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Sub-Micro-Pillar Compression and Nanoindentation of Nanocrystalline Nickel Tribofilms

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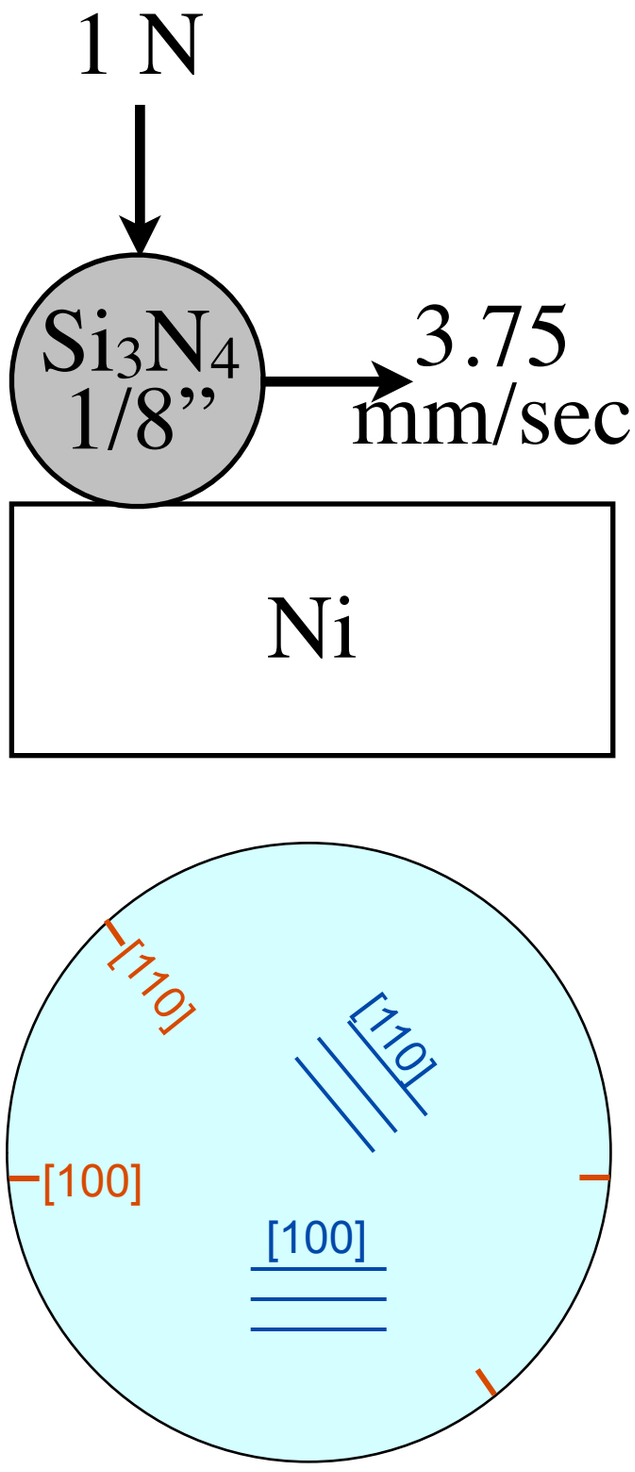
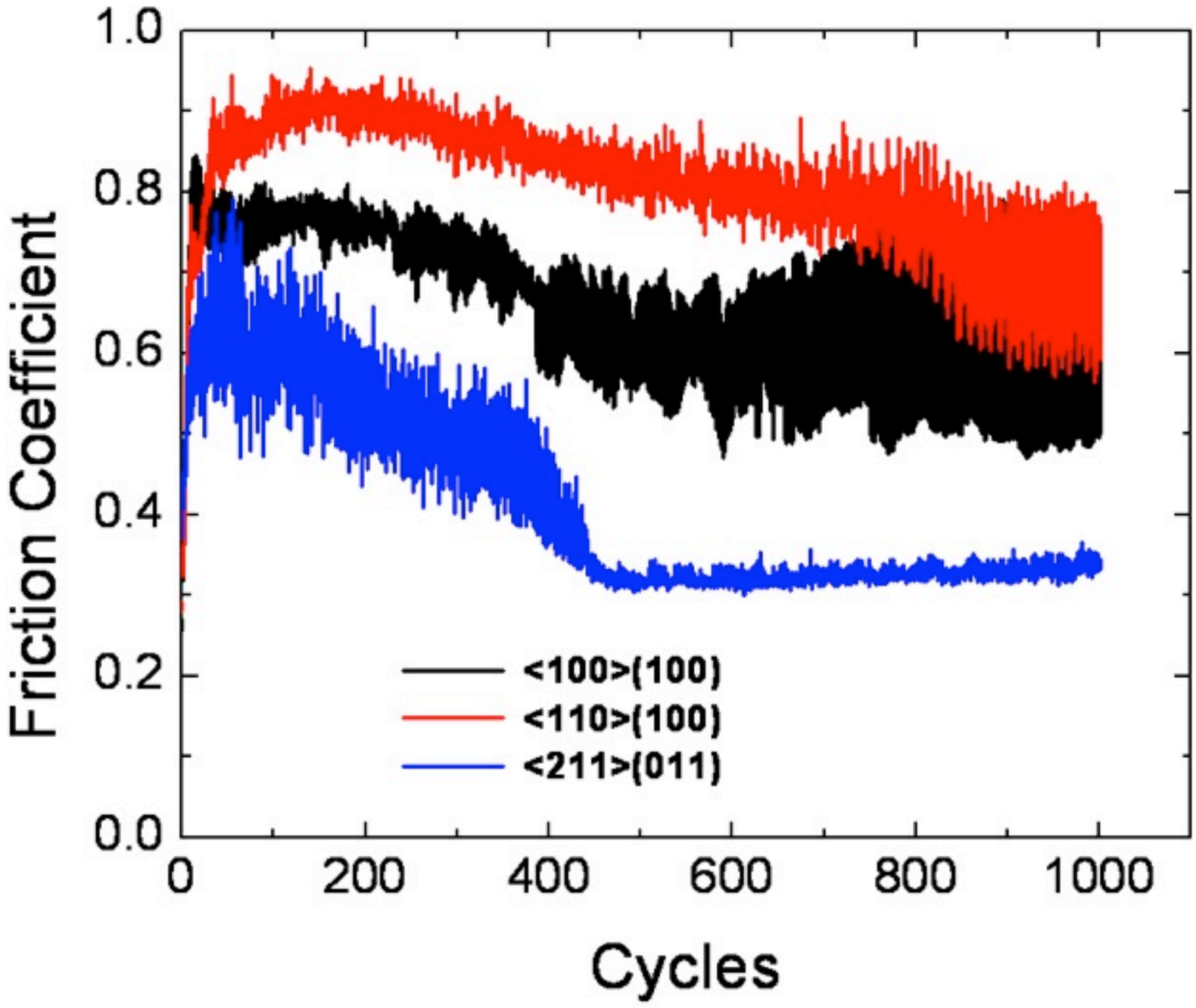
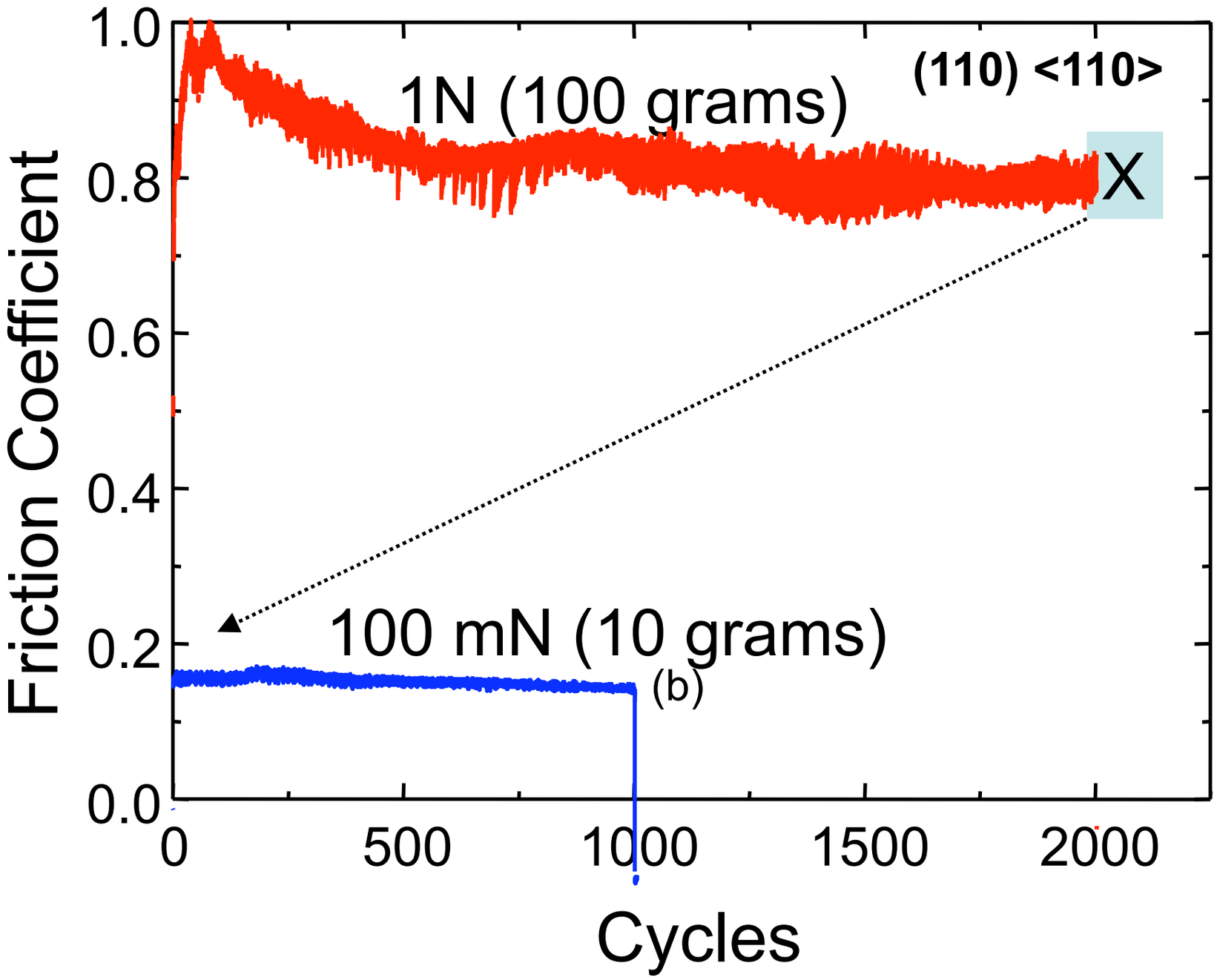
Prior Experiments: Friction Coefficient

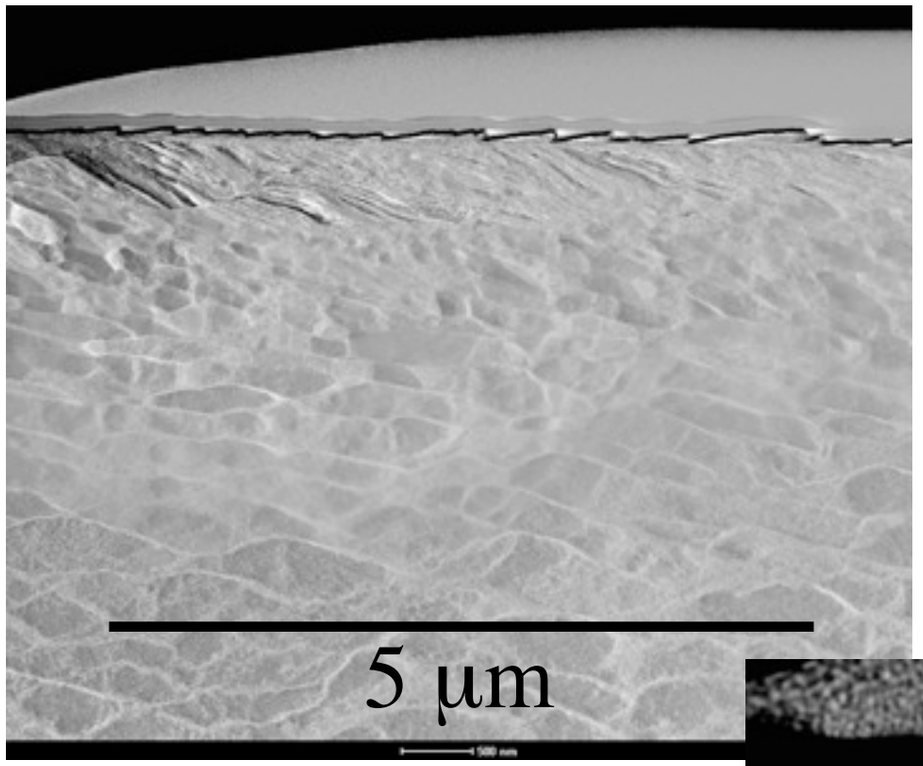


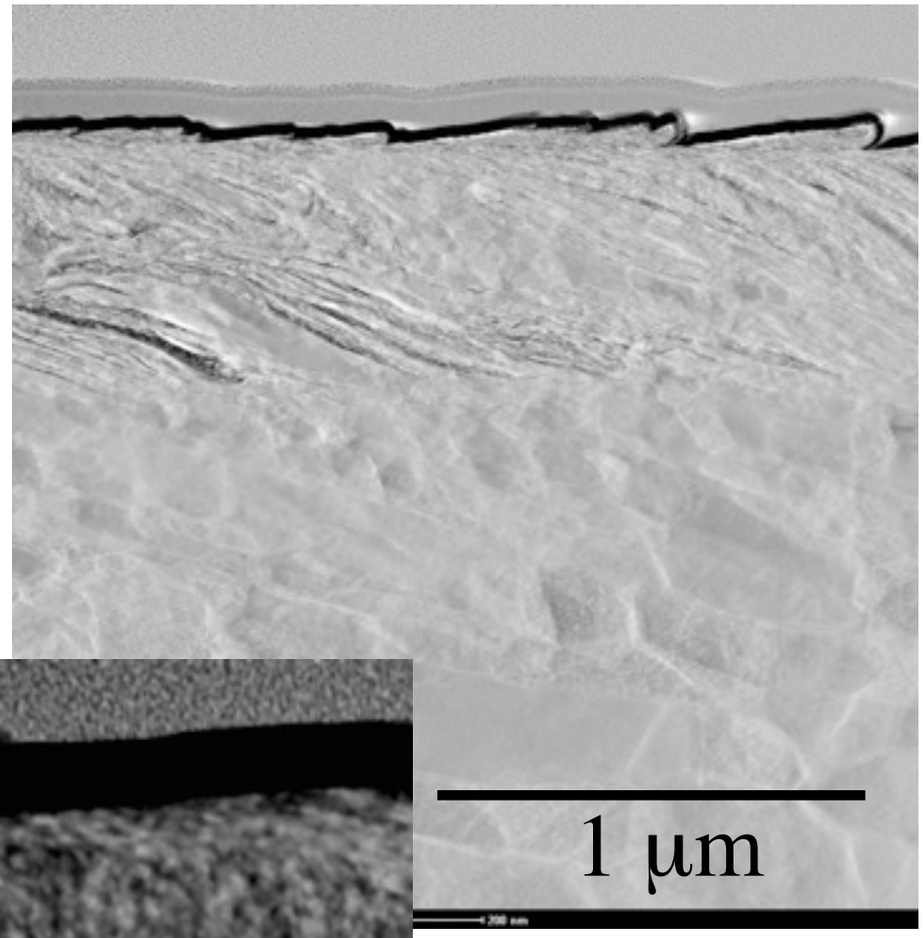


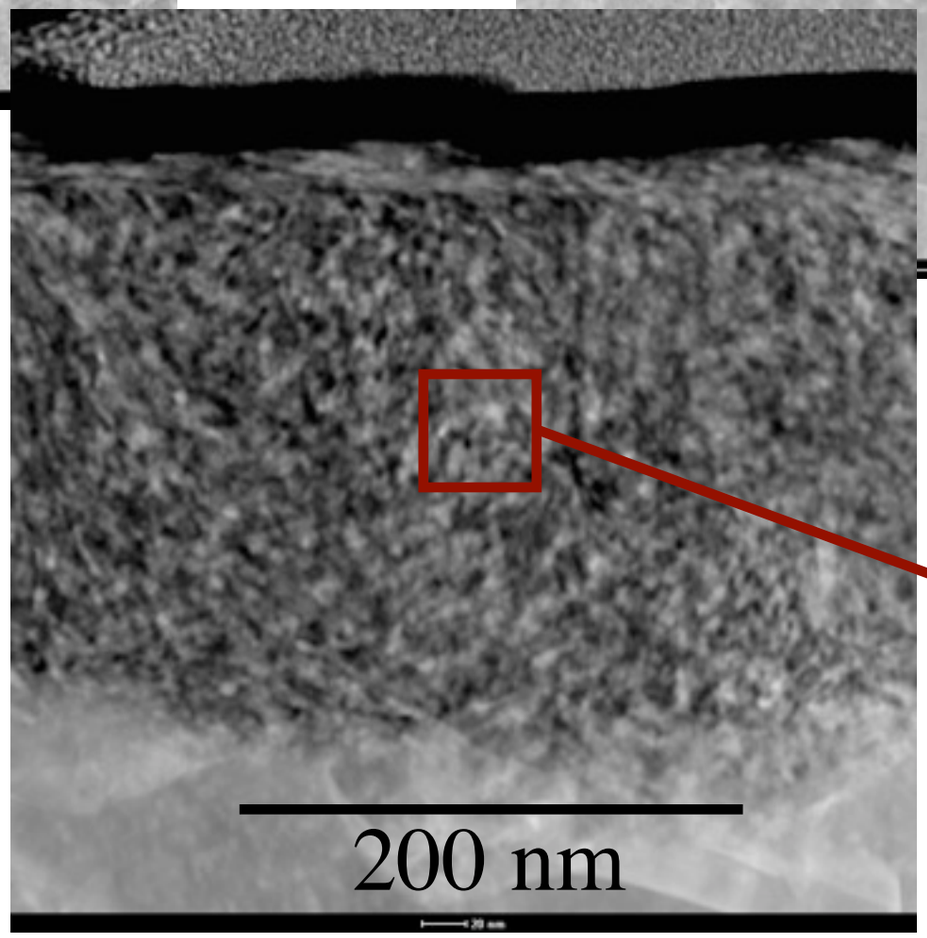
Prior Experiments: Friction Coefficient

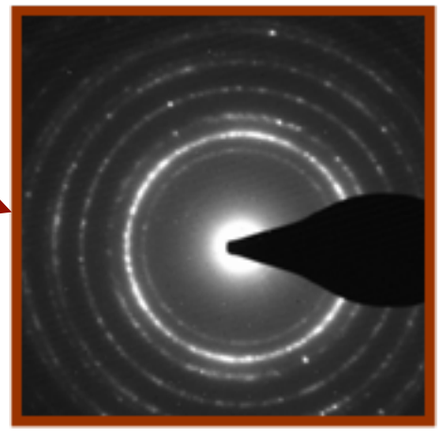


Prior Experiments: TEM







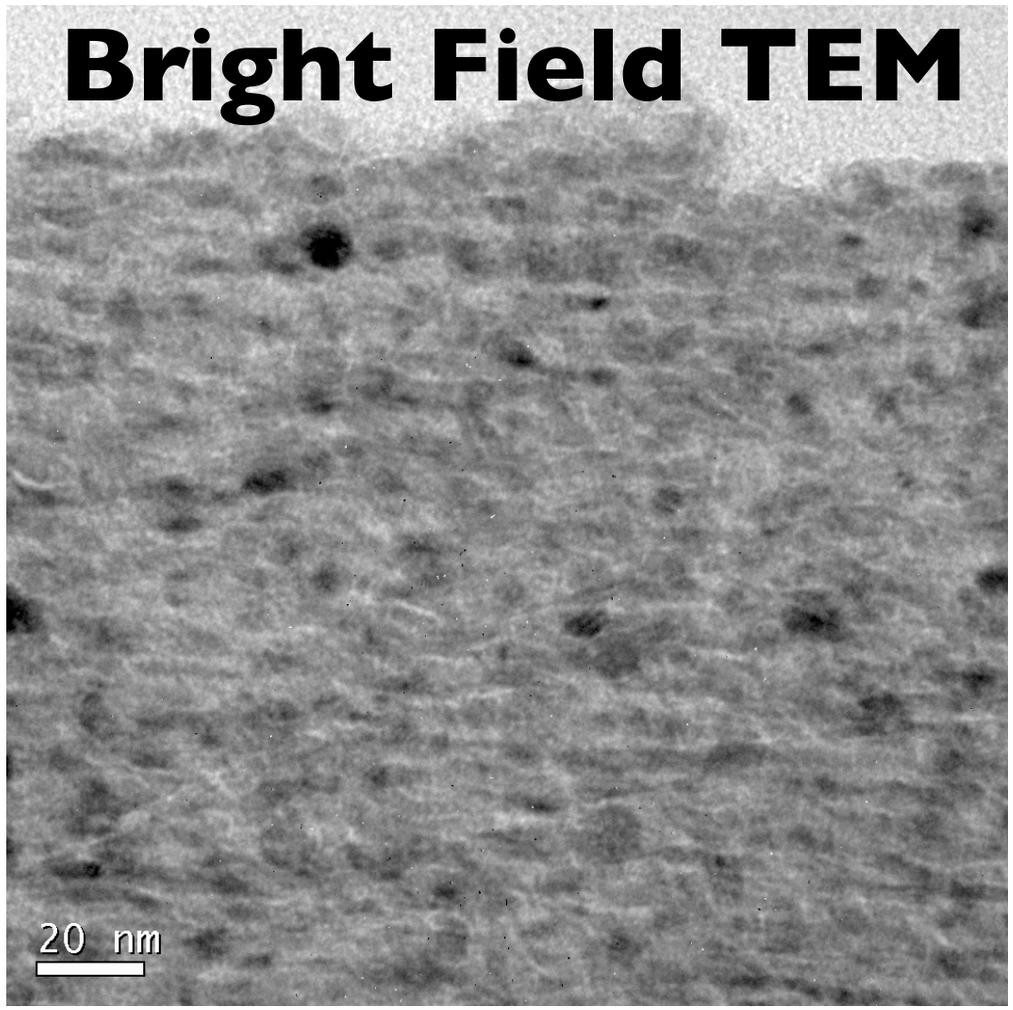


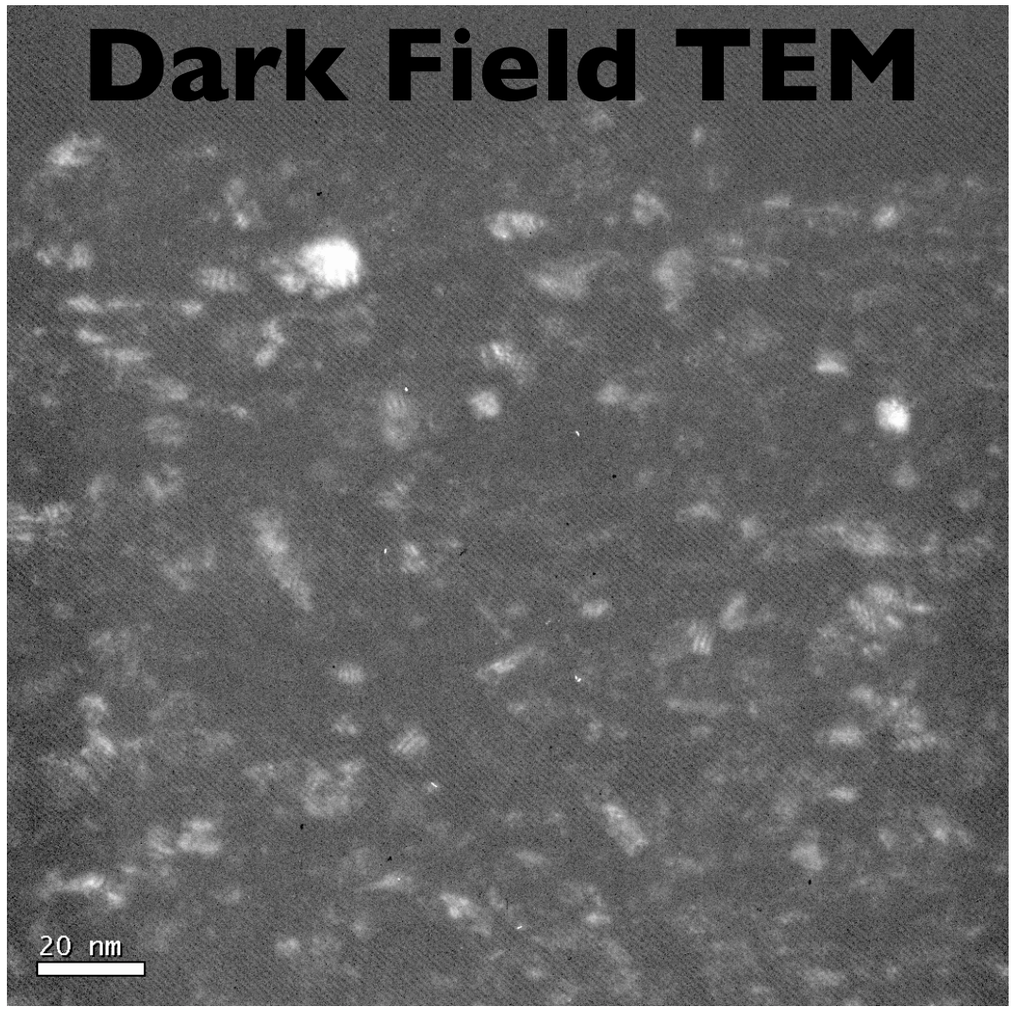
During wear, single crystal Ni develops complex subsurface microstructures.

See also, e.g., D.A. Rigney, "Large Strains Associated with Sliding Contact of Metals," *Mat. Res. Innovat.* **1** (1998) 231-4.

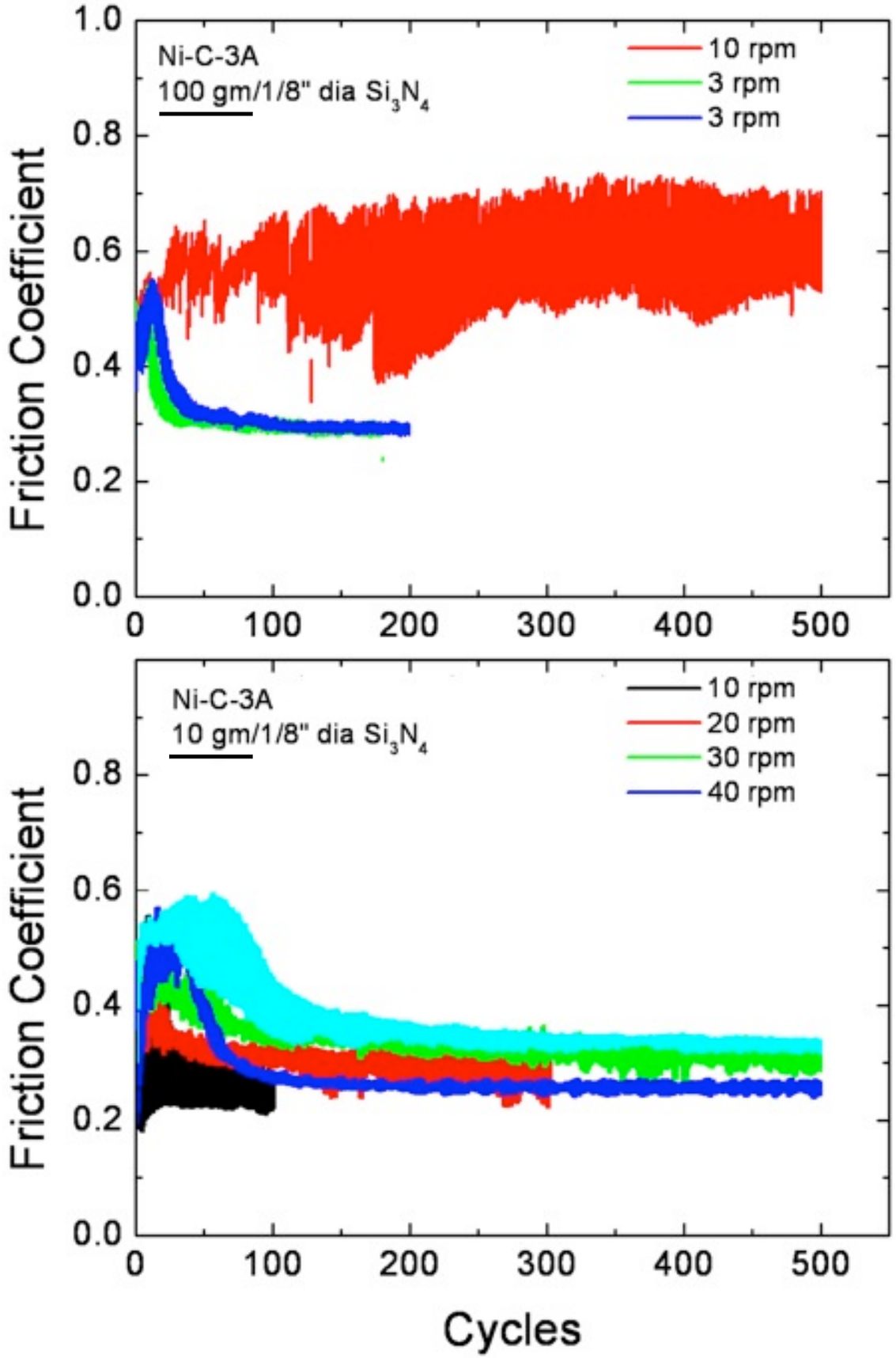
Prior Experiments: TEM

Higher magnification TEM images show
very small (< 10 nm) grains.

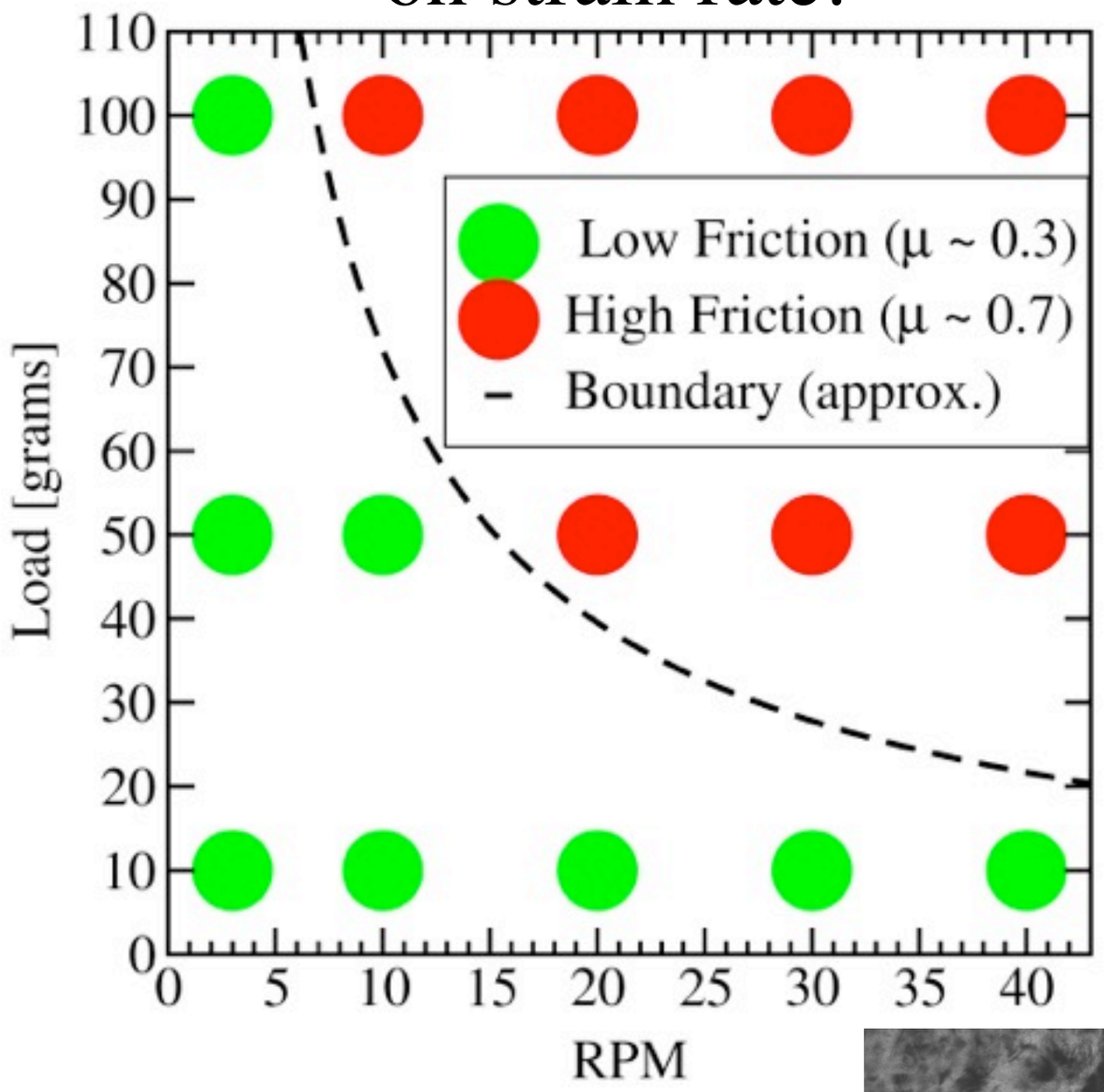


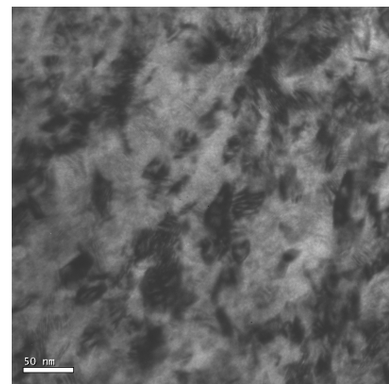


Prior Experiments: Strain Rate Dependence

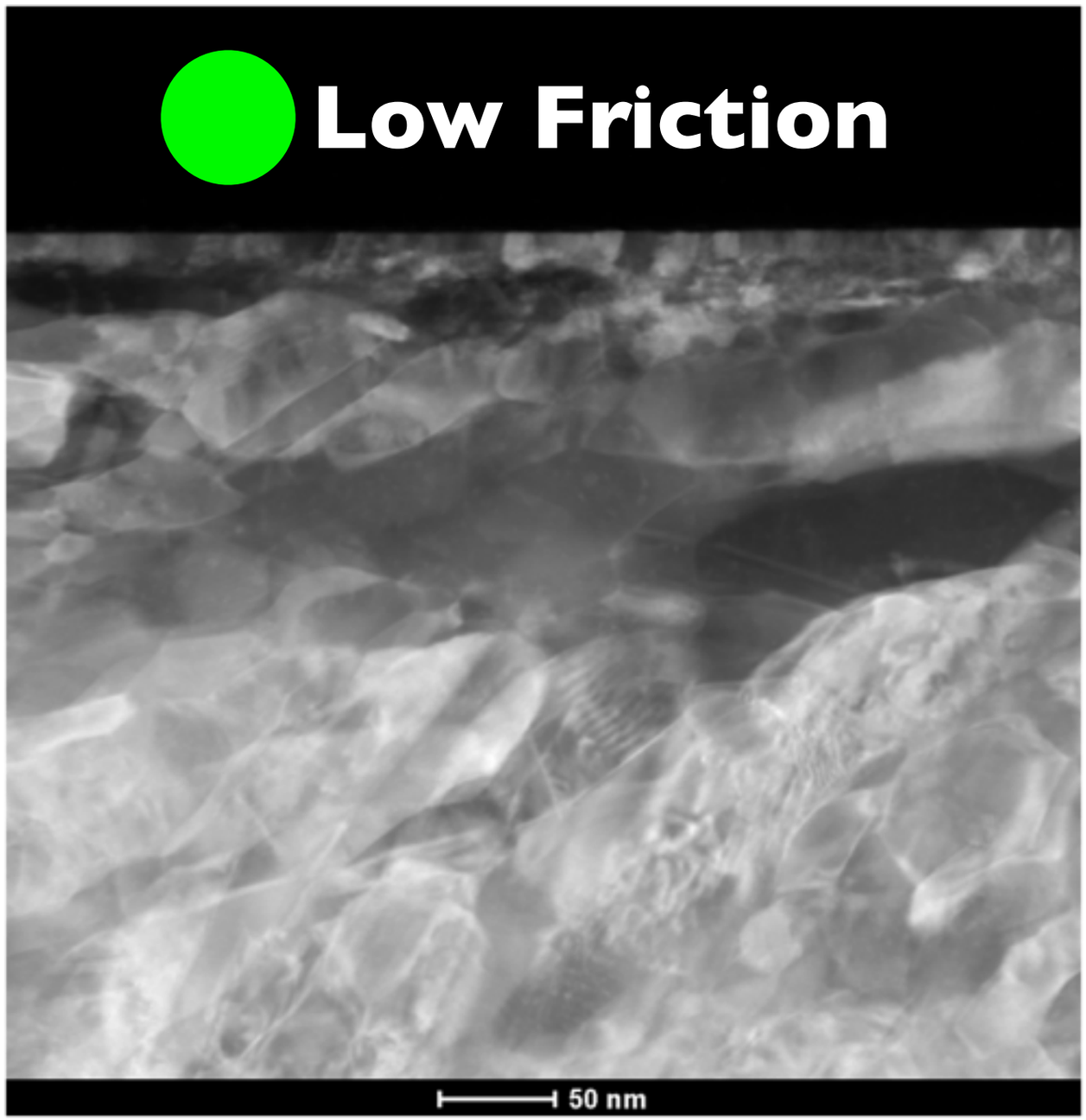


Transition to low friction shows a clear dependence on strain rate.

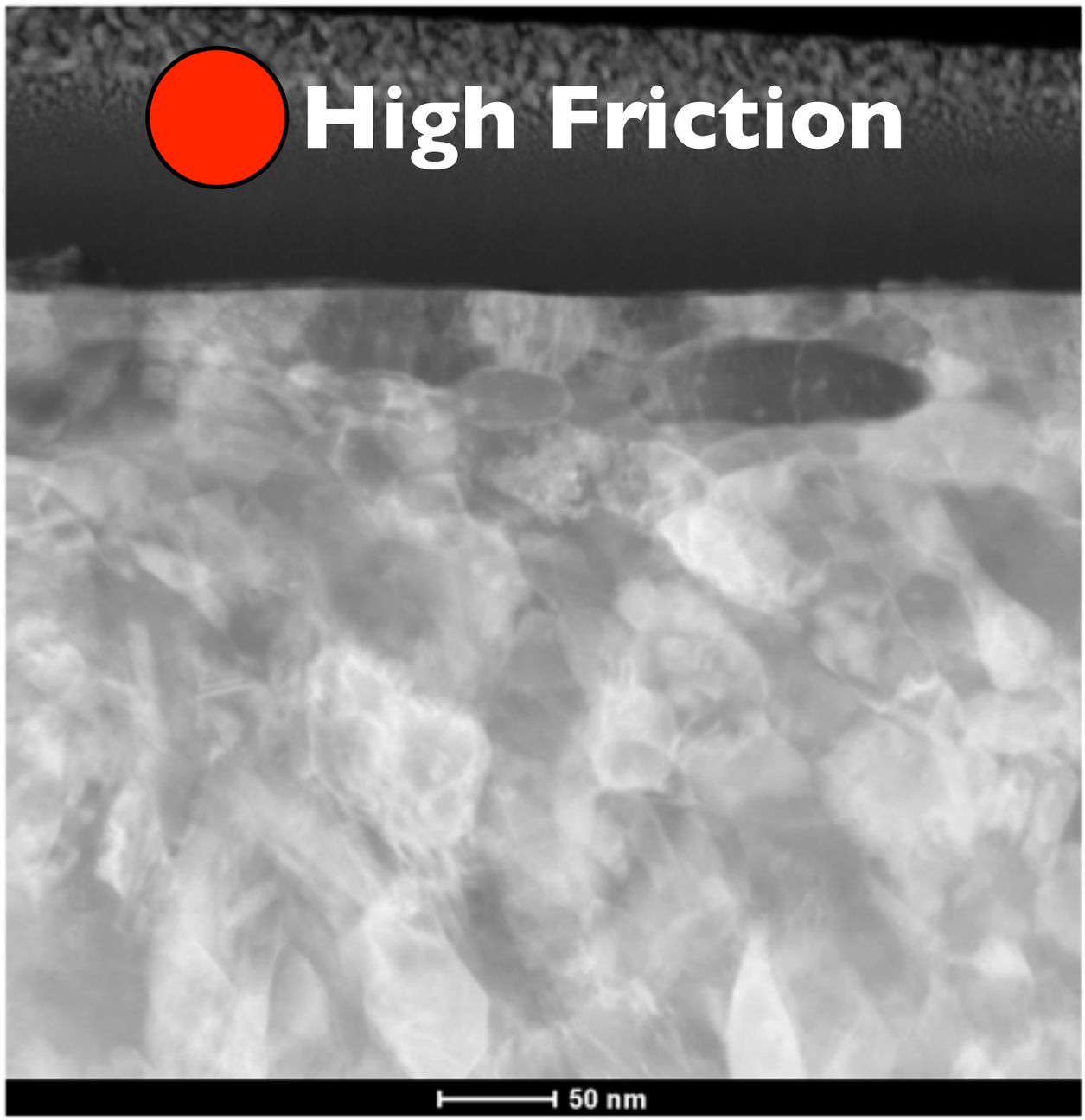




Prior Experiments: More TEM



100 g, 3 RPM

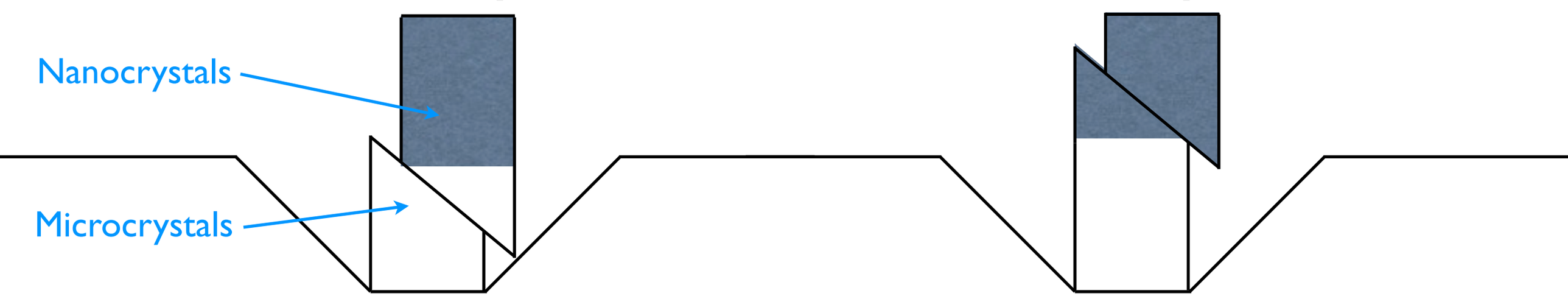


100 g, 20 RPM

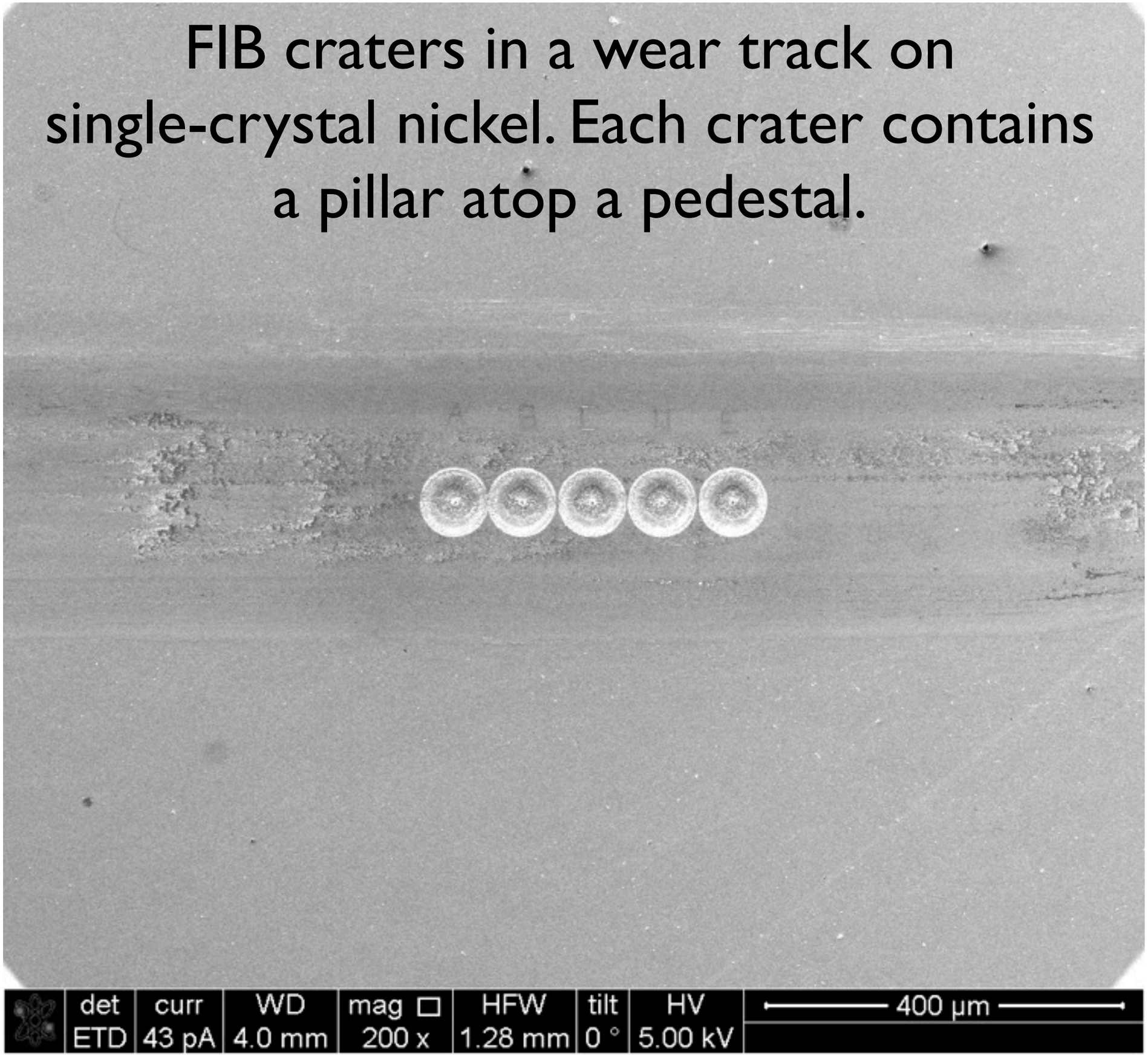
Direct Characterization of Mechanical Properties?

- **Use pillar compression and nanoindentation to directly determine the mechanical properties of the surface material.**

Softer Microcrystals - OR - Softer Nanocrystals



FIB Milling of Sub-Micro-Pillars in Wear Track



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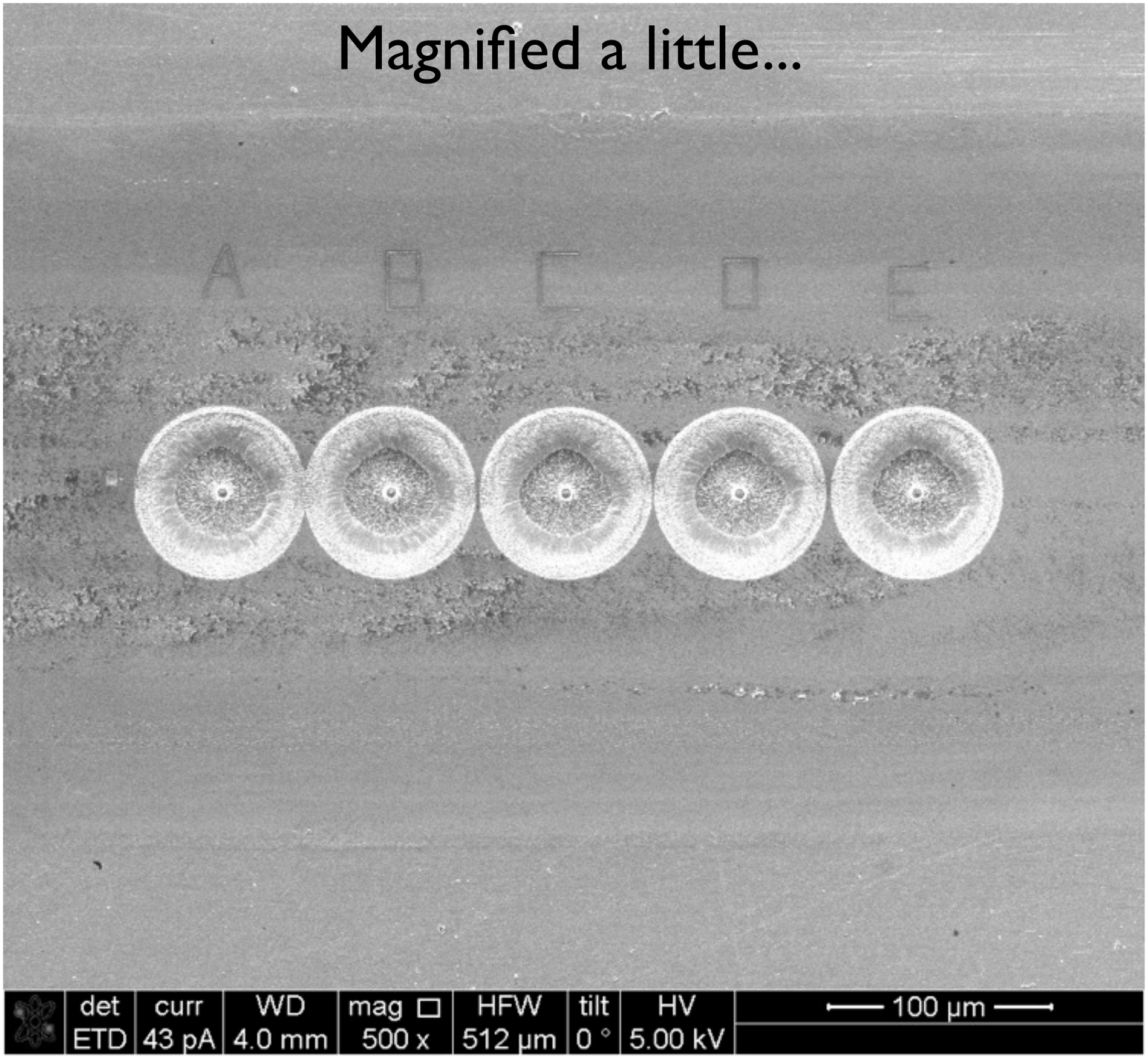

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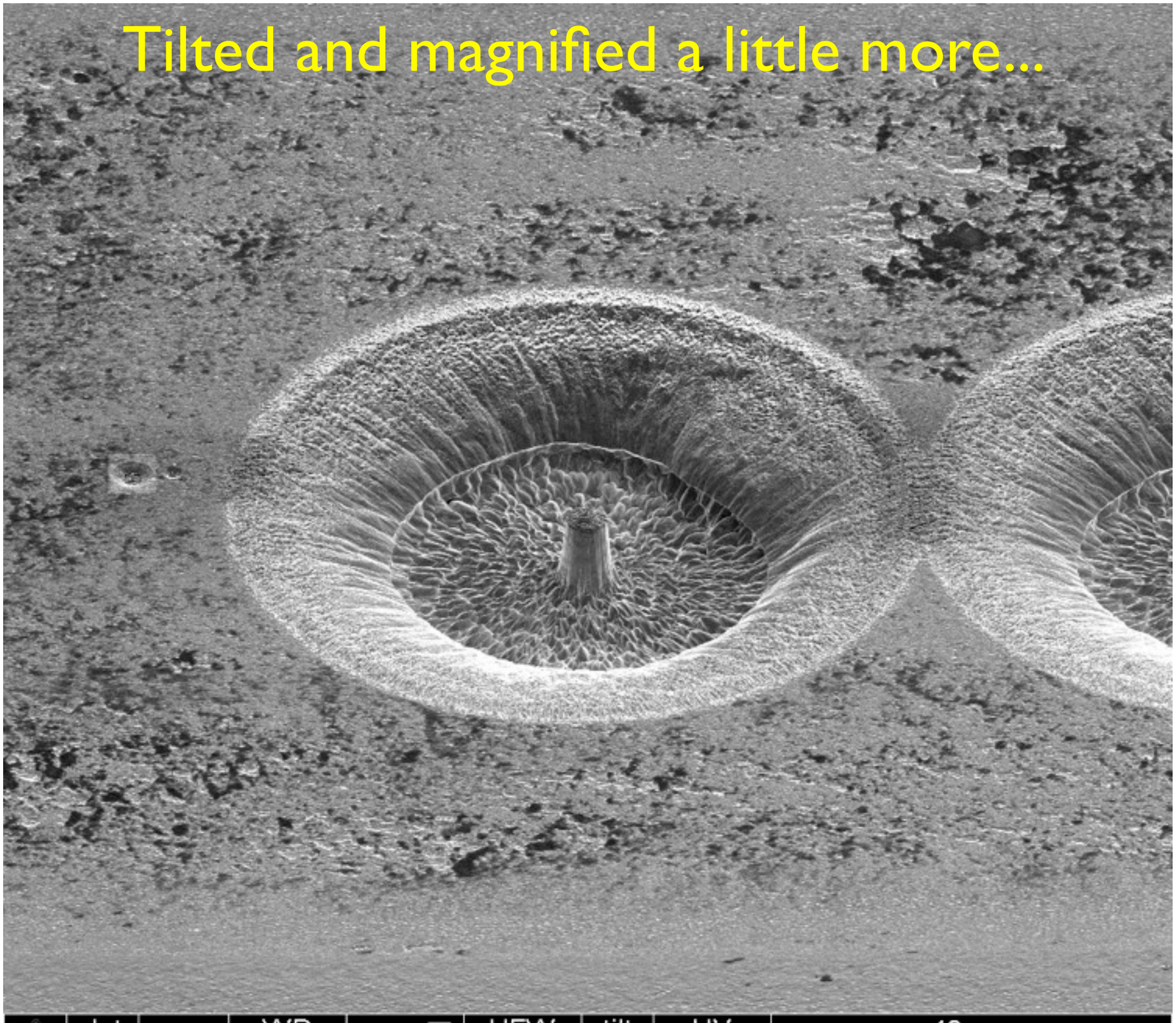
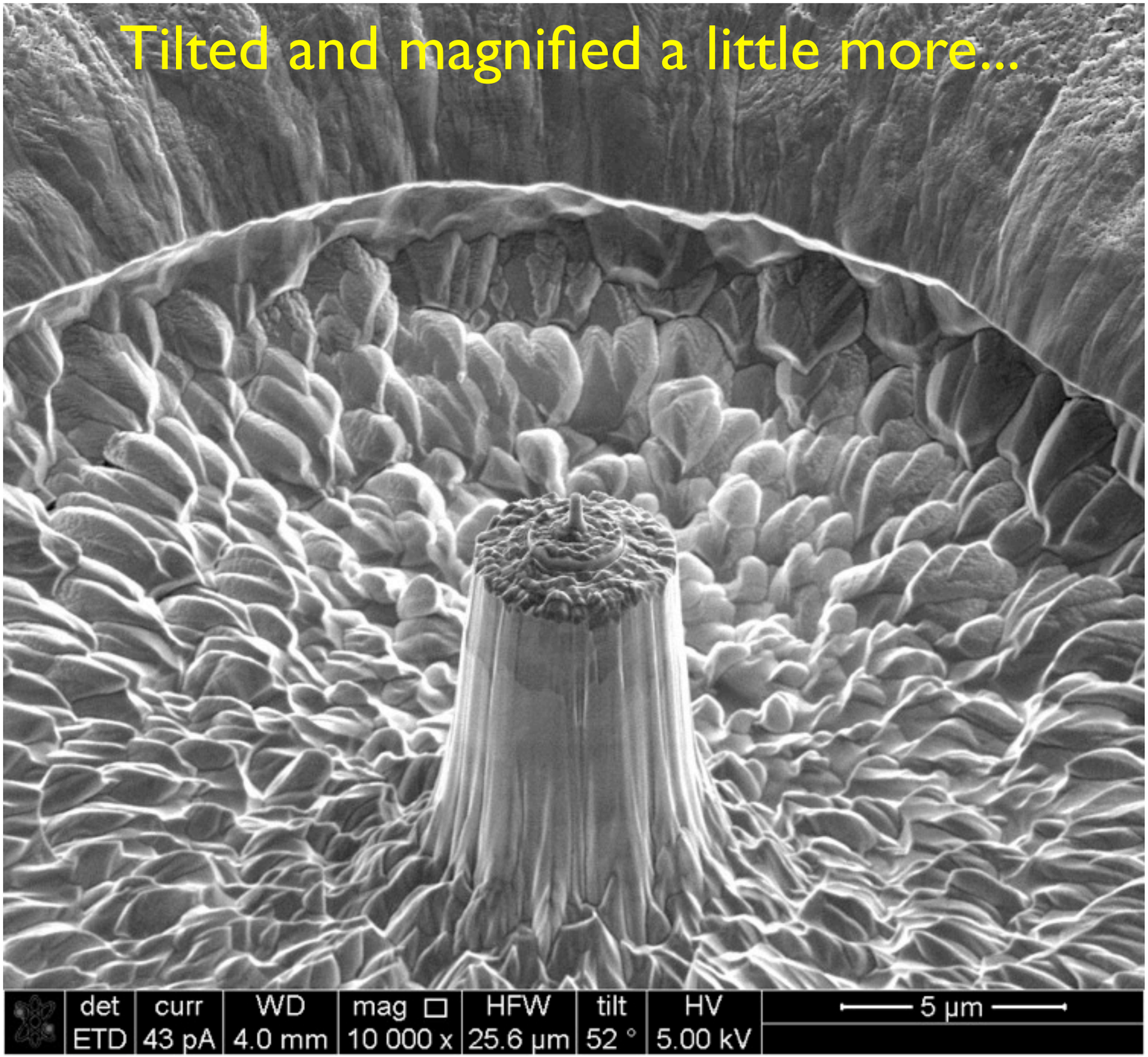


FIB Milling of Sub-Micro-Pillars in Wear Track



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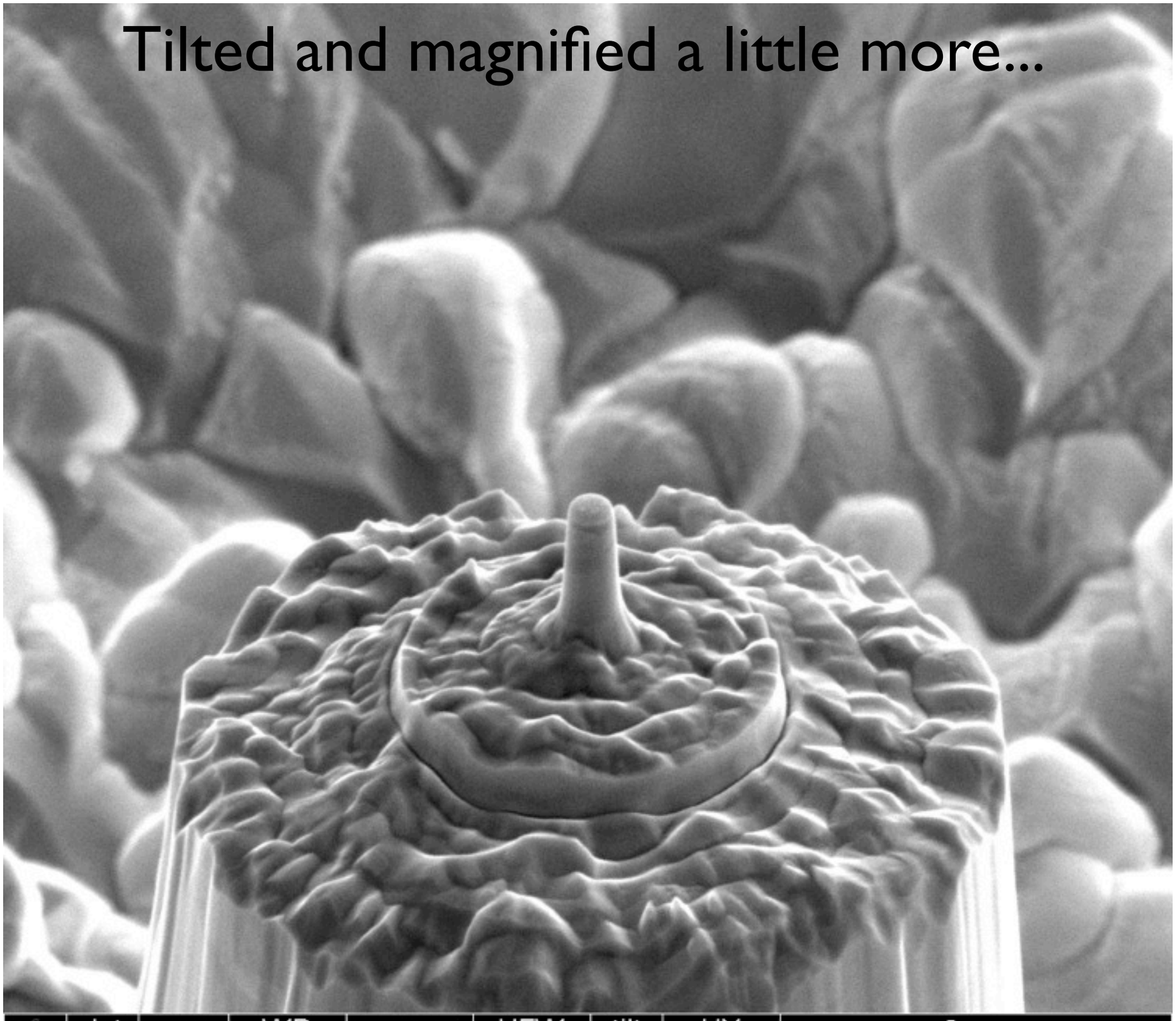
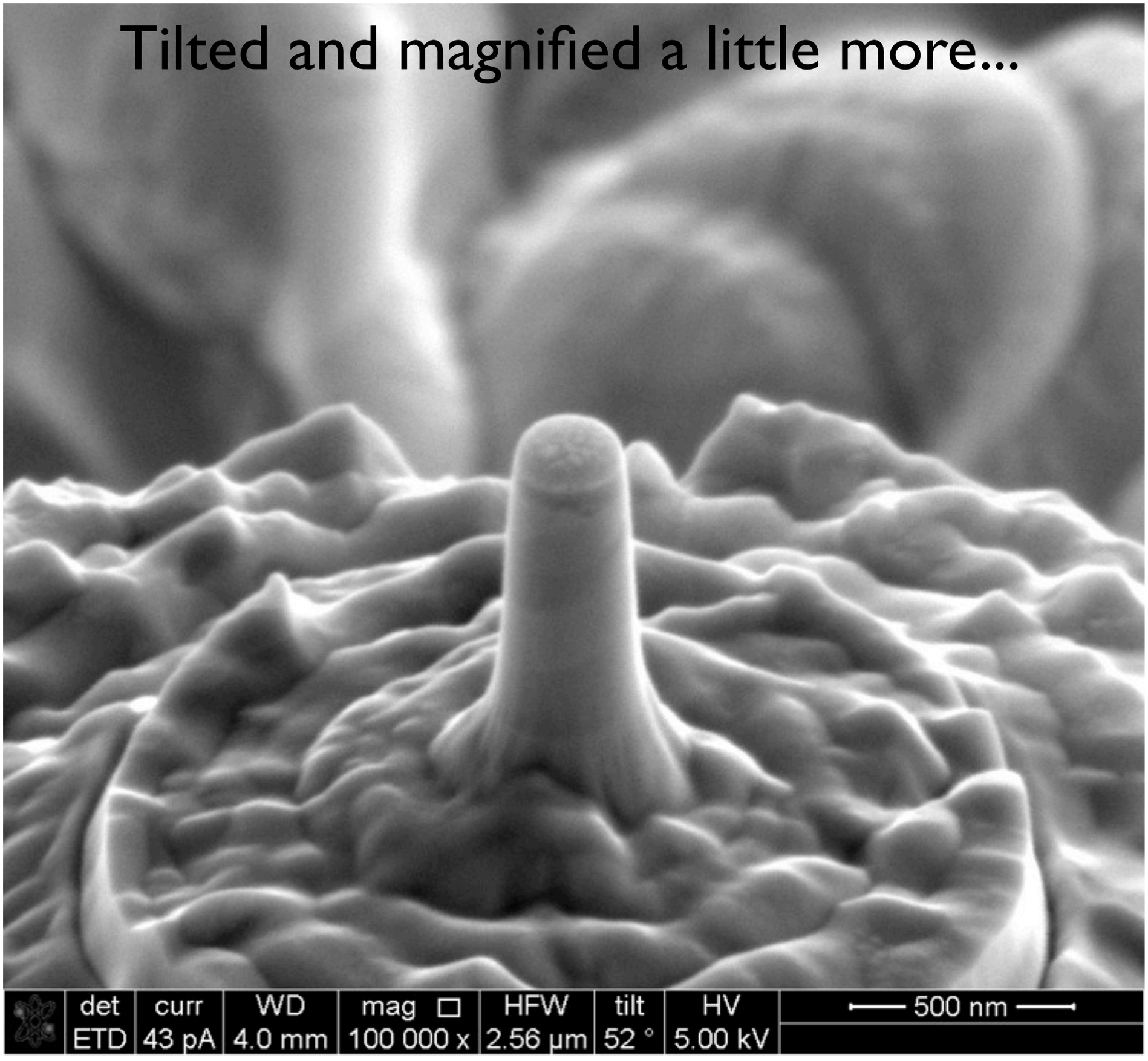
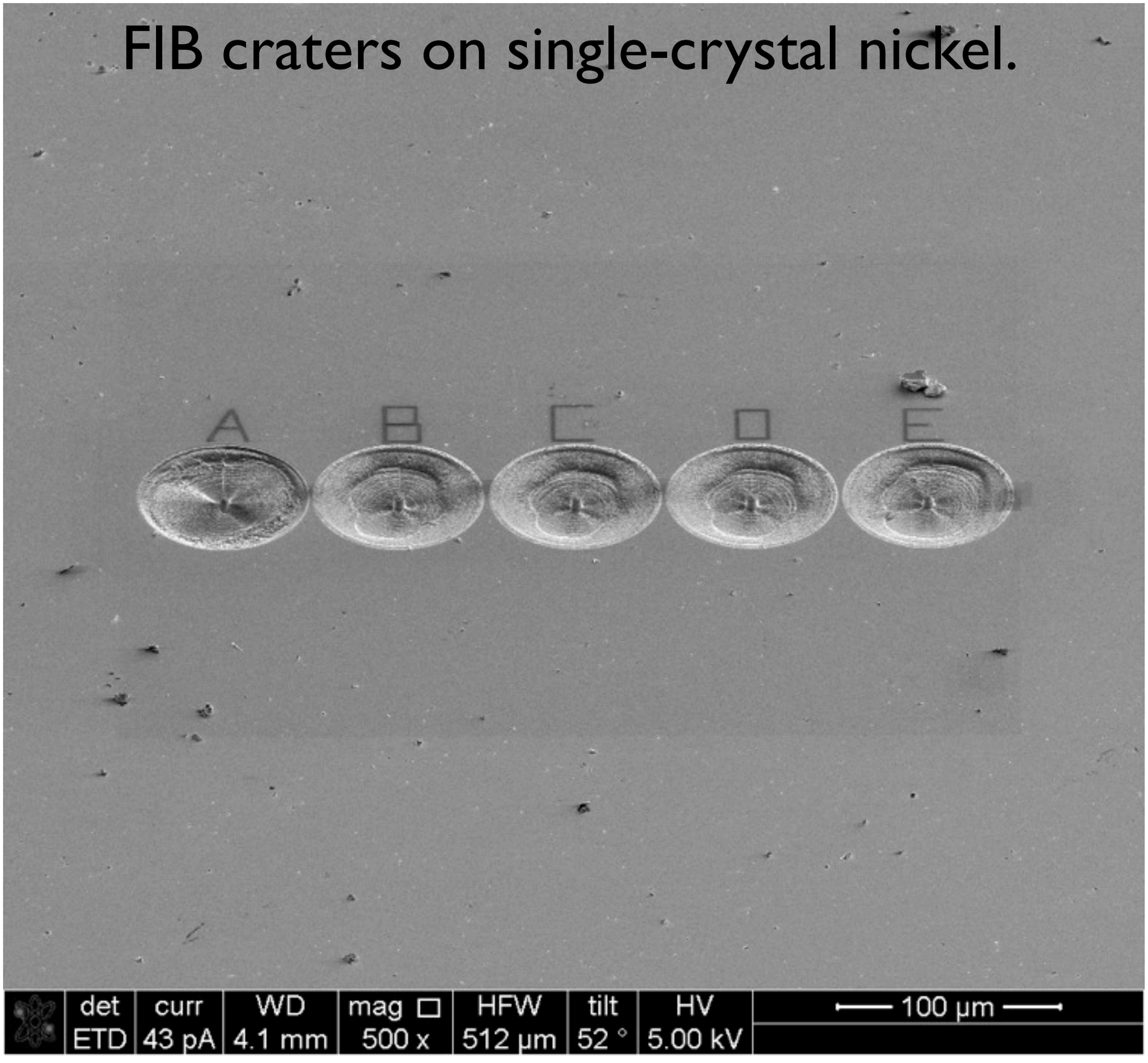


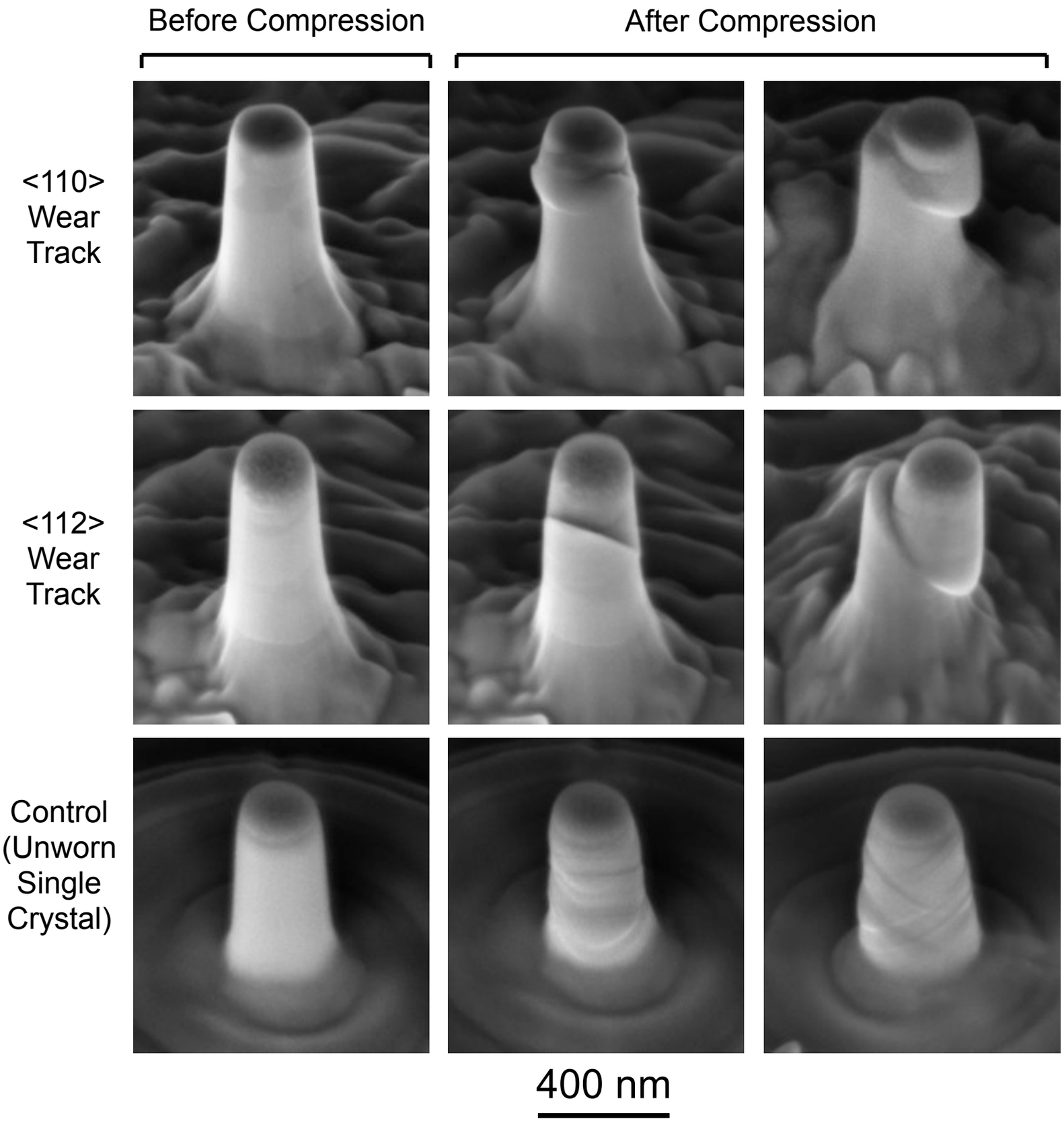
FIB Milling of Sub-Micro-Pillars in Wear Track



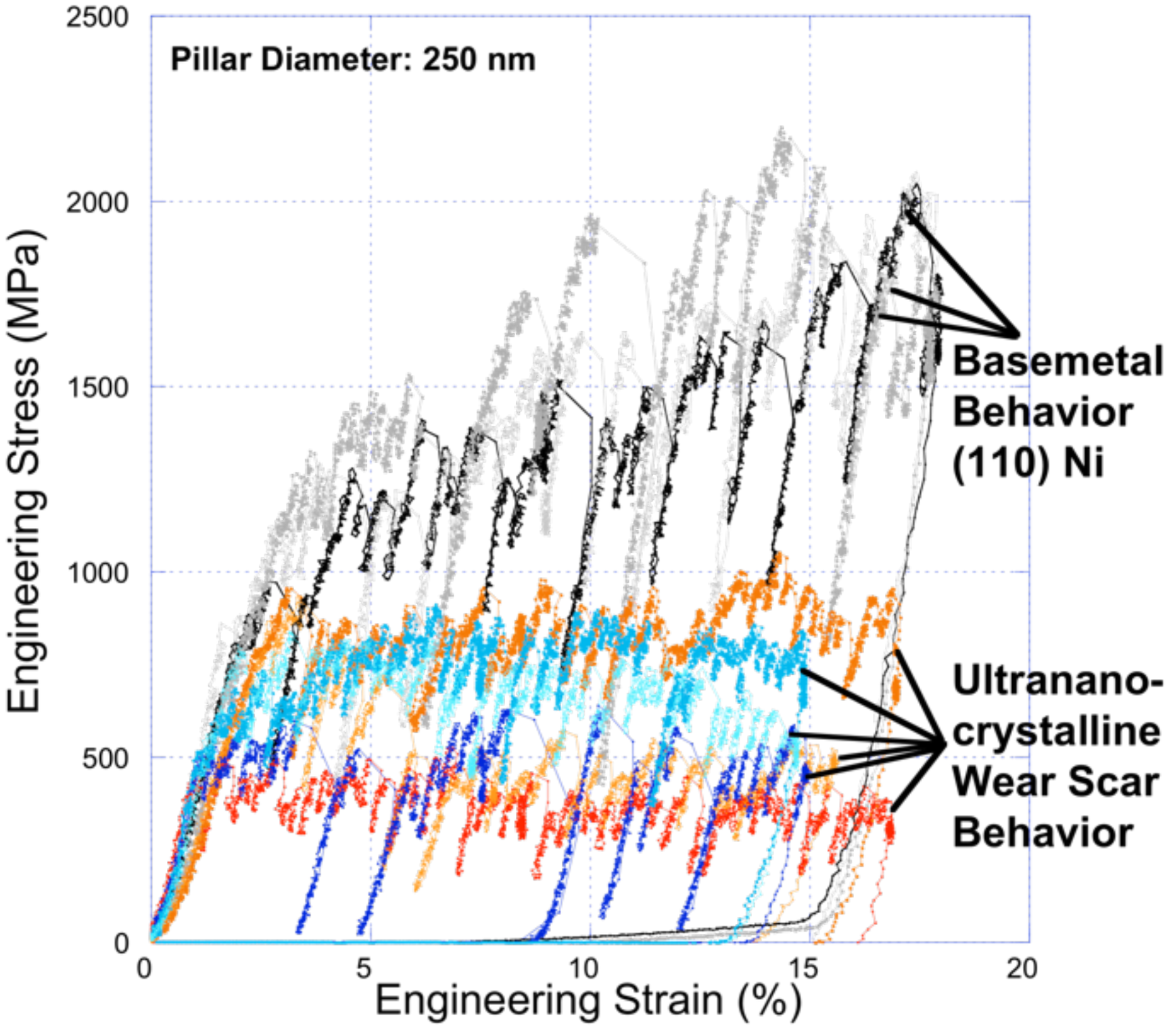
FIB Milling of Sub-Micro-Pillars in Single Xtal



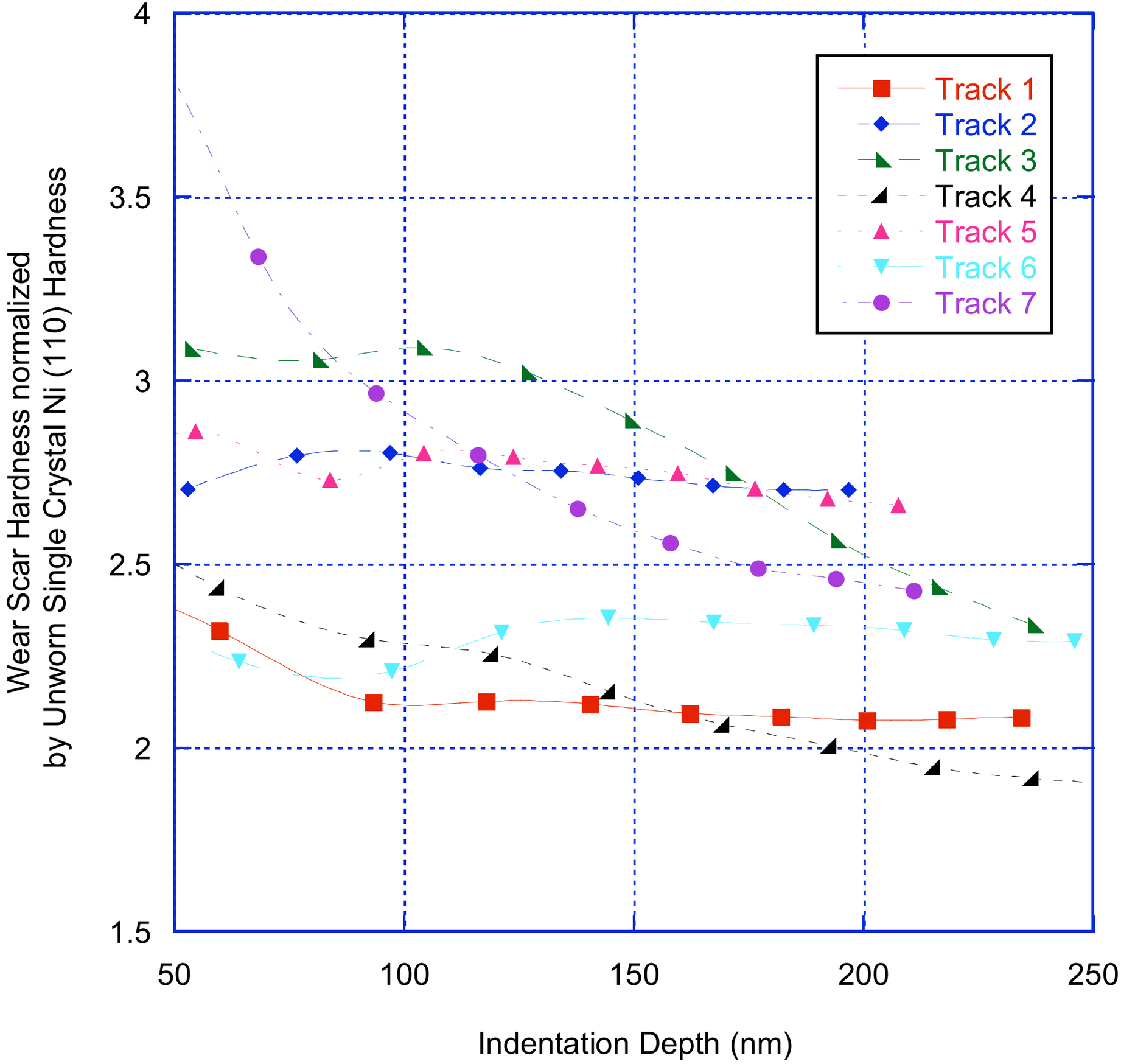
Pillar Compression Testing



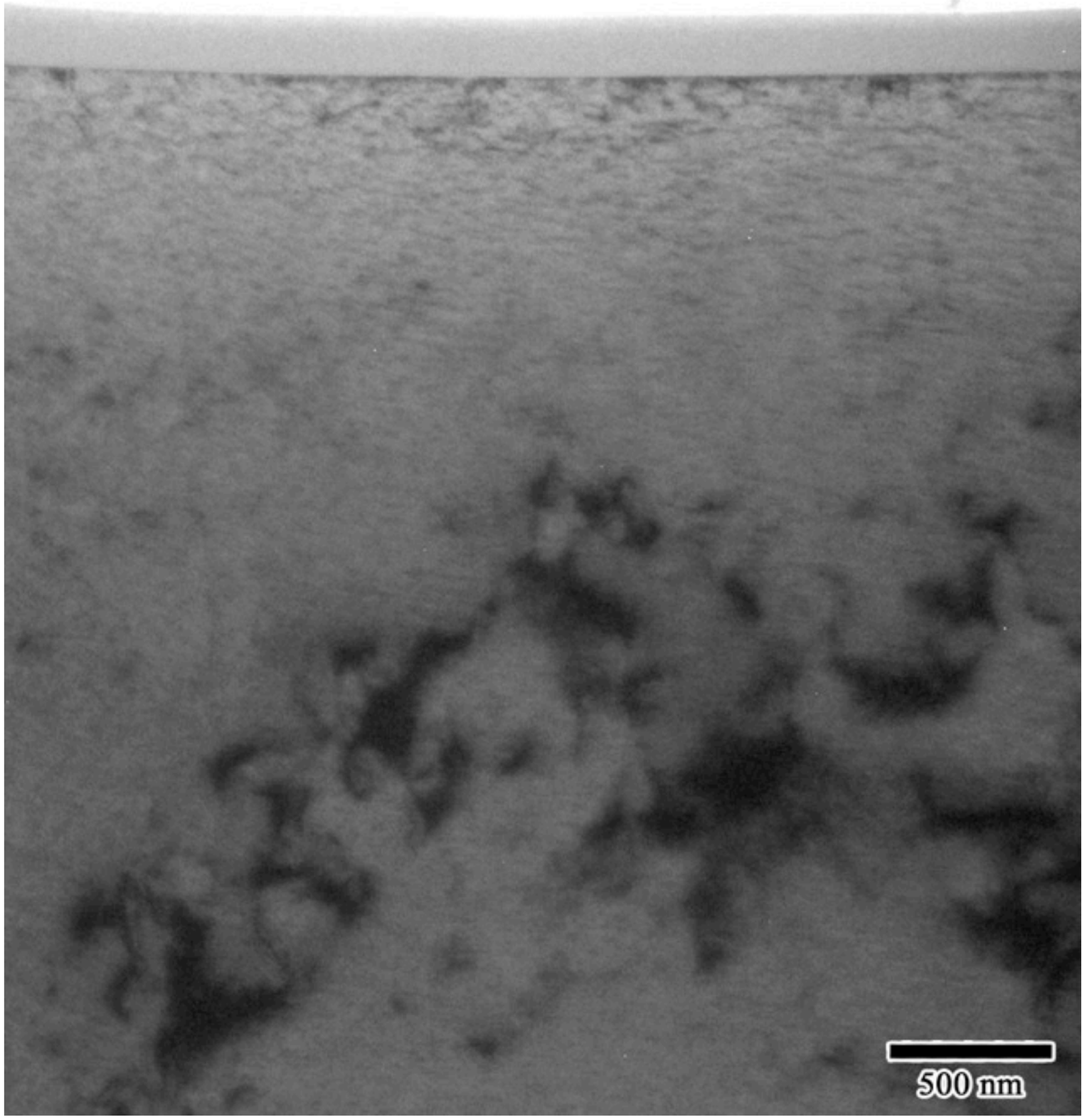
Pillar Compression Testing



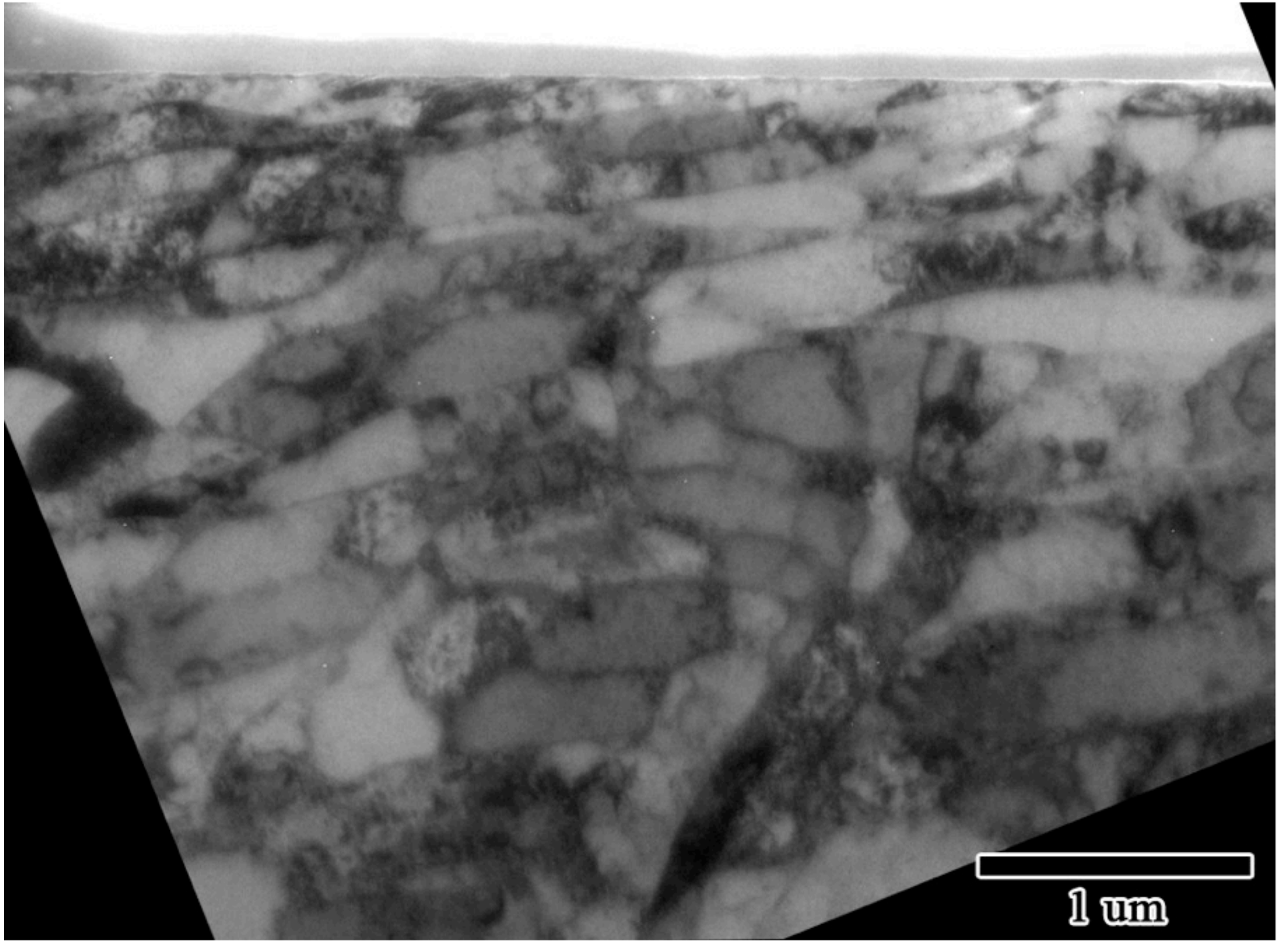
Nanoindentation Testing



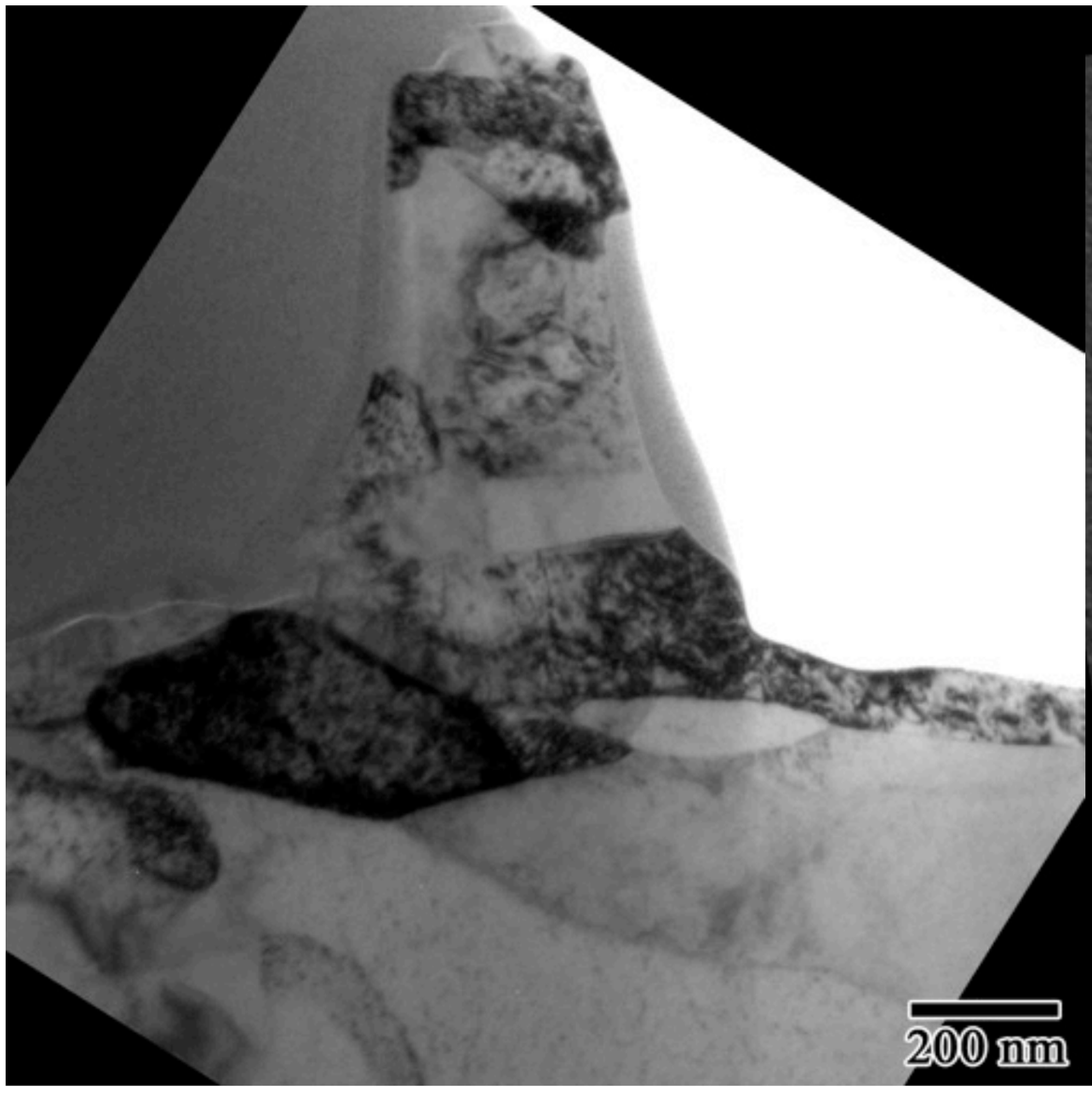
TEM of Single Crystal

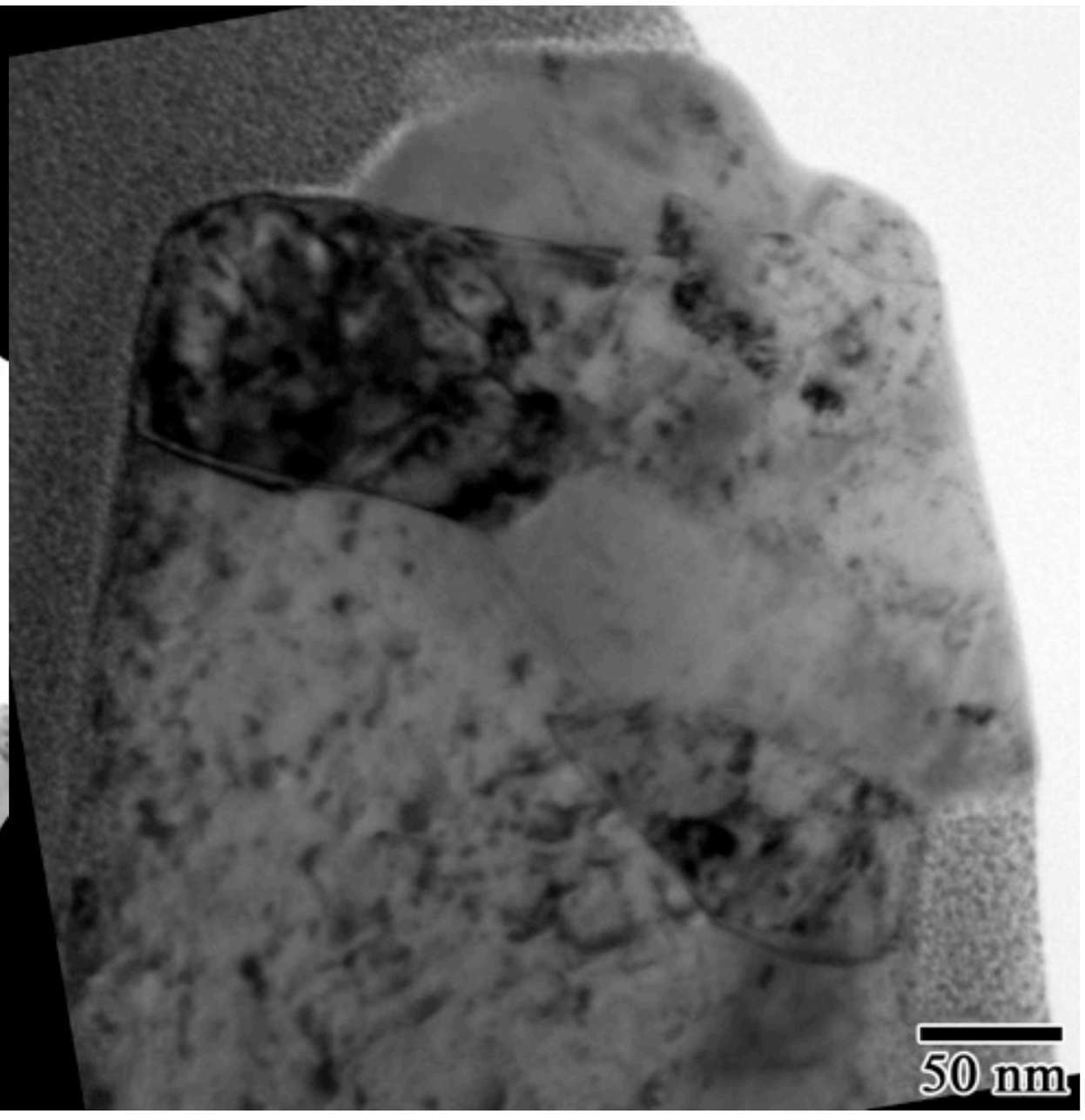


TEM of Wear Track #1

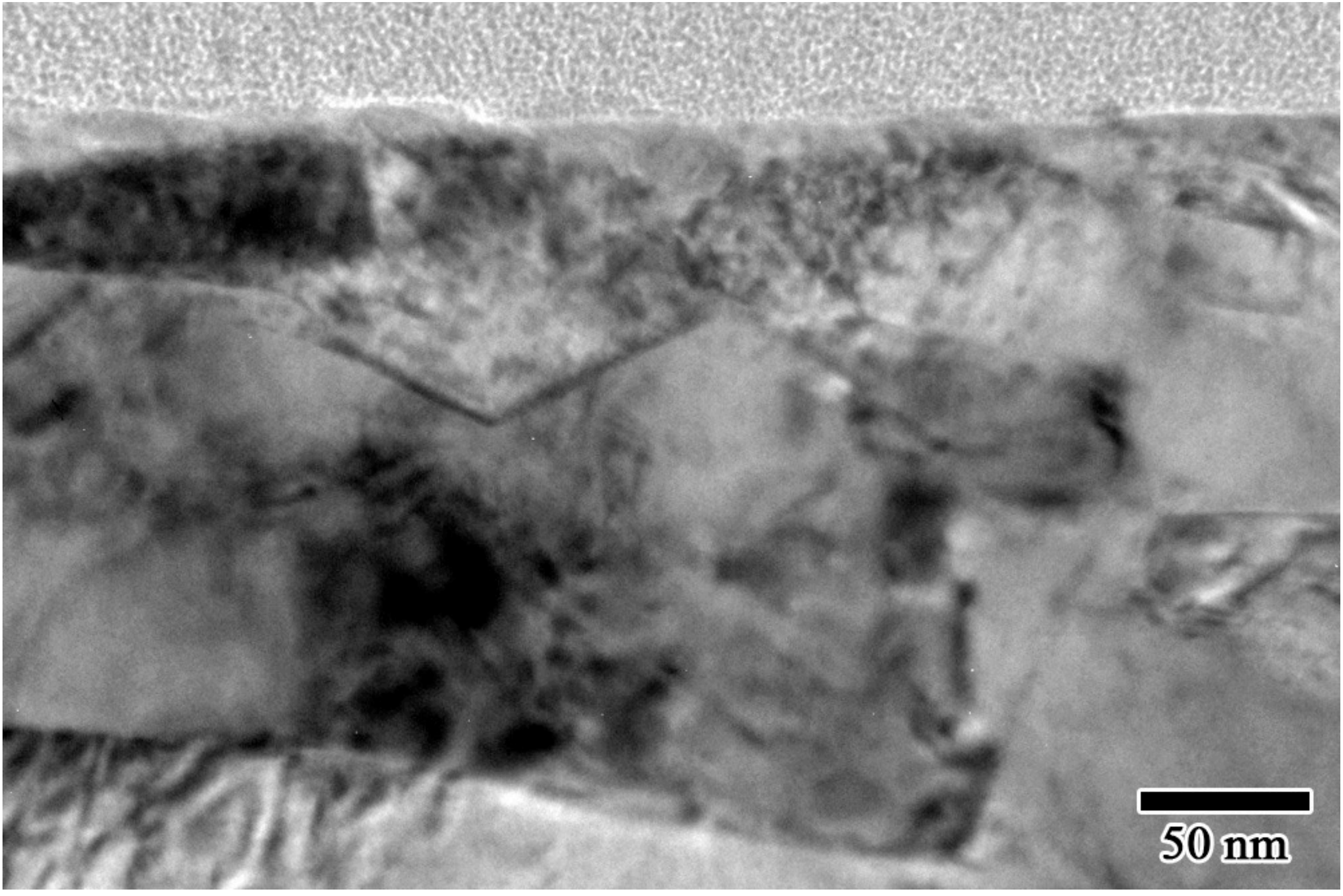


TEM of Wear Track #1 Pillar B

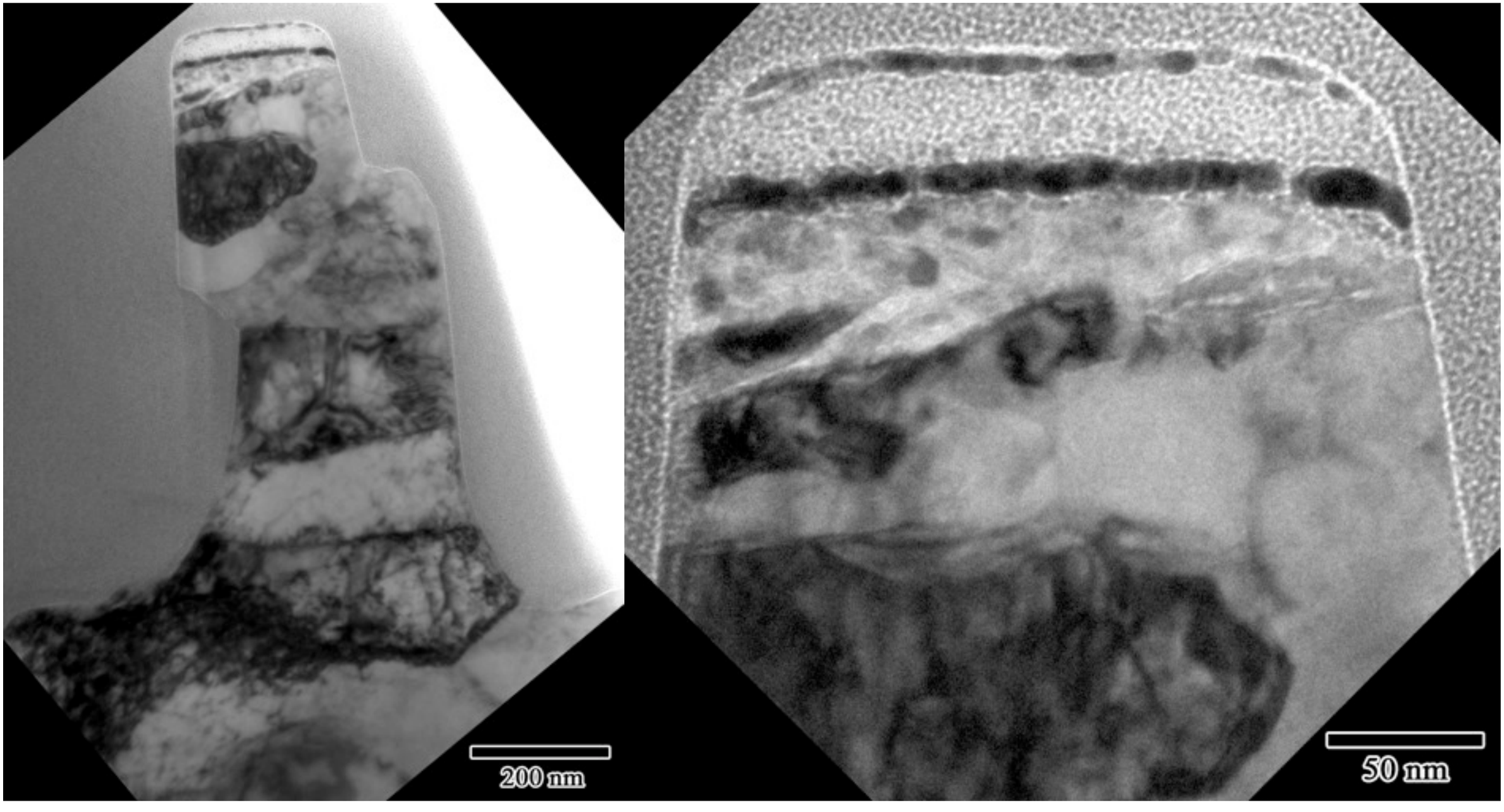




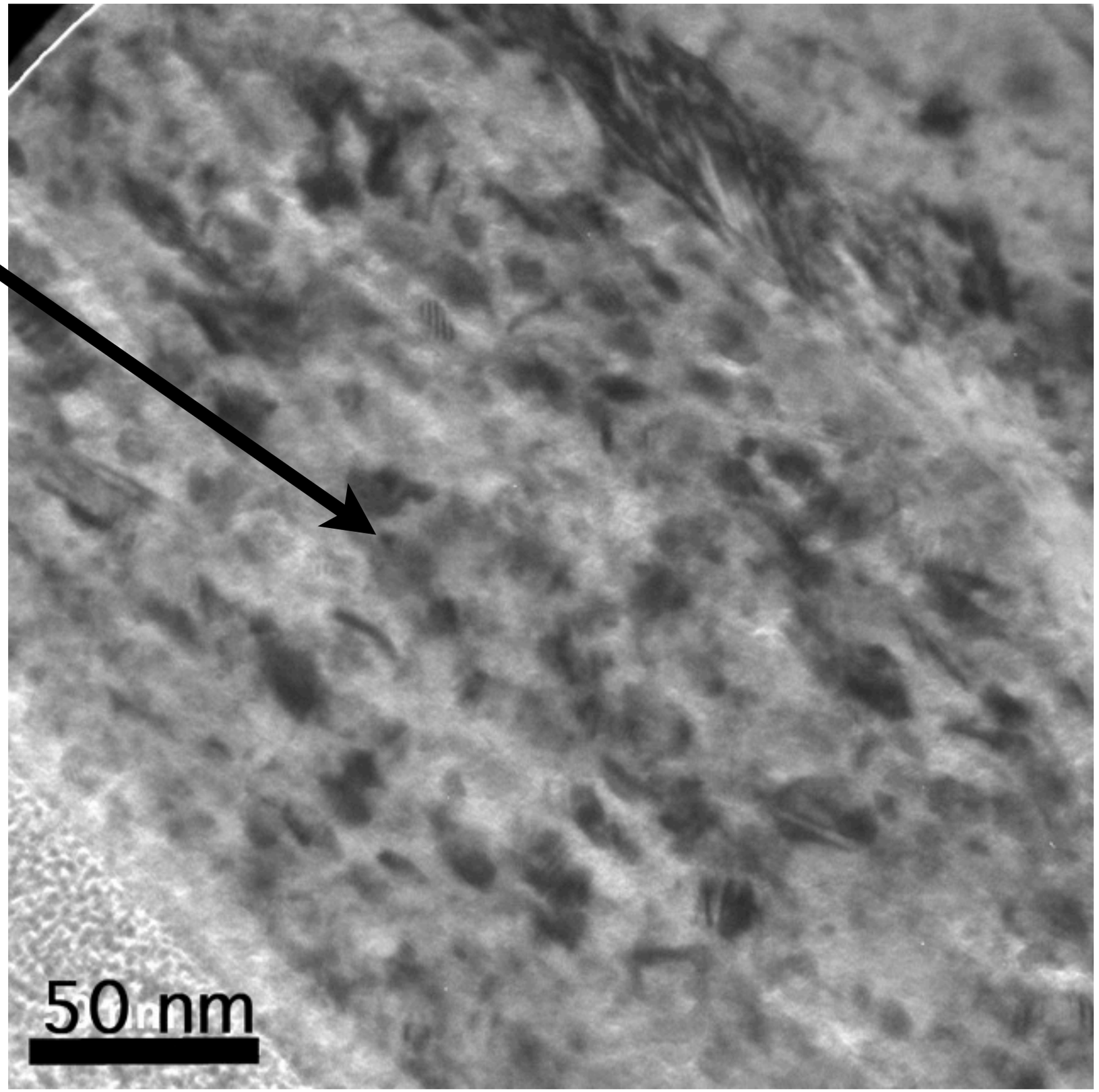
TEM of Wear Track #5



TEM of Wear Track #5 Pillar D



TEM of Wear Track #7 (untested)



Summary and Conclusions

- Prior experiments on single-crystal nickel suggest crystallography- and rate-dependent friction and wear behavior related to subsurface nanostructure formation.

- Focused ion beam milling was used to create sub-micro-pillars inside wear tracks and on the parent, single-crystal nickel surface.

- Pillar compression tests indicate that the pillars are significantly softer than the parent, single crystal.

- Nanoindentation tests indicate that the pillars are 100% to 300% harder than the parent, single crystal.

- Transmission electron microscopy shows that none of the tested wear tracks developed an ultra-nanocrystalline surface layer. Friction coefficients were high (0.5 - 0.8) in all cases.

- Nanoindentation shows harder wear tracks because grain boundaries inhibit dislocation motion. Pillar compression shows softer tracks because free surfaces allow dislocations to escape. Nanocrystalline pillars don't work harden because grain boundaries provide ready sources for dislocation nucleation.

Acknowledgements and Thanks

- Rand Garfield (tribology)
- Michael Rye (focused ion beam)
- Bonnie McKenzie (scanning electron microscopy)
- Chris Weinberger (insightful discussions)