Thin Film Mechanical Reliability: Environmental Effects

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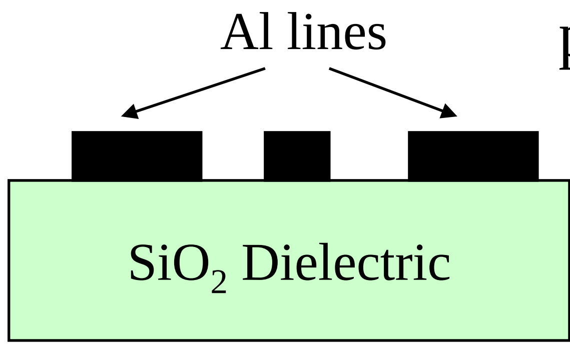
Workshop on Reliability Issues in Nanomaterials

17-19 August, 2004

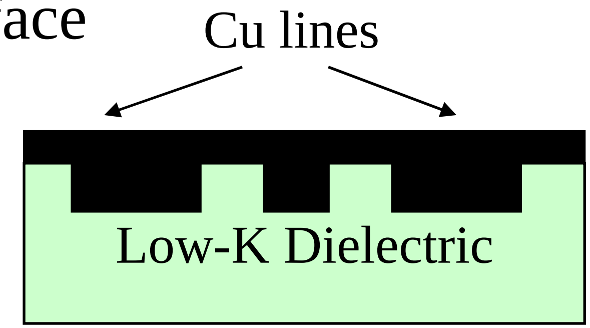
Boulder, Colorado

Al vs. Cu Processing

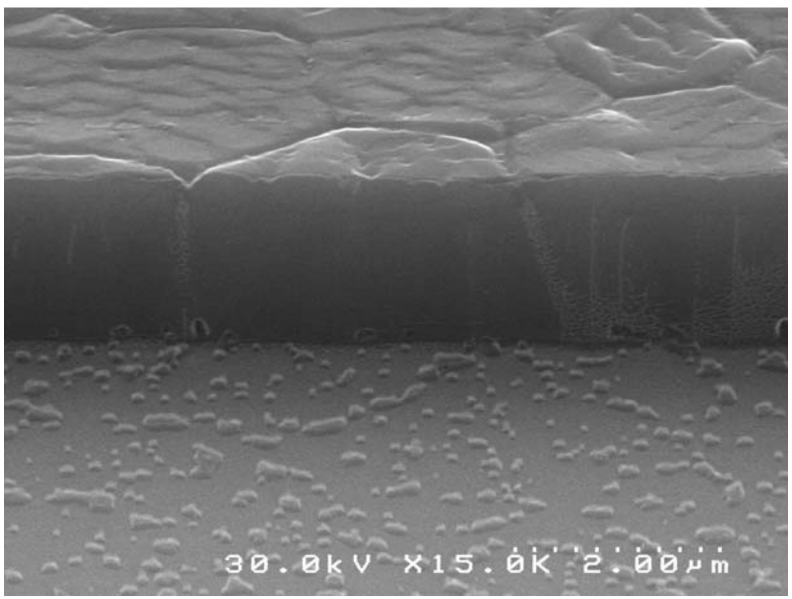
Cu is laid out in "sunken" or "dug-out" trenches rather than over the planar top surface

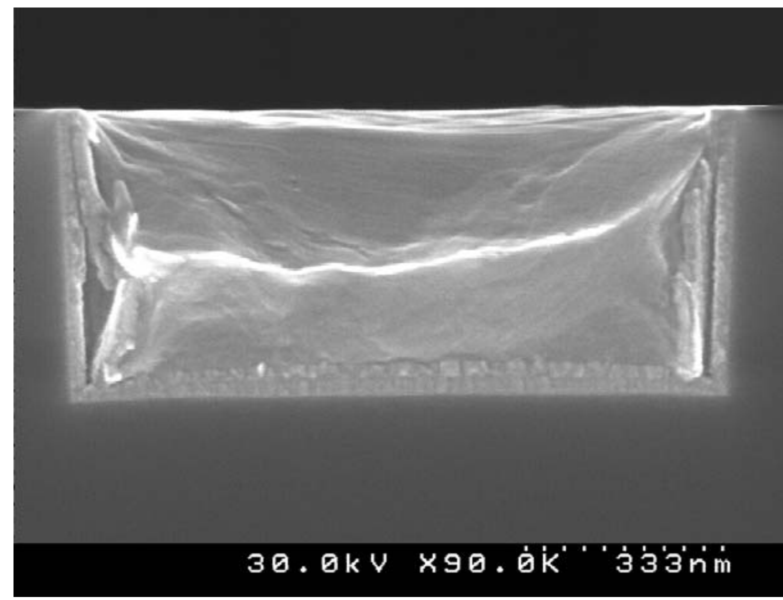


Sputtering

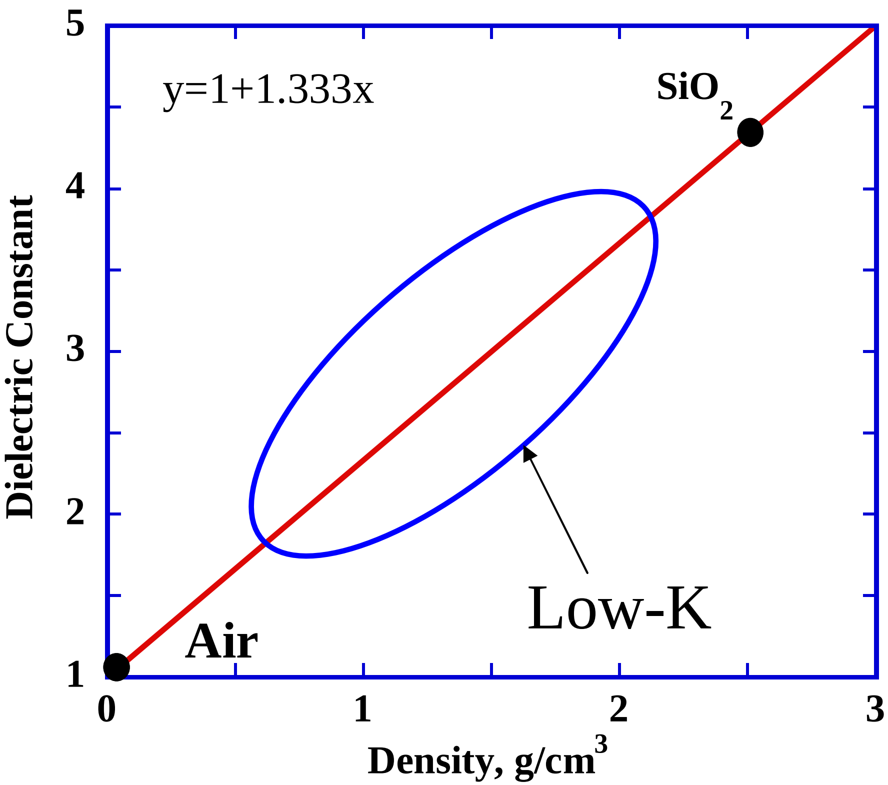


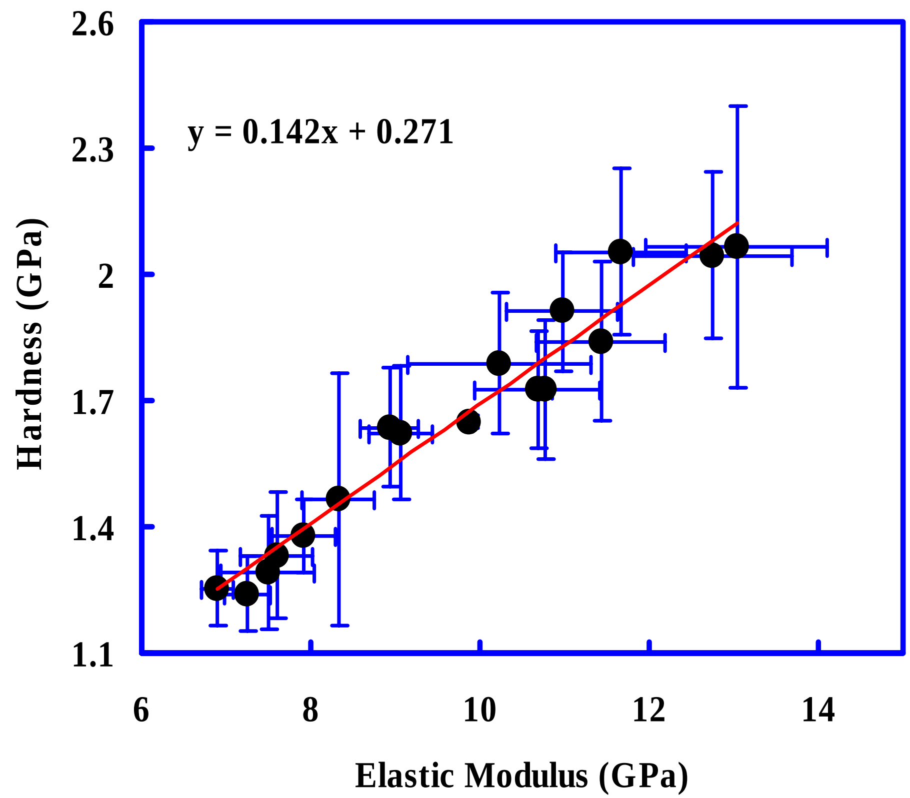
Electroplating





Low-K Dielectric Mechanical Properties



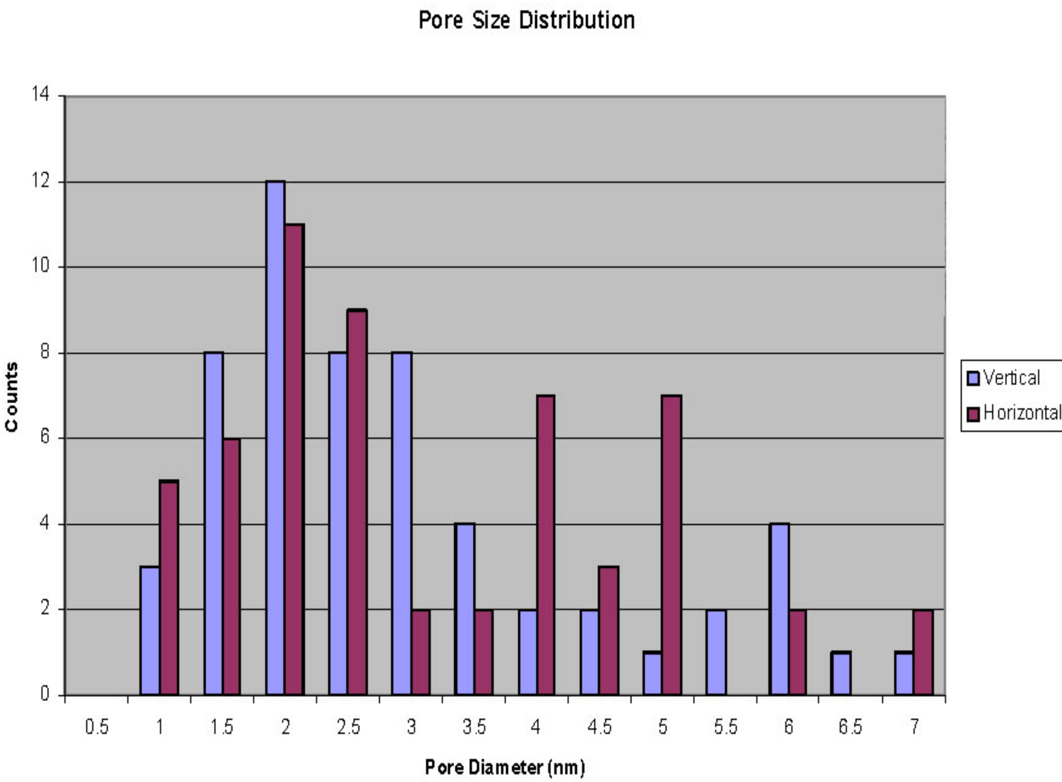


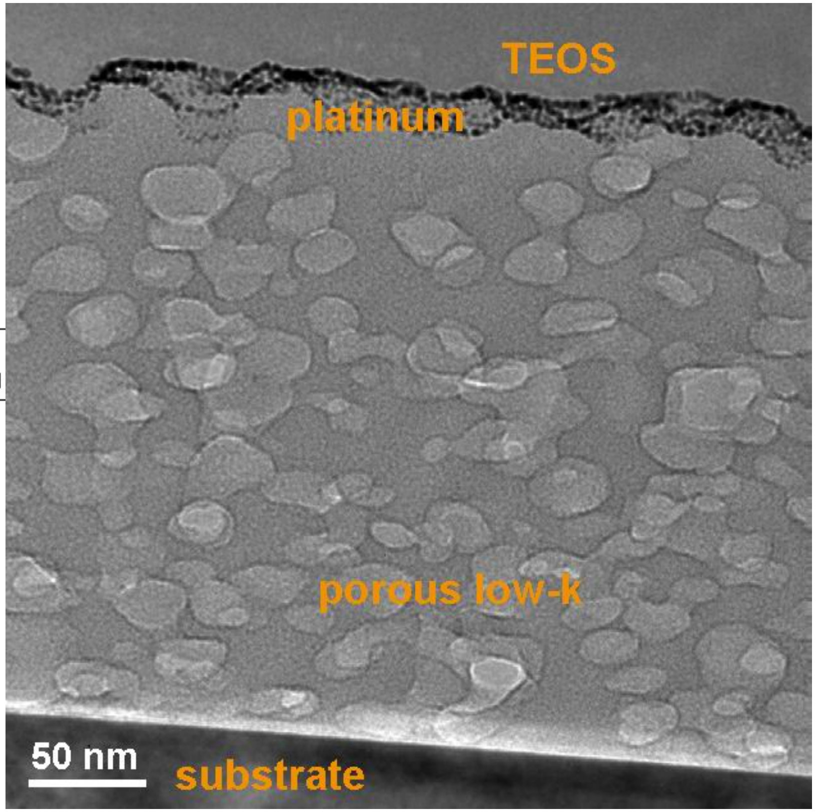
• Mechanical stability (Device should hold together during manufacturing, testing, operation)

• Elastic Modulus (1-14 GPa), Hardness (0.5-2.3 GPa), Adhesion (0.1 to 50 J/m^2), Fracture Toughness (~ 0.01 to 0.05MPa·m$^{1/2}$)

A.A. Volinsky, J.B. Vella, W.W. Gerberich, Thin Solid Films 429/1-2 pp. 201-210, 2002

Sematech low-k TEM





B. Foran and B. Kastenmeier, and D. S. Bright, "**Determination of Pore-Size Distributions in Low-k Dielectric Films by Transmission Electron Microscopy**" In CHARACTERIZATION AND METROLOGY FOR ULSI TECHNOLOGY: 2003 [March 24-28 Austin, TX], AIP Press, College Park Maryland. AIP Conference Proceedings # 683, pg 556-561

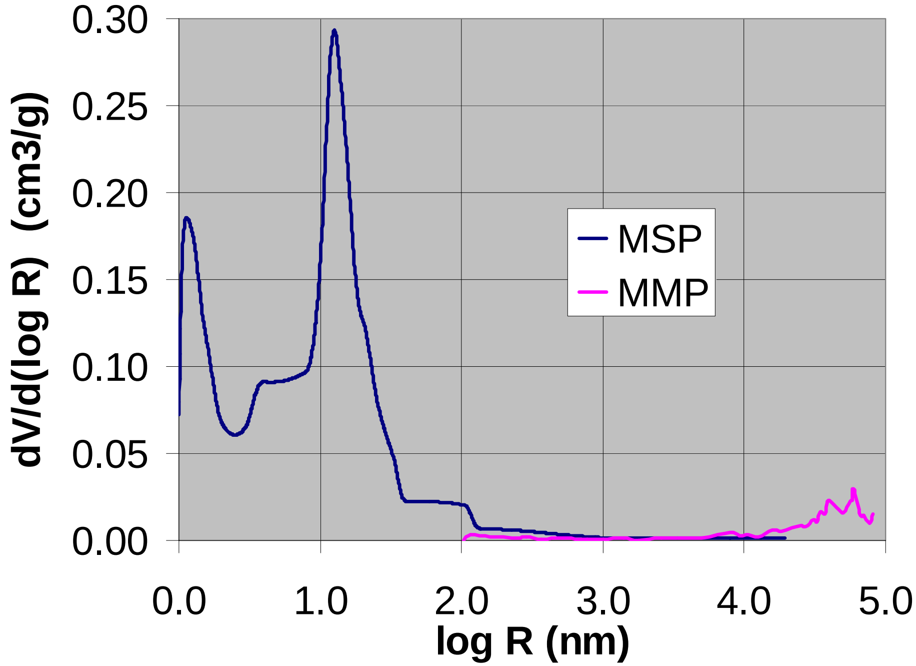
Brendan Foran, PCL-ATDF, International Sematech

Standard Porosimetry

The amount of liquid in the samples is determined by weighing. Hydrocarbons (octane or decane) are usually used as measuring liquids, since they completely wet all materials. Any liquid, including water, can be used for establishing hydrophobic and hydrophilic pores.

- Distribution of pore volume as a functions of the pore radius (~0.3 nm to $3x10^6$ nm)
- Average pore radius;
- Specific pore volume (porosity);
- Specific surface area ranging from 10^{-3} to 10^3 m^2/cm^3
- Wetting angle and its dependence on pore radius
- Differential characteristics of swelling

Pore volume distribution by standard and mercury porosimetry (Nafion 117)

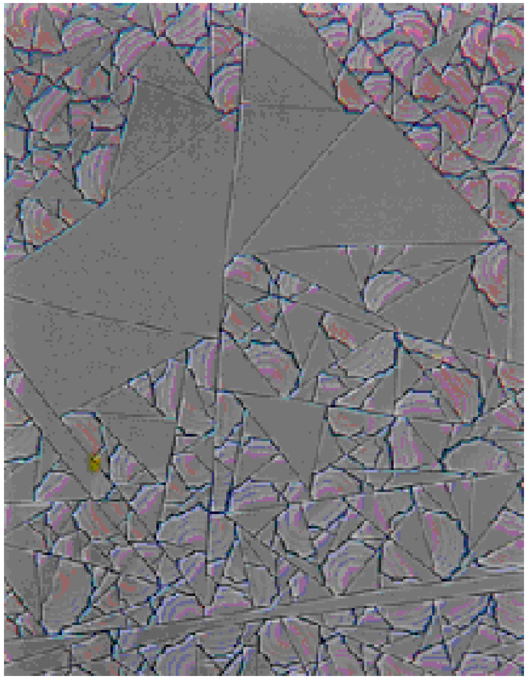


•Wetting angle and its dependence on pore radius

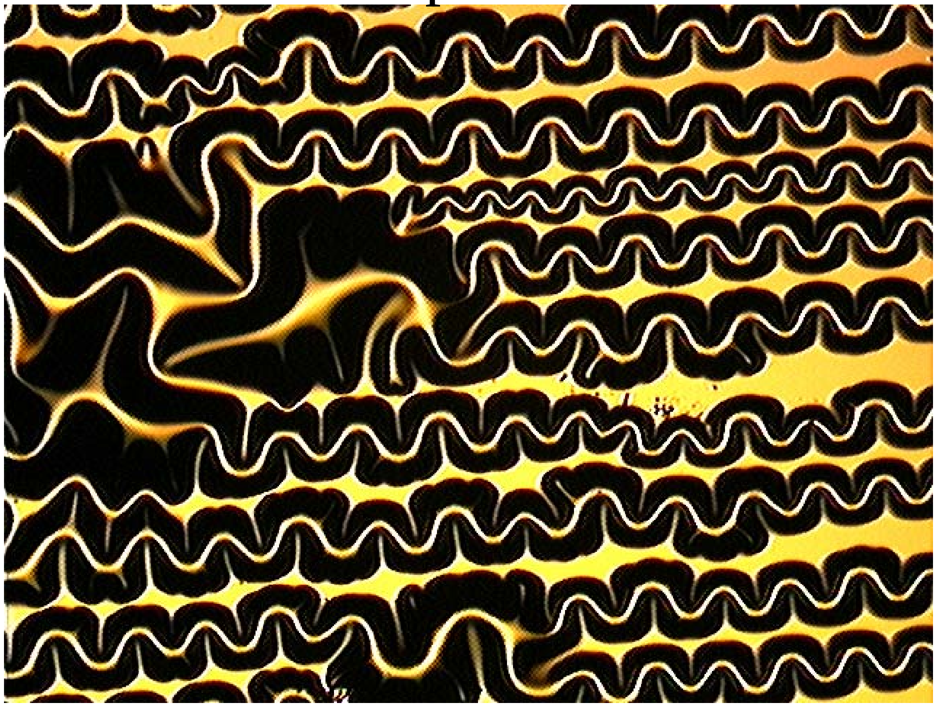
•Adsorption isotherms

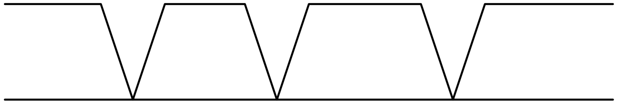
Fracture Stress Relief in Thin Films

Low-K dielectric film fracture in tension

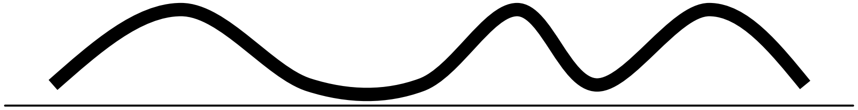


TiW film phone cord delamination in compression

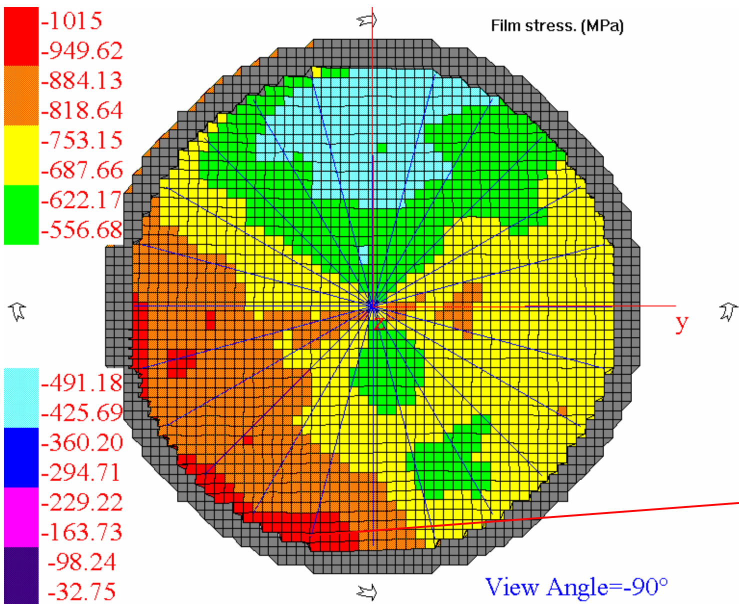


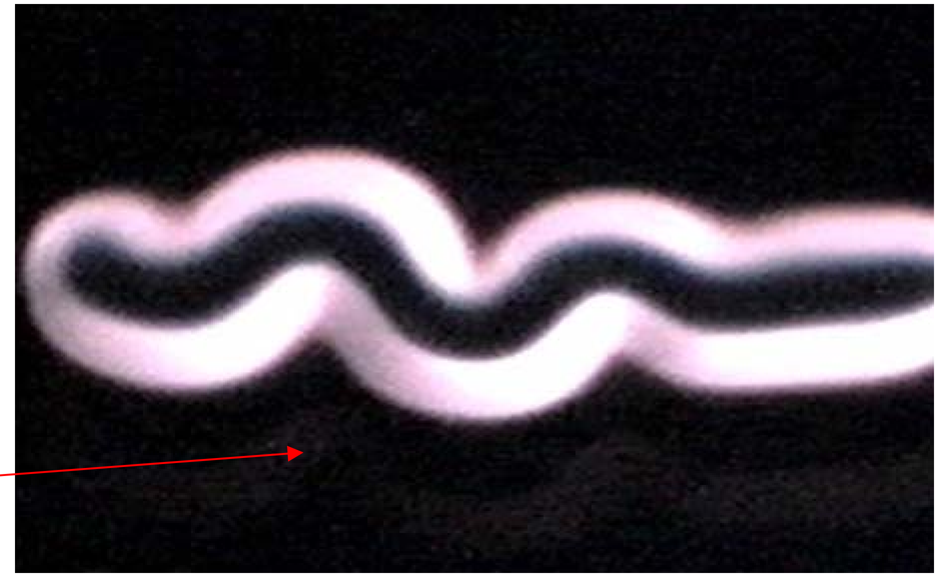


$$h_c = \frac{GE}{Z\sigma_R^2}$$



Motorola GaAs Device Failure





1μm W/150 nm Al/Si

$$G = Z\frac{\sigma_{RES}^{2}h}{E}$$

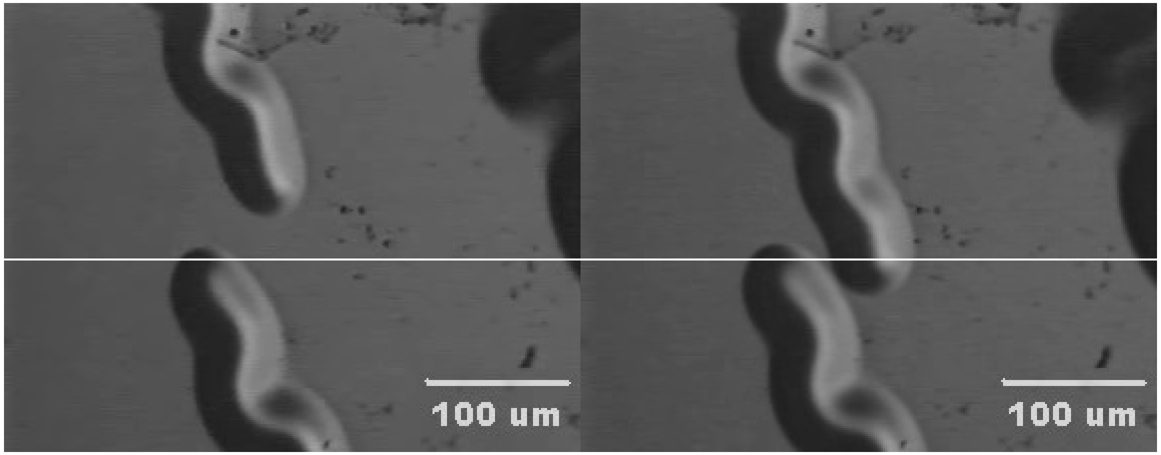
Z=0.5 to 0.8

$$G > \Gamma_i$$

For a 0.9 μm thick TiW film with 900 MPa compressive residual stress, the adhesion is lower than 2 J/m^2 if telephone cord delamination is observed (E_{Film} = 270 GPa)

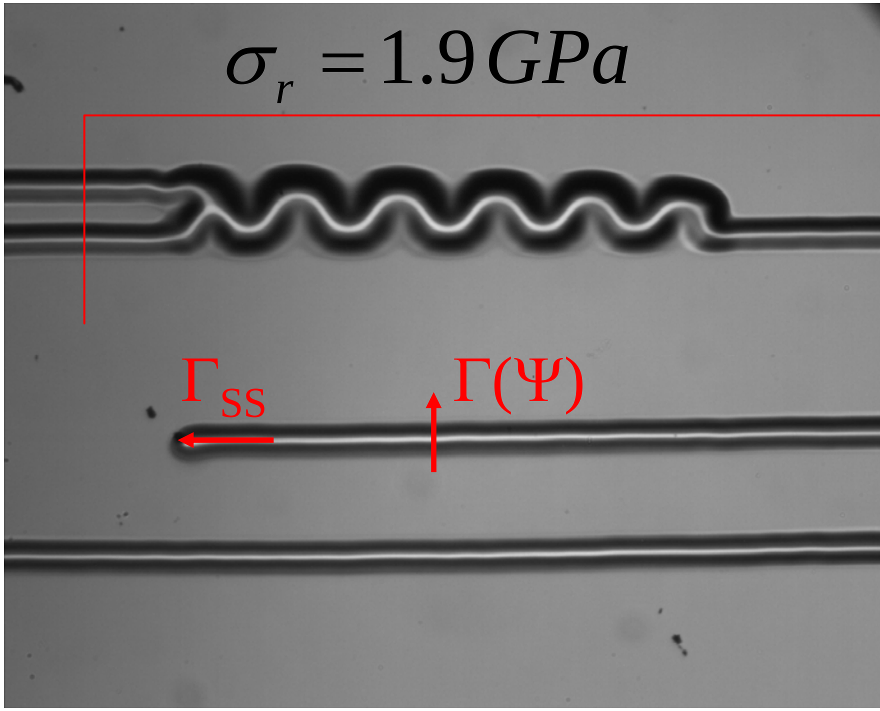
Water-induced Blister Growth

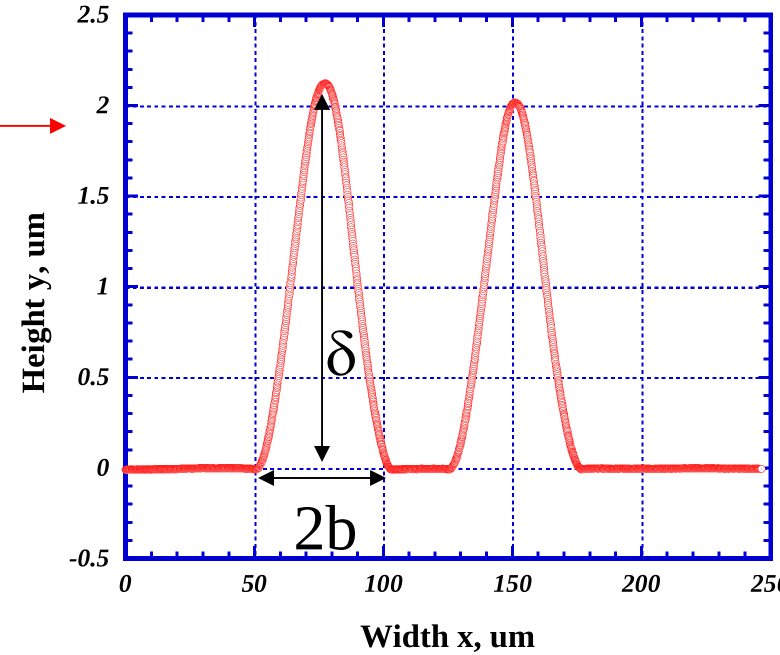
Water introduced from the top of the wafer



0 sec   No water exposure   30 sec

Stress/Adhesion Estimates





$$\sigma_B = \frac{\pi^2}{12}\frac{E}{(1-\nu^2)}\left(\frac{h}{b}\right)^2 = 275\,MPa$$

$$\Gamma_{SS} = \frac{(1-\nu^2)h\sigma_r^2}{2E}\left(1-\frac{\sigma_B}{\sigma_r}\right)^2 = 3.6\ J/m^2$$

$$\Gamma(\Psi) = \frac{(1-\nu^2)h}{2E}(\sigma_r-\sigma_B)(\sigma_r+3\sigma_B) = 6\ J/m^2$$

$$\sigma_r = \frac{3}{4}\sigma_B\left(\frac{\delta^2}{h^2}+1\right) = 1.9\,GPa$$

$G_{Superlayer}$=6.4 J/m^2

Acknowledgements

NACE International

Seagate Technology

Motorola/Freescale

Neville Moody, Sandia

David Bahr, WSU

Earl Johns, Seagate

James Kiely, Seagate

Patrick Waters, USF

John Hutchinson, Harvard