Computational Microelectronics
L23

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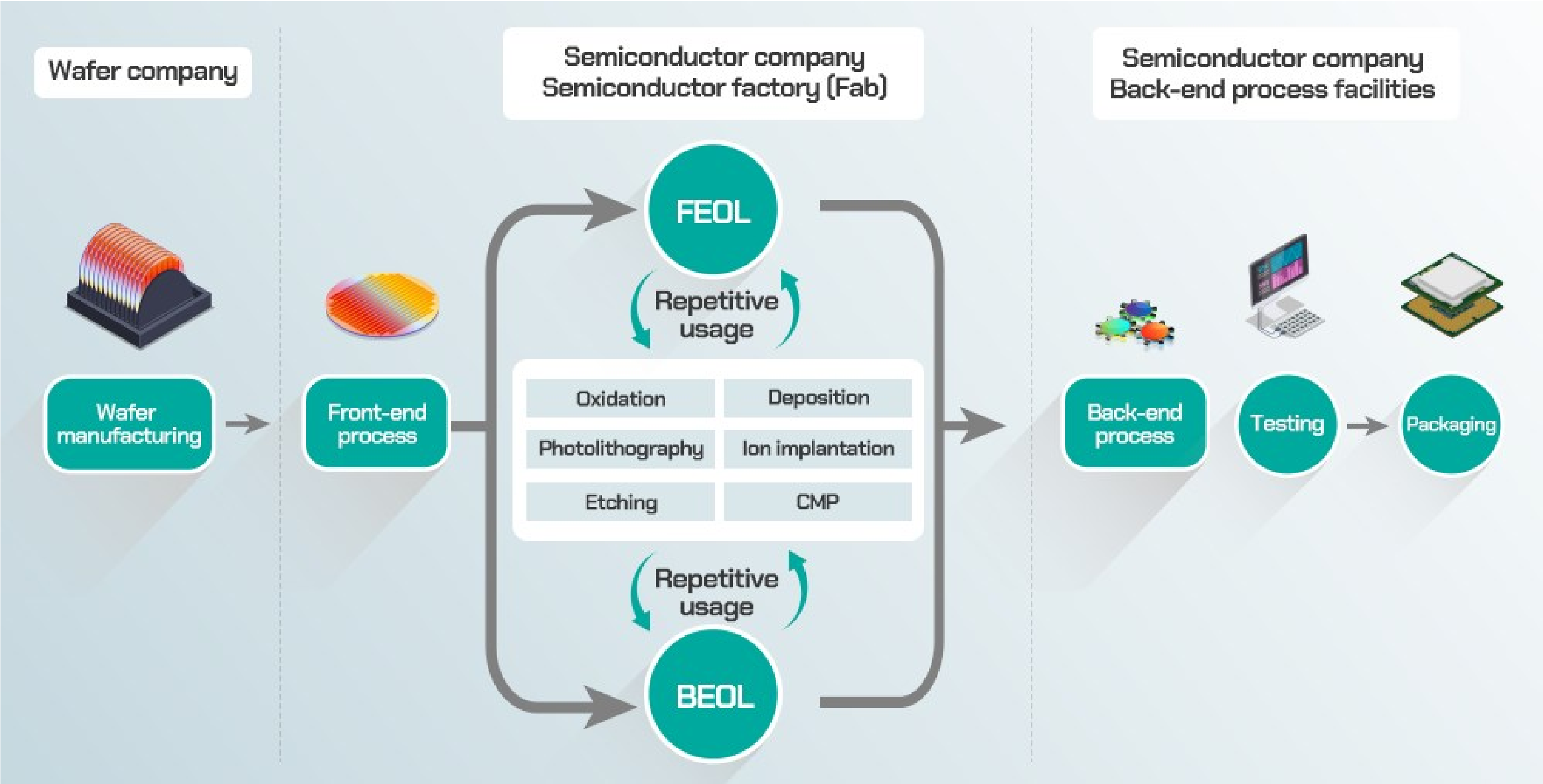
Thermal expansion

Scope of TCAD

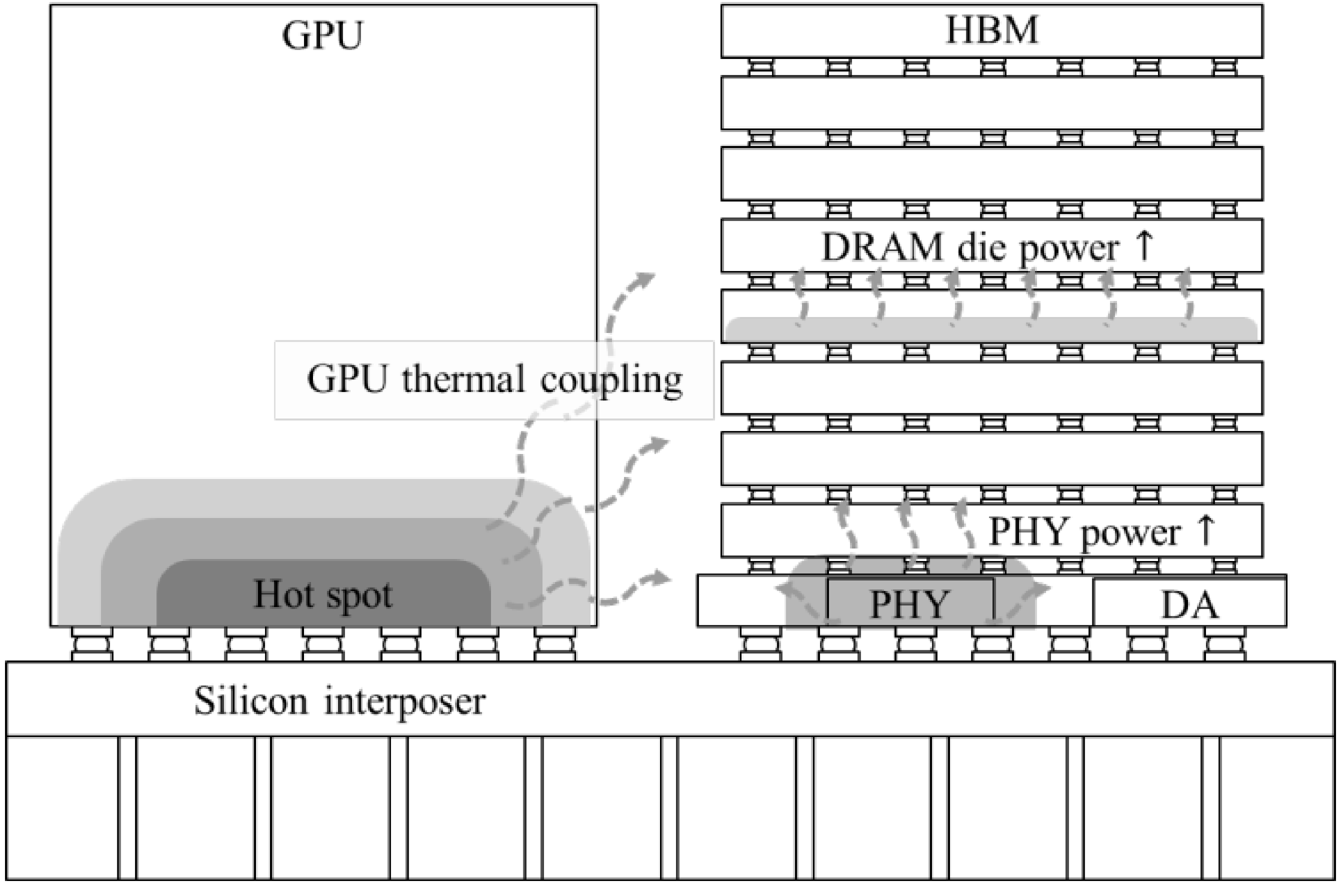
- TCAD serves to support the development process of semiconductor device technology.
  - Front-ent/back-end



Semiconductor manufacturing process (SK hynix)

Temperature as a key quantity

- GPU-HBM
  - Is this really in the scope of TCAD?



Thermal issues of HBM-GPU module on silicon interposer process (K. Son et al., EDAPS, 2023)

Thermal expansion

- Linear expansion
  - Coefficient of linear thermal expansion,

$$\alpha_L = \frac{1}{L}\frac{dL}{dT}$$

(For silicon, 2.6 X 10^{-6} K^{-1})

  - Then, the thermal strain becomes

$$\varepsilon_{thermal} = \frac{\Delta L}{L} = \alpha_L \Delta T$$

Bimetal strip

- S. Timoshenko, “Analysis of bi-metal thermostats,” Journal of the Optical Society of America, vol. 11, pp. 233-255 (1925)
  - Let us follow the paper. (Some figures are taken from that paper.)

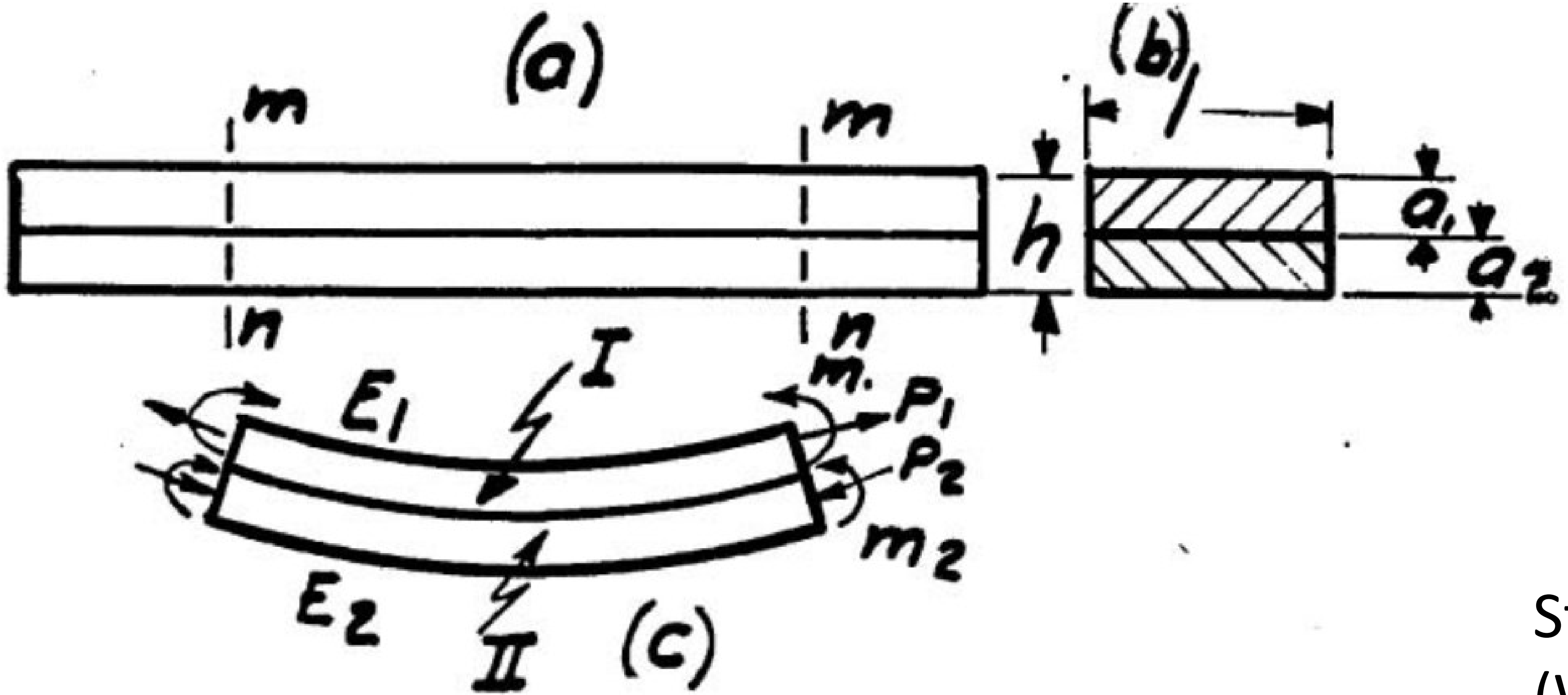


FIG. 1. *Deflection of a bi-metal strip while uniformly heated.*


Stephen Timoshenko (Wikipedia)

Conditions

- Coefficients of expansion, α_1 and α_2 ($\alpha_2 > \alpha_1$), remain constant.
  - Temperature from t_0 to t.
  - E_1 and E_2 denote their moduli of elasticity.

Stress / strain

  - a_1 and a_2 are metal thicknesses. (Don't be confused with α_1 and α_2.)

Equilibrium

- At any cross-section,

$$P_1 = P_2 = P$$

$$\frac{Ph}{2} = M_1 + M_2$$

  - P_1 is an axial tensile force and P_2 is an axial compressive force.
  - M_1 and M_2 are bending moments:

$$M_1 = \frac{E_1 I_1}{\rho}$$

$$M_2 = \frac{E_2 I_2}{\rho}$$

Radius of curvature

Manipulation

- Now we have one equation for calculating P and ρ:

$$\frac{Ph}{2} = \frac{E_1 I_1 + E_2 I_2}{\rho}$$

  - Another equation? Length at the interface

$$\alpha_1 (t - t_0) + \frac{P_1}{E_1 a_1} + \frac{a_1}{2\rho}$$

  - The same quantity from metal 2

$$\alpha_2 (t - t_0) - \frac{P_2}{E_2 a_2} - \frac{a_1}{2\rho}$$

  - These two expressions should be identical.

Result

- Now we have one equation for calculating P and ρ:

$$\frac{1}{\rho}=\frac{(\alpha_2-\alpha_1)(t-t_0)}{\frac{h}{2}+\frac{2(E_1I_1+E_2I_2)}{h}\left(\frac{1}{E_1a_1}+\frac{1}{E_2a_2}\right)}$$

  – A special case, $E_1=E_2$ and $a_1=a_2$, (with $I_1=\frac{a_1^3}{12}$ and $I_2=\frac{a_2^3}{12}$)

$$\frac{1}{\rho}=\frac{3}{2}\frac{(\alpha_2-\alpha_1)(t-t_0)}{h}$$

Deformation

- Now we have one equation for calculating P and ρ:

$$\delta = \frac{l^2}{8\rho}$$

  - Example)
    $\alpha_1 = 12 \times 10^{-6}\ \mathrm{K}^{-1}$
    $\alpha_2 = 19 \times 10^{-6}\ \mathrm{K}^{-1}$
    $h = 2\ \mathrm{mm}$
    $t = 600\ \mathrm{K}, t_0 = 300\ \mathrm{K}$
  - Then, $\frac{1}{\rho} = 1.575\ \mathrm{m}^{-1}$
  - When $l = 20\ \mathrm{mm}$, $\delta = 78.75\ \mu\mathrm{m}$.

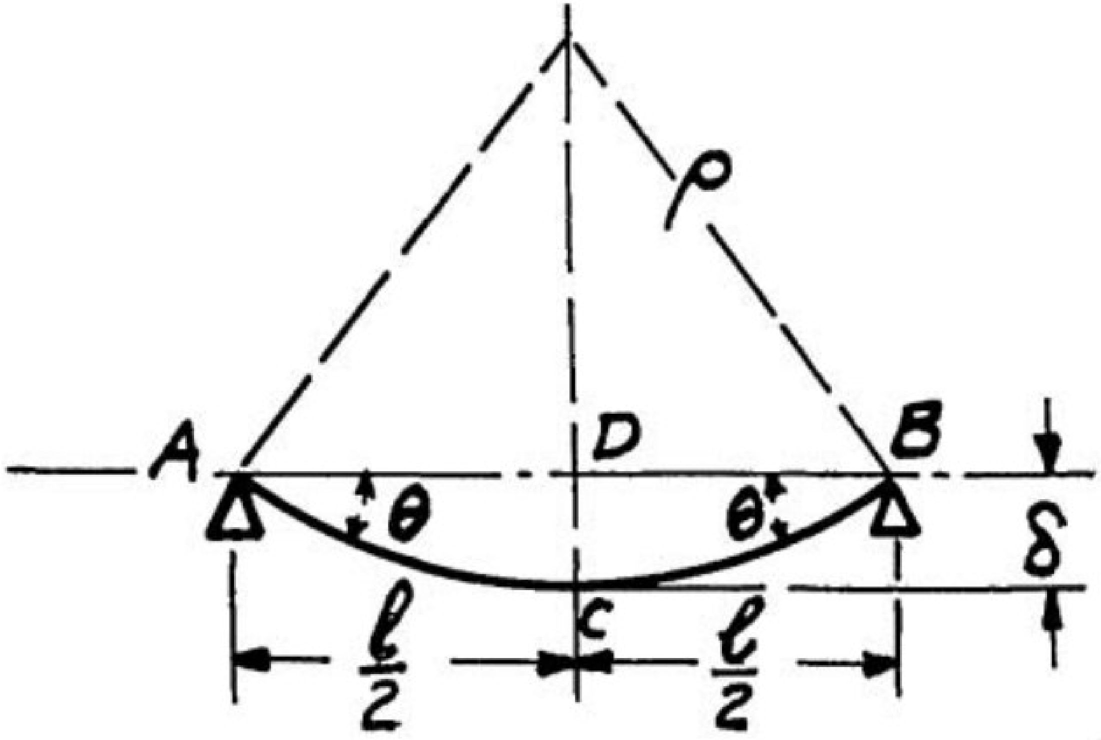


FIG. 2. *Deflection of a simply supported bi-metal strip.*

Thank you for your attention!