3.155J/6.152J Lecture 12: MEMS Lab Testing

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Information on Quiz

- Wednesday, Oct. 22, in-class
- Closed Book
- Covers lecture materials covered in problem sets through lithography
- Five questions, 20 pts. each
- A formula sheet will be provided
- Sample quizzes from previous terms and the formula sheet are on the course web site
  - Spring 2003 – Prepared by C. Ross
  - Fall 2002 – Prepared by R. O’Handley
    - Content somewhat different from this term
Outline

- Review of the Process and Testing
- Mechanics
  - Cantilever
  - Fixed-Fixed Beam
  - Second-order effects
    - Residual stress
    - Support compliance
- References
  - Senturia, Microsystems Design, Kluwer
The Process – Lab 1

- Grow 1.0 μm of Si-Rich Silicon Nitride (SiNₓ)
  - LPCVD Process (details to follow)
  - Characterize (UV1280)
    - Thickness
    - Refractive index
The Process – Lab 1

- Pattern Transfer
  - Deposit photoresist
  - Expose on contact aligner
  - Plasma etch using SF$_6$ chemistry
  - Strip resist
The Process – Lab 2

- KOH Undercut Etch
  - 20%, 80C
The Process – Lab 3

- Break the wafer into die
- Mount the die on a metal plate
- Test using the Hysitron Nanoindenter
Testing

- Cantilever
  - Young’s Modulus

- Fixed-Fixed Beams
  - Young’s Modulus
  - Residual Stress
The Mask – Fixed-Fixed Beams

Beam Length

50 100 200 500 1000

Beam Width

5 10 20 50 100
Cantilever Data

\[ F = k x \]
The stress - strain curve for a metal, showing the modulus, 0.2% yield strength, $\sigma_y$, and the ultimate strength, $\sigma_u$. 

\[ \sigma = \frac{F}{A_o} \]

\[ \varepsilon = \frac{\delta \ell}{\ell} \]
Material Properties: Brittle

Stress-strain curves for a ceramic in tension and in compression. The compressive strength $\sigma_c$ is 10 to 15 times greater than the tensile strength $\sigma_f$. We identify $\sigma_f$ with $\sigma_c$.
Fixed-Fixed Beam: Large Displacement

- Beam stretches under large displacement
  - Becomes ‘stiffer’
- Solved by Energy Methods
  - $c = w$

\[
F = \left(\frac{\pi^4}{6}\right) \left[\frac{EWH^3}{L^3}\right] c + \left(\frac{\pi^4}{8}\right) \left[\frac{EWH}{L^3}\right] c^3
\]

Ref: Senturia (Kluwer)
Effect of Residual Stress

- Not an issue in cantilevers
- For a point load, $F$, in the center of a bridge

$$F = \left\{ \left( \frac{\pi^2}{2} \right) \left[ \frac{\sigma_0 WH}{L} \right] + \left( \frac{\pi^4}{6} \right) \left[ \frac{EW H^3}{L^3} \right] \right\} c + \left( \frac{\pi^4}{8} \right) \left[ \frac{EW H}{L^3} \right] c^3$$

(10.70)

- Important when

$$\sigma_0 \approx \frac{EH^2}{L^2}$$

Ref: Senturia (Kluwer)
MEMS Lab Report

- Report Young’s Modulus extracted from
  - Cantilevers
  - Fixed-Fixed Beams
- Explain differences from ideal theory
- Compare to literature values for mechanical properties
- Assess the effects of:
  - Residual stress
    - Estimate from measurements
  - Experimental error
  - Compliant supports
  - Beam versus Plate
  - Others....