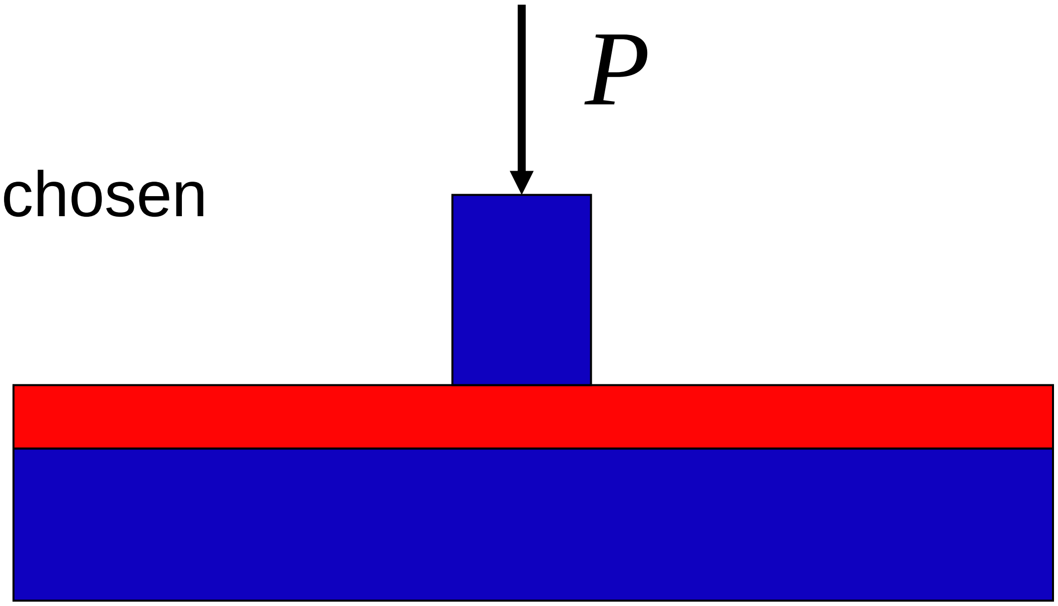




Flat Punch- a Film on a Substrate

Advantages:
Contact area is known (not load or displacement dependent

Disadvantages:
Alignment
Size must be carefully chosen



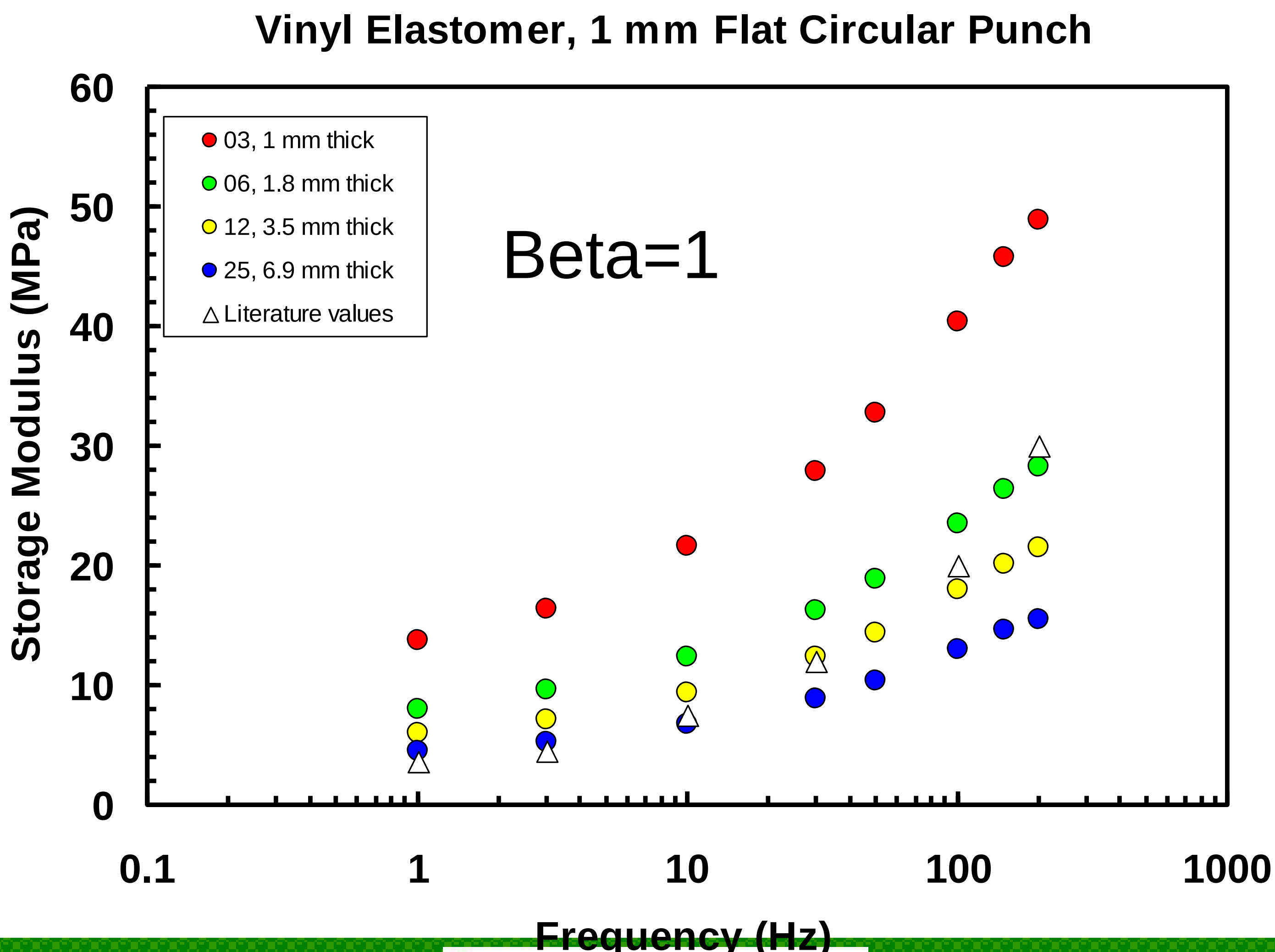
Values of Beta for Film on Substrate

W. C. Hayes, L. M. Keer, G. Herrmann and L. F. Mockros, J. Biomechanics, 1972 Vol 5, pp 541-555

$$S = \beta \frac{2}{\sqrt{\pi}} E_r \sqrt{A}$$

1) Showed that this equation was still valid for a film on a substrate
2) Calculated values for Beta (they used Kappa) as a function of a/h

Clear Effect of Substrate



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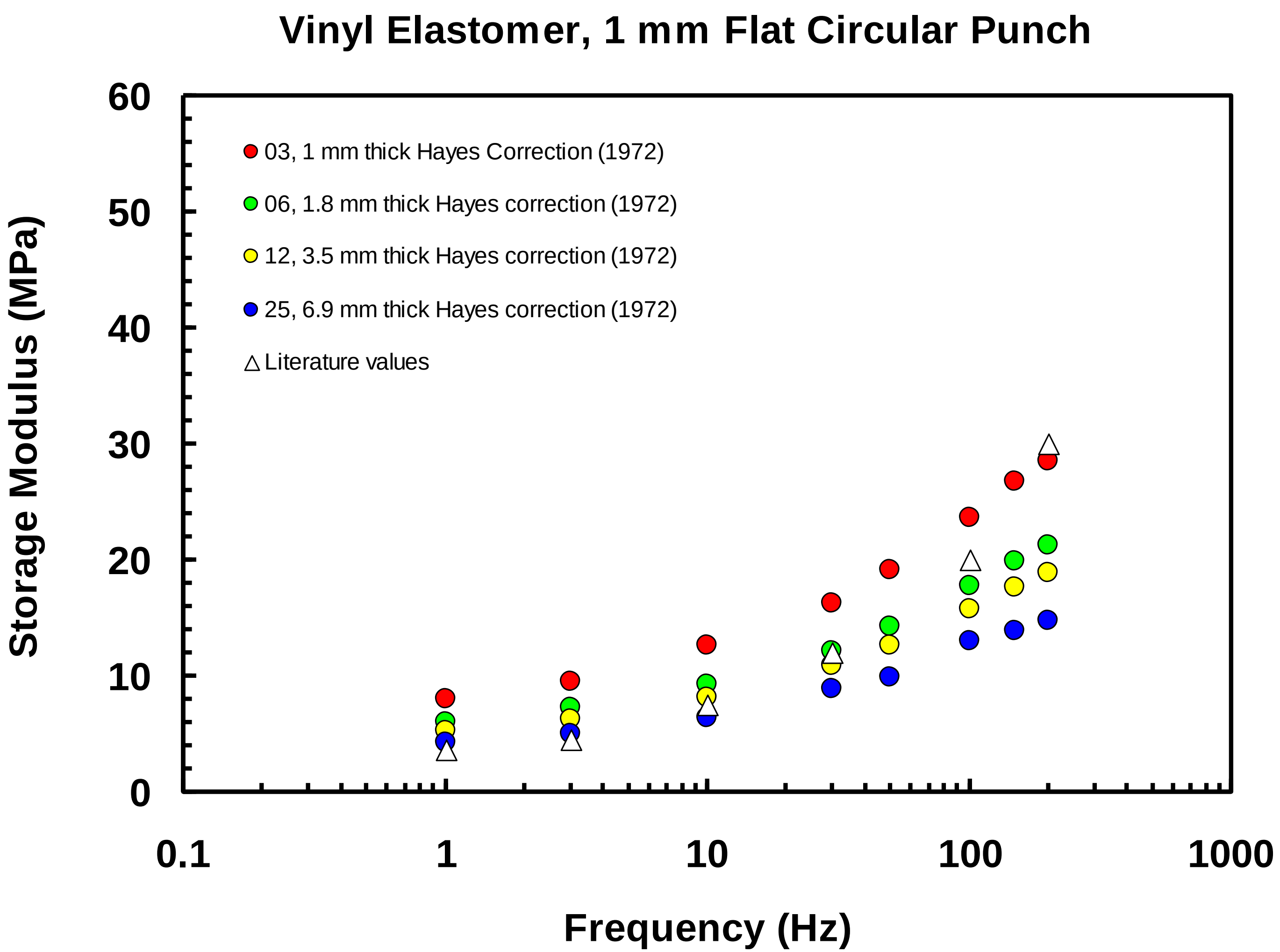
Applying Values of Beta



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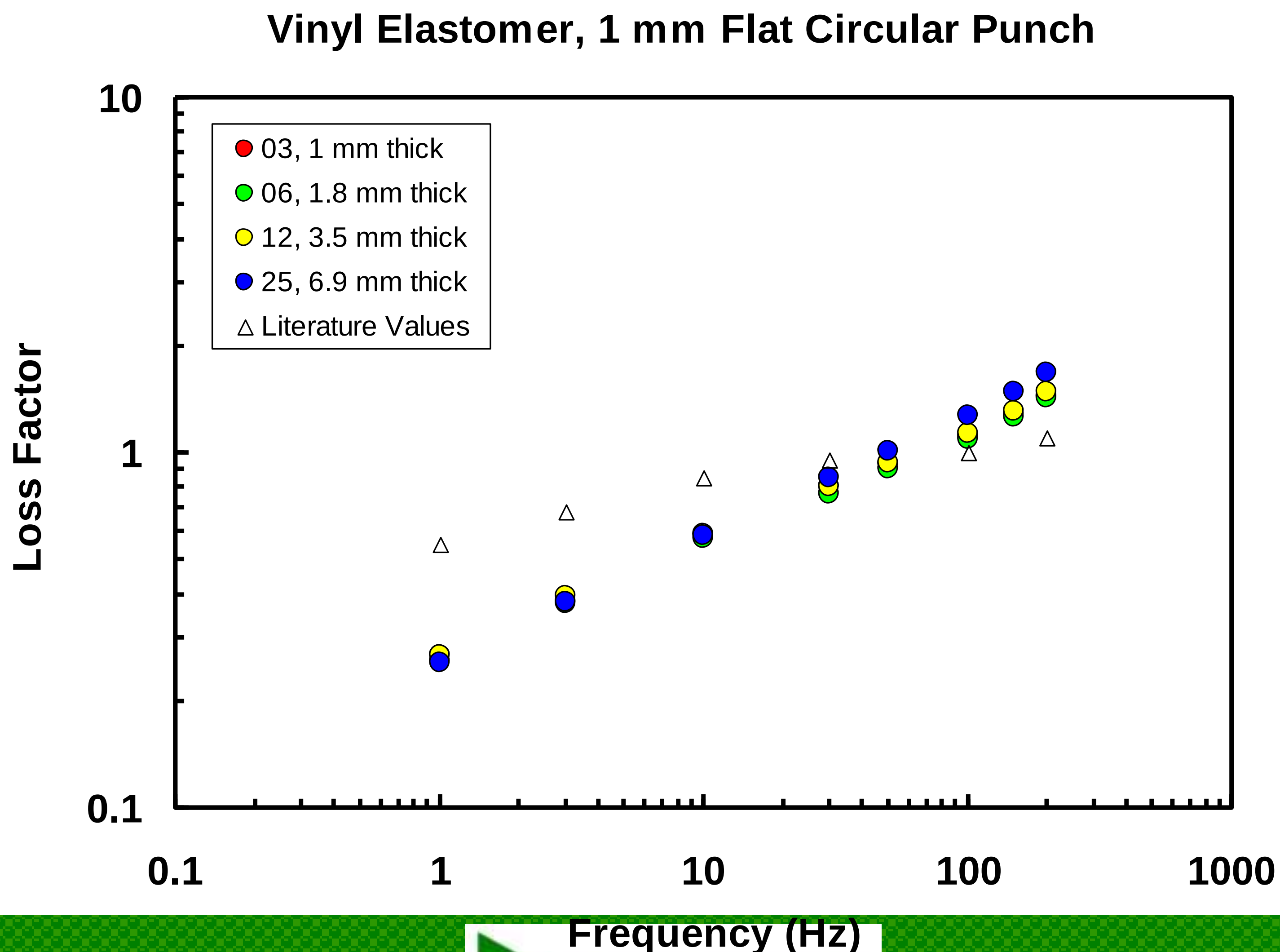
High Damping is Evident



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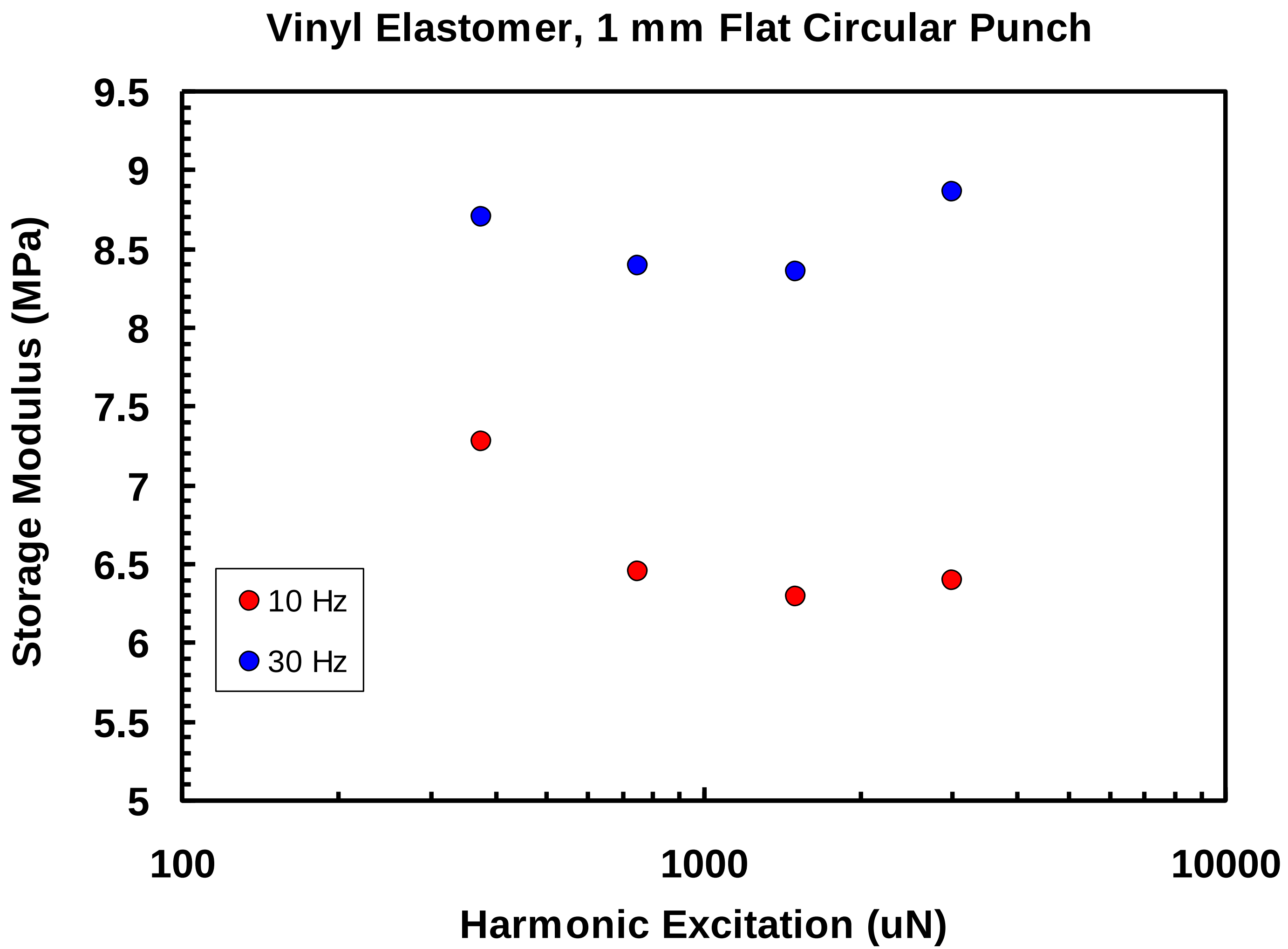
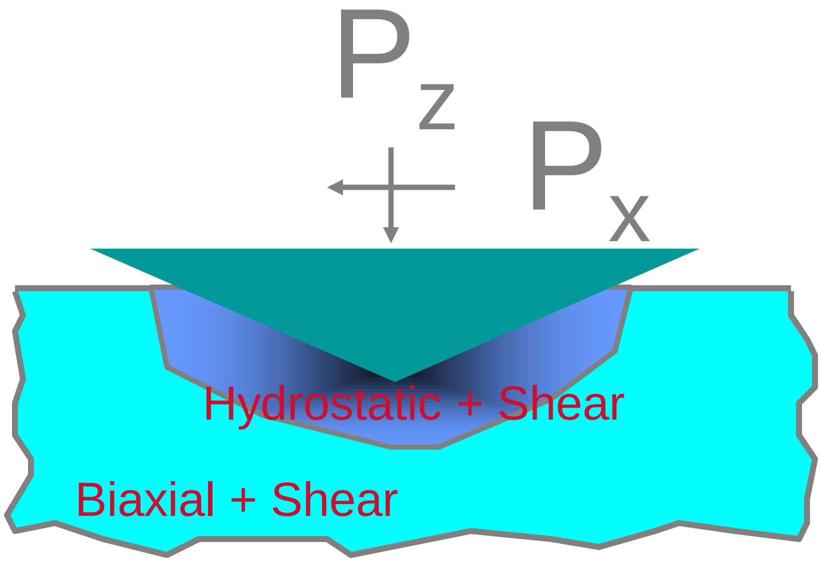
One Clear Problem



Less Familiar Territory – 2D Loading

- **More complex state of stress**
  - **Introduce a larger shear component**
  - **Control directionality of forces**
- **What can we measure?**
  - **Tribological Properties**
    - **Friction Coefficient**
    - **Friction Stress**
    - **Shear Properties**
  - **If there is no slip**
    - **Poisson's Ratio**
    - **Elastic Anisotropy**
    - **Stiffness of structures**



Mindlin Problem – Johnson Approach

R. D. Mindlin, J. App. Mech., Sept. 1949
K. L. Johnson, Contact Mechanics, Cambridge University Press, 1985

$$a = \left(\frac{3P_z R}{4E^*}\right)^{1/3}$$

$$\delta_z = \left(\frac{9P_z^2}{16R(E^*)^2}\right); \frac{1}{E^*} = \left(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}\right)$$

$$\frac{d\delta_z}{dP_z} = \frac{1}{2}\frac{1}{a}\frac{1}{E^*}$$

$$S_z \equiv \frac{dP_z}{d\delta_z} = 2aE^* \approx 2a\frac{E}{(1-\nu^2)}$$

$$a = \left(\frac{3P_z R}{4E^*}\right)^{1/3}$$

$$\delta_x = \frac{P_x}{8a}\left(\frac{1}{G^*}\right); \frac{1}{G^*} = \left(\frac{2-\nu_1}{G_1} + \frac{2-\nu_2}{G_2}\right)$$

$$\frac{d\delta_x}{dP_x} = \frac{1}{8a}\frac{1}{G^*}$$

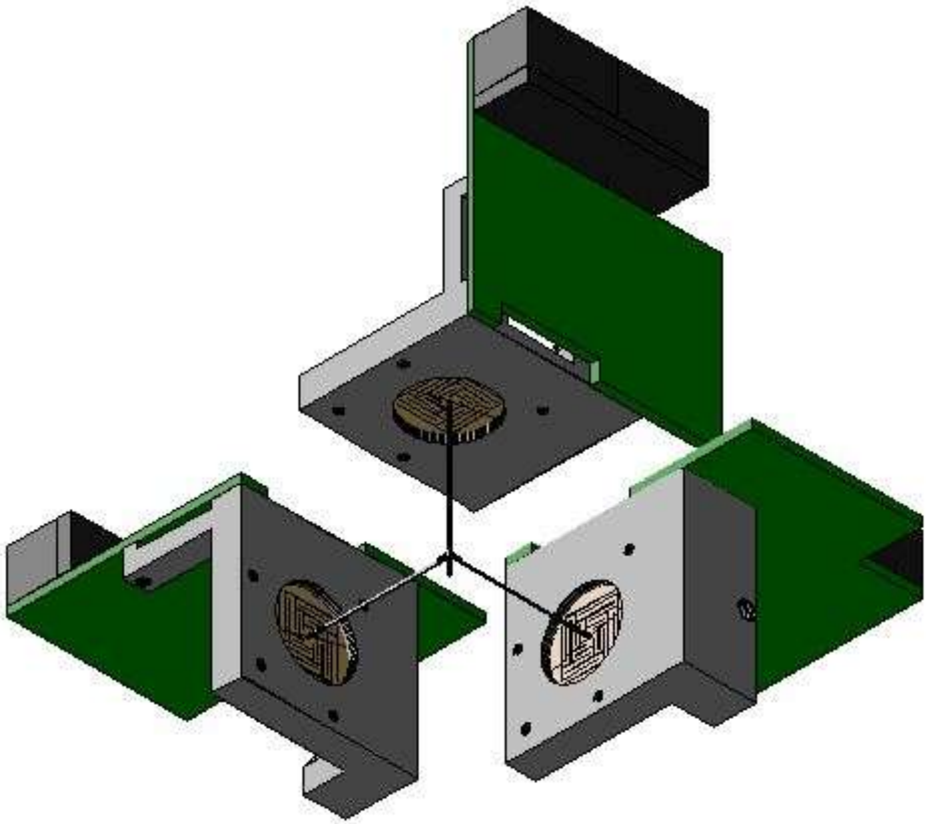
$$S_x \equiv \frac{dP_x}{d\delta_x} = 8aG^* \approx 8a\frac{G}{2-\nu}; G = \frac{E}{2(1-\nu)}$$

$$\frac{S_x}{S_z} = \frac{2(1-\nu)}{(2-\nu)}$$

A Capable System

- Must have unique control of forces both normal to the surface and in the plane of the surface
- Each axis must be as independent as possible (minimize interaction or cross-talk)
- Dynamically well-behaved and easily described

The Finished System



Material Set

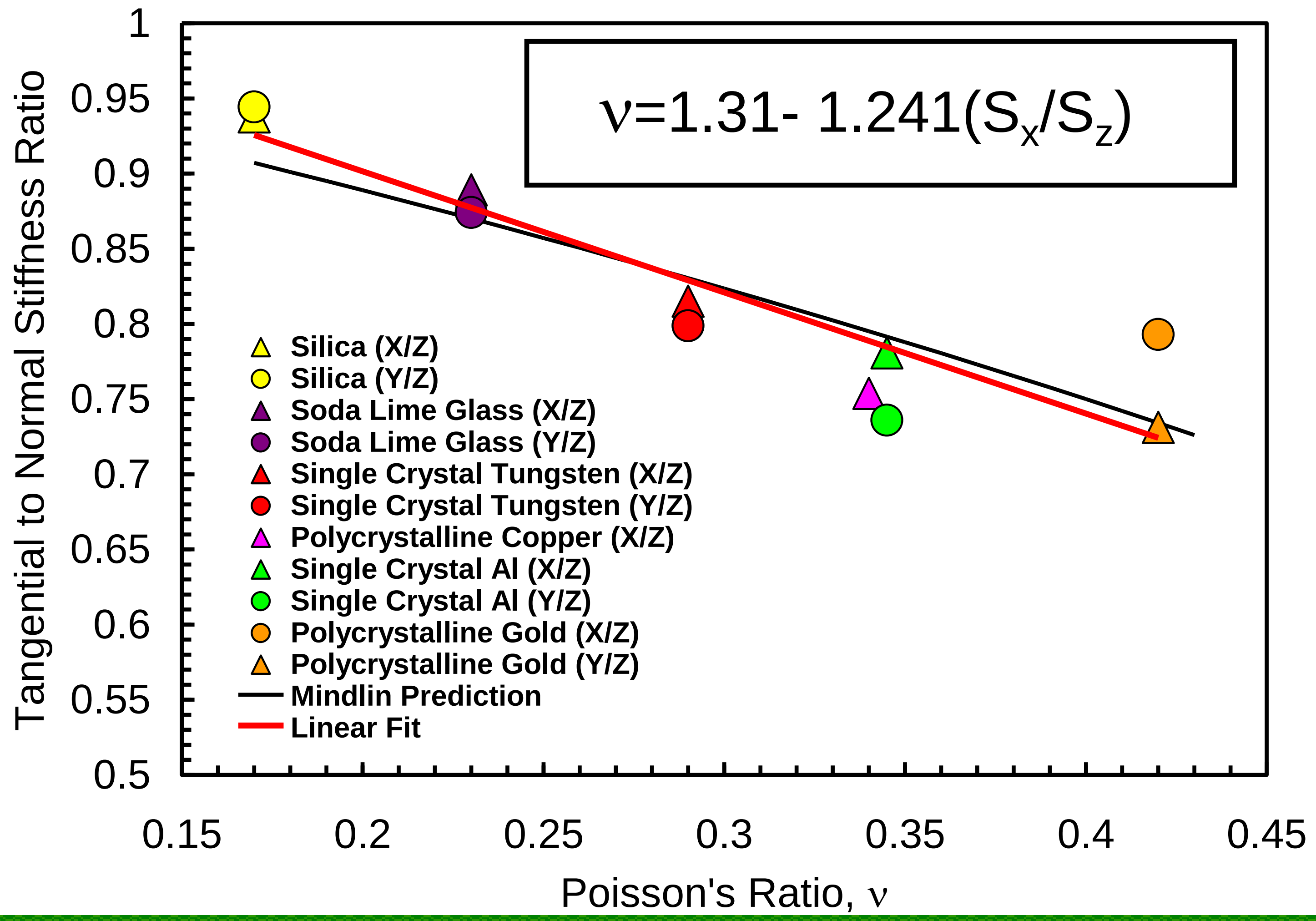
Material	Poisson's Ratio
Fused Silica[1]	0.17
Soda Lime Glass[1]	0.23
Single Crystal Tungsten[1]	0.28
Polycrystalline Copper [2,3]	0.34
Single Crystal Aluminum[2]	0.345
Polycrystalline Gold[2,3]	0.42

1 Isotropic

2 Varying Degrees of Anisotropy

3 Large Grained

Stiffness Ratio vs Poisson's Ratio



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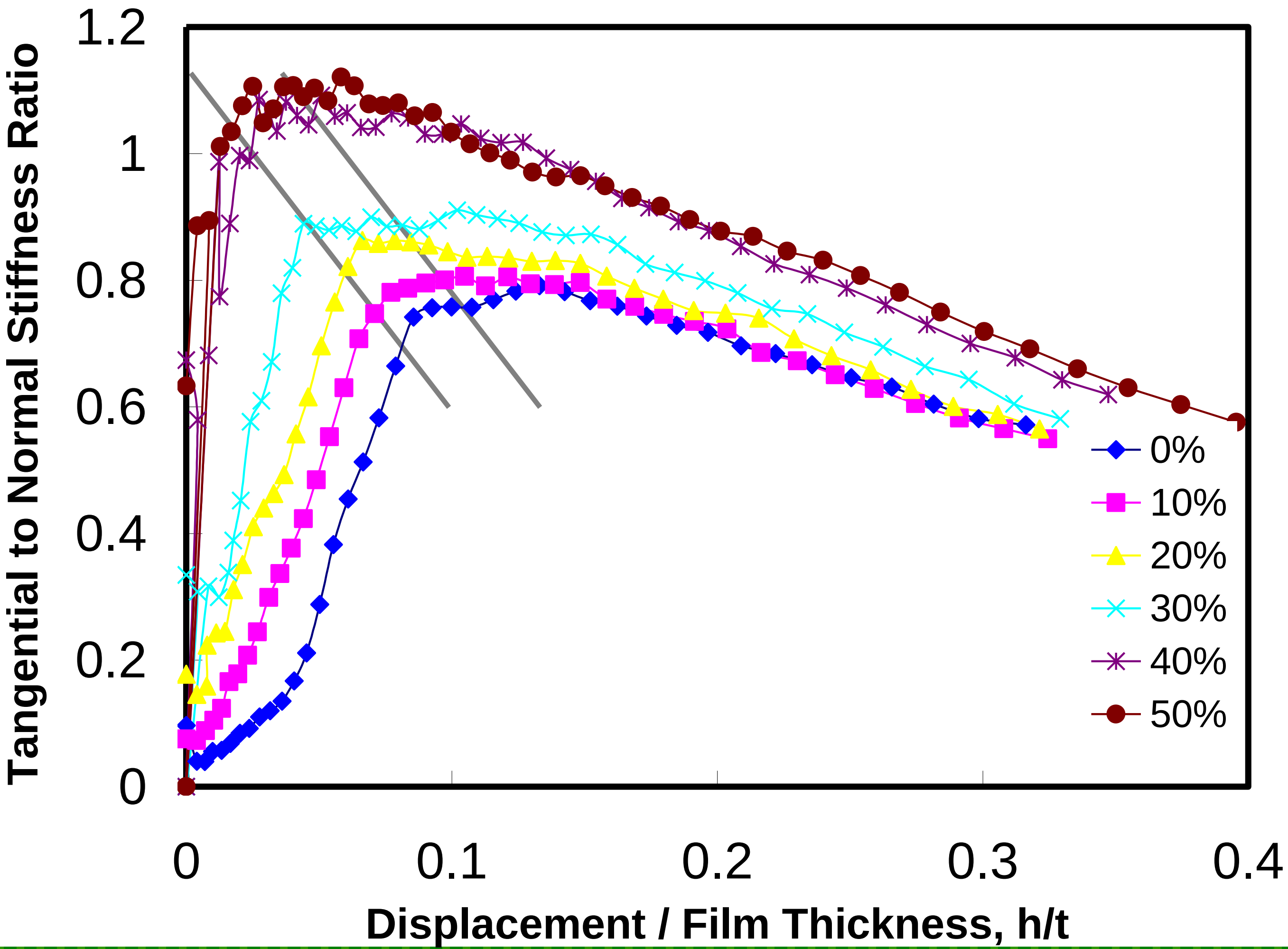
Porous Low-k Polymer Films

- Porous films widely investigated for use in semiconductor devices
  - Provide structural integrity
  - Prevent line-to-line crosstalk
- Porous films formed by sacrificial pore generation
- Films ranging from fully dense polymer to 50% starting porogen content
  - Most properties are studied as a function of porosity as this is controlling parameter (dielectric constant, thermal conductivity, modulus)

Nano Porous Polymer



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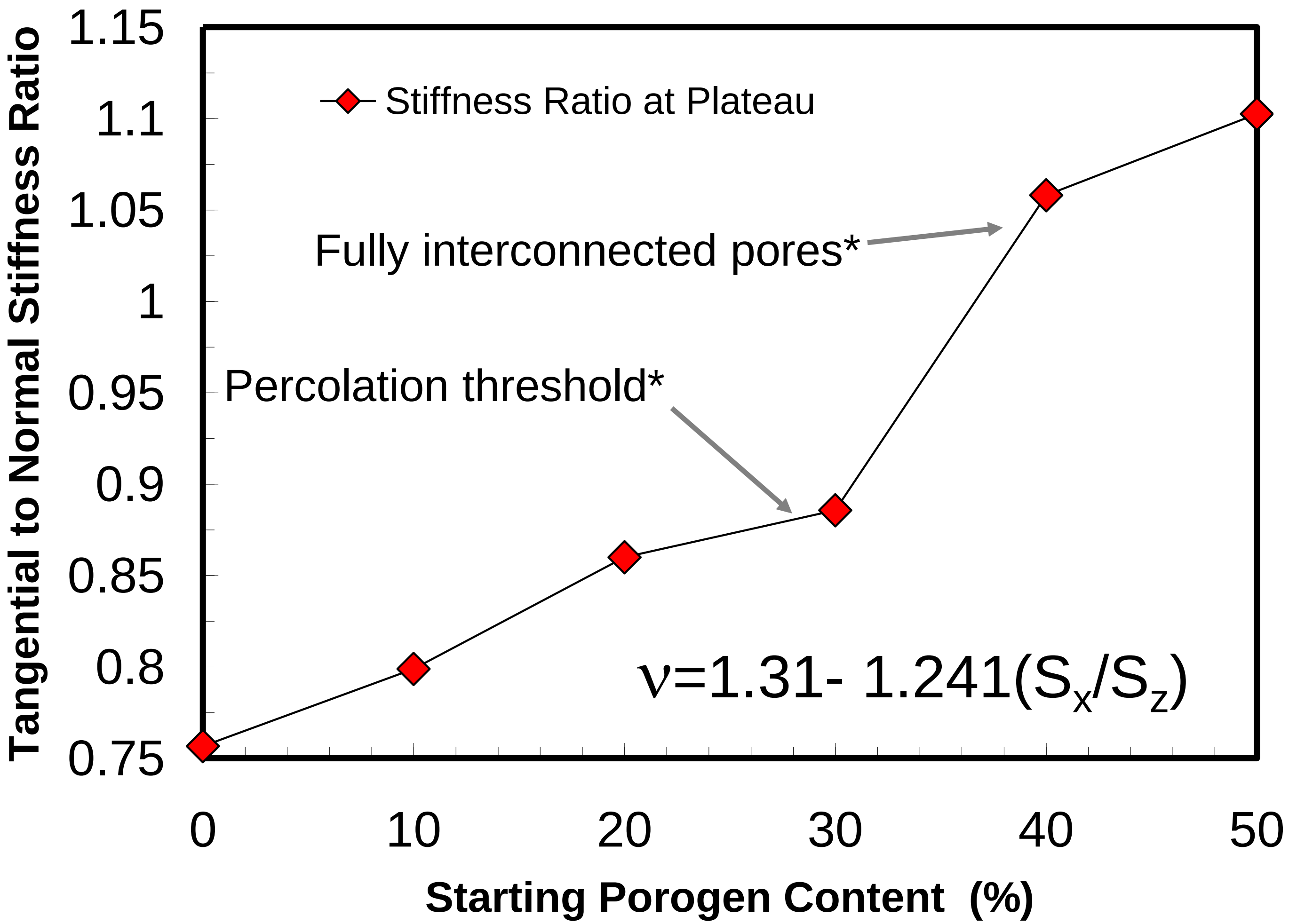
An Interesting Result



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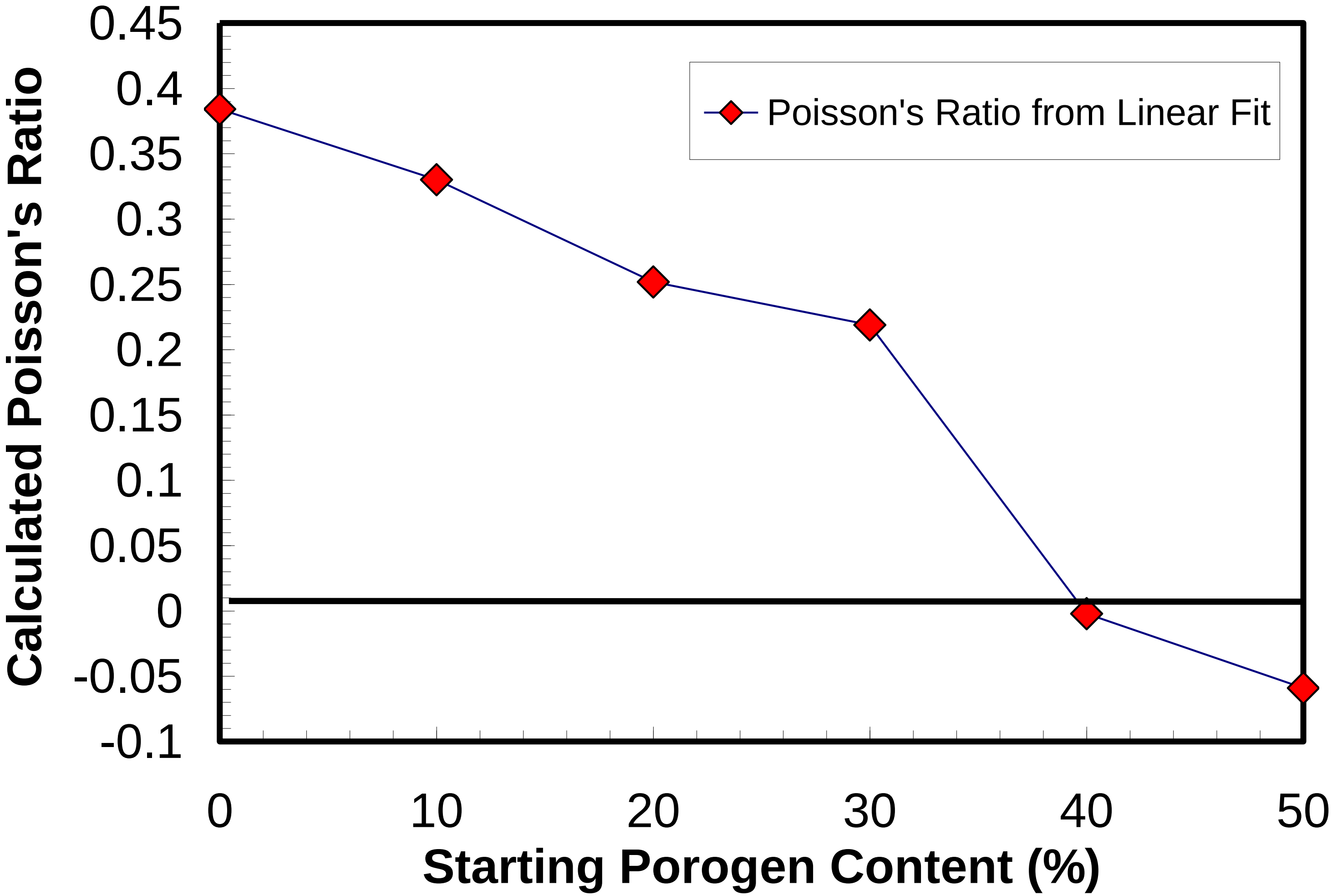
A Curious Calculated Result



Plausible Explanations

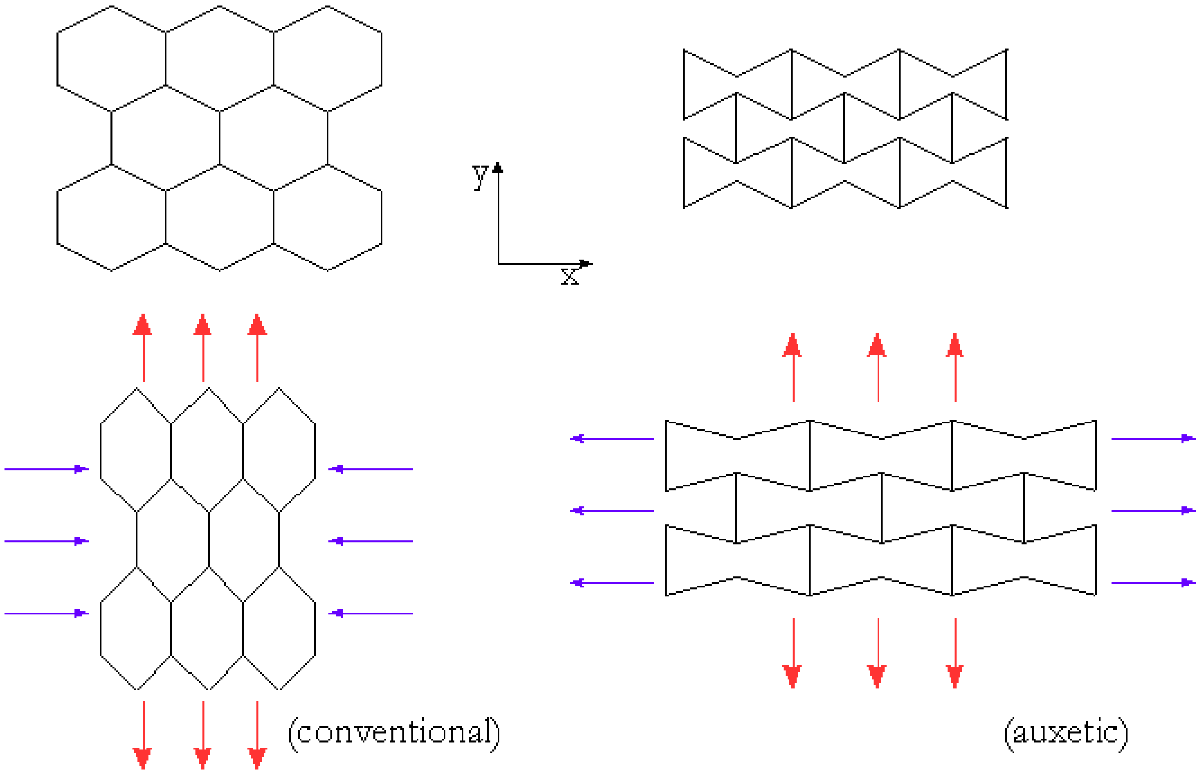
- Isotropic film
  - Negative poisson's ratio ? ?
- Anisotropic film
  - Model breaks down due to structural anisotropy

Negative Poisson’s Ratio

- **“Auxetic” Materials**
- **What are auxetic materials like?**
  - **Very few exist naturally (cork is one) but recently more have been fabricated by modifying the microstructure of existing materials e.g. foams, polymers.**

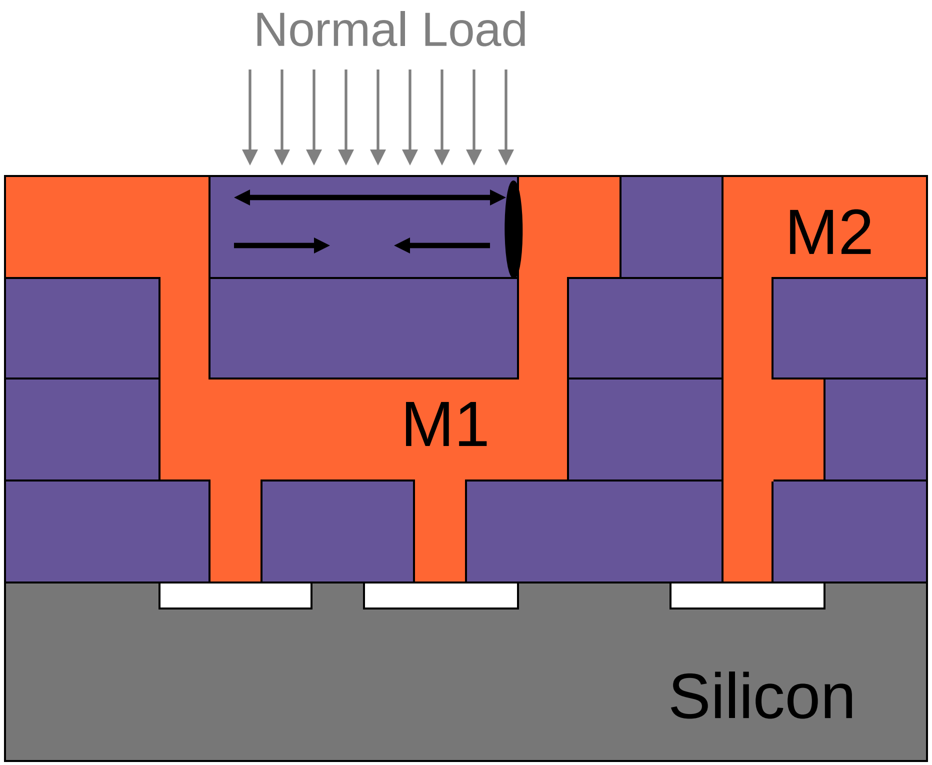
- **These materials are a lot like these films!!**

Structure of Auxetic Materials

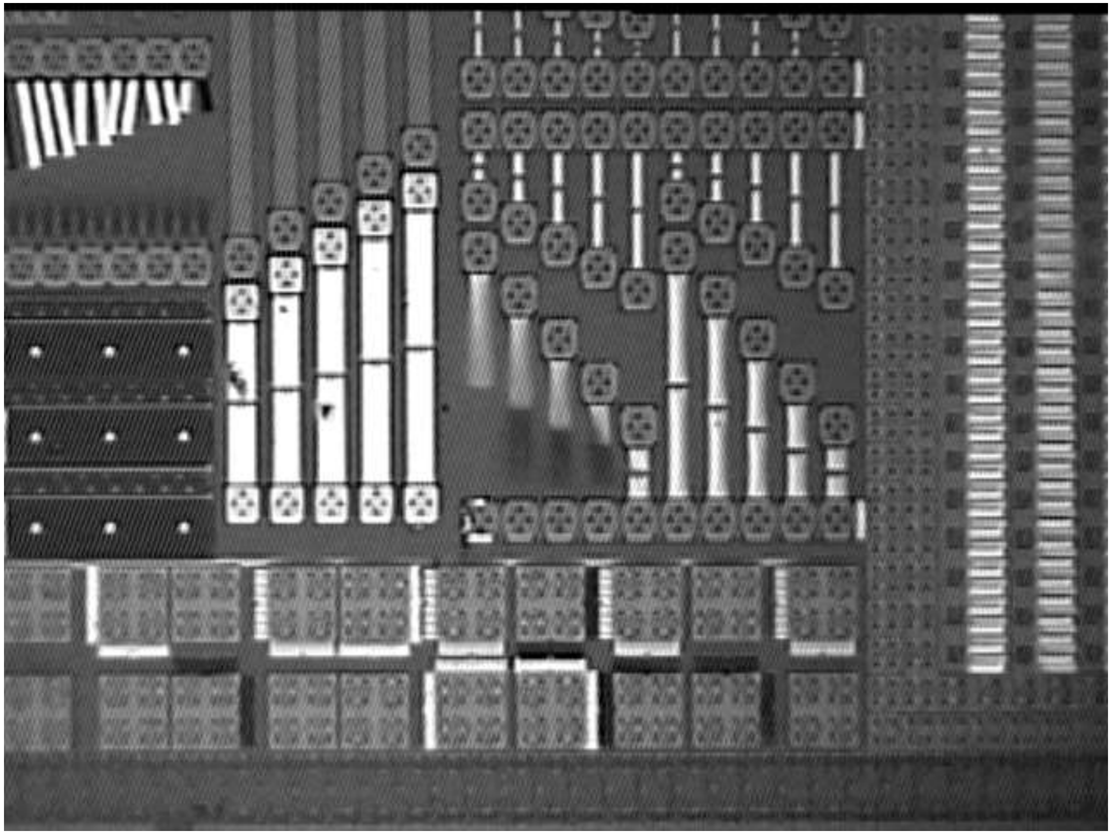


http://staff.um.edu.mt/jgri1/auxetic/auxetic_f2.html

Does This Matter?-Maybe



Testing of Free Standing Films



Warren C. Oliver and Erik G. Herbert, MTS Corporation
Johnathan Doan, Reflectivity

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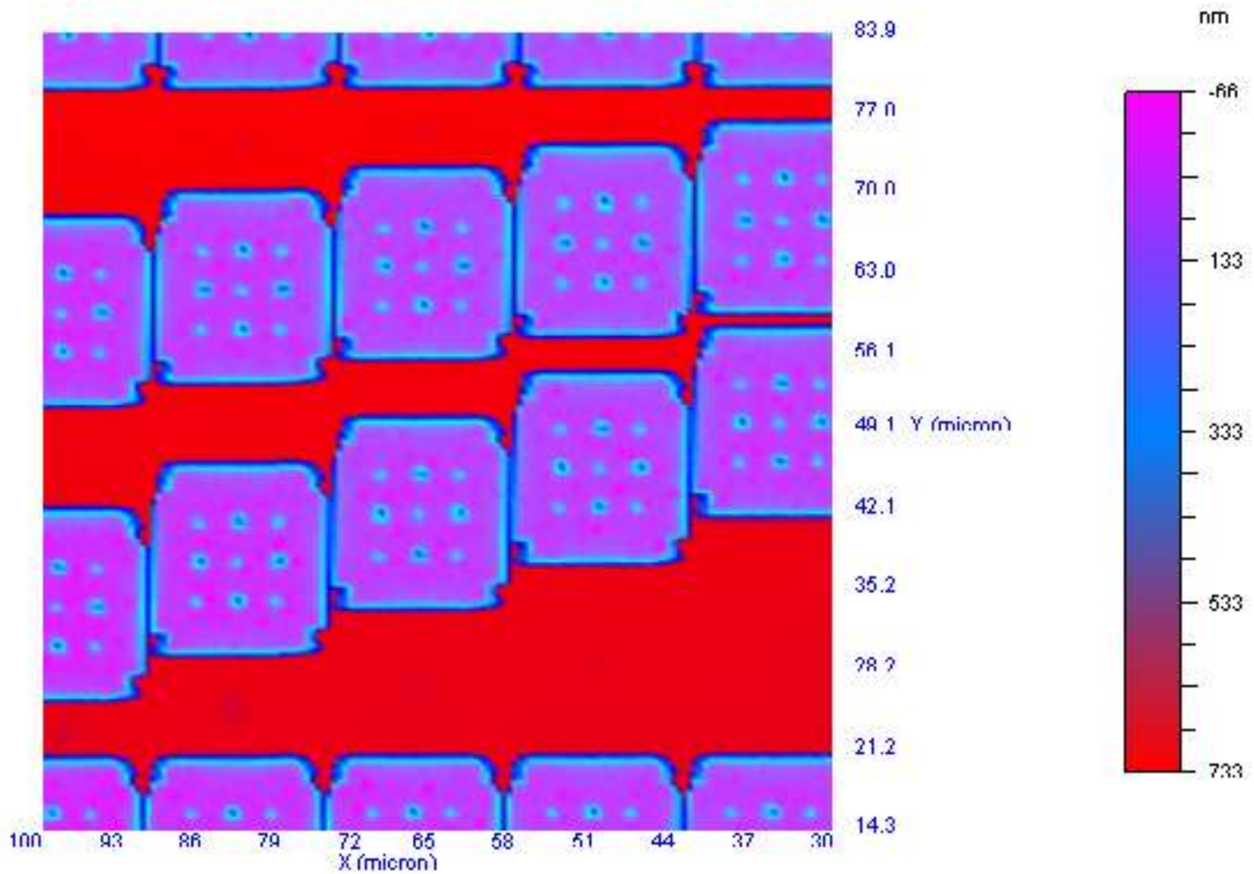
Nanovision Stage-a New Tool

Travel: 100 μm x 100 μm
Resolution/Noise: 2 nm
Flatness of travel: 1-2 nm
Accuracy: 0.01 %
Settling Time: 2 ms-
Capacitive feedback control

Leveled Targeting Scan



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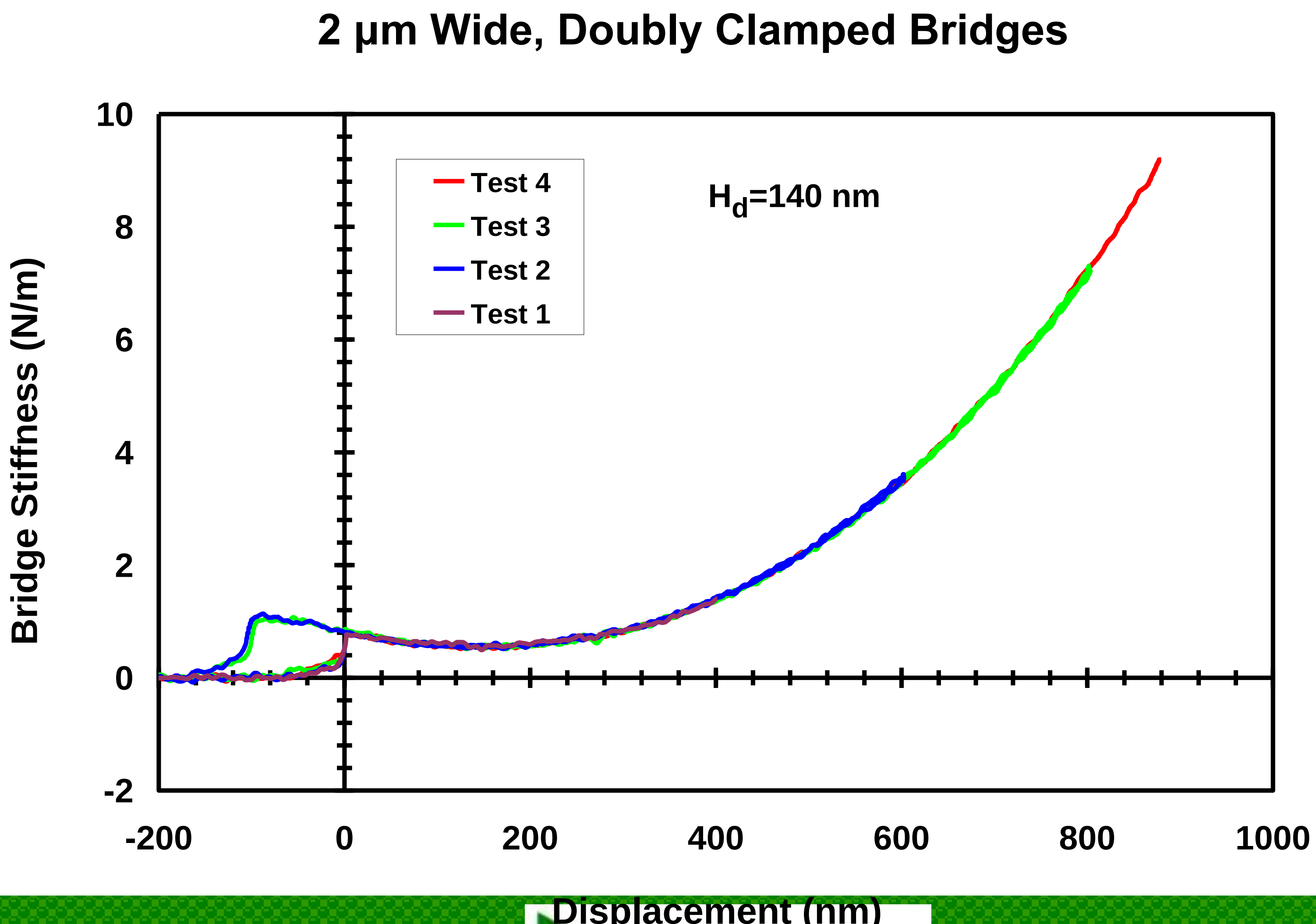
Reproducibility of The Results



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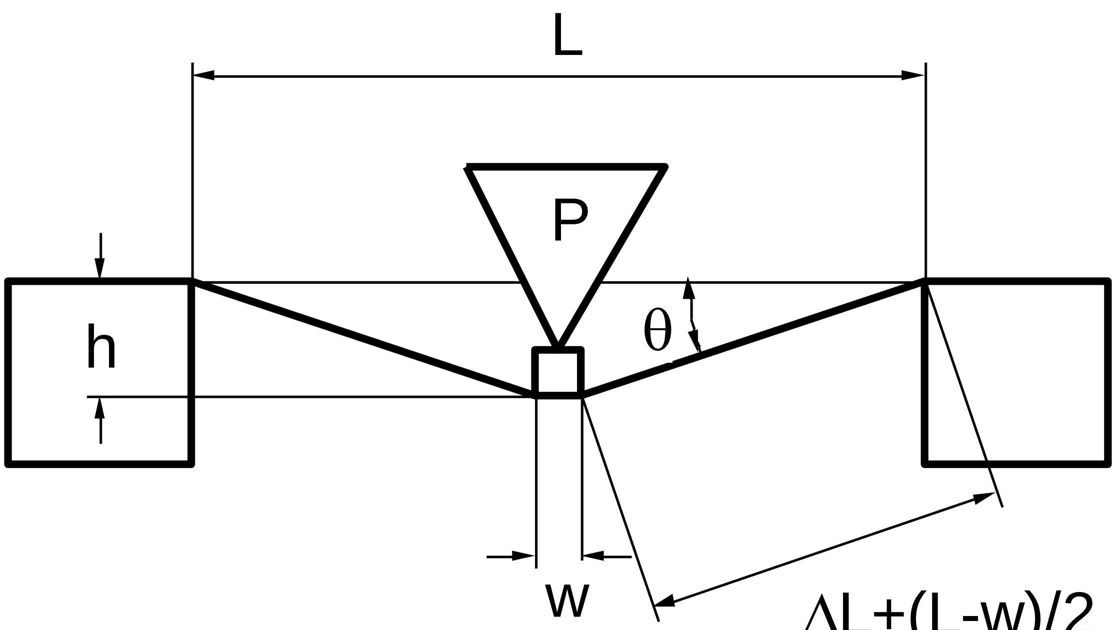
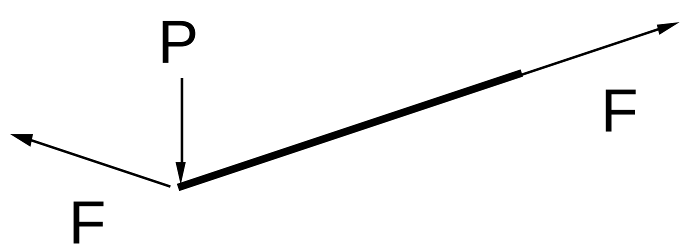
A Model Bridge Test Specimens



$$P = 2F\sin\theta = 2A(E\varepsilon + \sigma_r)\sin\theta$$



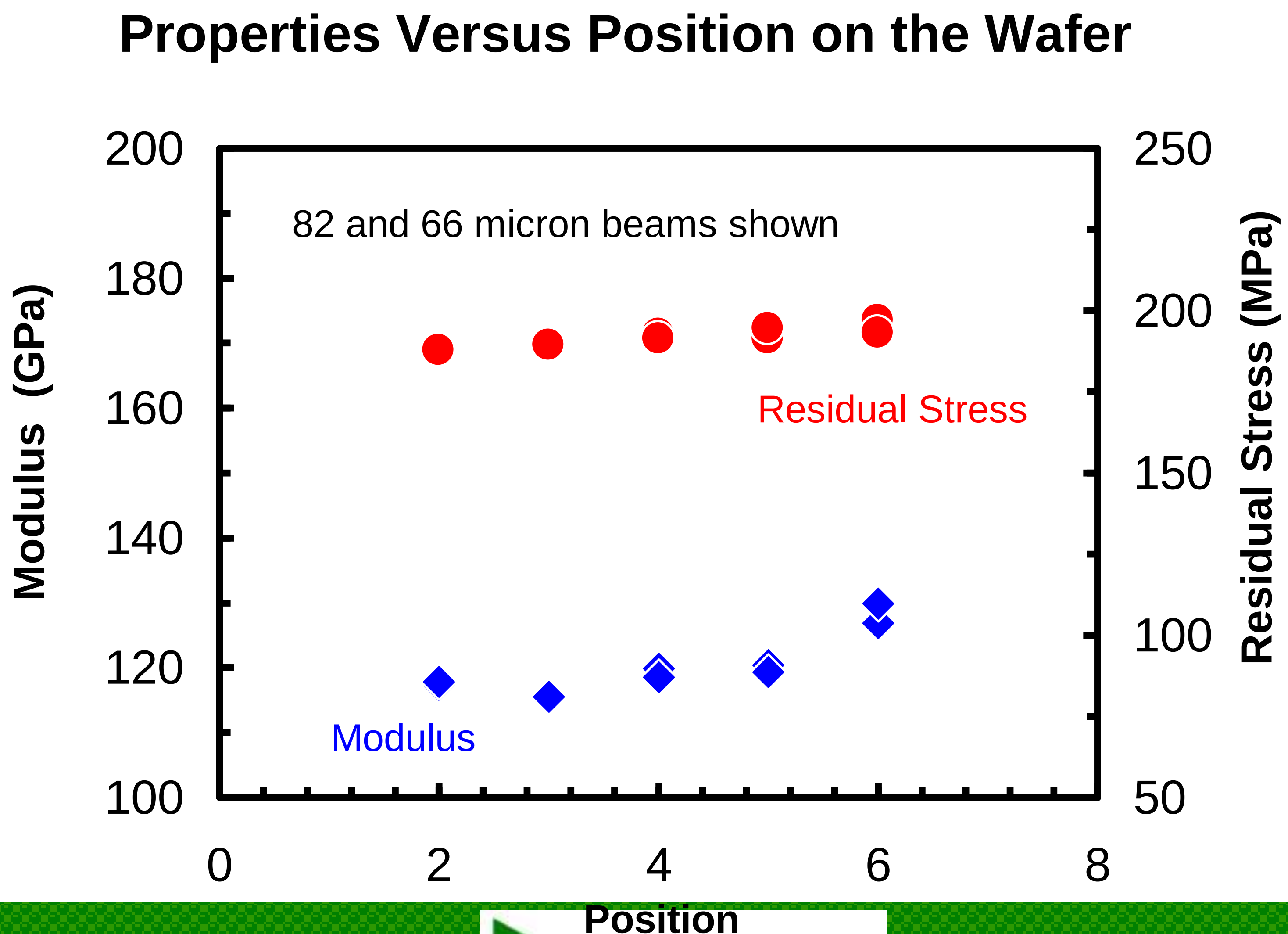
The Stiffness Relationship

$$P = \frac{4AEh}{(L-w)} + 2A\sin\left[\tan^{-1}\left(2h/(L-w)\right)\right](\sigma_r - E)$$

For not quite so small angles $\sin\theta = \theta - \frac{\theta^3}{3!}$ $\tan^{-1}\theta = \theta - \frac{\theta^3}{3}$

$$\frac{dP}{dh} = \frac{4A\sigma_r}{(L-w)} + \frac{24A(E-\sigma_r)h^2}{(L-w)^3}$$

Accurate and Precise Measurements



Conclusions:

- A flat punch may be useful for measuring the damping in materials although questions remain.
- The ratio of normal to lateral stiffness in a contact experiment can be correlated to Poisson's ratio
- Porous low K materials may have unusual mechanical properties
- Modulus and residual stress can be accurately measured using free standing film structures.