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Changes in Friction and Electrical Contact Resistance on Electroplated Gold Alloy Films Aged in Silicone Oils

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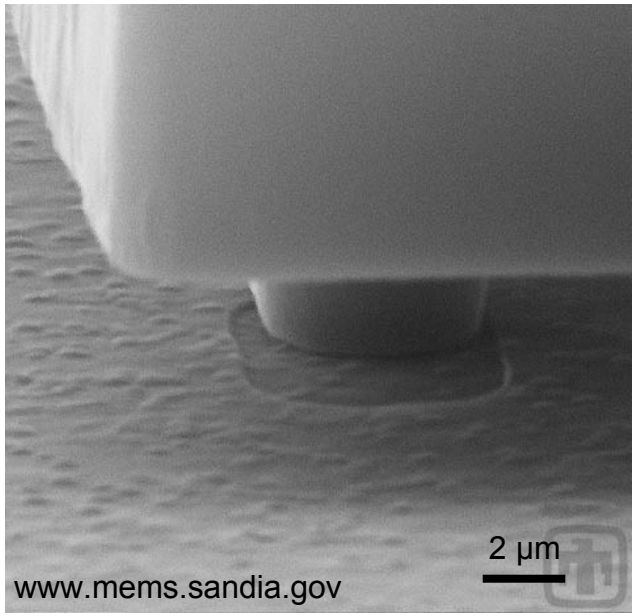
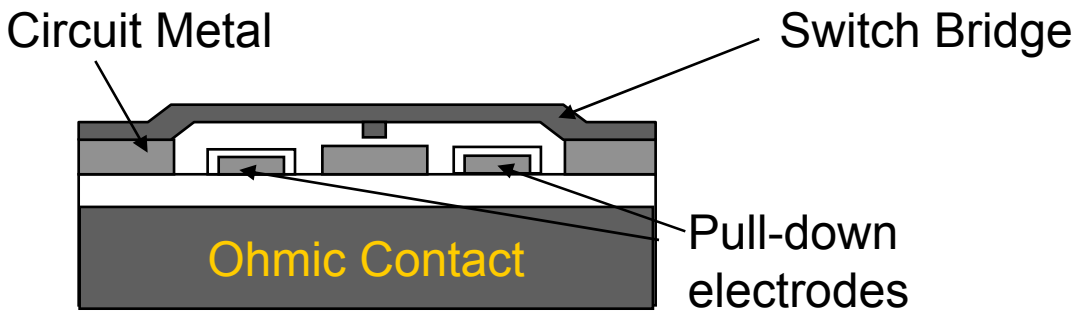
Outline

- Motivation and Overview
  - Gold alloy films as electrical contact surfaces
  - Role of silicone oil
- Experimental results
  - Linear wear testing
  - Electrical contact resistance (ECR) tests
  - Chemical analysis of oil and aged gold
- Conclusions

Ohmic Microsystem Contacts





The ideal electrical contact interface would include:

1) Low electrical resistance

2) Minimal adhesion

3) Low friction (sliding contact)

4) Minimal aging degradation

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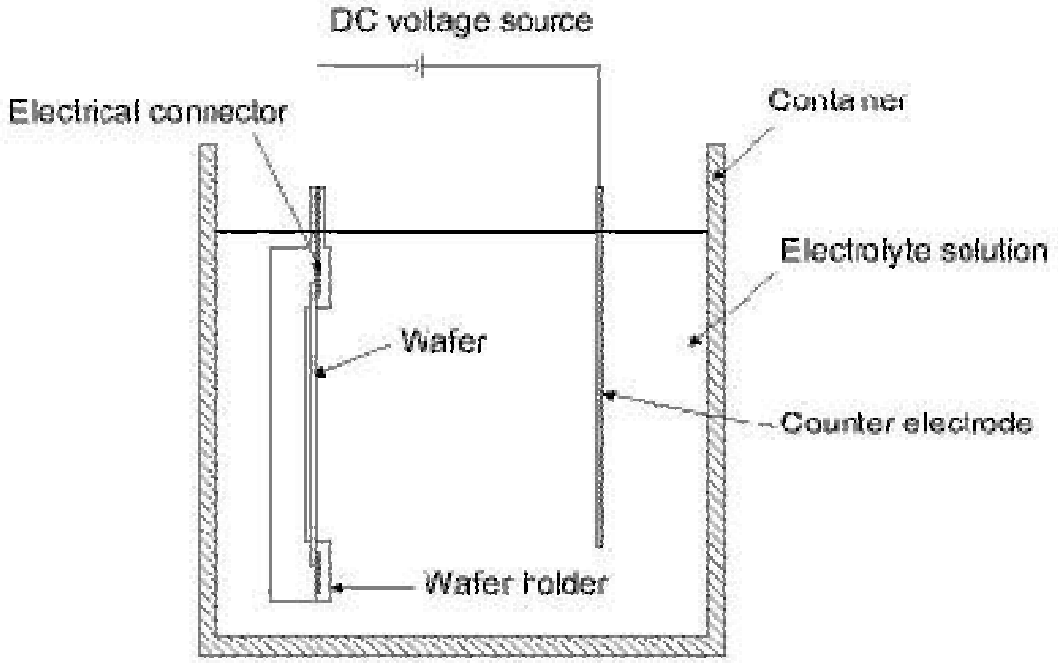
Electrodeposition of Hard Gold

- Typical Additives
  - Nickel, Cobalt, polymer, thorium
  - Goal is grain refinement (and SS hardening)
- Bath electrolytes
  - Free-cyanide base
- ASTM B488-01 (2006)



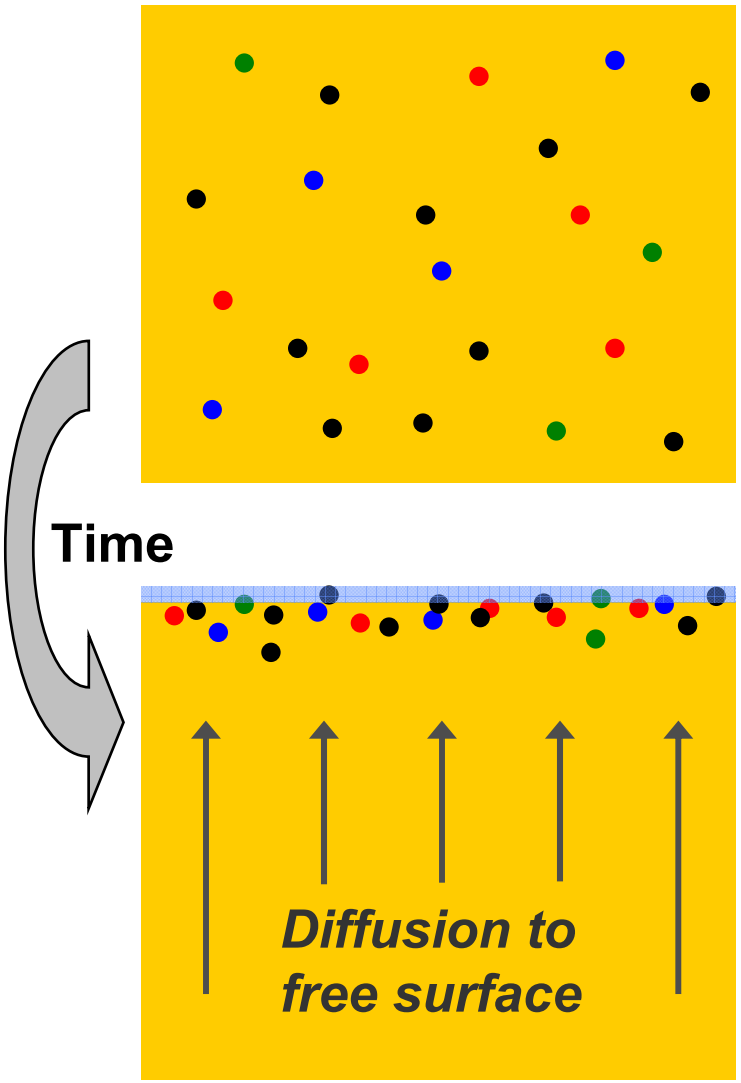
Purity (mass %Au)	Type I	Type II	Type III
	99.70%	99.00%	99.90%

Knoop Hardness	Grade A	Grade B	Grade C	Grade D
	<90	91-129	130-200	>200

Excluded from this calculation of purity are occluded or precipitated carbon, nitrogen, hydrogen, sodium and potassium

Electroplated Hard Gold Impurities

- Additives are intentionally and unintentionally codeposited with the gold
- Intentionally added impurities
  - Cobalt
  - Nickel
- Unintentionally included materials
  - Metallo-organic complex
  - Potassium
  - Carbon
  - Nitrogen



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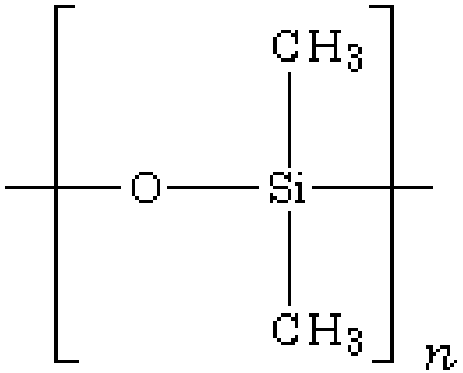
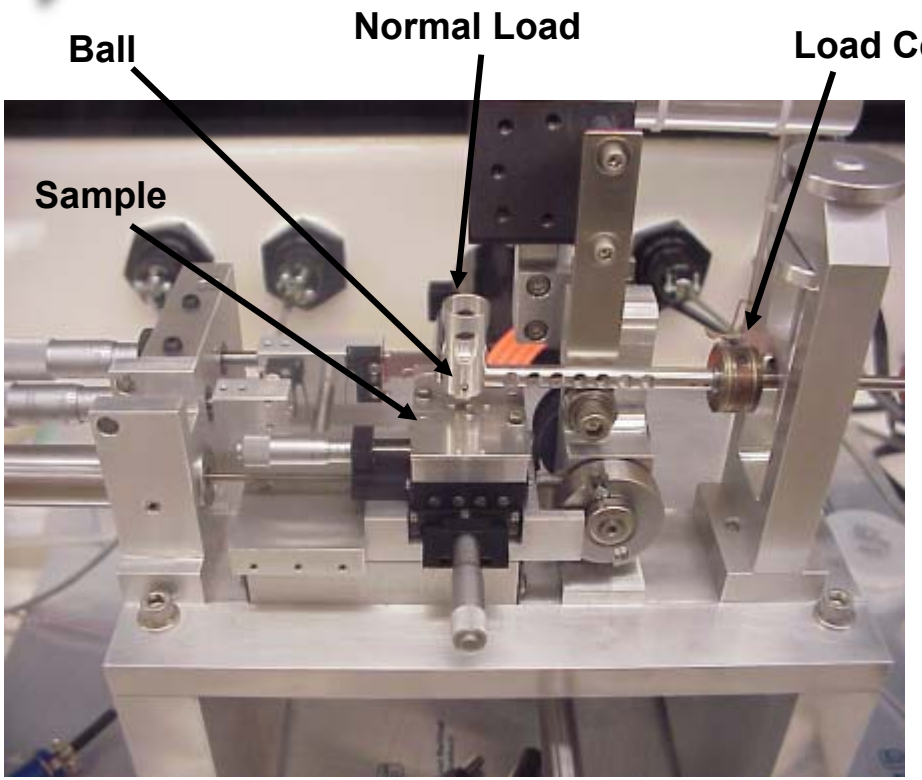
Silicone Oil Lubrication

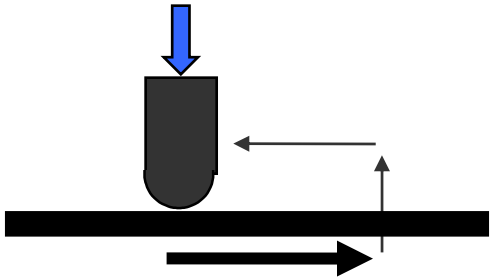
- **What is the role of the oil?**
  - **lubricant**
  - **damping**



- **Dow Corning (DC200) silicone oil fluids**
  - **Known to contain trace processing impurities**
  - **Give viscosities ranging from 5 cSt to 20 cSt, depending on application**
  - **Generally considered to be *robust and resistant to oxidation***

Linear Wear Testing





- Creates a unidirectional linear (wiping) motion across the sample
- Typical test conditions
  - Axisymmetric counterface
    - Ag-Cu-Pd Alloy Pin
  - 40 Hz
  - 1000 cycles
- Controlled Atmosphere
  - O_2 < 10 ppm
  - Dew point < -35 °C

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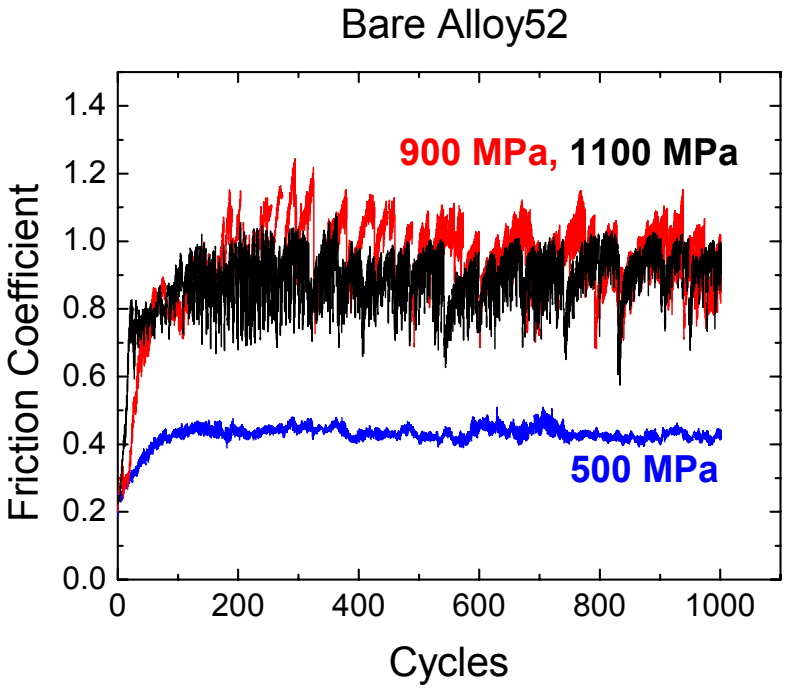
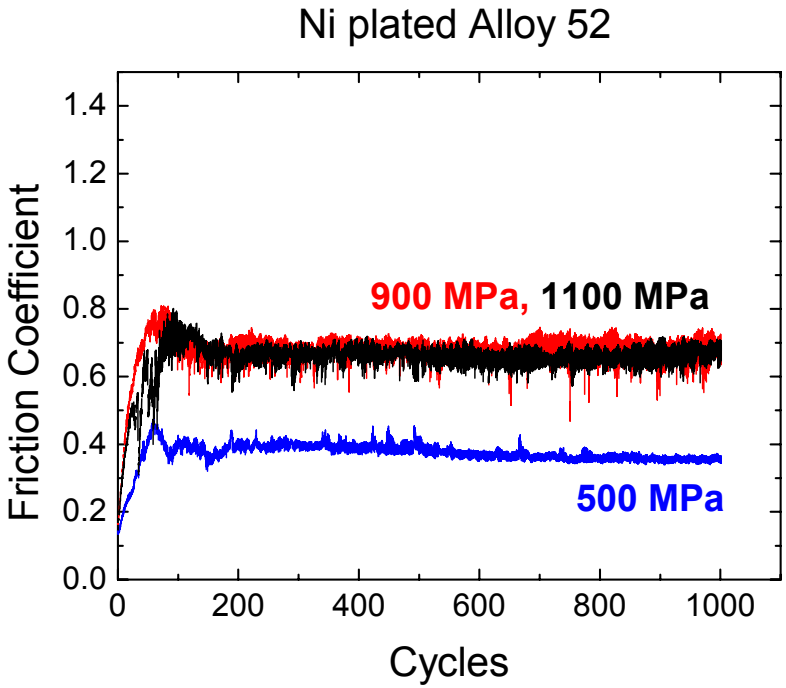
Friction of Alloy 52 and Ni plate





- **Contact pressures of ~ 500, 900 and 1100 MPa**
  - **Counterface: 3.125 mm Si_3N_4 sphere (Cerbec®)**
- **At low pressure, friction is ~0.4**
- **At high pressure, the tip plows into the substrate**
  - **Debris generation and severe wear**

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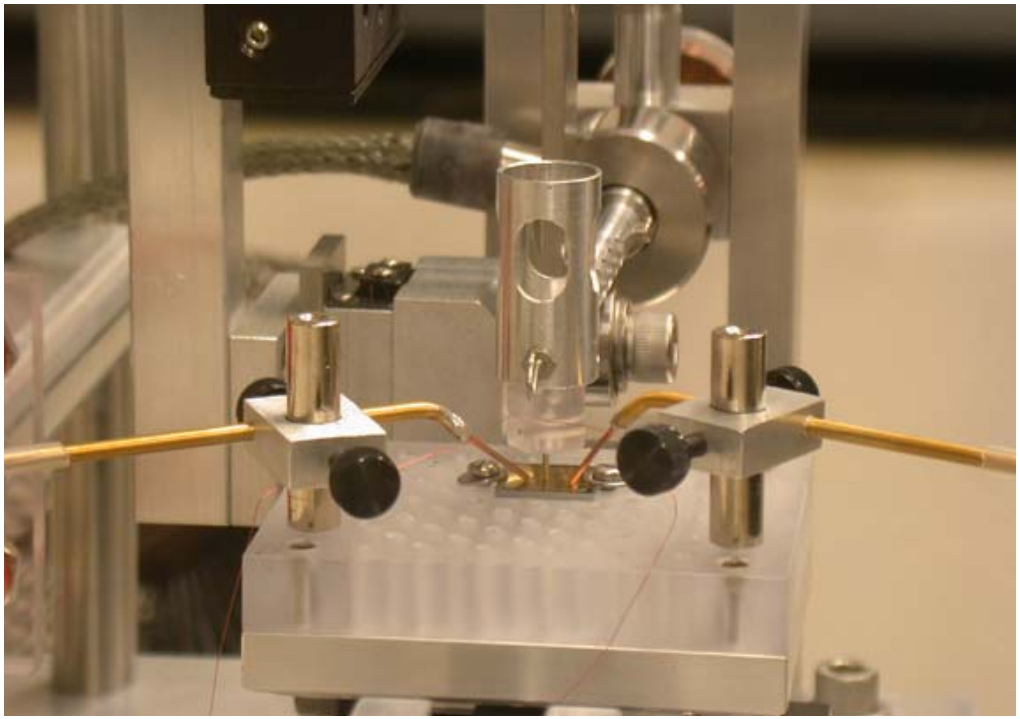
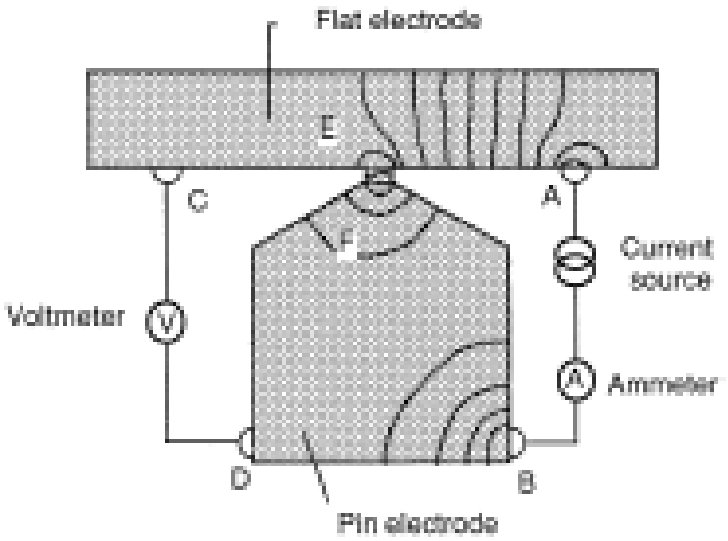
Sample Handling

- Samples are submerged and aged in silicone oils
  - 5 cSt and 20 cSt
  - 110 °C and 140 °C
- Samples were removed after 6 and 12 months
- Excess oil was removed from the surfaces by blowing pressurized nitrogen across the sample with a subsequent 50 °C furnace step
  - ~10's of monolayers left

Electrical Contact Resistance

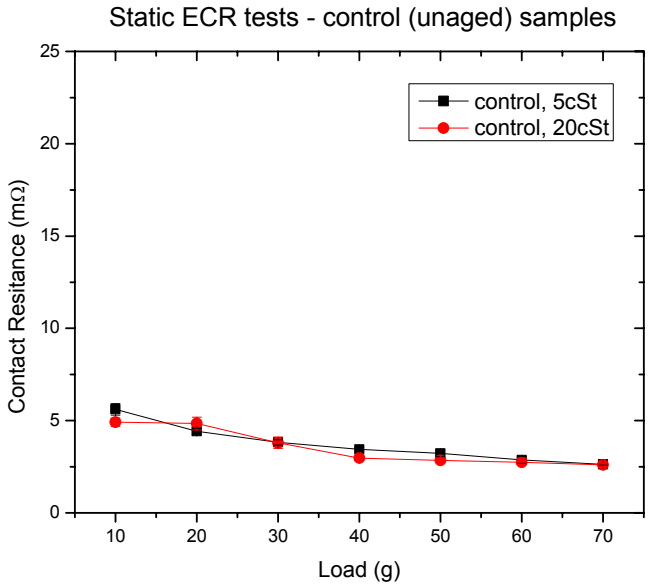


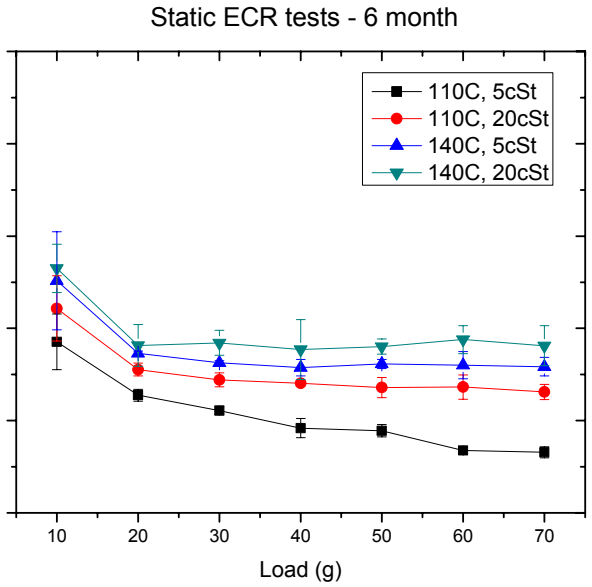


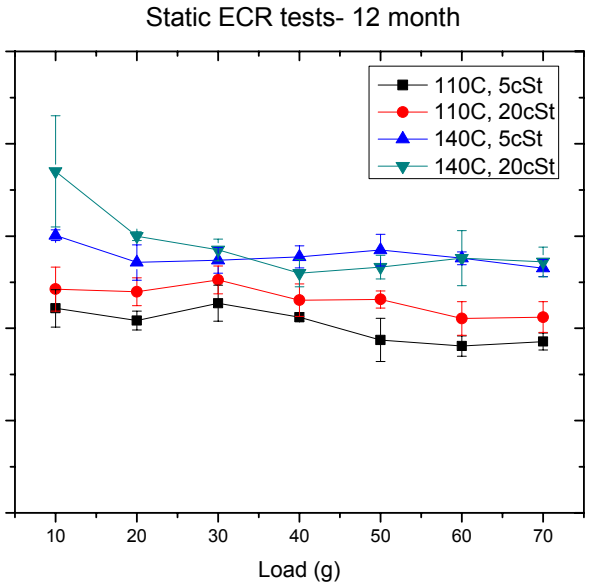
- **Pseudo 4-wire electrical contact resistance measurement**

Hannoe and Hosaka, *Microsystem Technologies*, **3**, pp. 31-35 (1996).

Static Contact Resistance Measurements







- **Noticeable change in static contact resistance due to accelerated aging**
  - **Largest change with highest temperatures**
  - **Higher viscosity oil appears to increase aging susceptibility**

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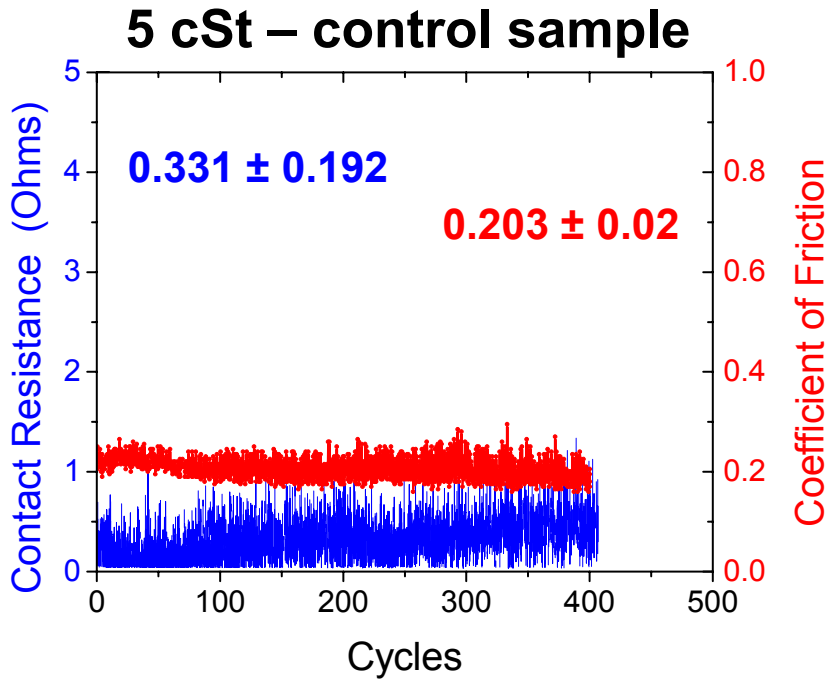
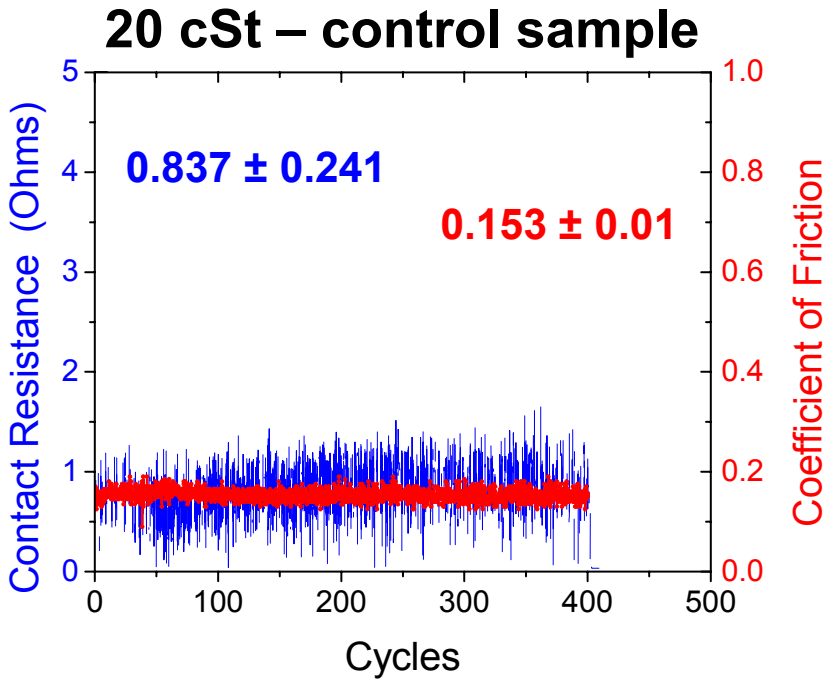
Sliding experiments – Control Samples



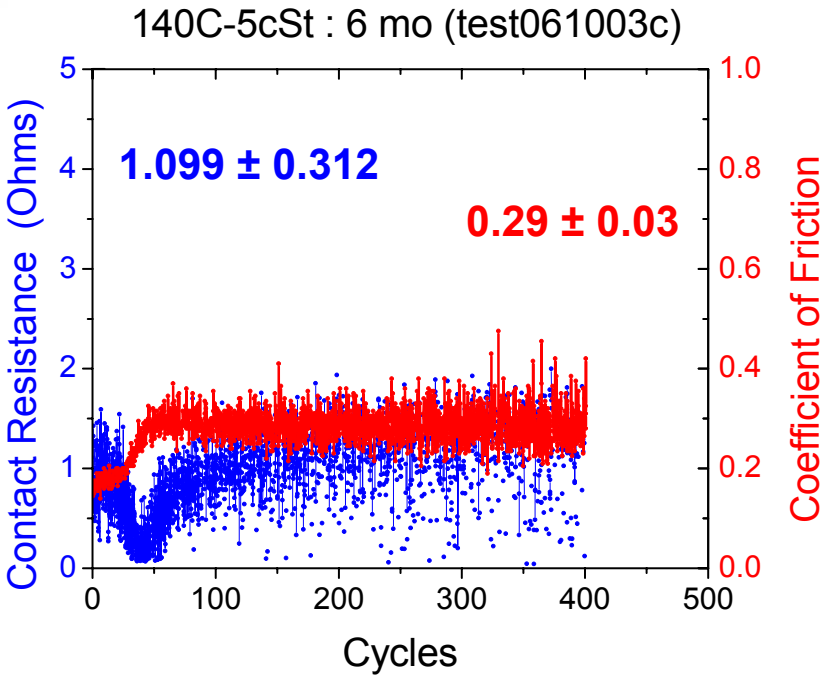


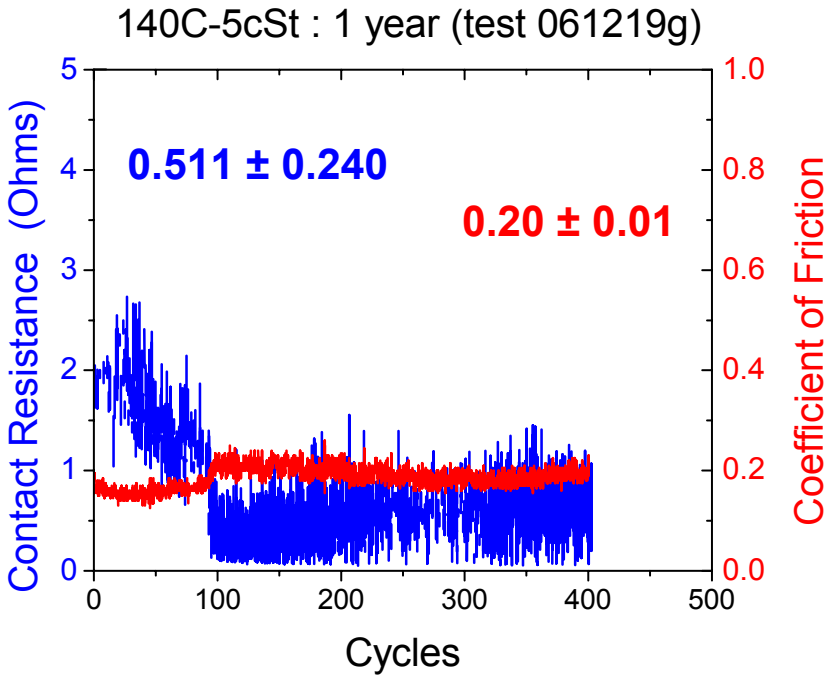
- **Contact stress ~ 450 MPa**
- **No noticeable run in behavior**

Friction averaged from cycles 100-300

Contact resistance averaged from cycles 100-300

Sliding experiments – Aged Samples





- **Indicate a "run-in" that wasn't present in the unaged samples**
  - **Wear through of surface film?**

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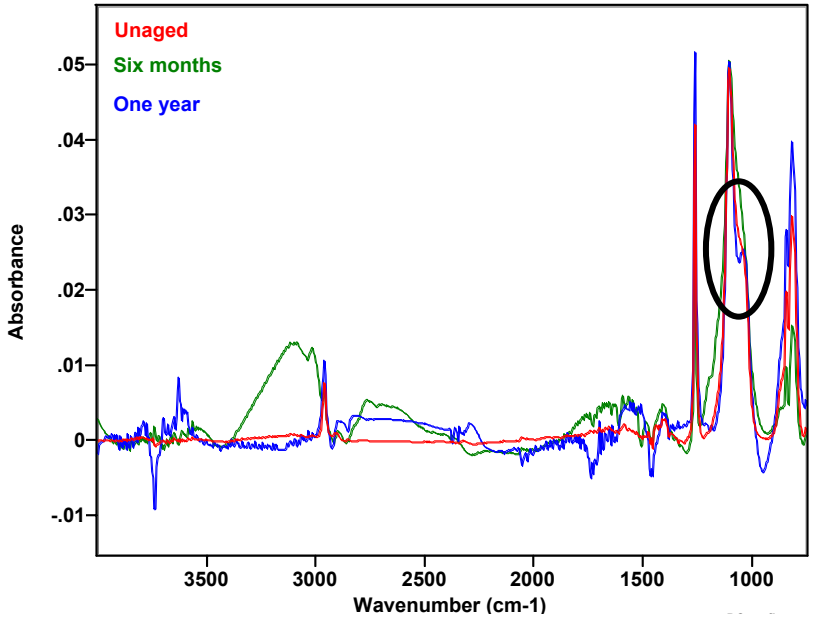
Auger Electron Spectroscopy

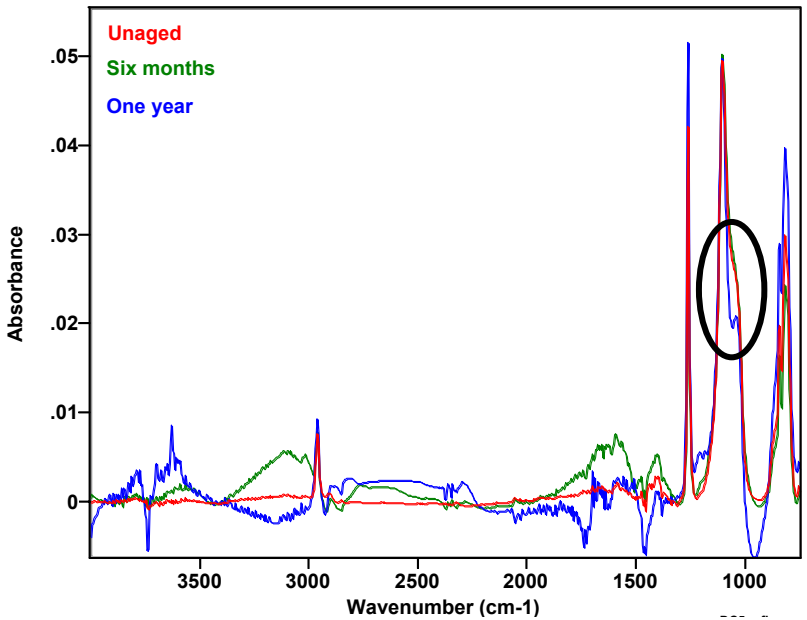
- Spectra indicate concentration of K, Cl, C, N, Co and C in the surface
  - Reaction/oxidation of these impurities is the likely cause of the increase in contact resistance with aging

IR Reflectance of Silicone Oil on Aged Surface

5 cSt oil aged at 110 °C



5 cSt oil aged at 140 °C



- **Change/shift in peak at ~ 1200 wavenumber implies potential cross-linking of oil with 12 month aging**
  - **Broad peak at 3000-3500 wavenumber from hydrogen-bonded water**

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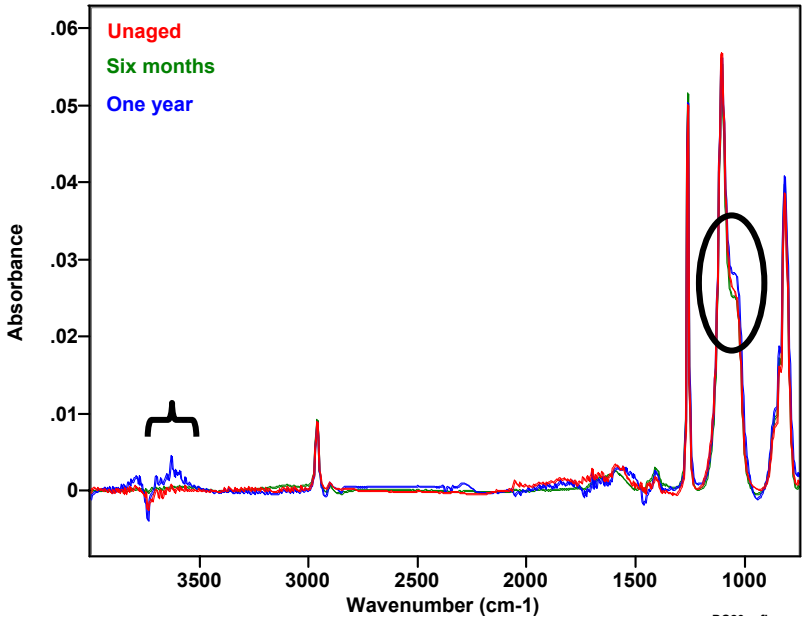
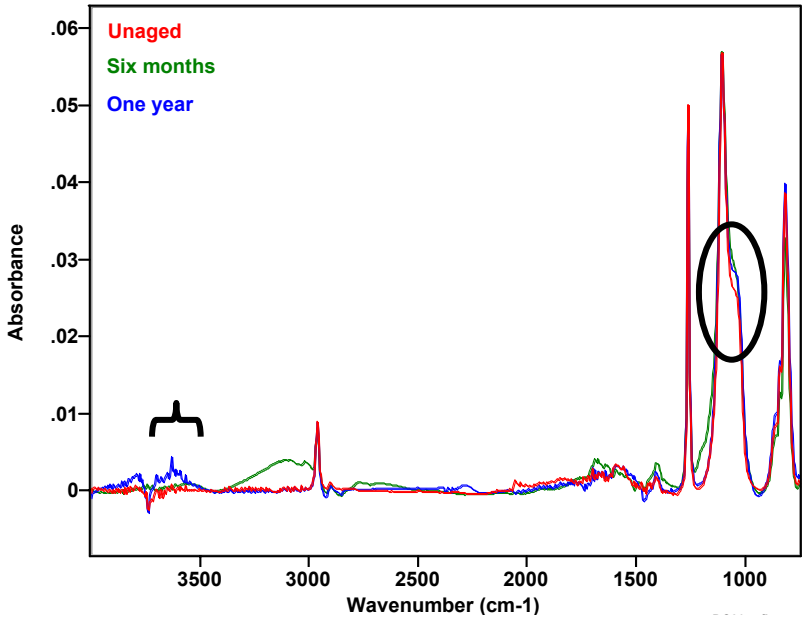
IR Reflectance of Silicone Oil on Aged Surface

20 cSt oil aged at 110 °C

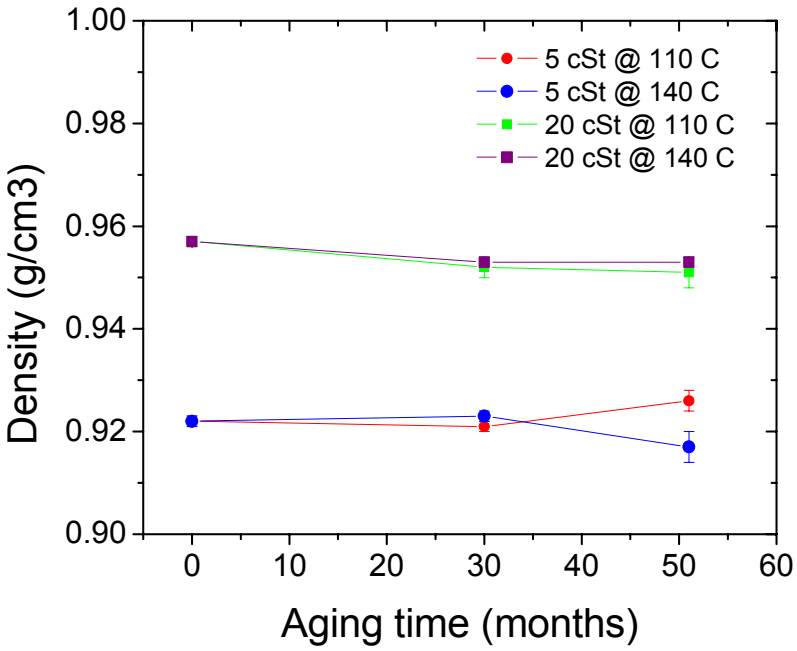


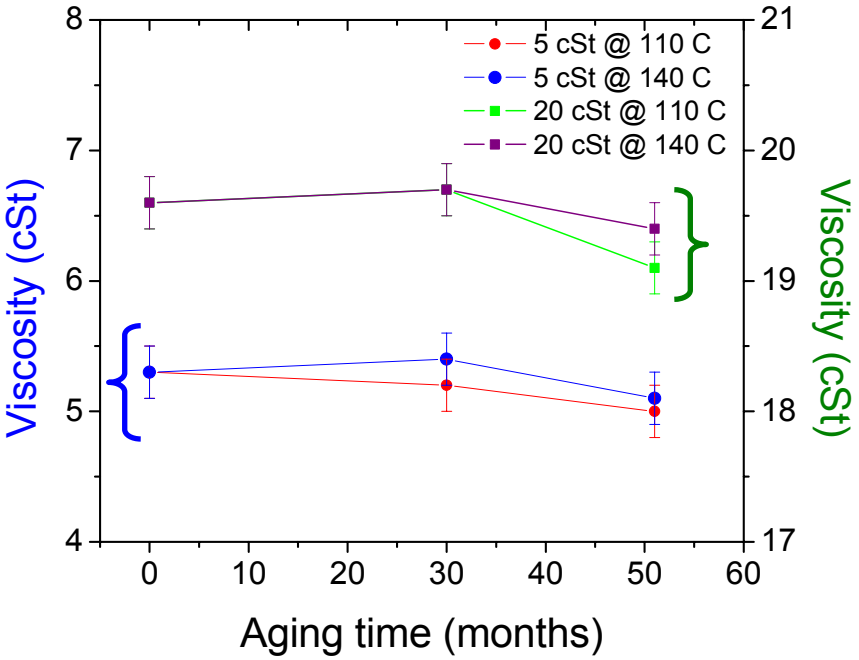
20 cSt oil aged at 140 °C



- **Broadening of peak at ~ 1200 wavenumber implies loss of cross-linking**
- **High wavenumber (~3500-3700) spectra from non-hydrogen bonded Si-OH**
  - **Indicates that broken cross-linking may be forming non-hydrogen bonded Si-OH bonds**

Analysis of Silicone oil aged with Au coupons





- **Changes in density are small, but do indicate possible degradation**
  - **Loss or formation of cross-linking due to oil aging**

- **Subtle drop in oil viscosity**

Data courtesy of Todd Alam, SNL

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Conclusions

- Hard gold coatings are useful as functional electrical contacts for sliding applications
  - Reduce friction by a factor of ~2-3
- Diffusion of impurities co-deposited with the gold plate generated an increase in the electrical contact resistance on the surface
- Silicone oil did show small changes in properties, possibly due to addition/scission of silicone chains

Acknowledgements and Questions

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Questions?

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