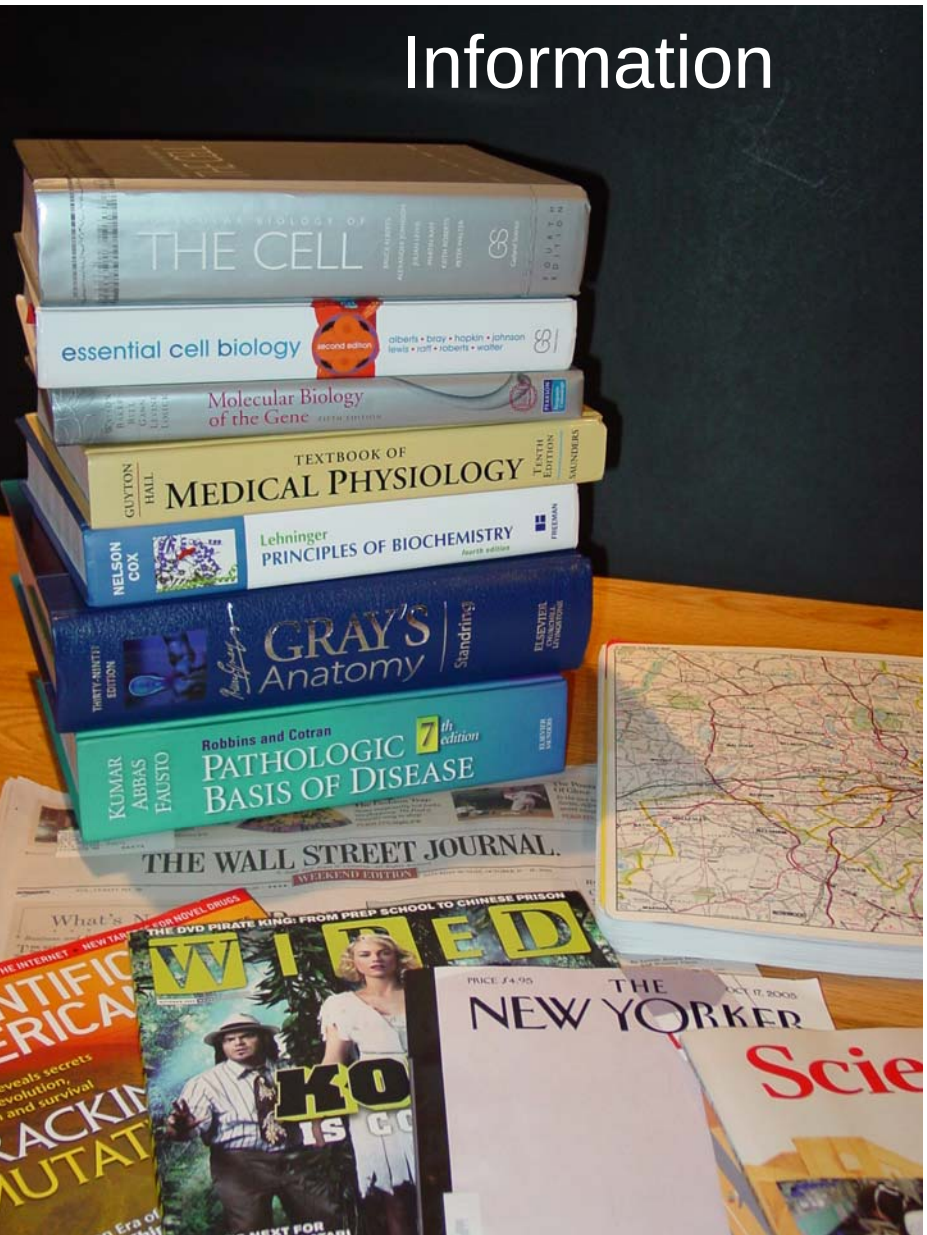
Delamination of stiff islands on stretchable substrates

Zhigang Suo

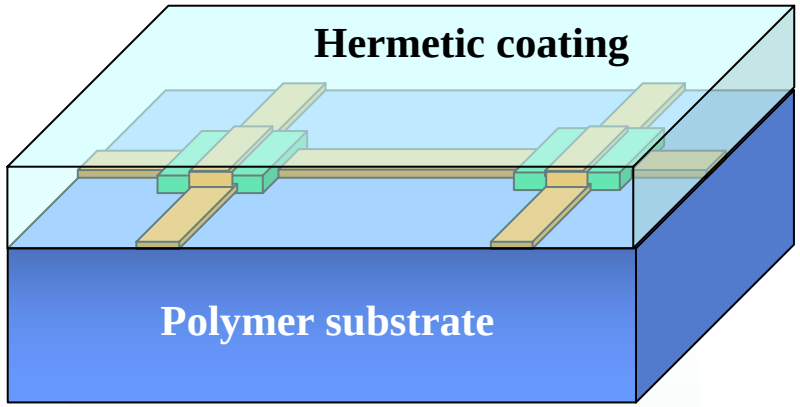
Harvard University

Lu, Yoon, Suo
Int. J. Mater. Res. 98, 717 (2007)

The future of knowledge?



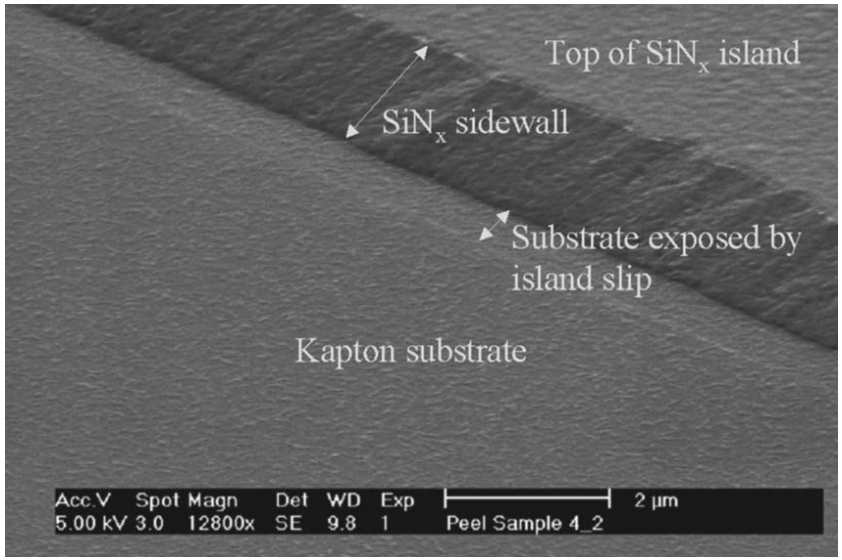
Flexible electronics

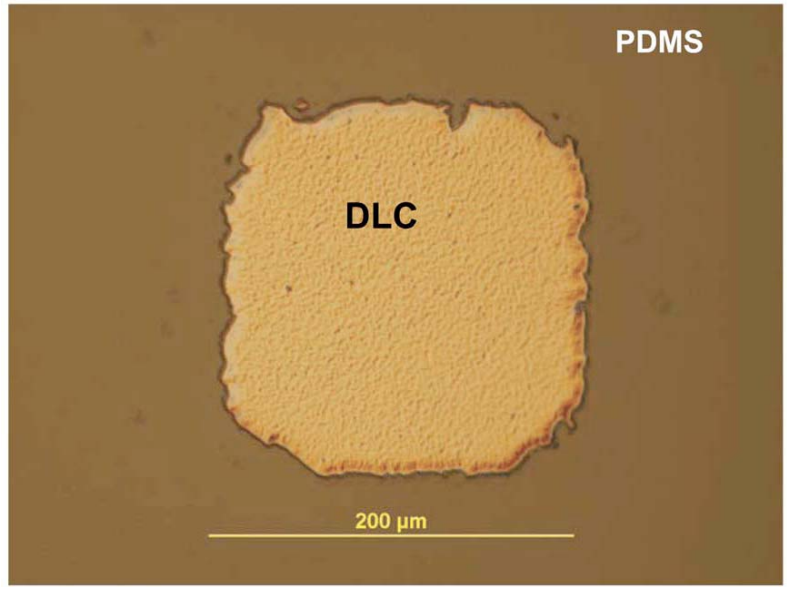


Mechanical Challenges

- Island debond
- Island crack
- Metal fatigue
- Coating crack

Island debond





$40 \times 40\ \mu m^2$ SiN_x square islands

Debond at 5.6% strain

$$\frac{E_{Kapton}}{E_{SiN_x}} = \frac{5GPa}{200GPa} = 0.025$$

Bhattacharya, Salomon & Wagner, 2006

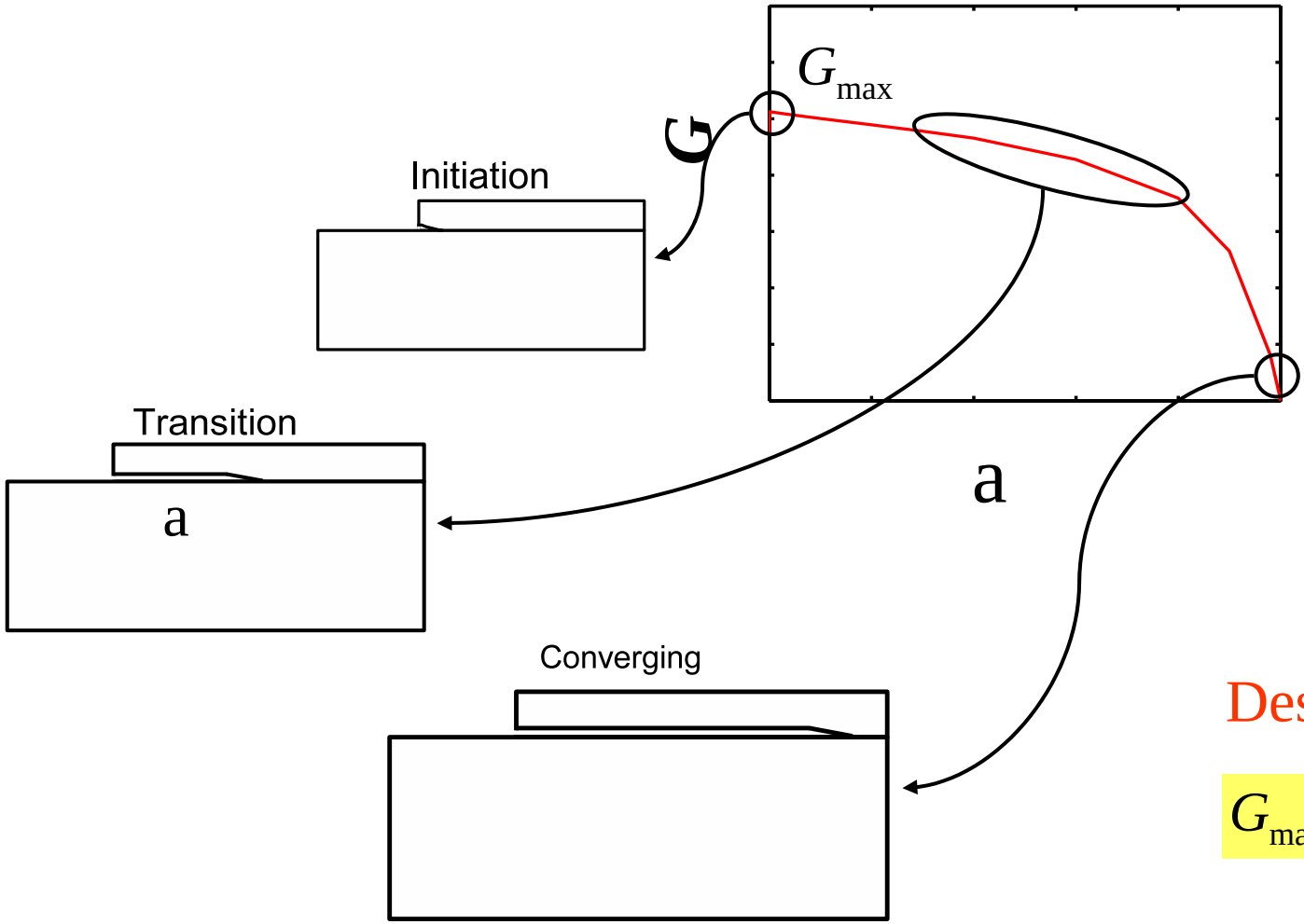
$200 \times 200\ \mu m^2$ DLC square islands

No debond at 25% strain

$$\frac{E_{PDMS}}{E_{DLC}} = \frac{1MPa}{100GPa} = 1 \times 10^{-5}$$

Lacour, Wagner, Narayan, Li, Suo, 2006

Energy release rate depends on flaw size



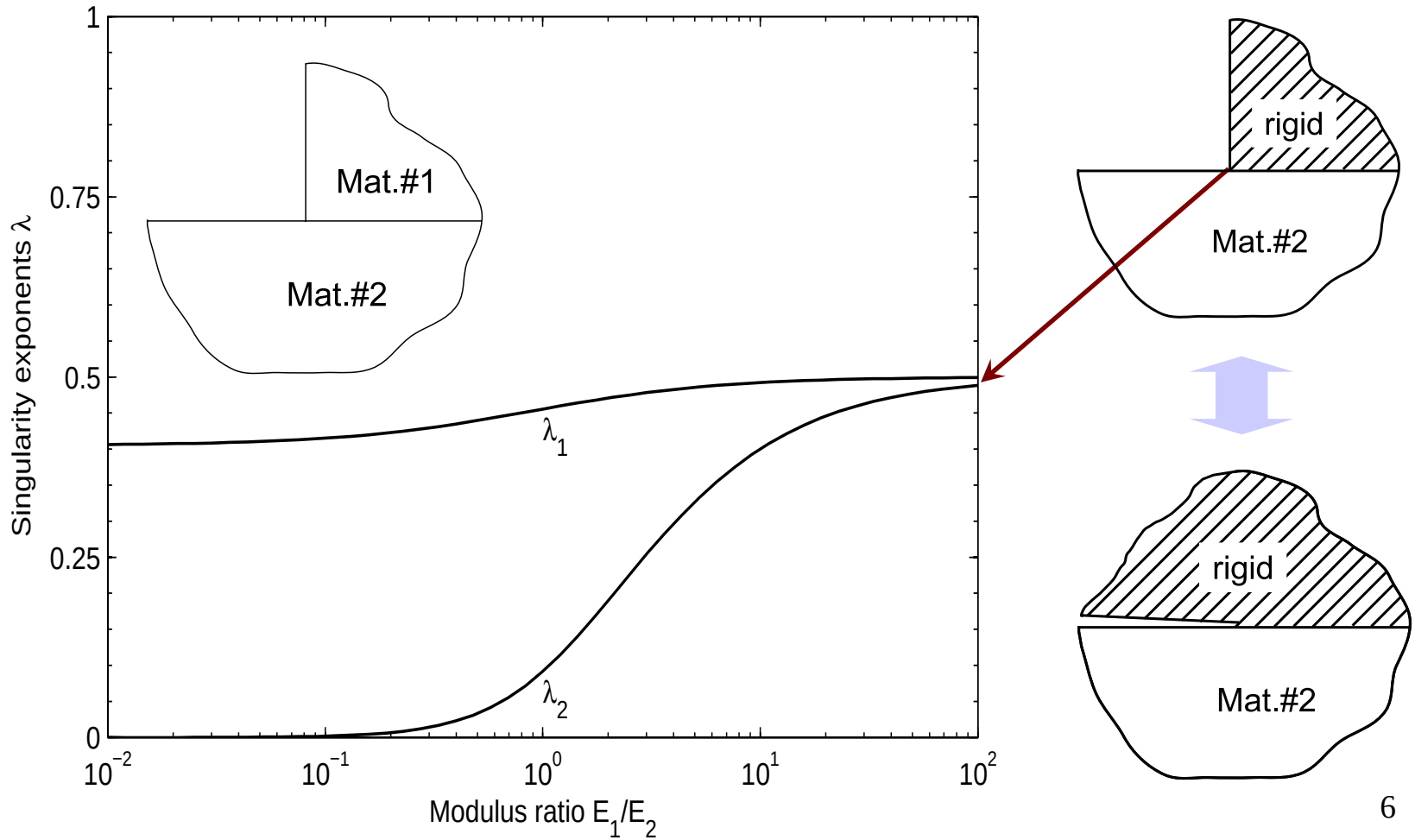
Design criterion

$$G_{max} < \Gamma$$

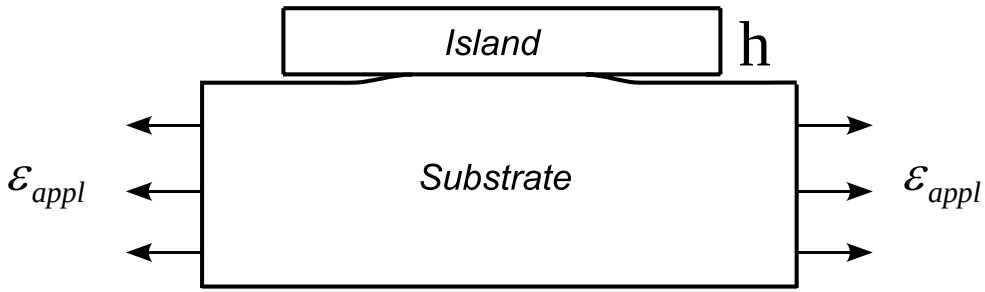
Initiation

$$\sigma_{ij}(r,\theta)=\frac{k_1}{r^{\lambda_1}}\Sigma_{ij}^{1}(\theta)+\frac{k_2}{r^{\lambda_2}}\Sigma_{ij}^{2}(\theta)$$

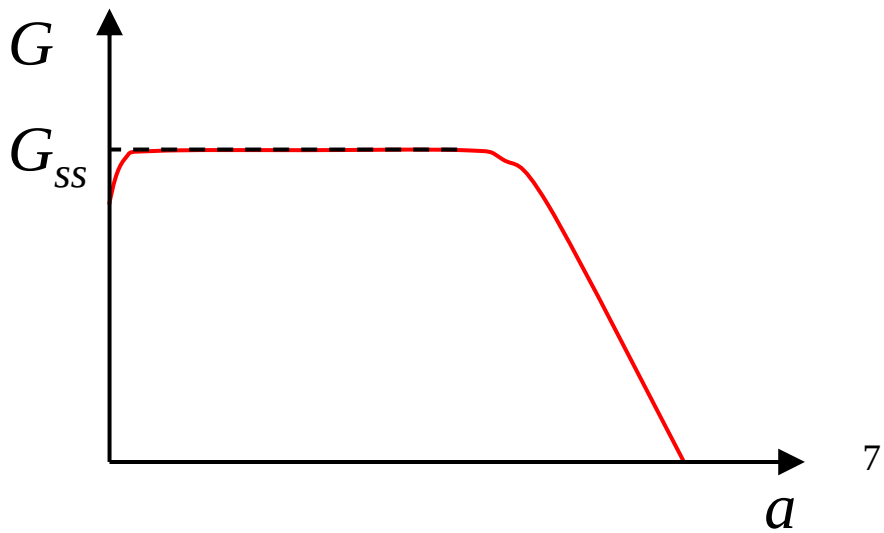
$$G \sim a^{1-2\lambda}$$



Steady state

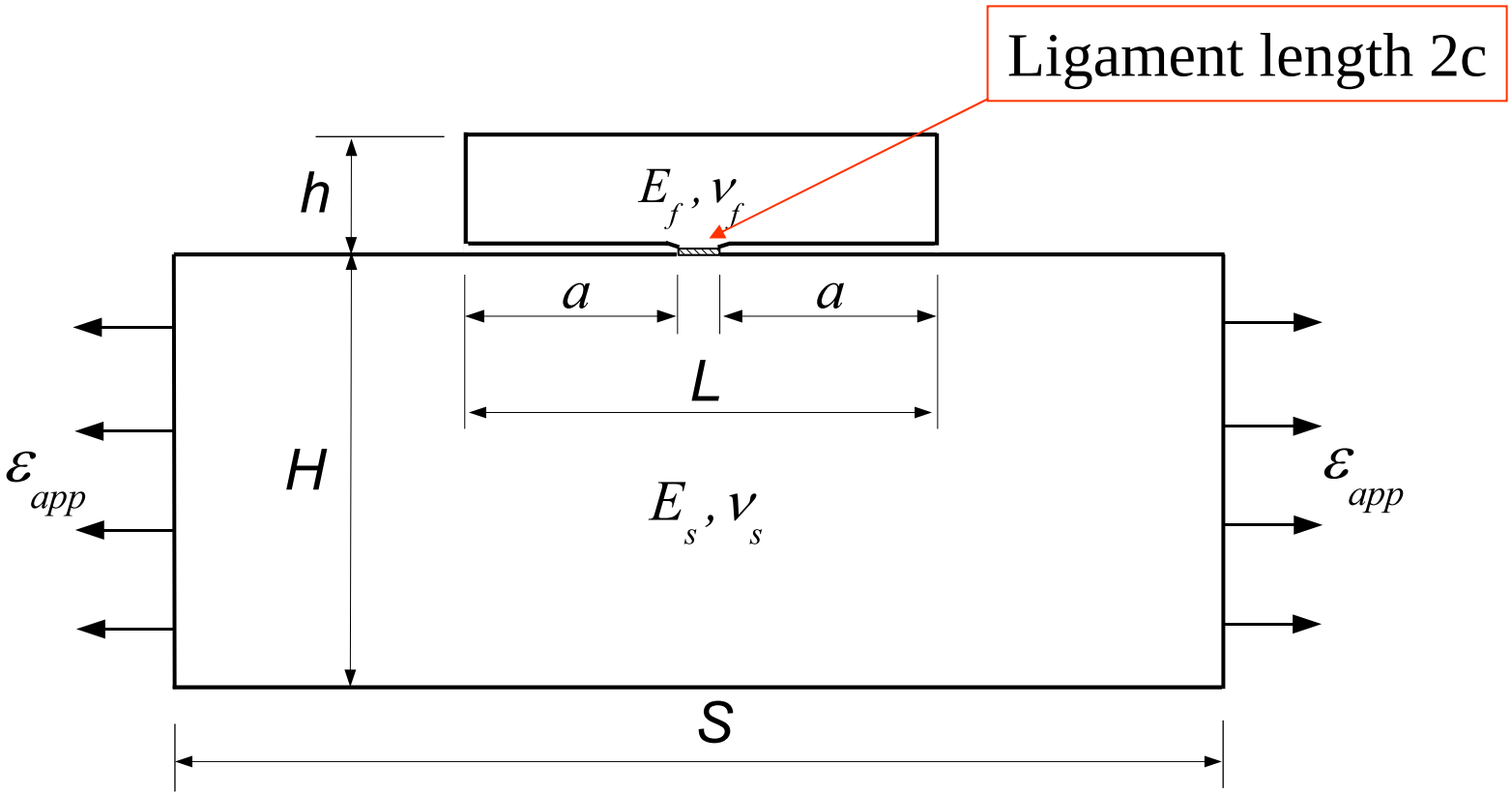


$$G_{ss} = \frac{g}{2} E_f \left(\varepsilon_{appl}\right)^2 h$$



Suo and Hutchinson, IJF (1990)

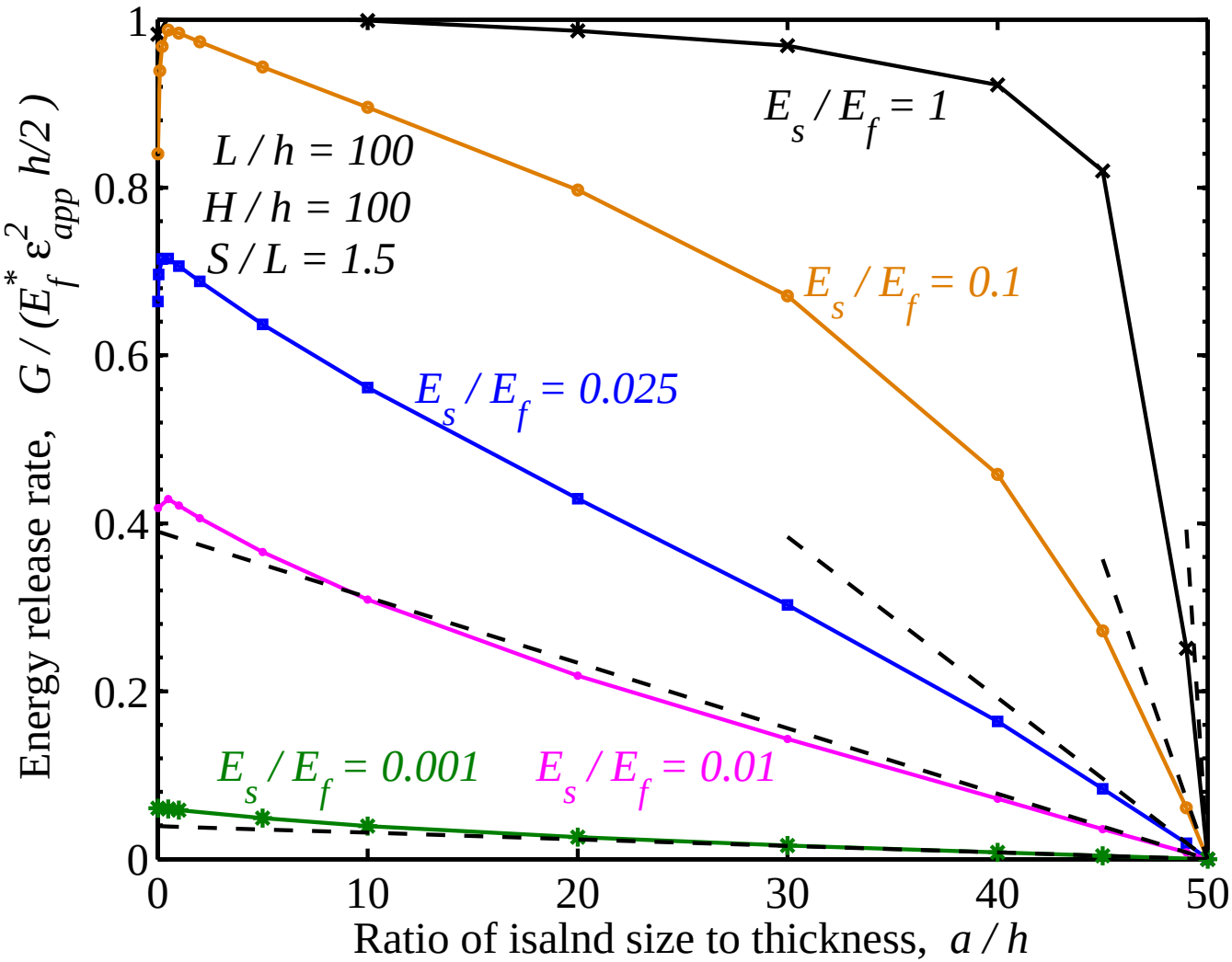
Converging debond



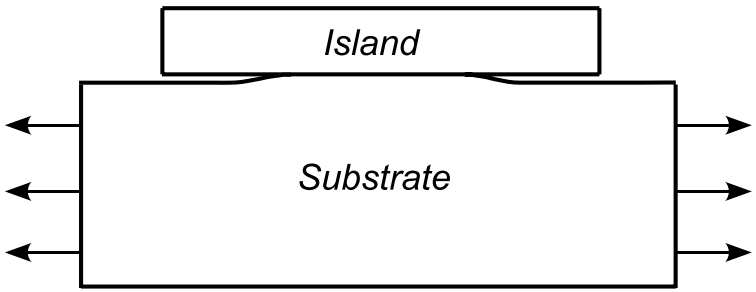
$$G = \frac{\pi}{8}\ \varepsilon_{app}^2 c \left(\frac{1}{E_s} + \frac{1}{E_f} \right)^{-1}$$

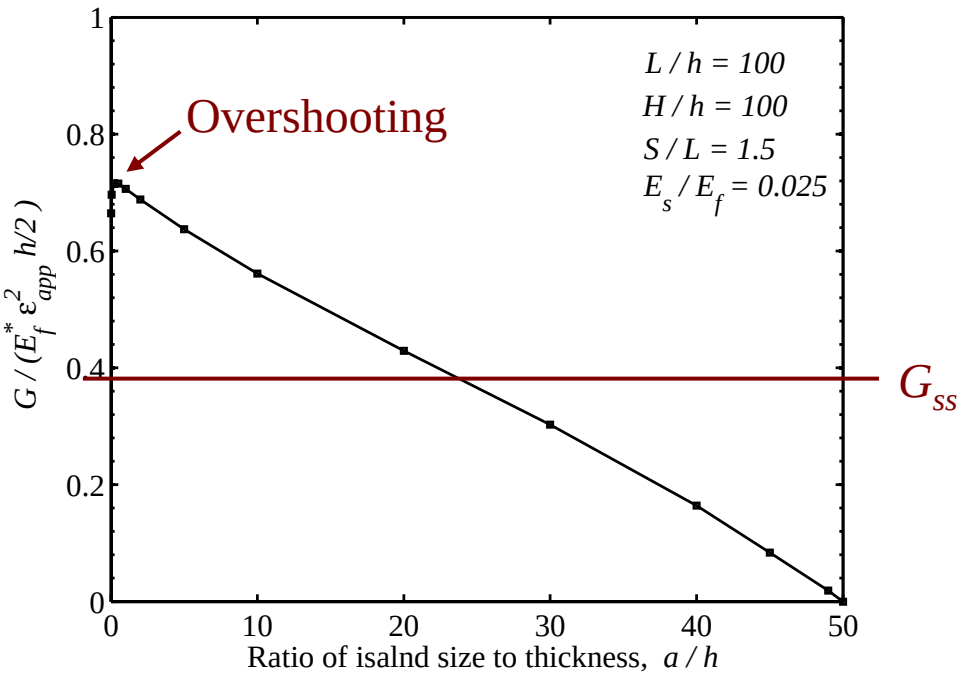
He, Evans & Hutchinson, 1996

Effect of substrate compliance on G(a)

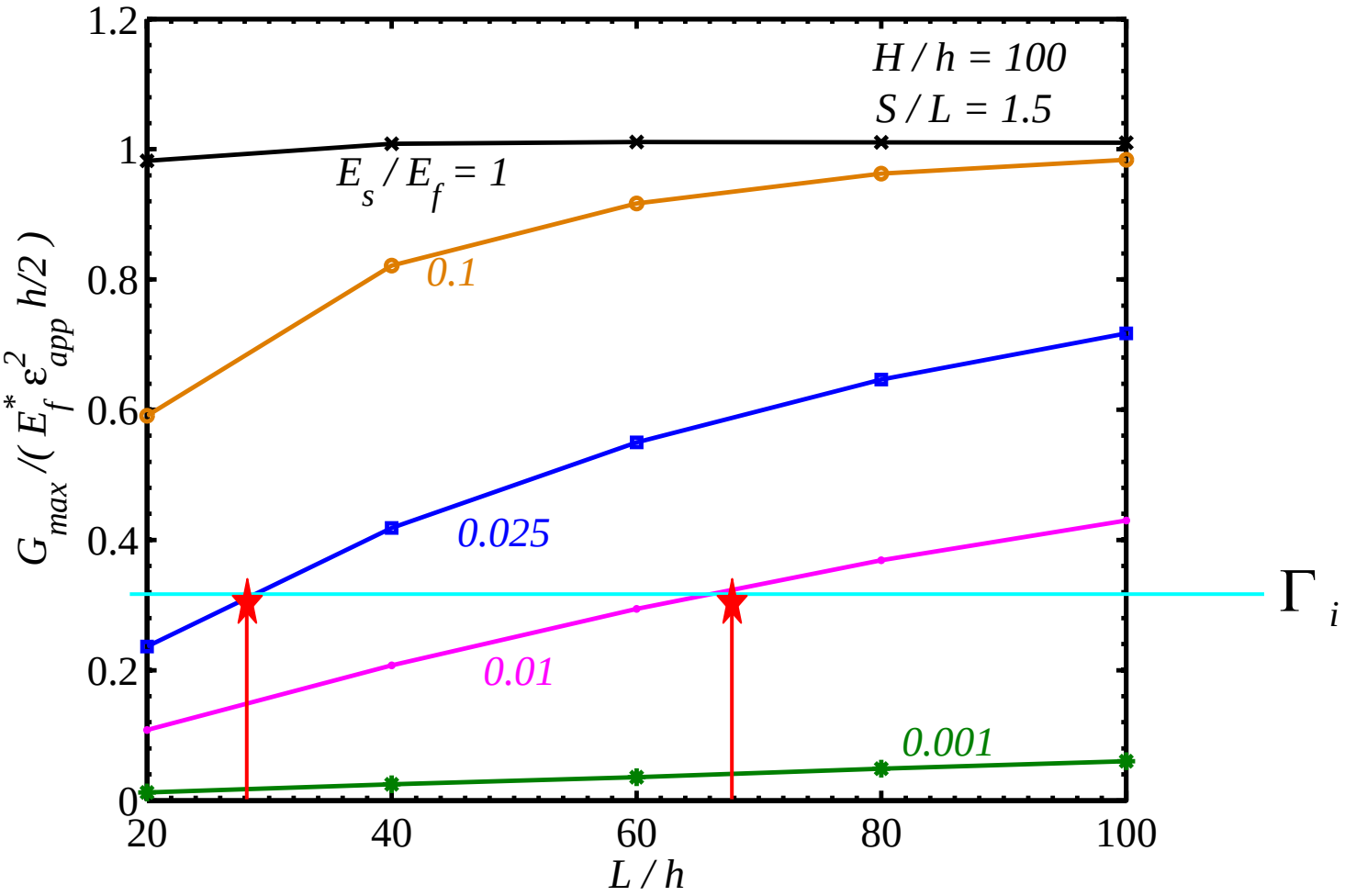


G_{max} overshoots G_{ss}





Critical island size



With the same interface toughness and the same applied strain, more compliant substrate allows larger critical island size

Summary

- Islands debond when exceeding critical size.
- G_{max} overshoots G_{ss}.
- Critical island size is large when the substrate is compliant.

Lu, Yoon, Suo, Int. J. Mater. Res. 98, 717 (2007)