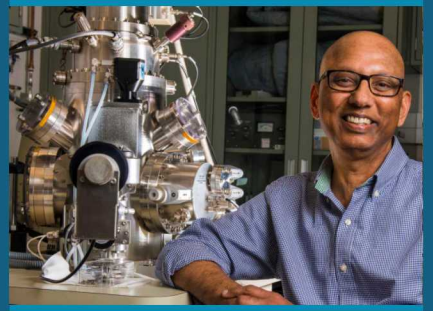
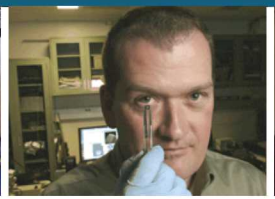
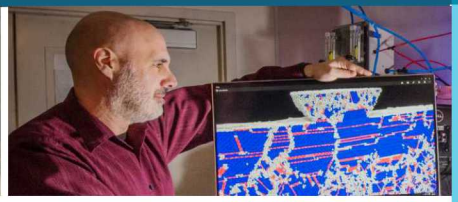
SAND2020-0957C

Formation Mechanisms of in situ generated DLC-Like Tribofilms







John F. Curry[1], Morgan Jones[1], Tomas F. Babuska[1,2], Brendan Nation[1], Brandon A. Krick[2], Michael T. Dugger[1], Michael Chandross[1], Nic Argibay[1]

[1]Material, Physical, and Chemical Sciences Center
Sandia National Laboratories
Albuquerque, NM

[2]Mechanical Engineering & Mechanics
Lehigh University
Bethlehem, PA

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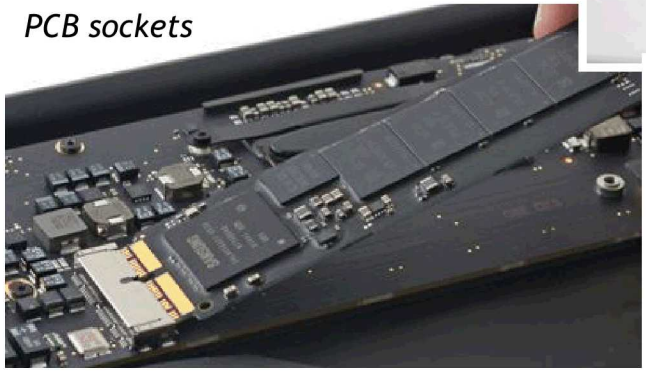
Motivation for Metals Tribology Research

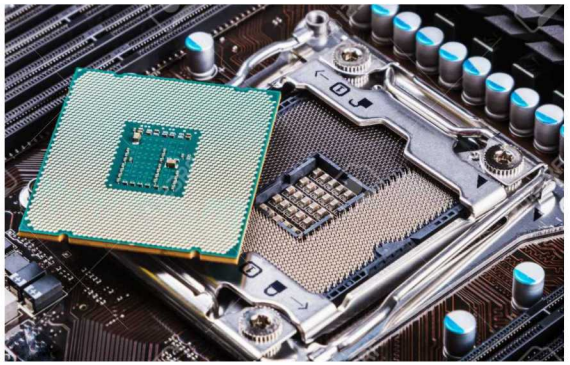
cell phones

wind turbine slip-rings
(sensors and blade pitch motors)

PCB sockets



CPU sockets



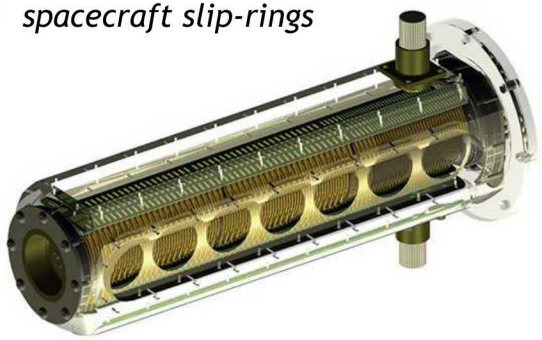
Estimated 150 Metric Tons ($6.9B) of Au used in Electrical Contacts per Year:

Refs: Gold Survey, Gold Fields Mineral Survey Ltd, 2011
Gold Bulletin 2010, Vol. 43-3, C. Hagelüken and C.W. Corti,
Gold Bulletin 1986, Vol. 19-3, T.D. Cooke

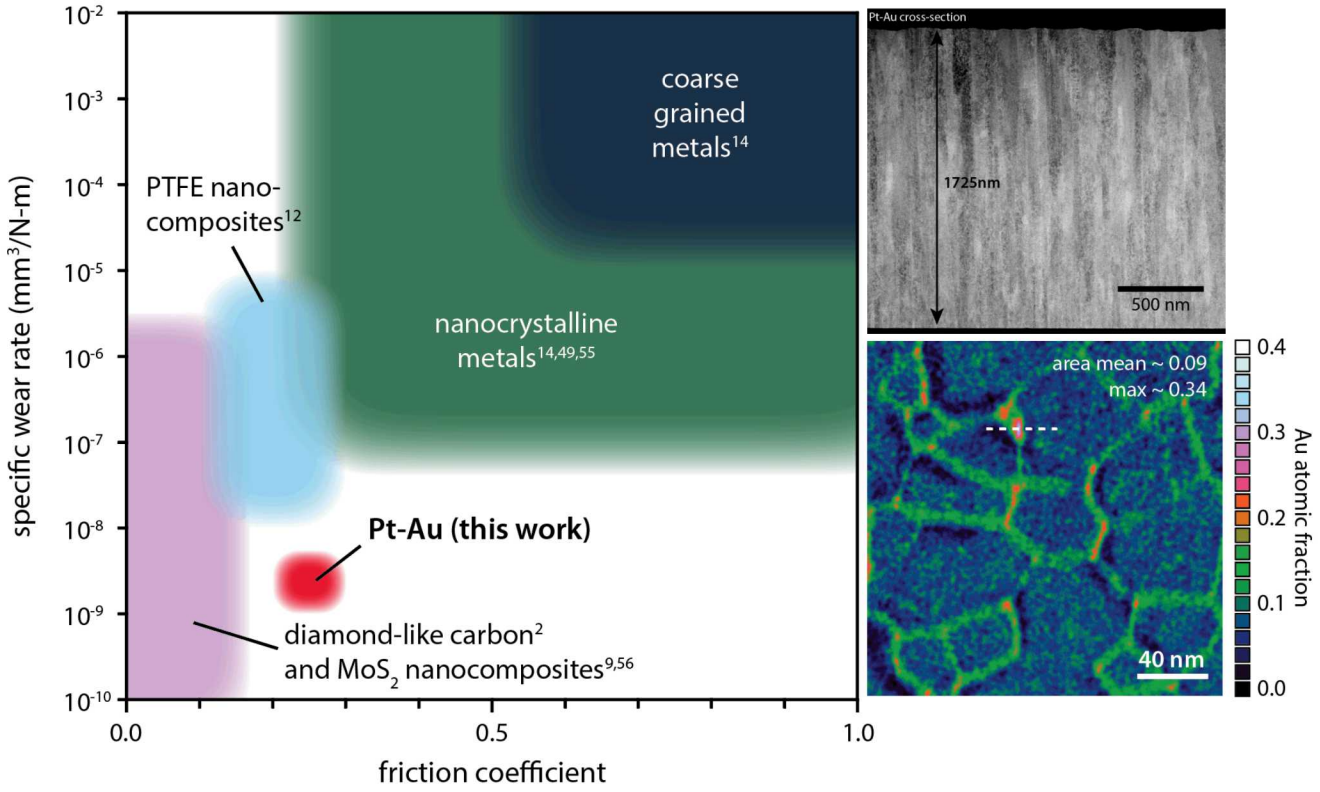
45 connectors

EV charging

spacecraft slip-rings



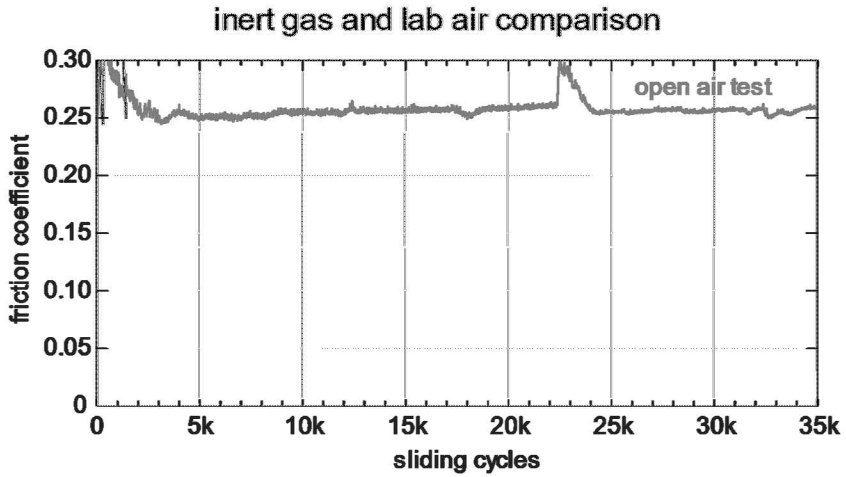
Discovery: Ultra-Low Wear Pt-Au



- Development of stable, ultra-nanocrystalline alloys with high fatigue resistance, helping shut down delamination driven wear

Curry et al, Adv. Mater. 2018

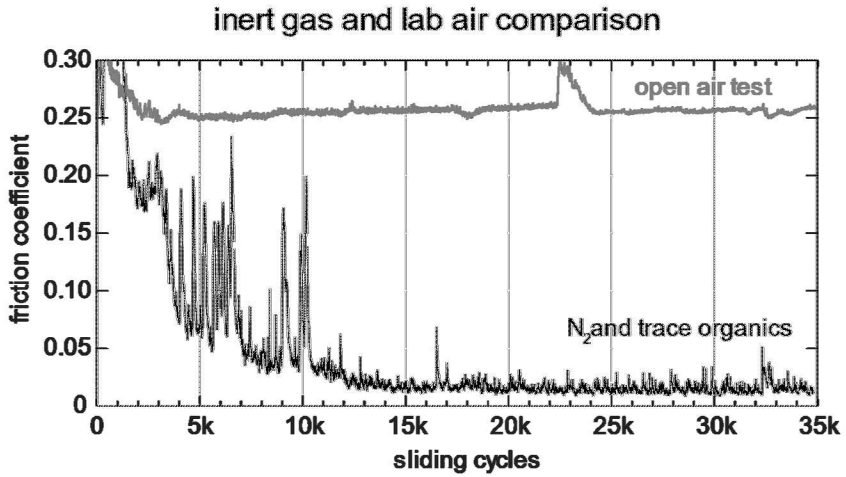
Environmental Sensitivity



- Great friction performance in lab air ($\mu \sim 0.25$)…

Argibay et al, Carbon 2018

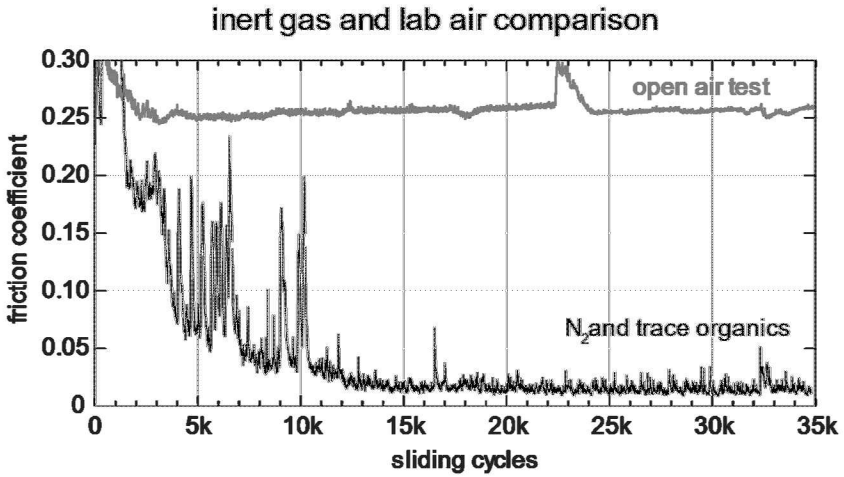
Environmental Sensitivity

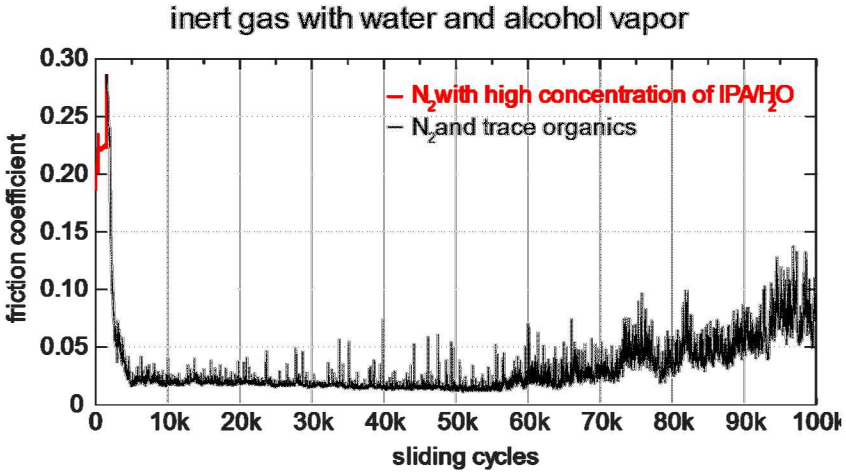


- Great friction performance in lab air (μ~0.25)…
- Testing in inert environments lowers friction?

Argibay et al, Carbon 2018

Environmental Sensitivity

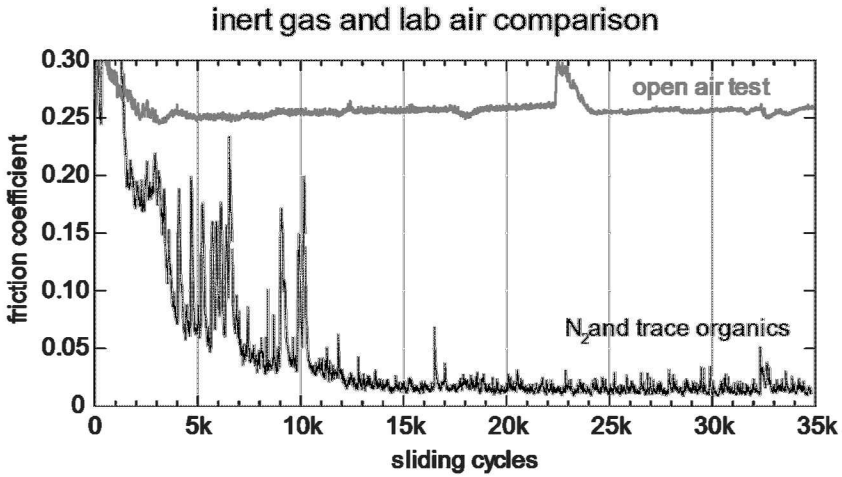


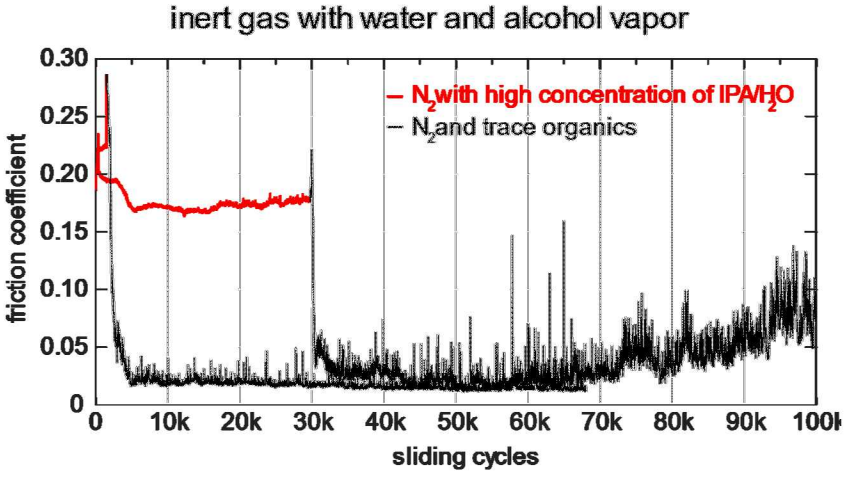


- Great friction performance in lab air ($\mu \sim 0.25$)…
- Testing in inert environments lowers friction?
- Priming the enclosure with hydrated IPA accelerates drop…

Argibay et al, Carbon 2018

Environmental Sensitivity





- Great friction performance in lab air ($\mu \sim 0.25$)…
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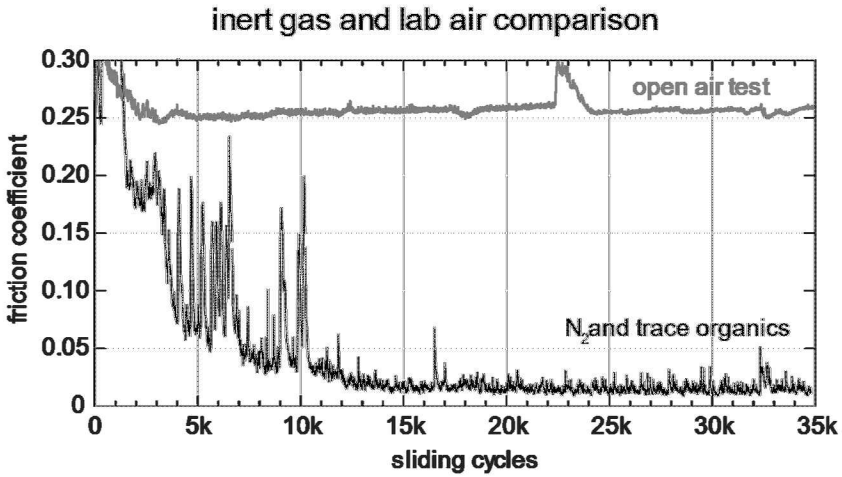
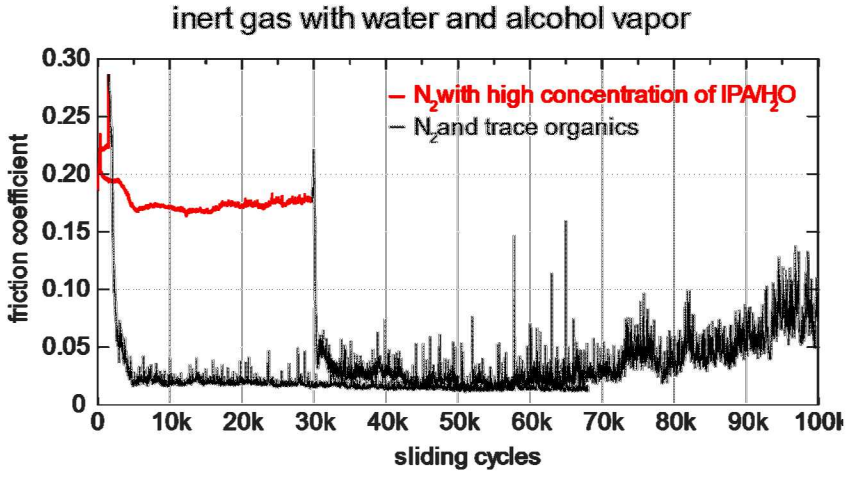
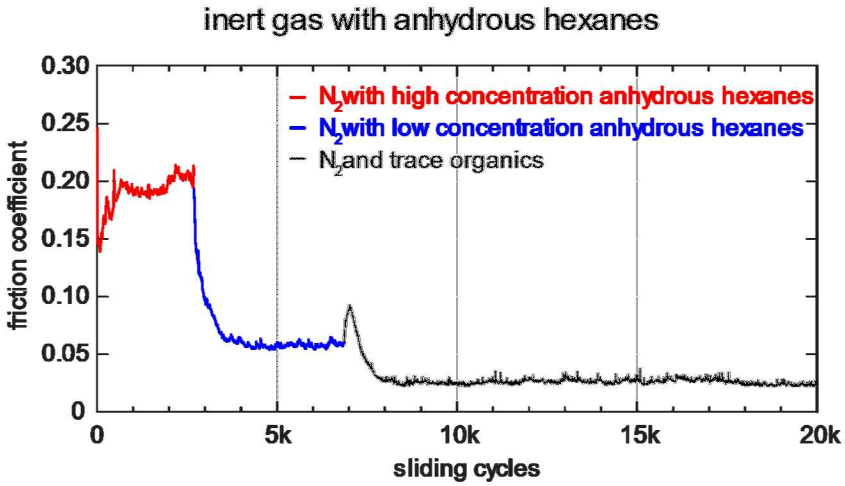
Argibay et al, Carbon 2018

Environmental Sensitivity



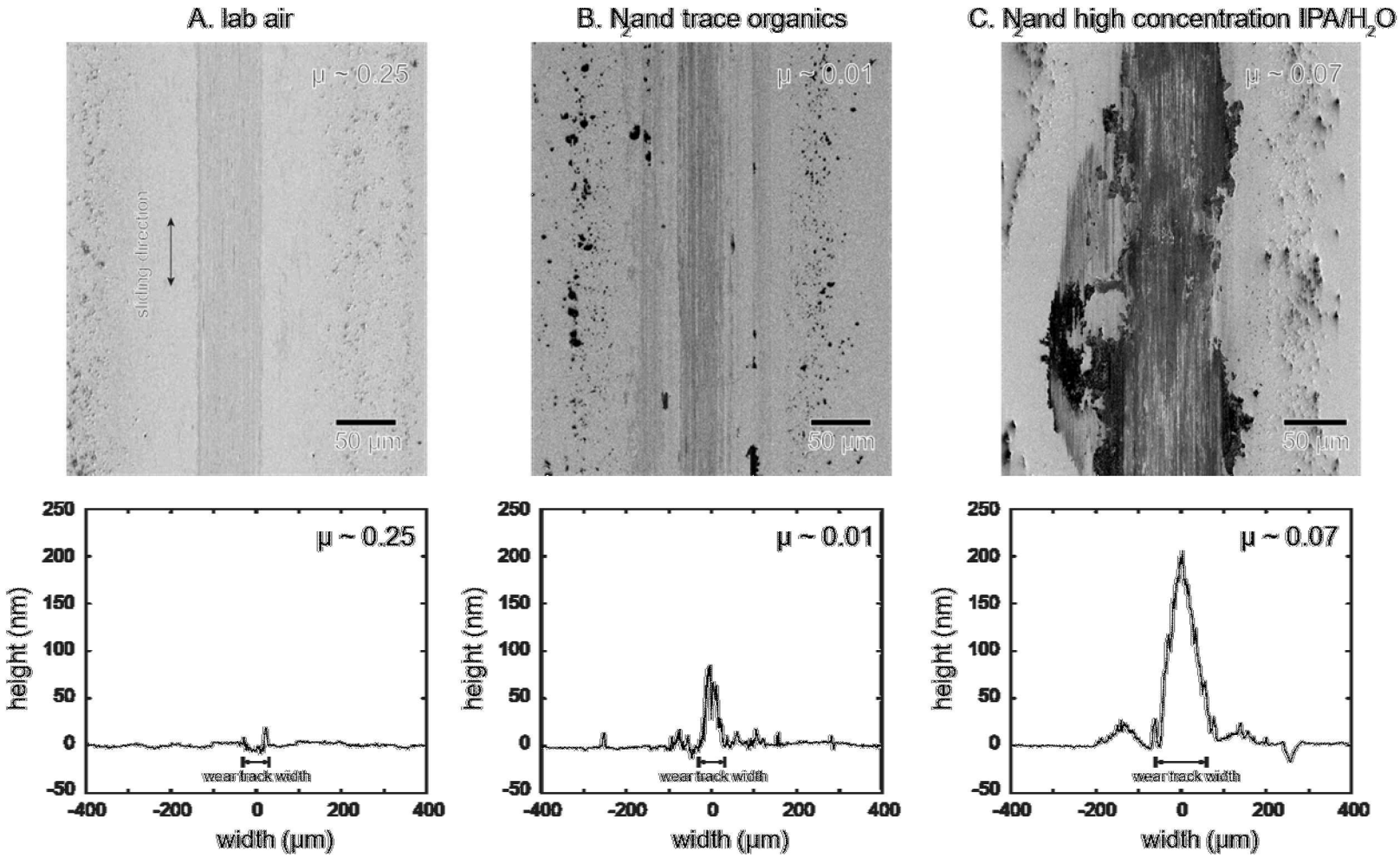


- Great friction performance in lab air (μ~0.25)…
- Testing in inert environments lowers friction?
- Priming the enclosure with hydrated IPA accelerates drop… and prolongs it
- Any amount of anhydrous hexanes increased friction, with higher/lower friction at higher/lower concentrations
- Unclear what role water/oxygen play



Argibay et al, Carbon 2018

Accumulation is Key

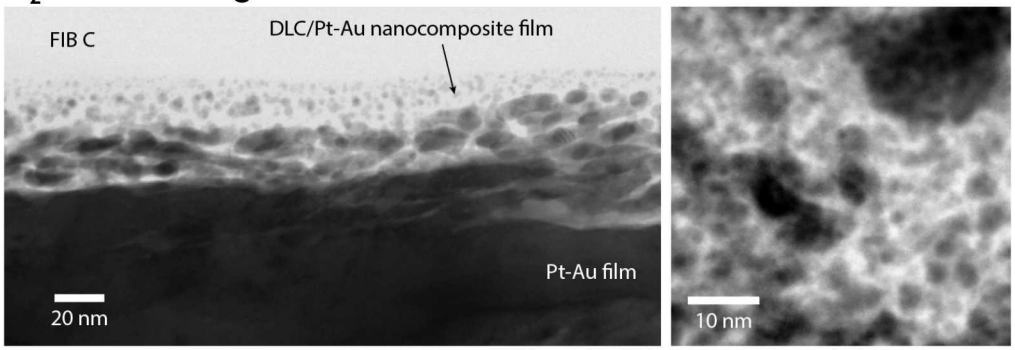


- Concentration also affects film growth in wear scar
- Highest concentrations produces thick films unable to reach low friction state

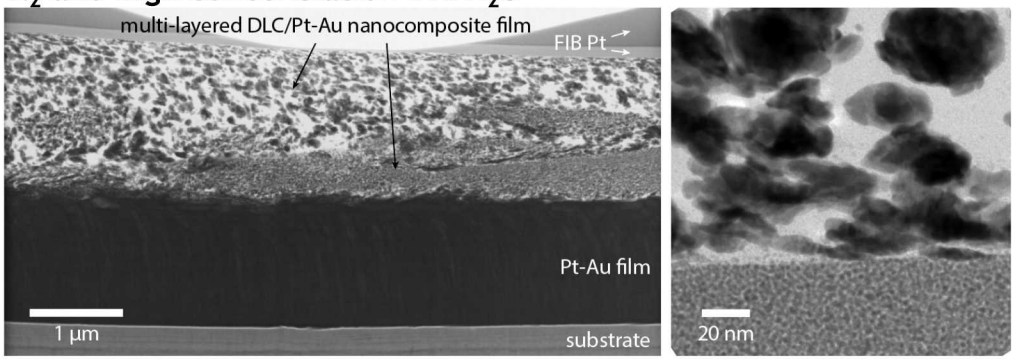
Argibay et al, Carbon 2018

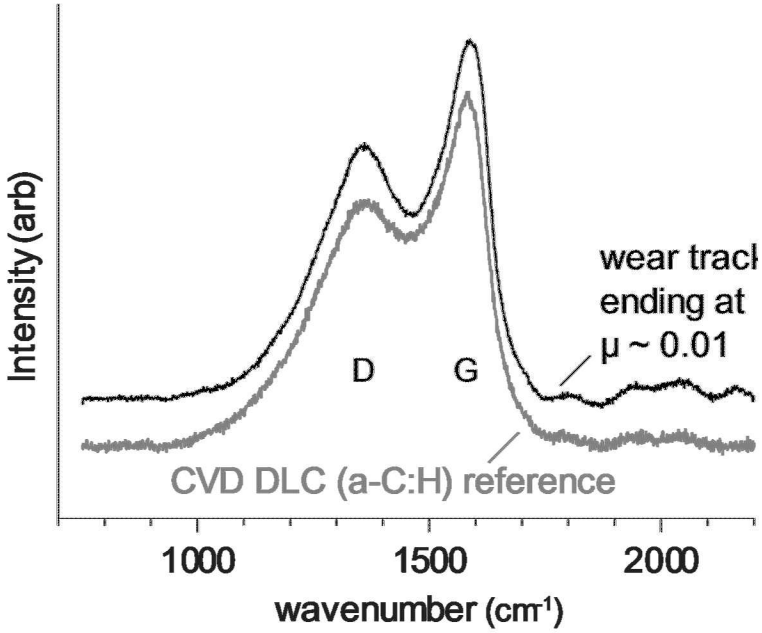
Diamond-like carbon nanocomposite

N_2 and trace organics



N_2 and high concentration IPA/H_2O





- Films are actually composite of Pt-Au nanoparticles and DLC, confirmed by TEM & Raman
- High concentrations exhibit phases of larger, less mixed/layered particles, possibly limiting mixing & Pt interaction at surface

Argibay et al, Carbon 2018

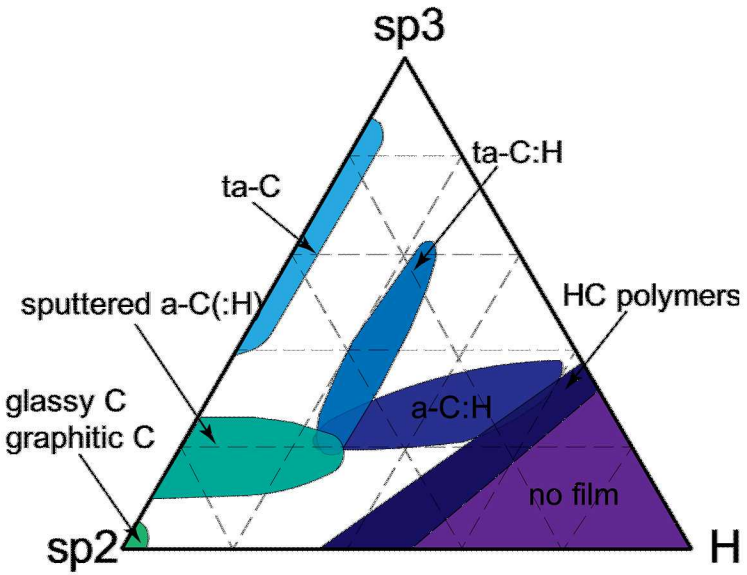
Literature Comparison

solid lubricant	deposition methods	μ_{ss}	Fn	environment
graphite (sp2 bonding)	evaporation, pyrolysis	0.2 - 0.5	0.5 - 1 N	dry N2/UHV
	of HC polymers	0.1 - 0.2	0.5 - 1 N	humid air
DLC (mixed sp2/sp3 bonding)	rf and dc sputtering, ion beam, CVD	0.6 - 0.7 a-C	10 N	dry N2/UHV
		0.001 - 0.05 a-C:H	10 N	dry N2/UHV
		0.1 - 0.2 a-C	10 N	humid air
		0.2 - 0.3 a-C:H	10 N	humid air

* hydrogen content in a-C:H DLC can vary between 20-60 at %
** sp3 bonding in a-C:H DLC can vary between 20-65%

- Find similar behaviors for tribofilms generated on Pt-Au to DLC in literature

- Likely similar to polymeric tribofilms observed by McClimon et al (Trib Lett 2019)

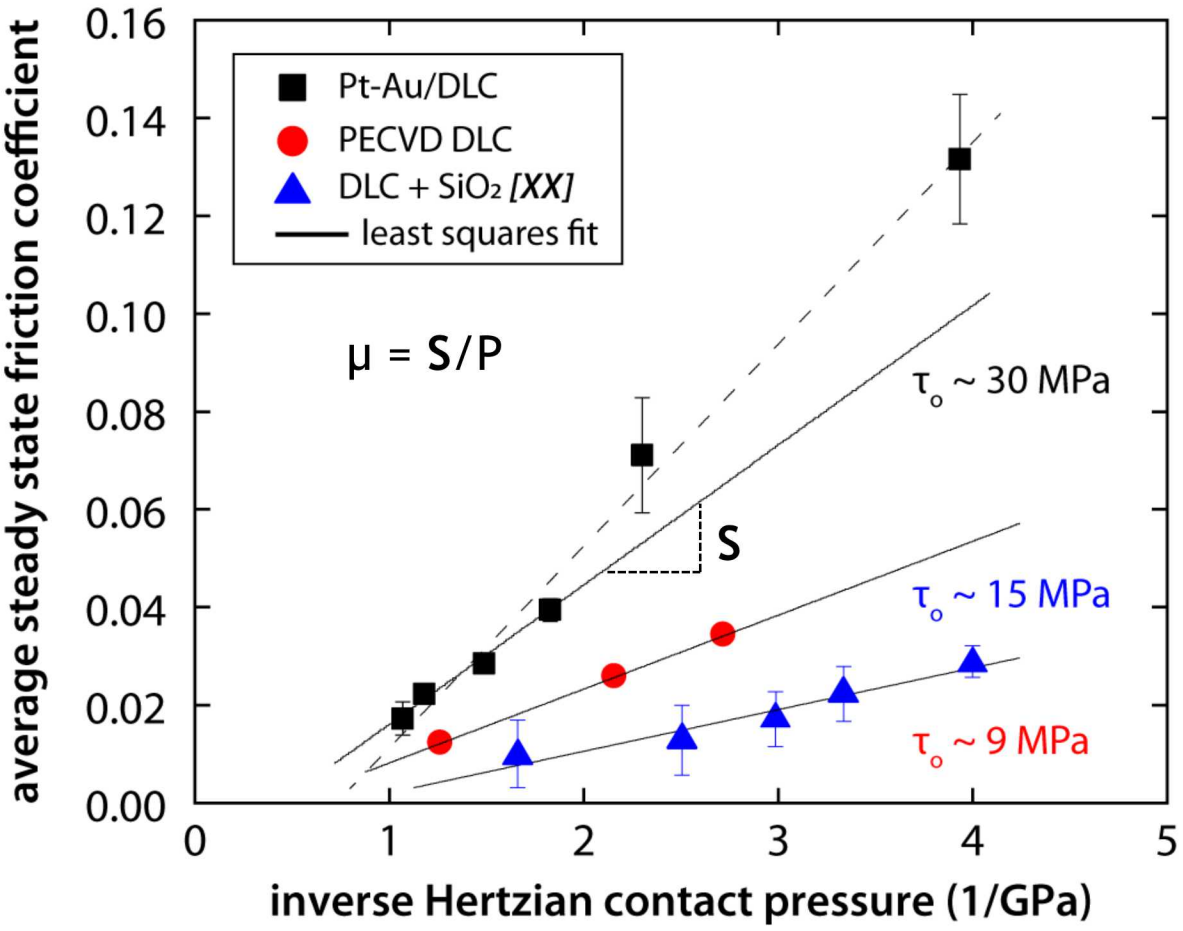


Another Way to Qualify the "DLC" Tribofilm

- Can derive shear strengths from Hertzian contact model

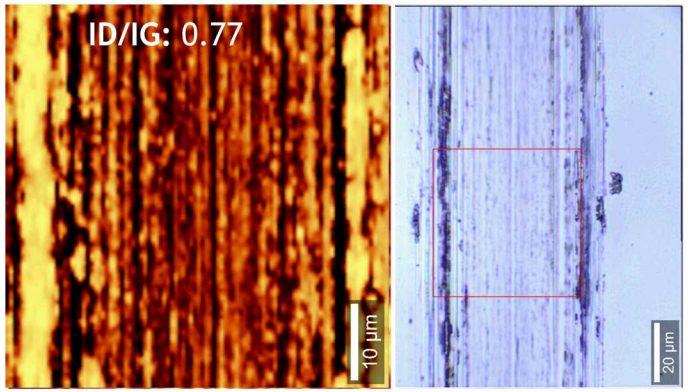
- Shear strength comparable to commercially available

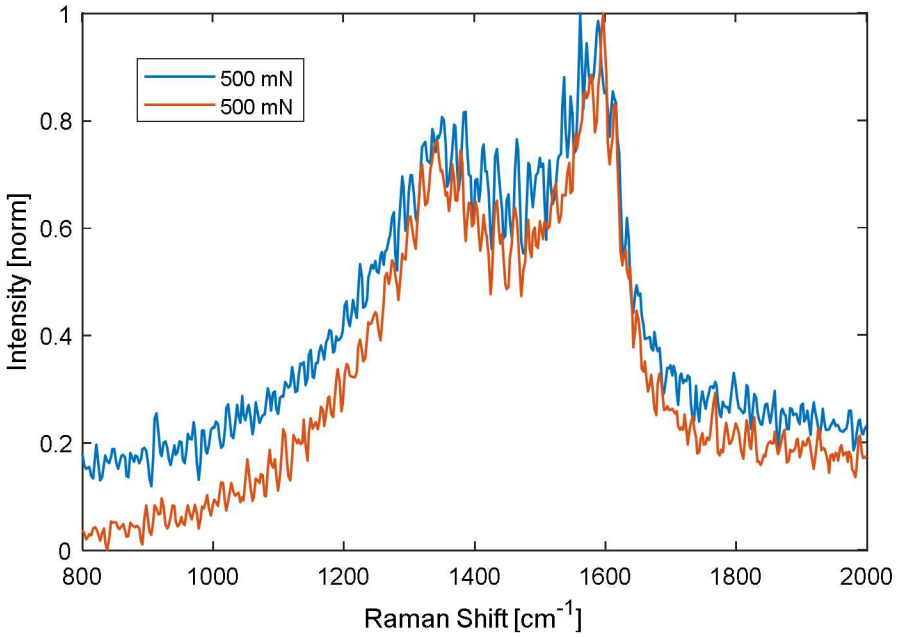
- Discrepancies may be due to composite nature of film and lower hydrogenation (20 vs 40%)



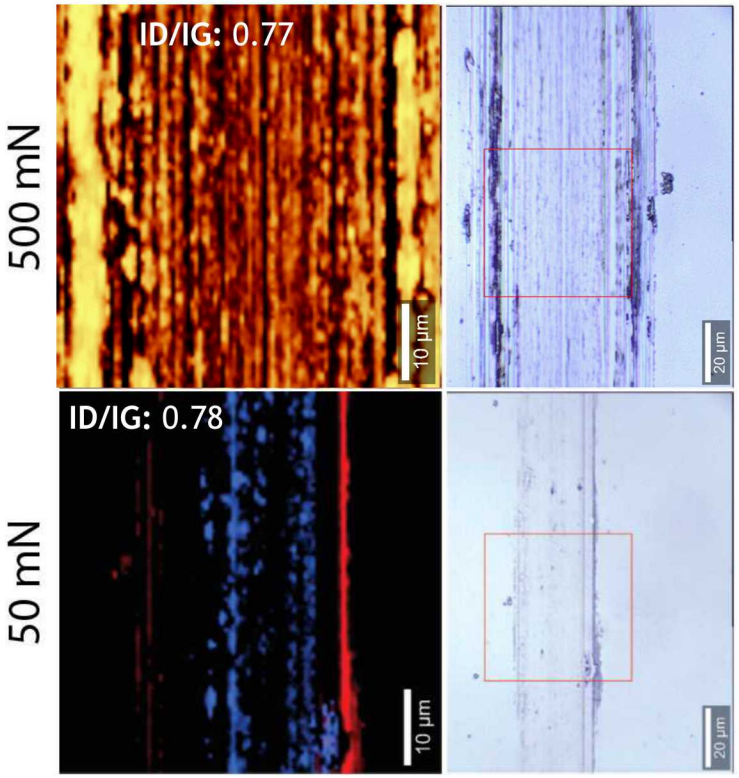
Stress Dependent Formation

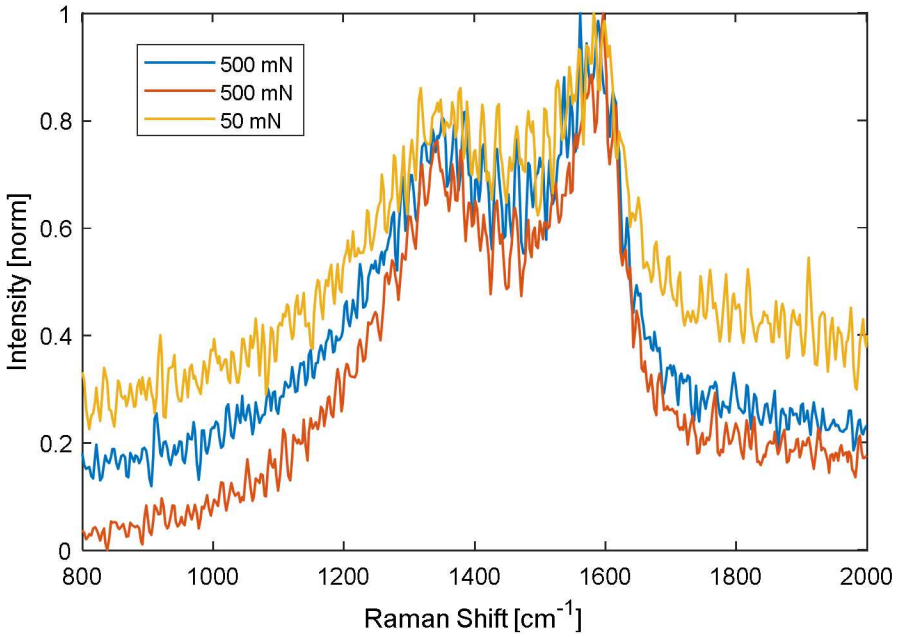
500 mN





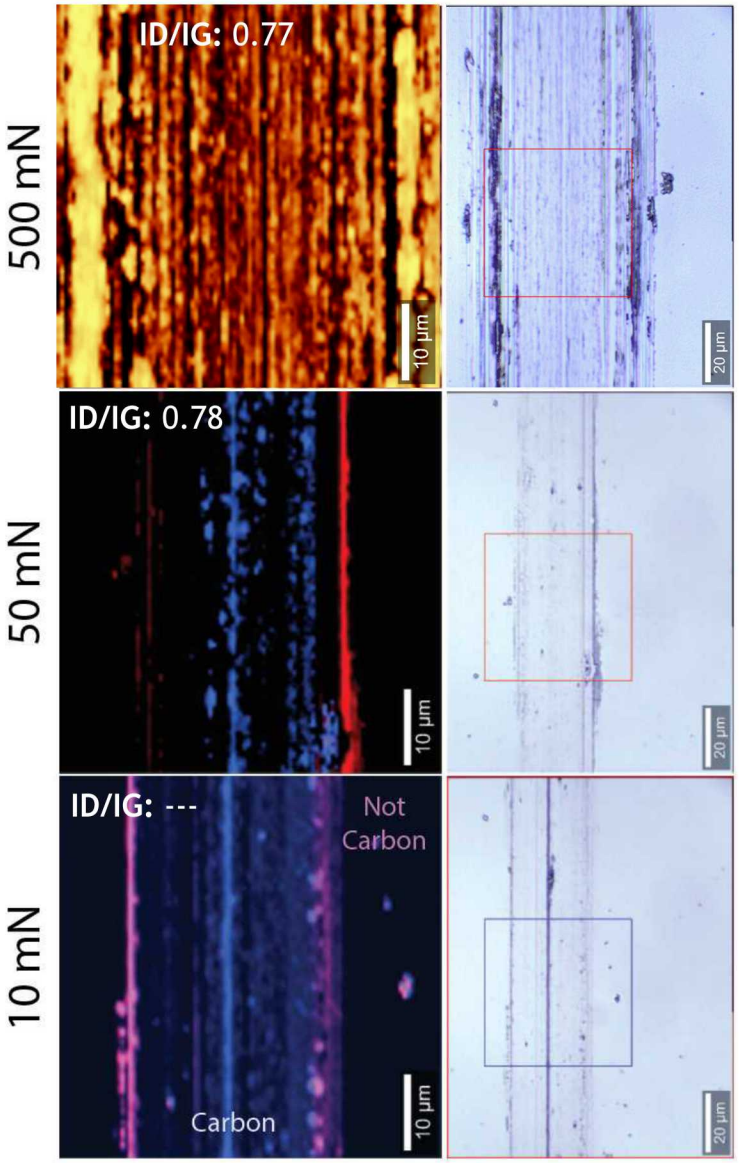
Stress Dependent Formation

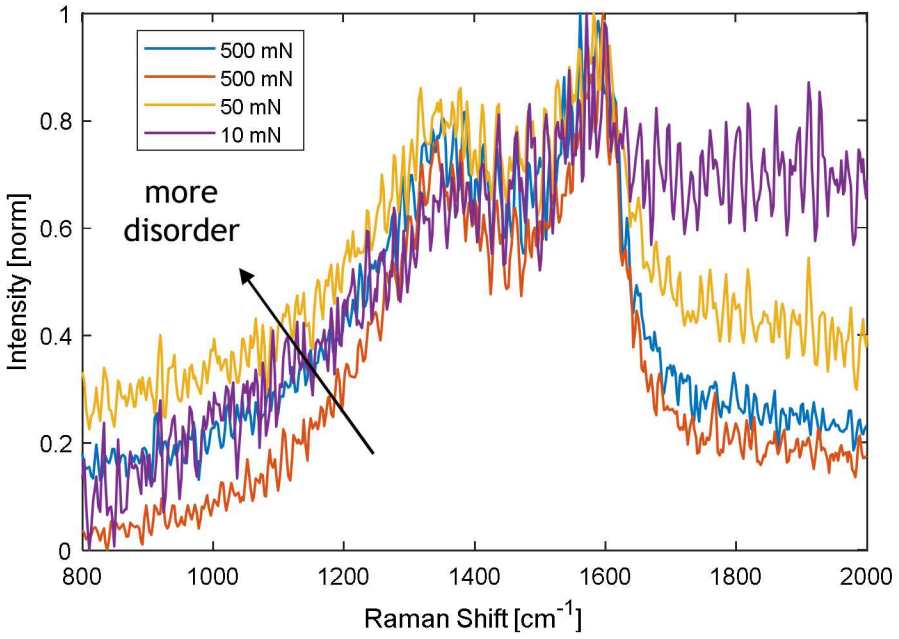




- Decreasing load leads to decreasing amounts of carbon coverage & lower signal to background

Stress Dependent Formation

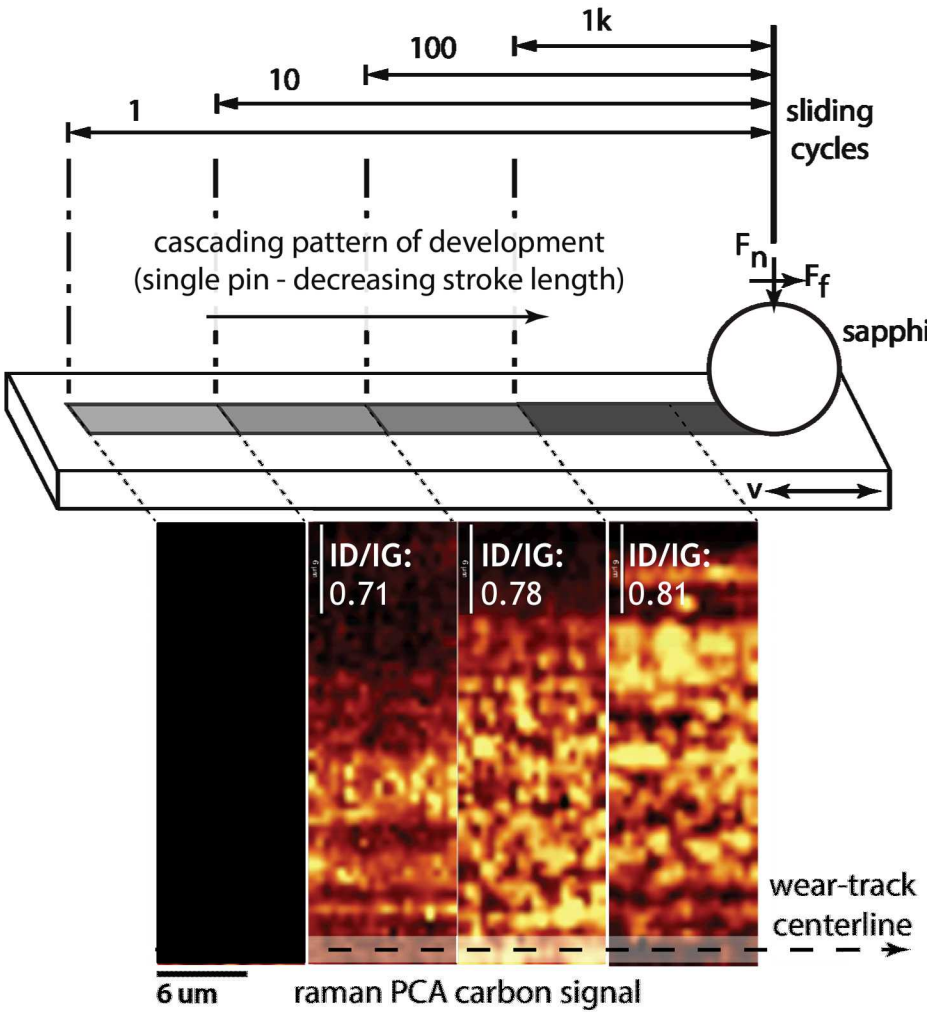


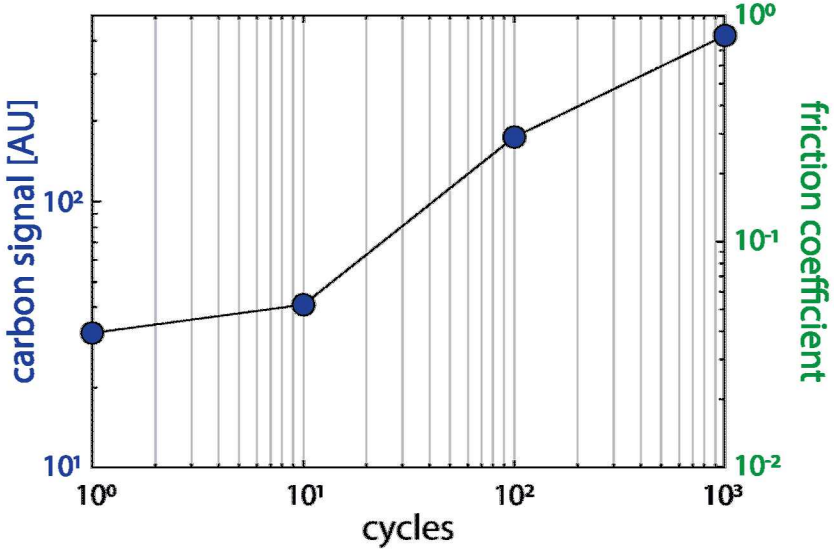


- Decreasing load leads to decreasing amounts of carbon coverage & lower signal to background

- Changes are small, but noticeable between differing lines w.r.t. greater disorder with decreasing load in spectrum

Time Dependent Formation

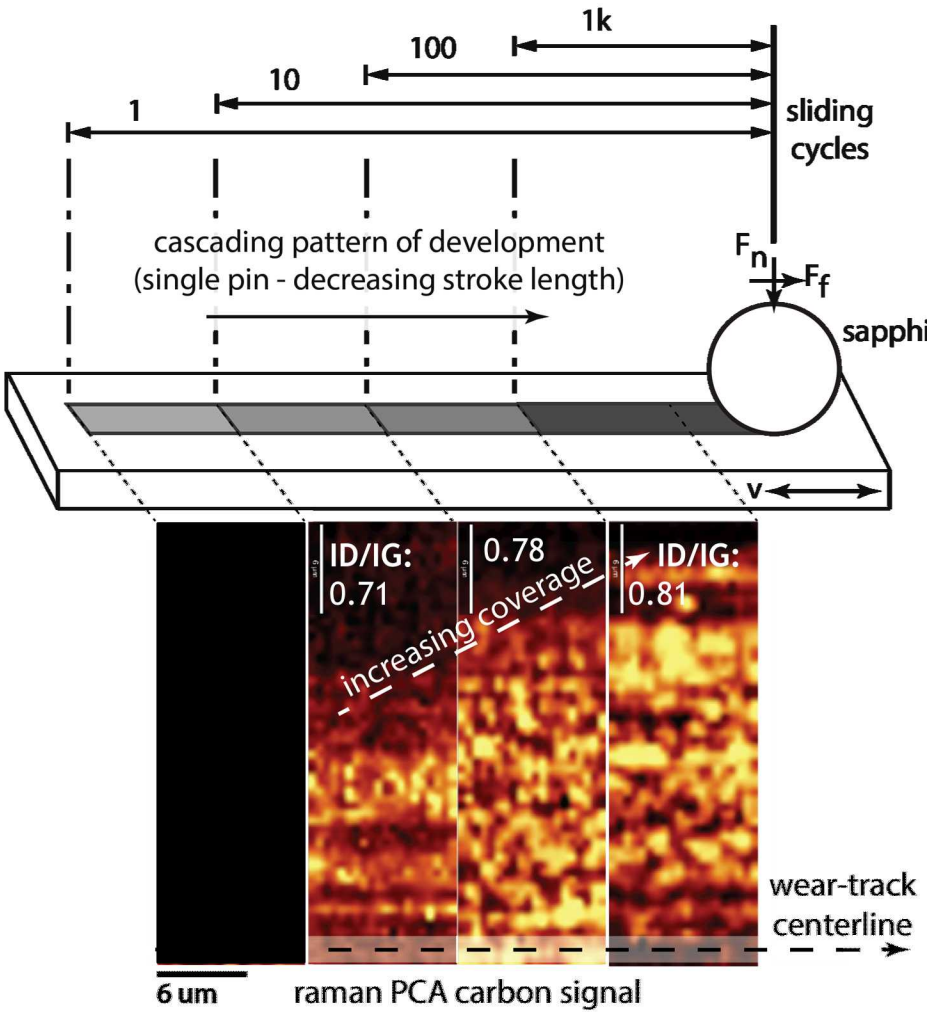


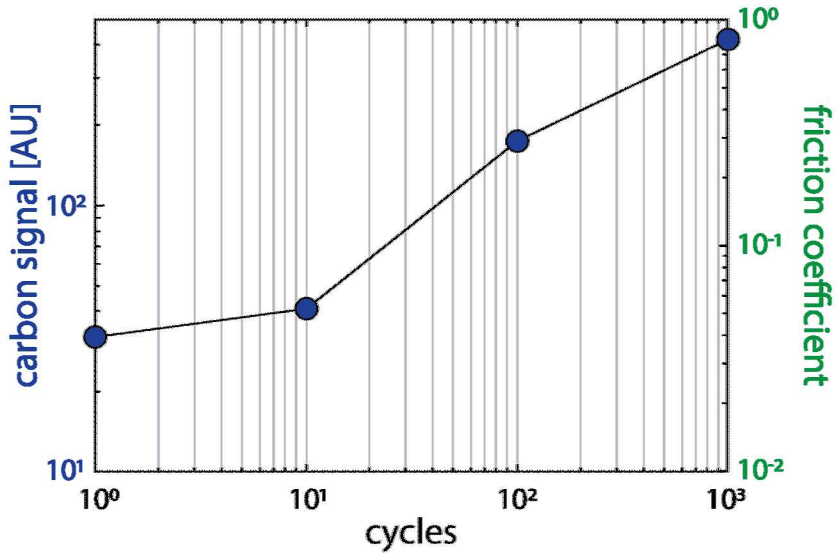


- Stripe tests elucidate time dependent behaviors

- Increasing cycle count leads to:
  - Stronger carbon signals in wear track

Time Dependent Formation

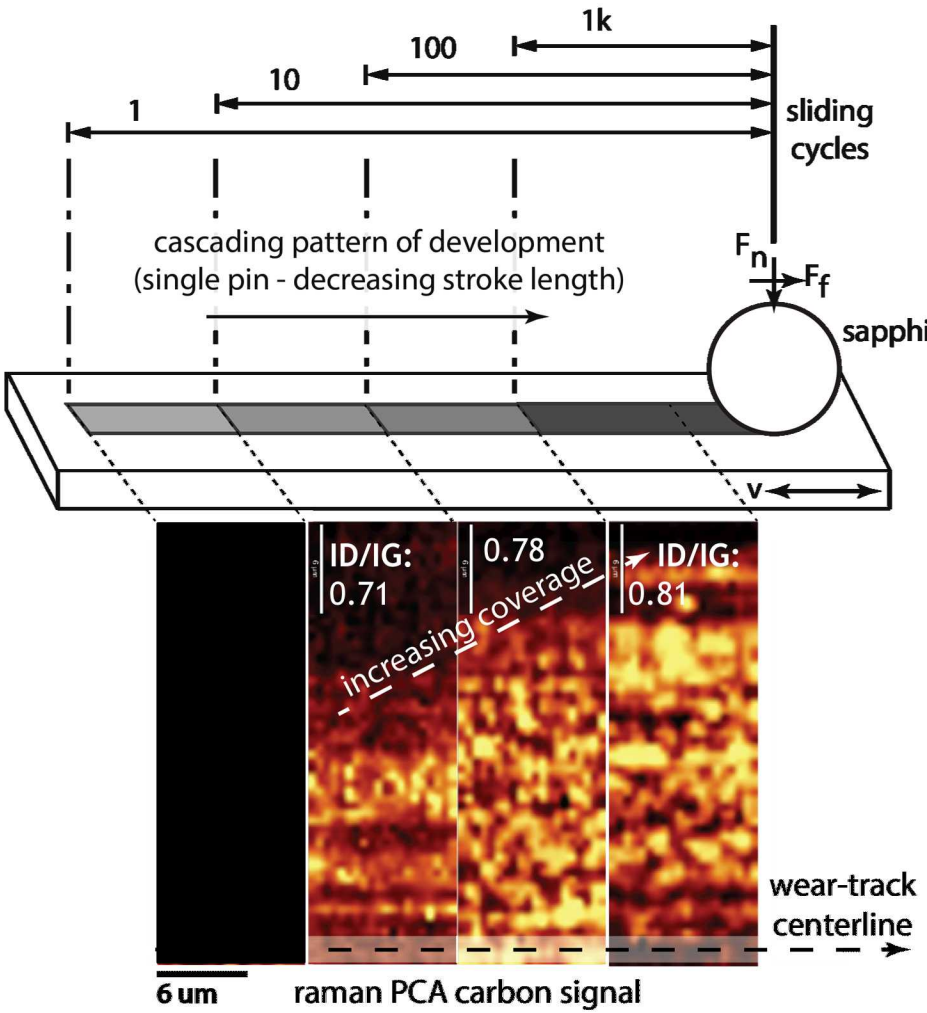


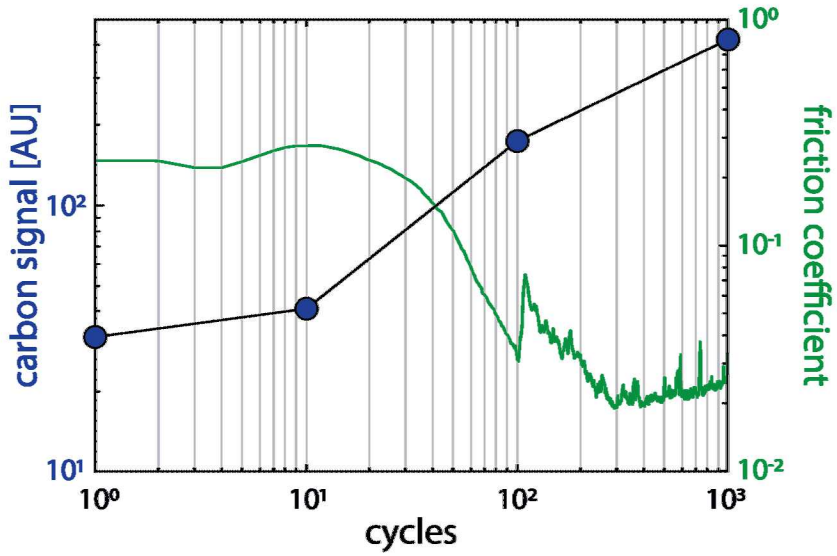


- Stripe tests elucidate time dependent behaviors

- Increasing cycle count leads to:
  - Stronger carbon signals in wear track
  - Higher coverage in wear scar

Time Dependent Formation

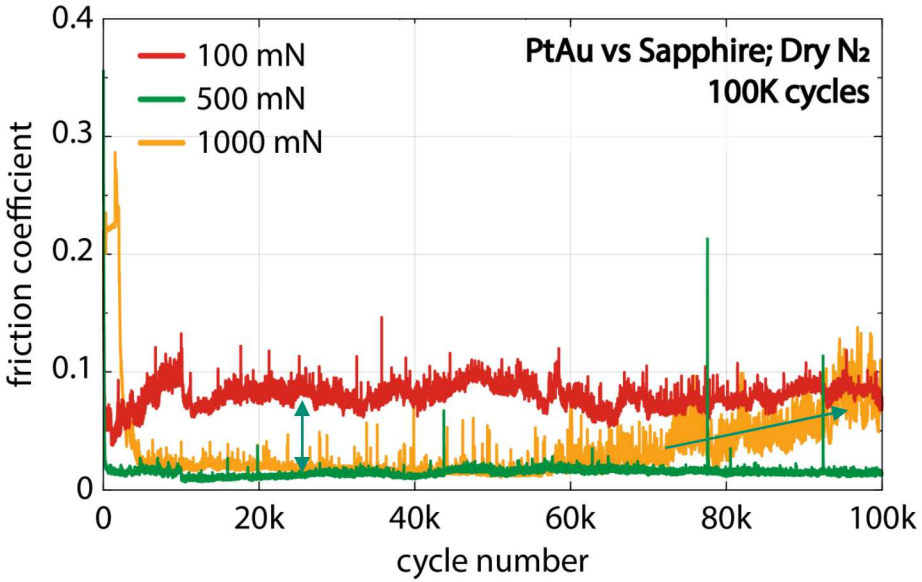




- Stripe tests elucidate time dependent behaviors

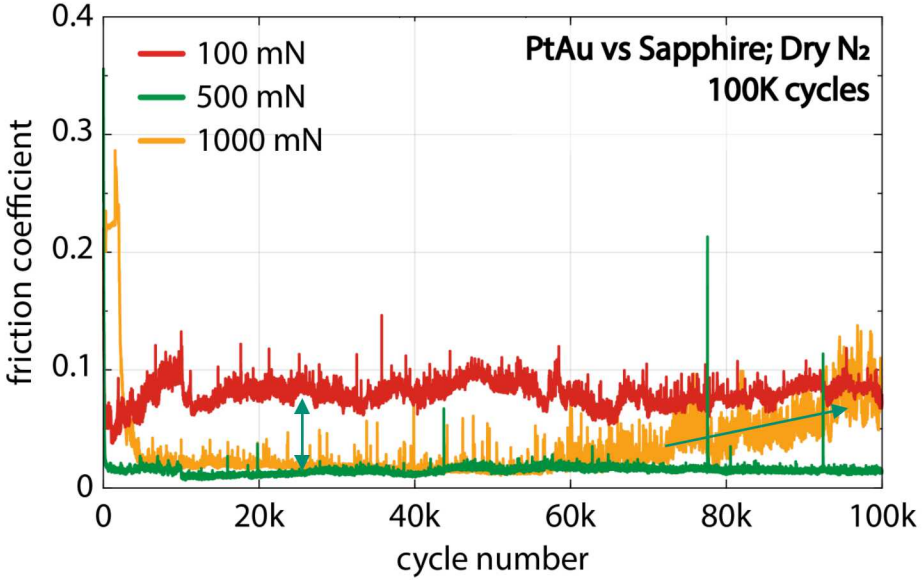
- Increasing cycle count leads to:
  - Stronger carbon signals in wear track
  - Higher coverage in wear scar
  - Decreasing friction coefficient

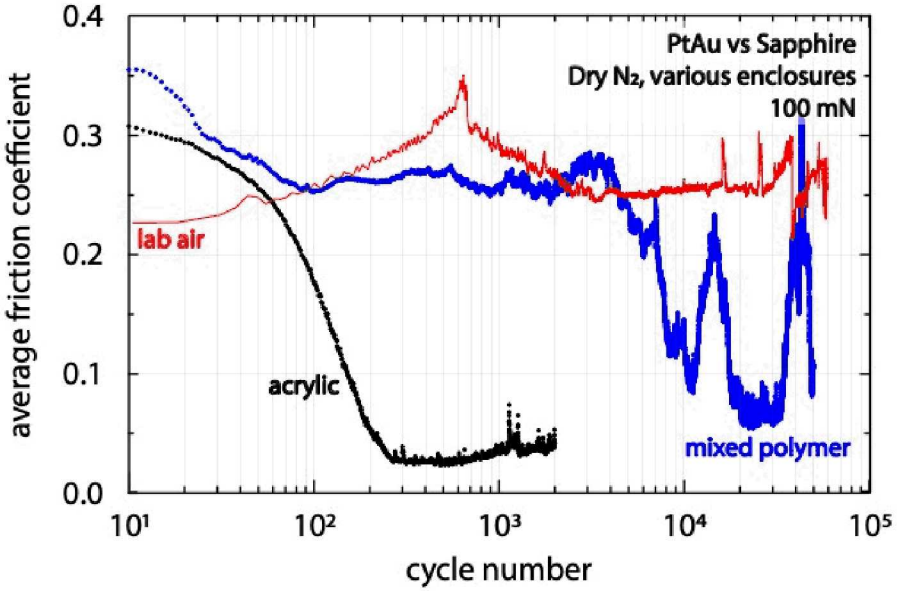
Thresholds: Load



- Long cycle (100k) studies reveal changing behavior for each load; apparent threshold between 0.1-1N

Thresholds: Load & Composition

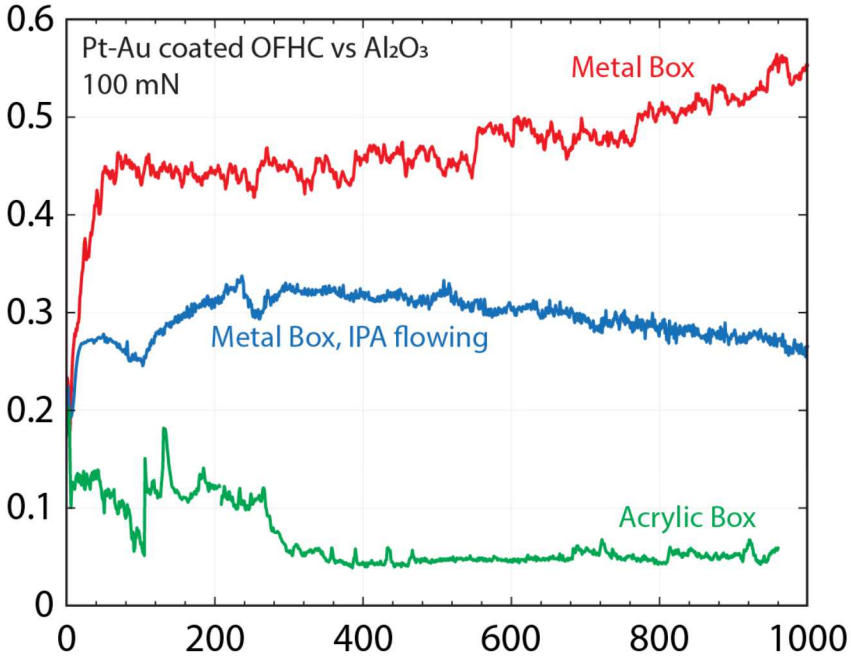


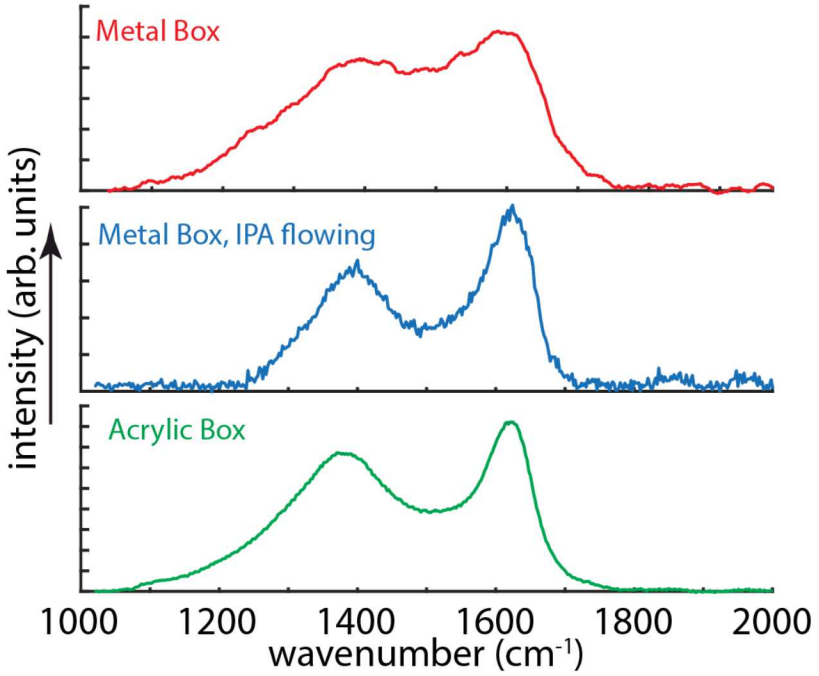


- Long cycle (100k) studies reveal changing behavior for each load; apparent threshold between 0.1-1N

- Even in other plasticized enclosures, formation can be prolonged and in some cases not form

Separate Lab Formation Study (Lehigh U)

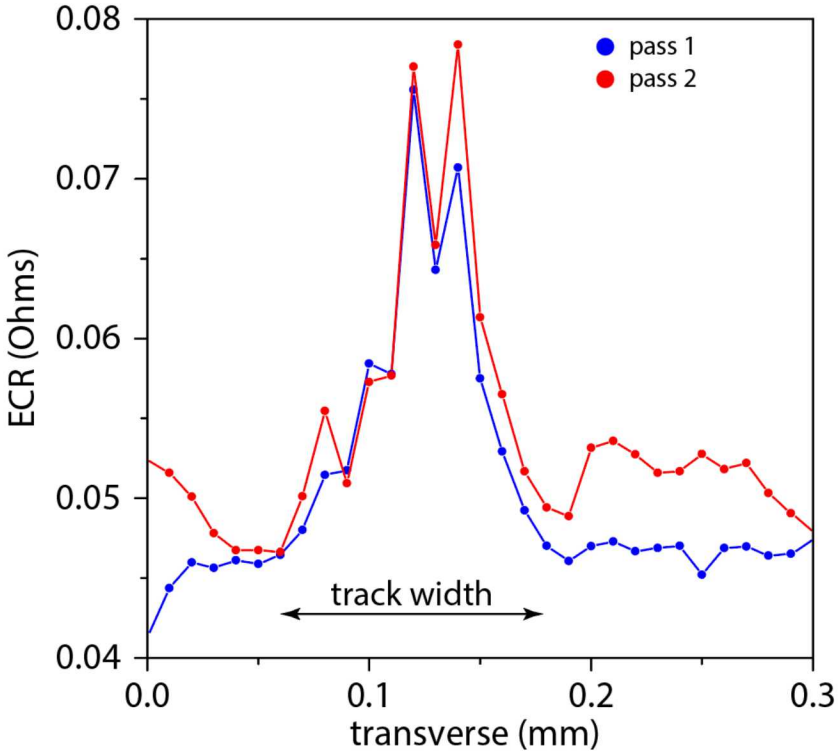


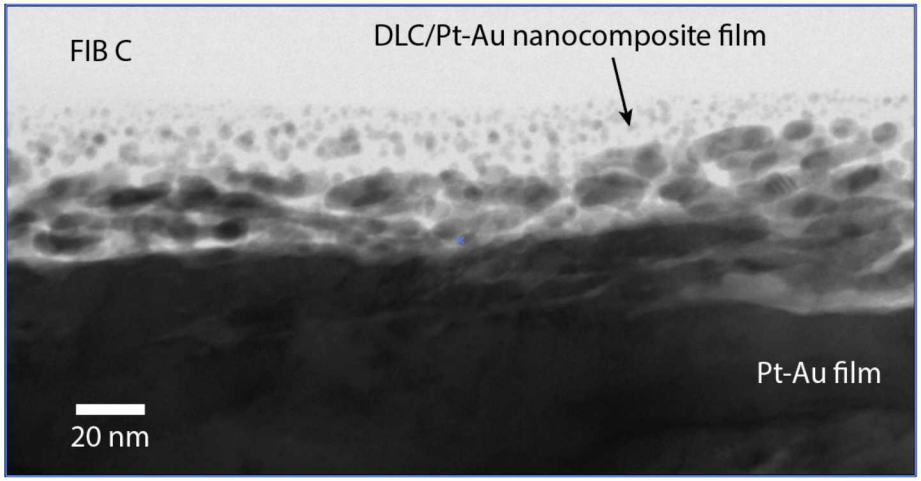


- Lehigh U Tribology laboratory able to form films only in acrylic enclosures

- Metallic enclosures still formed carbonaceous deposits and mixed lubrication when flowing IPA

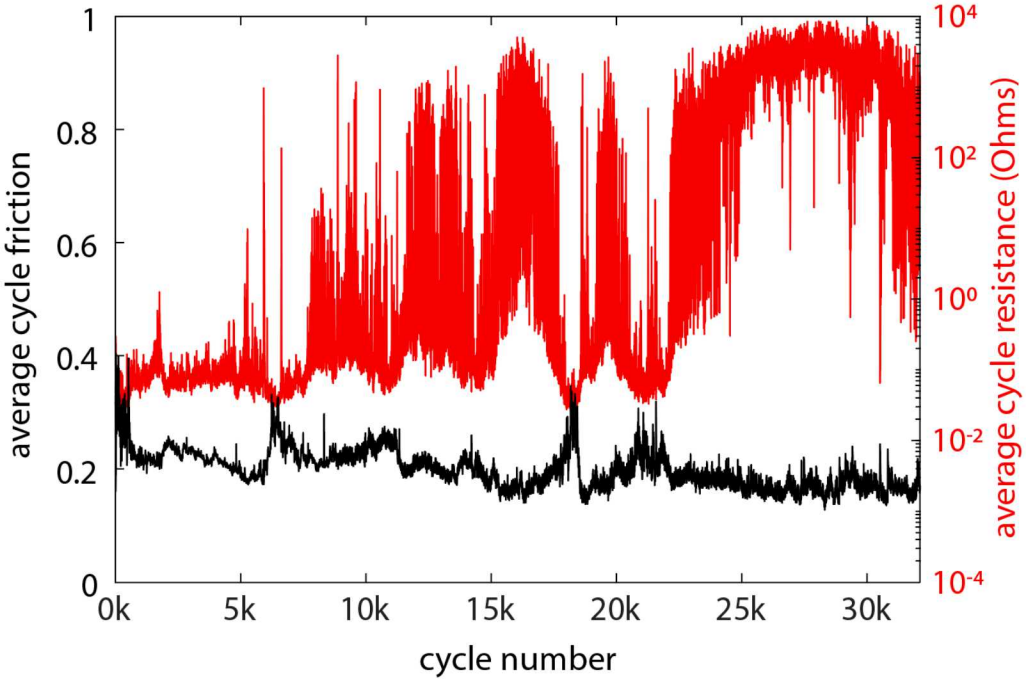
ECR of Tribofilms

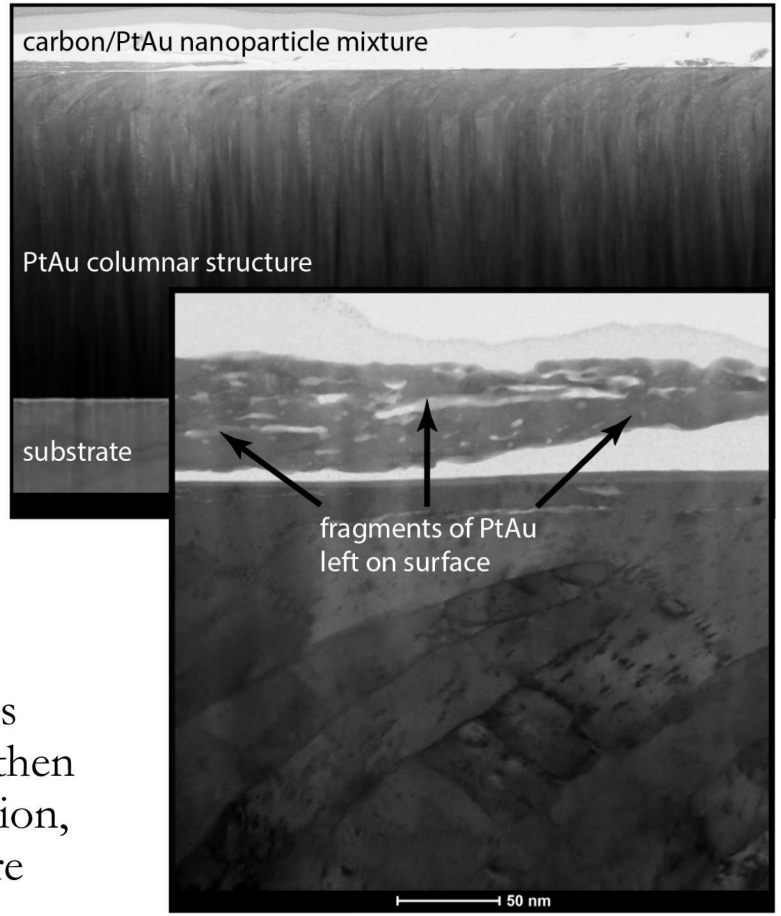




Low friction tracks (μ<0.05) formed vs sapphire are conductive!

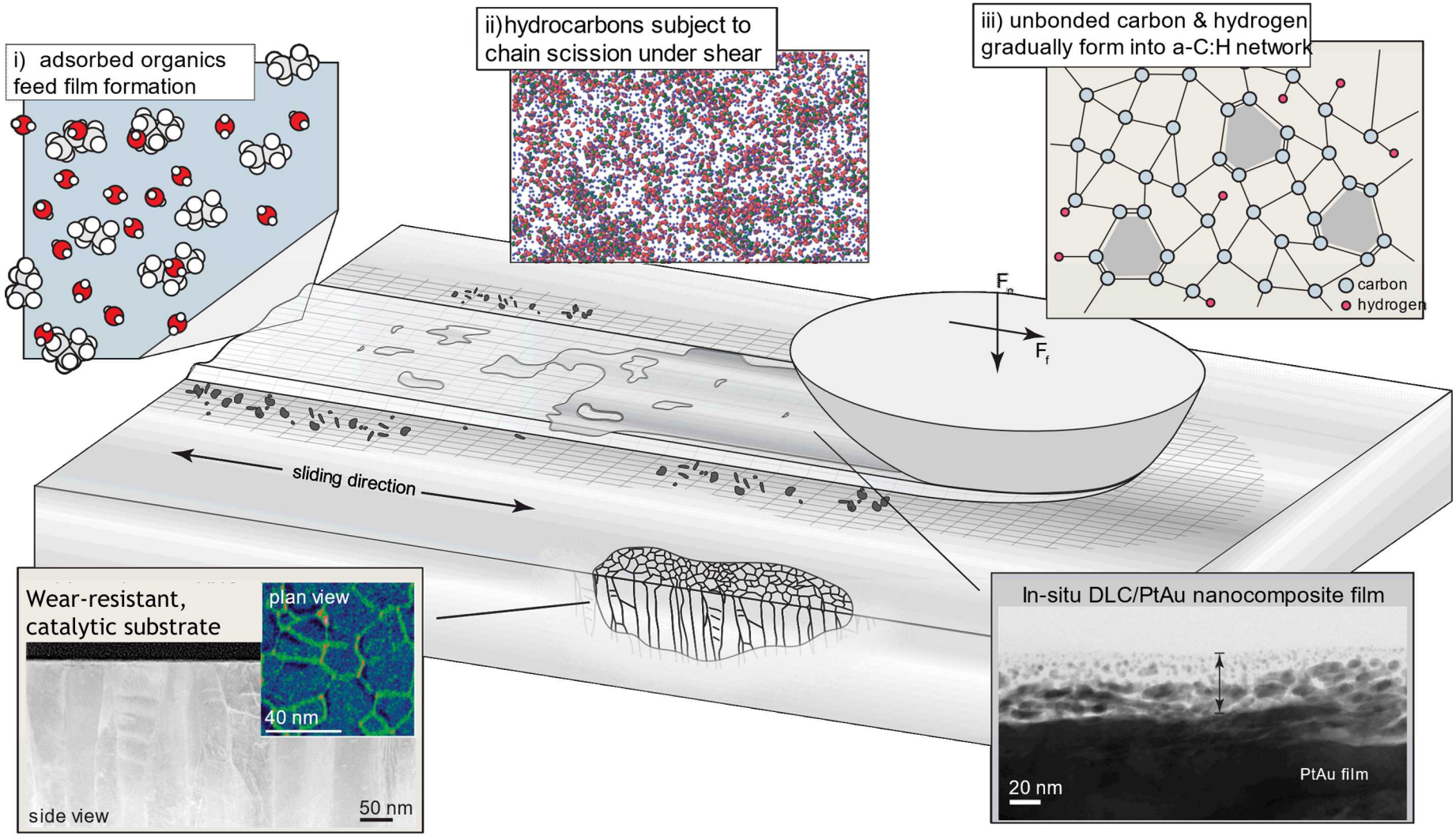
ECR of Tribofilms





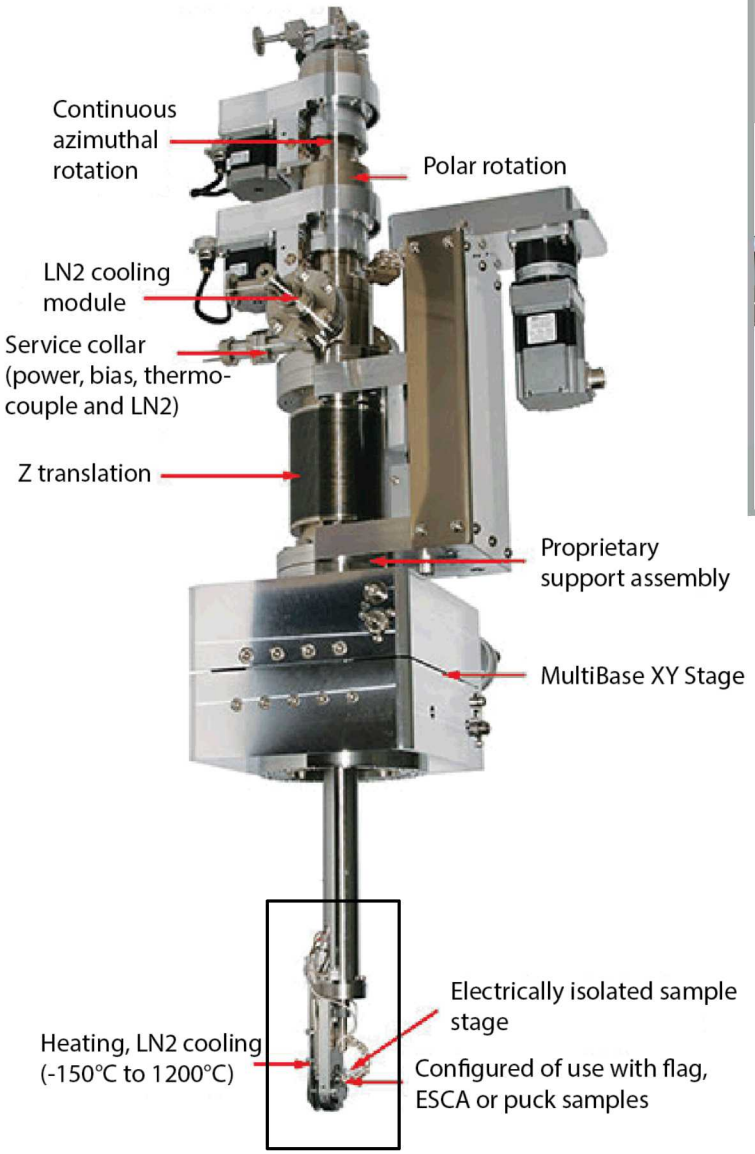
hard gold alloy vs. PtAu showed increased resistivity as carbon film grew over 30k cycles. Starts at ~ 20 mΩ, then experiences drastic increase at ~ 7k cycles. TEM, friction, and ECR shows much different behavior than sapphire on PtAu.

Mechanisms of Formation



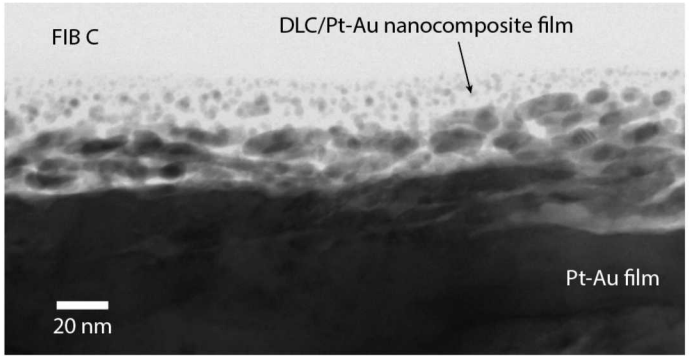
Argibay et al, Carbon 2018

Next Steps: In Situ Characterization



- 5-axis vacuum manipulator with analytical stage
- Designed to fit under various probes (and beamlines)
- Developed mini tribometer to fit underneath
  - Piezo flexure loading; Si strain gages for force sensing
  - Flag style sample grips; rotatable head for multiple tests
  - Modular design with adaptable stiffness flexures
  - **Enable novel in-situ experiments; portable system**

Conclusions

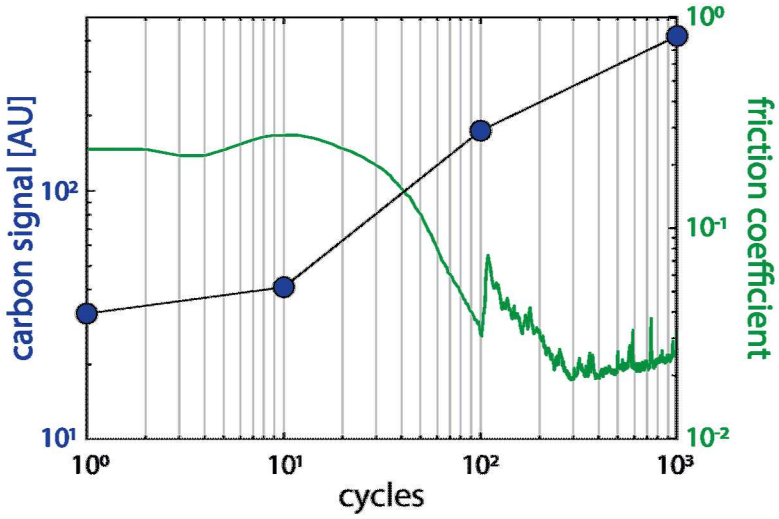


Outcomes

- DLC-like tribofilms with Pt-Au nanoparticles observed in TEM

- Raman, ERDA & friction behavior suggest formation of DLC-like tribofilm

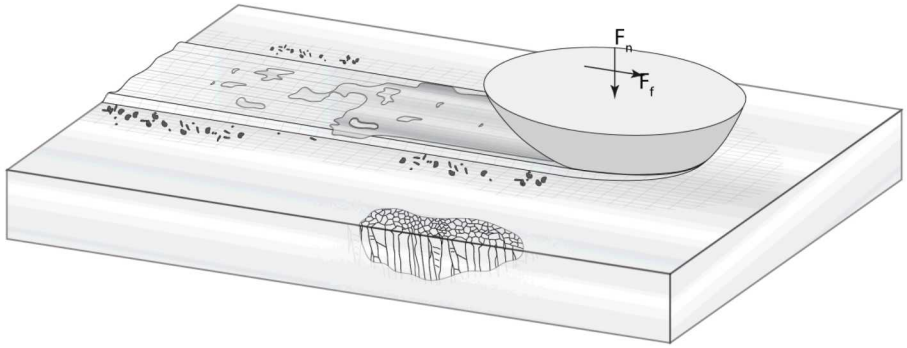
- Observable shear strengths similar to H-DLC & load/sliding history dependent formation mechanisms



Future Work

- <u>Understand the chemistry:</u> In situ studies to observe formation processes, ideal loads, species for formation

- Assess relationship between growth rate, temperature for activation energies and reaction rates



Thanks!

APPENDIX