Lecture 13: Mechanics of Materials II

- Announcements:
- HW#3 due today at 7 p.m. in the EE245 box
- HW#4 online
- Sound for last Friday's video recording is at http://itunes.apple.com/itunes-u/electrical-engineering-c245/id460480361
- They are putting videos on Youtube and sound on iTunes
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- Reading: Senturia, Chpt. 8
- Lecture Topics:
  - Stress, strain, etc., for isotropic materials
  - Thin films: thermal stress, residual stress, and stress gradients
  - Internal dissipation
  - MEMS material properties and performance metrics
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- Last Time:

Linear Thermal Expansion

temperature ↑ → solids expand in volume

Definition. linear thermal expansion coefficient

$$\left.\begin{array}{l}\text{Linear Thermal}\\ \text{Exp. Coefficient}\end{array}\right\} \triangleq \alpha_T = \frac{d\varepsilon_x}{dT} \quad [\text{kelvin}^{-1}]$$

Remarks.

① α_T values tend to be in the 10^{-6} to 10^{-7} range

② $10^{-6}\,K^{-1} = 1\,\mu\text{strain}/K$

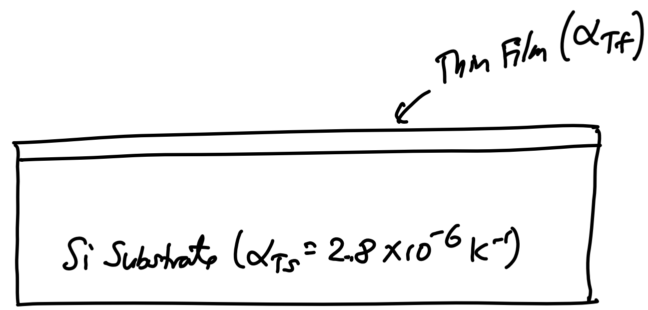
③ In 3D, get a volume thermal exp. coefficient

$$\frac{\Delta V}{V} = 3\alpha_T \Delta T$$

④ For moderate ΔT's → $\alpha_T \approx$ constant

for large ΔT, then $\alpha_T = f(T)$

Ex. Thin-Film Thermal Stress



Assume.

① Substrate is much thicker than the film.

② Film is deposited stress free @ T_d ← deposition temperature

③ Then the whole thing is cooled to room temperature, T_r.

Thermal Strain of the Substrate: (in one plane dimension)

$\epsilon_S = -\alpha_{TS} \Delta T$, where $\Delta T = T_d - T_r$

If the film were not attached to the substrate:

$$\epsilon_{f,free} = -\alpha_{Tf} \Delta T$$

But the film is attached to the substrate

→ thickness sub >> thickness film ∴ substrate wins!

→ therefore, the actual strain experienced by film is that of the substrate:

$$\epsilon_{f,attached} = -\alpha_{TS} \Delta T$$

Thus:

Thermal Mismatch Strain $= \epsilon_{f,mismatch} = (\alpha_{Tf} - \alpha_{TS}) \Delta T$

→ Note this is biaxial strain (assuming the film is deposited isotropically onto the substrate)

$$\sigma_{f,mismatch} = \underbrace{\left(\frac{E}{1-\nu}\right)}_{E'} \epsilon_{f,mismatch}$$

Ex. Thin film is polyimide → $\alpha_{Tf} = 70 \times 10^{-6} K^{-1}$

$E' = 4GPa$

deposited @ 250°C, then cooled to RT = 25°C

$\Delta T = 225K$

$$\epsilon_{f,mismatch} = (70 - 2.8)\mu(225) = 1.5 \times 10^{-2}$$

$[\mu = 10^{-6}, m = 10^{-3}, k = 10^3, G = 10^9]$

$$\sigma_{f,mismatch} = (4G)(1.5 \times 10^{-2}) = 60.5 MPa$$

(G = 10^9)

↑ stress is (+) → tensile

[(-) would be compressive]

↑ SiO_2