The chemical functionalization of DLC to create an oleophobic and hydrophobic surface with high thermal and oxidative stability

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Improve DLC Surface

- Short-term goal
  - Increase hydrophobicity and oleophobicity
  - Maintain after exposure to thermal oxidation
  - No detrimental effects to DLC tribology
- Long-term goal
  - Eliminate stiction in real-world applications
    - Deposits, fouling, coking, residuals
    - Mold release
    - Lower energy interactions with fluids / friction

DLC – 2 types

- DLC on Fuel Injector Needle Tip
  - Difficult test shape, proprietary formulation

- DLC - Deposited on 304 stainless steel coupon (Richter Precision, Inc.)
  - TitanKote **C14** (“C14 DLC”), non-hydrogenated
  - 1-3um; advertised friction coefficient (μ) = 0.06 – 0.15 (air?)
- Analytical characterization
  - Raman / XPS
  - Contact angle
  - Friction coefficient

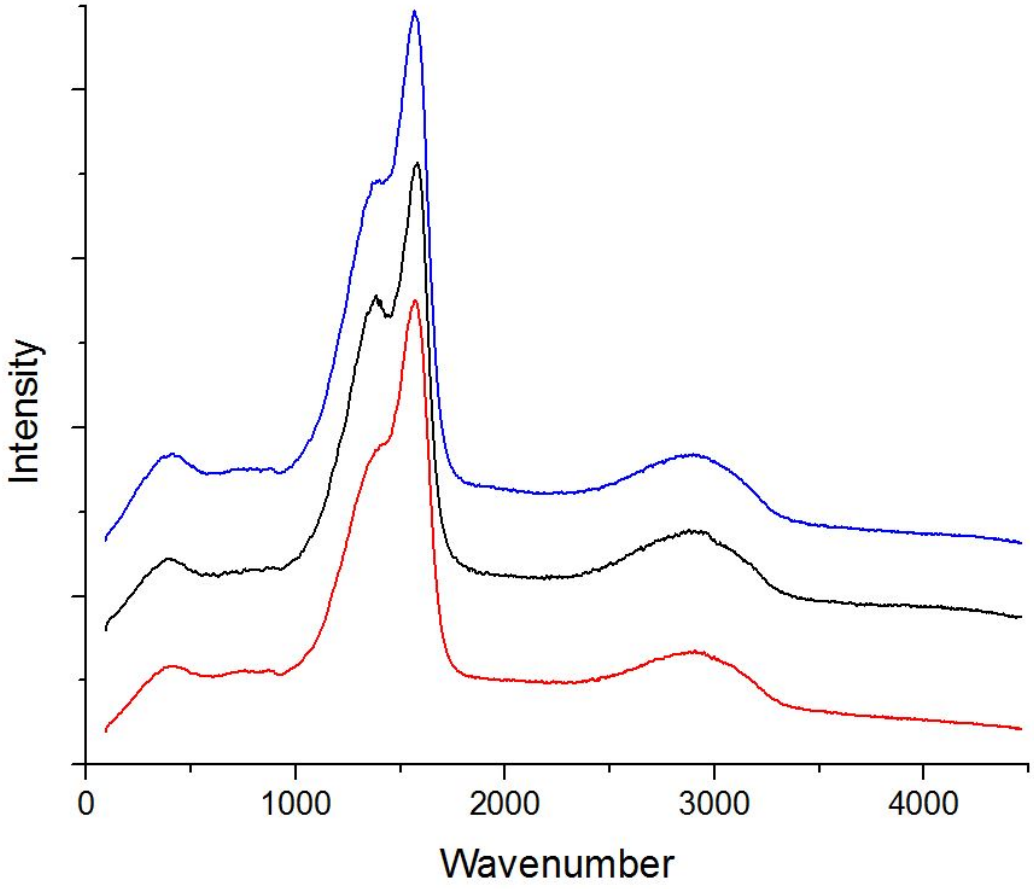
Functionalized DLC suface

- Organofluoroalkoxysilane, vapor phase thermal bonding process (patent pending)
  - 3-dimensional functionalization on to all exposed surfaces and fine structure
  - Scalable for bulk processing
- “DLC-F”

Thermal Oxidation Exposure

- Simulation of environmental extremes
  - High temperature – 300 C
  - Oxidative atmosphere – Room air
  - Extended period – 6hr or more
  - Oversimplified…
- “DLC-FT”

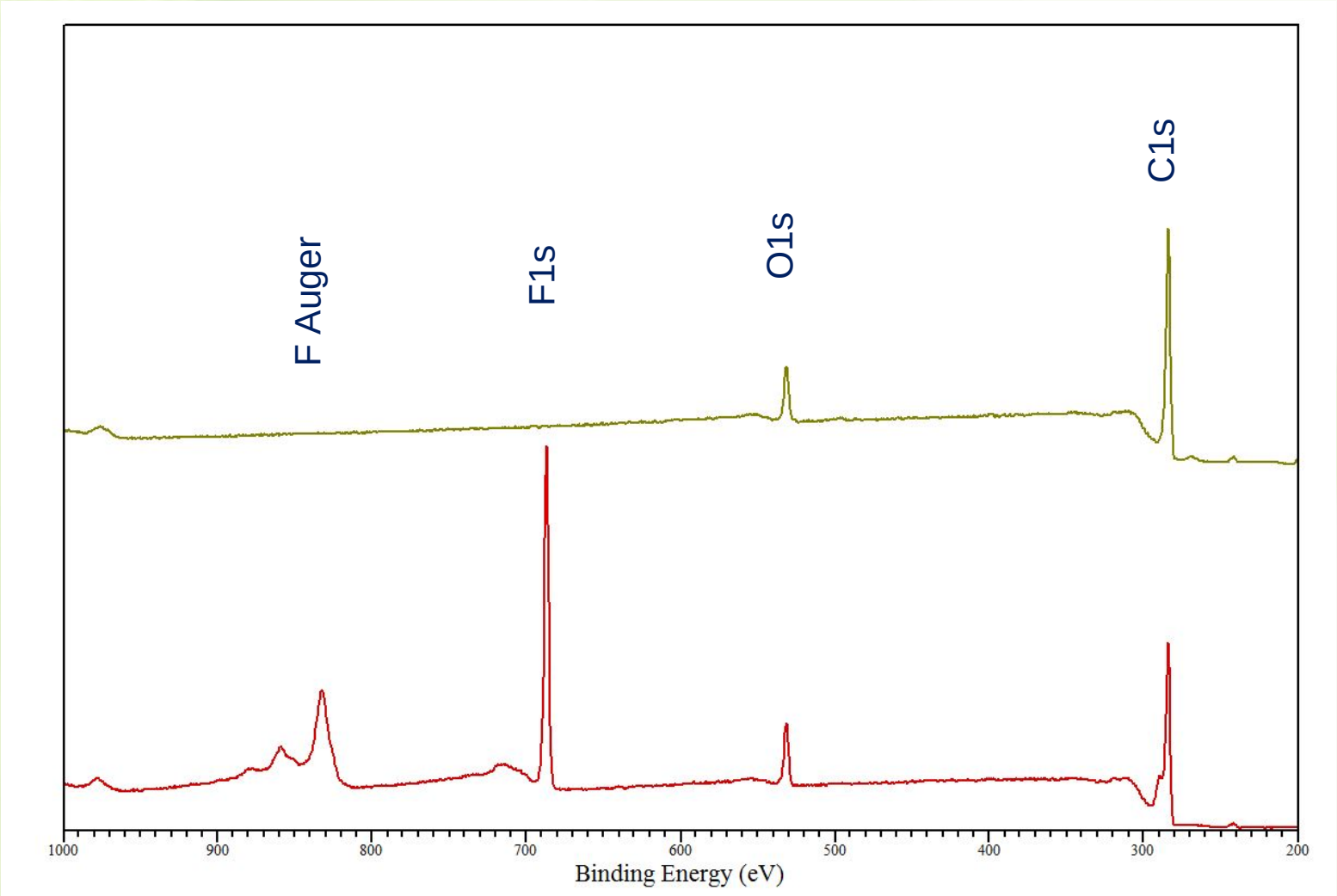
Raman Comparison – C14 DLC



DLC-FT: 6hr @ 300C in air
DLC-F: organofluoro-functionalized

DLC

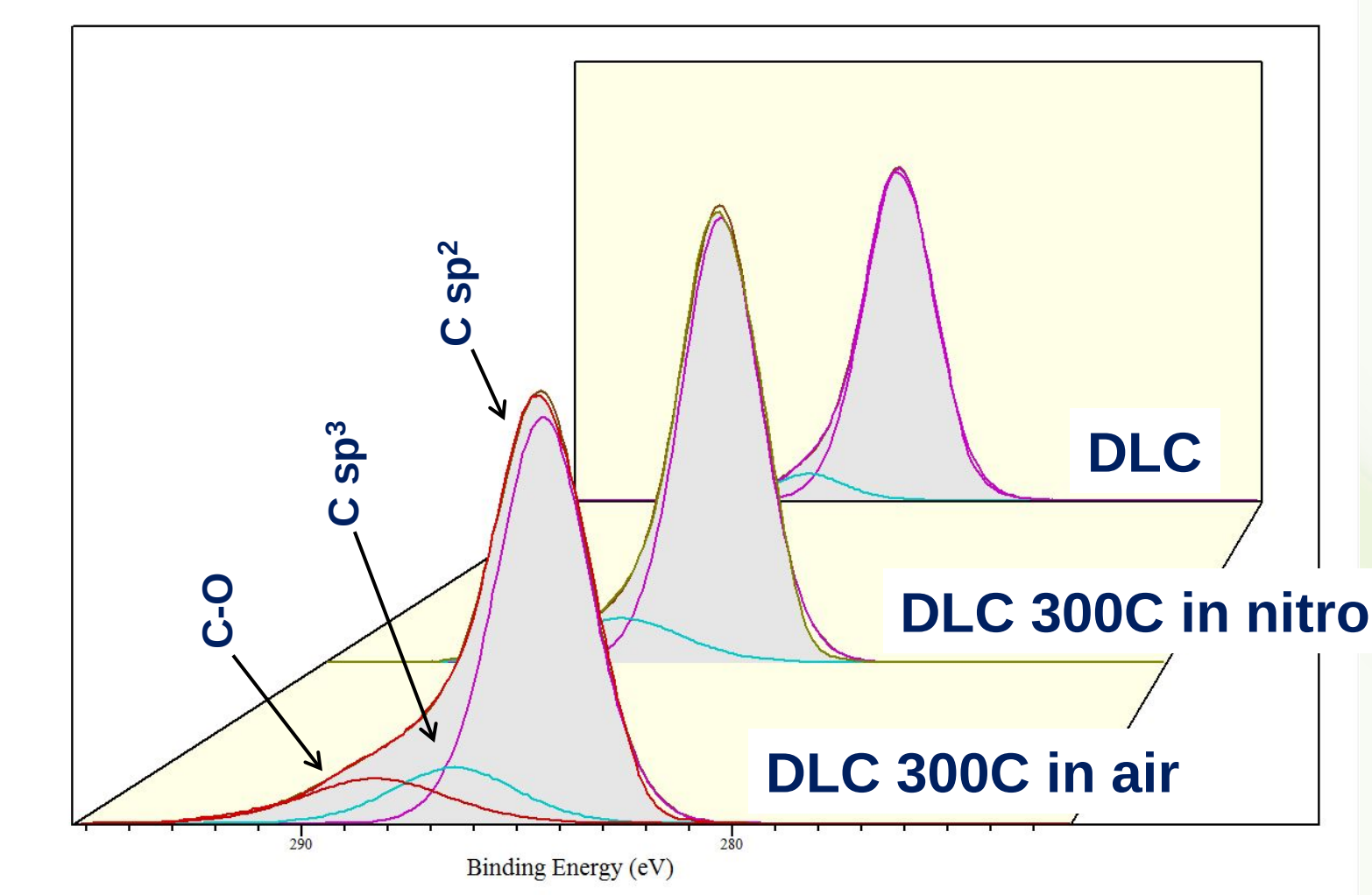
XPS: (C14) DLC vs. DLC-F



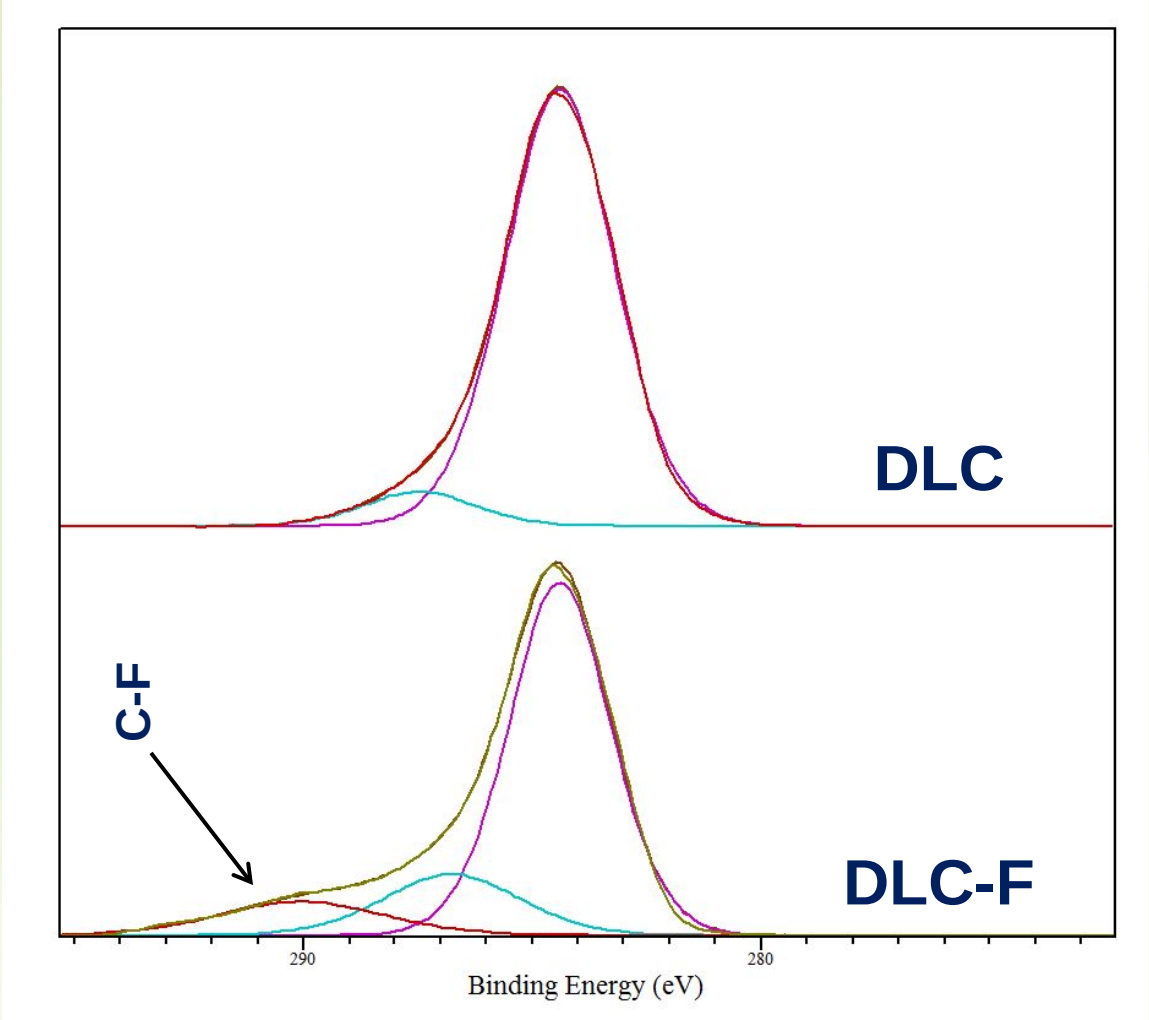
DLC

DLC-F

XPS: C1s of DLC with 6hr Exposure



XPS: C1s of DLC vs. DLC-F



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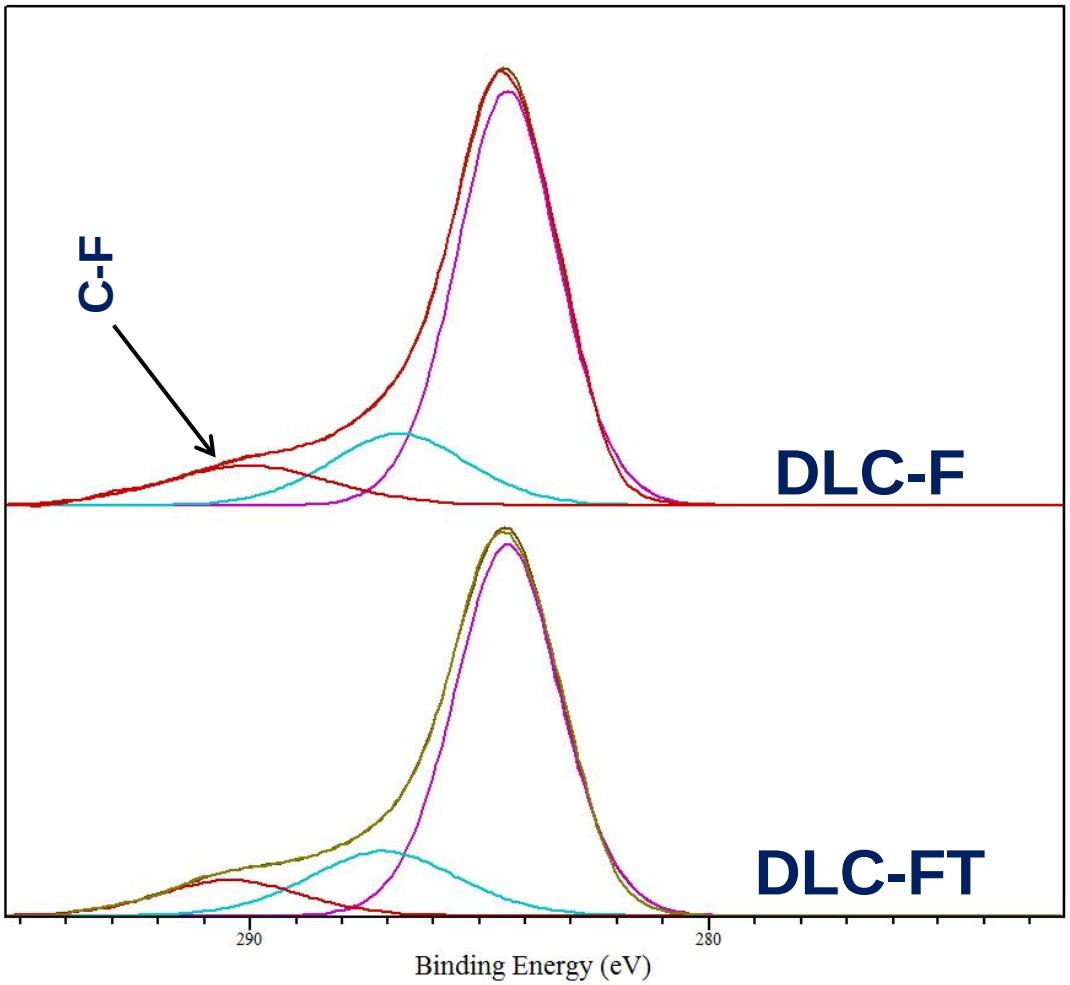
DLC-F = organofluoro functional

XPS: C1s of DLC-F vs. DLC-FT



- No change in C-F BE after exposure

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DLC-FT = fluoro after 6hr at 300C in air

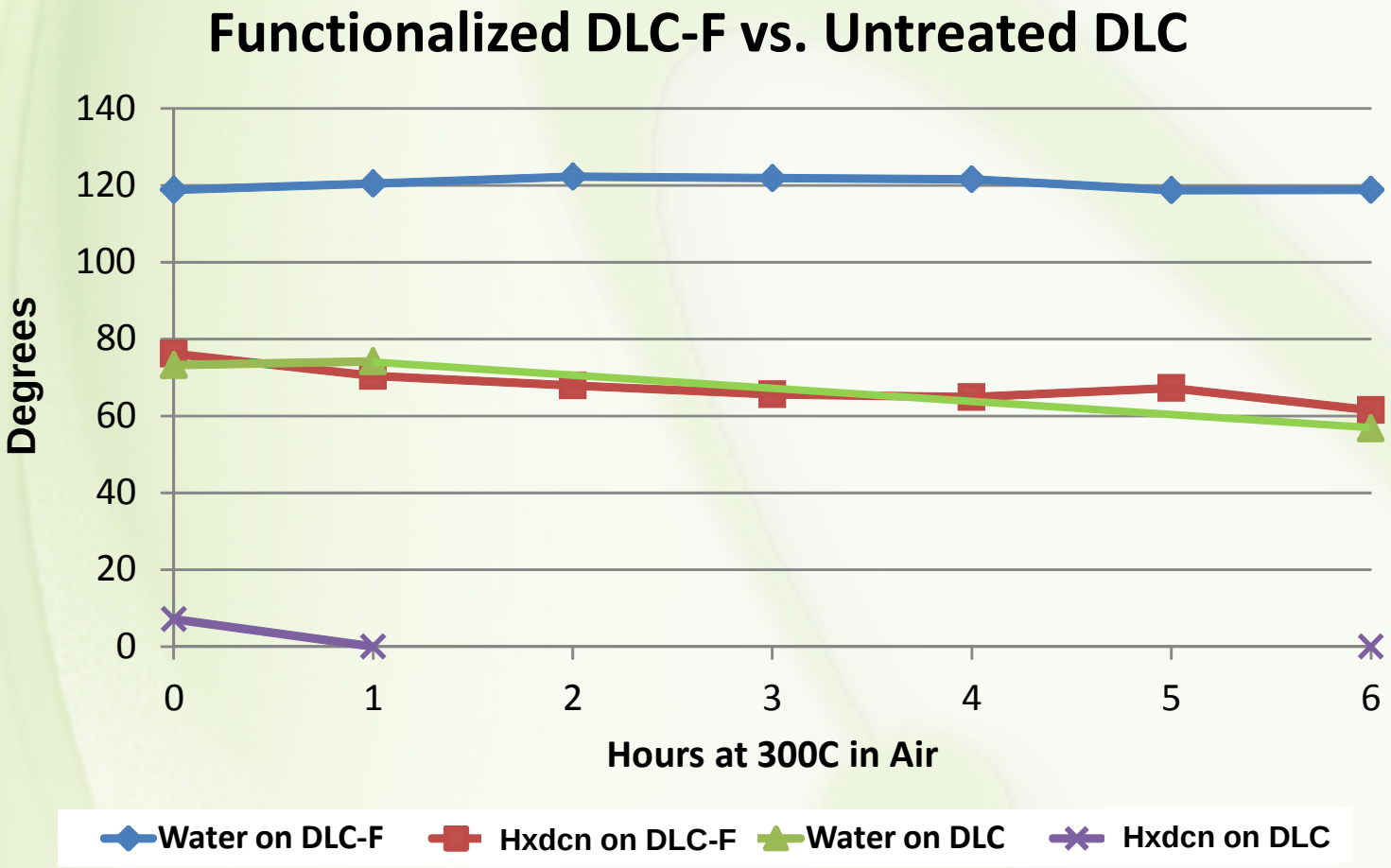
Contact Angle Comparison

- Untreated vs. Fluoro-Functional
- Pre-thermal oxidation exposure

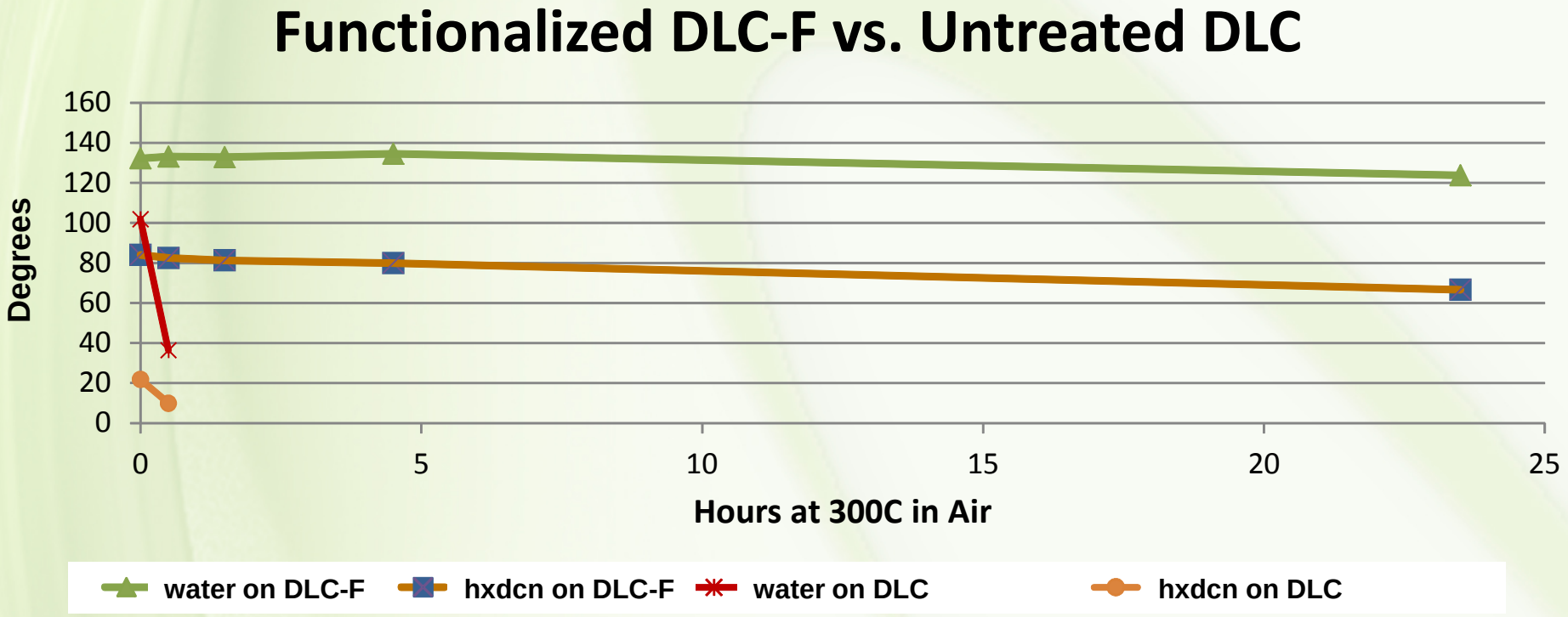
DI Water	Untreated	Fluoro-functional	% Change
C14 DLC on 304SS	75˚	119˚	+59
DLC on injector needle	101˚	132˚	+19

Hexadecane	Untreated	Fluoro-functional	% Change
C14 DLC on 304SS	9˚	76˚	+744
DLC on injector needle	20˚	84˚	+320

Contact Angle Trends with Thermal Oxidation Exposure: C14 DLC on 304SS



Contact Angle Trends with Thermal Oxidation Exposure: DLC on Needle

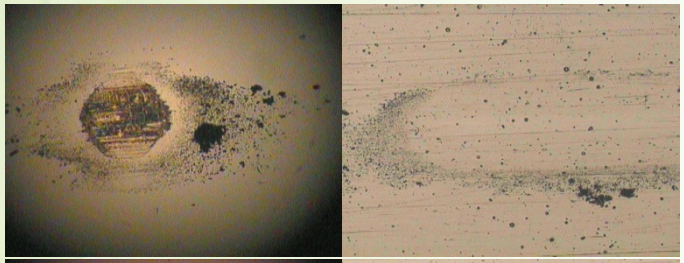


Friction Comparisons – C14

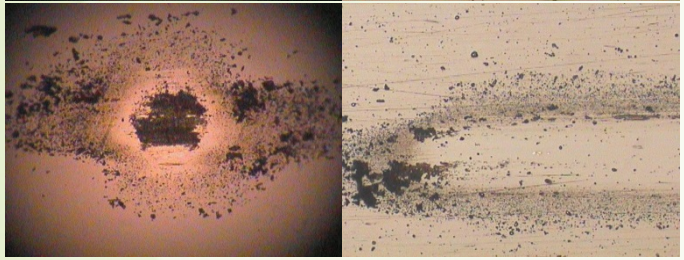
	Friction coeff. in Air	Friction coeff. in dry N_2
DLC	0.18	0.87
DLC; 6hr in N2	0.10	0.58
DLC; 6hr in Air	0.18	0.56
DLC-F (fluoro func.)	0.21	0.77
DLC-FT; 6hr in Air	0.23	0.02

440C ball

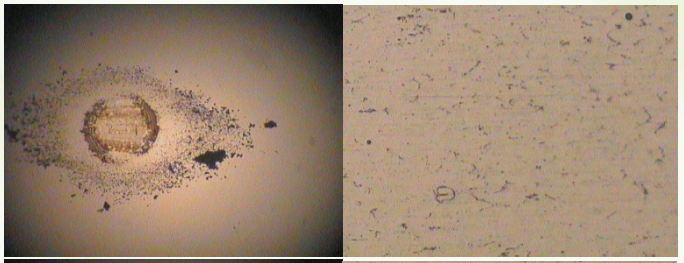
DLC
air test



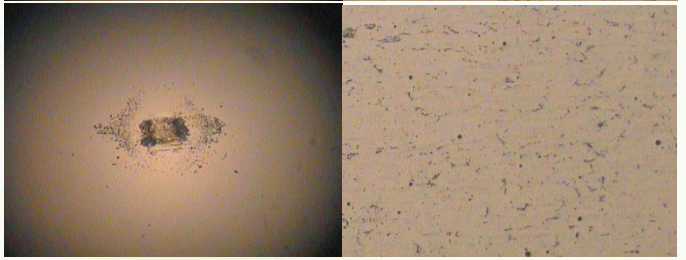
DLC
N2 test



440C ball



DLC-FT
air test



DLC-FT
N2 test

All friction data courtesy of Dr. Seong Kim and Ala' Al-Azizi
The Pennsylvania State University

Conclusions

- Functionalized DLC surface with organofluorosilyl- moiety
  - Improved hydrophobicity
  - Vastly improved oleophobicity
- Stabilized DLC to thermal and oxidative effects without detrimental tribological effects
- Unexpected improvement in dry friction performance after thermal oxidation exposure. Deserves further exploration.

Acknowledgments

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