Cohesive Strength Characterization of Brittle Low-K Films

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Introduction-Motivation

- TM Characterization challenge
  - Mature techniques available for hardness, modulus (indentation) and adhesion (4 point bending).
  - Thin film cracking is an important reliability problem.
    - New porous and low k ILDs are very susceptible to cracking
    - Tensile residual stress compare to compressive stress of conventional SiO_2, SiOF.
  - Need a technique to quantity cohesive energy and critical thickness for cracking.
    - At early development stage thin blanket films are often the only ones available.
    - Failure criteria for material screening / selection.
    - Need quick turn measurements for process improvement and monitor.

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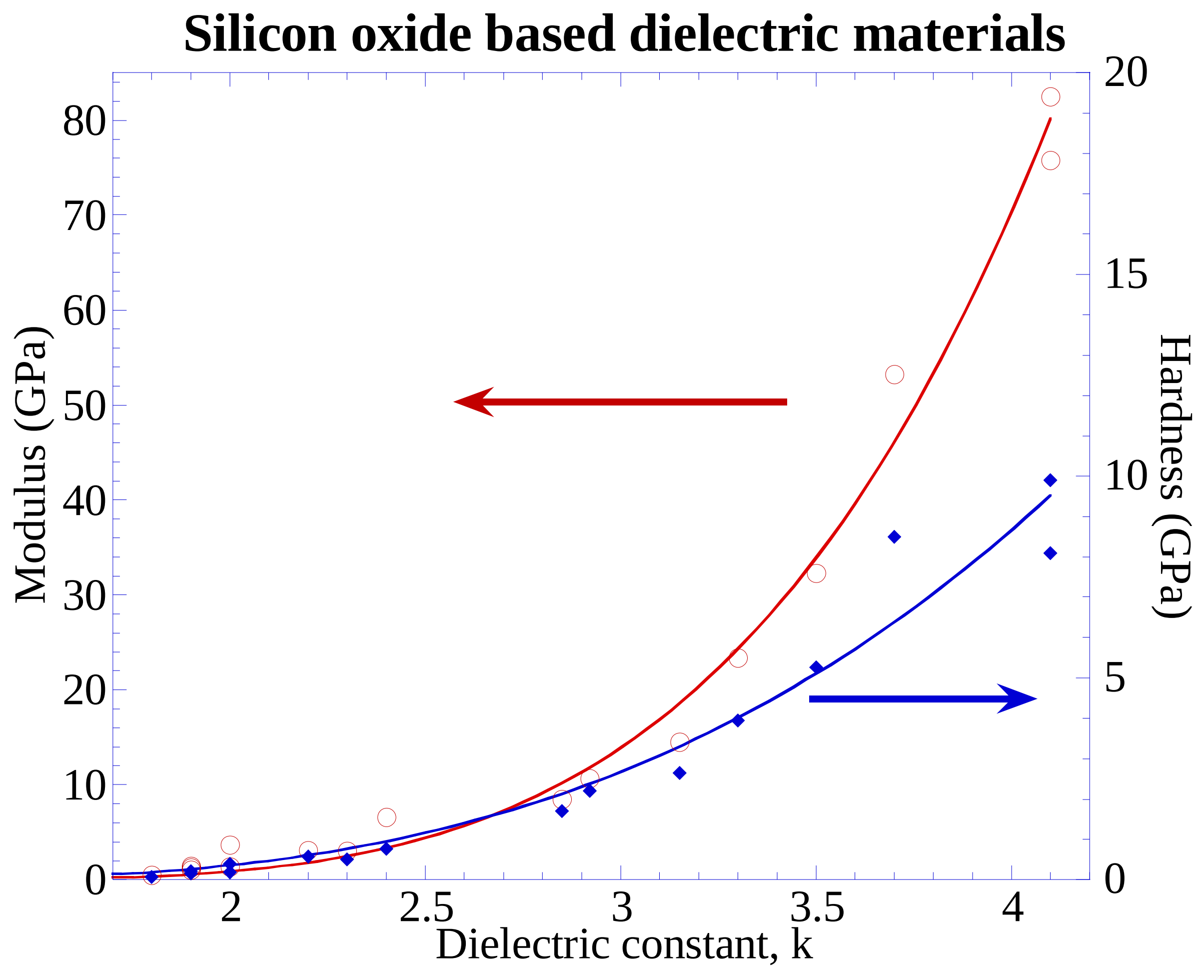
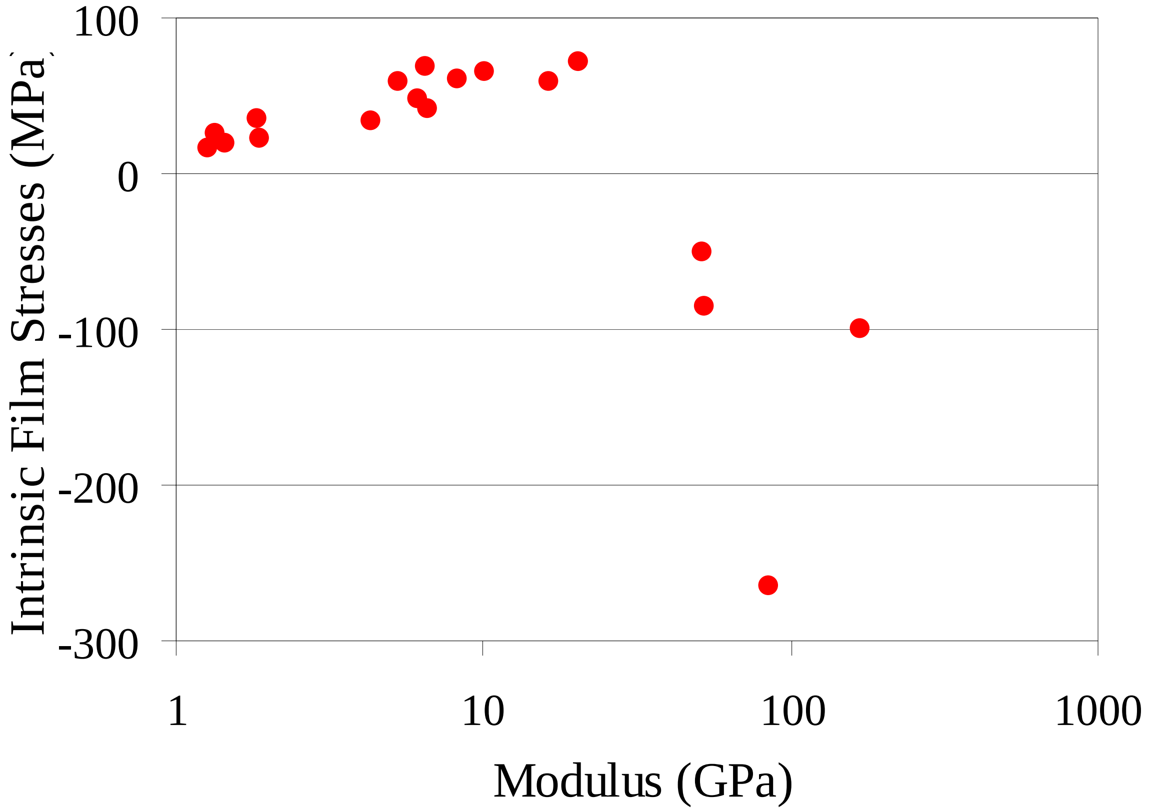
Introduction

- There will always be a trade-off between mechanical properties and dielectric constant.



Introduction--Challenge

- Film residual stress becomes tensile for materials with lower modulus (and k) while conventional SiOx and SiOF have compressive residual stress. If not properly comprehended, film is subjected to cracking!



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Thin Film Characterization Techniques

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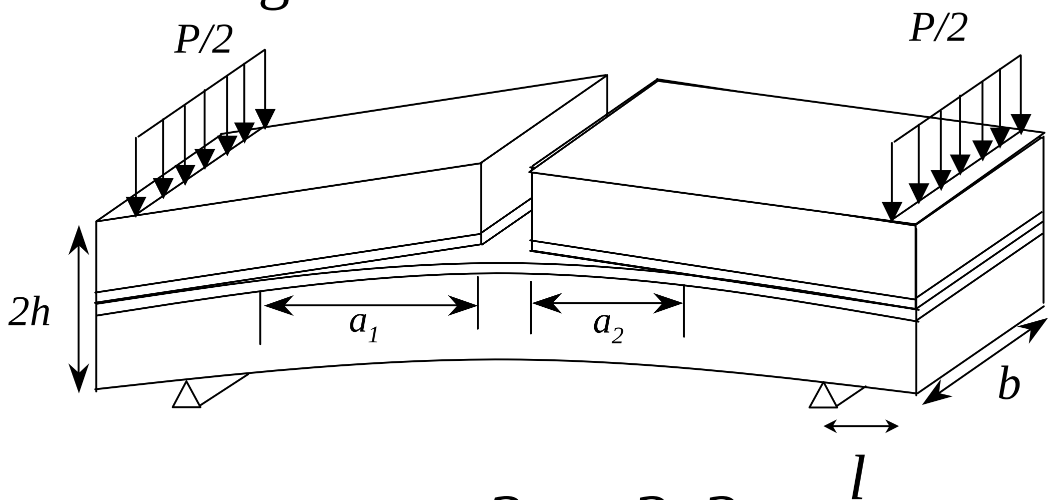
- 4 Point Bending

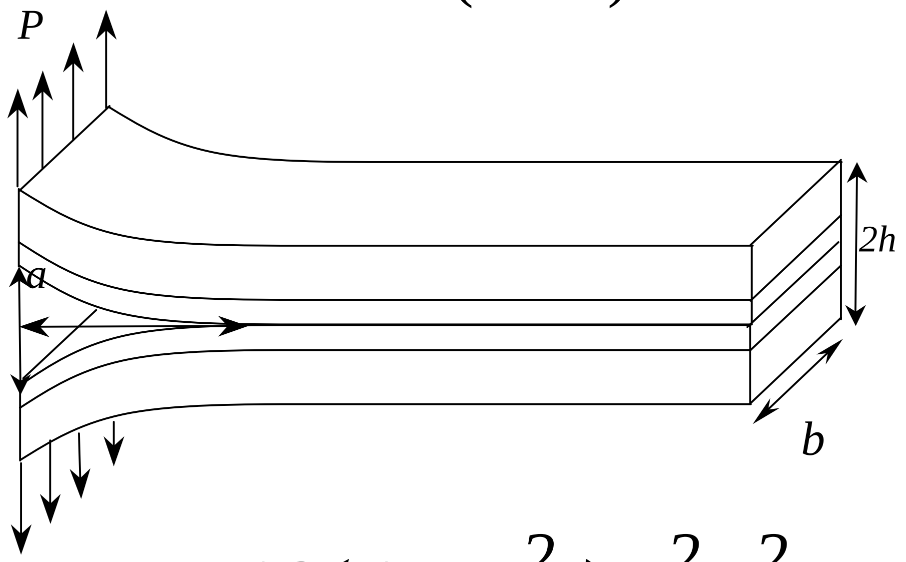


$$G = \frac{21(1-\nu^2)P^2 l^2}{16 E b^2 h^3}$$

  - Basic technique used at Intel for interfacial adhesion energy
  - Mix mode $\Psi \sim 45^o$
  - Only get cohesion data when film is weaker than interfaces.
  - Need surface analysis to determine failure mode.

Thin Film Characterization Techniques

- Dual Cantilever Beam(DCB)

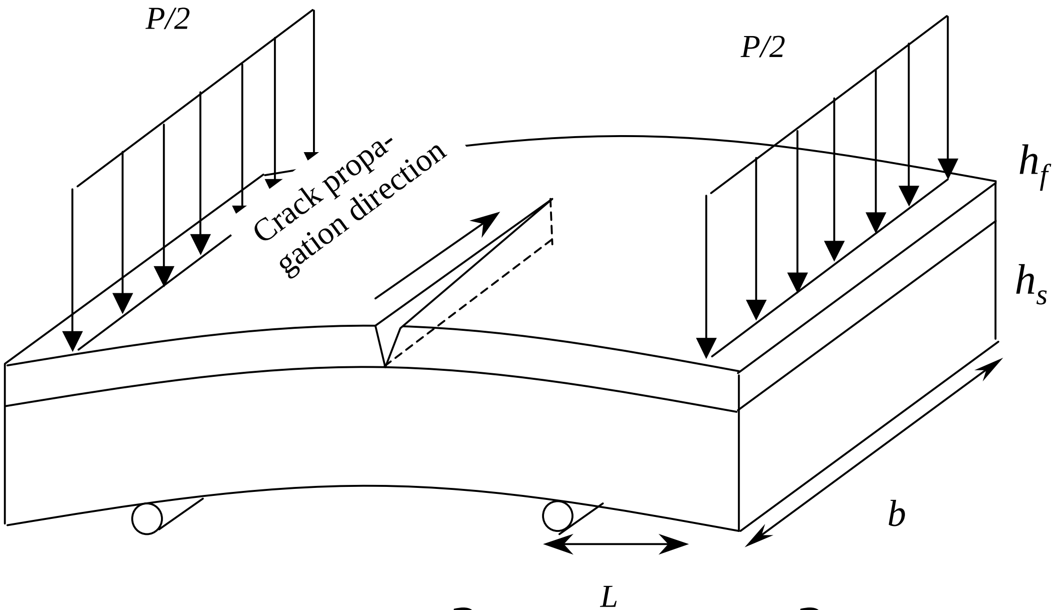


$$G = \frac{12(1-\nu^2)P^2a^2}{Eb^2h^3}$$

- Alternative technique for interface adhesion measurement.
- Mainly Mode I.
- Only get cohesion data when film is weaker than interfaces.
- Need surface analysis to determine failure mode.

Thin Film Characterization Techniques

- **Channel Cracking**



$$G = g_{el} \frac{\sigma_f^2 h_f (1-\nu_f^2)}{E_f}$$

- **Pure Mode I**
- **Guarantee cohesive failure mode**

Channel Cracking

Total film stress $$\sigma_f = \sigma_0 + \frac{3PL}{h_s^2 b}\,\frac{1-\nu_s^2}{1-\nu_f^2}\,\frac{E_f}{E_s}$$

Residual Stress

Applied stress through bending

G: Fracture Energy

g_{el}: depends on film-substrate elastic mismatch. Calculated by FEM

σ_f: Total film stress, including residual stress and applied stress

E_f, E_s: Elastic moduli of film and substrate

ν_f, ν_s: Poisson ratio of film and substrate

h_f, h_s: thickness of film and substrate

P: applied load

L: distance between inner pin and outer pin

b: sample width

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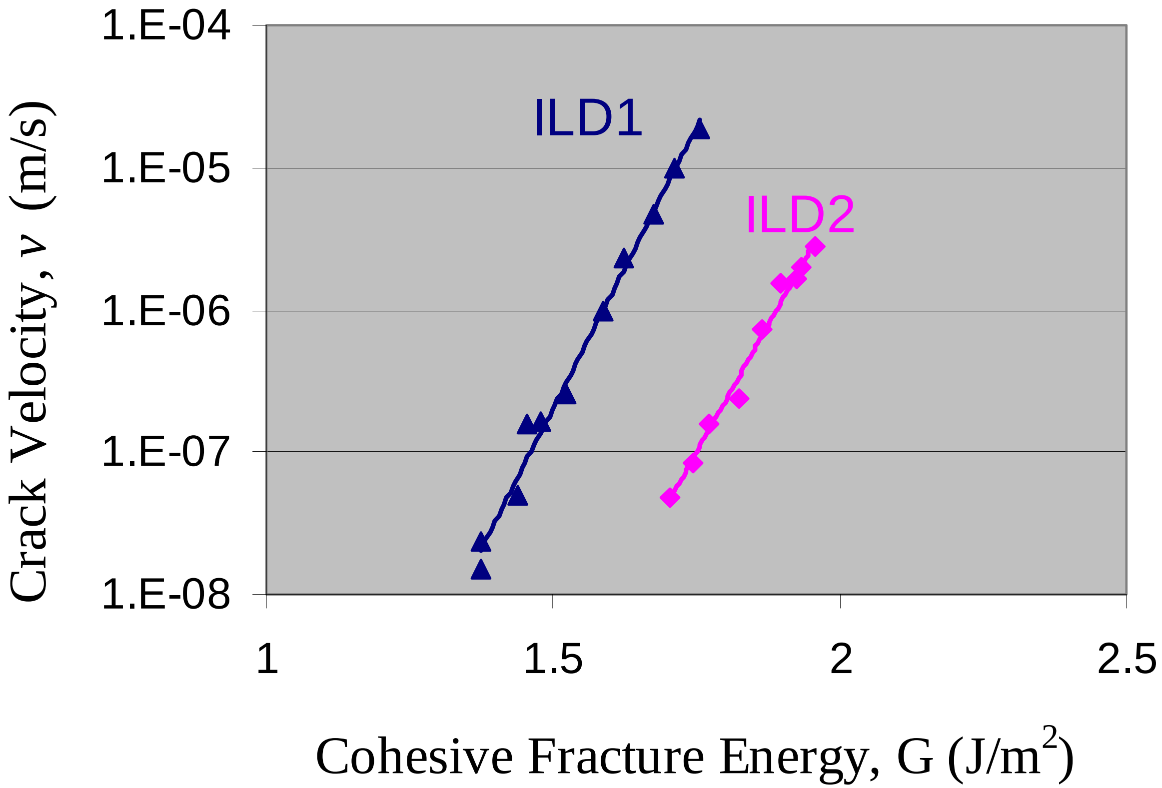
Channel Cracking

- Channel cracking measures cohesive fracture energy for ILD thin film.
  - Fracture energy is measured for a range of crack propagation velocities.



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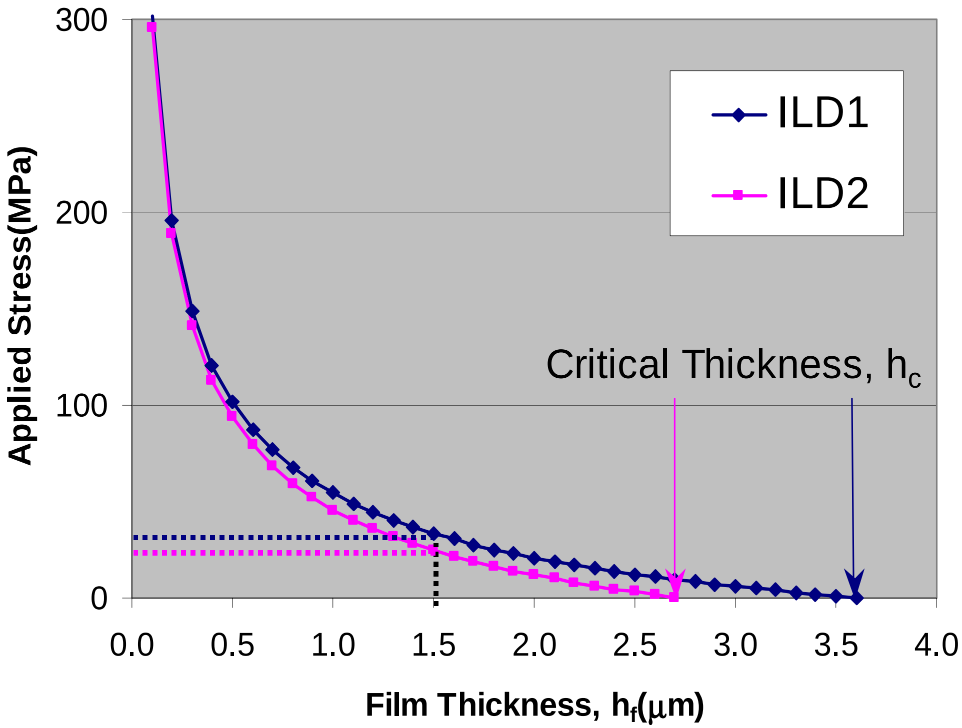
Concern: Residual Stress

- Residual stress is different ➔ Contribution to G is different
  - ILD#1, σ_0=60MPa; ILD#2, σ_0=70MPa
- External (applied) stress is a better metric of reliability performance.

$$\sigma_{applied} = \sigma_f - \sigma_0$$

$$= \sqrt{\frac{GE_f}{(1-\nu_f^2)g_{el}}}\sqrt{\frac{1}{h_f}} - \sigma_0$$

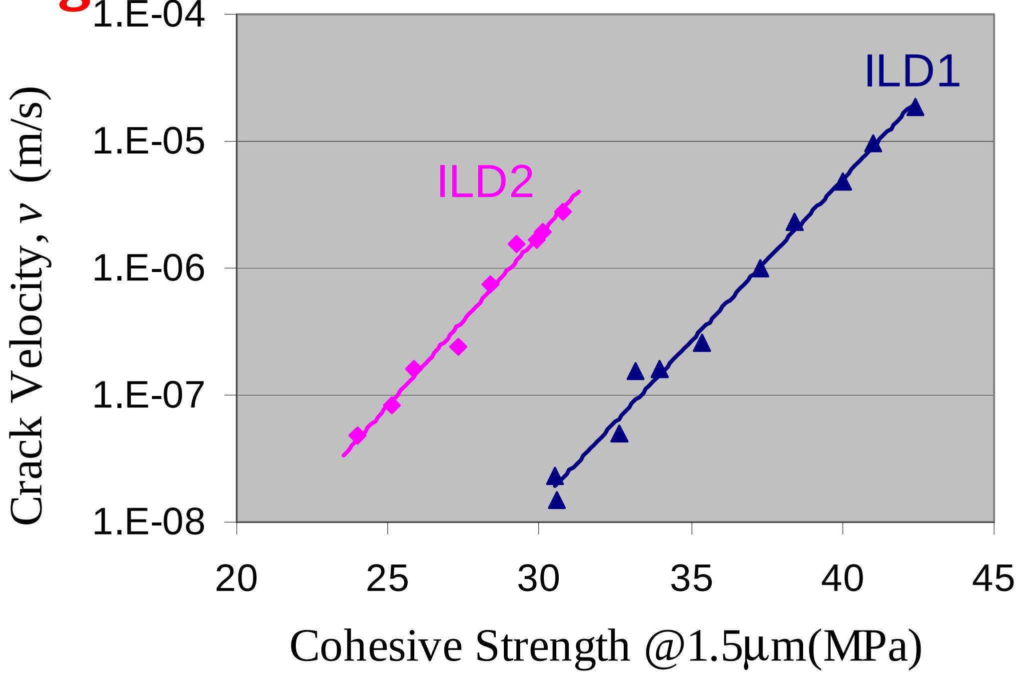
Constants (Film properties)



New Metric--Cohesive Strength

- Applied stress has to be normalized to fixed film thickness(ex. 1.5μm) to compare films of different thickness.
- **Cohesive strength-- the new metric for ILD ranking in terms of the maximum external stress the film can sustain before cracking.**

$$\sigma_{1.5\mu m} = \sigma_f \sqrt{\frac{h_f}{1.5\mu m}} - \sigma_0$$

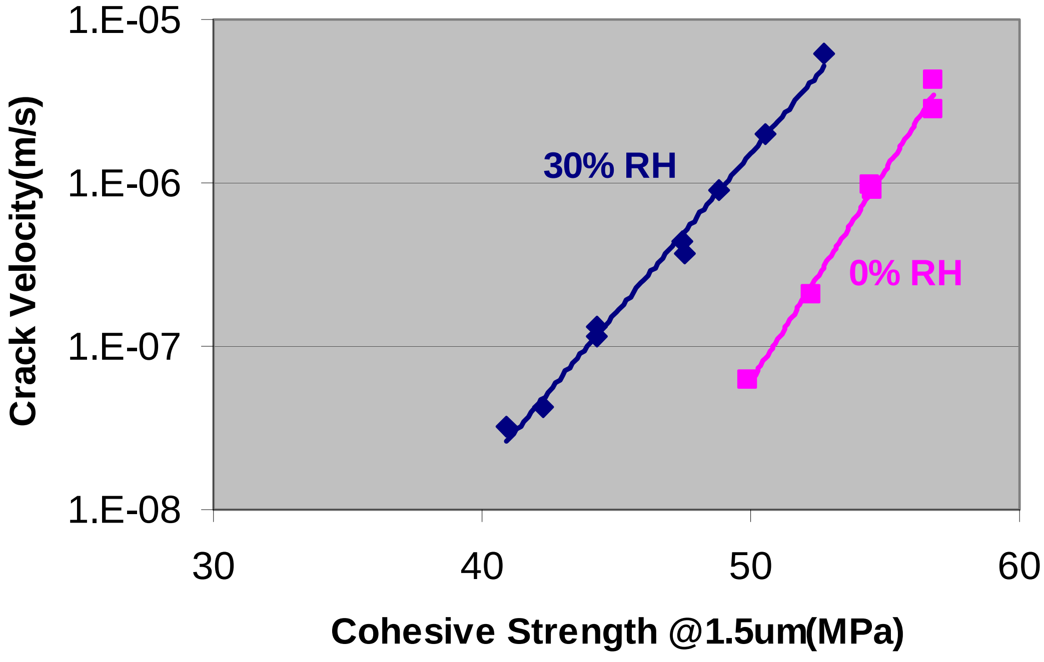


Application of Channel Cracking

- Critical thickness h_c can be predicted
  - the cracking threshold thickness in absence of external stress
  - maximum film thickness that can be deposited before cracking.

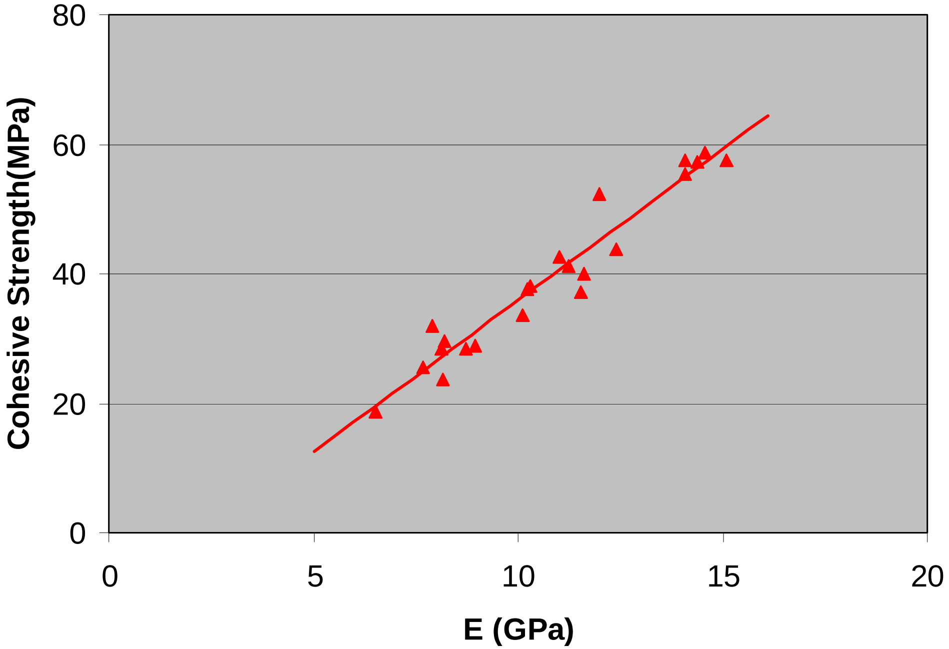
$$h_c = h_f \frac{\sigma_0^2}{\sigma_f^2}$$

- Environmental effect on film property, eg. humidity
  - Silica based low-k material is subject to stress corrosion



Cohesive Strength & E, k

- Cohesive strength is found to linearly increase with film modulus.
- Cohesive strength will decrease as k decreases — Trade-off between mechanical properties and performance always exists.
- Need to find the sweet spot to meet performance requirements as well as reliability requirements.



Summary

- A new thin film characterization metric "Cohesive Strength" is defined.
- "Cohesive Strength" is measured by the channel cracking technique and is defined as the external stress applied through bending at fixed film thickness and fixed crack velocity.
- Can predict critical thickness h_c—the maximum deposited thickness before the films cracks from its own intrinsic stress.
- Humidity effects on cracking threshold may be studied with channel cracking.