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MEMS Material Property Test Structures

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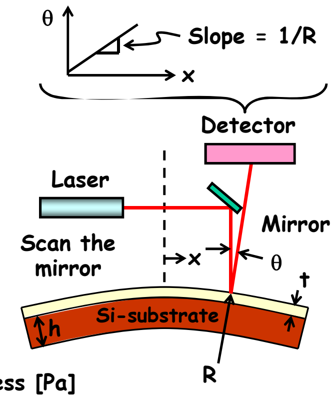
Stress Measurement Via Wafer Curvature

- Compressively stressed film → bends a wafer into a convex shape
- Tensile stressed film → bends a wafer into a concave shape
- Can optically measure the deflection of the wafer before and after the film is deposited
- Determine the radius of curvature R, then apply:



$$\sigma = \frac{E'h^2}{6Rt}$$

σ = film stress [Pa]
E' = E/(1-ν) = biaxial elastic modulus [Pa]
h = substrate thickness [m]
t = film thickness
R = substrate radius of curvature [m]

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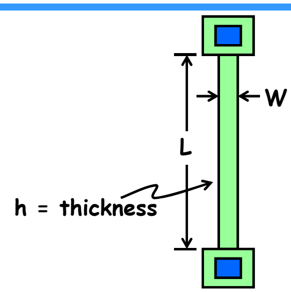
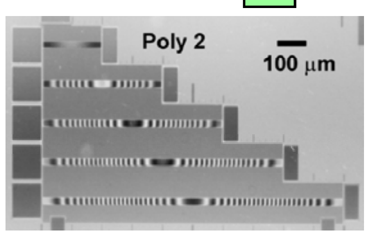
MEMS Stress Test Structure

- Simple Approach: use a clamped-clamped beam
  - Compressive stress causes buckling
  - Arrays with increasing length are used to determine the critical buckling load, where



$$\sigma_{critical} = -\frac{\pi^2}{3}\frac{Eh^2}{L^2}$$

E = Young's modulus [Pa]
I = (1/12)Wh³ = moment of inertia
L, W, h indicated in the figure



  - Limitation: Only compressive stress is measurable

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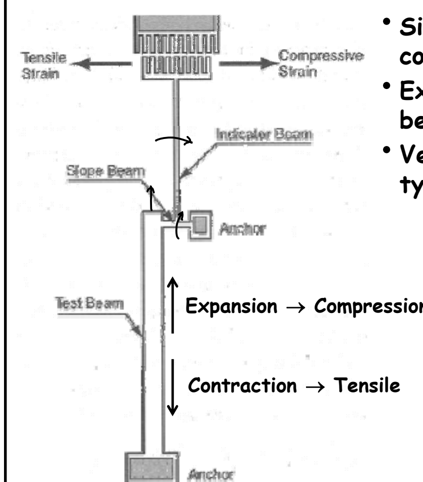
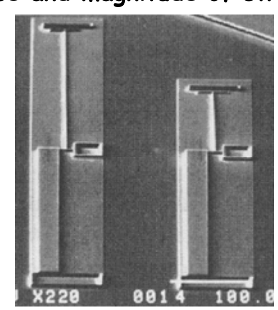
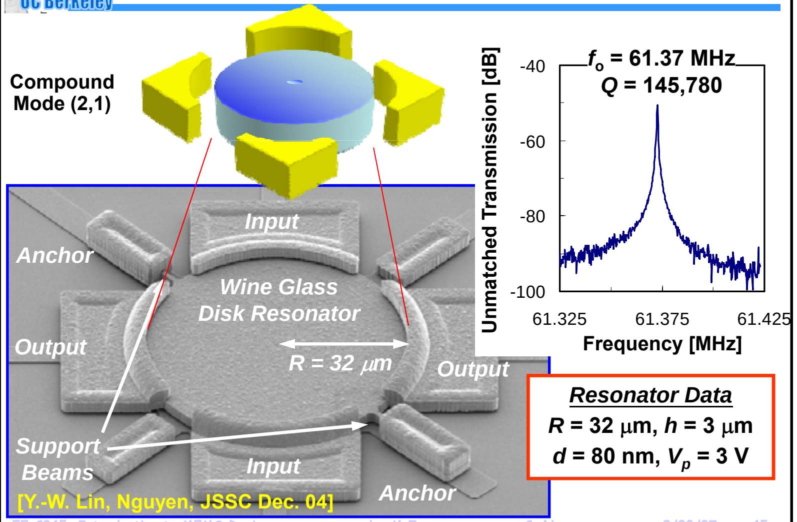
More Effective Stress Diagnostic



- Single structure measures both compressive and tensile stress
- Expansion or contraction of test beam → deflection of pointer
- Vernier movement indicates type and magnitude of stress



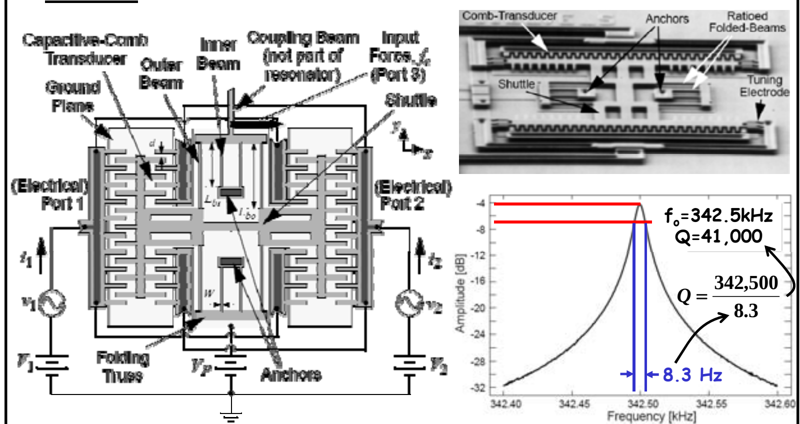
Q Measurement Using Resonators



Resonator Data
R = 32 μm, h = 3 μm
d = 80 nm, V_p = 3 V

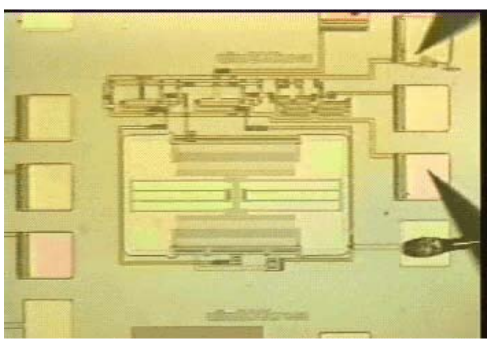
Folded-Beam Comb-Drive Resonator

- **Issue w/ Wine-Glass Resonator**: non-standard fab process
- **Solution**: use a folded-beam comb-drive resonator



Comb-Drive Resonator in Action

- **Below**: fully integrated micromechanical resonator oscillator using a MEMS-last integration approach



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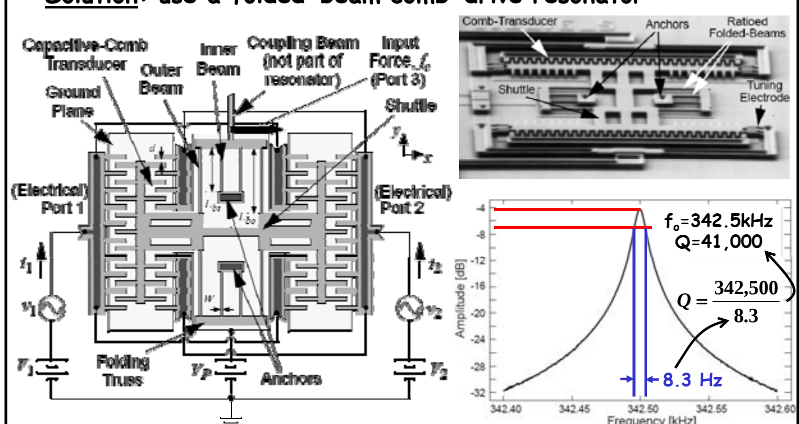

Measurement of Young's Modulus

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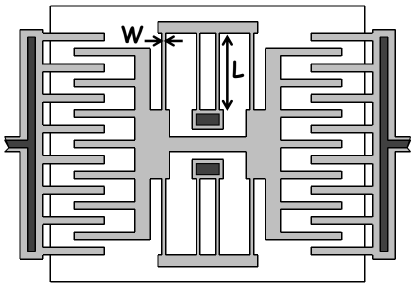
- Use micromechanical resonators
  - Resonance frequency depends on E
  - For a folded-beam resonator:

Resonance Frequency = $$f_o = \left[\frac{4Eh(W/L)^3}{M_{eq}} \right]^{1/2}$$

Young's modulus (E); Equivalent mass (M_{eq})

h = thickness



- Extract E from measured frequency f_o
- Measure f_o for several resonators with varying dimensions
- Use multiple data points to remove uncertainty in some parameters