EM 388F Term Paper

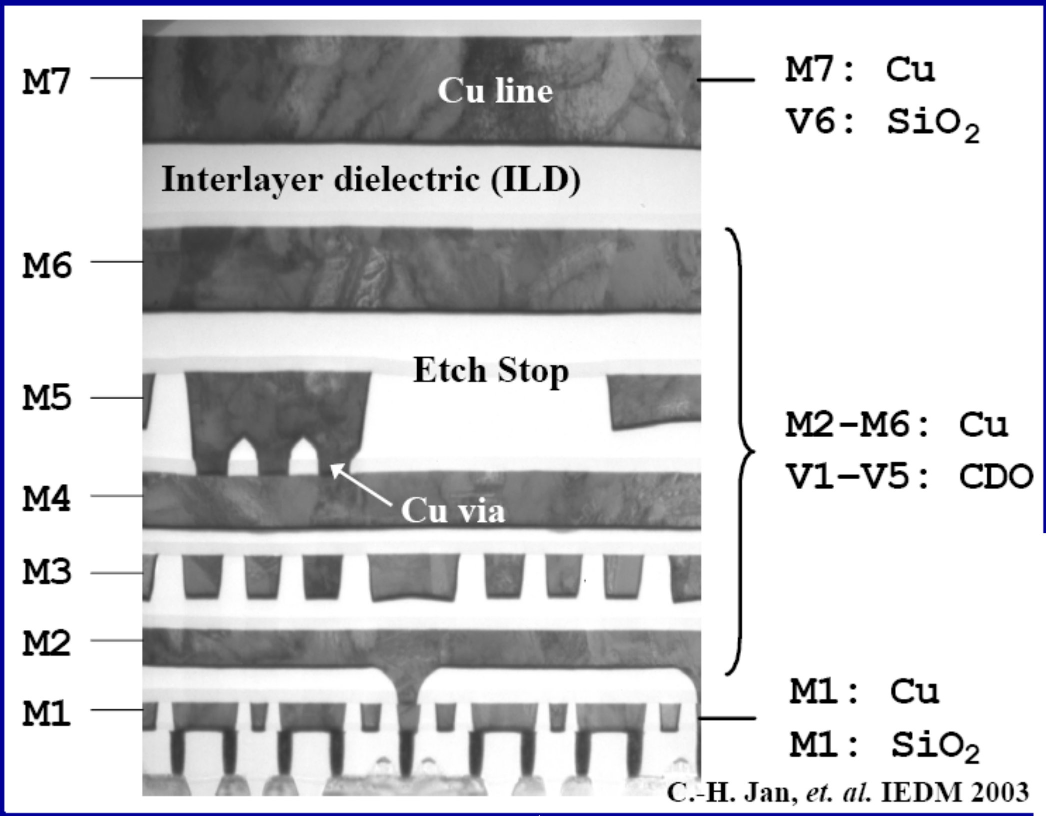
Channel Cracking in Low-K Interconnect Structures

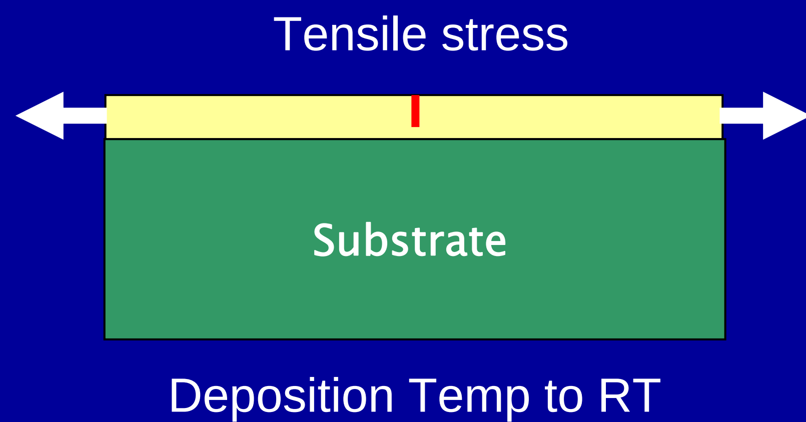
Xuefeng Zhang
Material Science & Engineering
April, 2008

Outline

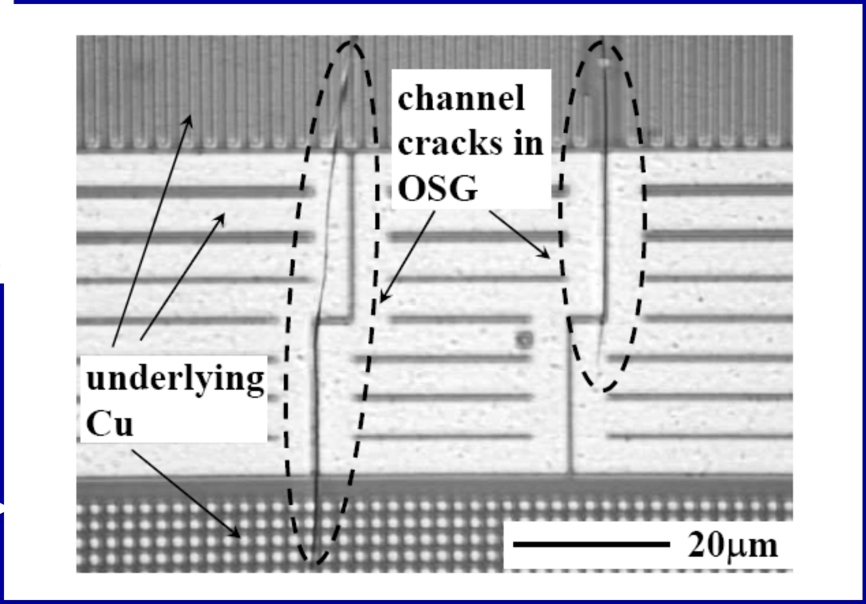
- Introduction
- Analytical analysis of channel cracking
- Experimental measurement of energy release rate
- Effect of low k film properties
  - Modulus
  - Thickness
- Effect of underlying layers on G
  - Mechanical properties
  - Thickness
  - Patterned structure
- Environmental effect on channel cracking
- Summary and reference

Introduction to Channel Cracking



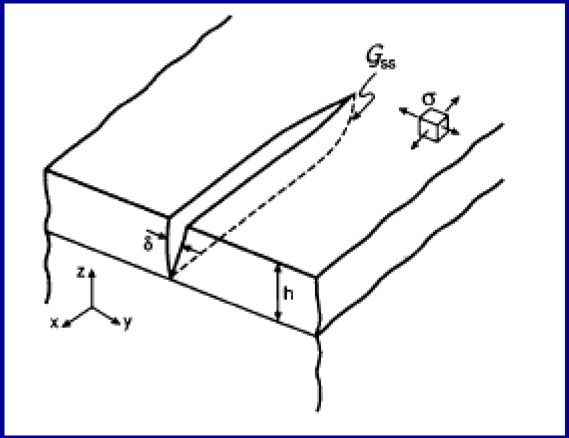


Cu/low k interconnect for 90nm



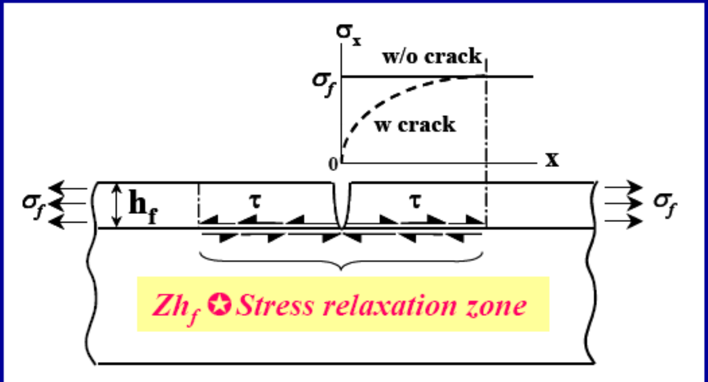
Channel cracks in organosilicate glass

Analytical Analysis of Channel Cracking



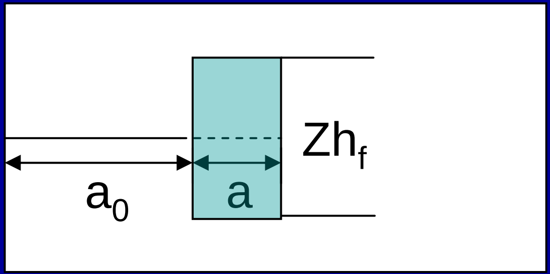
$$G_{ss} = \frac{1}{2h}\int_0^h \delta(z)\sigma(z)\,dz.$$

$\sigma(z)$ **represents the stress distribution on the crack plane before cracking.**
$\delta(z)$ **represents displacement profile for a plane strain crack**



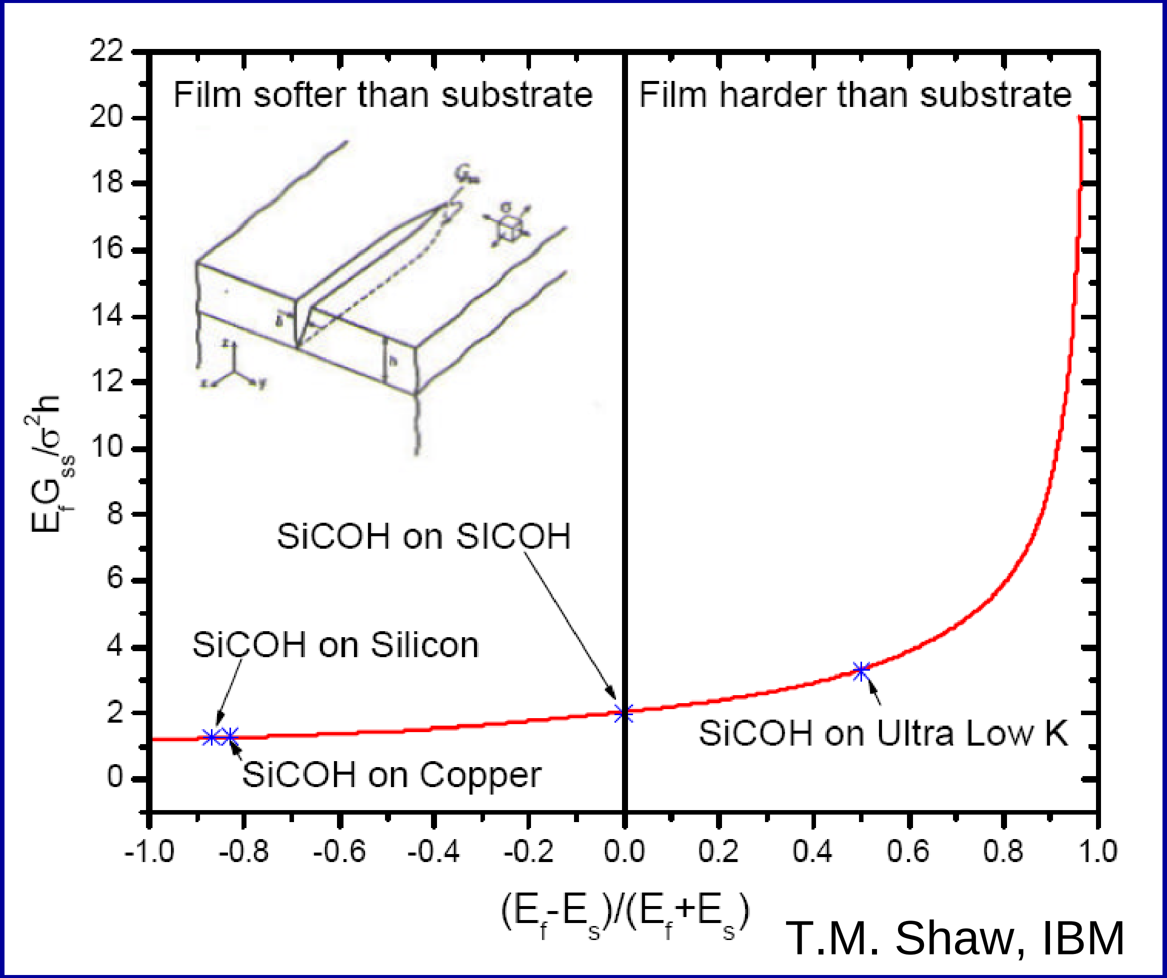
When the crack length a_o is much larger than the film thickness h, the stress field around the crack becomes invariant as the crack propagates. The volume in which the stress relaxes scales as azh^2, so the total elastic energy change is

$$\Delta U \sim \frac{ah^2\sigma^2}{E_f}$$



$$G = \frac{\Delta U}{\Delta A} = Z\frac{ah^2\sigma^2}{E_f\,ah} = Z\frac{h\ \sigma^2}{E_f}$$

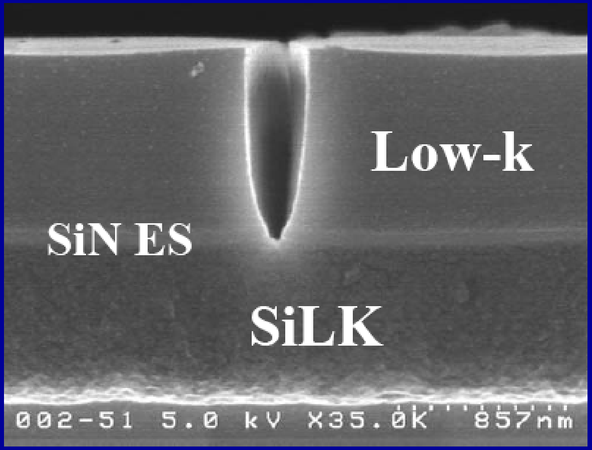
Effect of Elastic Mismatch on Z



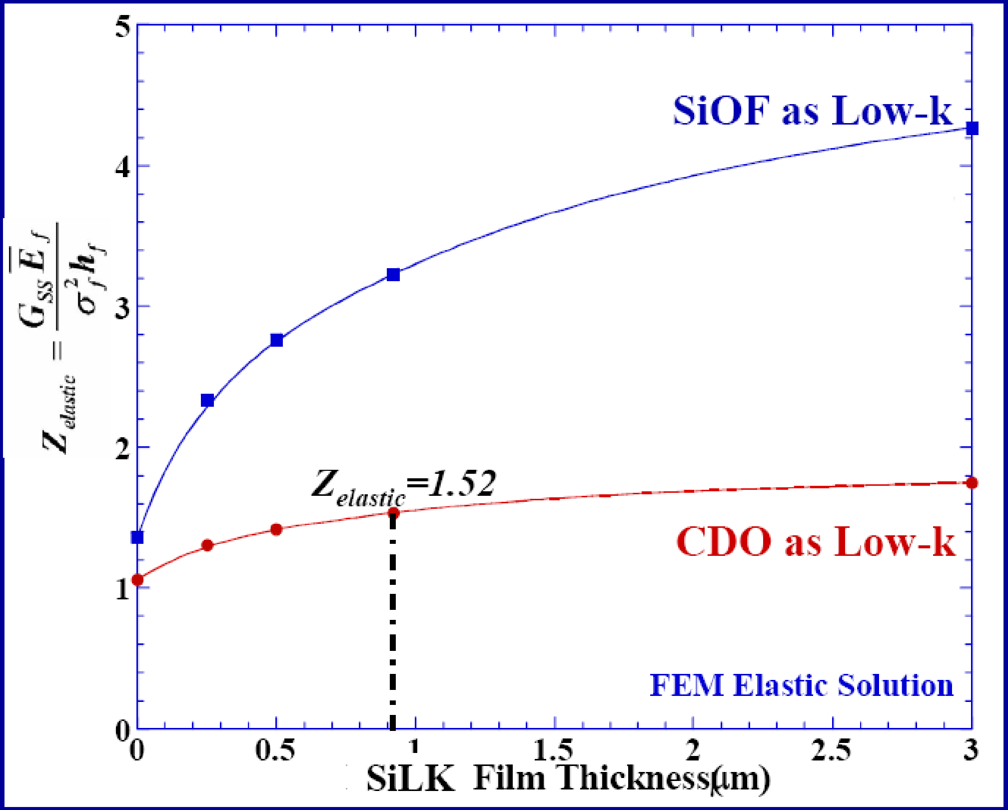
Elastic mismatch factor

- **Magnitude of Z a strong function of elastic mismatch between film and underlying substrate**
- **Plasticity in underlying substrate further increases Z**

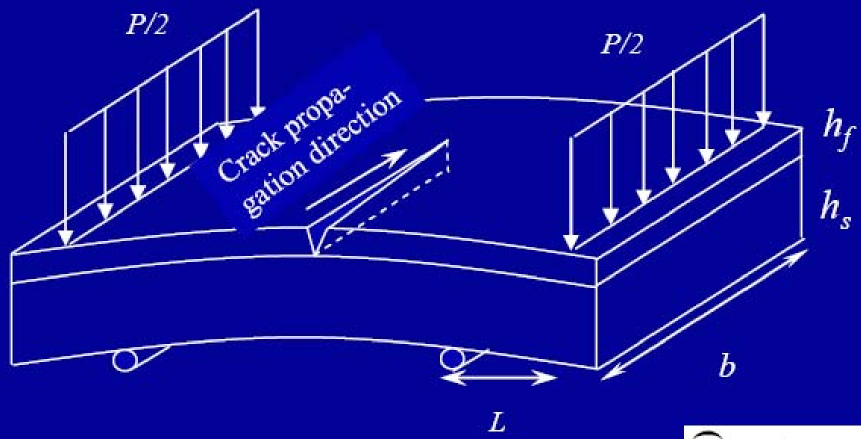
Impacts of film properties and underlying layers on Z

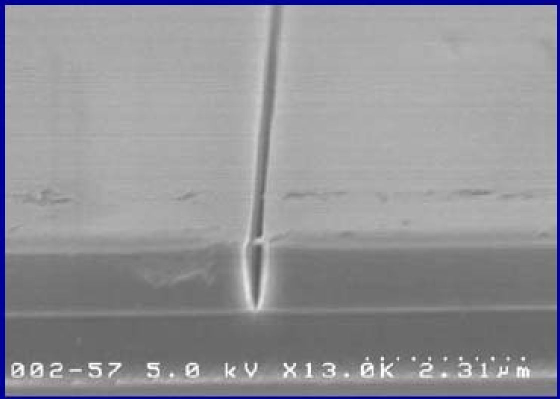


- Thin compliant underlying layer enhances Z
- Impact increase with thickness
- Enhancement saturated at film thickness ranges from 1-5 µm depends on the elastic mismatch



Channel Cracking for Characterization of CDO Fracture Behavior

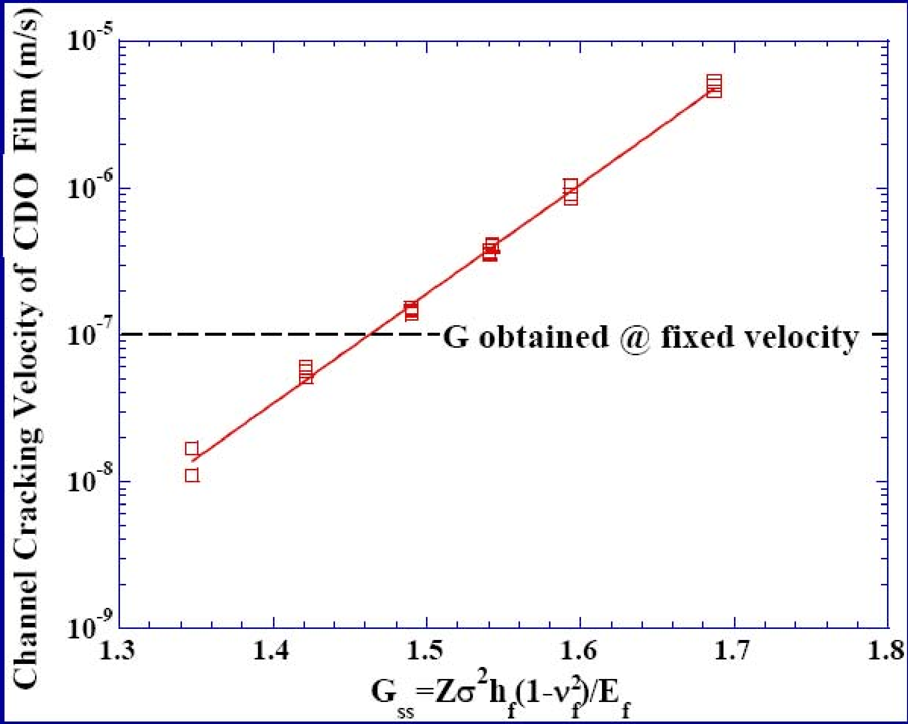




G_{ss}: steady state energy release rate

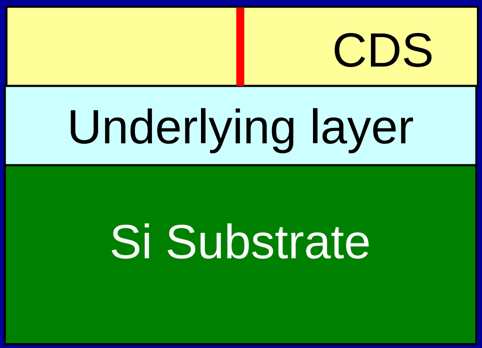
Z: depends on mechanical properties of surrounding components

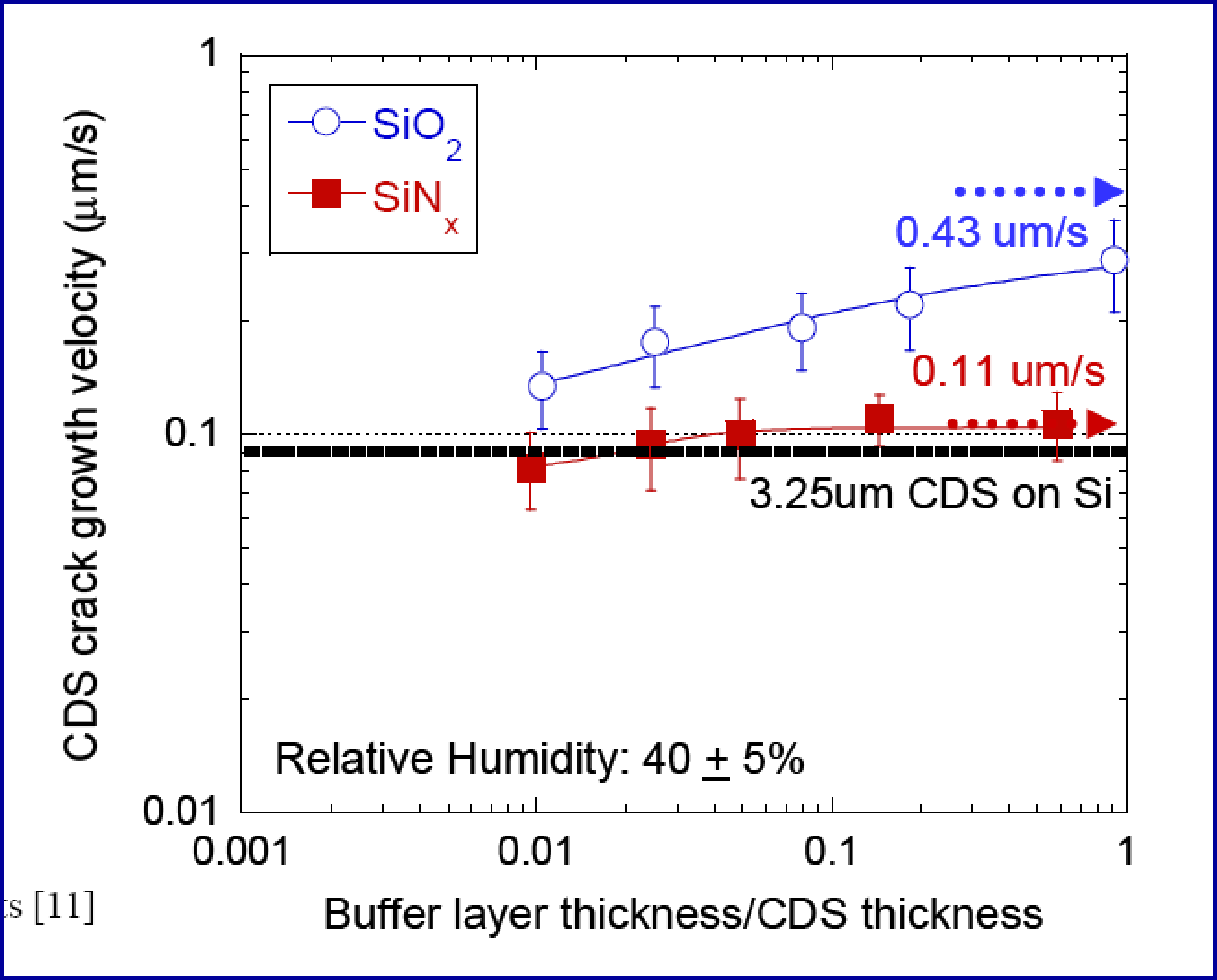
σ_f: total stress of film, including residual stress σ_0 and applied through bending



J. He and G. Xu, Intel Inc

Effect of underlying buffer layer





Comparison between different technology nodes

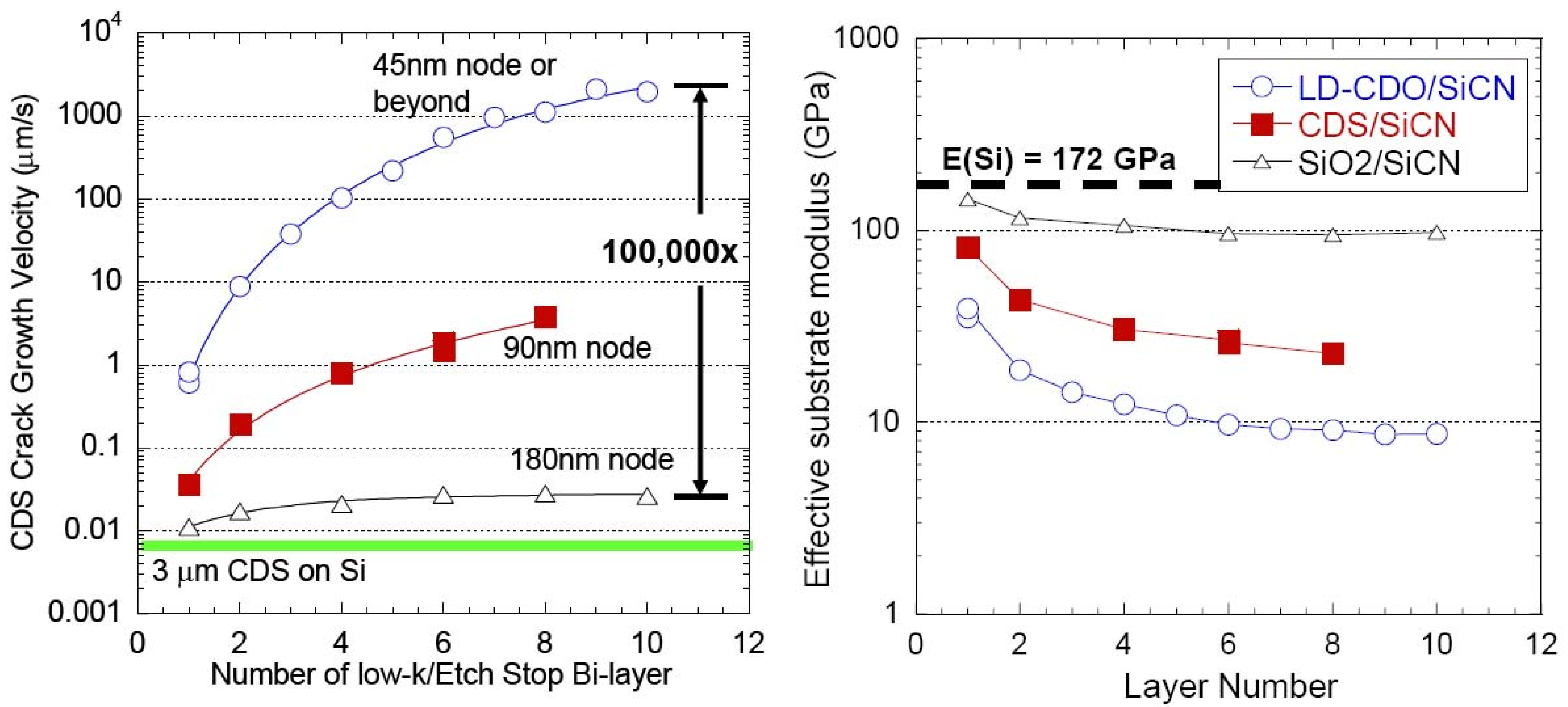
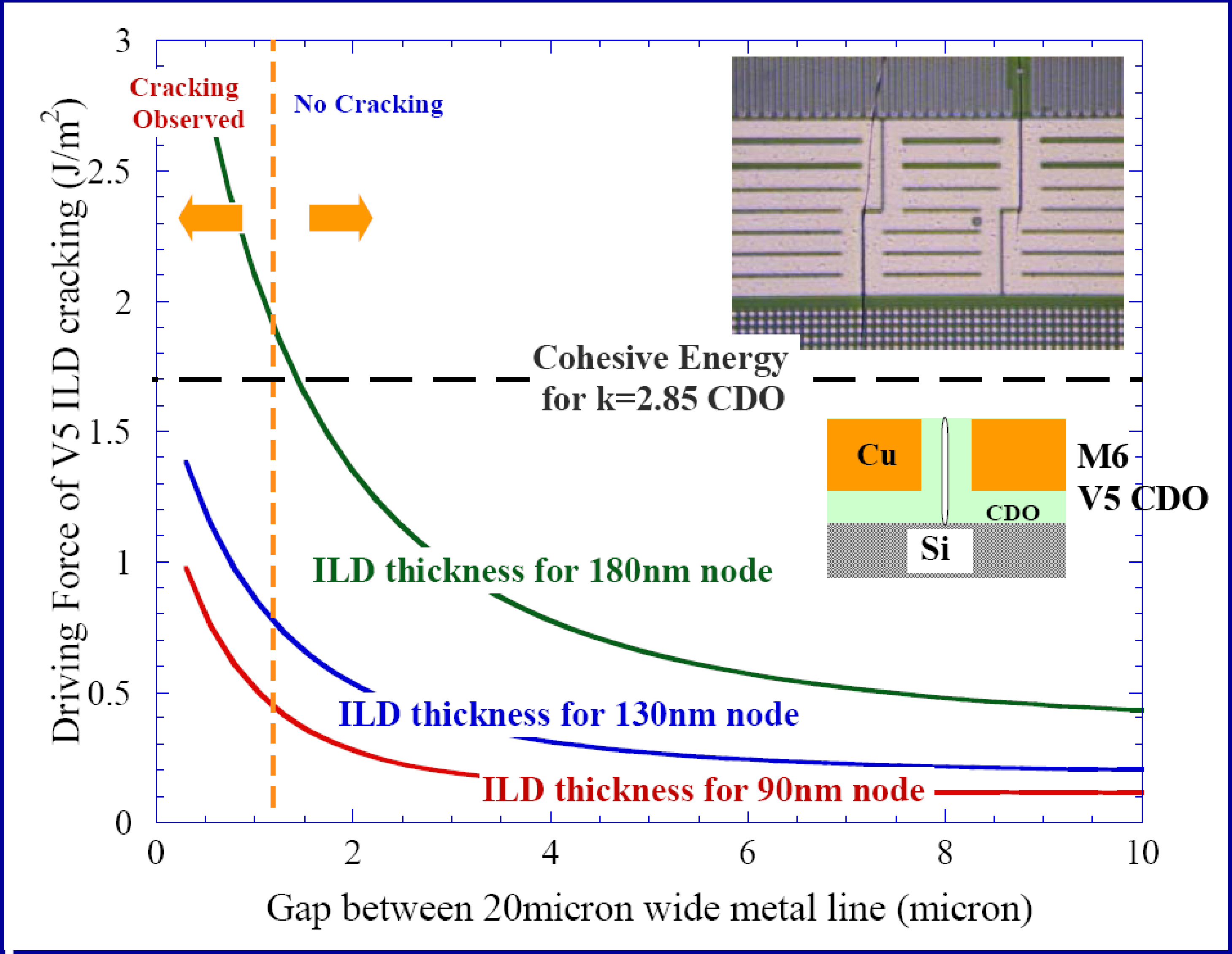


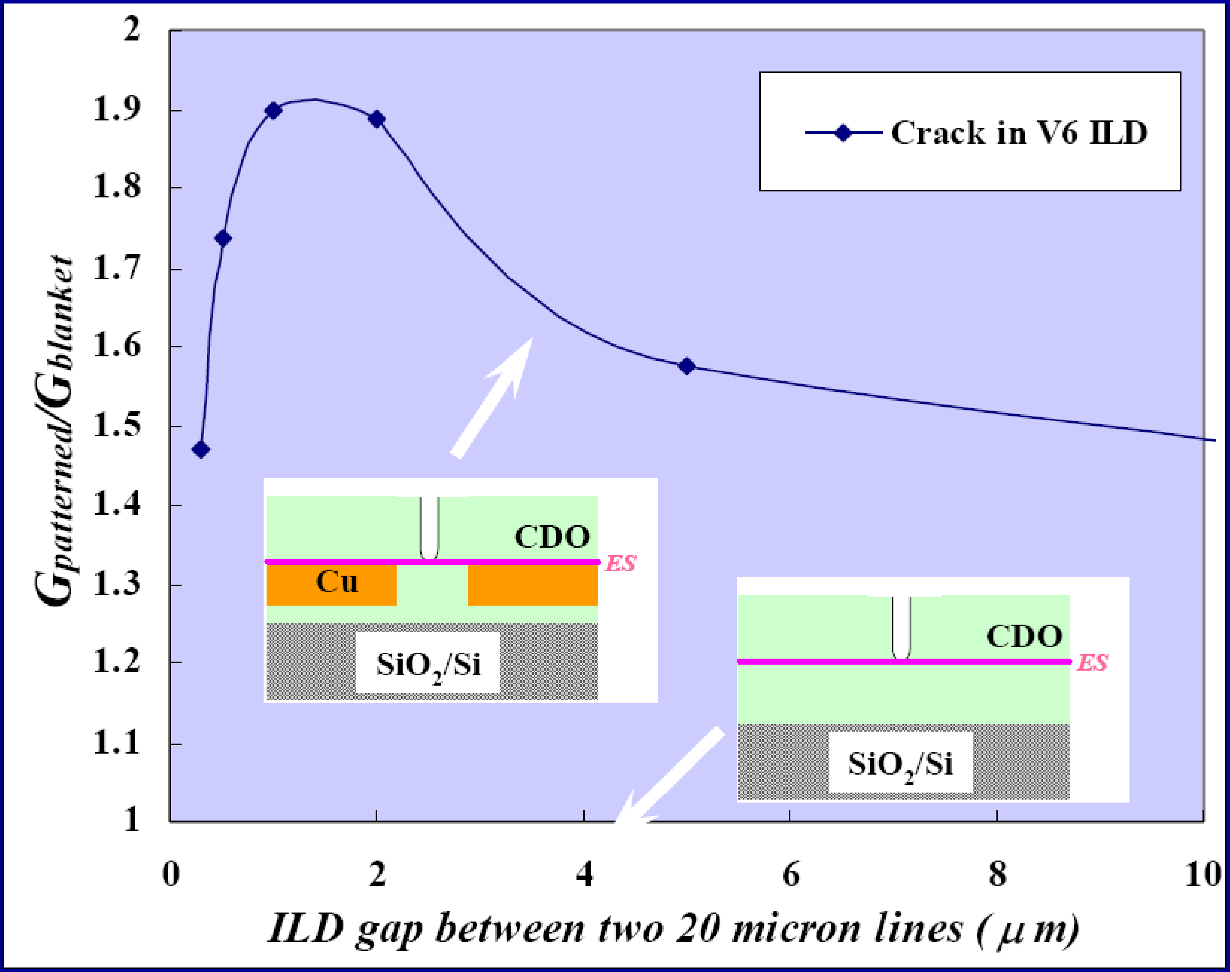
FIG. 9. CDS crack growth velocity as a function of low-k/etch stop layers.

FIG. 10. Effective substrate modulus values as a function of layer number.

Impact of Metal Pattern

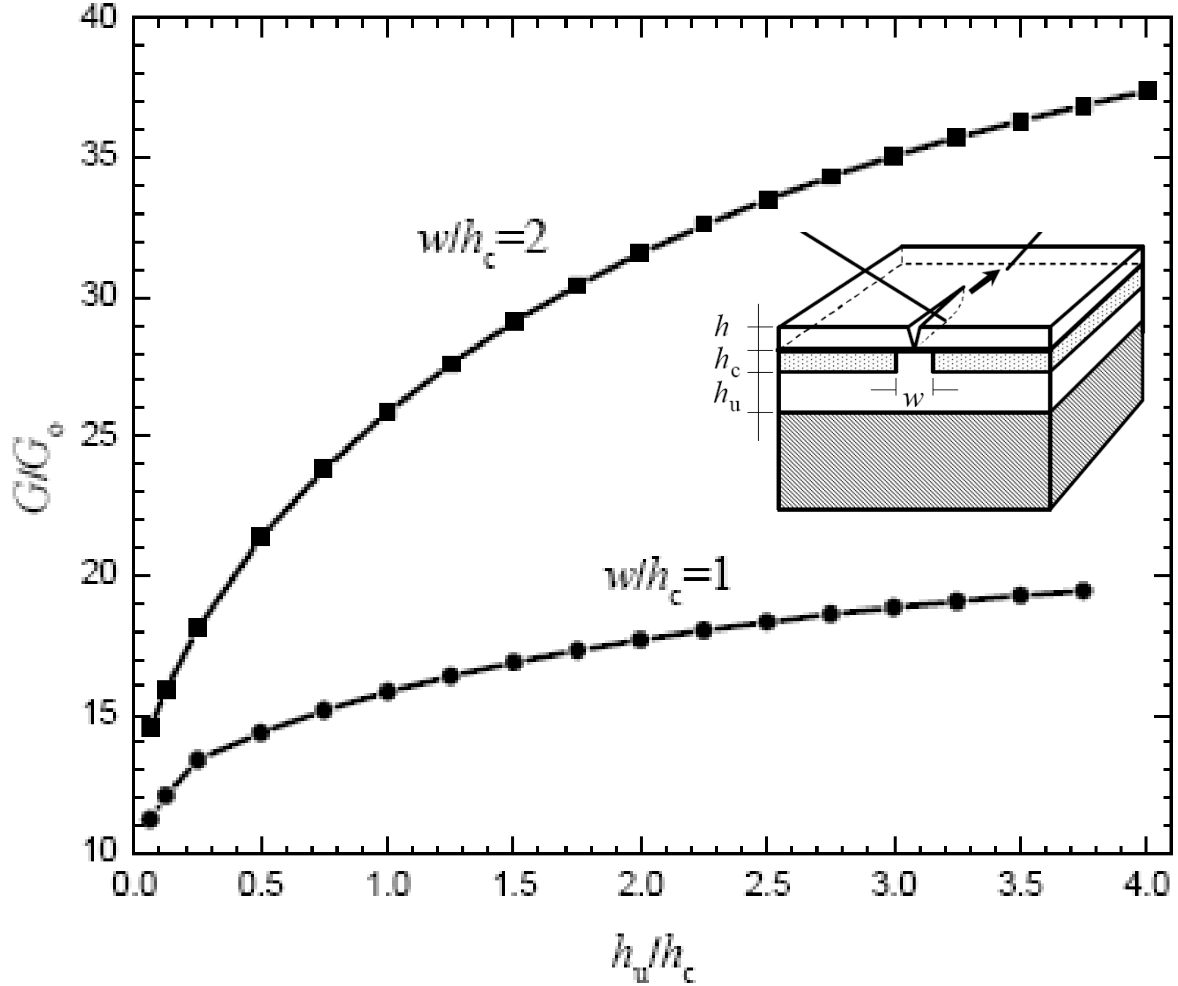


Channel Cracking on top of Patterned Structure



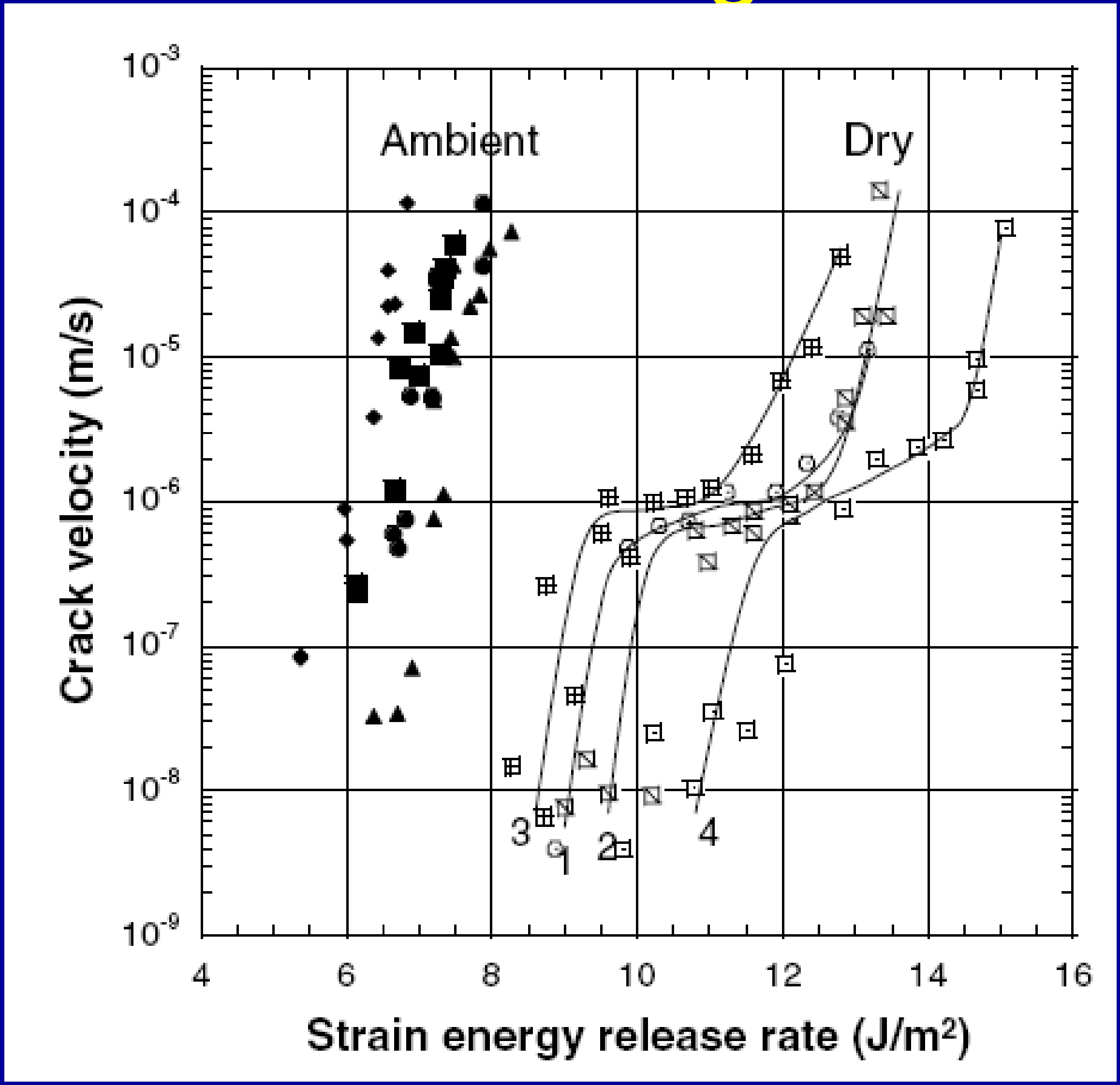
- **Driving force for channel cracking on top of narrow compliant ILD section can be higher than either of the limiting blanket film cases**

Effect of Underlying Layer Thickness



ig 3: Effects of low-k underlayer thickness on the energy release rate.

Moisture-assisted Channel Cracking in Thin Film



Region I: Reaction Control

Region II: Diffusion Control

Region III: Approach fast fracture

Moisture causes sub-critical crack growth even when k<kc

Summary and Reference

- Film mechanical properties and thickness are very important in determining the energy release rate of channel cracking
- Confinement of the thin film has huge effect on the crack driving force
- Moisture can induce subcritical crack growth in the film and degrade the fracture toughness

*[1] Hutchinson, J.W. and Suo, Z. (1991). Advances in Applied Mechanics **29**, 63–191.*

[2] J. He, G. Xu*, and Z. Suo, Stress Workshop, 2004*

[3] X. H. Liu, Z. Suo, Q. Ma and H. Fujimoto, Eng. Fract. Mech., 66, 387–402.

[4] Ting Y. Tsui, etc., Mater. Res. Soc. Symp. Proc. Vol. 863, 2005

[5]K.W. McElhaney, Q. Ma, Acta Materialia 52 (2004) 3621–3629