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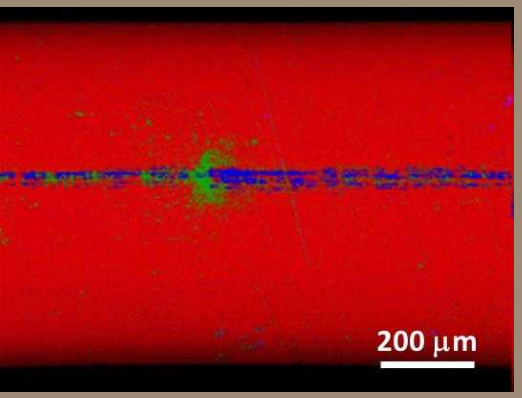

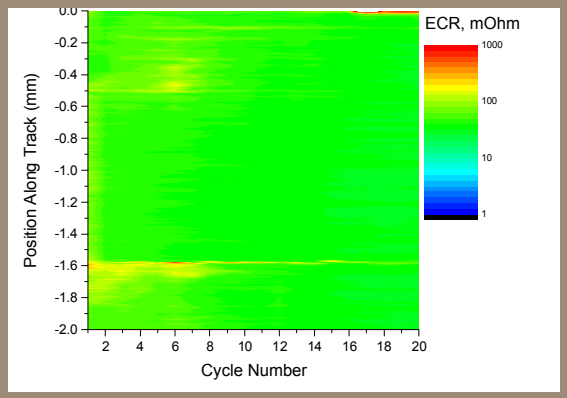

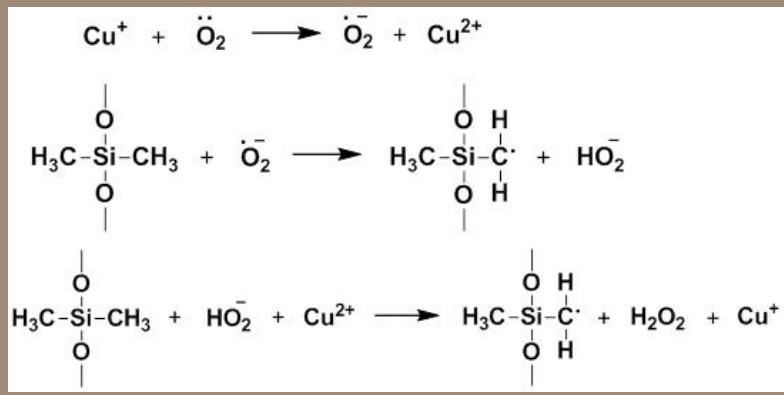

Tribochemical Degradation of Switch Damping Fluids at Sliding Contacts

M.T. Dugger, B.L. Nation and T.M. Alam

Materials Science and Engineering Center

Sandia National Laboratories

28th International Conference on Electrical Contacts, 6-9 June 2016

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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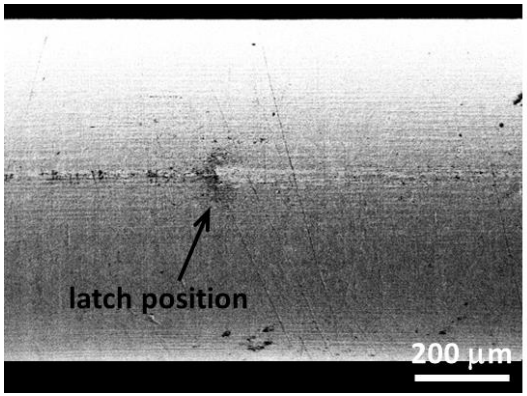
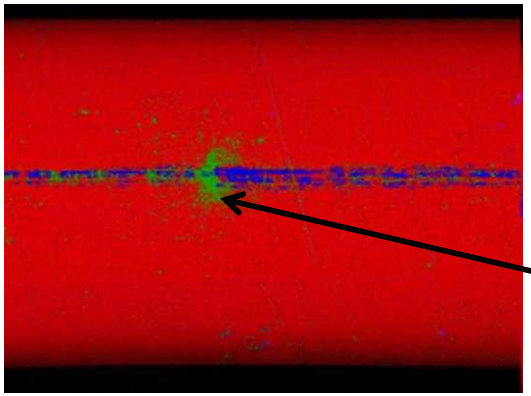
Motivation: Accelerometer Switch Contacts

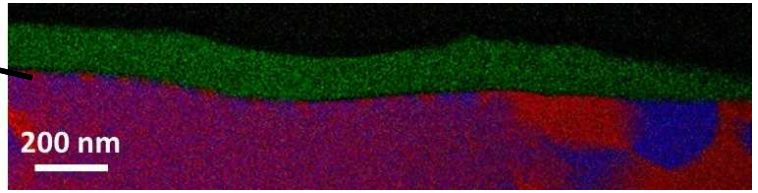
A fluid-damped accelerometer exhibits increased electrical contact resistance (ECR) after storage

- contacts are hardened Pd-Ag-Cu and Au-Cu-Pt electrical contact alloys (Deringer-Ney)
- the device is filled with 20 cSt polydimethylsiloxane (PDMS) fluid





Red = Paliney-7
Blue = Neyoro-G transfer
Green = Si-C-O deposit



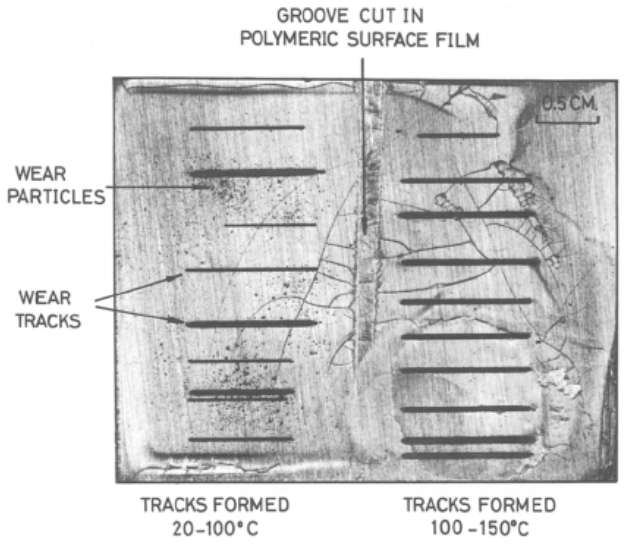
EDS/AXSIA image of a focused Ion Beam (FIB) cross section through deposit

atomic %

	Pd	Ag	Cu	Pt	Ni	Zn	Au
Paliney-6	39.8	33.9	24.2	0.5	1.6	0.01	NA
Paliney-7	34.8	29.4	23.3	5.4	NA	1.6	5.4
Neyoro-G	NA	6.0	33	6.3	NA	2.2	52.5

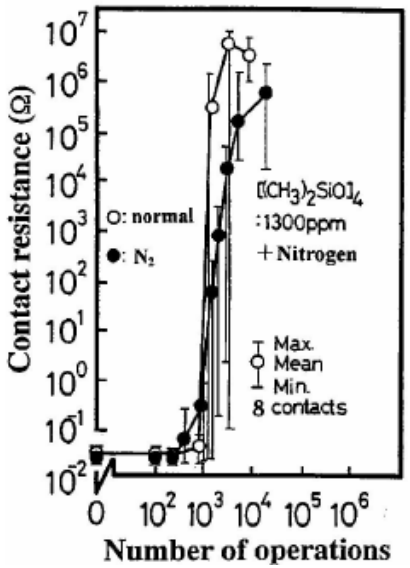
Literature on Silicone-Metal Interactions

Film Formation on Copper at > 100^{0}C



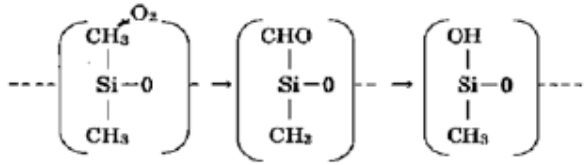
D. Tabor and R.F. Willis, Wear **13** (1969) p. 413-442

Thermal Decomposition in Make-Break Arcs



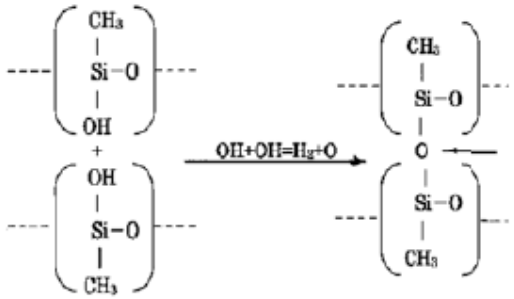
T. Tamai, Proc. IEEE Holm Conference on Electrical Contacts, Montreal, QC, Canada, 25-27 Sept. 2006, pp. 26-31

Proposed Side-Group Oxidation and Crosslinking



$CH_3+O_2=CHO+H_2O$, $CHO+O_2=OH+CO_2$

(a) Oxidation process of CH_3



(b) Vulcanization between molecules D_4

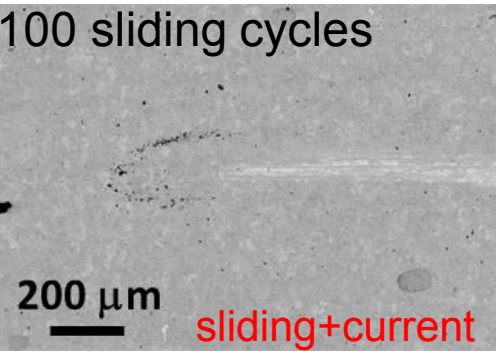
T. Tamai, S. Sawada and Y. Hattori, Proc. ICEC 2012, Beijing, China

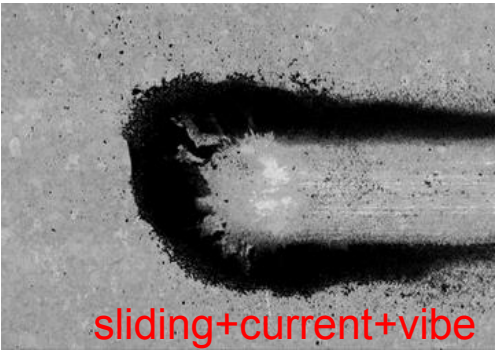
PDMS crosslinks on some metals at elevated temperature

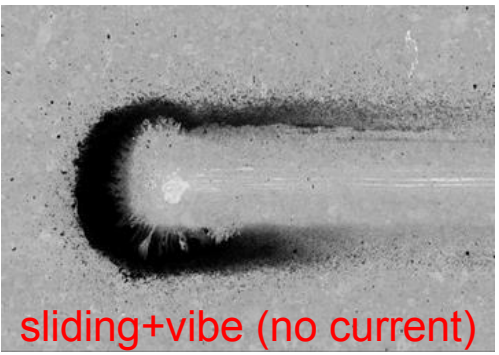
Spectroscopic evidence of reaction mechanism is not available

“Tribochemical” Degradation of PDMS

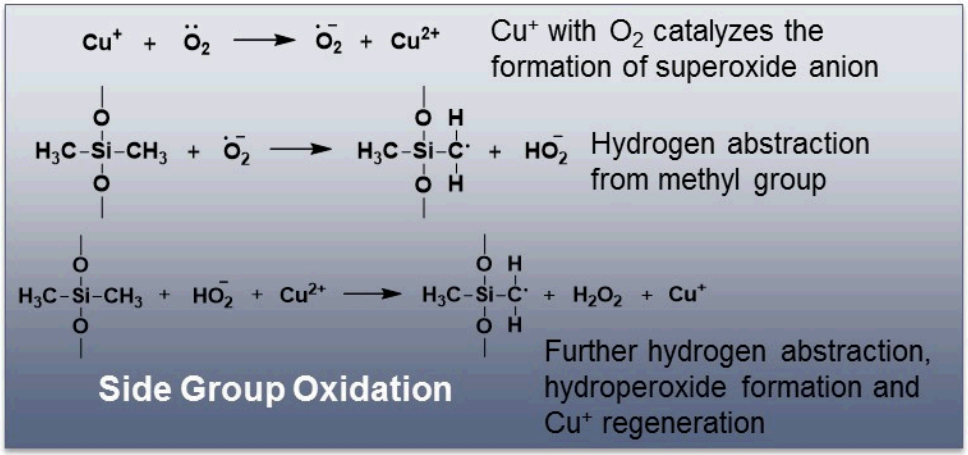
Backscattered electrons, 100 sliding cycles







Demonstrated Reaction Pathway



Nuclear Magnetic Resonance (NMR) Spectroscopy

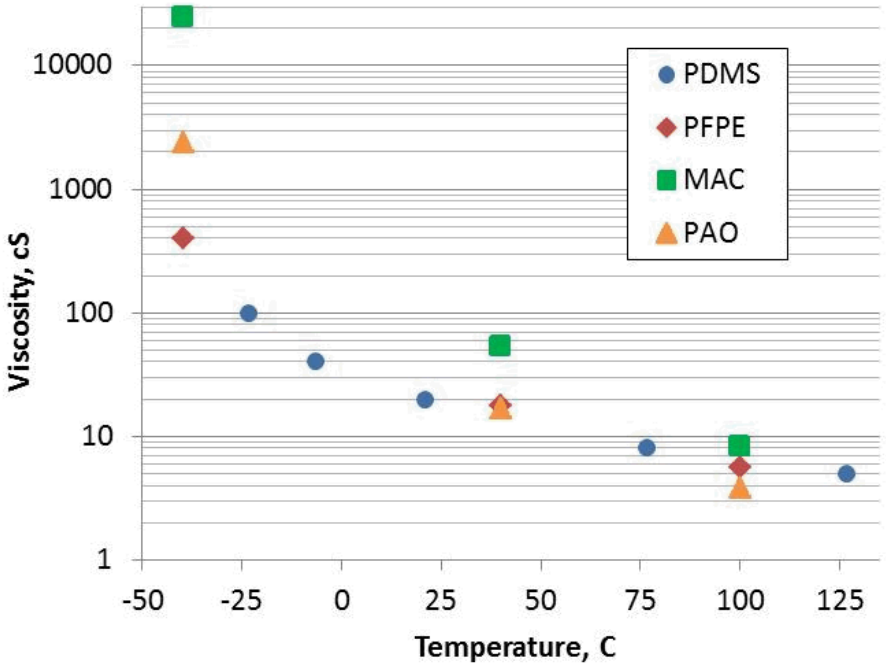
Crosslinked PDMS deposit is created during mechanical contact, *without current* (*M.T. Dugger et. al, Holm 2014*)

Material Changes to Avoid Fluid Degradation

Property	PDMS	PFPE	MAC	PAO
Pour Point, °C	-65	-80	-59	-69
Surface Tension, mN/m	20.6	23		27
Specific Gravity at 25°C	0.95	1.81	0.84	0.82
Refractive Index	1.4		1.465	1.456
Flash Point, °C	204	NA	300	226

Alternate Fluids:

- Perfluoropolyether (PFPE)
- Multiply-alkylated cyclopentane (MAC)
- Polyalphaolefin (PAO)

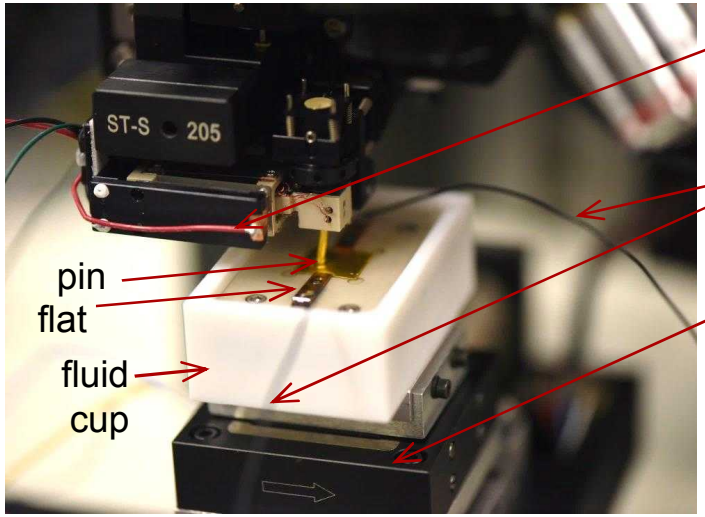


Metals in Sliding Contact

Sample	Pd	Ag	Cu	Pt	Ni	Zn	Au
Paliney-7	34.8	29.4	23.3	5.4	NA	1.6	5.4
Neyoro-G	NA	6.0	33.0	6.3	NA	2.2	52.5
Au	NA	NA	NA	NA	NA	NA	99.9
Cu	NA	NA	99.9	NA	NA	NA	NA

- Investigate tribochemical degradation of alternative damping fluids
- Experiment with self-mated metals to verify reaction hypothesis

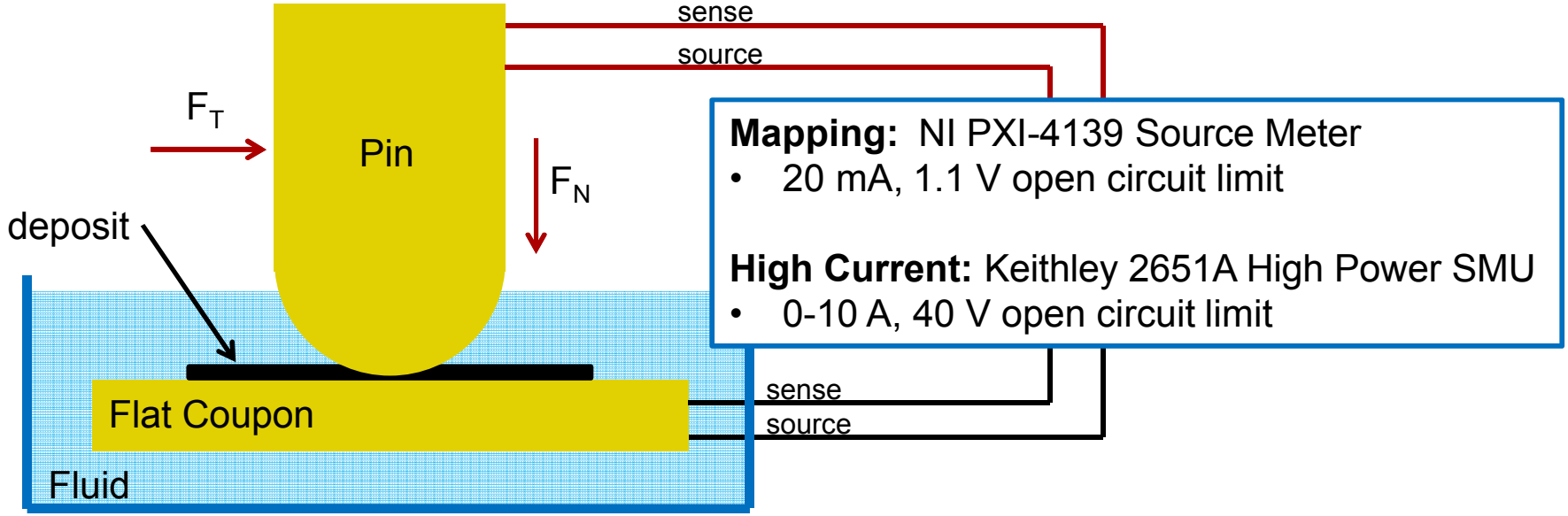
Lab Experiments with Individual Contacts



Nanotribometer modified for 4-wire Electrical Contact Resistance measurement

Test parameters:

- N = 50 mN
- pin radius = 1.6 mm
- track length = 1 to 2 mm
- fluid volume = 5 mL

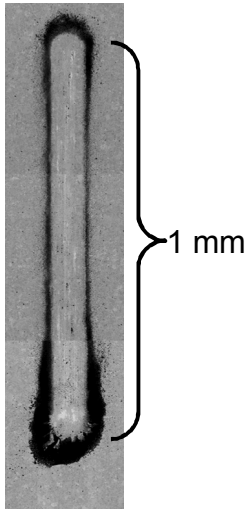


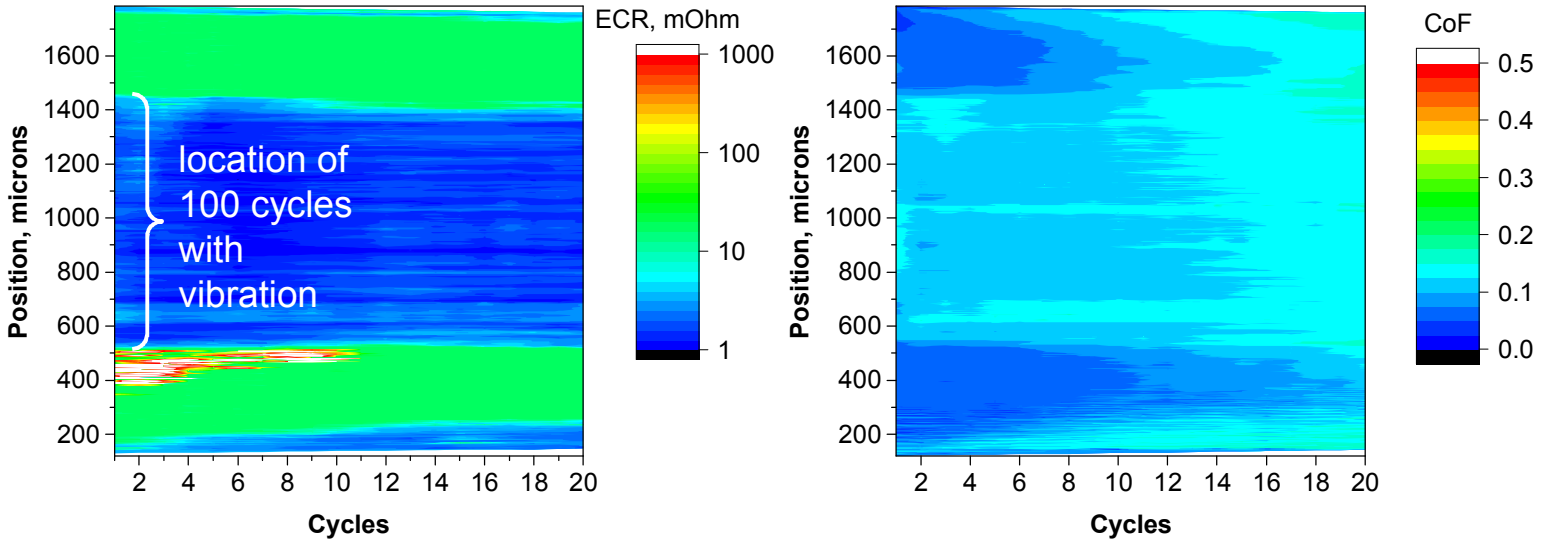
Relating Deposit to ECR Change

Procedure:

1. Measure CoF and ECR along 2 mm track for 3 cycles with no vibration
   a. 88 mN (9 gf) contact force
   b. 20 mA DC current, with 1.1 V open circuit limit
2. Perform 100 cycles sliding with vibration on central 1 mm
   a. 50 μm displacement amplitude orthogonal to sliding direction, 100 Hz
3. Measure CoF and ECR along 2 mm track for 20 cycles with no vibration

initial wear track with vibration

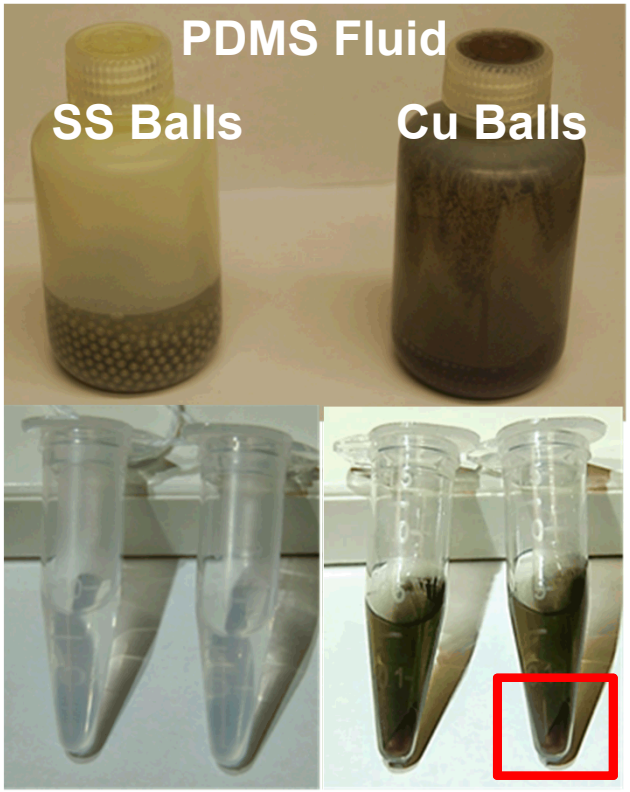




Increased ECR is observed when pin slides over deposit

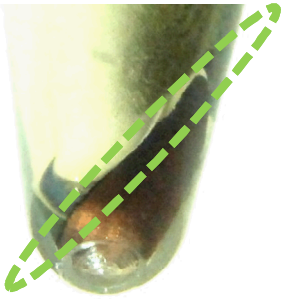
The “Tumble Test”

rock tumbler



bottles filled with 3.2 mm dia. balls, covered with damping fluid, tumbled 12 hrs.

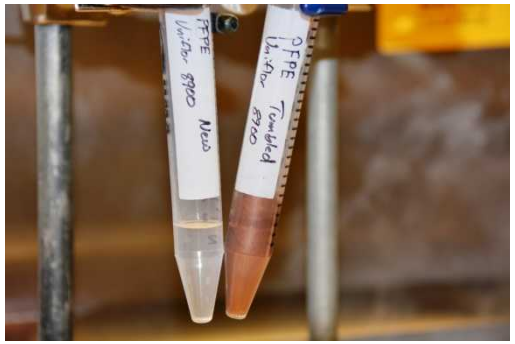
fluid centrifuged
to isolate deposits



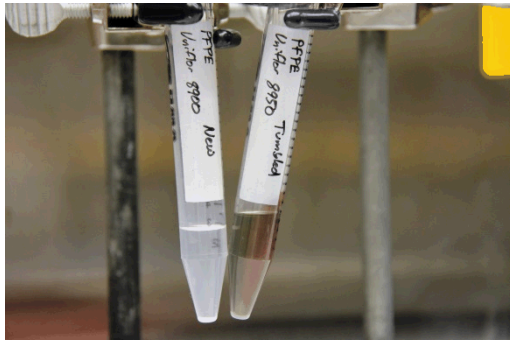
- Solid deposit collected from centrifuge vial, dissolved in solvent
- Nuclear Magnetic Resonance Spectroscopy (NMR) performed to probe local chemical environment and molecular structure

Fluorocarbons – ^{19}F NMR

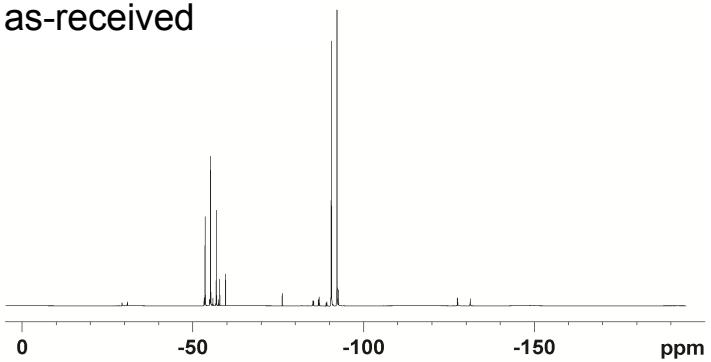
PFPE1



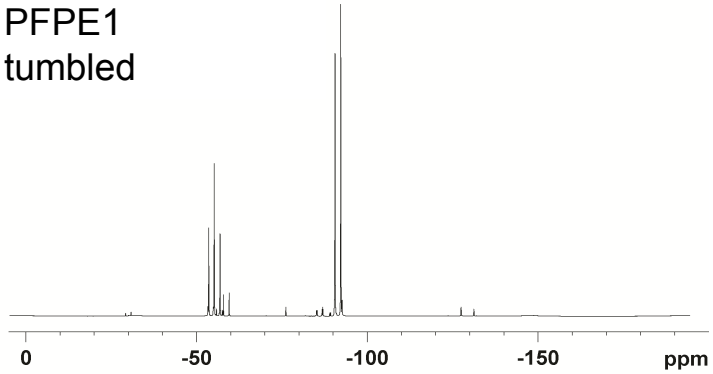
PFPE2



PFPE1
as-received



PFPE1
tumbled

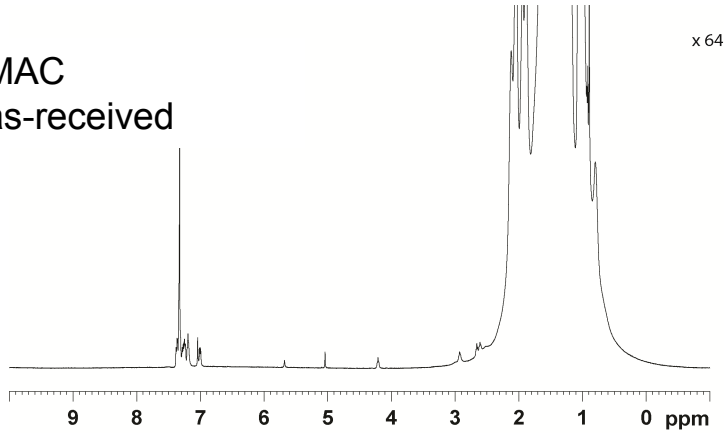


^{19}F (ppm)

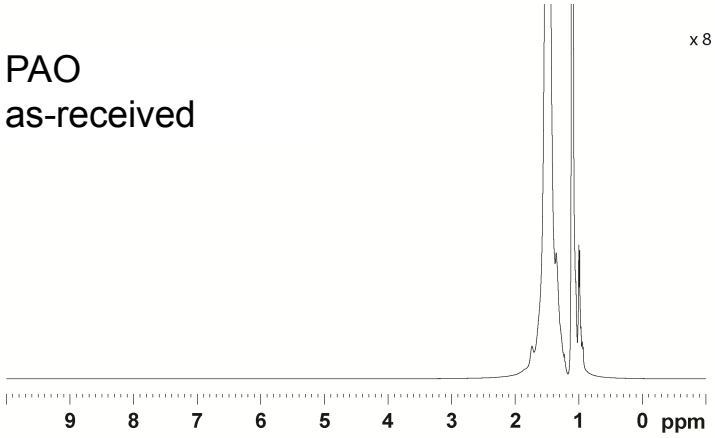
- No differences observed in ^{19}F chemistry pre- and post tumble
- No evidence for mechanical degradation of PFPE

Synthetic Hydrocarbons – ^{1}H NMR

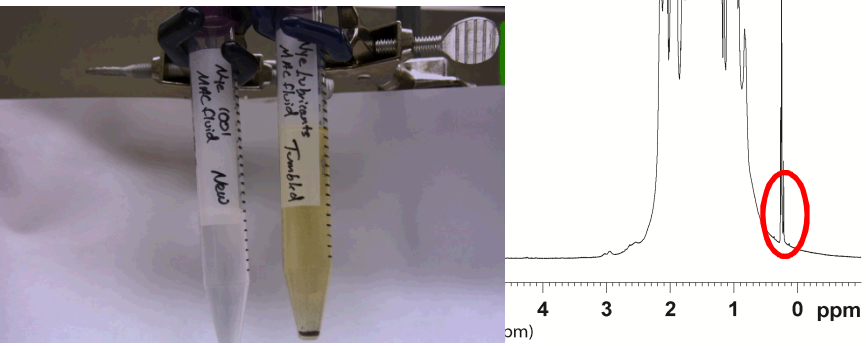
MAC
as-received



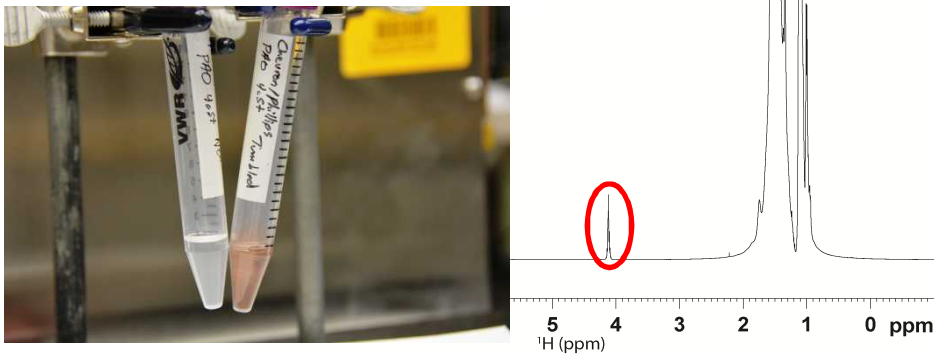
PAO
as-received



MAC
tumbled



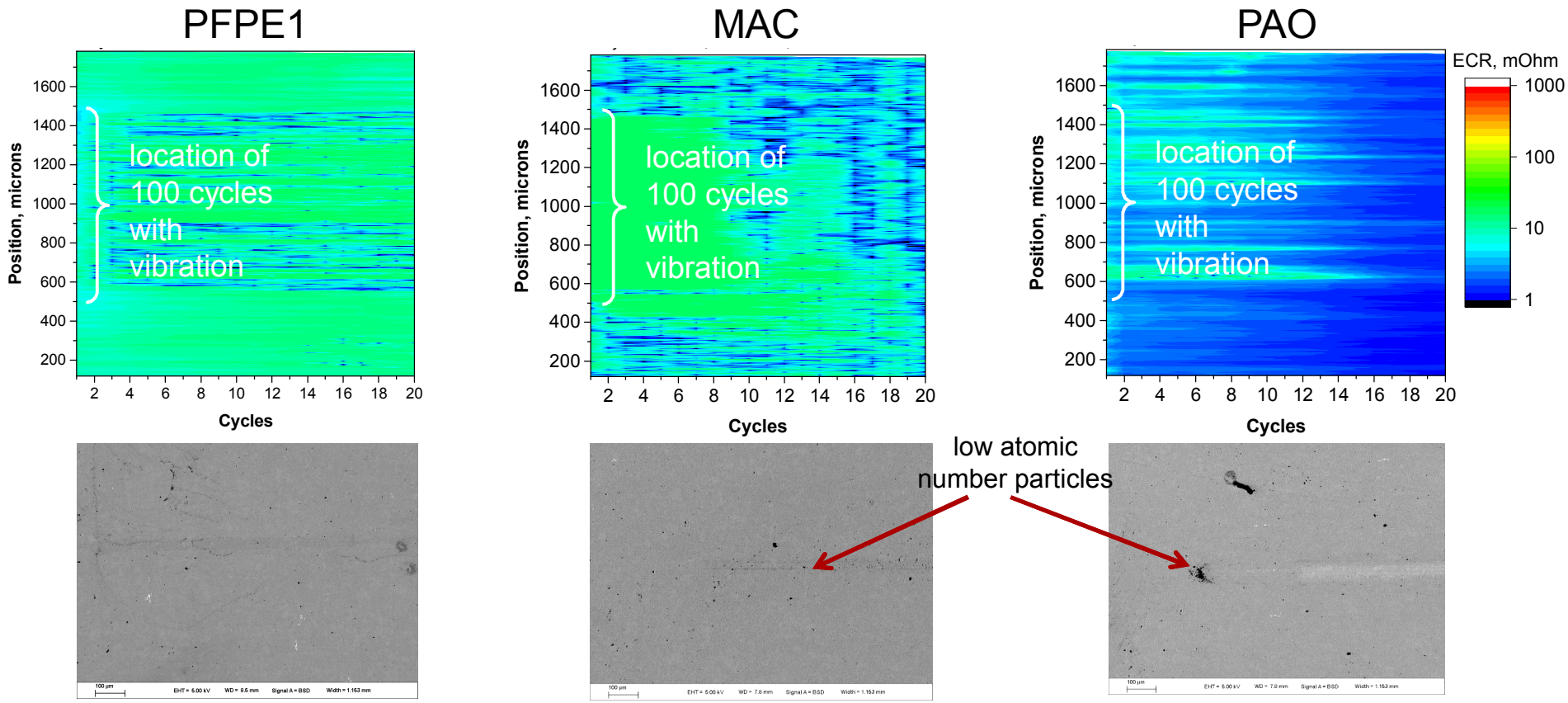
PAO
tumbled



- Additional peaks are evidence of ^{1}H in new chemical environments
- Evidence for mechanical degradation of fluid

Sliding Contacts in Alternate Fluids

Neyoro-G pin on Paliney-7 flat, 50 mN load

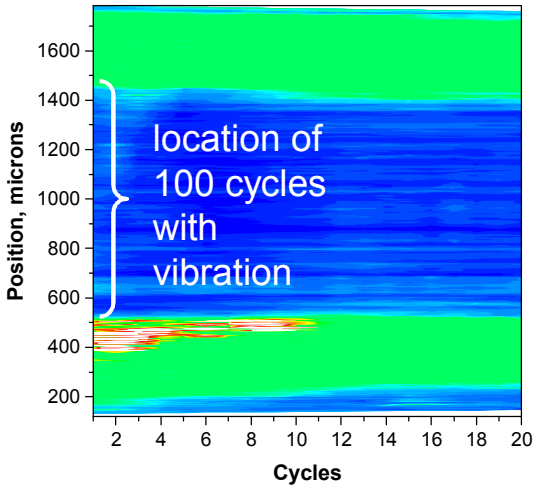


- Indication of prior 100 cycles of sliding contact in ECR maps
- Electrical contact resistance < 100 mΩ everywhere for all fluids
  - no SEM evidence of low atomic number particle formation in PFPE fluids

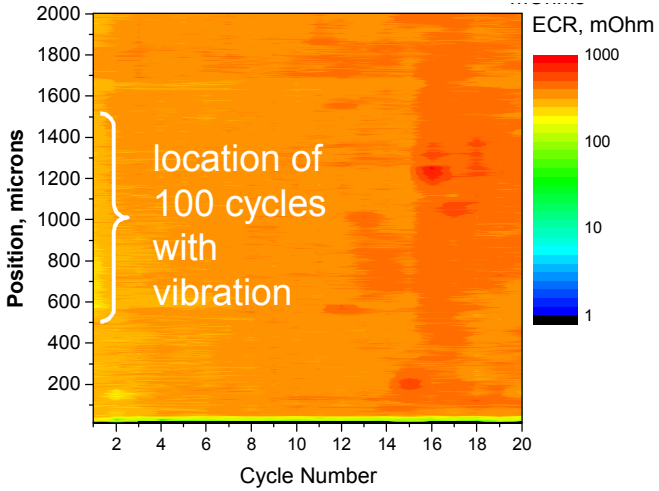
Metals Sliding in PDMS Fluid

20 cS PDMS fluid, 50 mN load

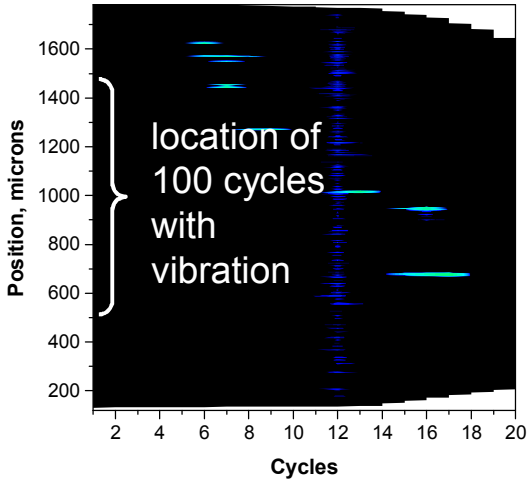
Paliney-7 on Neyoro-G



Cu on Cu



Au on Au



- Electrical contact alloys form deposit at edges of sliding track
- Cu exhibits ECR of 100's of mΩ everywhere
  - dynamic deposit formation during ECR mapping
- Au exhibits ECR of a few mΩ everywhere; no deposit formation

Conclusions

Gold surfaces do not catalyze the degradation of PDMS fluids

- methyl side group oxidation that leads to PDMS crosslinking does not occur in self-mated gold contacts
- sliding contact between Cu and Cu-containing alloys in PDMS fluid promotes the formation of an insulating deposit

Alternative damping fluids are resistant to the tribochemical degradation exhibited by PDMS

- synthetic hydrocarbons exhibit minor deposit formation without significant ECR impact, but NMR suggests radical formation
- fluorocarbons do not exhibit deposit formation or features in NMR spectra indicating changes in molecular structure
  - compatibility of fluorocarbon fluids with other materials in accelerometers must still be verified

Acknowledgments

Sandia Colleagues:

- Mat Celina for discussions on polymer degradation
- Nic Argibay for electrical contact discussions
- Bonnie McKenzie and Amy Allen for SEM and EDS

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