ME 517: Micro- and Nanoscale Processes

Lecture 3: Scaling

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Scaling Laws

Scaling laws for force (WSN Trimmer, Sensors and Actuators, 19, 267, 1989).

$$F = \begin{bmatrix} s^{1} \\ s^{2} \\ s^{3} \\ s^{4} \end{bmatrix}$$

$$a = F/m = [s^{F}]\,[s^{-3}] = \begin{bmatrix} s^{-2} \\ s^{-1} \\ s^{0} \\ s^{1} \end{bmatrix}$$

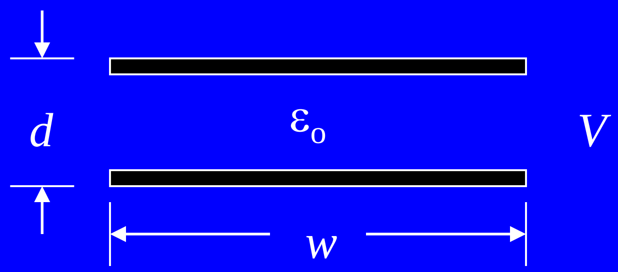
$$t = (2x/a)^{1/2} = (2xm/F)^{1/2} = ([s^{1}]\,[s^{3}]\,[s^{-F}])^{1/2} = \begin{bmatrix} s^{1.5} \\ s^{1} \\ s^{0.5} \\ s^{0} \end{bmatrix}$$

$$P = Fx/t = [s^{F}]\,[s^{1}]([s^{1}]\,[s^{3}]\,[s^{-F}])^{1/2} = \begin{bmatrix} s^{0.5} \\ s^{2} \\ s^{3.5} \\ s^{5} \end{bmatrix}$$

$$P/V = [s^{F}]\,[s^{1}]([s^{1}]\,[s^{3}]\,[s^{-F}])^{1/2}\,[s^{-3}] = \begin{bmatrix} s^{-2.5} \\ s^{-1} \\ s^{0.5} \\ s^{2} \end{bmatrix}$$

Electrostatic Forces

Parallel plate capacitor of
w-width
d-distance between plates
V- voltage



$$U = \frac{1}{2} C V^2$$

$$C = \varepsilon_o \frac{w^2}{d} \qquad V = Ed$$

$$U = \frac{1}{2} \varepsilon_o w^2 d E^2$$

$$F = -\frac{dU}{dx} = -\frac{1}{2} \varepsilon_o \frac{d}{dx} [w^2 d E^2]$$

Continuum dielectric behavior $E = s^0$ $F = s^2$

Continuum breakdown $E = s^{-0.5}$ $F = s^1$

Magnetic Forces

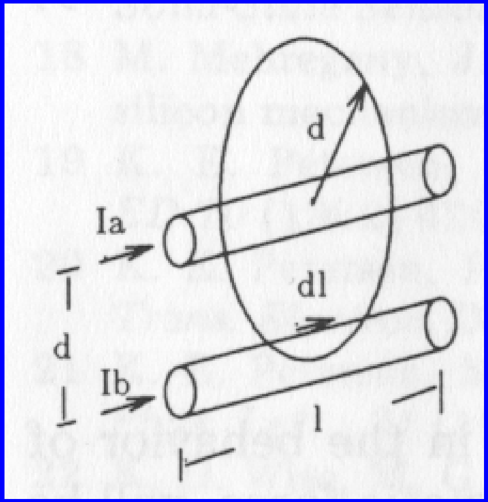
Two wires carrying current

$$dF_b = I_b d\vec{l}_b x \vec{B}a$$

$$\nabla x \vec{B} - c^{-2}\frac{\partial E}{\partial t} = \mu_o \vec{J}$$

$$B_a = \frac{\mu_o i_a}{2\pi d}$$

$$F_b = i_b l B_a = \frac{\mu_o l i_b i_a}{2\pi d}$$



Constant current density J (Trimmer case C)

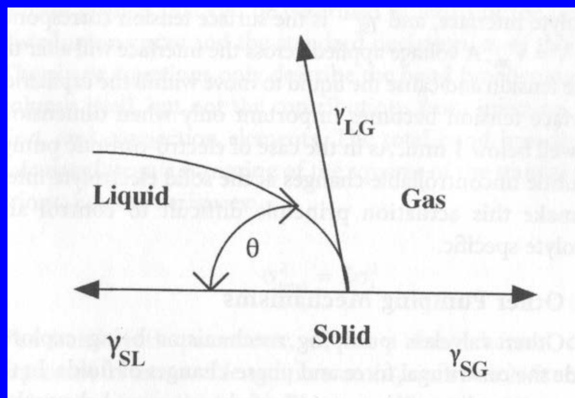
$$i = \int J dA = JA$$

$i = [s^0]\ [s^2]$

$F_b = [s^4]$

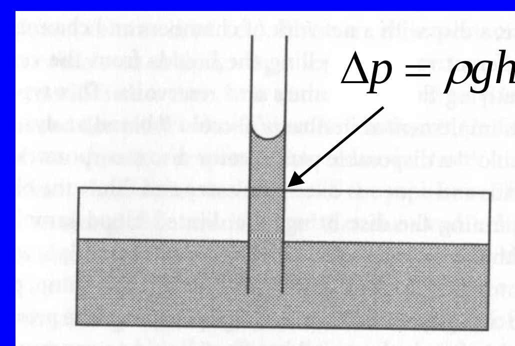
Surface Tension

Surface tension (γ) is the increase in energy as the surface area is increases.



Young's Equation

$$\gamma_{SL} + \gamma_{LG}\cos\theta = \gamma_{SG}$$

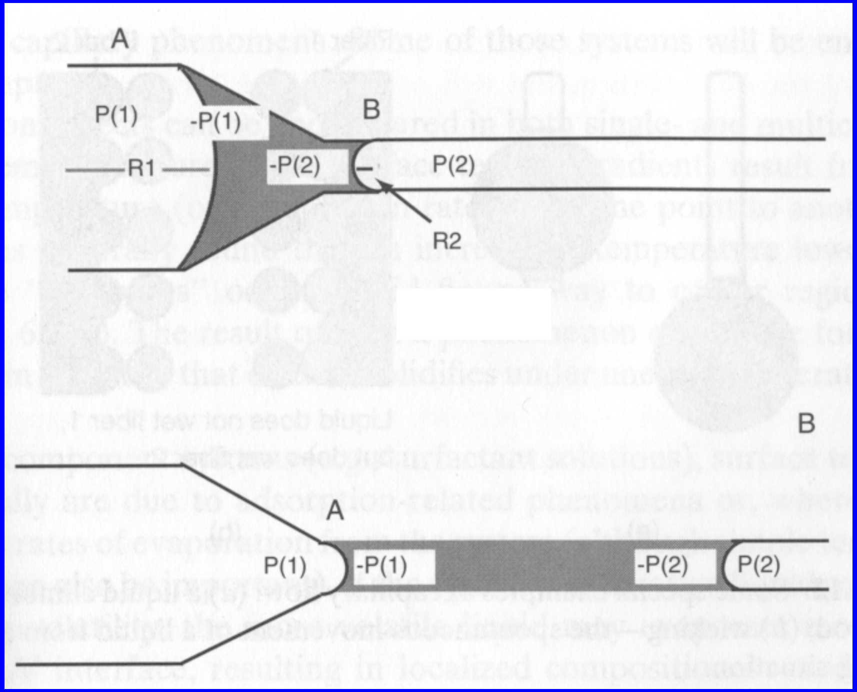


$$\Delta p = \frac{2(\gamma_{SG} - \gamma_{SL})}{r} = \frac{2\gamma_L \cos\theta}{r}$$

γ_{water} = 72.8 mN/m
r = 10^{-6} m
Δp ~ 100 kPa or 1 atm

Surface Tension

Capillary tube wetting



$$\Delta p = 2\gamma \cos\theta \left(\frac{1}{R_1} - \frac{1}{R2} \right)$$

θ < 90 and $R_1 > R_2$
then Δp <0

θ < 90 and $R_1 < R_2$
then Δp >0

$$F_b = [s]$$

Outline of Microfabrication Section

- Introduction to Microfabrication
- Lithography
- Dry Etching Techniques
- Additive Techniques
- Bulk Micromachining
- Surface Micromachining
- Novel, quick, advanced techniques

Project 1:

- Choose some topic of interest to you in the ‘small’ world
- Can work in small groups of 1-4 people
- Write a one paragraph abstract describing the topic and the scope of what you will write about.
    - Due next Fri, Jan 24

Supplementary References

MEMS Handbooks

- M. Madou, *Fundamentals of Microfabrication*, CRC Press 2000. ISBN 0-8493-9451-1
- M. Gad-el-Hak, *The MEMS Handbook*, CRC Press, 2002. ISBN 0-8493-0077-0.
- G.T.A. Kovacs, *Micromachined Transducers Sourcebook*, McGraw-Hill Co, 1998. ISBN 0-07-290722-3.

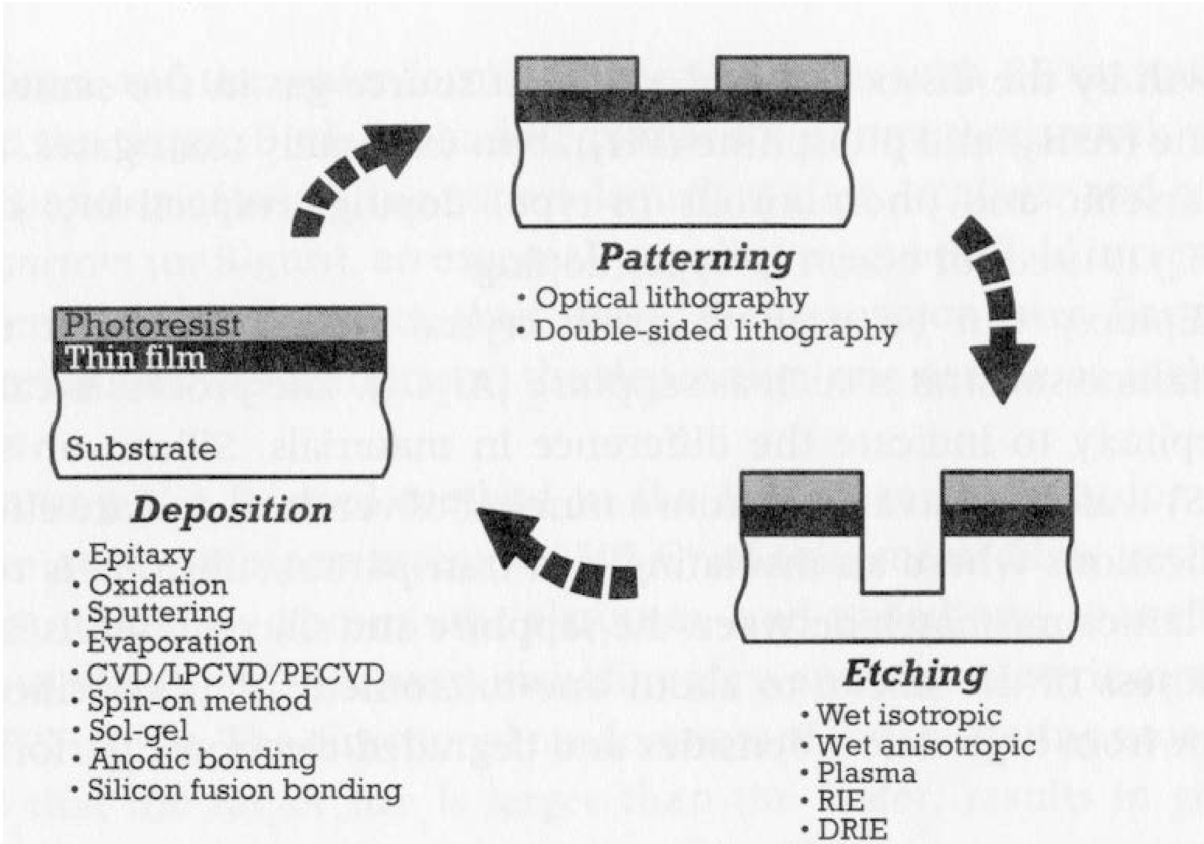
Electrical Engineering and Solid-State Physics texts

- S. A. Campbell, *The Science and Engineering of Microelectronic Fabrication*, Oxford University Press, 2001. ISBN 0-19-513606-5.
- N.W. Ashcroft, N.D. Mermin, *Solid State Physics*, B. Saunders Co, 1976. ISBN 0-03-083993-9.
- C. Kittel, *Introduction to Solid State Physics*, J. Wiley & Sons, 1986. ISBN 0-471-87474-4.

Outline of Introduction to Microfabrication and Lithography

- Basic Microfabrication Processes
- MEMS Materials
  - Silicon: Chemistry and Materials Properties
  - Metals
- Solid State Properties
  - Piezoresistivity
  - Piezoelectricity
- Photolithography
  - Photoresists
  - Resolution
  - Other Forms of Lithography

Basic Processes in Microfabrication



An Introduction to Microelectromechanical
Systems Engineering, N. Maluf, Artech House, 2000.