1) Thermal Sensing and Actuation → Chapter 5 in text book

→ materials expand when heated → thermal expansion

a. Linear Expansion Coefficient → material property

→ a relative dimensional change per unit temperature increase : $\alpha = \frac{\Delta L / L}{\Delta T}$, $[\alpha] = \times 10^{-6}/^{o}C$ → Note : Book error α & β

→ also called the "Coefficient of Thermal Expansion" (CTE) or "Thermal Expansion Coefficient" (TEC)

→ Volumetric Expansion Coefficient : $\beta = \frac{\Delta V / V}{\Delta T} \cong 3\alpha$

Example values for CTE : Table 5.2, p. 183

Al → 25 <2.5 is error in book>

Al Oxide → 8.7

Si → 2.6

Au → 14.2

SiO_2 → 0.35

Ni → 13

Ti → 8.6

Differences in CTE between two attached materials results in stress, strain and sometimes mechanical failure when the temperature changes from the bonding temperature

→ often a major problem in microfabrication

ex: $CTE_{Si}/CTE_{SiO_2} = 2.6/0.35 = 7.4$

→ Si expand or contracts 7.4 x more than SiO_2 for a temp increase or decrease

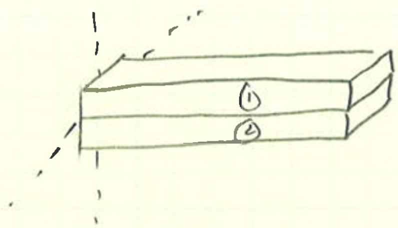
<u>Ex</u>: how much does a Si cantilever elongate for a 100° temperature increase? (beam is 1mm. long)

$$d = L \alpha \Delta T$$

$$= (1\times10^{-3})(2.6\times10^{-6})(100) = 0.26\,\mu m$$

b. <u>Thermal Bimorph</u>

Consider a beam clamped on one end made of two materials with different CTE's, bonded longitudinally:

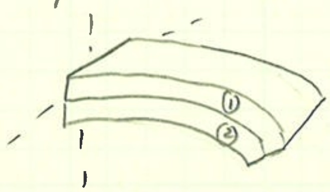


→ at bonding temperature

let $CTE_{①} > CTE_{②}$

if Temperature increases: ① expands more than ②

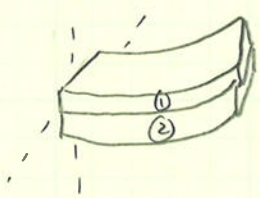
∴



→ beam bends down

if Temperature decreases: ② contracts more than ②

∴

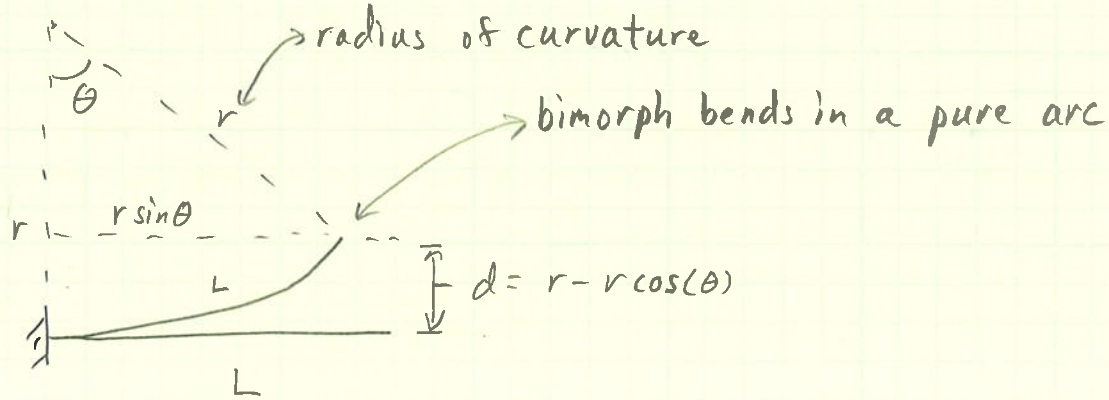


→ beam bends up

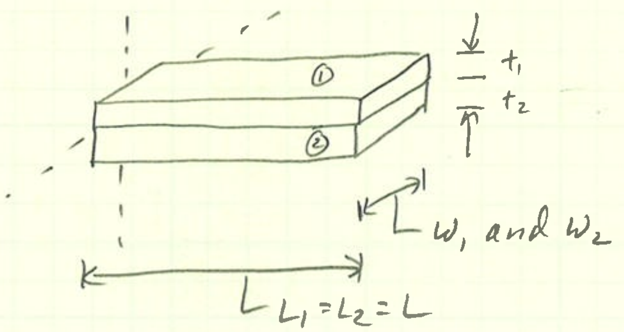
① Sensing Temperature: measure deflection or strain to determine temperature

② Actuator → add a resistive heater onto the bimorph and use Joule heating to deflect the bimorph

1. Mathematical Modeling the Bimorph



$L = r\theta \rightarrow [\theta] = \text{rad}$



material ① → α_1, E_1

② → α_2, E_2

$r \equiv$ radius of curvature

$$\frac{1}{r} = \frac{6 w_1 w_2 E_1 E_2 t_1 t_2 (t_1 + t_2)(\alpha_1 - \alpha_2) \Delta T}{(w_1 E_1 t_1^2)^2 + (w_2 E_2 t_2^2)^2 + 2 w_1 w_2 E_1 E_2 t_1 t_2 (2t_1^2 + 3t_1 t_2 + 2t_2^2)}$$

→ Why use thermal Bimorph actuators?

→ tolerant of enviroments PPA/CDA's will not work:

(1) dirty (dust, etc)

(2) in liquids (water, bio, etc)

(3) easy to make an angular displacement based on input energy → current ⇒ heat ⇒ ΔT ⇒ θ

2. Thermal Sensors (covered in detail in Sensors course)

(1) Micro Thermocouples

→ temperature dependent voltage between 2 dissimilar metals bonded at a point → Seebeck effect

(2) Thermal Resistor

↳ conductors ⇒ resistance increases with temperature

$$R_T = R_0(1 + \alpha_R(T - T_0))$$

α_R = temperature coefficient of resistance

(3) Thermistor

→ semiconductor temperature dependent device

$$R = R_0 e^{[B(1/T - 1/T_{ref})]}$$

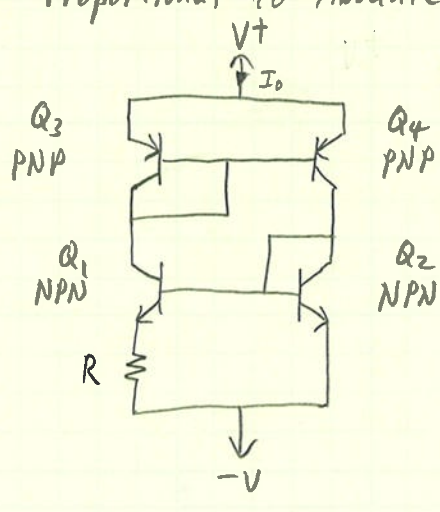
→ response is nonlinear with temperature

→ low cost → used for medical thermometers

(4) Thermodiodes, Thermotransistors and the PTAT

→ temperature dependent current (also fabrication dependence)

→ PTAT → "Proportional To Absolute Temperature"



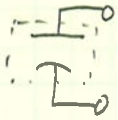
$$I_0 \approx \frac{2k_B T}{qR} \ln\left(\frac{A_{E2}}{A_{E1}}\right)$$

→ removes fab. tol. dependence

→ often used in MEMS device in order to calibrate out temperature effects → most MEMS devices (i.e. sensors) are sensitive to temp. changes

3. <u>Piezoelectric Actuation and Sensing</u> → Chapter 7 in textbook

→ Consider a "special capacitor" with charge permanently trapped in between the electrodes

Q_0  V_0 → $Q_0 = CV_0$

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d_0}$$

if Q_0 is constant and V_0 is increased, C must decrease

Q_0 = Constant, $V_0 \uparrow : C \downarrow \rightarrow d_0 \uparrow$

→ Increasing V_0 results in plates moving further away

→ Decreasing V_0 " " " " closer together

Likewise: forcing the plates closer {i.e. d_0}

results in: $d_0 \downarrow : C \uparrow : V_0 \downarrow$

→ Piezoelectric crystals work in a similar way

→ these crystals possess multiple minute polarized crystallites ("domains") that are normally randomly oriented throughout the bulk crystal

→ by exposing the crystal to a high electric field at elevated temperature, the domains most closely aligned to $\vec{E}$ will grow at the expense of the others, and the crystal lengthens in this direction. This effect remains when temp is lowered and $\vec{E}$ removed.

This process is called "Poling"