SAND2006-6227C

Mechanical and Tribological Behavior of Polymer-Derived Ceramics Constituted from SiCxOyNz

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Materials Science & Technology 2006

October 15-19, Cincinnati, Ohio

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for the United States Department of Energy under contract DE-AC04-94AL85000.

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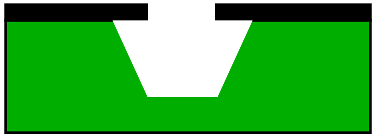
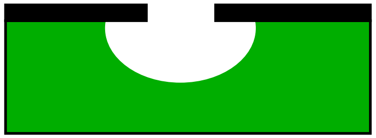
A variety of fabrication methods can be used to construct microsystems

Bulk Micromachining

- subtractive process; pattern and etch
- well established for Si; also done in GaAs



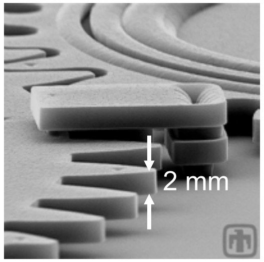
anisotropic



isotropic

Surface Micromachining

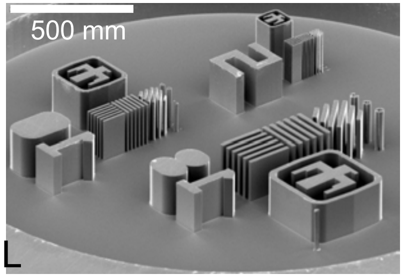
- additive process; structural (Si) and sacrificial (SiO_2) layers
- dissolve sacrificial layers to free structures



SNL

Lithographie, Galvanoformung und Abformung (LIGA)

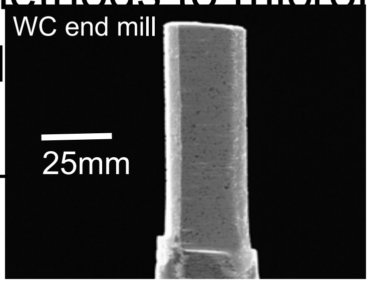
- plate or press into thick polymer mold
- micron to centimeter scale parts

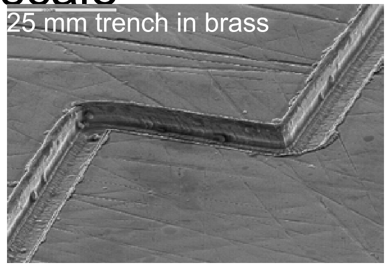


T. Christenson, SNL

Meso-Machining

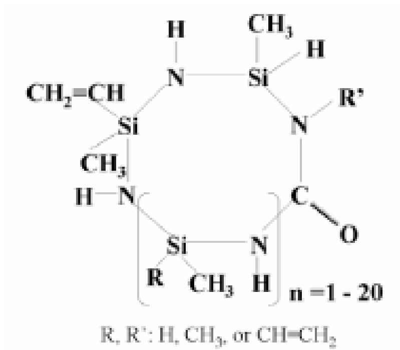
- subtractive process; push machining methods to micron scale
- micro-milling, micro-EDM, plunge EDM



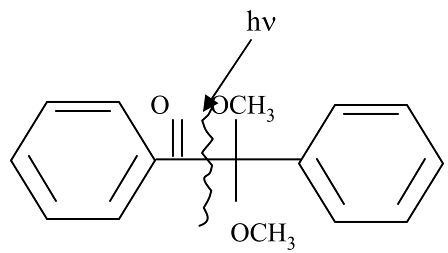


G. Benavides, SNL

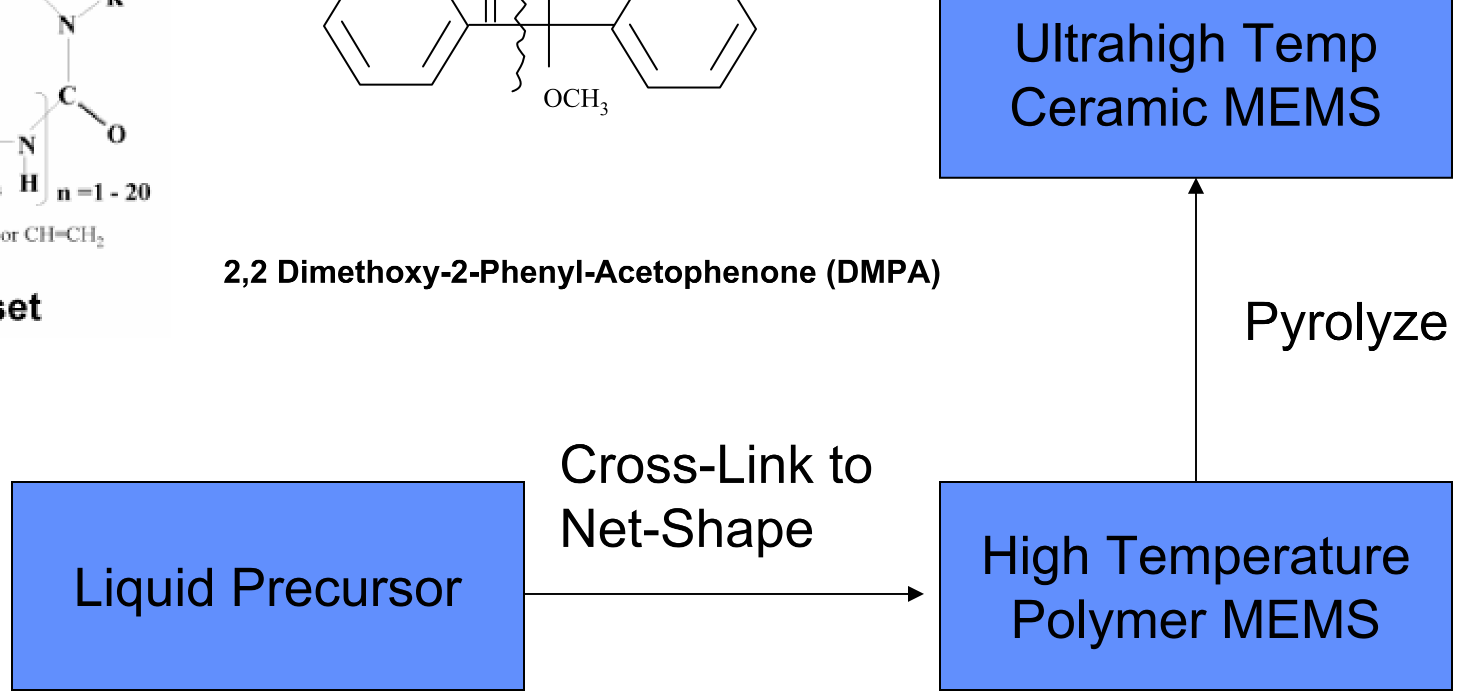
Schematic illustration showing the fabrication route for polymer-derived ceramics



Ceraset



2,2 Dimethoxy-2-Phenyl-Acetophenone (DMPA)



Polymer Micromachining

Micro-casting

SiCN MEMS

Polysilazane MEMS

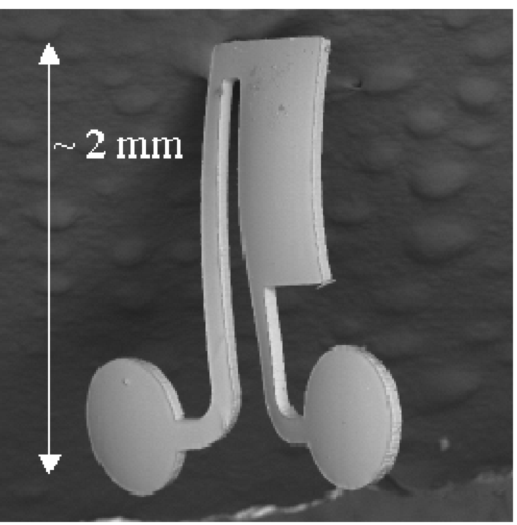
Cast in SU8 molds, followed by de-molding

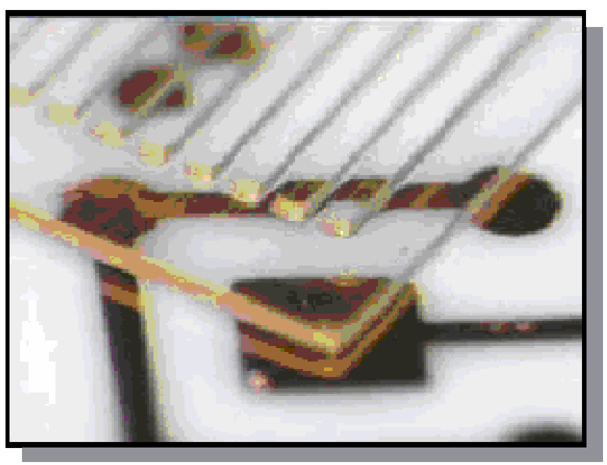
Direct Photopolymerization

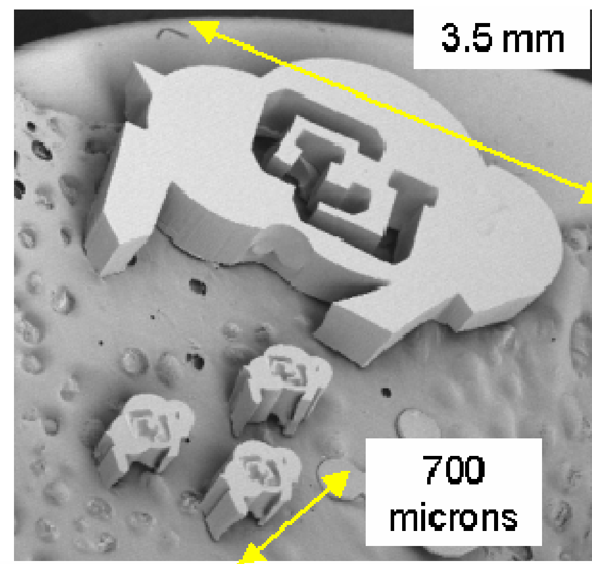
SiCN MEMS

Polysilazane MEMS

Treat precursor as a negative photoresist

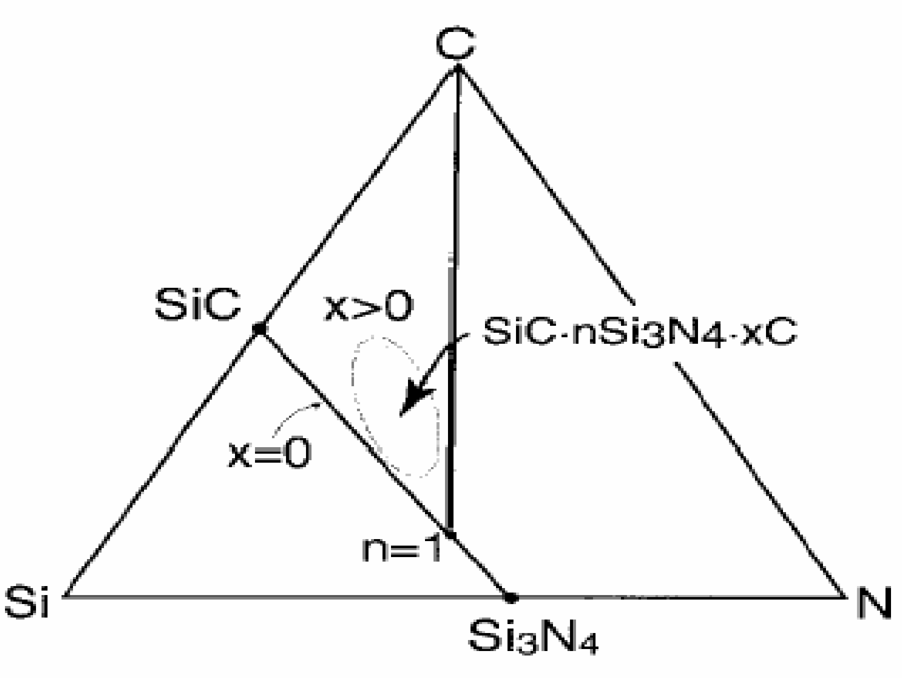






Preceramic polymer buffaloes, 500 microns thick

Composition diagram and the properties of SiCN PDC materials



	SiCN	SiC	Si_3N_4
Density (g/cm^3)	2.35	3.17	3.19
E Modulus (GPa)	150	405	314
Poisson's Ratio	0.17	0.14	0.24
CTE ($x\ 10^{-6}/K$)	~ 3	3.8	2.5
Hardness (GPa)	25	30	28
Strength (MPa)	1100	418	700
Toughness ($MPa.m^{1/2}$)	3.5	4 - 6	5 - 8
Thermal Shock FOM*	2300	270	890
Creep rate at 1350 °C (s^{-1})	$< 10^{-8}$	$\sim 10^{-9}$	$\sim 10^{-9}$
Oxidation rate at 1350 °C ($cm/hr^{1/2}$)	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-5}$

* strength/(E-modulus.CTE)

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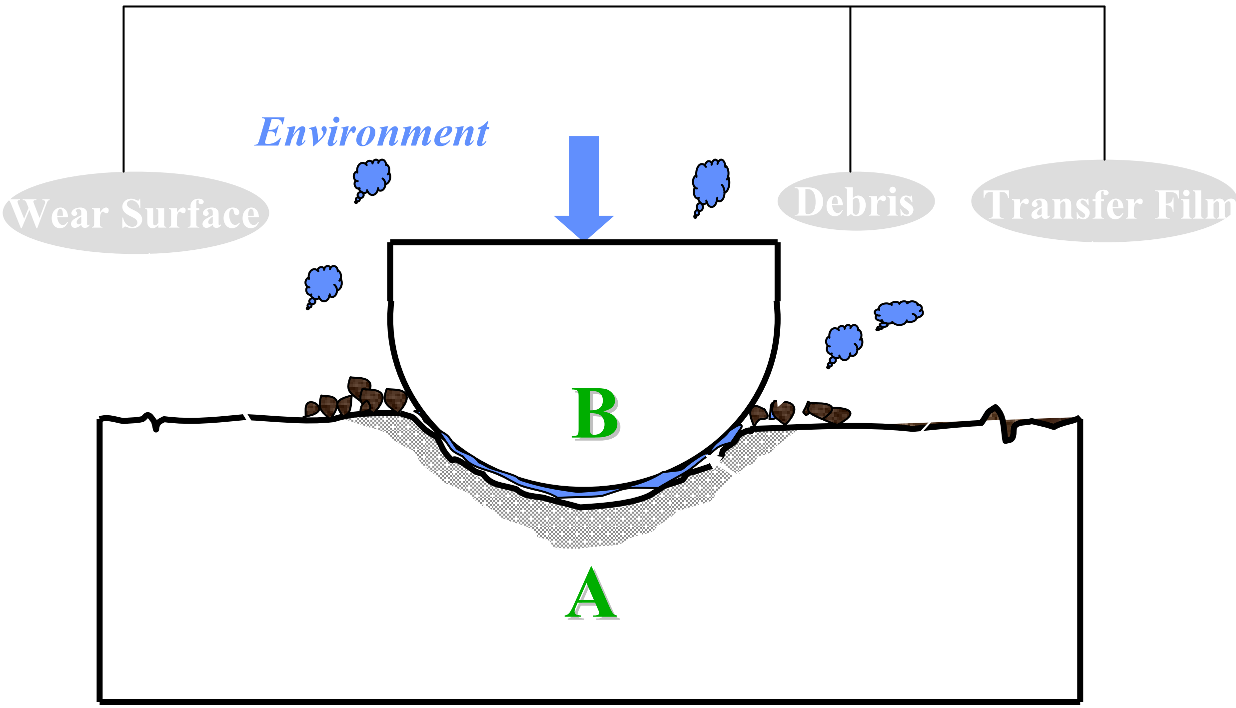
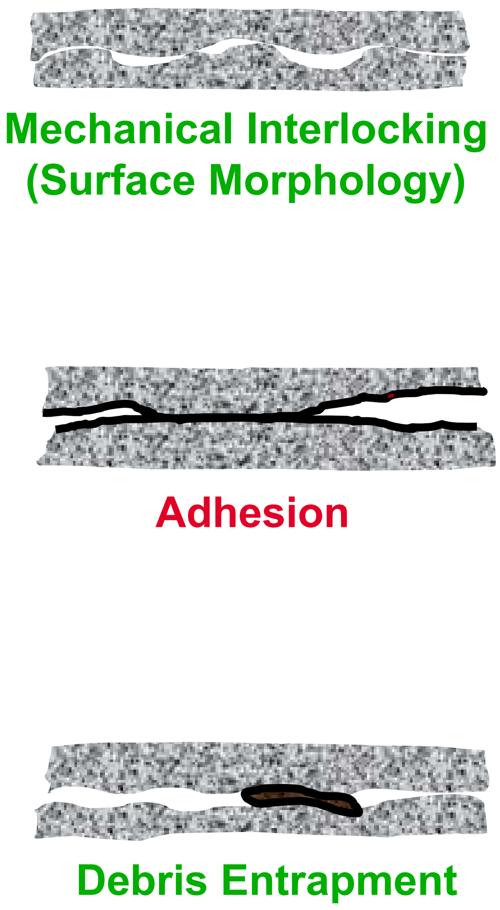
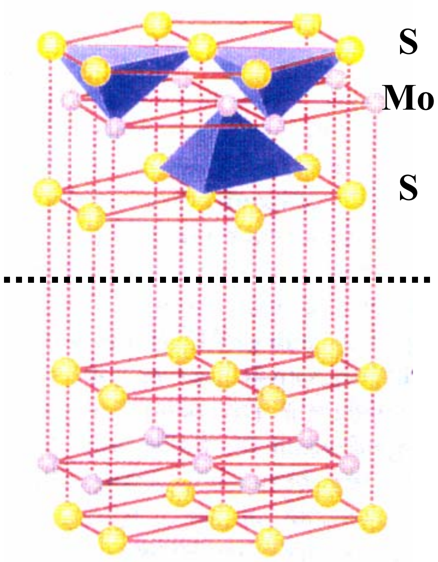
Tribology @ Micro-level: a systems property

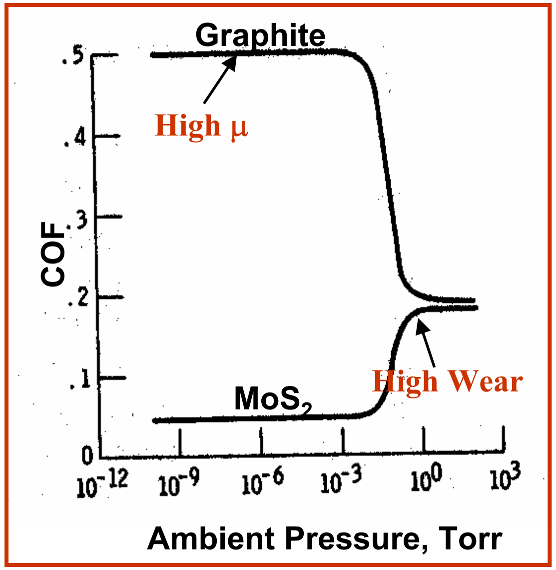


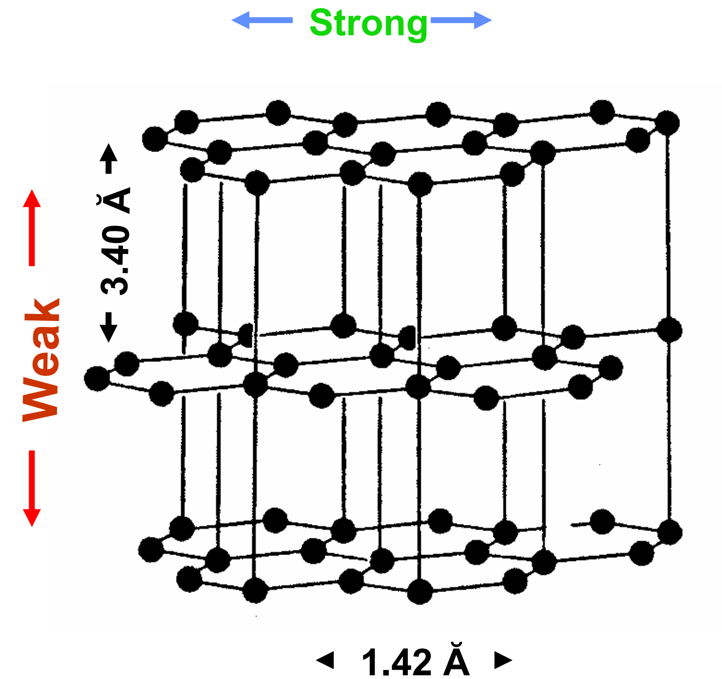


No material can act as a solid lubricant in all environments and under all operating conditions

MoS_2: Extremely low COF (0.01-0.05) and long wear life, **but only in dry environments**.



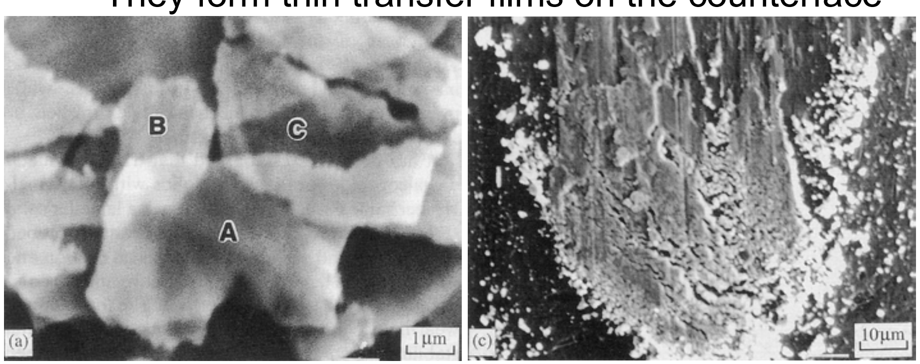




Mo/W Disulfide

Graphite

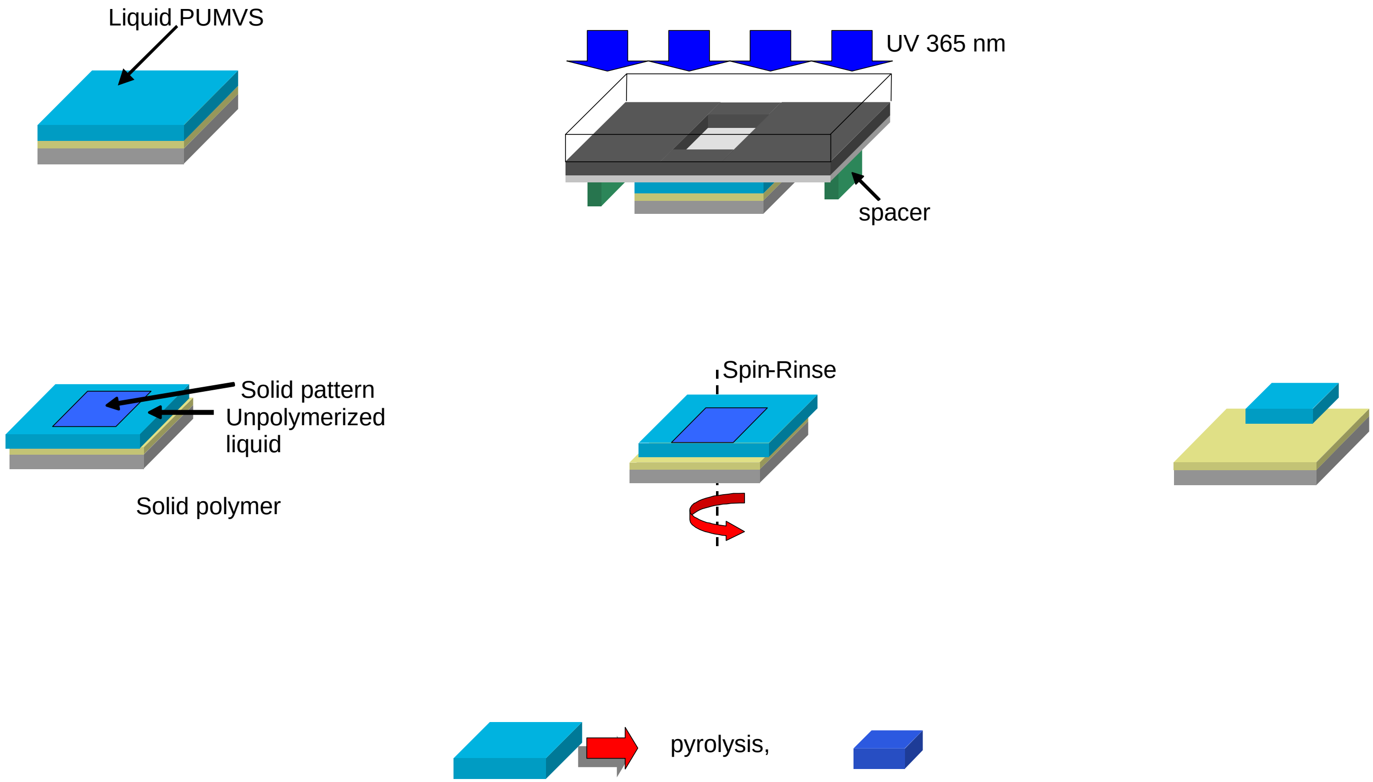
They form thin transfer films on the counterface



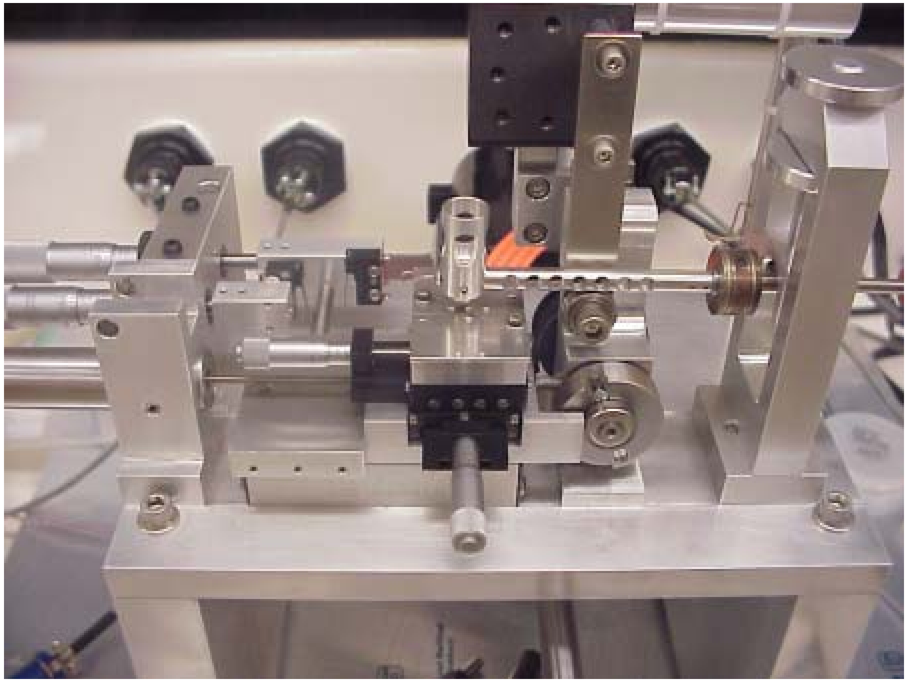
- Graphite needs moisture or adsorbed gases in the environment (>100 ppm) (they either act as intercalants, or passivate the dangling covalent bonds) to lubricate.
- In vacuum, graphite exhibits high friction and wear—a phenomenon known as “dusting”, first observed in the late 1930’s when graphite brushes in aircrafts experienced accelerated wear at high altitudes.

S. V. Prasad and J. S. Zabinski, *J. Mater. Sci. Lett*. 12 (1993) 1413-1415

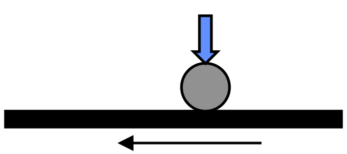
A simplified process was used for making tribology test coupons (Courtesy of Sandeep Shah)



Tribological measurements were made in controlled environments



Linear Wear Tester
(Ball-on-Flat configuration)



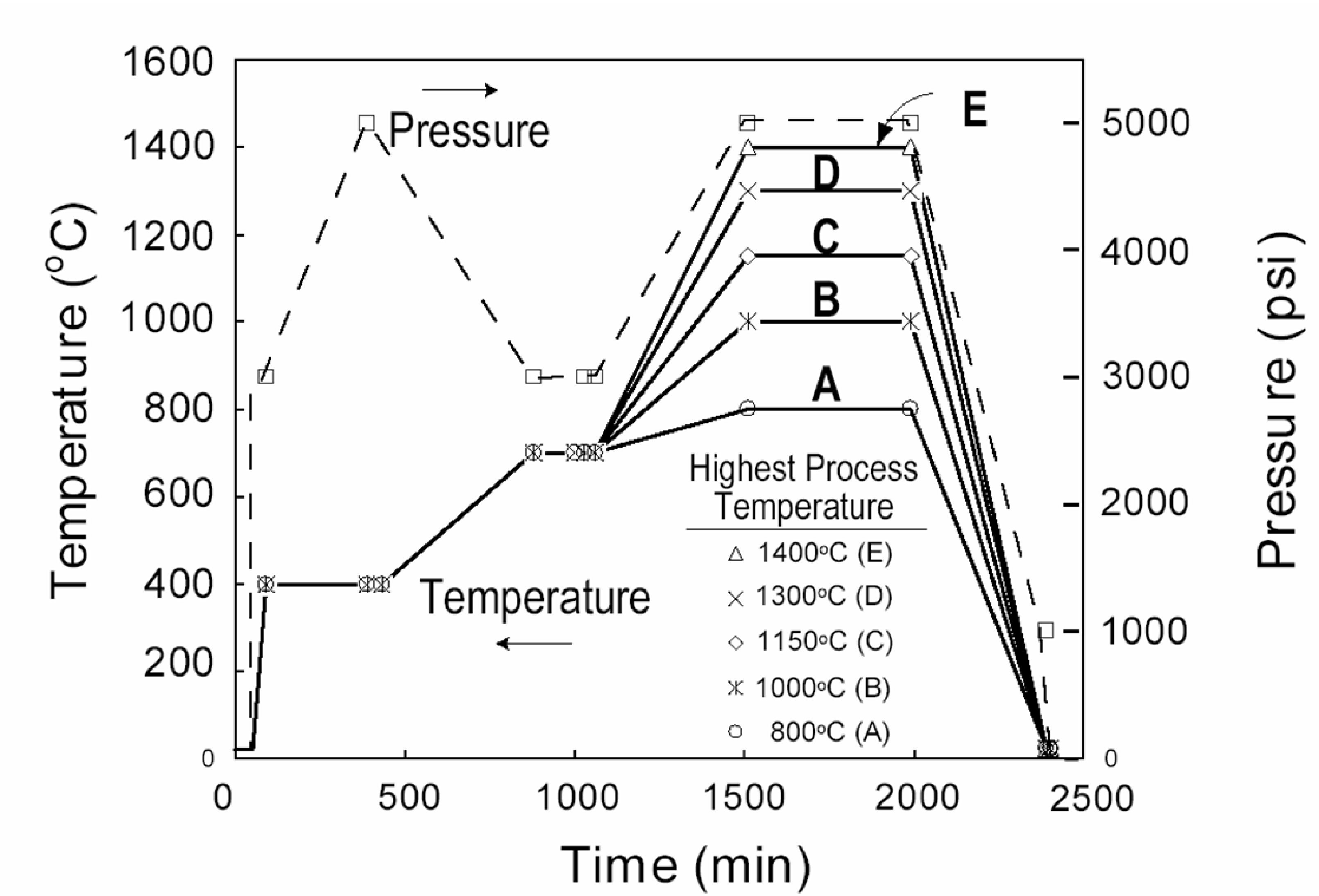
Counterfaces: Si_3N_4 and 440C Steel Balls (3.175 mm dia)

Normal Loads: 0.44 GPa, 0.75 GPa, 0.95 GPa

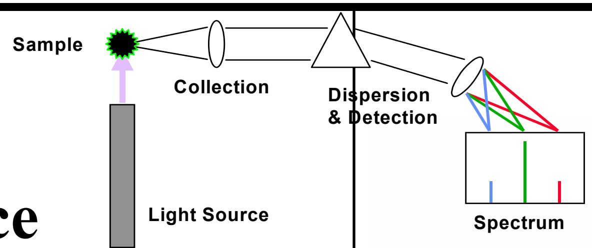
Environments: Dry Nitrogen, Dry Air, Air with 20, 40, 50 and 80% RH

Environmental Control

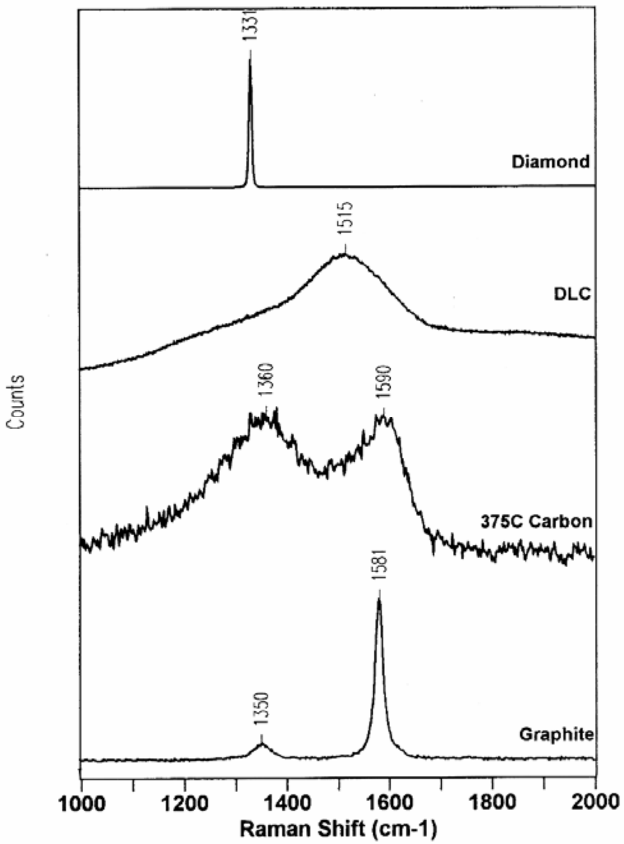
Pyrolysis cycles

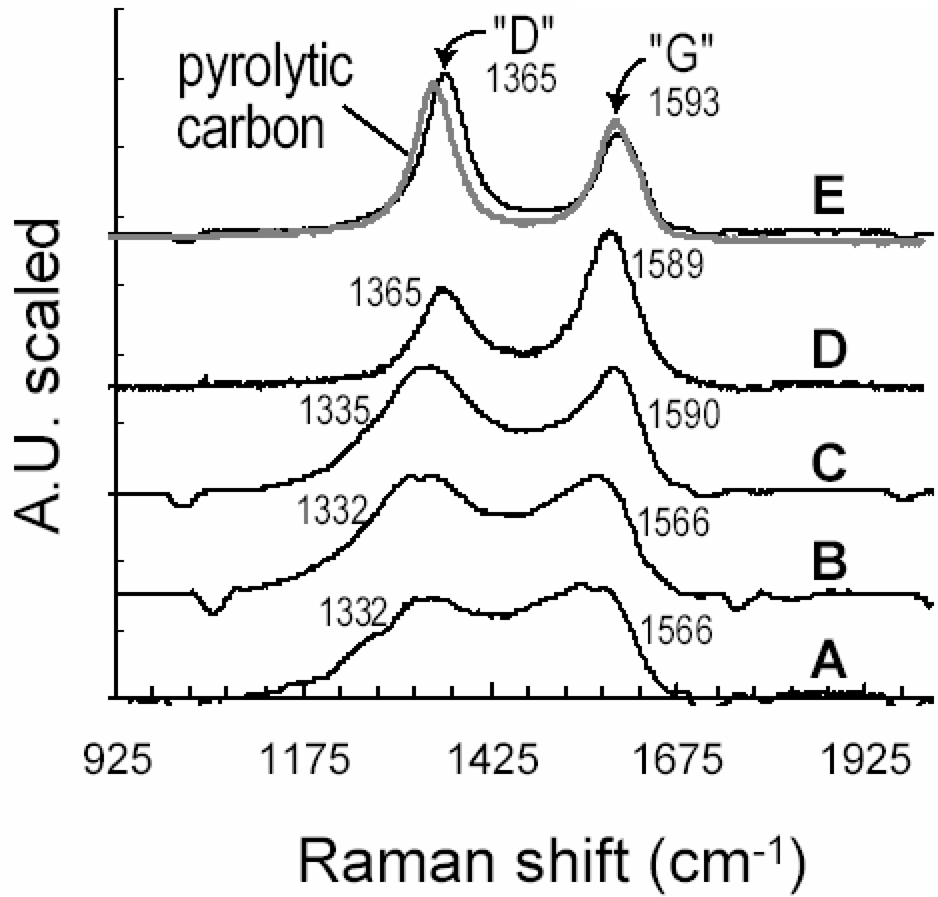


Raman spectra (Argon laser: 458 nm wavelength, Spot Size: 1 μm)

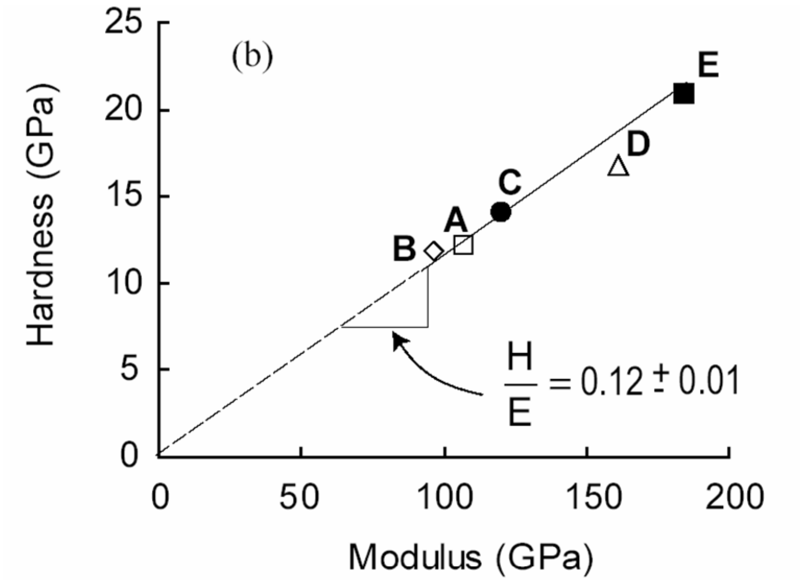


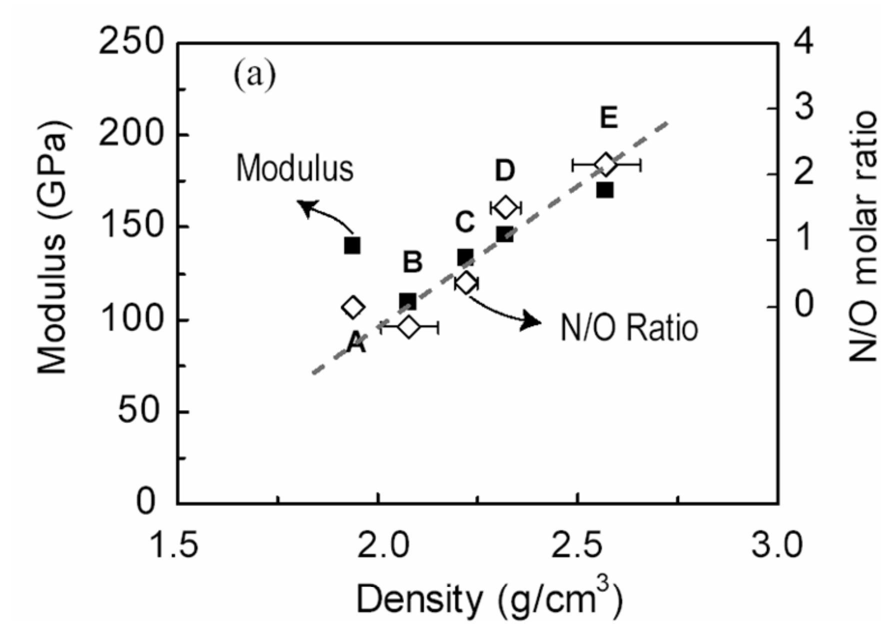
Reference



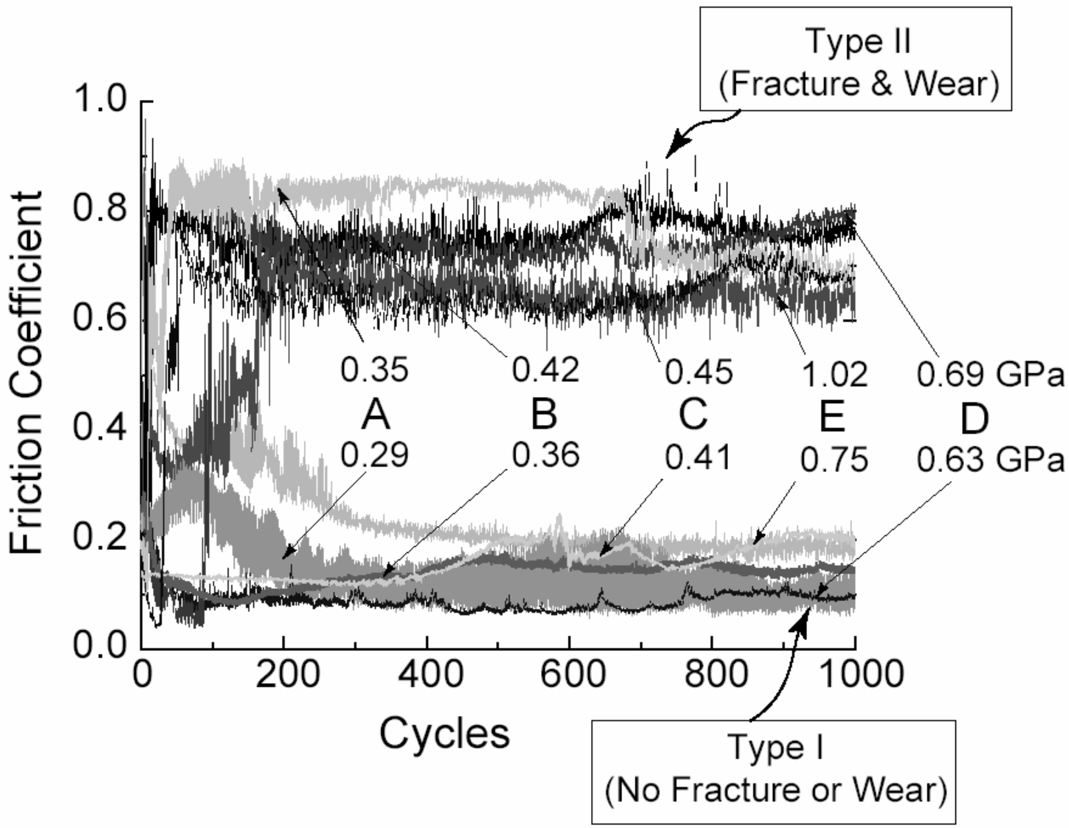


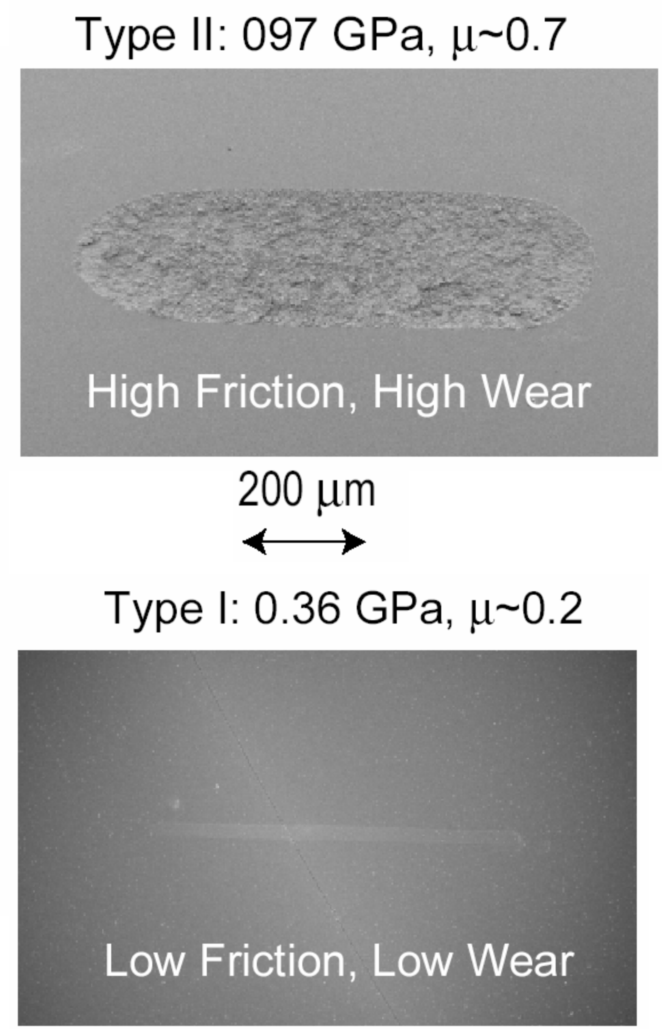
Mechanical behavior and composition



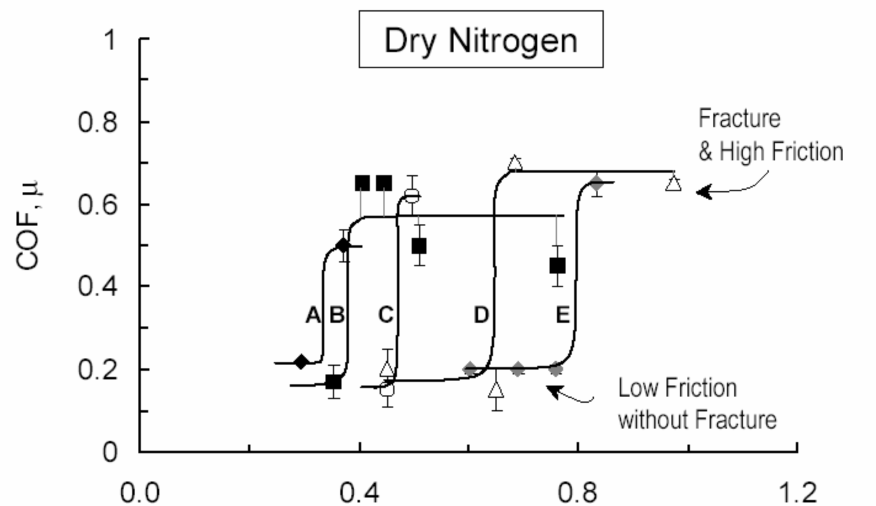


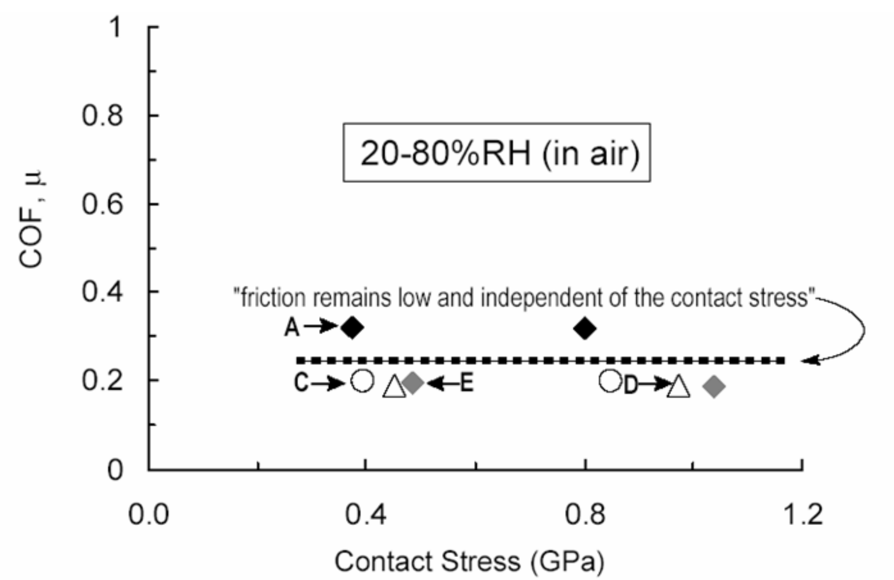
Friction behavior in dry nitrogen

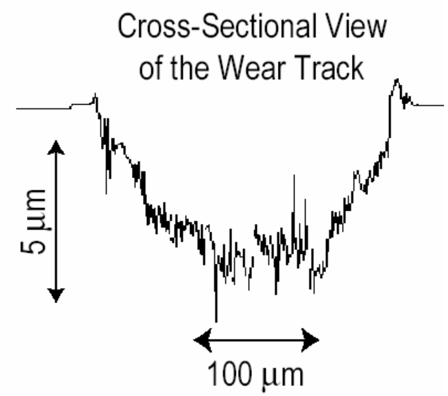


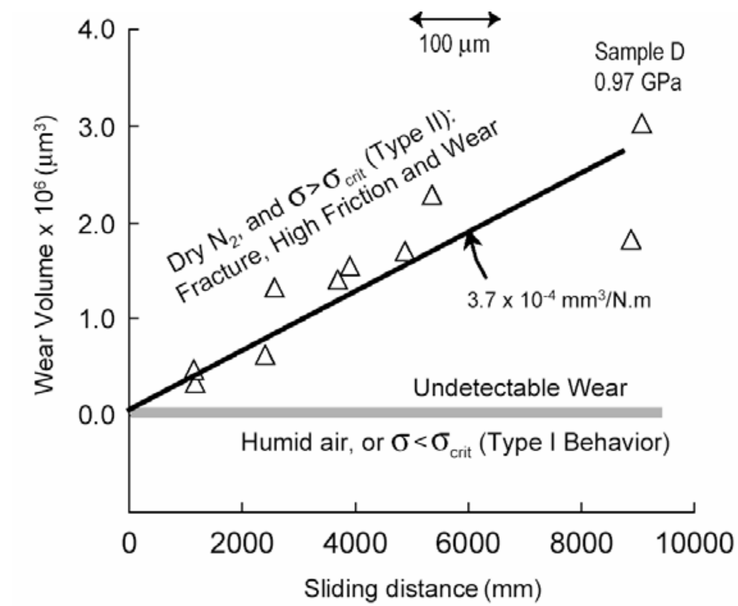


Summary of tribological data showing environmental effects on friction and wear transitions

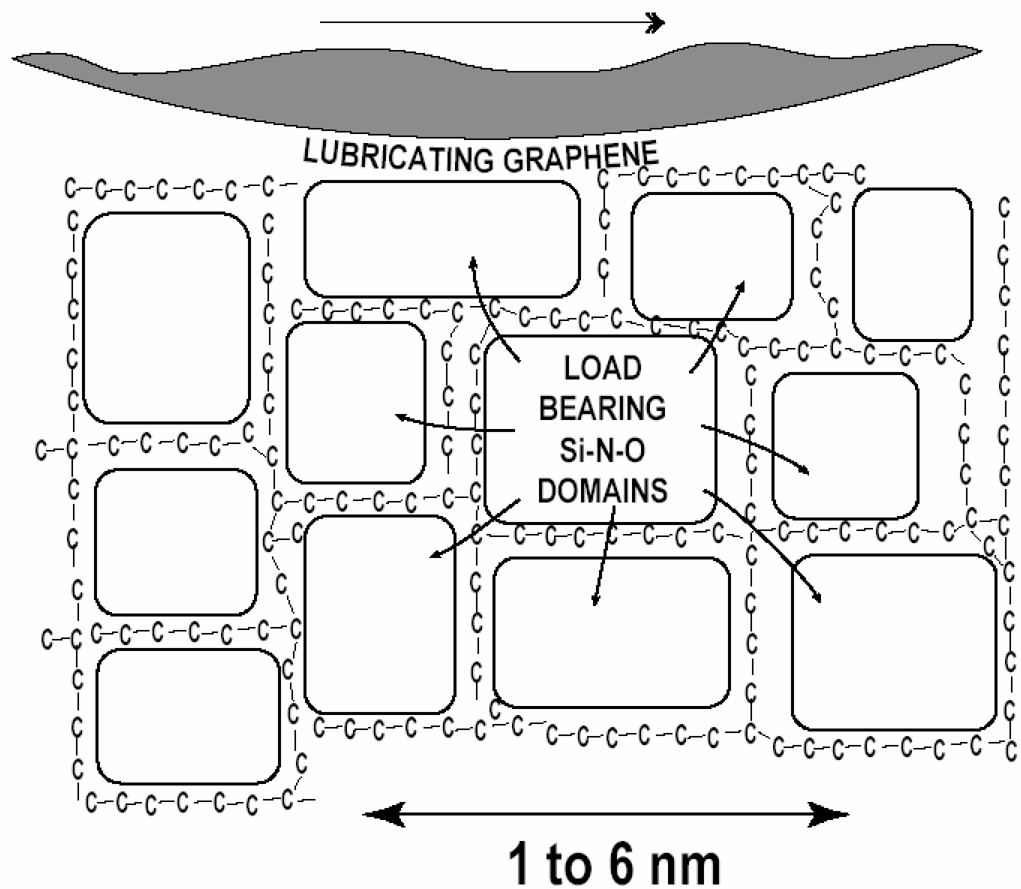








Schematic depiction of dual-phase structure in SICNO



Conclusions Remarks

- SiCNO showed two distinct regimes of tribological behavior: one identified by low μ, and negligible wear, and the other by high friction and high wear.
- The onset of fracture under a critical value of the applied contact stress is believed to lead to the transition from low friction to high friction behavior. The transition apparently moved to contact stresses beyond the experimental regime in humid environments (where only the low friction behavior was seen).
- This result is thought to be related to an increase in the work of fracture of the PDC in the presence of water molecules at the crack tip when the crack propagation velocity is of the same order as the sliding friction velocity (that is, non-stress-corrosion type of fracture conditions).

Acknowledgements

- Regan Stinnett and Sandia's MESA Institute for financial assistance to Tsali Cross
- Rand Garfield for friction measurements
- Dave Tallant and Gina Simpson for Raman spectroscopy
- Bonnie Mckenzie and Dick Grant for scanning electron microscopy