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CORRELATIVE NANOMECHANICAL MEASUREMENTS

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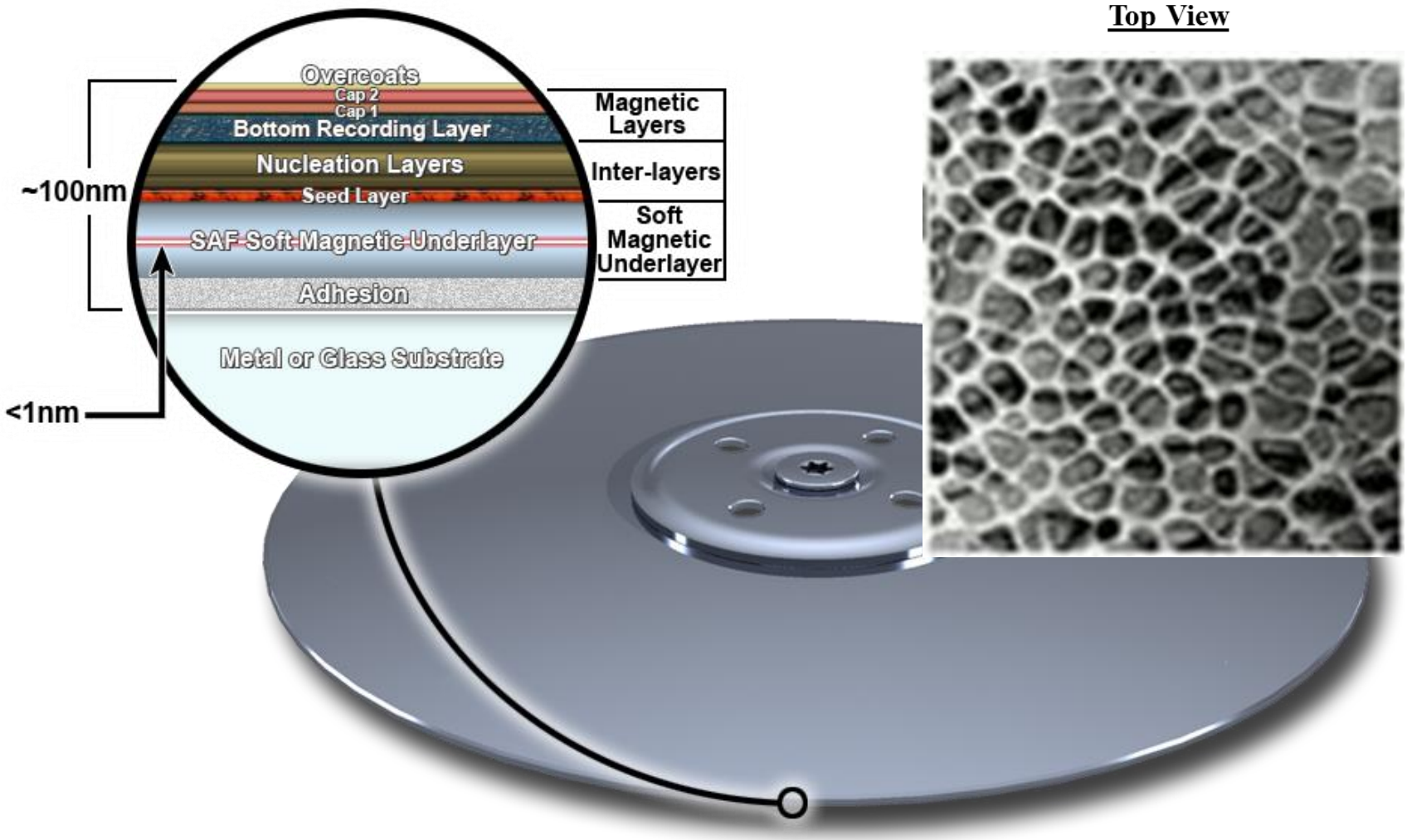
CORRELATIVE NANOMECHANICAL MEASUREMENTS FOR COMPLEX ENGINEERED SYSTEMS

Anonymous Collaborators!!!

Complex, Engineered, System



I. Understanding damage mechanisms

1. Co-deposited films for a direct comparison

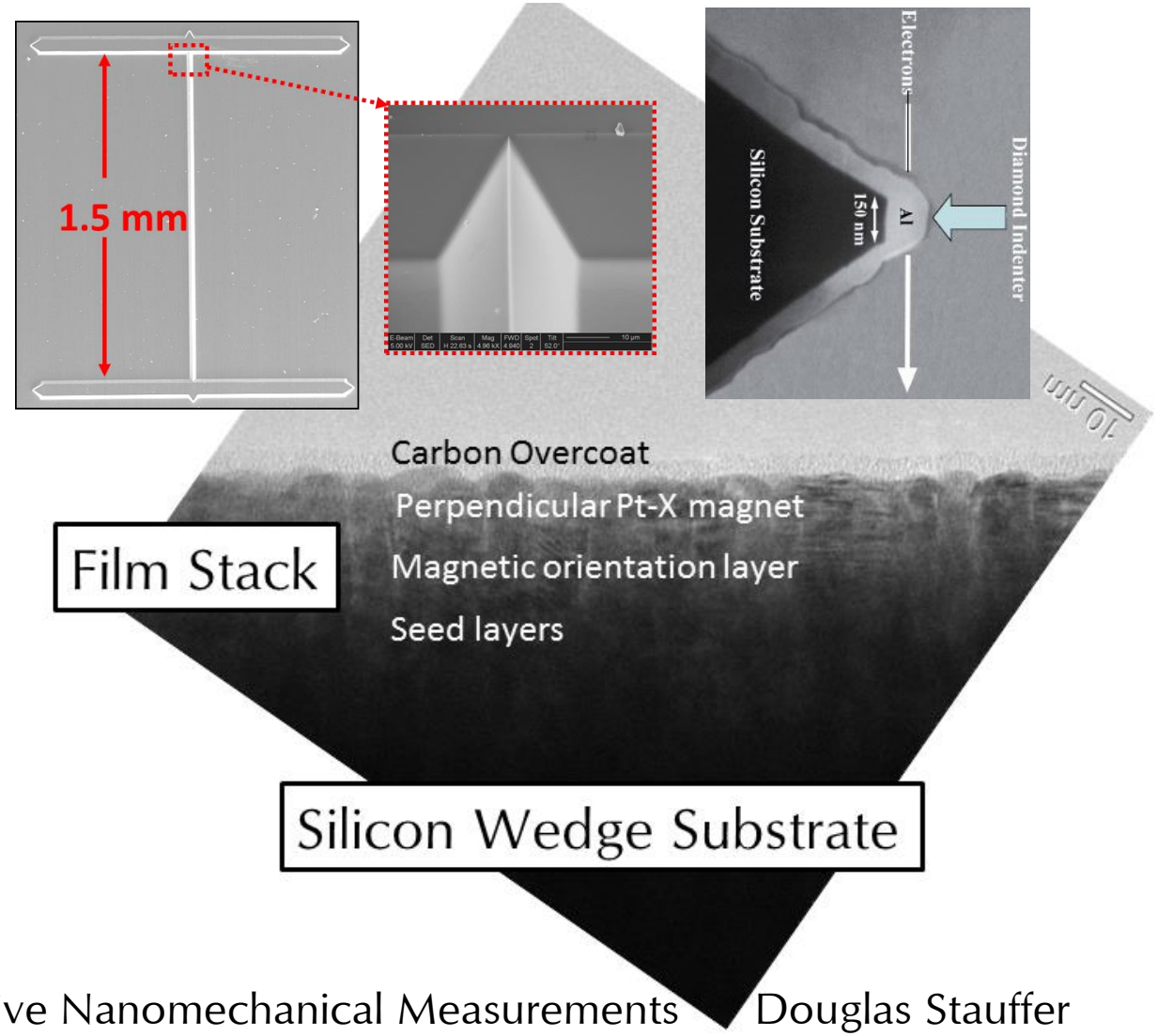
   between *in* and *ex situ* mechanical testing

2. Indentation to look at controlled stress-field statistics
   - Hardness and modulus as a function of depth/strain
3. *In Situ* TEM testing to look at deformation mechanisms
4. *In Situ* TEM scratch testing
   - – moving towards realism in measurements

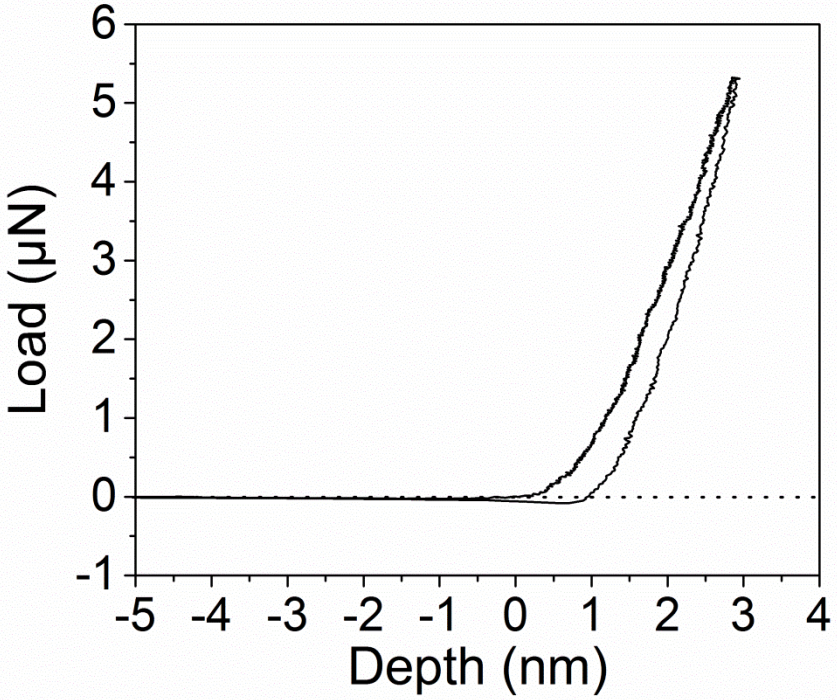
Film Deposition

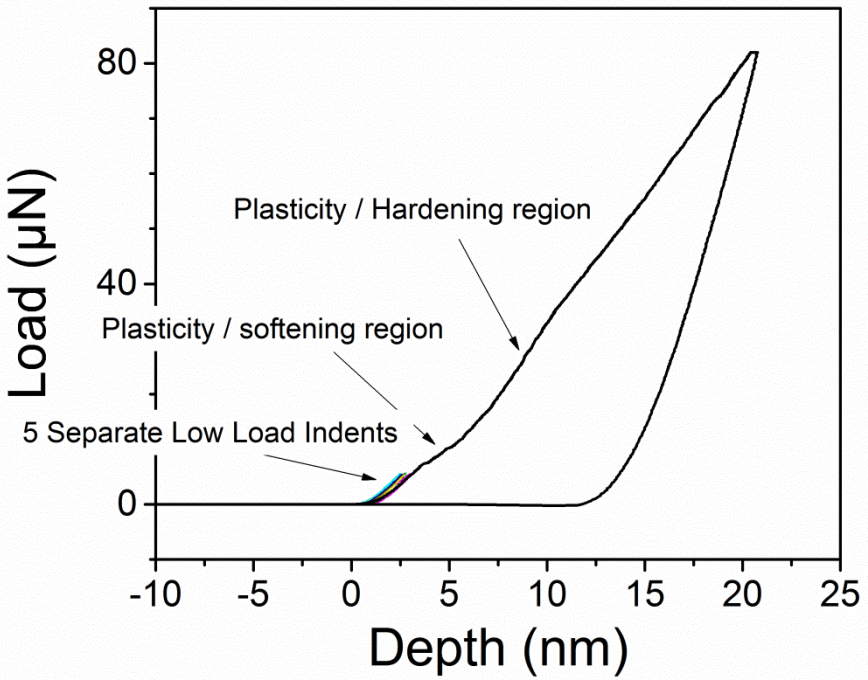
TEM PicoIndenter®

PI 95

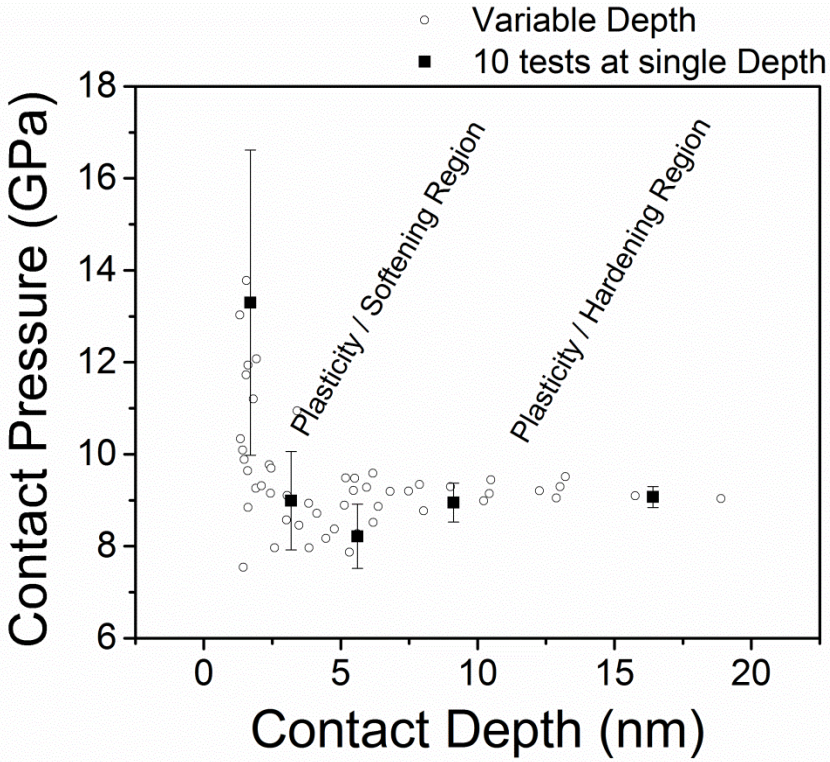


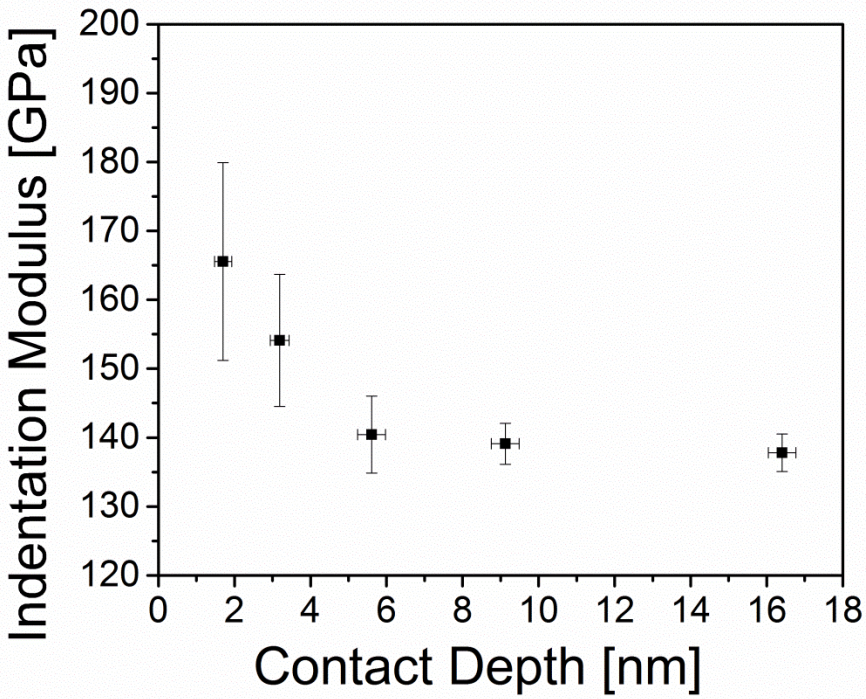
Indentation





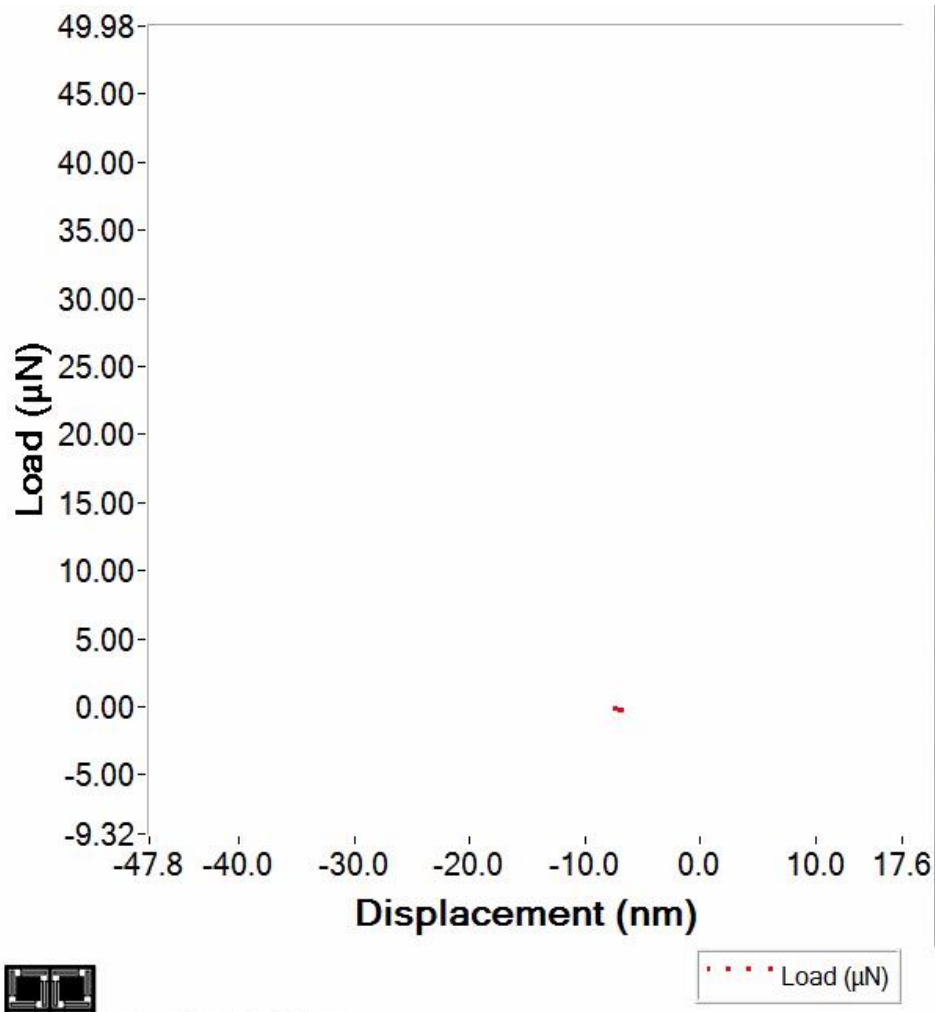
Hardness/Modulus

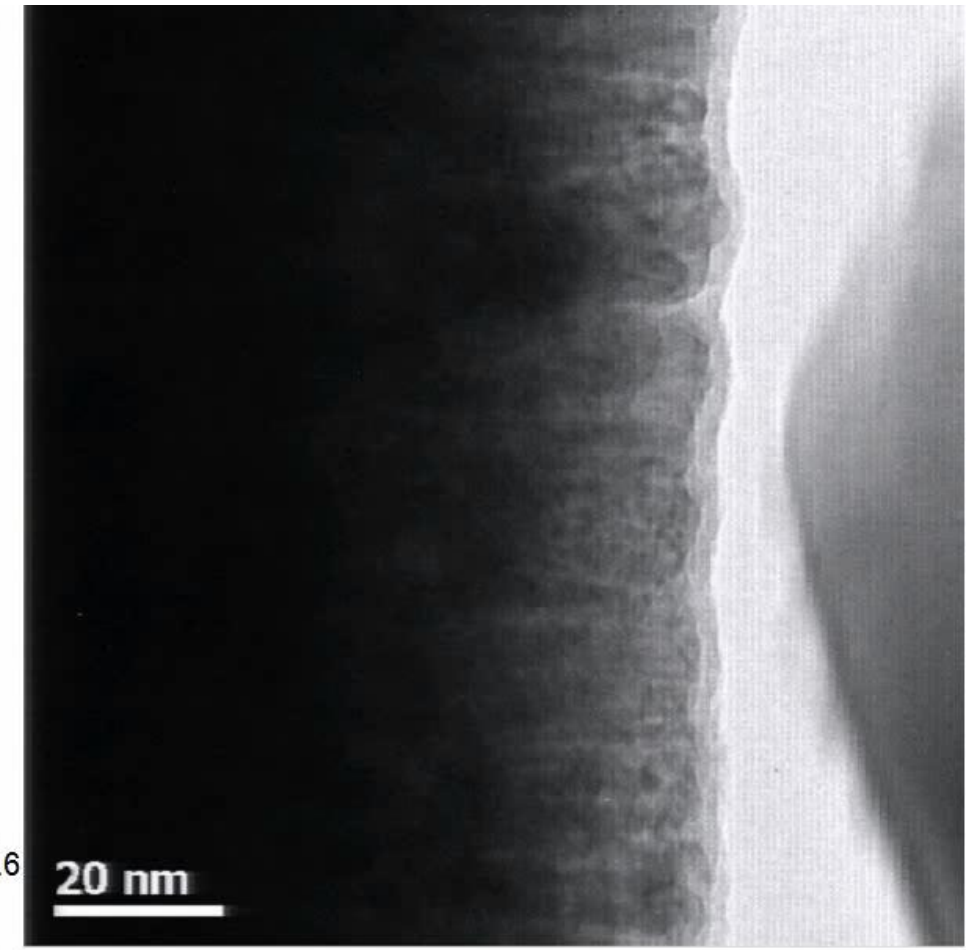




In Situ – Low Load

In Situ – Increasing Load





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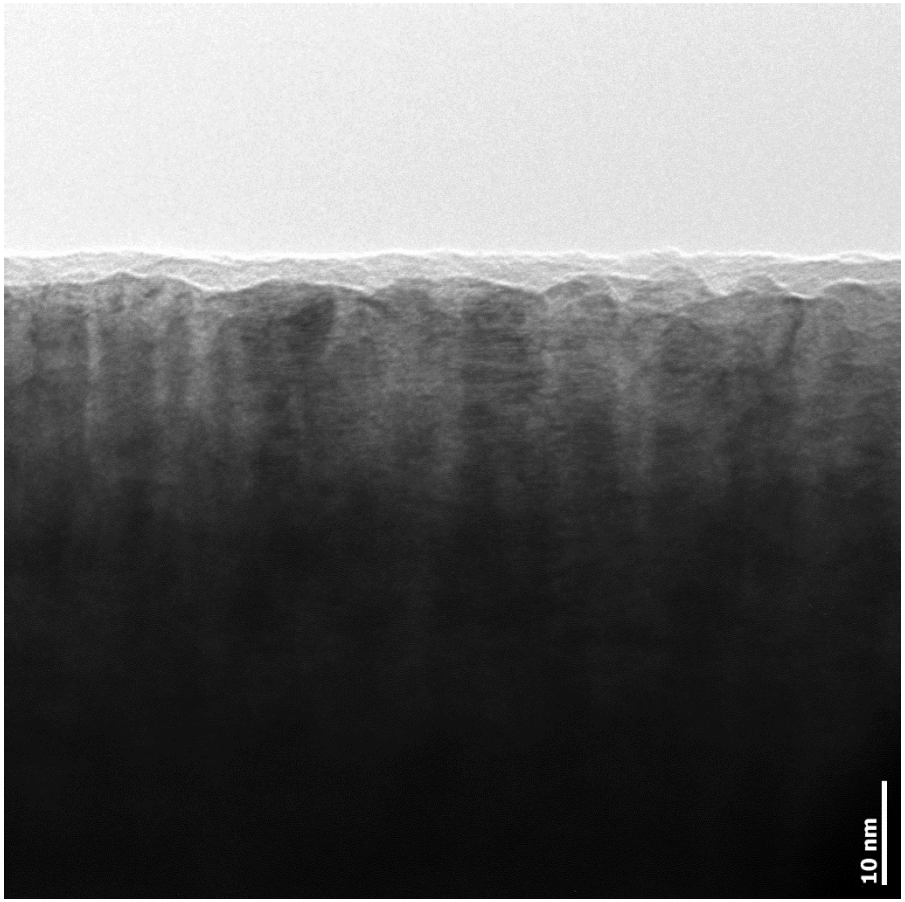
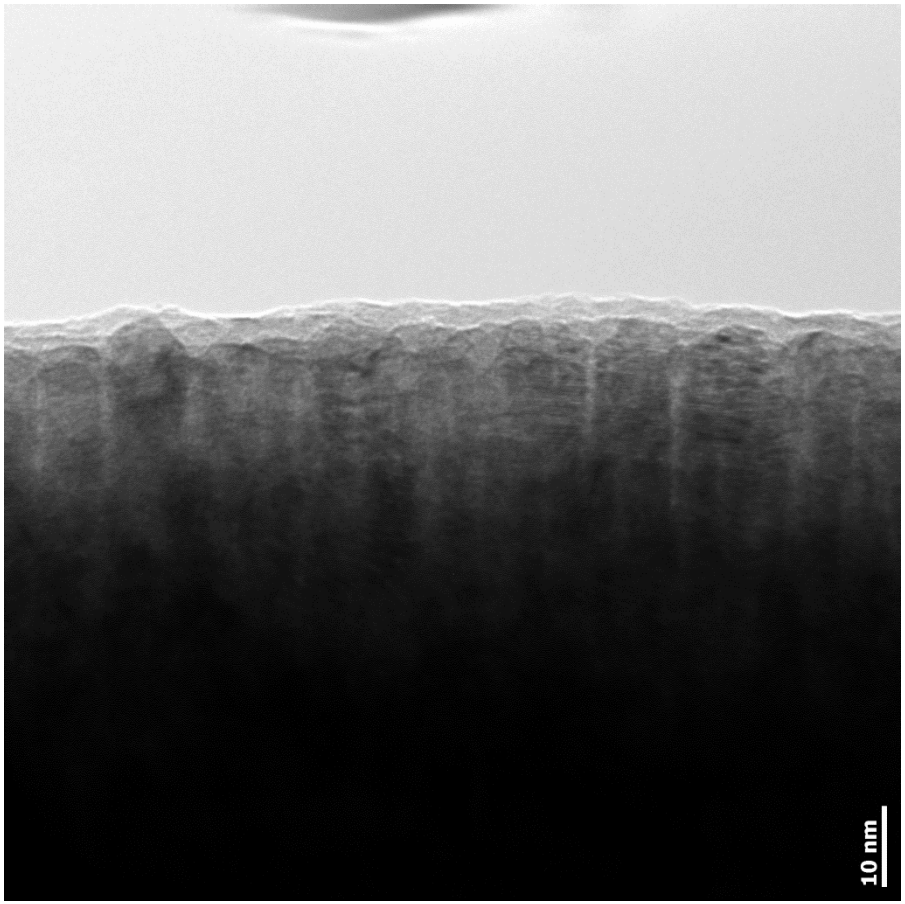
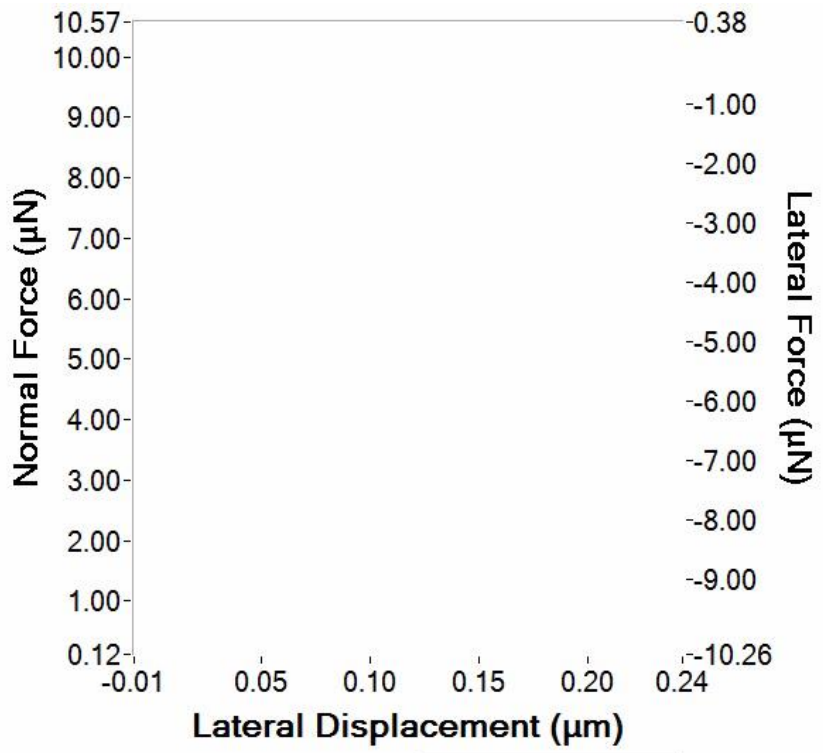
In Situ – Increasing Load

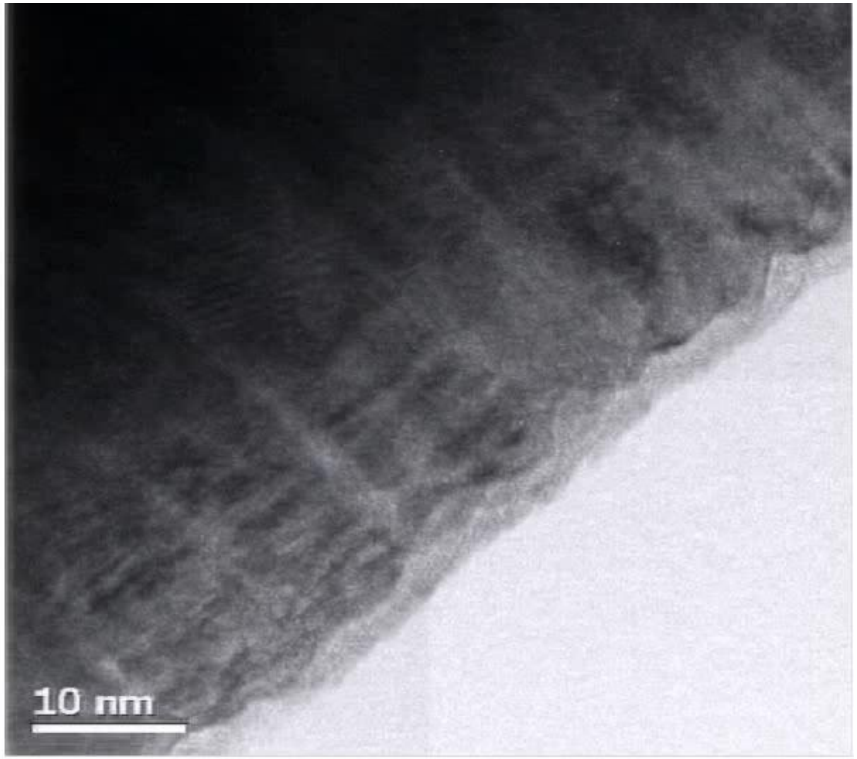


In Situ – Increasing Load

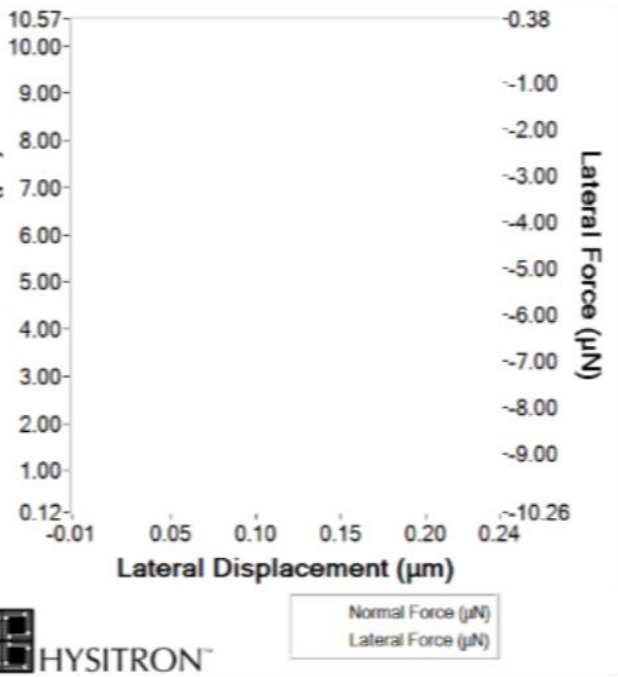


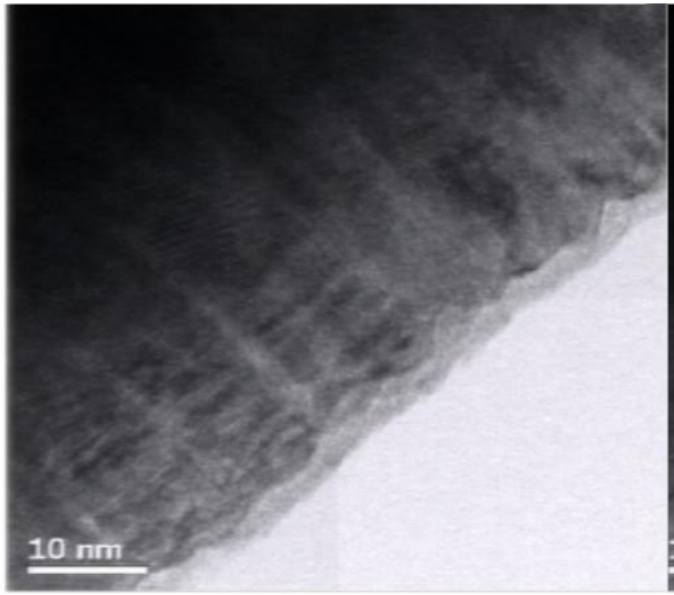
In Situ – Scratch

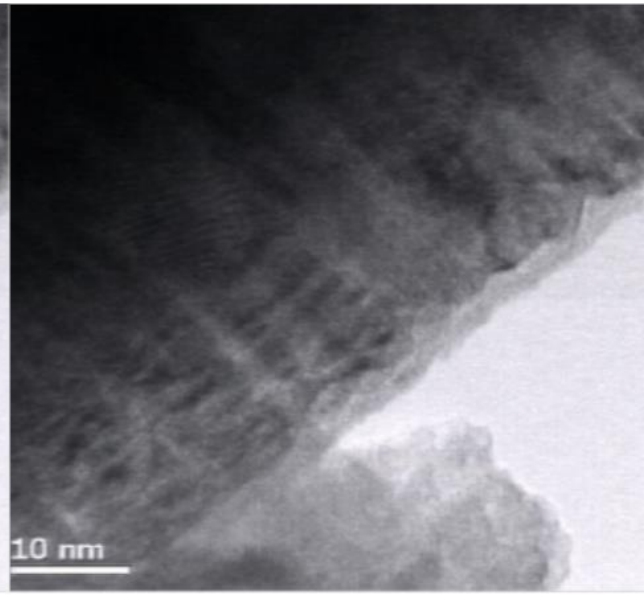




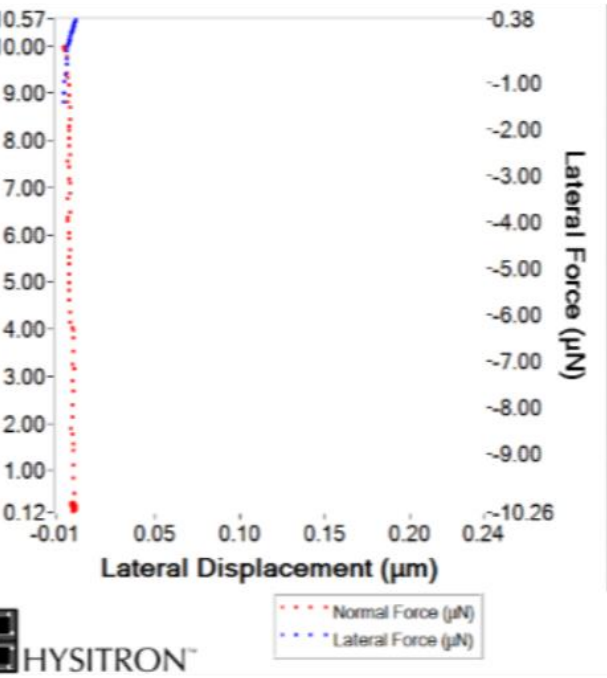
Tribology - Grain Rotation

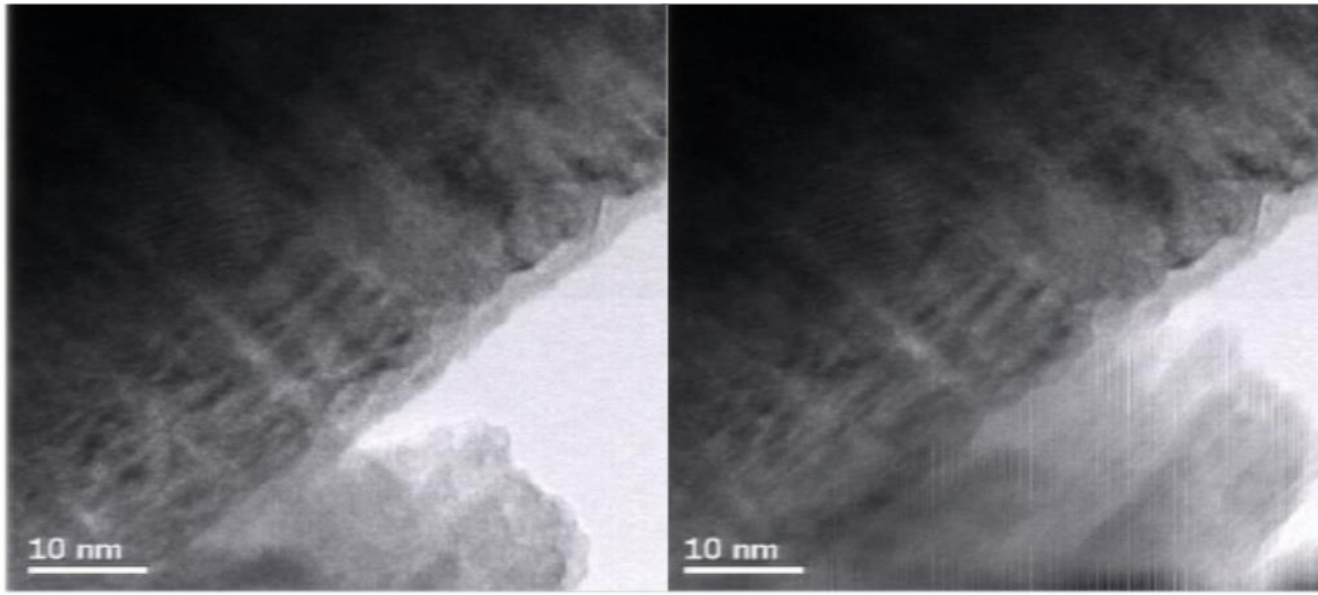






Tribology - Grain Rotation





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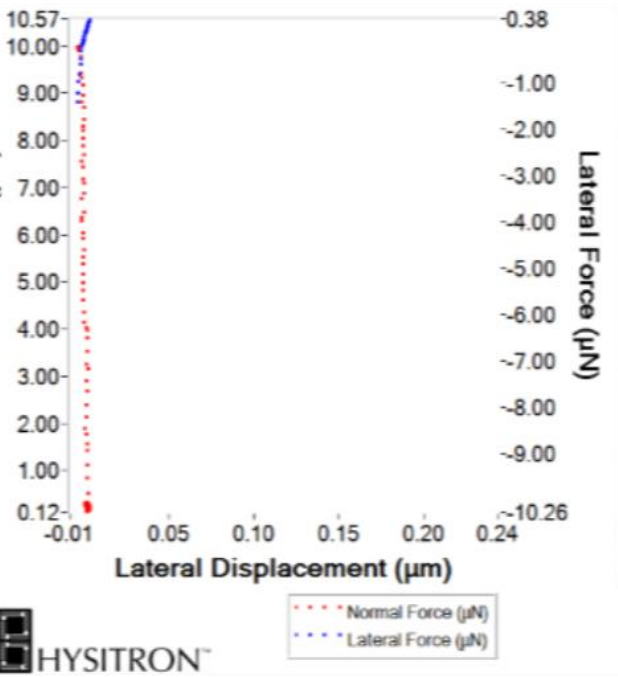
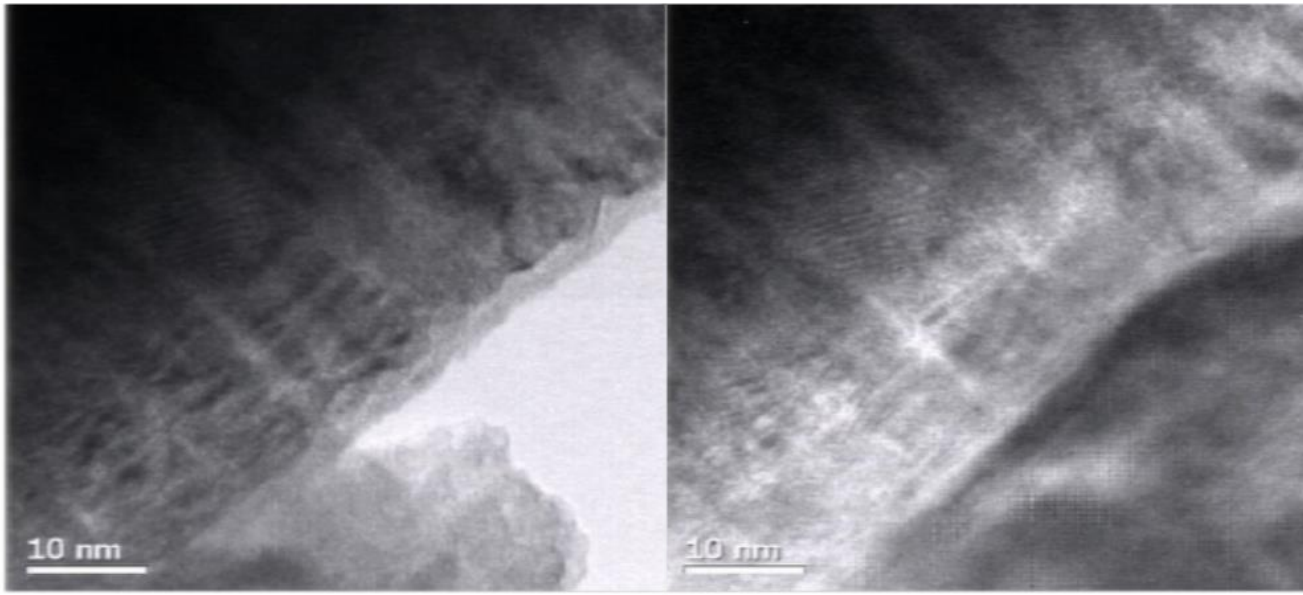
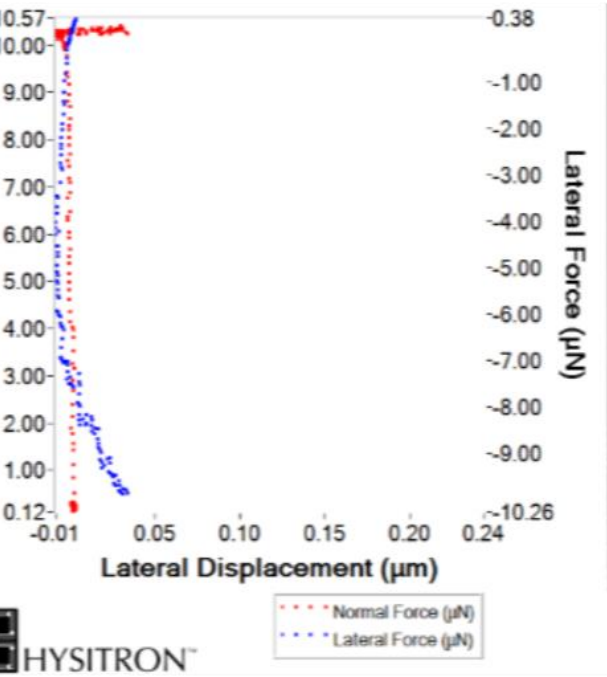
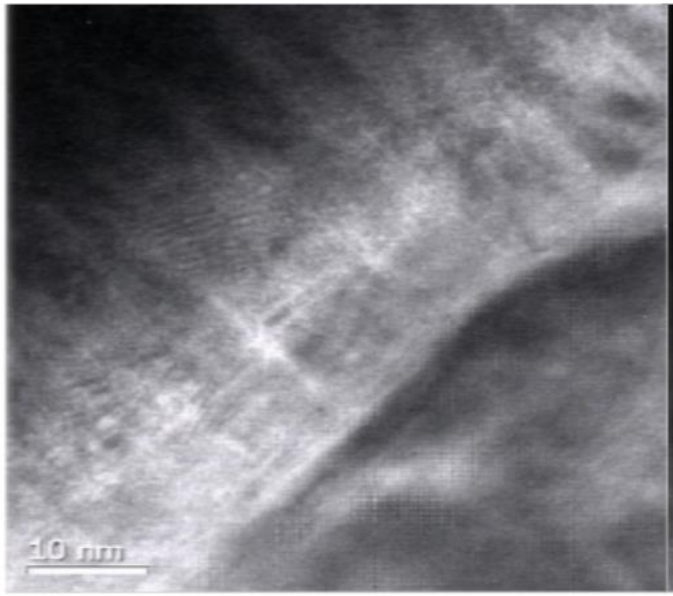
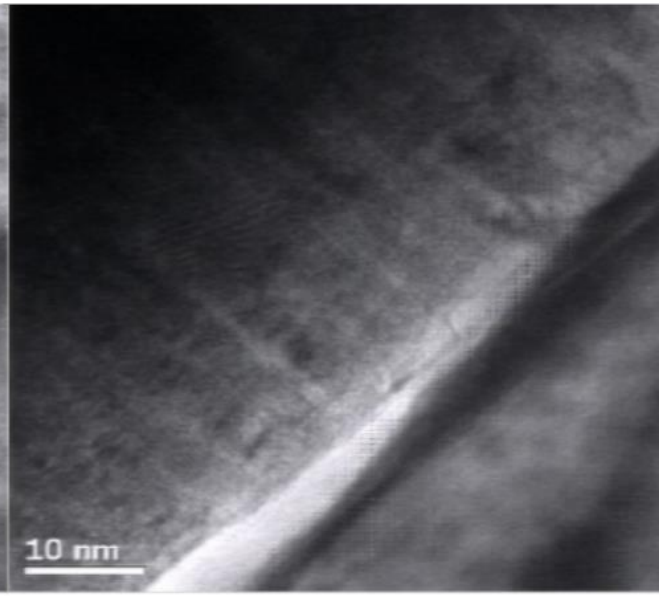




Tribology - Grain Rotation

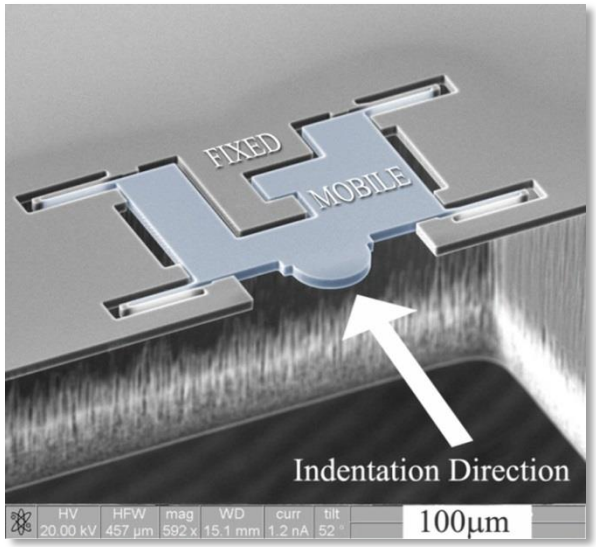


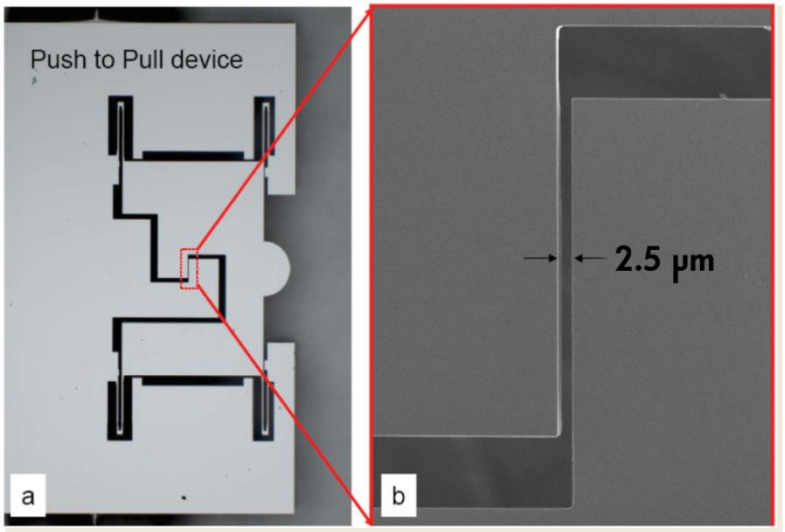




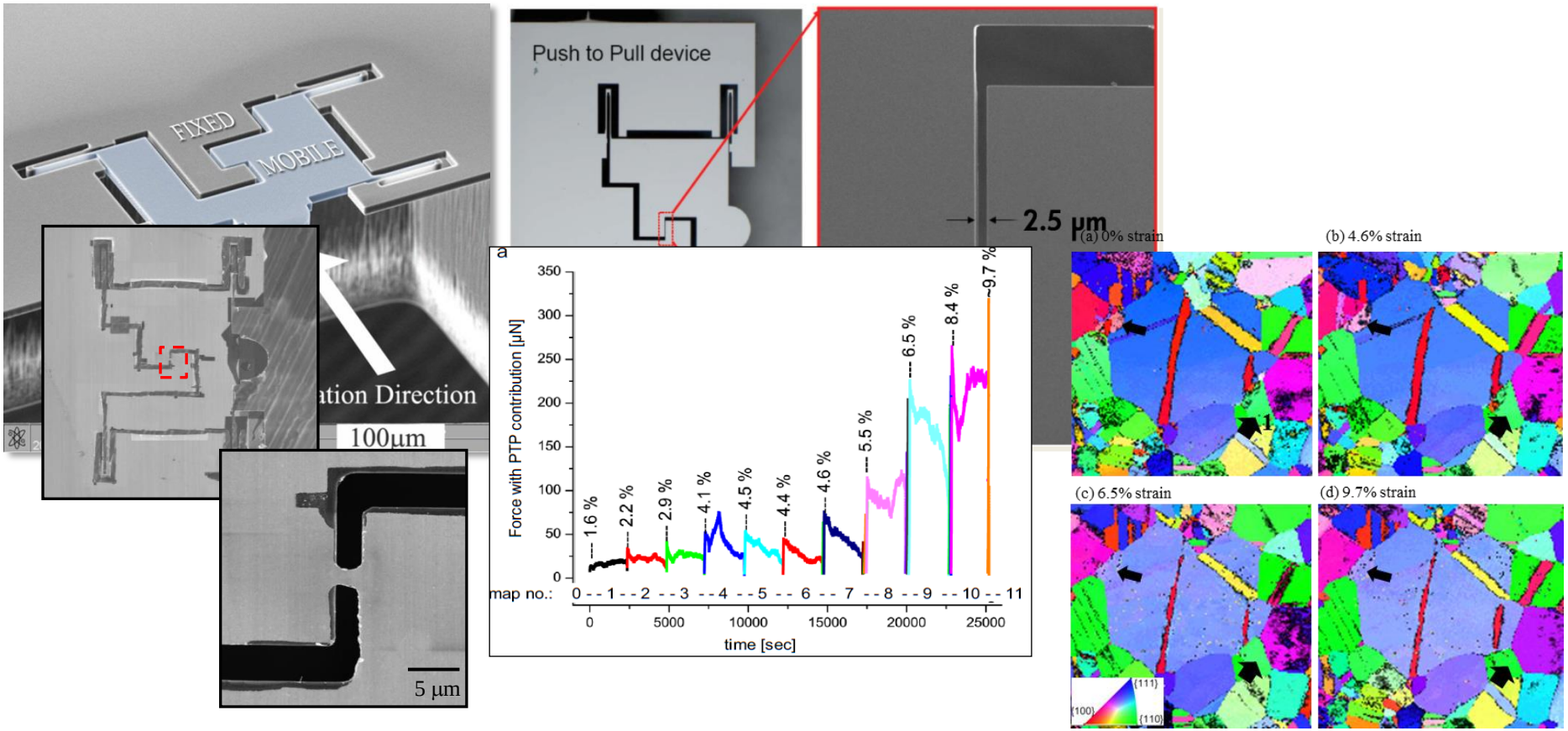
I. Fatigue in Cu thin films

In Situ TEM Tensile Testing





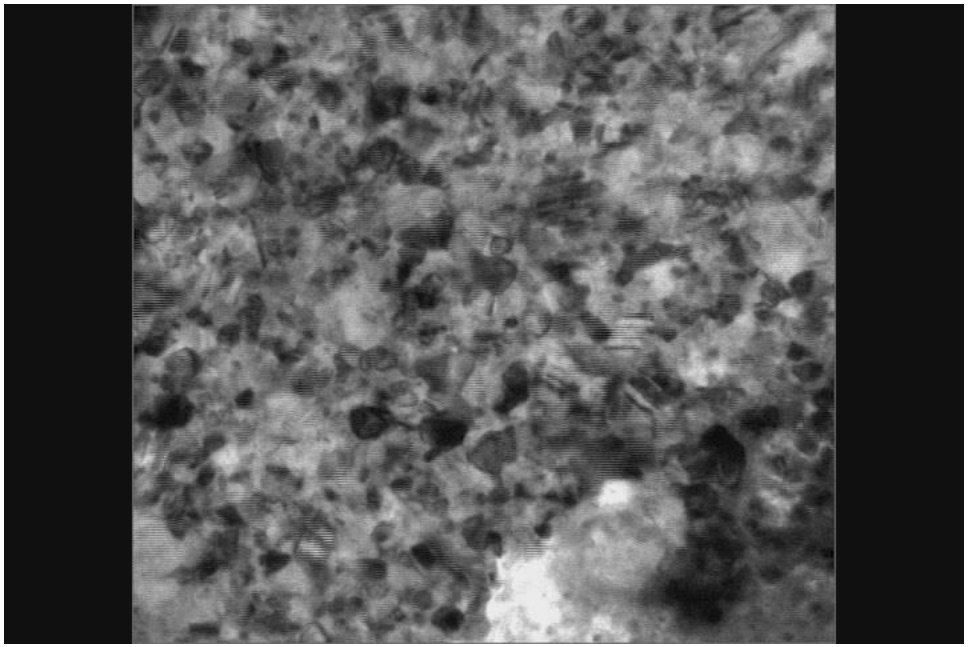
In Situ TEM Tensile Testing



Courtesy Christian Kübel, Karlsruhe Institute of Technology / Karlsruhe Nano Micro Facility

Combination of *in situ* straining and ACOM TEM: a novel method for analysis of plastic deformation of nanocrystalline metals, A. Kobler, A. Kashiwar, H. Hahn, C. Kübel, *Ultramicroscopy*, 128, 68-81 (2013); DOI: 10.1016/j.ultramic.2012.12.019

Crack Initiation



Pull in tension to 150μN

Cycle at 1 Hz

$$R = 0.5 = \frac{P_{min}/A}{P_{max}/A} = \frac{100\mu N}{200\mu N}$$

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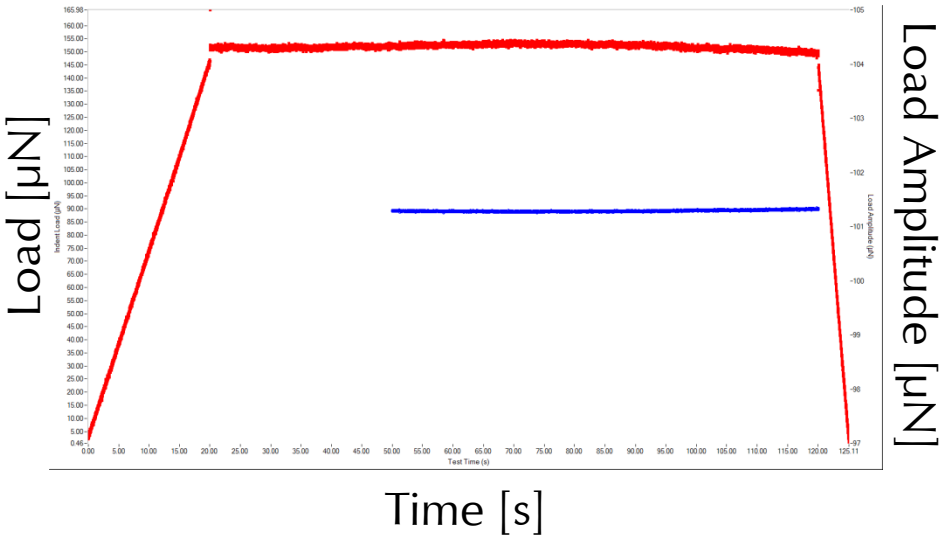
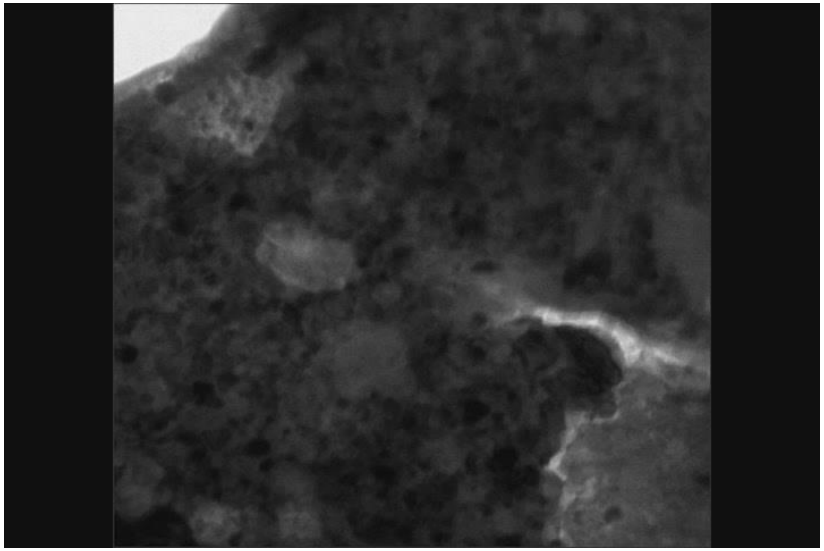
Crack Growth

R = 0.5 @200Hz,





~257,000 cycles

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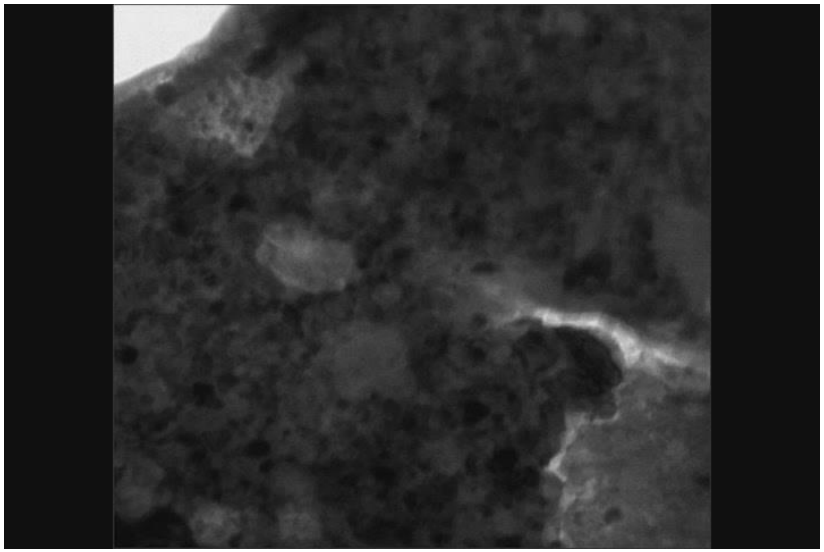
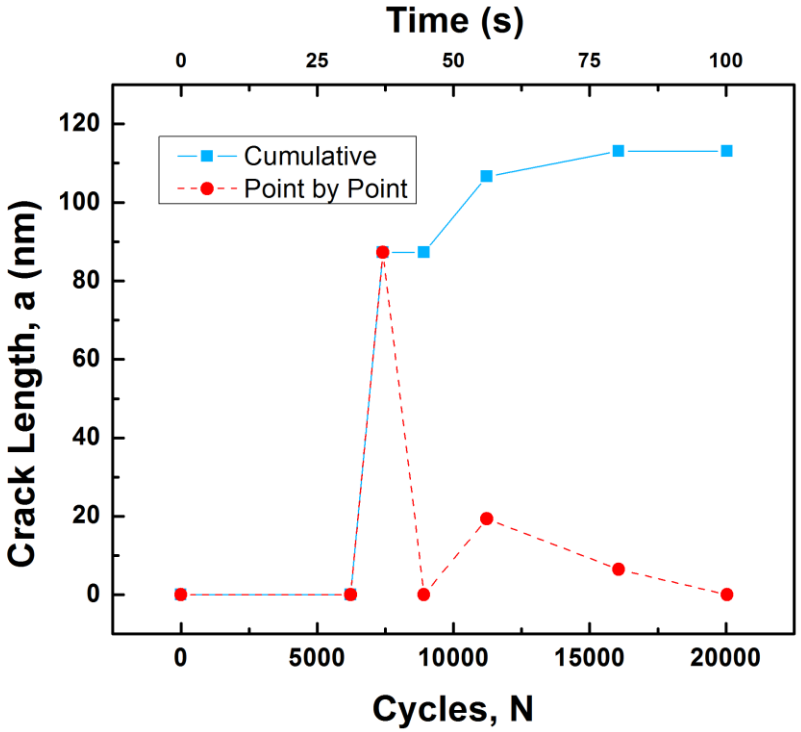
- 256,960 total cycles before this graph starts





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Acknowledgements

Anonymous Industrial Collaborators

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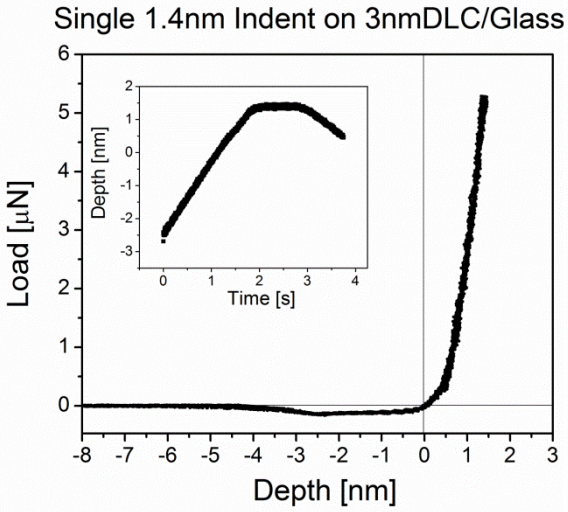
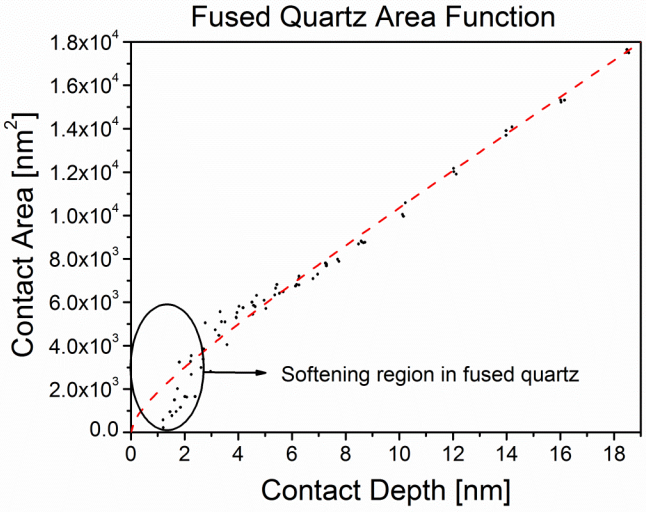
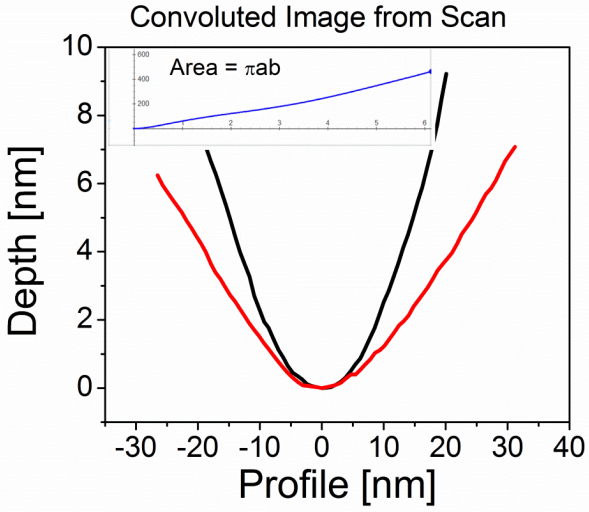
Shallow Indentation: xProbe







Approach from Air
Find positive deflection for zero point

Density of fused quartz changes at sub 4nm contact depths, need to use high resolution tip imaging to find the tip shape for shallow indents