Spring semester 2012

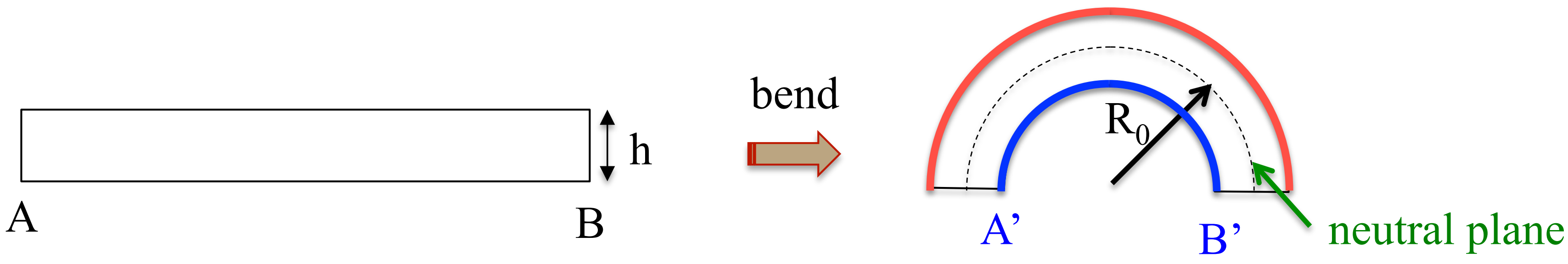
MICRO-514
Flexible electronics

Lecture 3
Mechanical concepts (cont.)
Wednesdays, 8am to 10am
BM 5202

Outline

- Bending strain
- Minimizing the strain in the electronic strack
- Typical mechanical failure

Mechanical strain



$$surface\ bending\ strain = \varepsilon = \frac{A'B' - AB}{AB}$$

$$\boxed{\varepsilon = \frac{(R-h/2)d\Theta - Rd\Theta}{Rd\Theta} = -\frac{h}{2R}}$$

“Bending stiffness” ≈ E · t

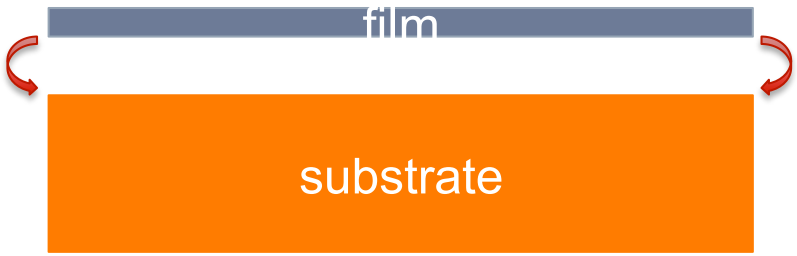
- Glass substrate
  - $E_G \times t_G$ = 100GPa x 100µm = 10^7 N.m
- Polyimide substrate
  - $E_{PI} \times t_{PI}$ = 5GPa x 50µm = $2.5.10^5$ N.m
- Silicon film
  - $E_{Si} \times t_{Si}$ = 250GPa x 100nm = $2.5.10^4$ N.m
- Silicone rubber
  - $E_{PDMS} \times t_{PDMS}$ = 1MPa x 100µm = 100 N.m

÷1000

÷10

÷0.01

Bending stiffness



Young's modulus, thickness

Film: E_f, d_f

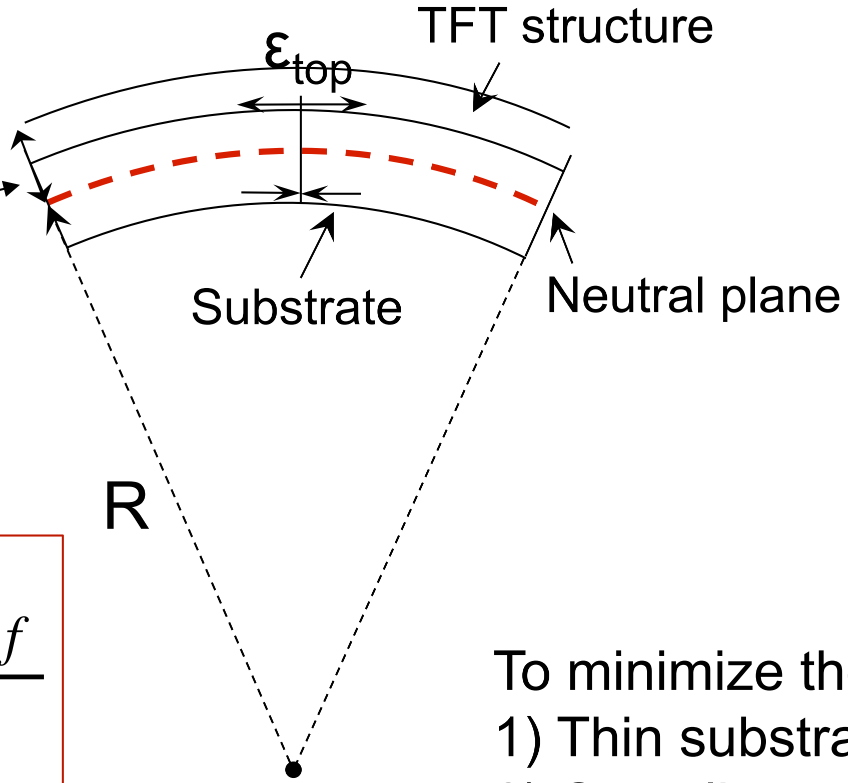
Substrate: E_s, d_s

$E_f \cdot d_f << E_s \cdot d_s$	The substrate dominates; The film complies with it.	Ex. Film on glass
$E_f \cdot d_f \approx E_s \cdot d_s$	Equal strength of film and substrate	Ex. Film on plastic
$E_f \cdot d_f >> E_s \cdot d_s$	The film dominates, The substrate complies with it	Ex. Film on rubber

Bending a film-on-substrate stack

Stiff substrates $E_f \cdot d_f << E_s \cdot d_s$ *(often $d_f << d_s$)*

Distance from top to neutral plane $d = \dfrac{d_f + d_s}{2}$



$$\boxed{\varepsilon_{top} = \frac{d}{2R} = \frac{d_s + d_f}{2R}}$$

To minimize the strain use:

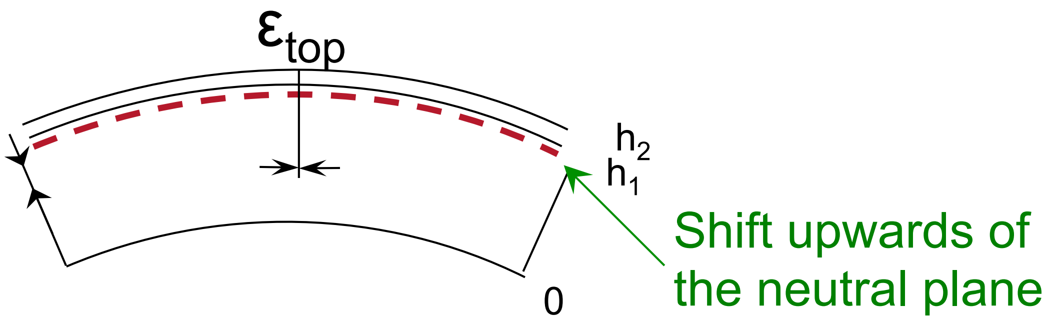
1) Thin substrate
2) Compliant substrate
3) Encapsulation

Bending a film-on-substrate stack

Compliant substrates $E_f \cdot d_f \approx E_s \cdot d_s$

Distance from top
to neutral plane

$$d < \frac{d_f + d_s}{2}$$



In pure bending mode, the neutral plane is located at the "weighted average" of the mid-points of each layer

mid-point of each layer $$h_{mi} = \frac{h_i + h_{i+1}}{2} = h_i - \frac{d_i}{2}$$

Z. Suo et al, 1999, Applied Physics Letters, 74 8, 1177-1179.

Strain at the top surface

- Case: Thin film f bonded to substrate s

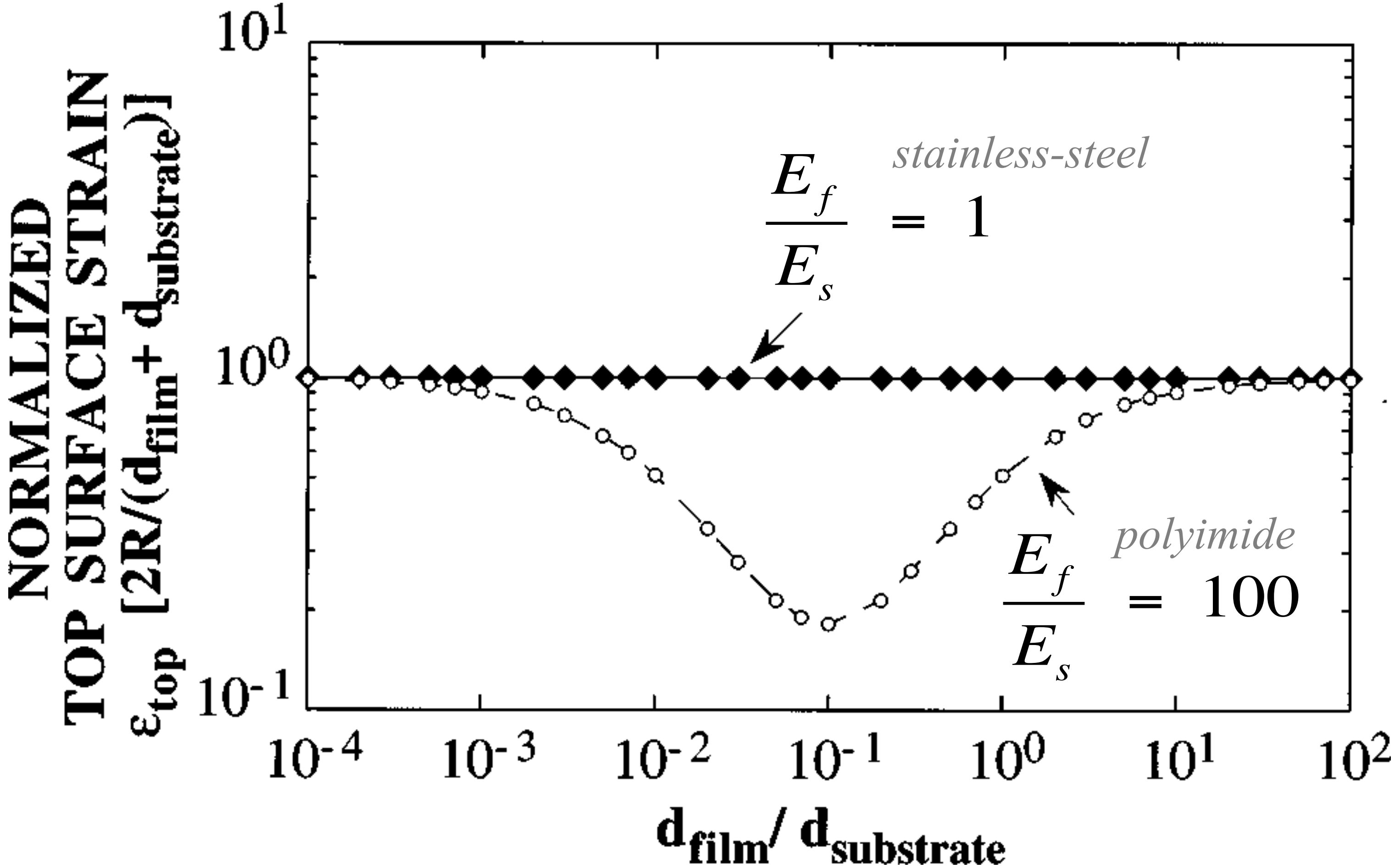
$$\boxed{\varepsilon_{top} = \left(\frac{d_s + d_f}{2R}\right)\frac{1+2\eta+\chi\eta^2}{(1+\eta)(1+\chi\eta)}}$$

with $\eta = d_f / d_s$
$\chi = E_s / E_f$

Z. Suo et al, 1999, Applied Physics Letters, 74 8, 1177-1179.

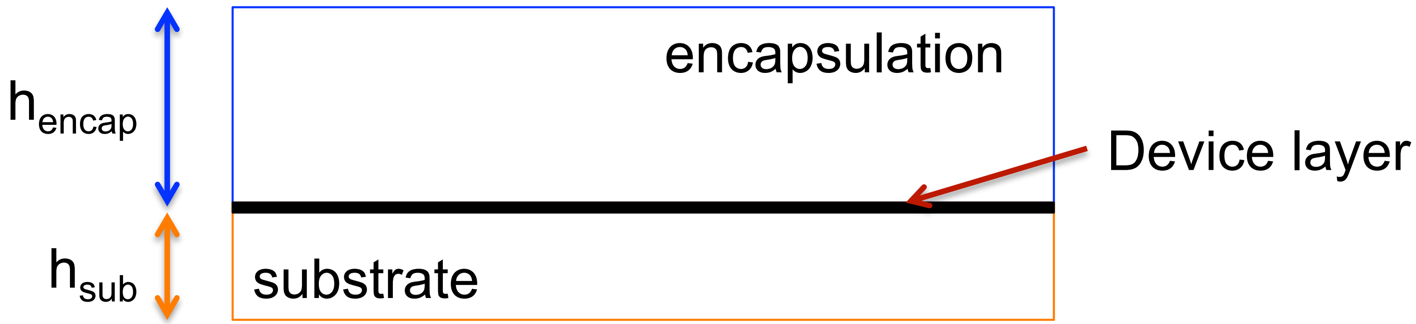
Film on compliant substrate

Strain in the film as a function of film/substrate thickness ratio



Z. Suo et al, 1999, Applied Physics Letters, 74 8, 1177-1179.

Placing devices in the neutral plane

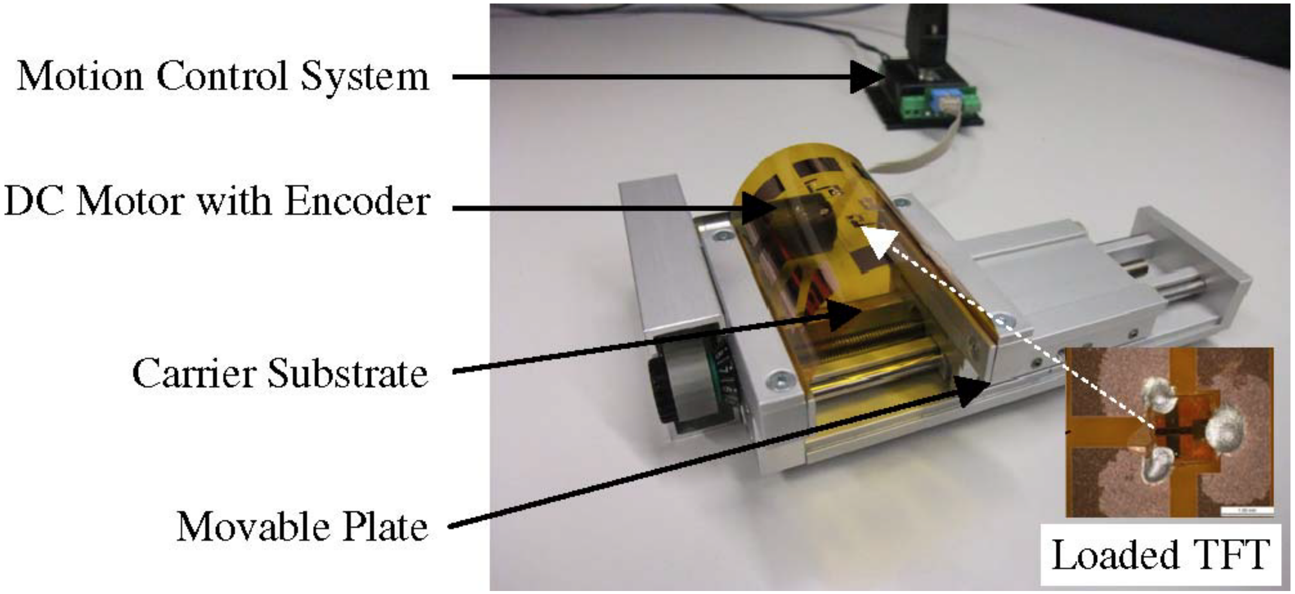


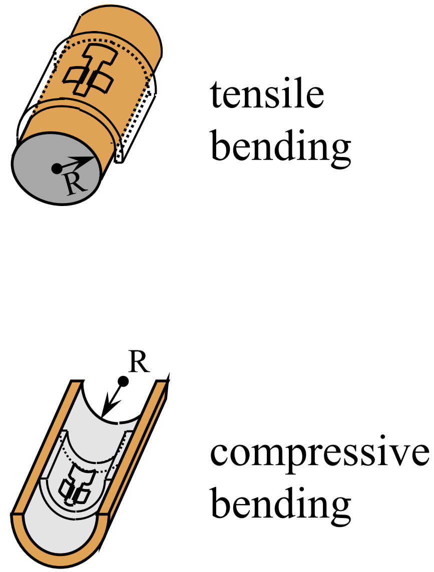
When the stiffness of the circuit is negligible, the circuit comes to lie in the neutral surface if

$$E_{sub} \cdot h_{sub}^2 = E_{encap} \cdot h_{encap}^2$$

Bending experiments

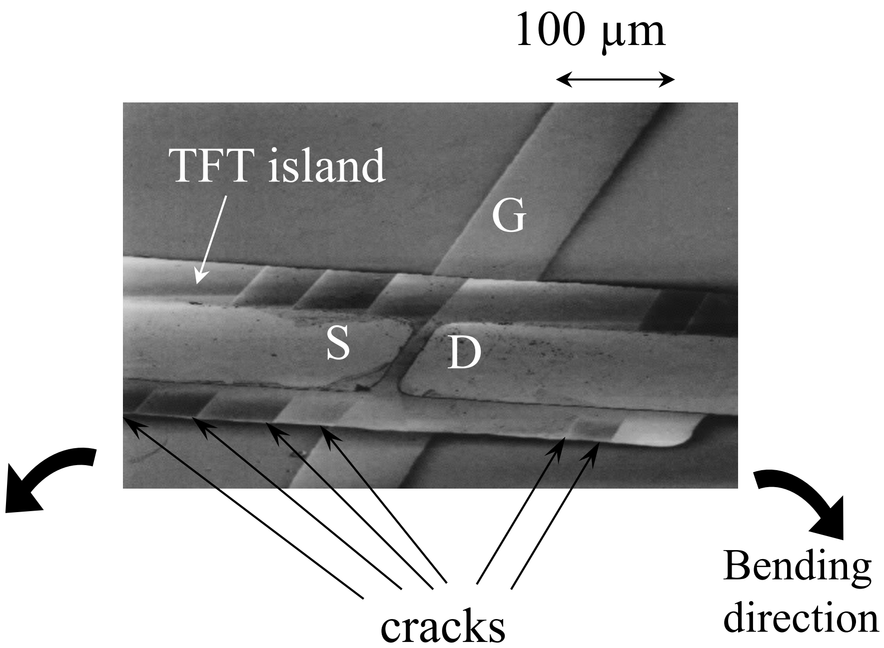
- Thin Film Transistor (TFT) on foil probed during bending
- The uniaxial strain in the TFT depends on the bending radius R





K. Cherenack et al, 2010, IEEE Electron Device Letters, 31 11, 1254-1256.

Mechanical failure at large strain

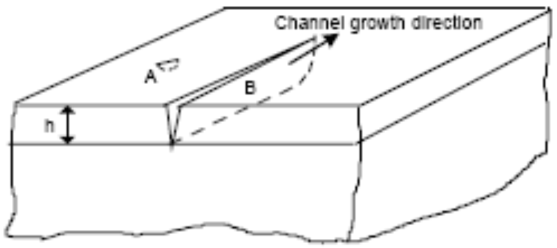


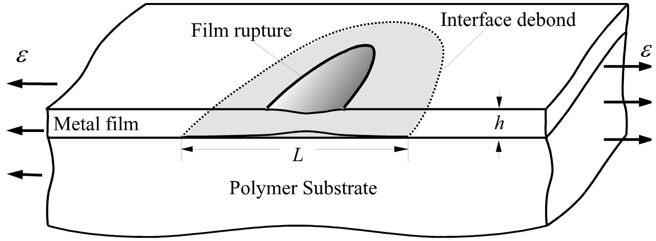
Tensile strain: **fracture** of the thin films at ~ **0.5%** strain (2mm = R)

H. Gleskova et al, 1999, Applied Physics Letters, 75 19, 3011-3013.

Mechanical failure in thin films of device materials

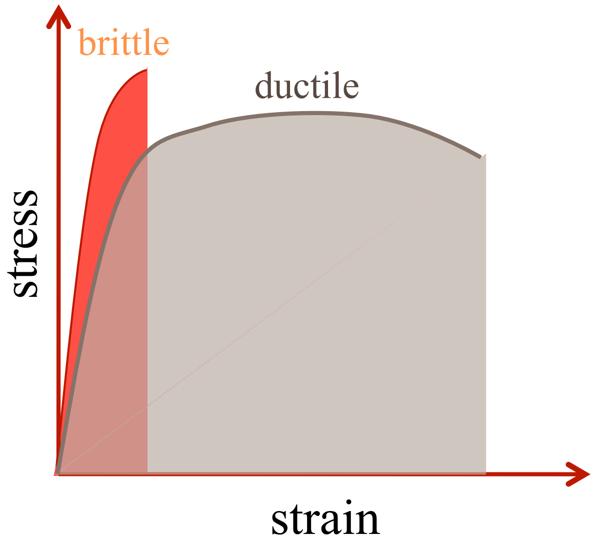
- Brittle behaviour
- Ductile behaviour





Crack propagates

- Semiconductors
- Dielectrics
- Metal oxides



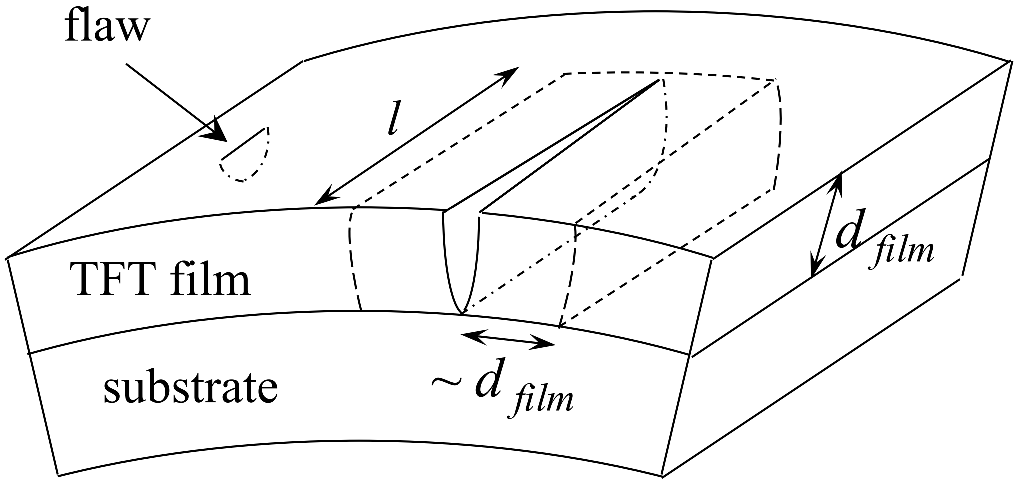
Film necks

- Metals

Z. Suo, Harvard University,
http://www.seas.harvard.edu/suo/

Fracture mechanism under tension

- Crack formation starts at a pre-existing flaw
- The top surface of the TFT film withstands the highest strain

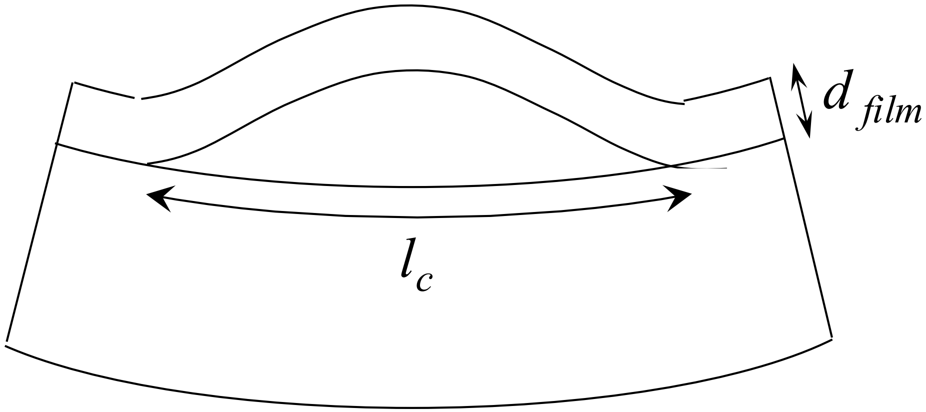


⇒ Passivate surface to suppress crack initiation

H. Gleskova, Princeton University

Fracture mechanism under compression

- Crack formation starts from a pre-existing debonded area, followed by buckling



Critical unbonded length:

$$l_c = \frac{\pi \, d_{film}}{\sqrt{3\left(1-\upsilon_{film}^2\right)}} \sqrt{\frac{Y_{film}}{\sigma_{film}}}$$

For $\varepsilon = \dfrac{\sigma_{film}}{Y_{film}} \sim 0.02$

$$\boxed{l_c \sim 10 d_{film} \sim 10 \mu m}$$

⇒ Good adhesion is important

H. Gleskova, Princeton University

Summary of lecture 3

- Thin ⇒ flexible

- Maximum bending depends on the thickness and elastic modulus of the film and substrate

- Encapsulation can minimise the strain in the device layer and prevent catastrophic cracking