Indentation-induced delamination and adhesion work evaluation at elevated temperature in industrial semiconductors

Speaker: PJ Wei

24 April, 2023

Outlines

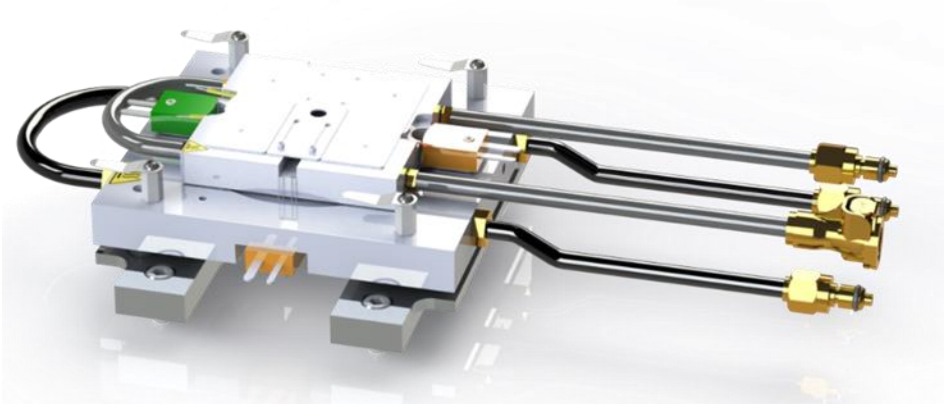
- Basic Mechanisms of Adhesion Measurements and Correlation between Results Collected by Different Techniques
- Applications of thin film adhesion measurement at Elevated Temperature

Basic Mechanisms and Methodology Correlation

Interface Bonding Issues of Adhesion in Thin Film Industries

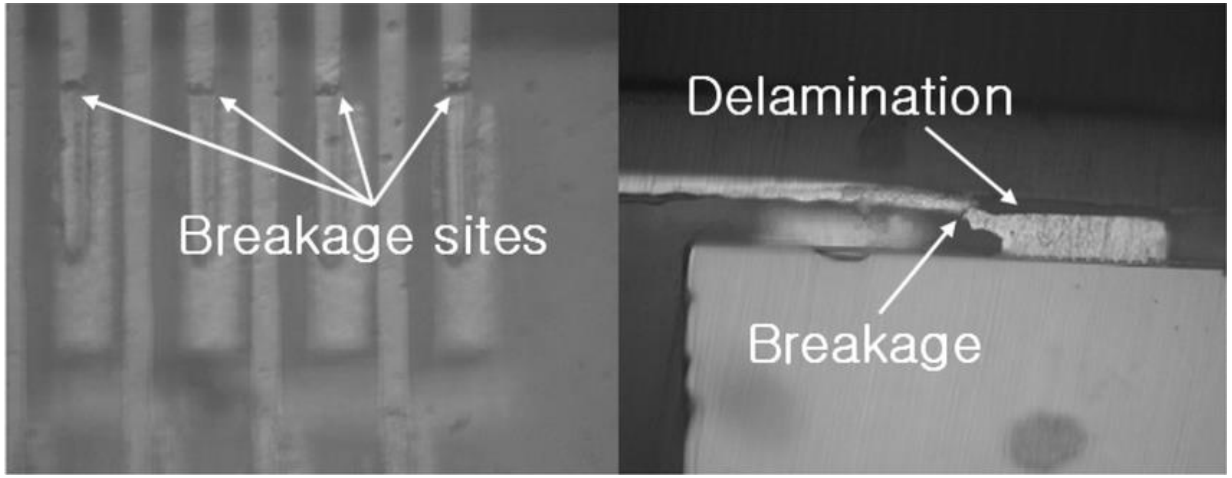
xSol® - Heating, Cooling, Humidity

Heating: 800°C • Cooling: -120°C • Humidity: 10-75% RH



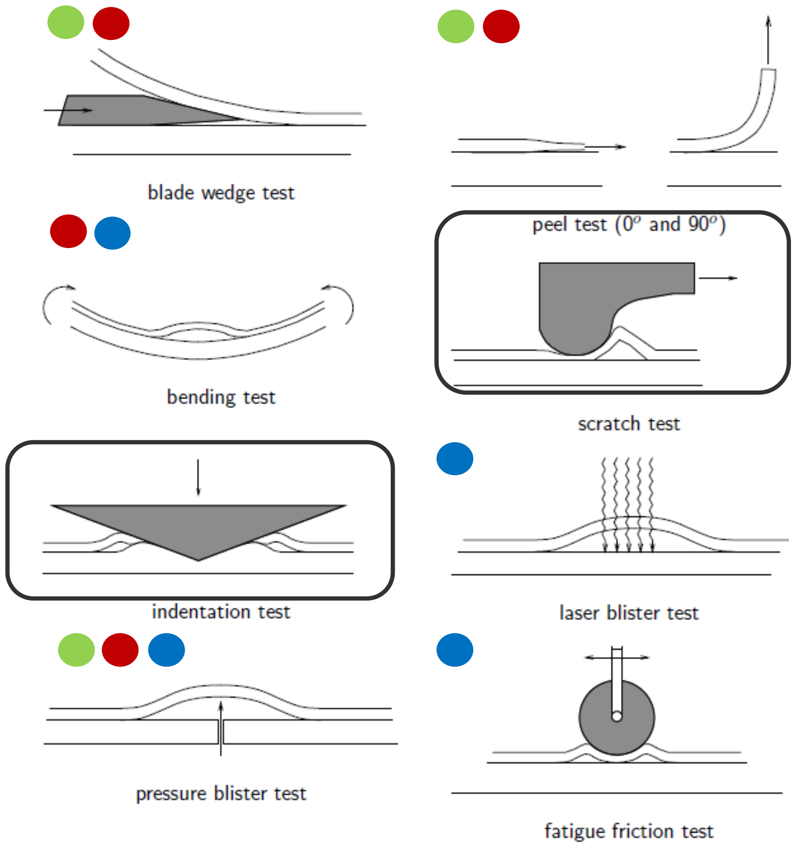
https://www.researchgate.net

https://outdoorsmagic.com/article/toughest-outdoor-watches-2022/



Overview of Adhesion Metrology Techniques
Measurements for Interfacial Bonding

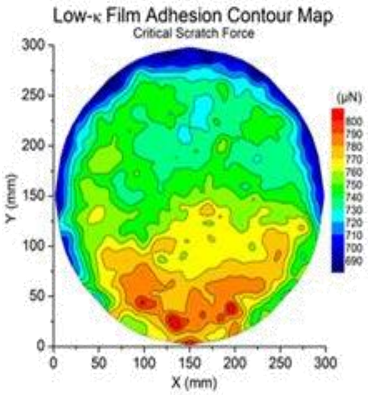
- special sample preparation
- Low spatial resolution
- Ex-situ measurement



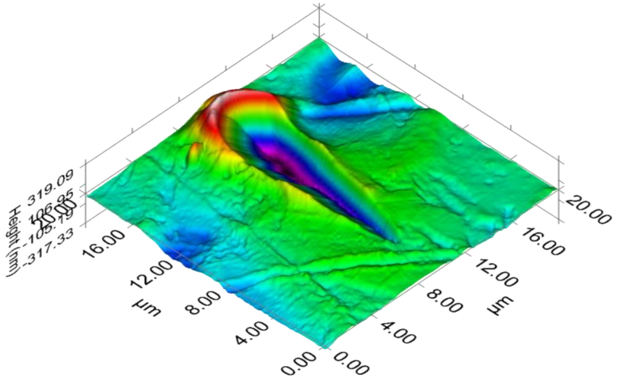
Methods to measure thin film adhesion

Nano indenter’s Advantages:

1. Direct measurements
   Nanoindentation or nanoscratch tests can directly performed on product surface.
   No sample preparations are needed.
2. High spatial resolution
   Nanoindentations or nanoscratches are at sub-micron or micron scale.

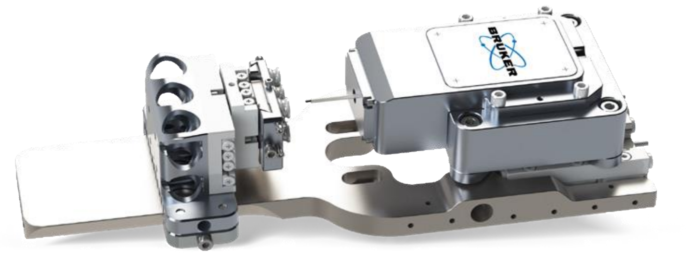


12” Wafer Adhesion Mapping



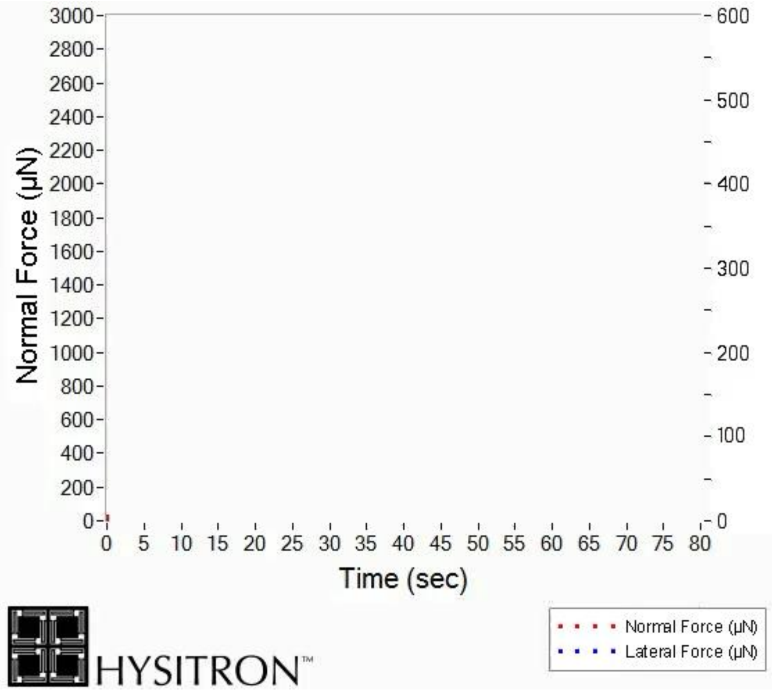
SPM of Nano scratch

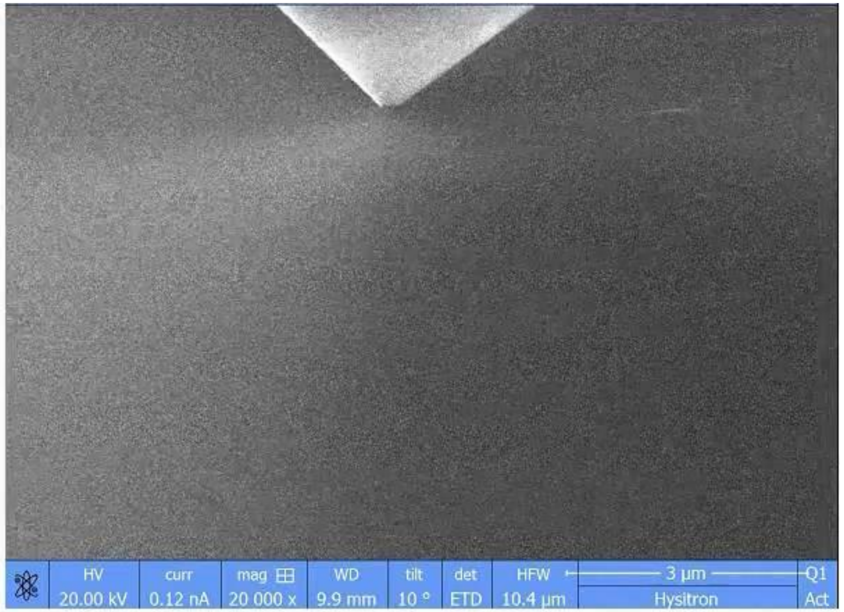
Scratch-Induced Cohesion and Adhesion on Low-k Film



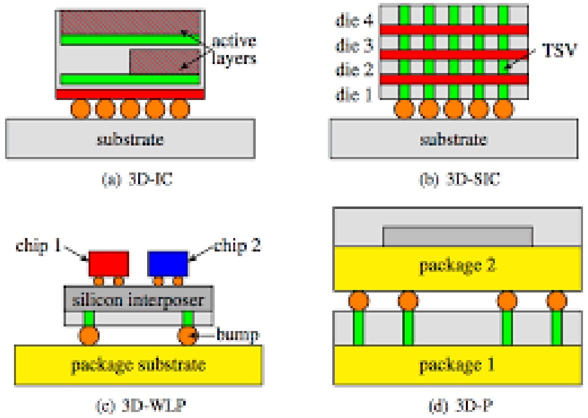
Hysitron PI 89 Picoindenter

In-situ Nano-Scratch in SEM

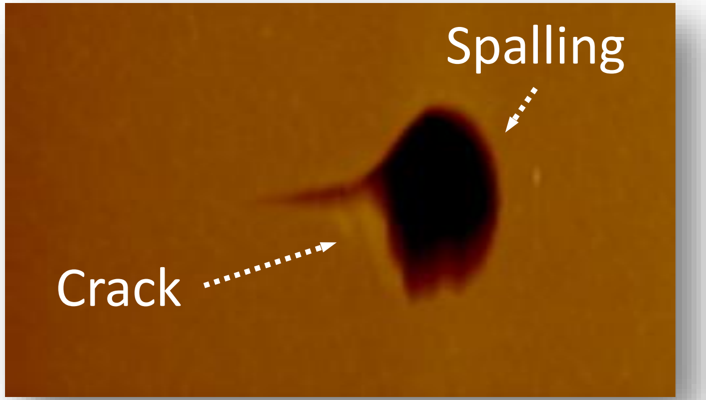




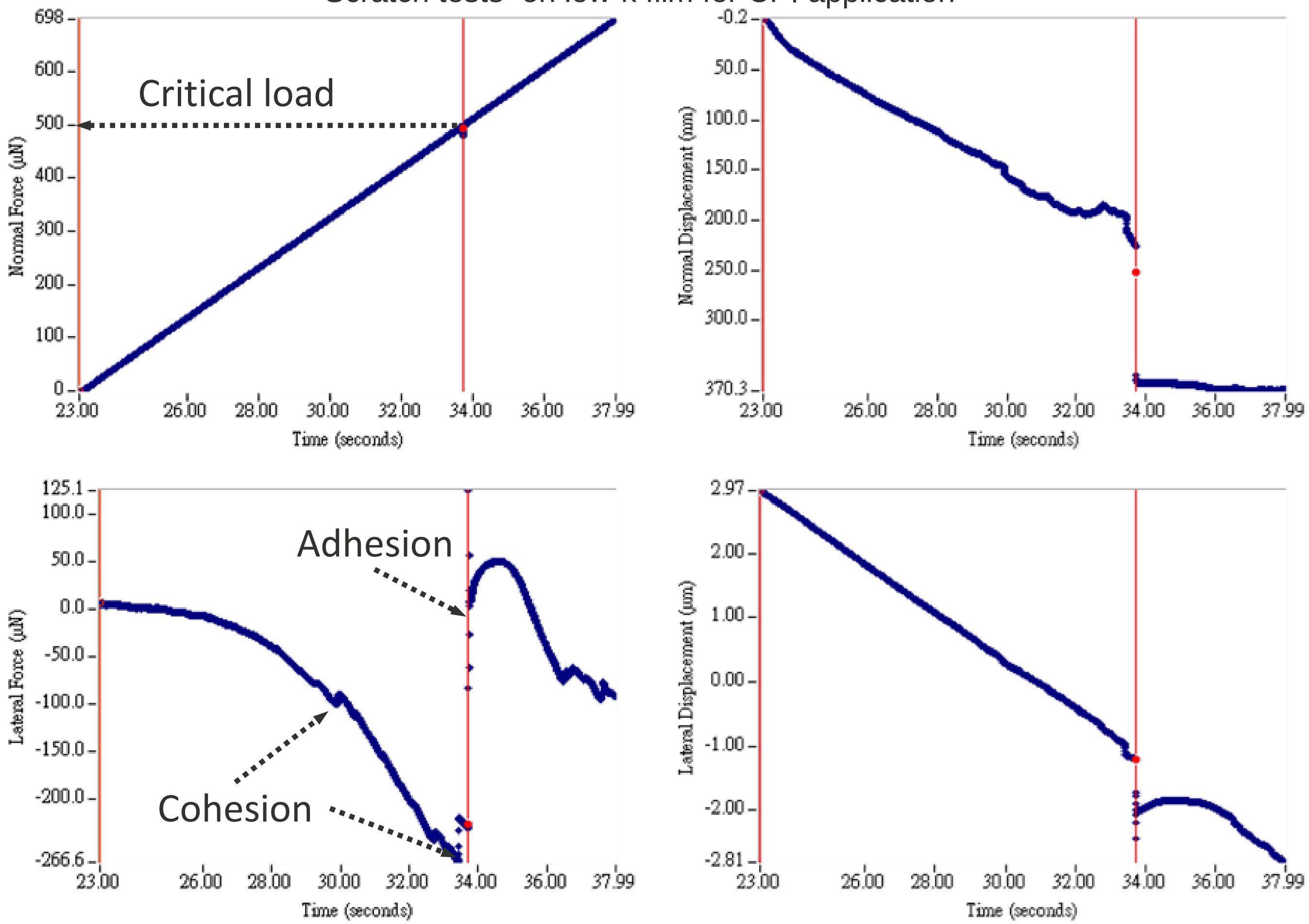
Scratch-Induced Cohesion and Adhesion of Low-k Film



https://www.iue.tuwien.ac.at

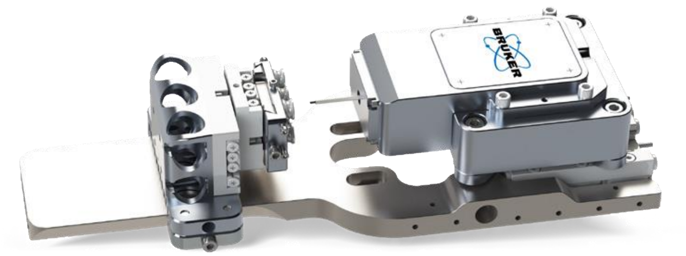


Scratch tests on low-k film for CPI application

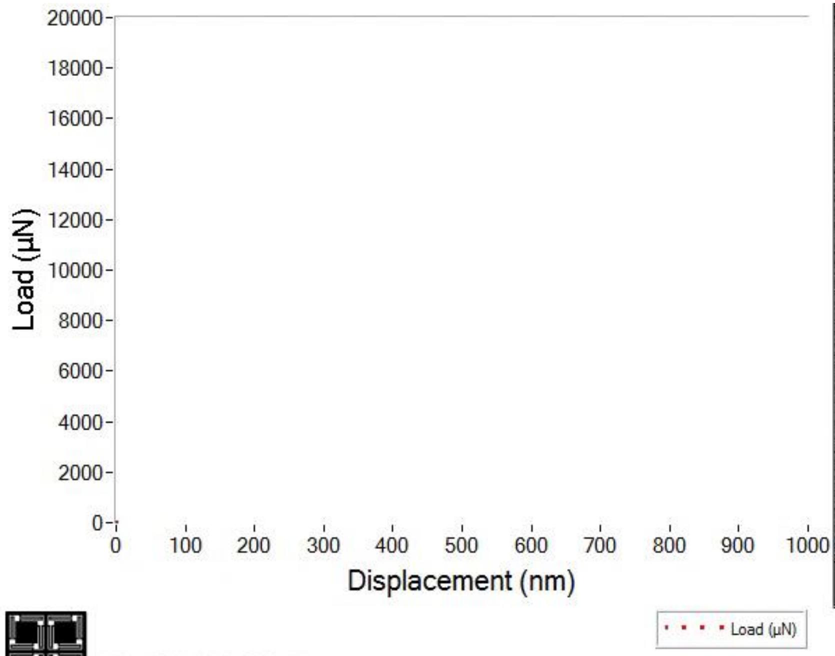


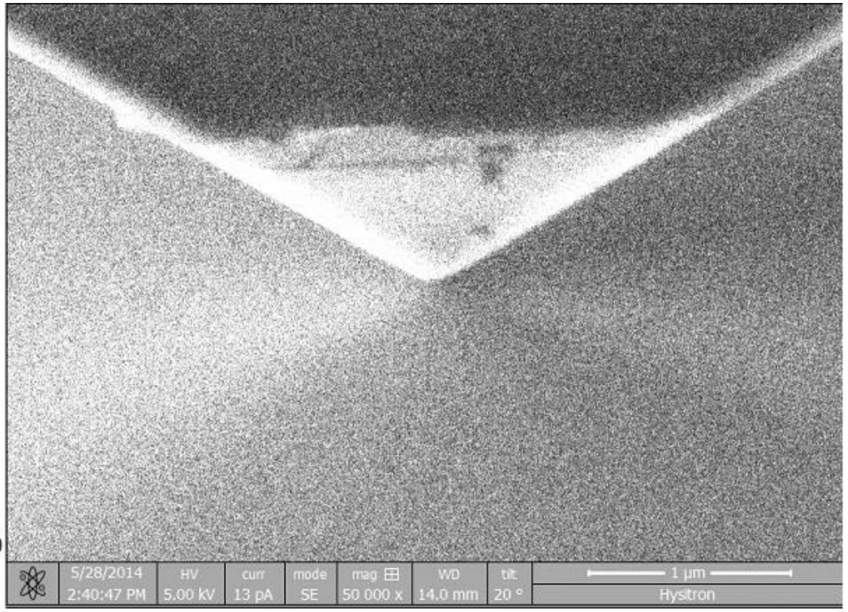
Indentation-Induced Cohesion and Adhesion on Hard Coating

In-situ Nano-Indentation in SEM



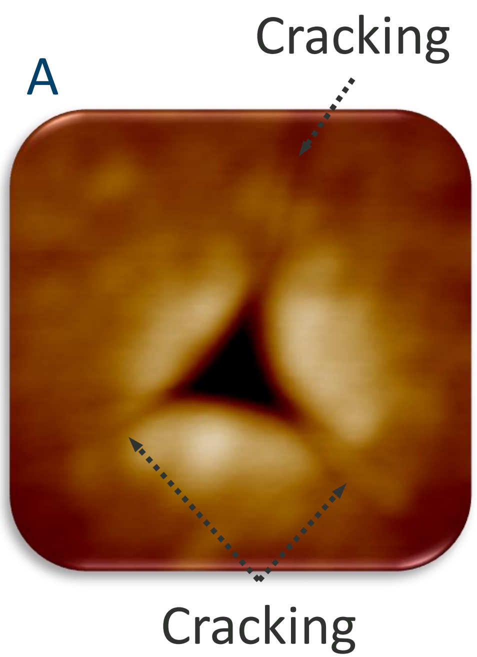
Hysitron PI 89 Picoindenter

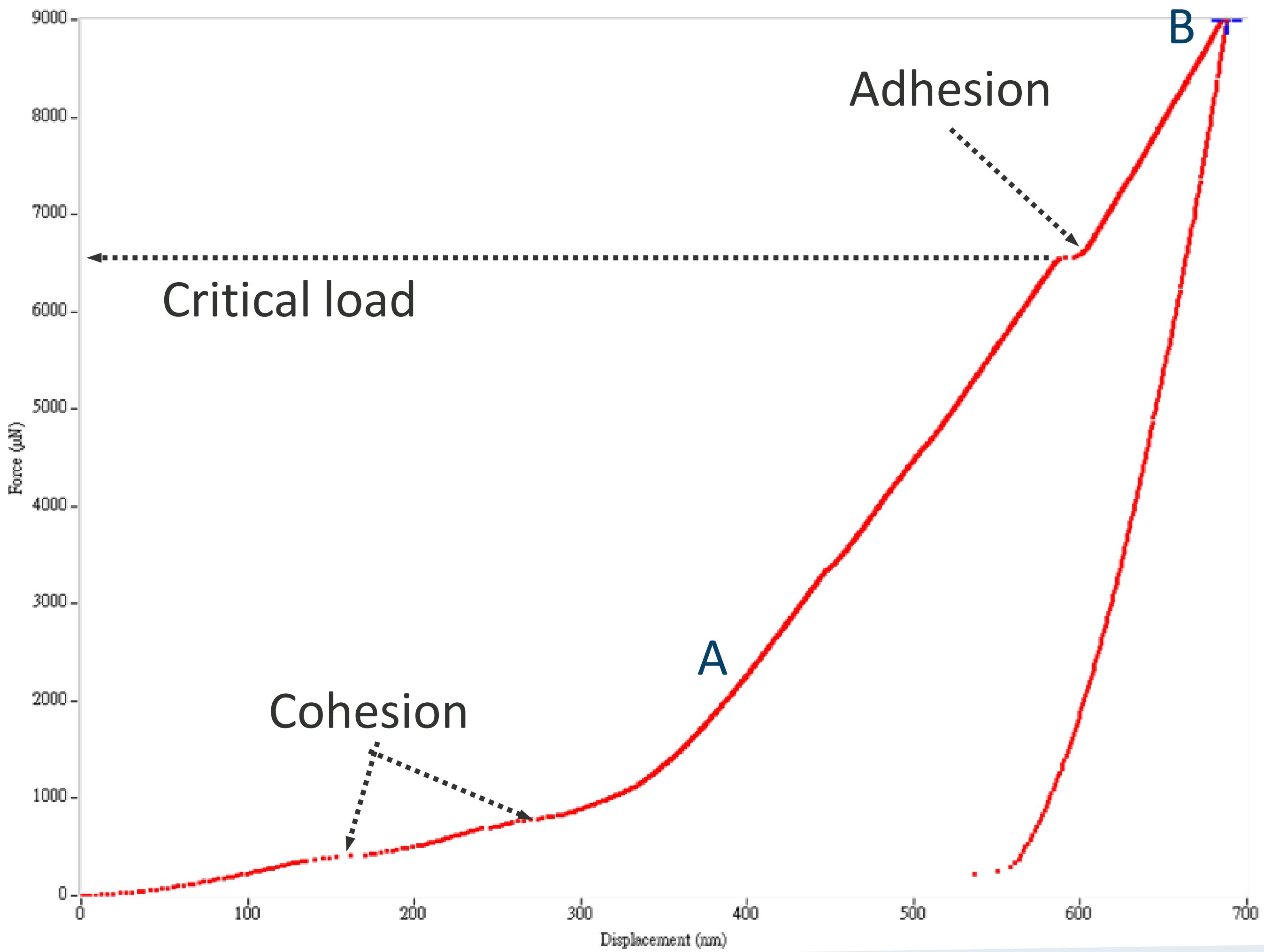


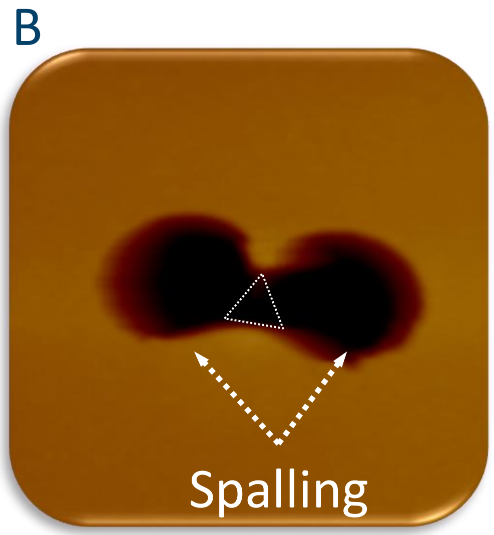


HYSITRON™

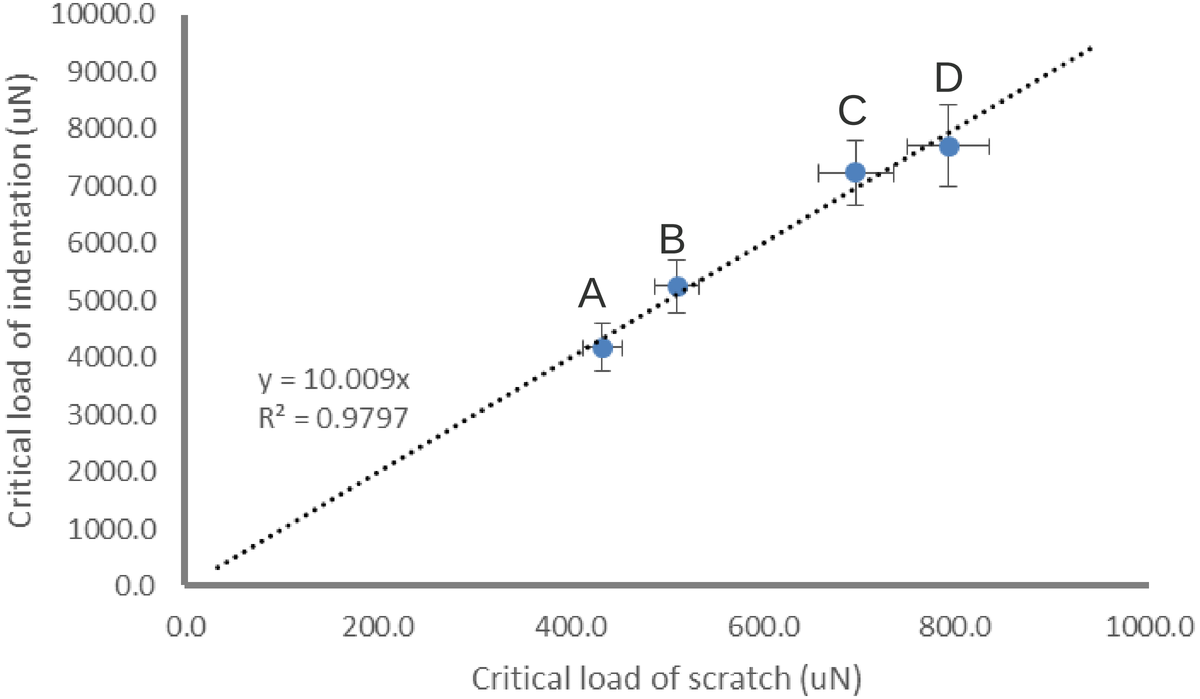
Indentation-Induced Cohesion and Adhesion
Check of Post- SPM Imaging



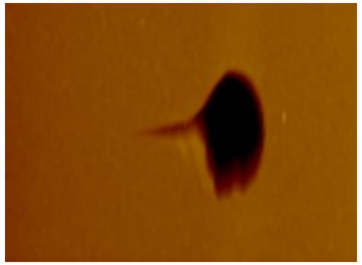




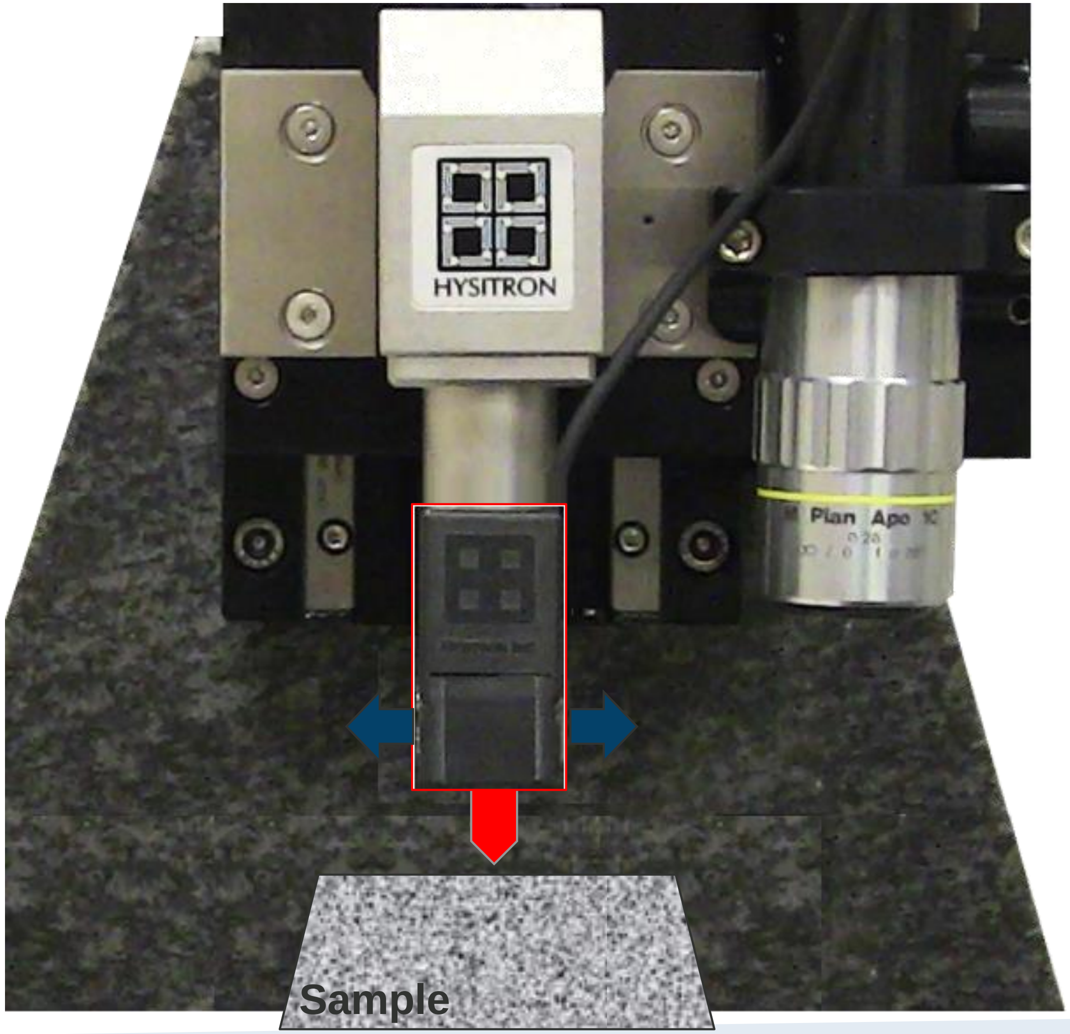
Correlation of Critical Load Results



Sample	Scratch Method		Indentation Method	
	Ave (uN)	Std (uN)	Ave (uN)	Std (uN)
C	696.2	38.7	7231.2	573.5
D	792.5	42.2	7702.0	715.7
A	433.3	19.9	4173.5	419.4
B	510.7	22.9	5249.3	464.3



High Speed Indentation with Pop-in Signal



How it works:

- Approach routine makes contact with the sample
- Electrostatic actuation to perform experiment and withdraw
- Between indents, piezo is moved to next position

TI-980: up to 6 indents/s

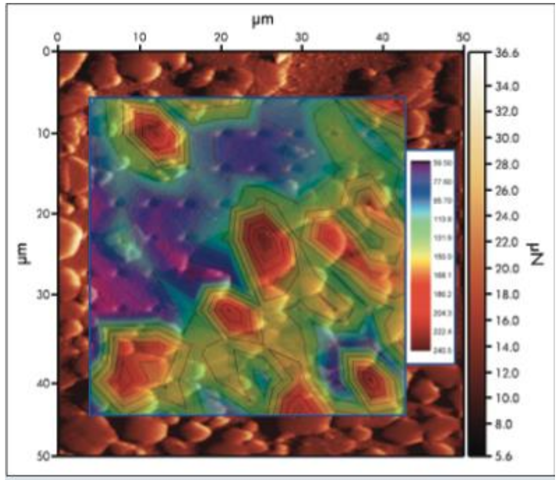
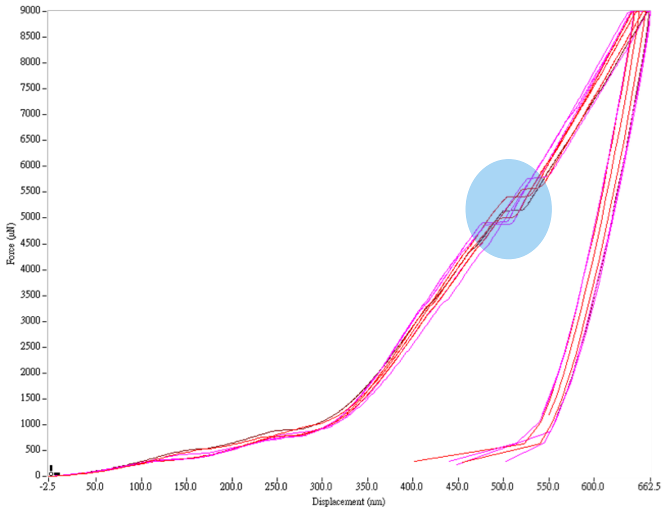
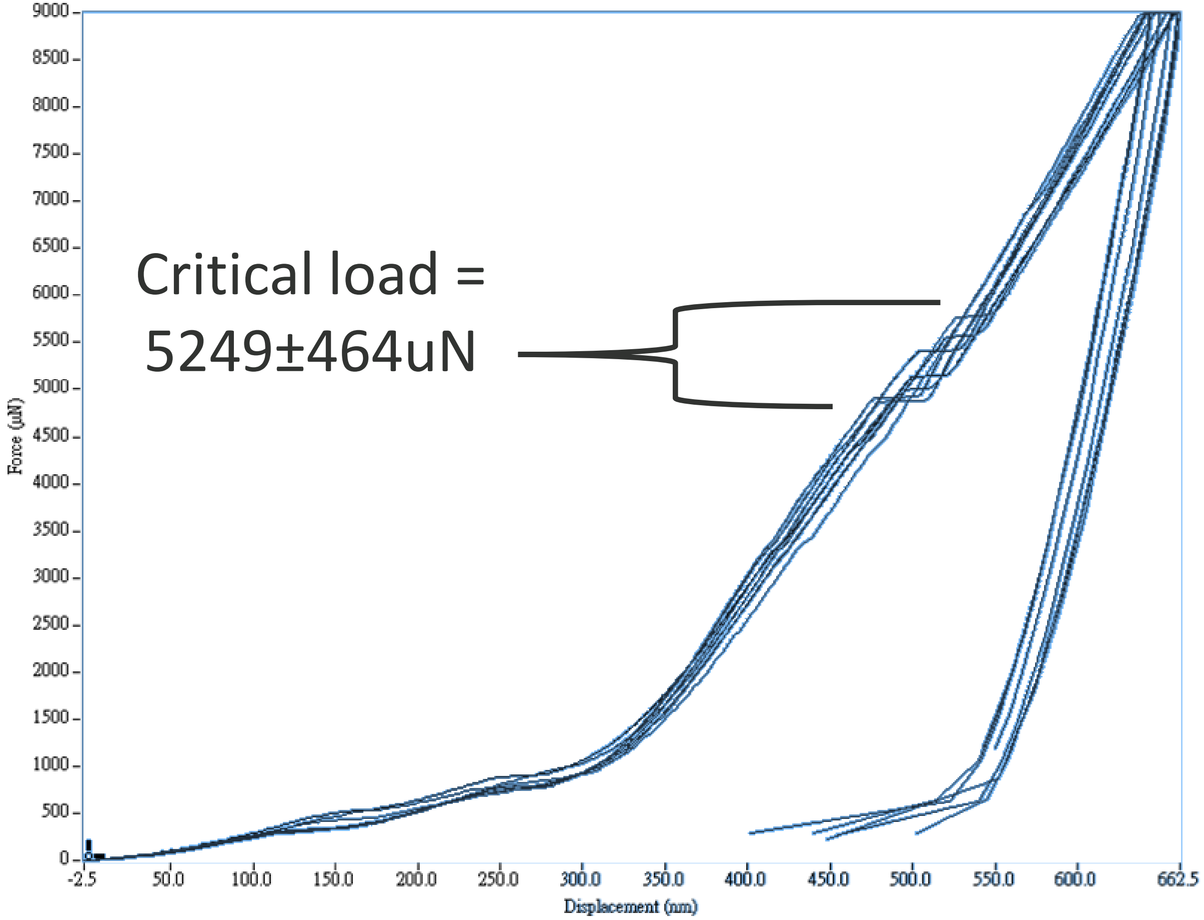


Figure 3: Cu-W alloy modulus map overlaid on an in-situ SPM image.

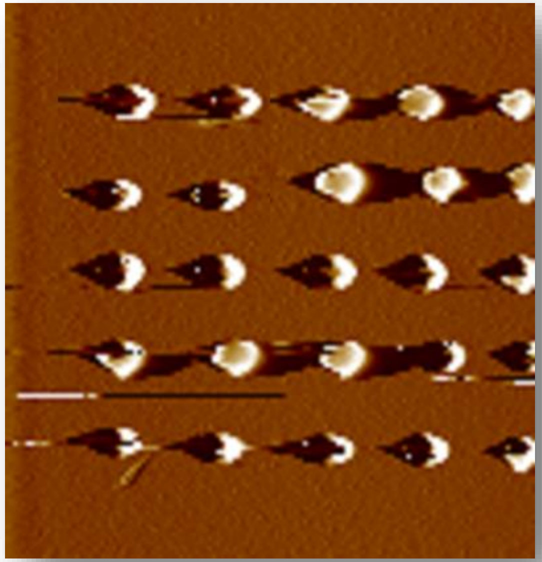


Indentation-Induced Delamination Using XPM

Totally 25 indents on low-k film



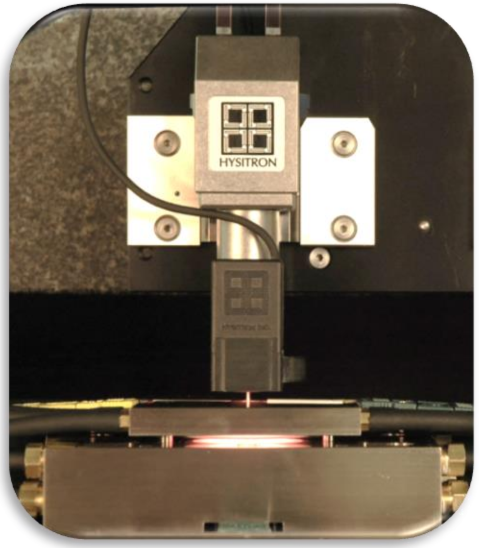
Post-SPM image after XPM



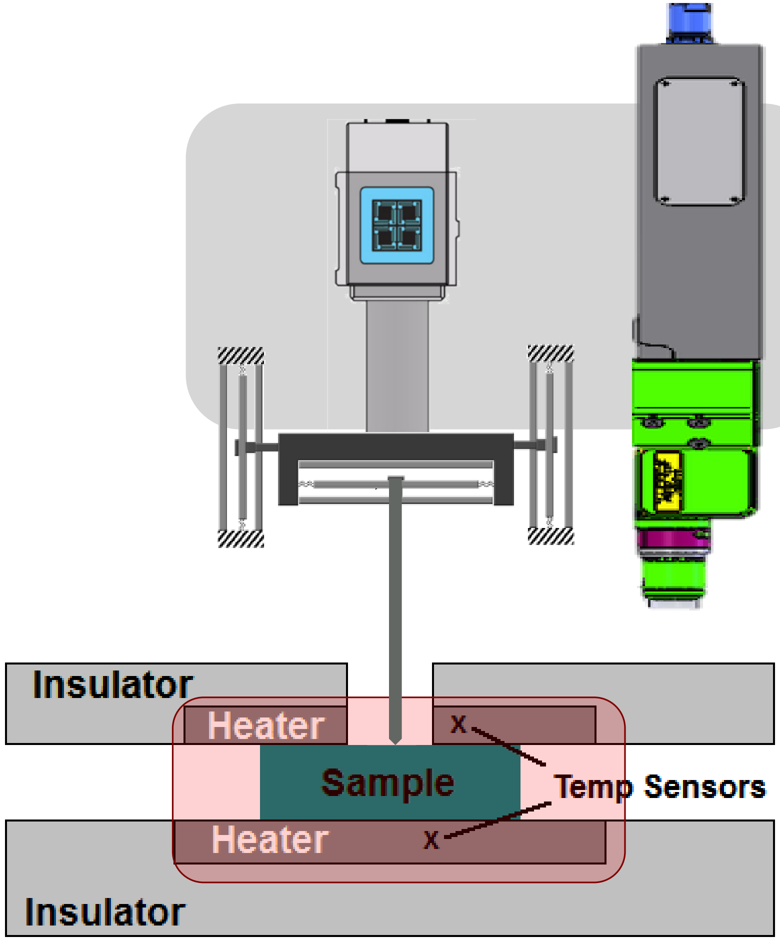
Cube corner tip
Applied load: 9mN
Array: 5x5 @ 30s
Spacing: 15um

Challenges at Elevated Temperature

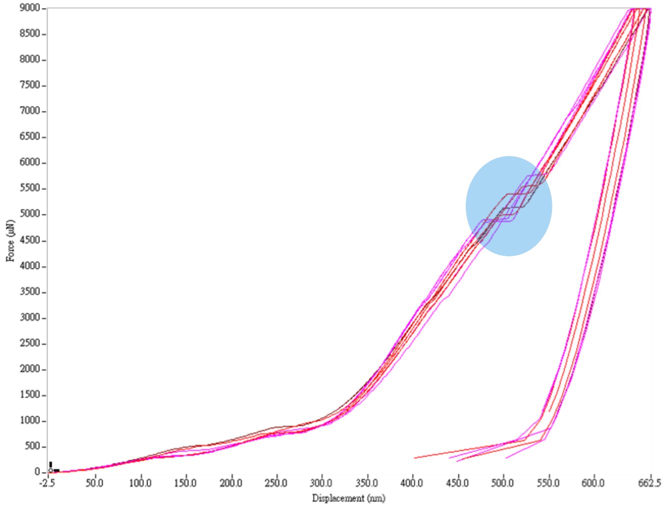
XPM Indentation at Elevated Temperature



xSol heating on TI980



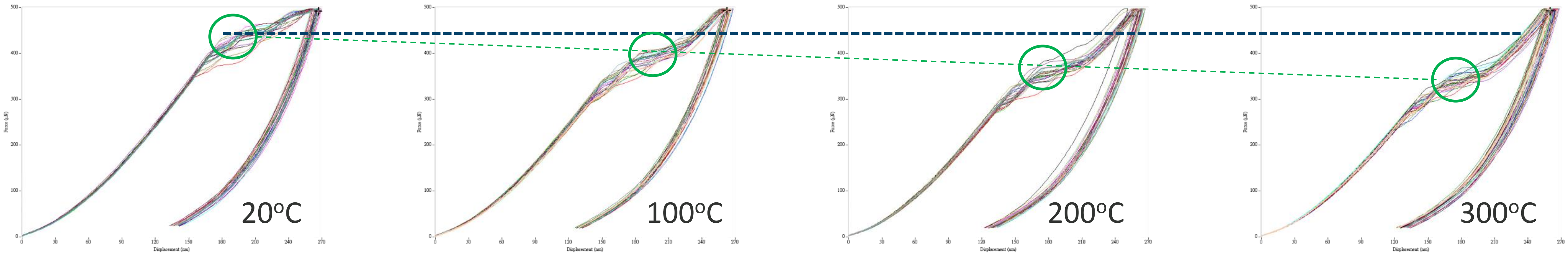
XPM at high temperature



XPM Results at Different Temperature Levels

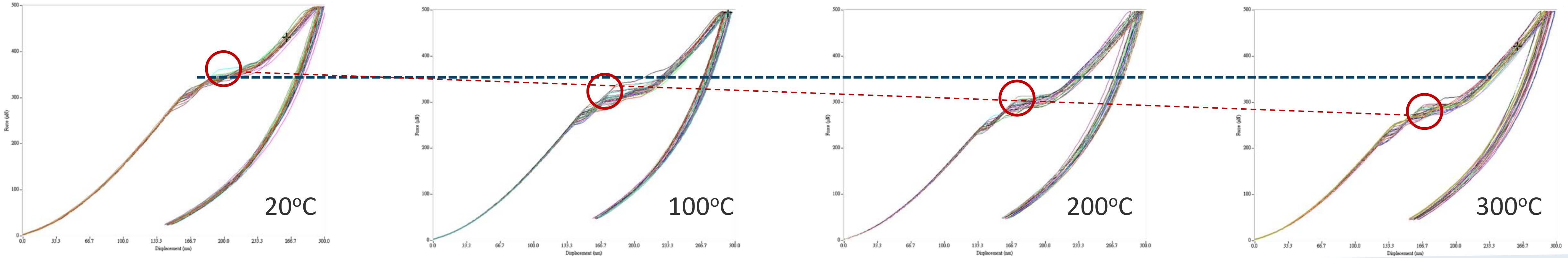
Low-k Films on Silicon

Sample 2

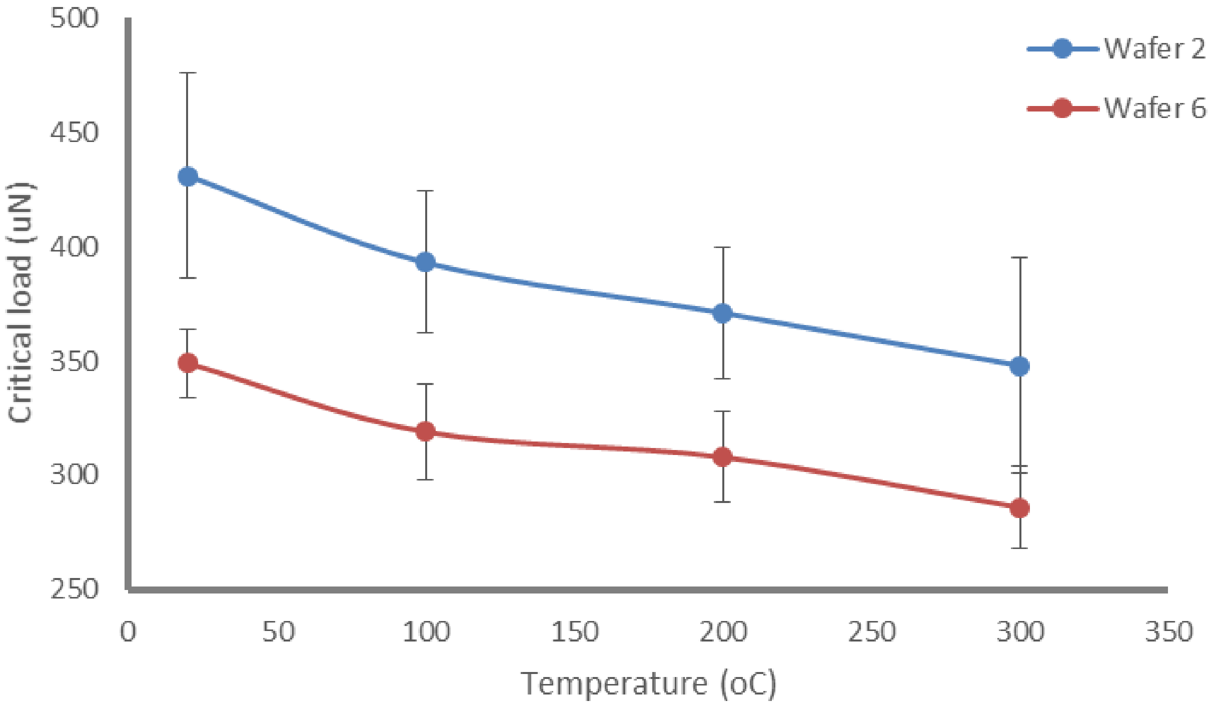


: Baseline of critical load at 20°C

Sample 6



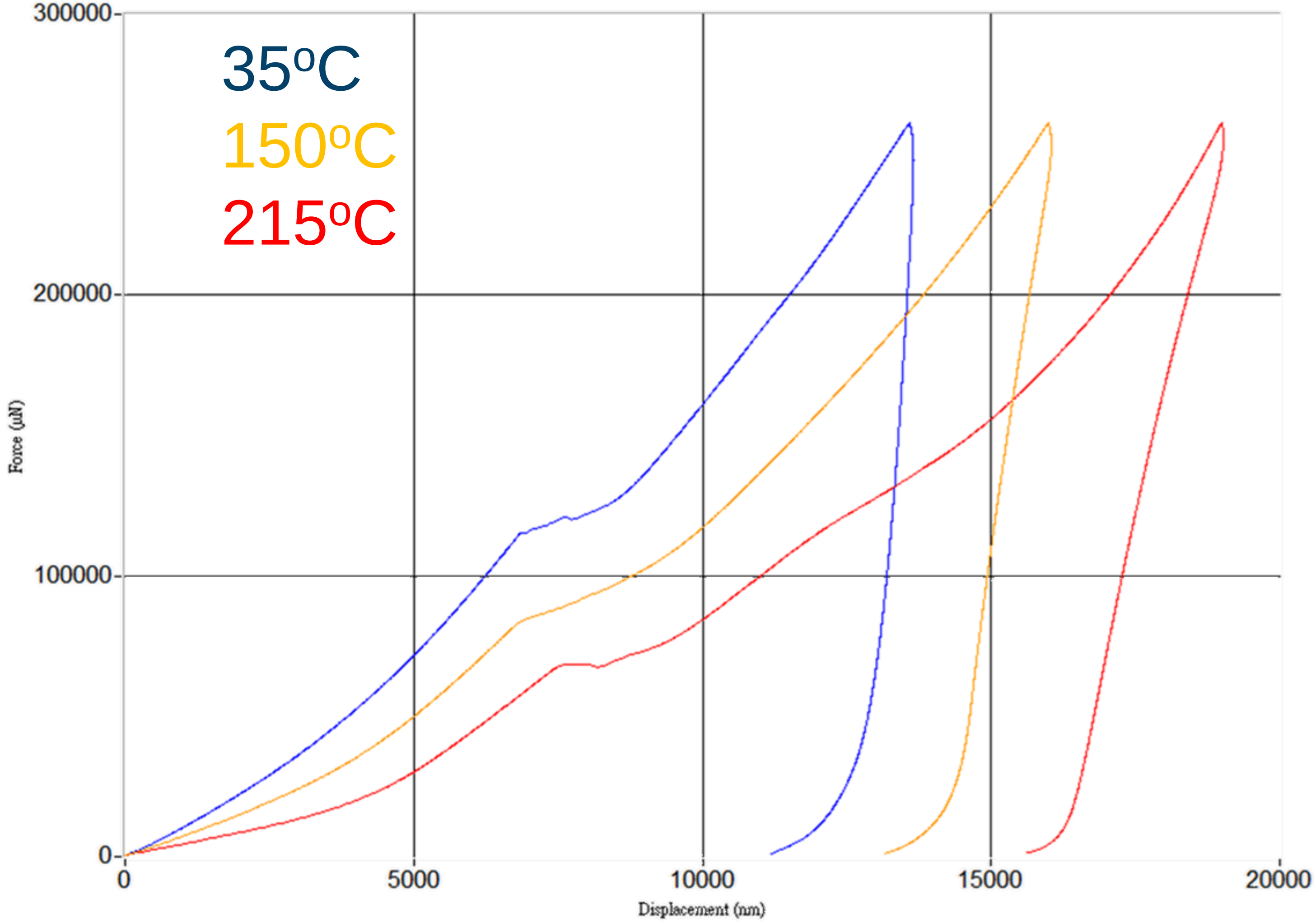
Comparison of Critical Load Results at All Temperature Levels
Low-k Films on Silicon



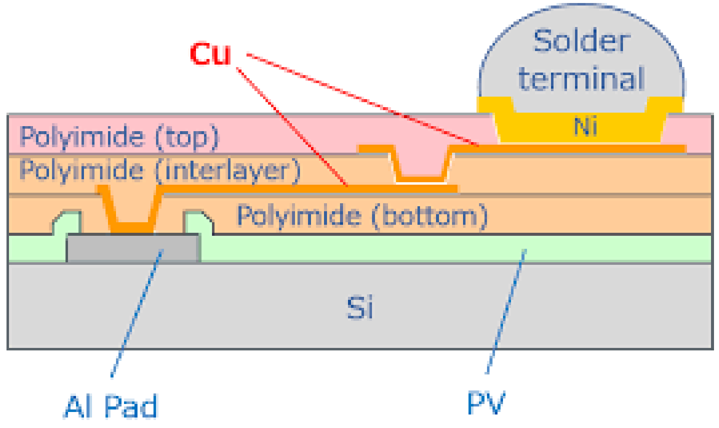
Wafer 2	20°C	100°C	200°C	300°C
ave (uN)	431	393	371	348
std (uN)	45	31	29	47
cv	10.4%	7.9%	7.8%	13.5%

Wafer 6	20°C	100°C	200°C	300°C
ave (uN)	349	319	308	286
std (uN)	15	21	20	18
cv	4.3%	6.6%	6.5%	6.3%

High Load Indentations at Elevated Temperature
Polymer Film on Copper

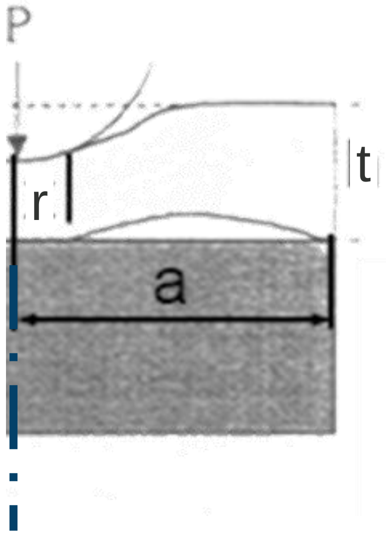


T (ºC)	L_{crit} (uN)	H (GPa)	E (GPa)
35	115218.2	0.4963	6.02
150	84091.46	0.3906	4.69
215	68276.05	0.1101	1.59

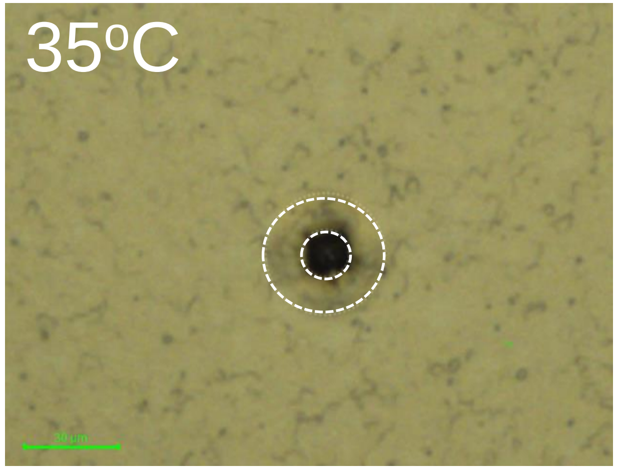


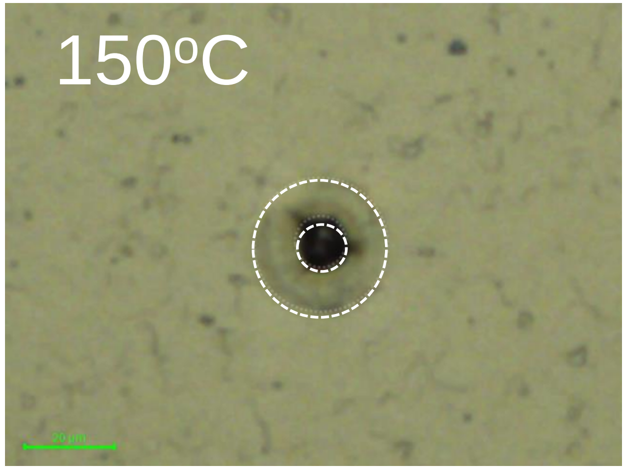
https://halocarbon.com/more-than-moore-through-advanced-semiconductor-packaging/

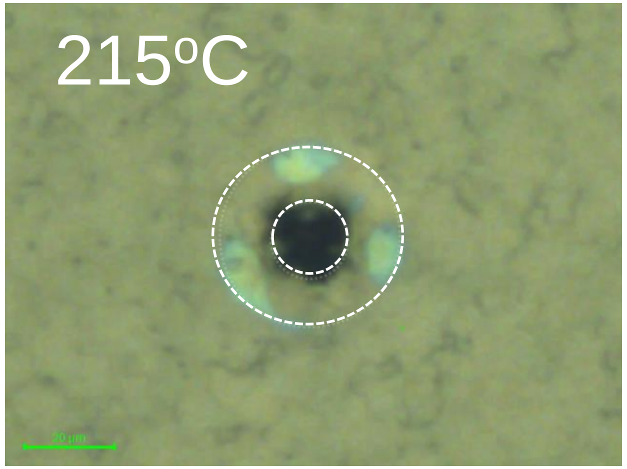
Adhesion Work Calculation at Temperature Levels
Polymer Film on Copper



Post Optical image







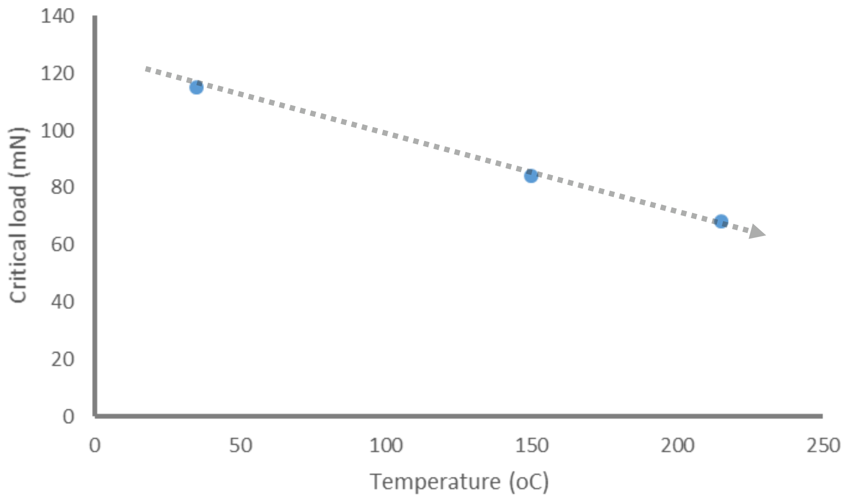
$$G = \frac{0.627 \cdot H^2 \cdot t \cdot (1-\nu^2)}{E} \cdot \left(\frac{1}{1+\nu+(a/r)\cdot(1-\nu)}\right)^2$$

L.G. Rosenfeld, et al., *Journal of Applied Physics* **1990**, *67(7)*, 3291

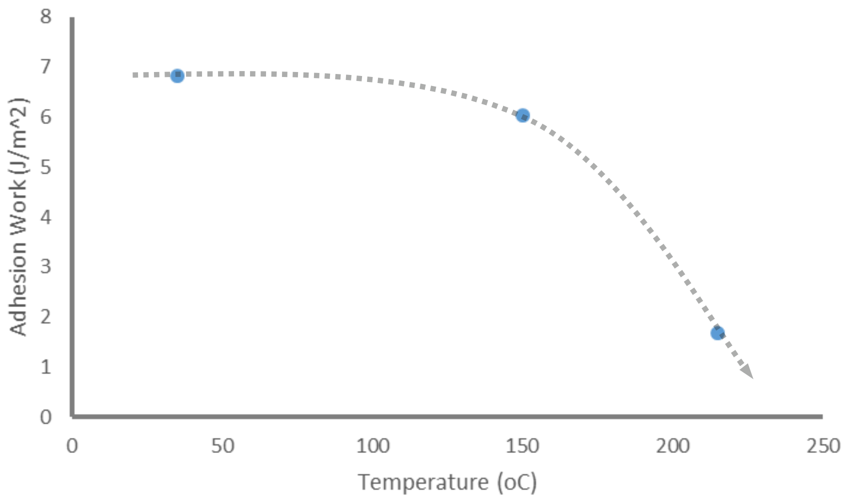
v	H (GPa)	T (ºC)	E (GPa)	t (nm)	L_{crit} (uN)	a (um)	r (um)	G (J/m^2)
0.3	0.49	35	6.02	10000	115218.2	30.3	11.5	6.81
0.3	0.39	150	4.69	10000	84091.5	40.7	16.0	6.04
0.3	0.11	215	1.59	10000	68276.1	41.9	17.4	1.68

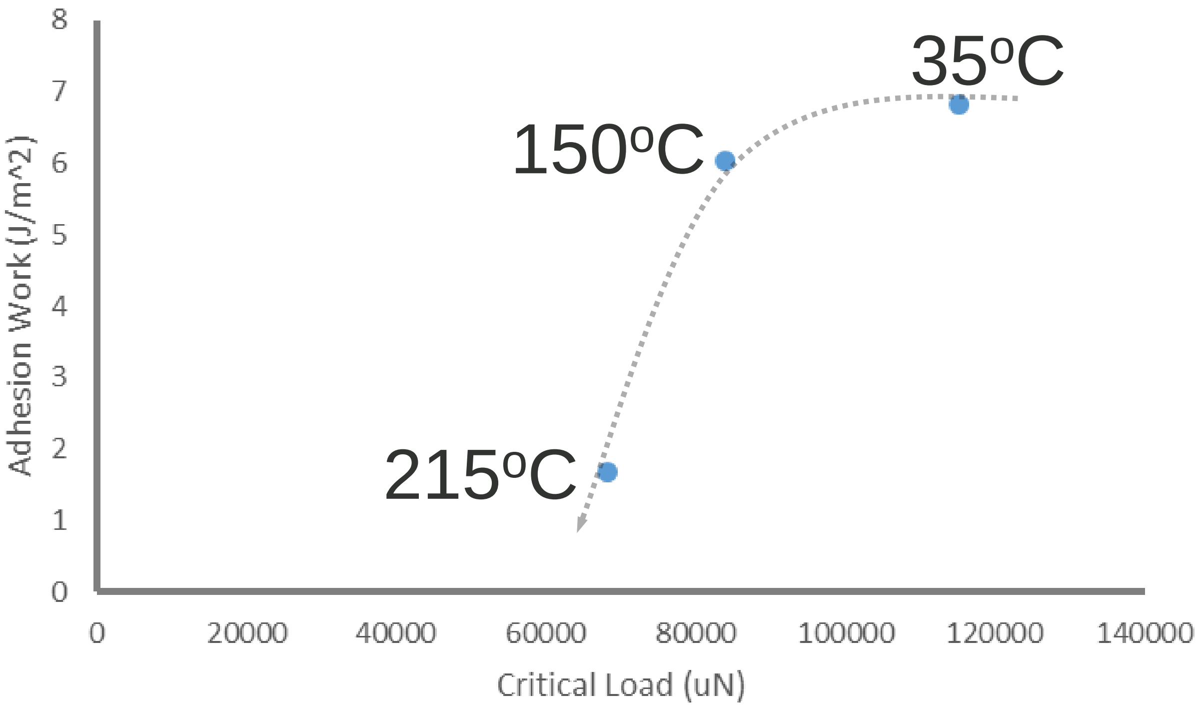
Poisson ratio is assumed to be 0.3 at all temperature levels.

Adhesion Work Calculation at Temperature Levels
Polymer Film on Copper



H (GPa)	T (^oC)	E (GPa)	Lcrit (uN)	G (J/m^2)
0.49	35	6.02	115218.2	6.81
0.39	150	4.69	84091.5	6.04
0.11	215	1.59	68276.1	1.68

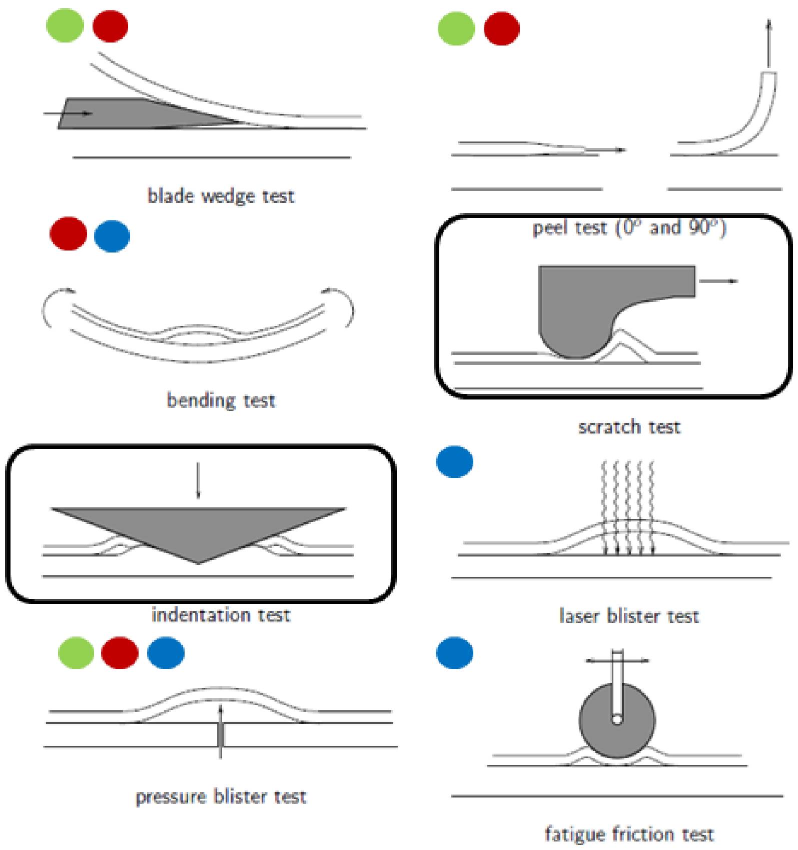


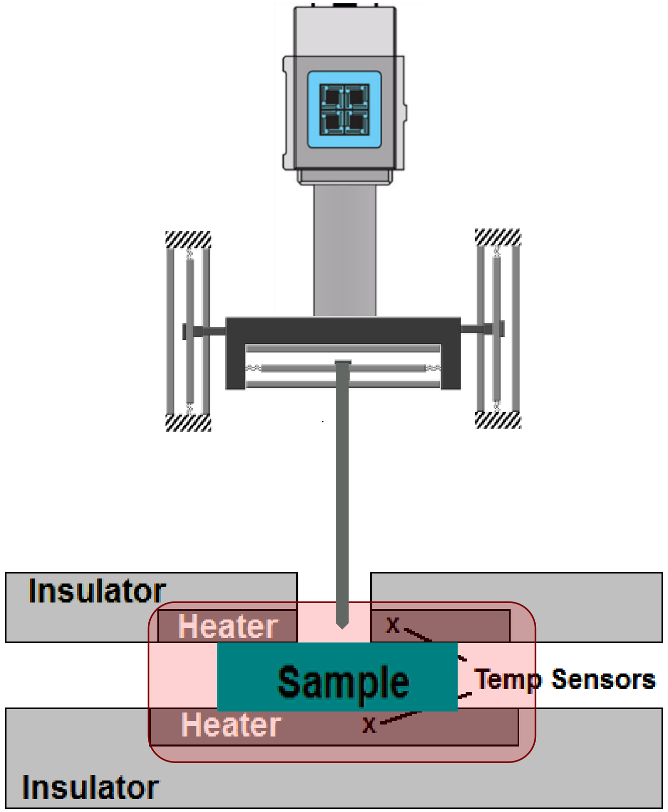


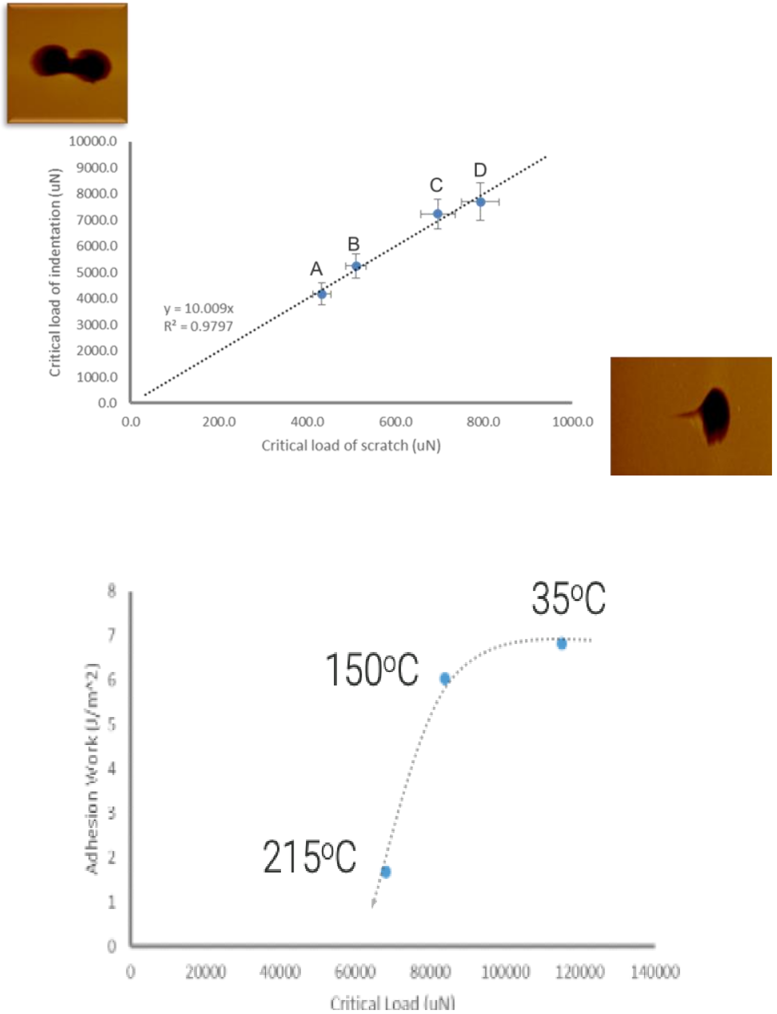
Take Away

Take Away

- special sample preparation
- Low spatial resolution
- Ex-situ measurement







Thank you!

PJ Wei
Pal-Jen.Wei@bruker.com