Issues of Stress and Strain in Semiconductor Manufacturing

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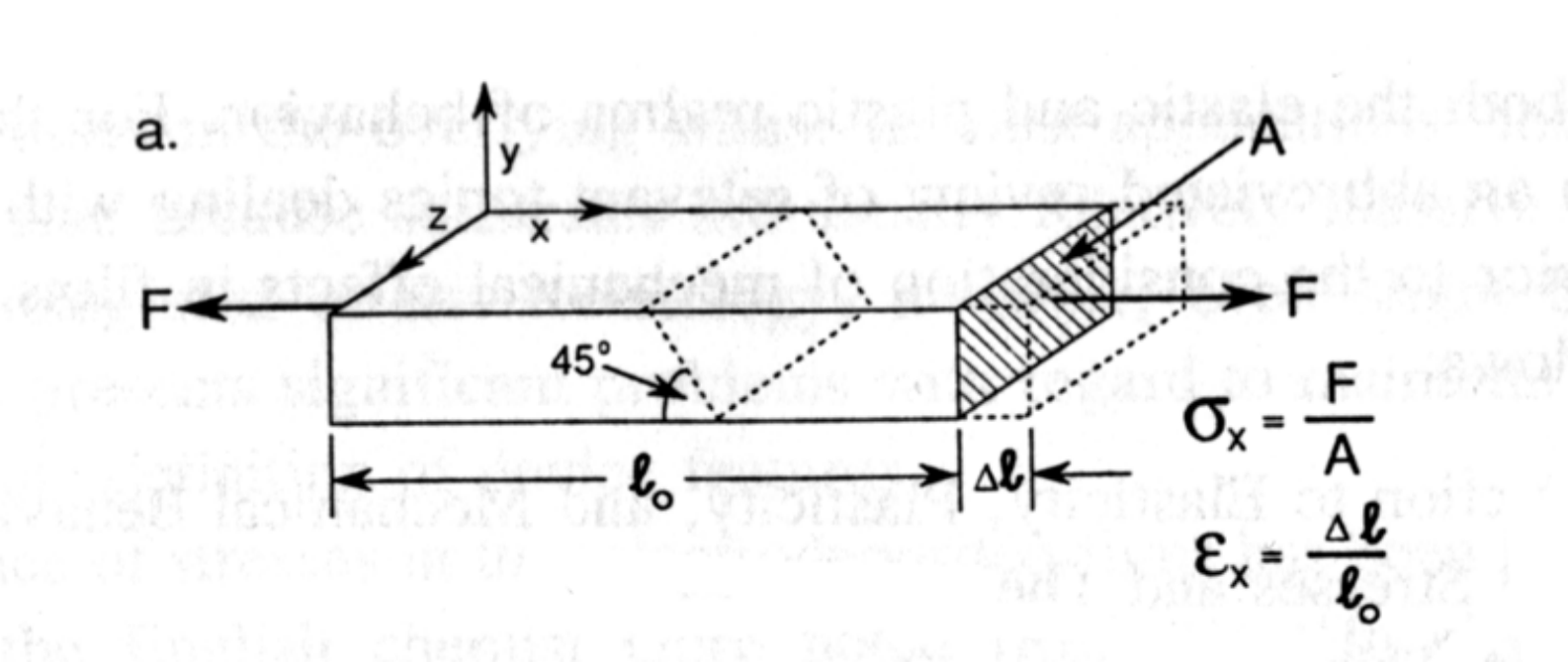
Outline

- Stress and Strain
- Stress in Thin Films
- Calculation of film stress
- Stress Control

Stress and Strain

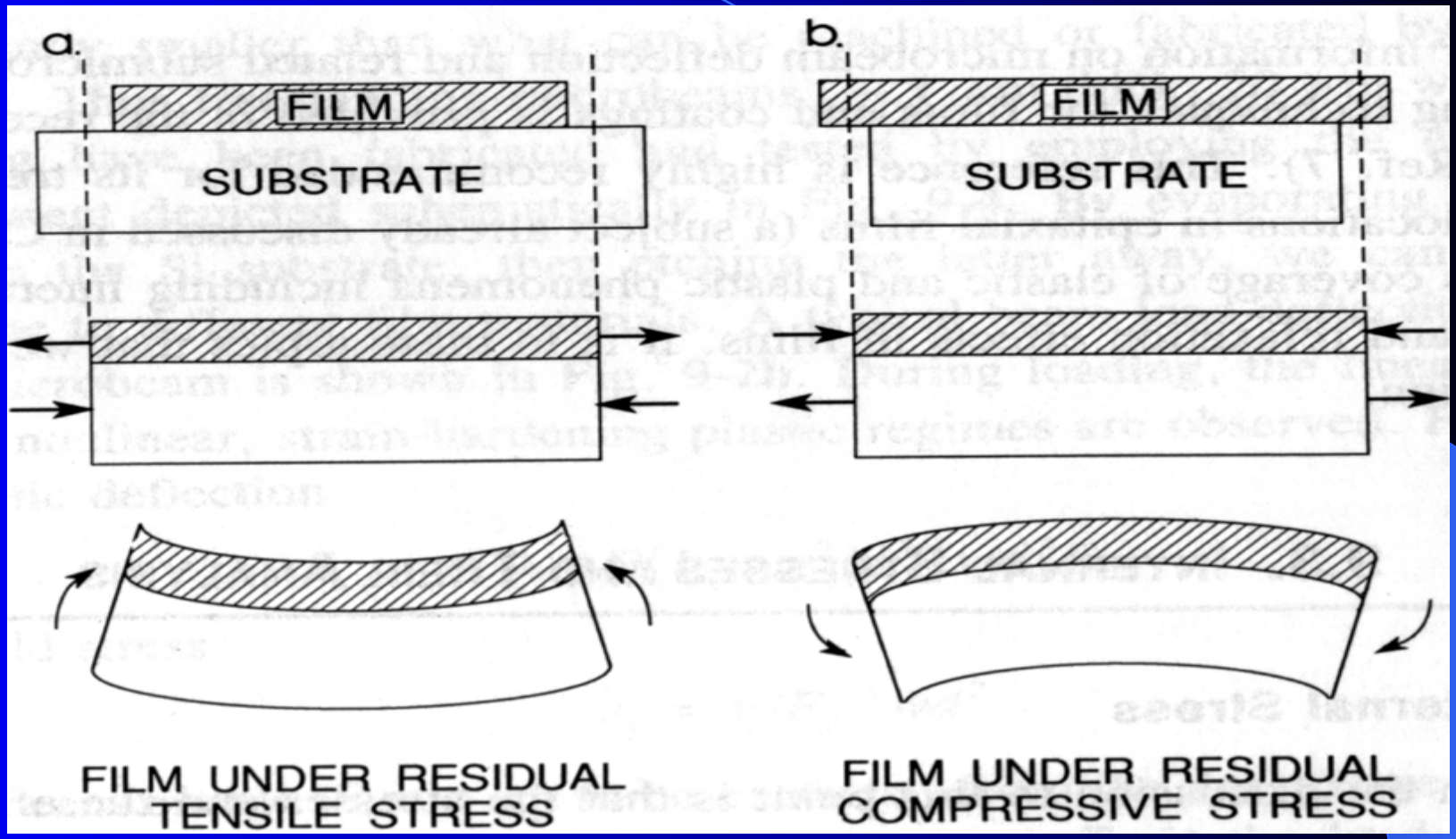


- Tensile Stress $= \sigma_x = F_x / A$
- Shear Stress $= \sigma_y = F_y / A$
- Strain $= \varepsilon_x = \Delta l / l_0$
- Poisson's Ratio $= v = - \varepsilon_y / \varepsilon_x$
- Hooke's Law : $\sigma = E \varepsilon_x$
- Hooke's Law (3D): $\varepsilon_x = (1/E) (\sigma_x - v (\sigma_x + \sigma_y))$

Stresses – Causes

- Thermal stress
  - Film deposition at a temperature different from room temperature
  - Different coefficient of expansion for film and substrate
- Intrinsic Stress
  - Due to microstructure created in film as atoms are deposited

Stress in Thin Films



Film wants to be smaller

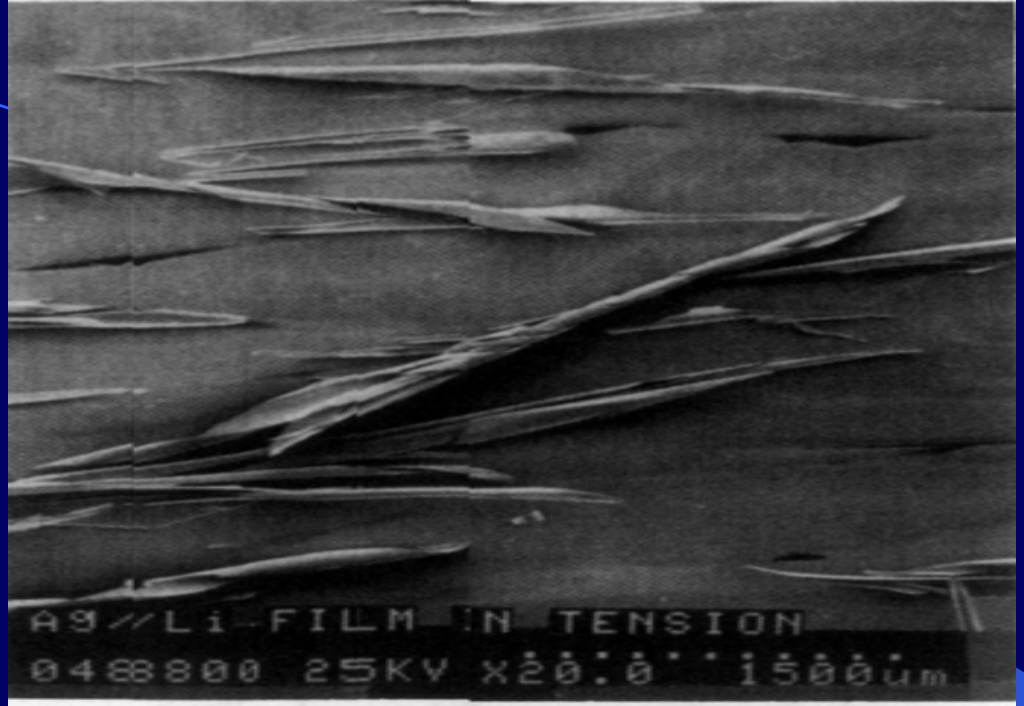
Film wants to be larger

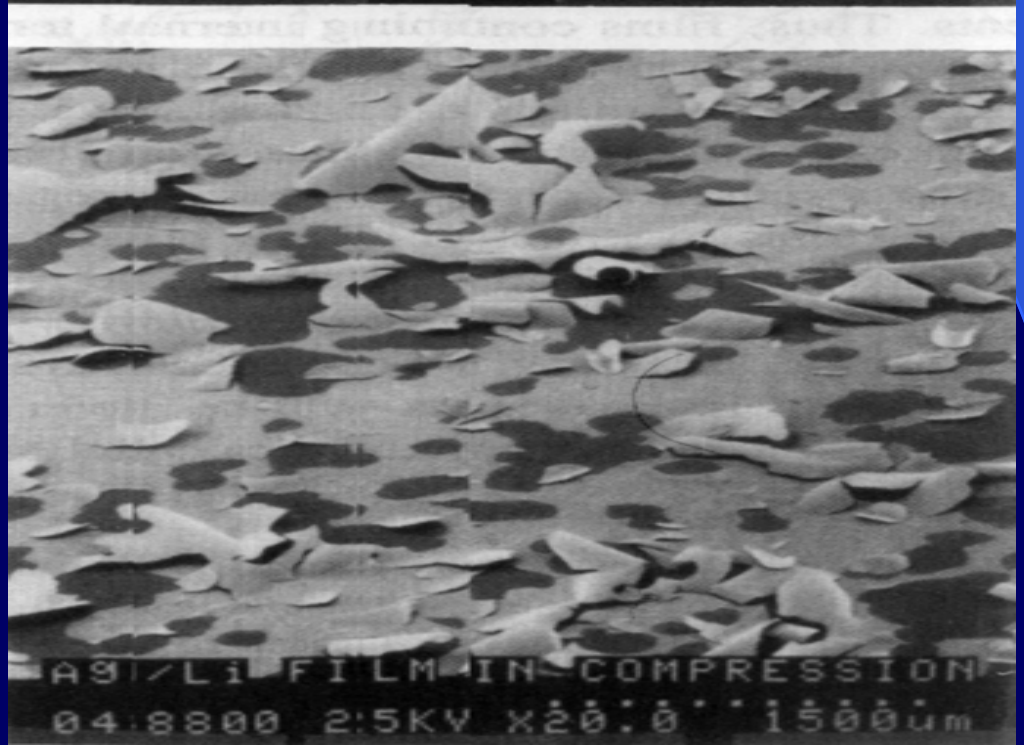
Stress in Thin Films - Causes

- Tensile stress (film wants to be smaller)
  - Lower coefficient of expansion than substrate
  - Microvoids formed in film during deposition – attraction of atoms across voids causes stress
- Compressive stress (film wants to be larger)
  - Higher coefficient of expansion than substrate
  - Heavy ions or energy particles hitting the film during deposition thereby packing the atoms tightly

Tensile film failure

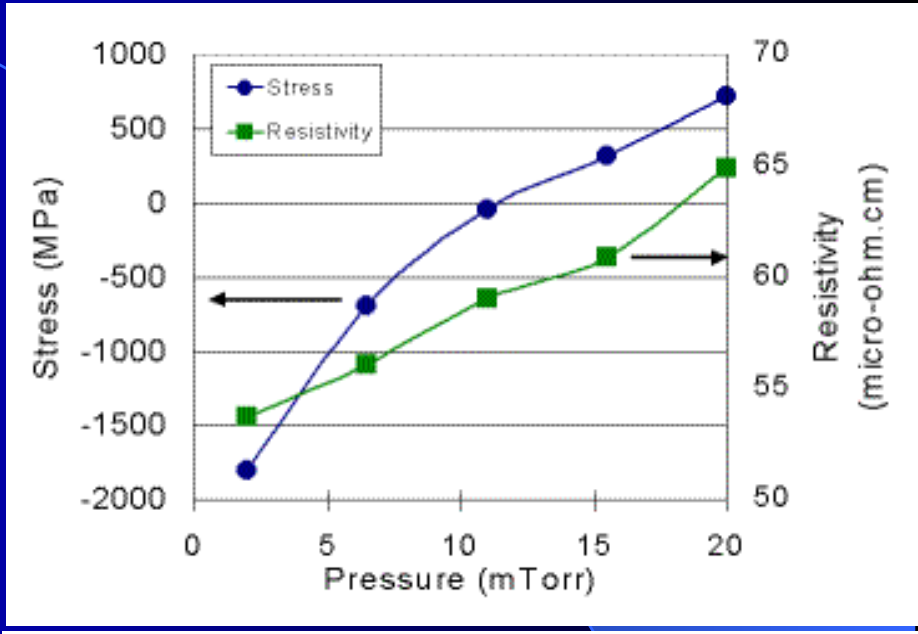
Compressive film failure

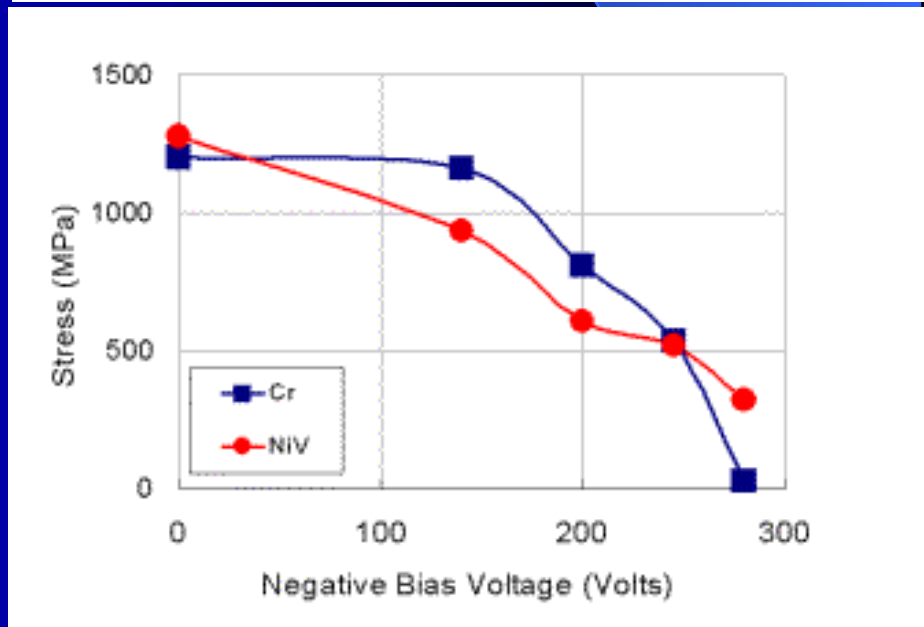




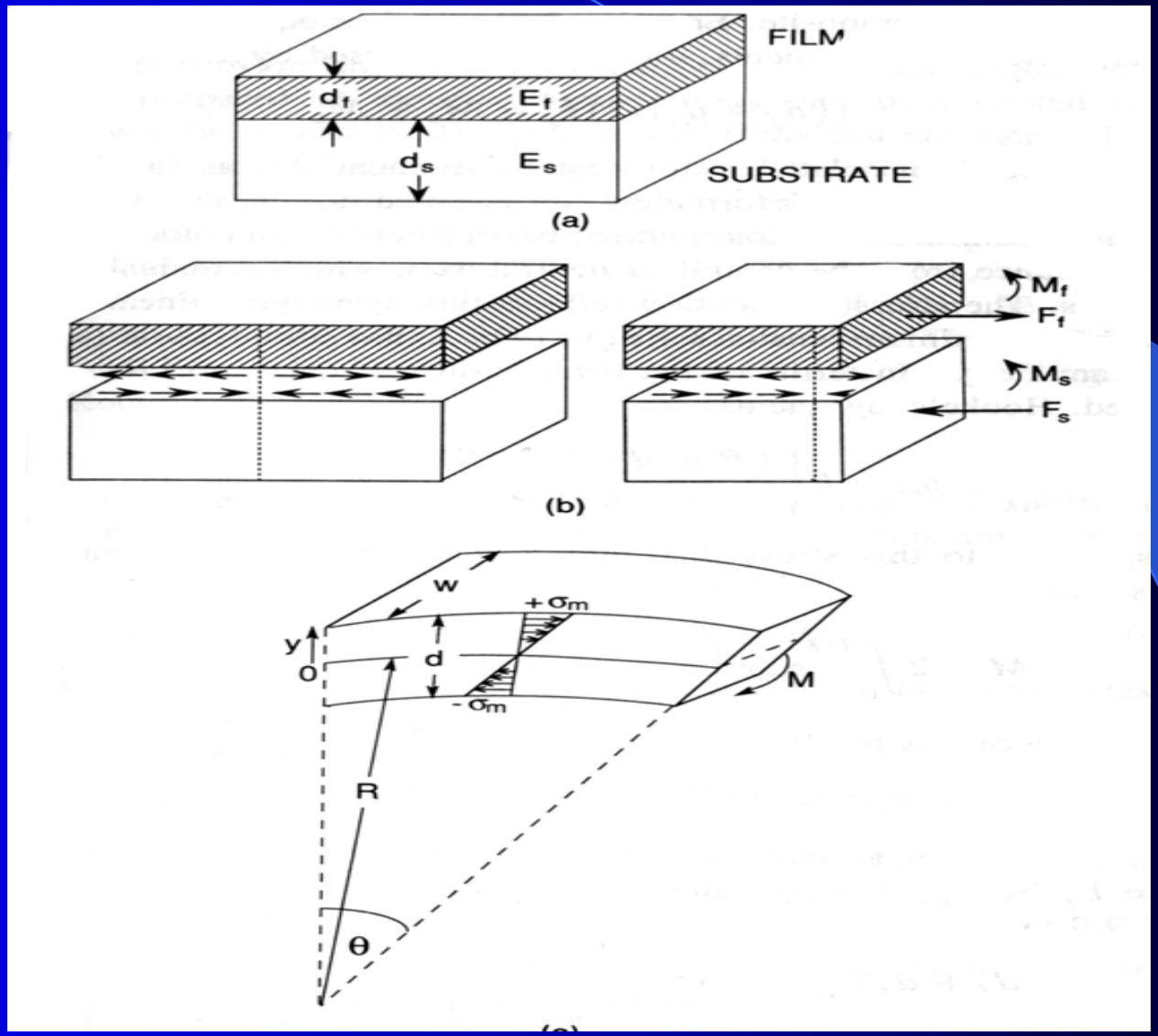
Examples

- Sputtered deposition of high mass TiW
  - Compressive film
  - As pressure increases => K.E. of sputtered atoms => Reduces compressive stress.
  - Increased resistivity => less dense structure
- Sputtered deposition of NiV and Cr films
  - Ion bombardment increases high density of defect clusters





Calculation of film stress – Stoney Formula



Stoney Formula (contd.)

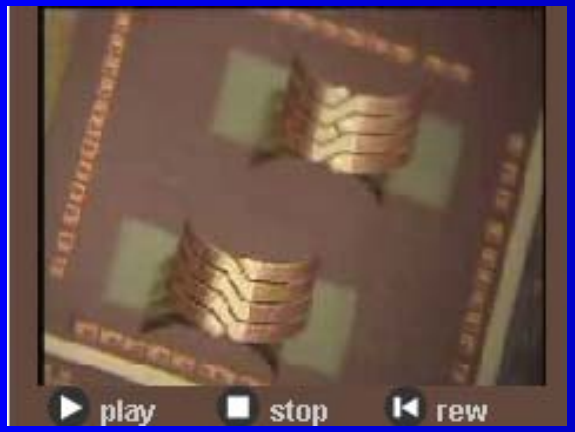
- Use of curvature to measure stress
- Derived using interfacial forces and end moments
- $\sigma_f = \frac{F}{d_f w} = \frac{1}{6R} \cdot \frac{E_s d_s^2}{(1-\nu_s)\, d_f}$
- Calculation of σ_f in most literature omits $(1-\nu_s)$ correction
- For Thermal Stress

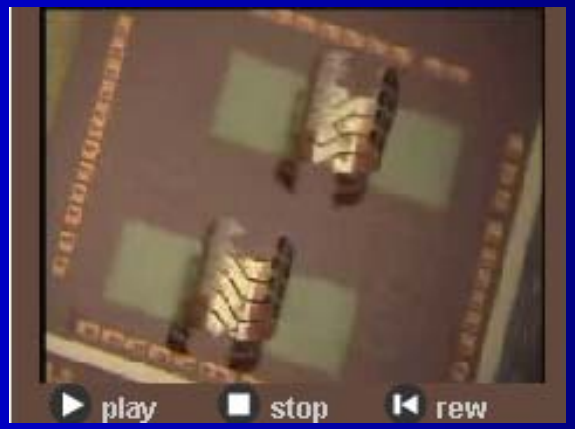
  $\sigma_f = \delta E_s d_s^2 / 3\, l^2 (1-\nu_s)\, d_f$

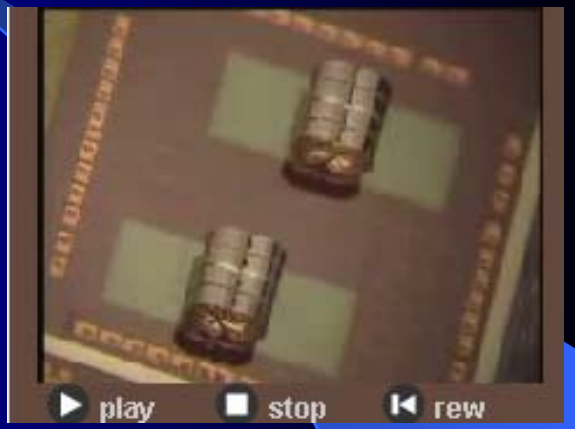
Stress Control

- Traditionally aim is to keep stress at a minimum for durability and reliability
- However, for out-of-plane structures, controlled stress is needed
- Example:
  1. On-chip, out-off-plane microinductor
  2. Flattening of Silicon micromirrors
  3. 3D nanosprings

On-chip, out-off-plane microinductor

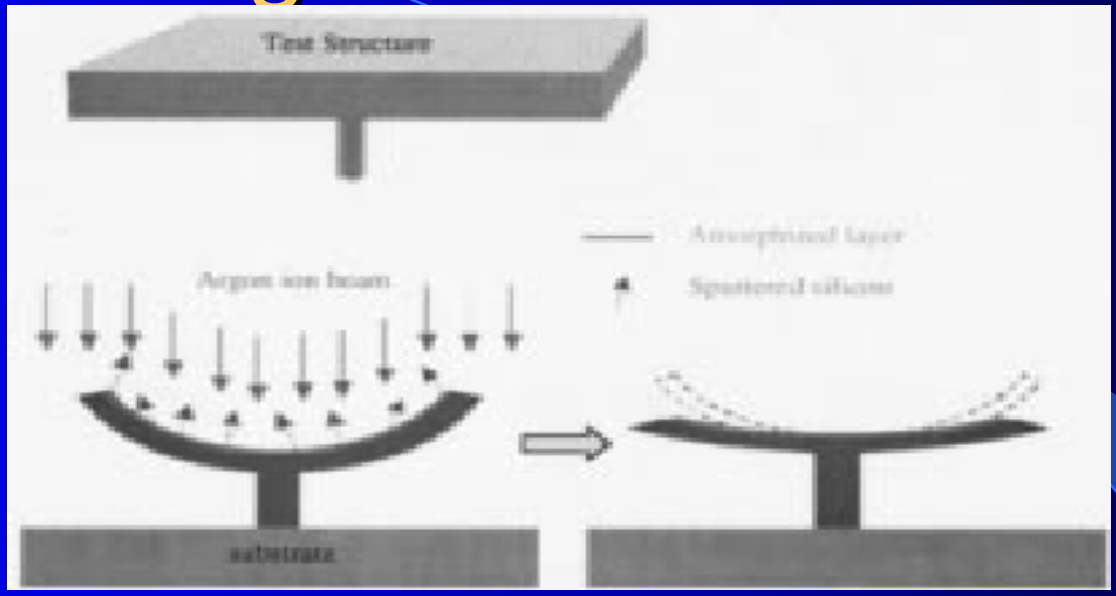






- High-Q inductors
- Wide range of substrates
  (including fully active circuit wafers)
- Reference: Xerox PARC

Flattening of Silicon Micromirrors



- Accelerated Argon bombards upper surface
- Change of curvature effected by
  - Disrupting crystalline structure of topmost film layer
  - Eroding of film in a sputter etching process
- Ref: Elimination of stress-induced curvature in Thin-Film Structures, Bifano et al.

Nanosprings

- Stress Gradients used
- Sacrificial layer removal
- Film curls to relax intrinsic stress
- Reference: Advanced Packaging Magazine