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Friction and Surface Deformation in Electrodeposited Gold Alloy Thin Films

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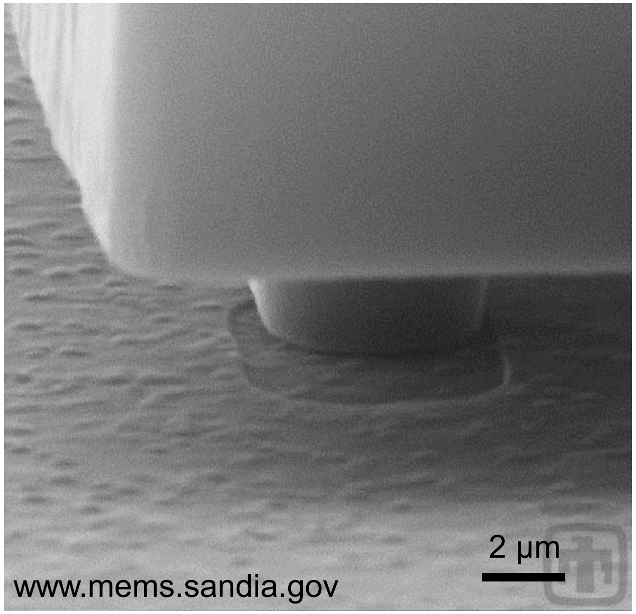
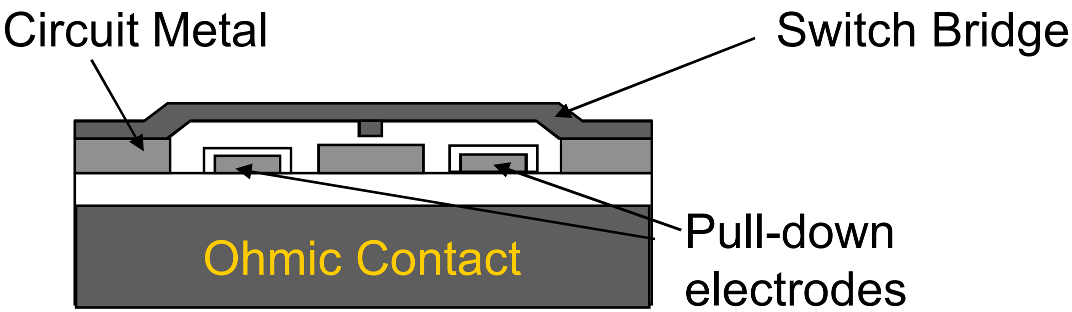
Outline

- Motivation and Overview
  - Hard gold films as electrical contact surfaces
  - Friction vs. microstructure issues
- Experimental results
  - Linear wear testing
  - FEM simulations
  - Current/Future work
- Conclusions

Ohmic Microsystem Contacts





The ideal electrical contact interface would include:

1) Low electrical resistance

2) Minimal adhesion [D. Dickrell – 8G]

3) Low friction (sliding contact)

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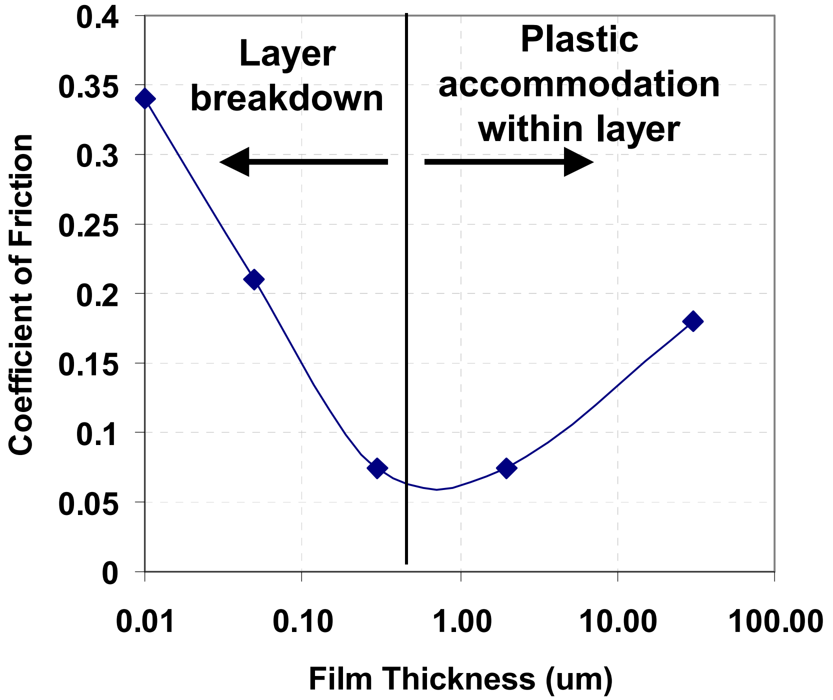
Contribution of Bowden and Tabor

- Hard materials have high shear strengths
  - High frictional coefficients
- Low shear strength metals are usually soft
  - Large contact areas
- Solution is to use a layered system
  - Thin film of soft metal over substrate of hard metal



Thickness of film can greatly influences the overall tribological response of a system

Bowden and Tabor, 1950

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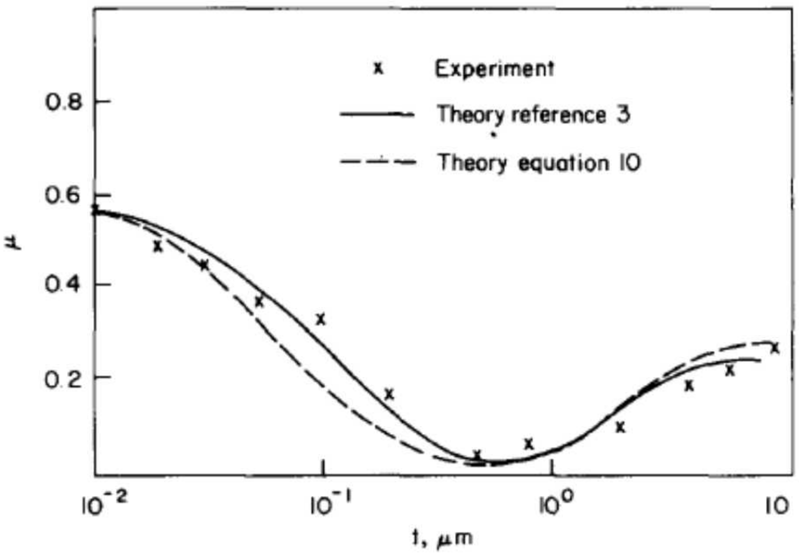
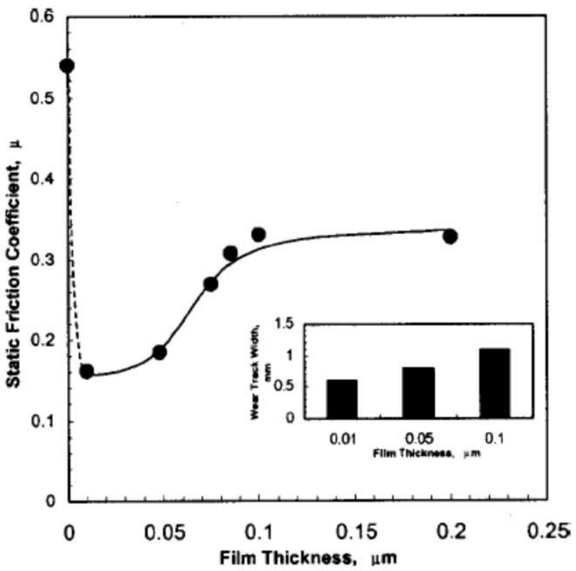
Other material systems

lead on steel



silver on steel

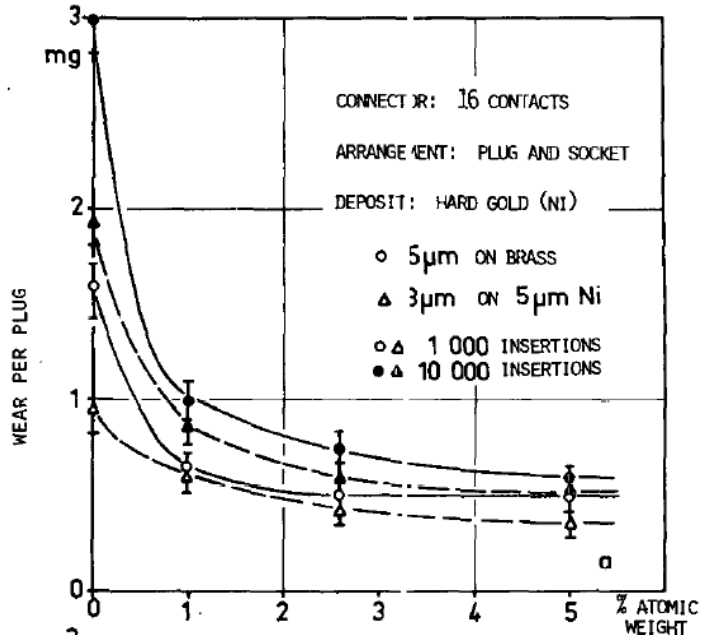


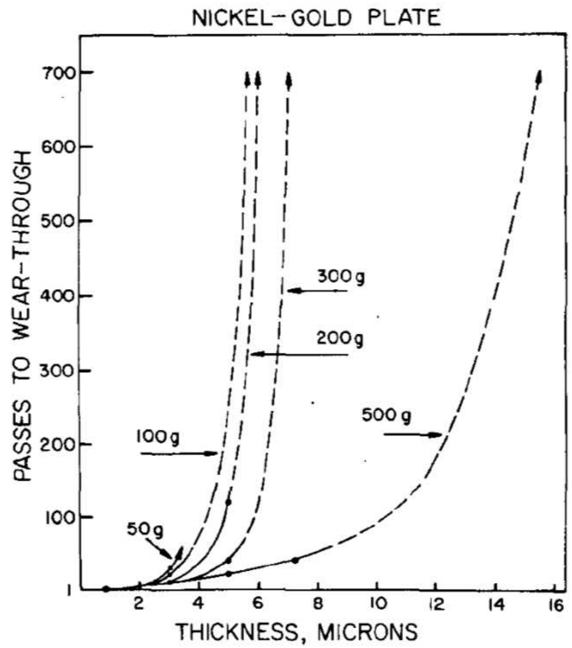
- **Behaviors of lead and silver on hardened steels**
  - **Hard substrate with low shear strength coating is the key**

Liu et al., ASME J. Tribo., 2002

Halling., Tribol. Int. 1979

Variables of Electroplated Gold





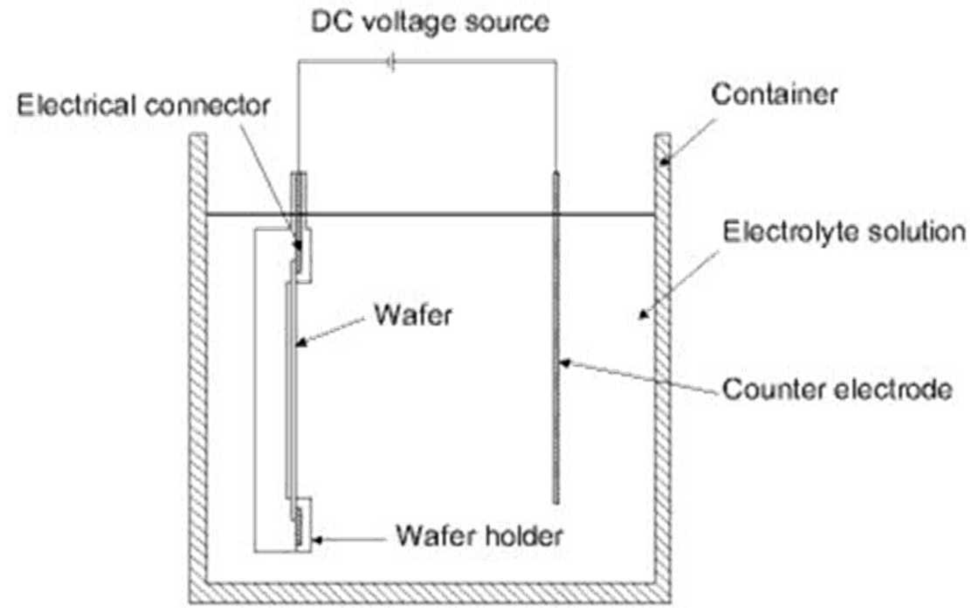
- Additives intentionally included into the films
  - Improves wear resistance
- Film thickness is related to wear-through

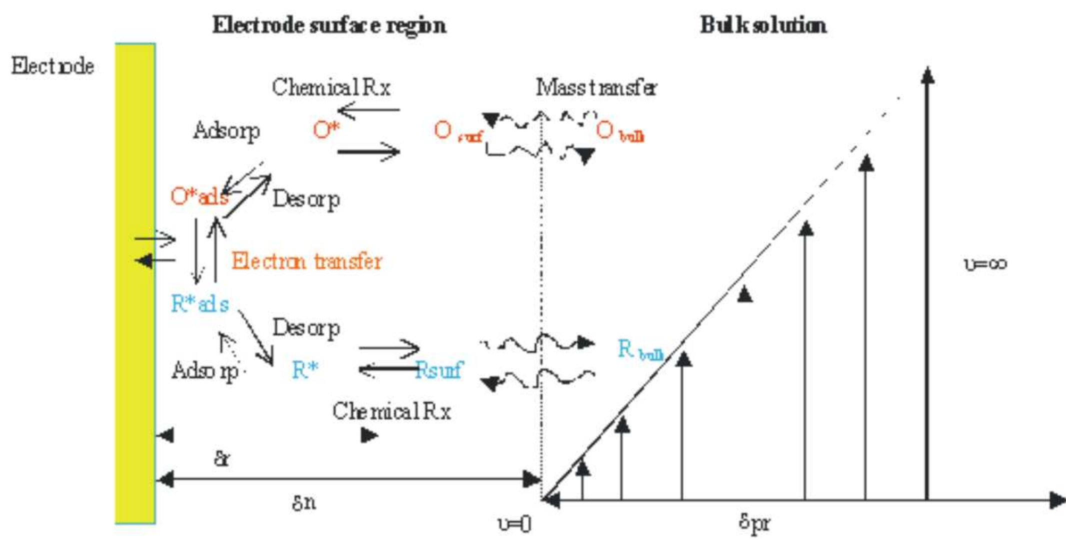
Horn and Merl, IEEE Trans. Parts, Hybrids, Packag., 1974

Antler, IEEE Trans. Parts, Hybrids, Packag., 1973

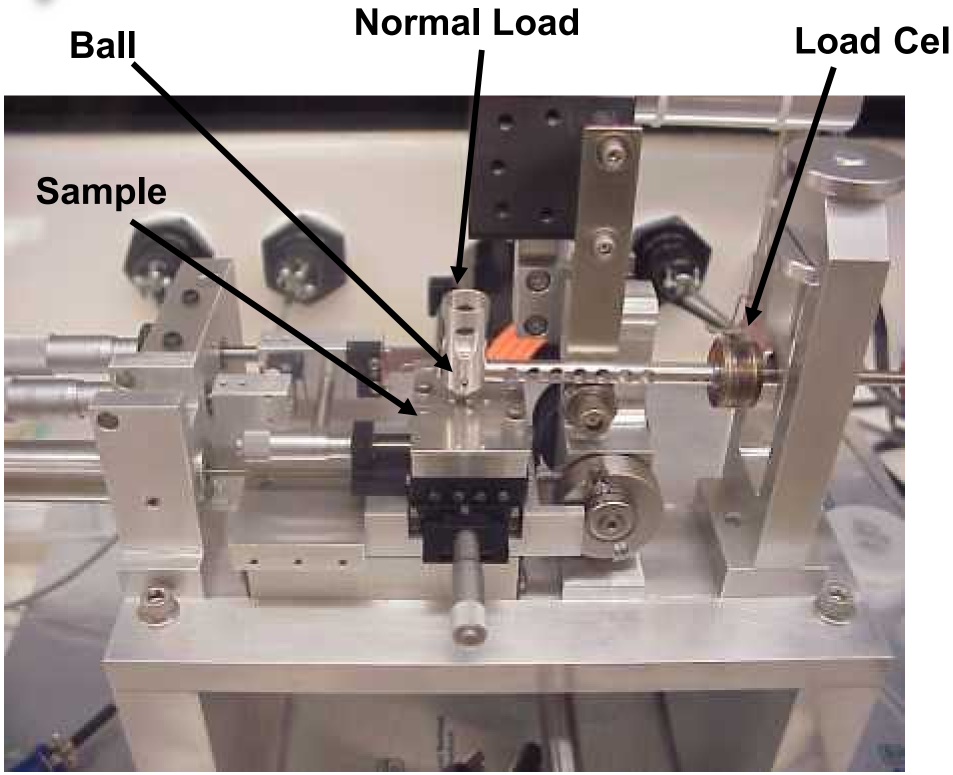
Electrodeposition of Hard Gold

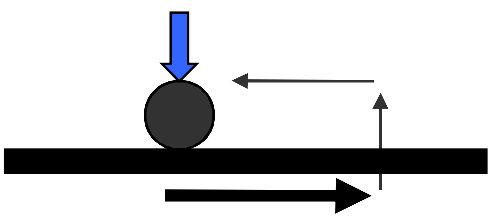
- Typical Additives
  - Nickel, Cobalt, polymer, thorium
  - Goal is grain refinement (and SS hardening)
- Bath electrolytes
  - Free-cyanide base
  - Thiosulfate complex
- ASTM and/or MIL-G-45204
  - Hardness ranges





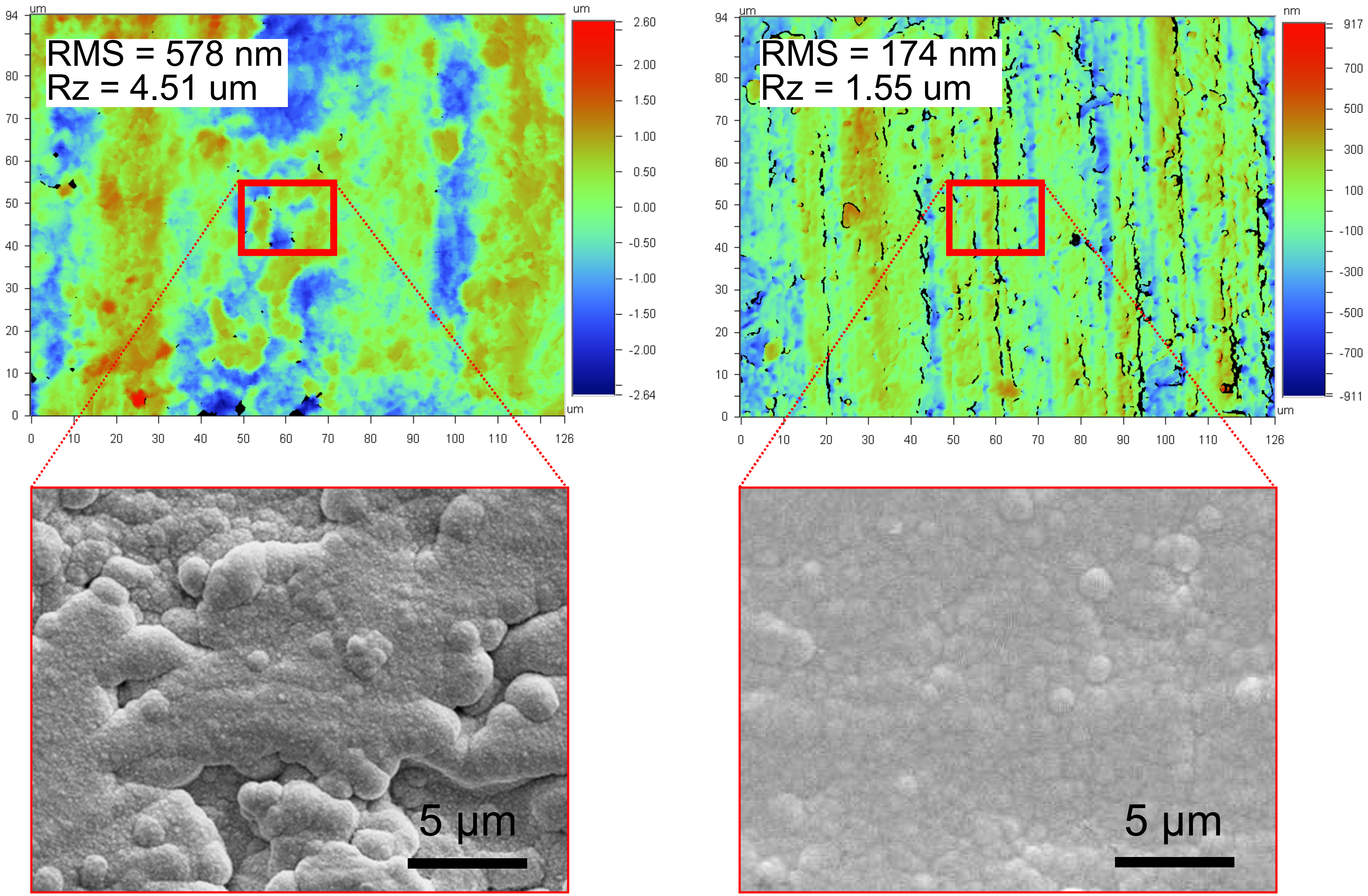
Linear Wear Testing



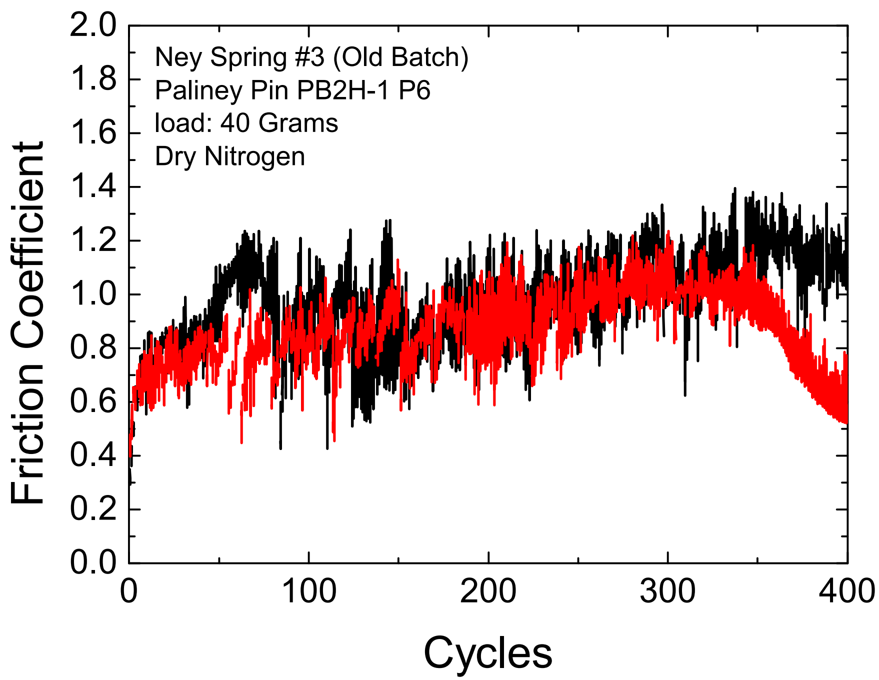


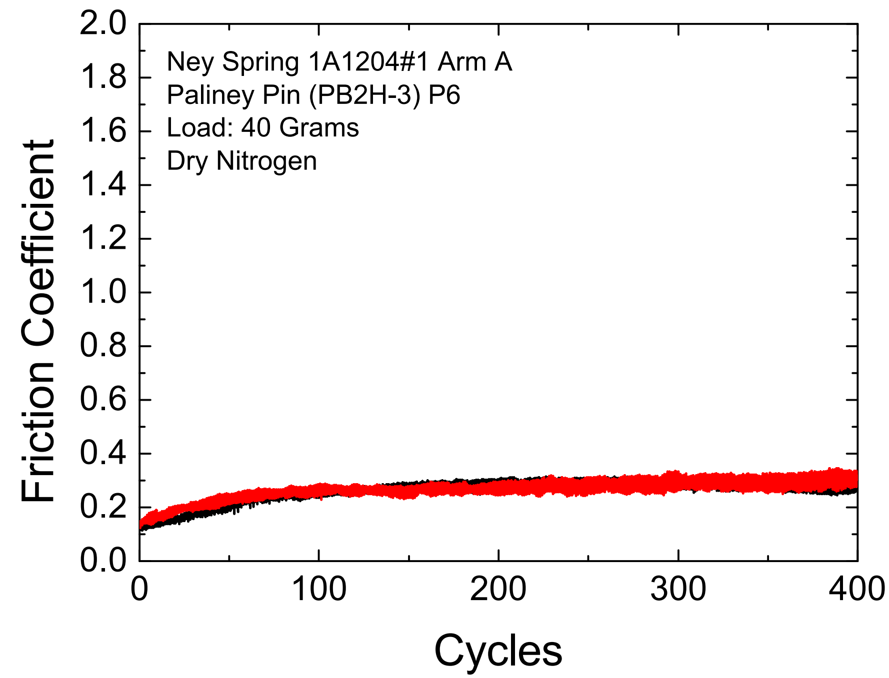
- Creates a unidirectional linear (wiping) motion across the sample
- Typical test conditions
  - 1/8” Si_3N_4 ball
  - 380 µm Paliney Pin
  - 40 Hz
  - 1000 cycles
- Controlled Atmosphere
  - O_2 < 10 ppm
  - Dew point < -35 °C

Grain size and roughness of Hard Gold



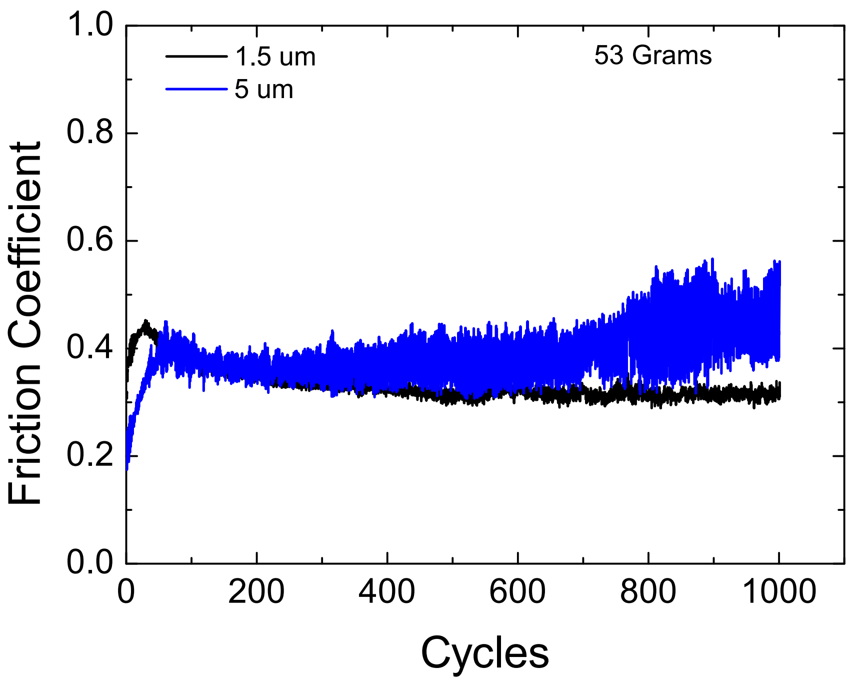
Grain Size Effects

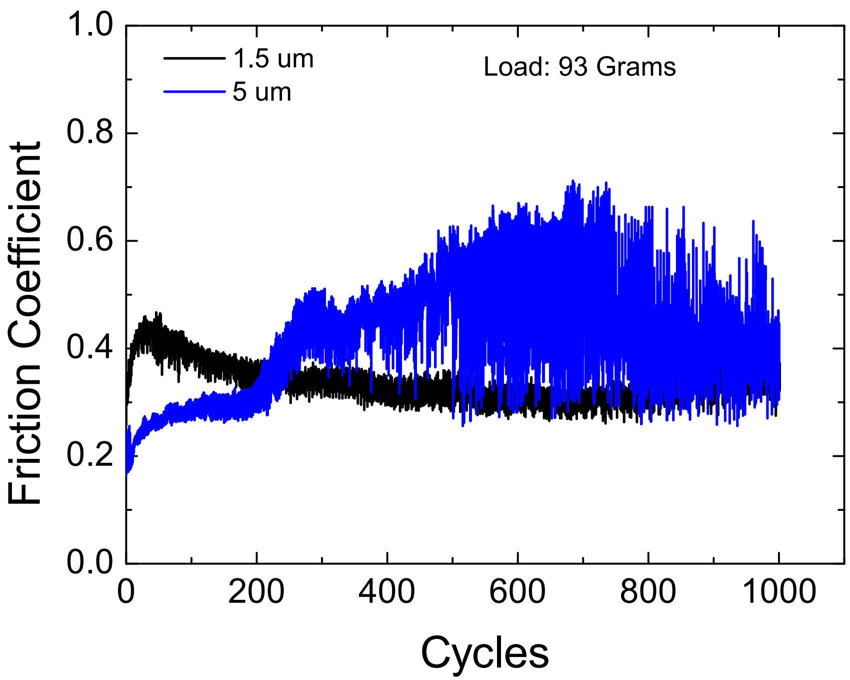




- **Nominally identical films (chemically)**
- **Larger grain size shows much greater frictional coefficient**

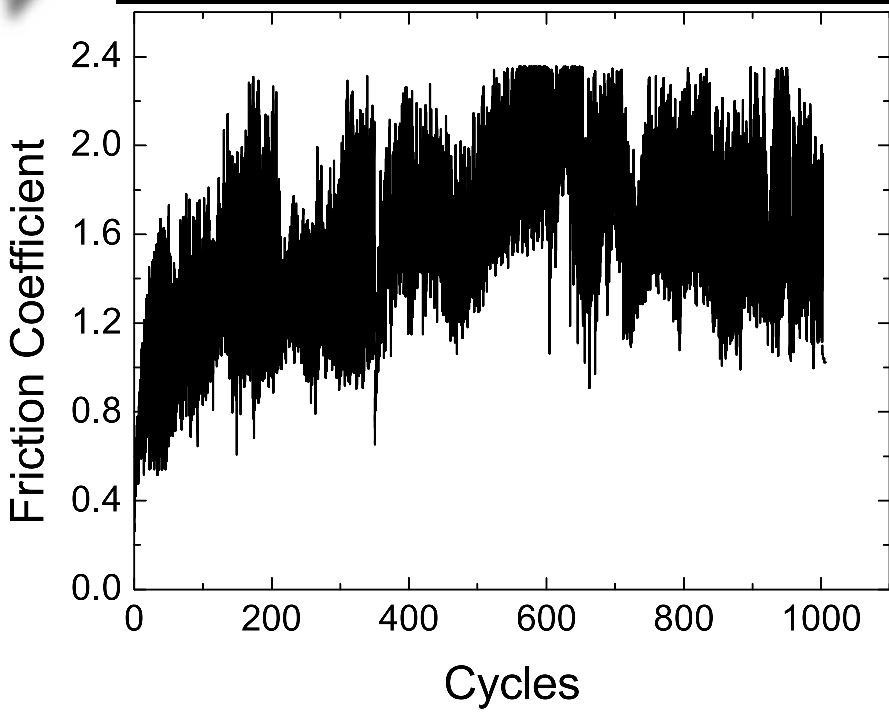
Hard Gold Thickness Effects

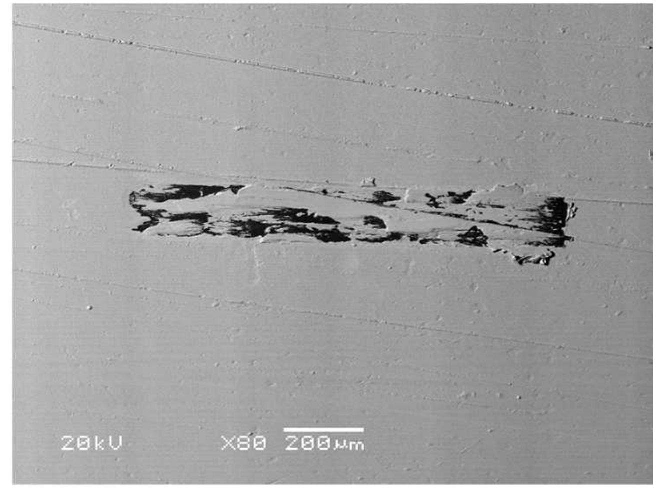




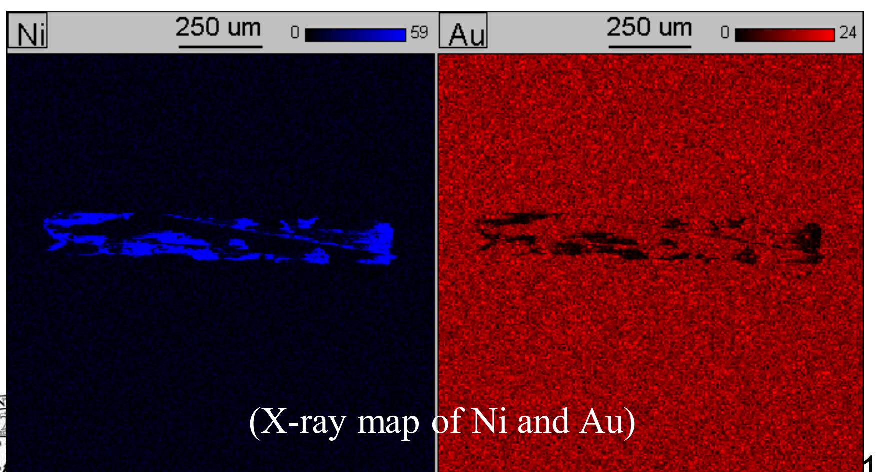
- **Counterface – Paliney Pin (380 µm radius)**
- **Increasing the gold thickness changes frictional coefficient**
  - **Large fluctuations due to …film deformation (grooving)**

Soft Gold Friction Testing

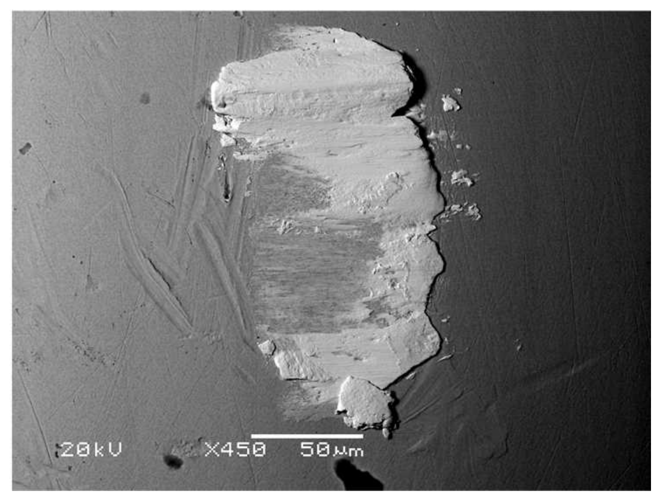




(Backscatter image of wear scar)

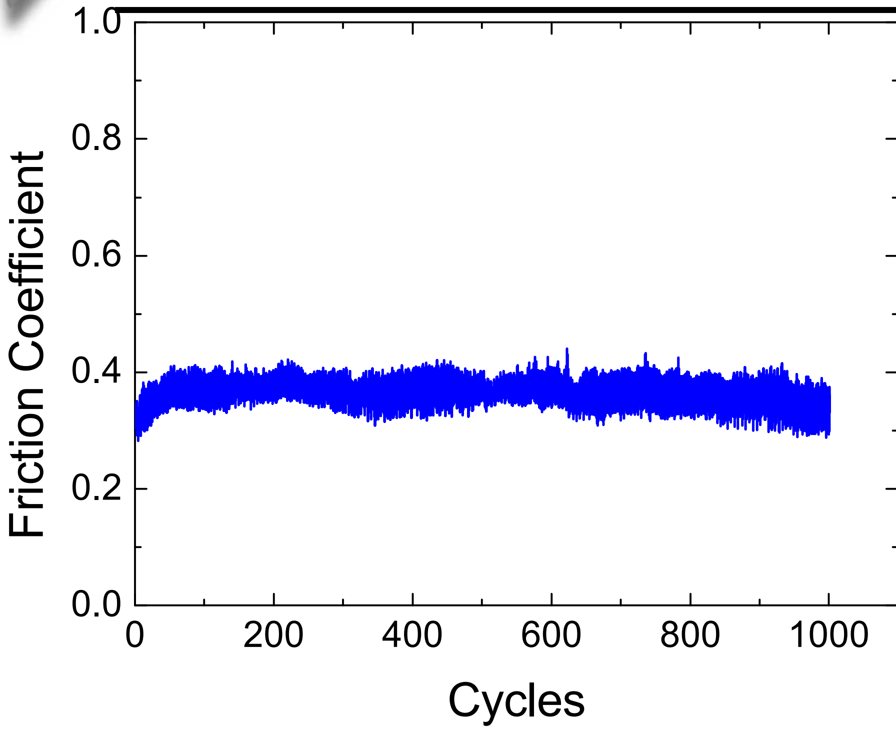


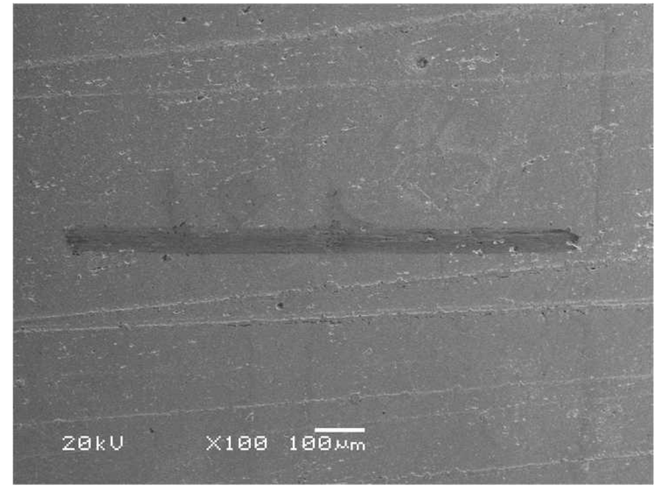
(X-ray map of Ni and Au)



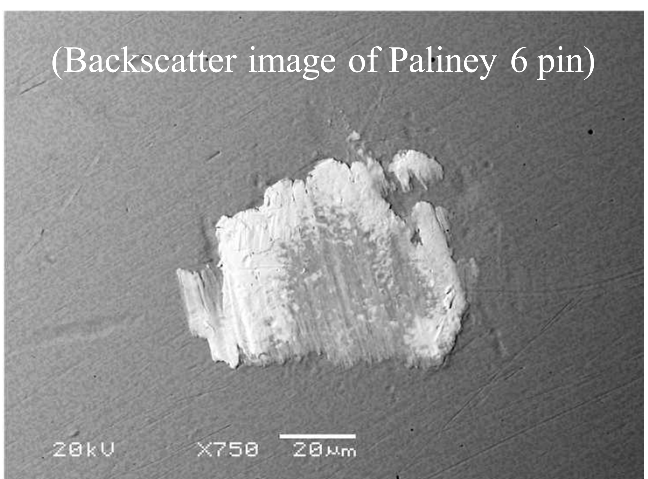
(Backscatter image of Paliney 6 pin)

Hard Gold Fricton Testing

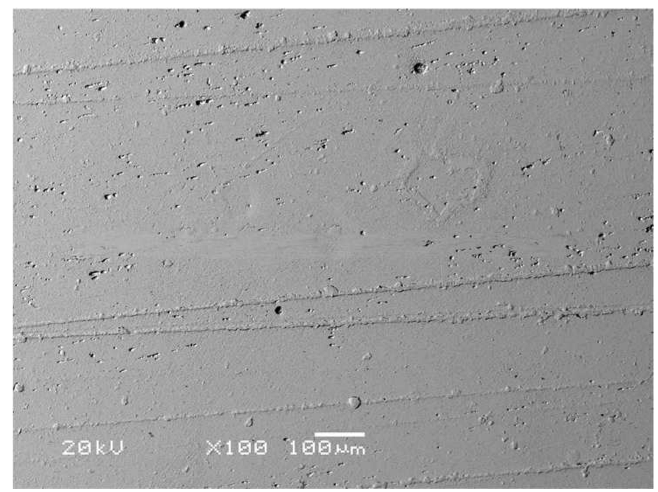




(SEM image of wear scar)

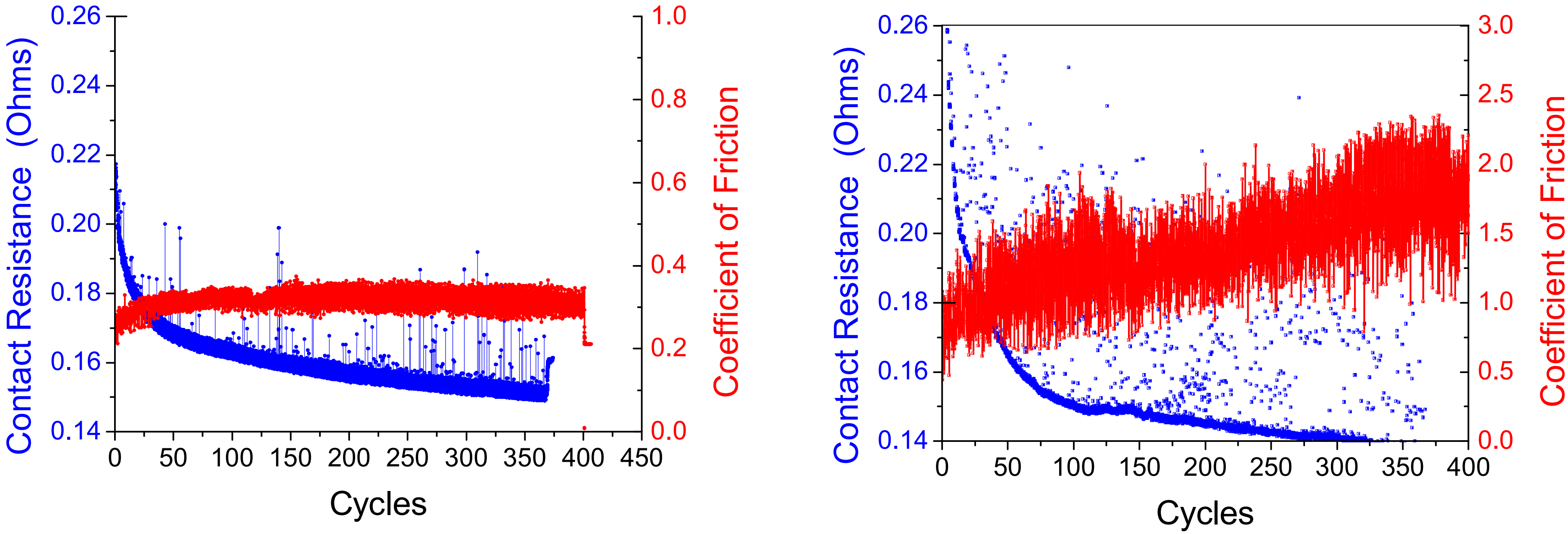


(Backscatter image of Paliney 6 pin)



(Backscatter image of wear scar)

Hard Gold and Sliding Contact Resistance

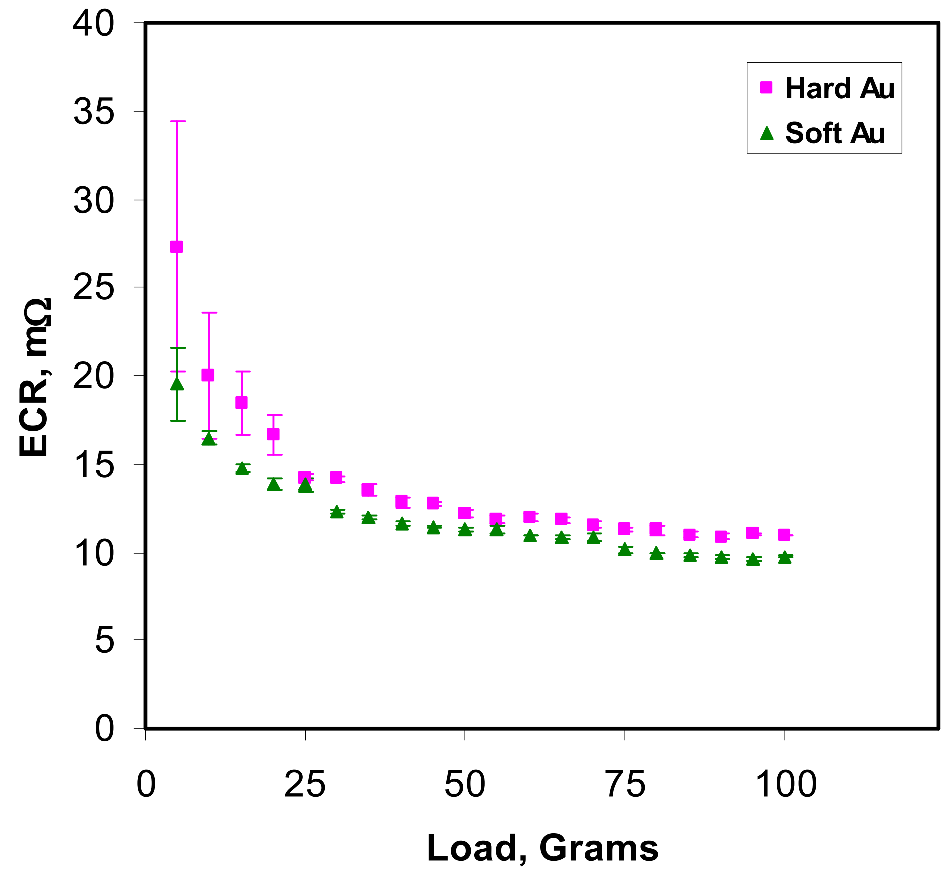


- **Paliney Pin**
  - **50 mN load (5 grams)**
- **Similar contact resistance values even with greatly different frictional coefficients**

ECR and Static Load

- Contact resistance related to applied load

- Contact area



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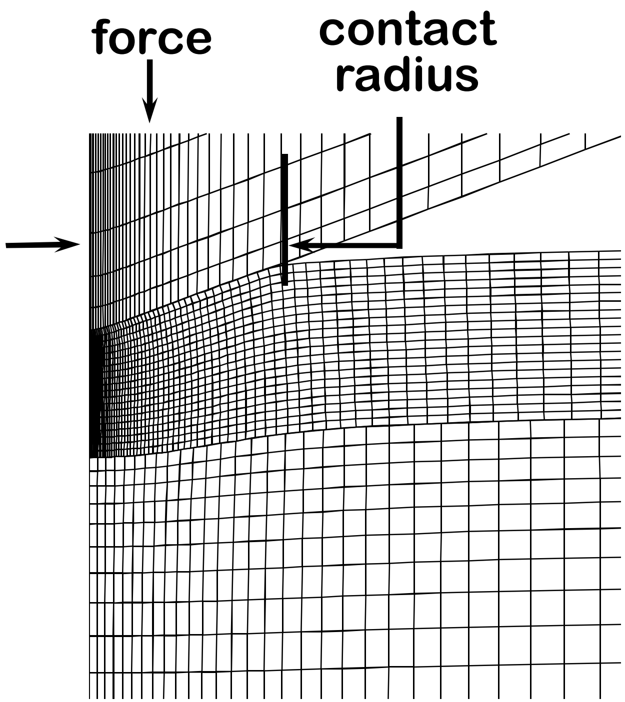
Modeling of Contact

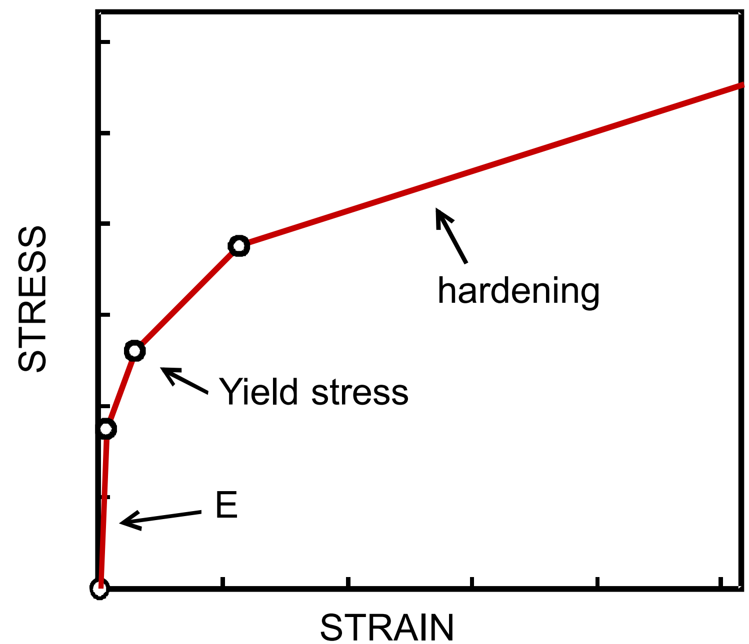
- Meshes are generated specific to each sample, including layer thickness and pin shape.
- Specific material properties are assigned to each component in the mesh



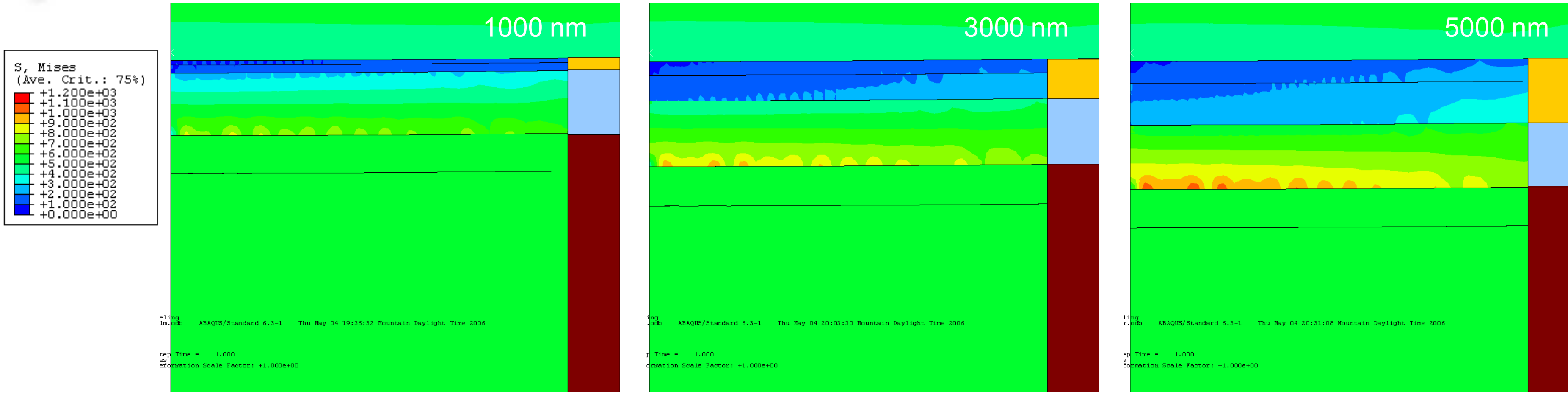
2D axisymetric mesh

$\sigma = E\varepsilon$ **for $\varepsilon < Y_0 / E$**

$\sigma = K\varepsilon^n$ **for $\varepsilon \geq Y_0 / E$**



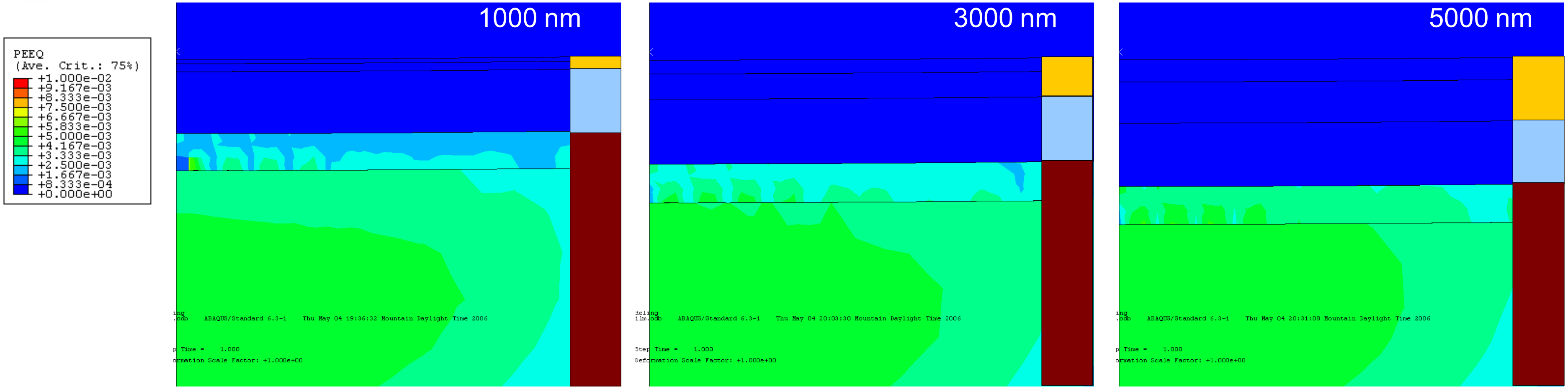
Mises Stress – Large Pin (R = 1600 μm)



- **Large probe distributes the load**
  - **Regions of peak stress are relatively deep in the substrate**

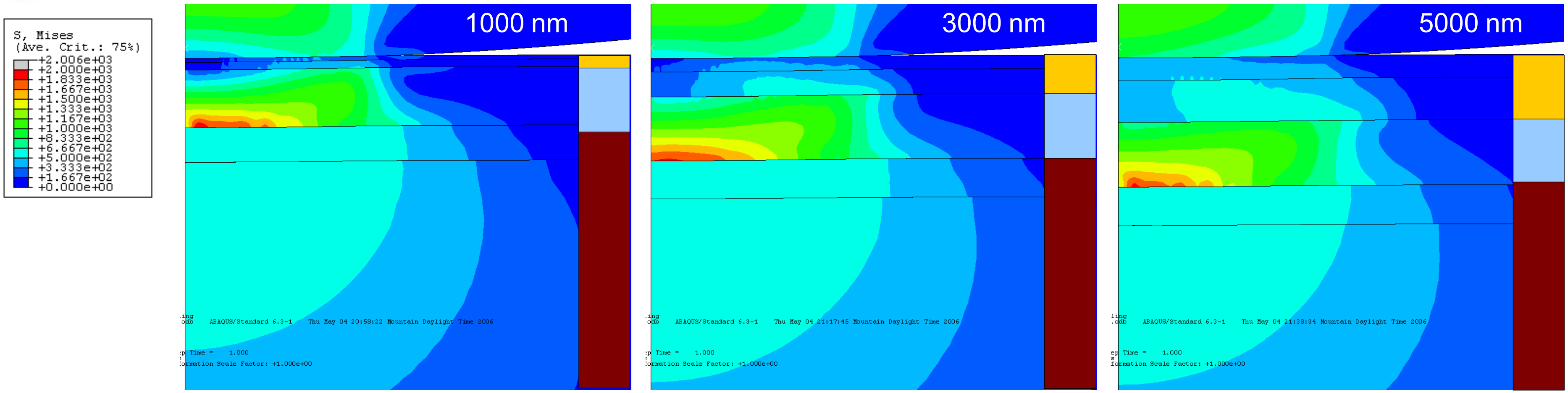
- **Majority of the stress is carried by the stiffer (and harder) nickel and Alloy52**

Plastic Strain – Large Pin (R = 1600 μm)



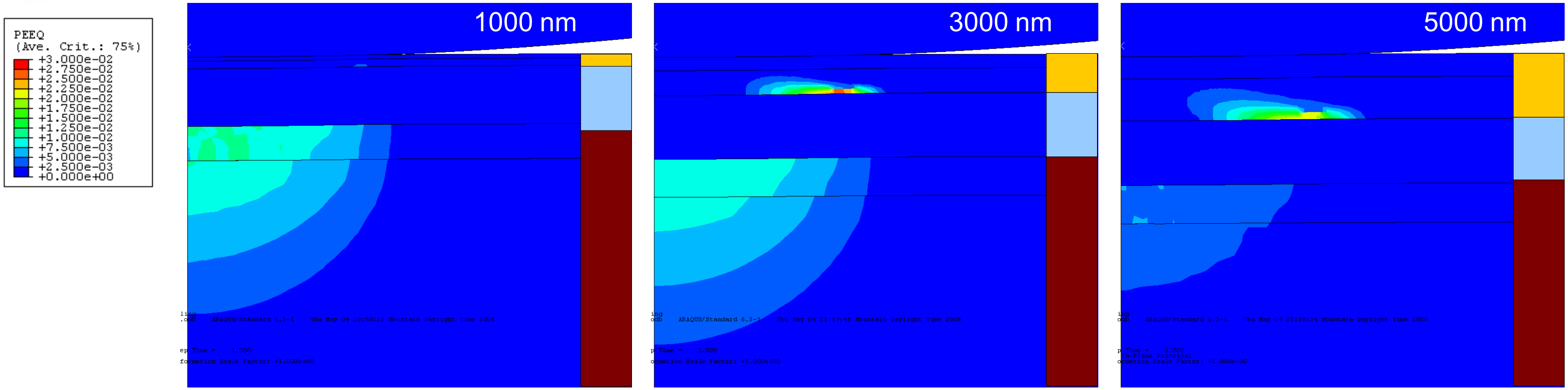
- **Plasticity is limited to substrate**
- **Depth of peak stress is ~ 20 microns**

Mises Stress – Medium Pin (R = 400 μm)



- **The stresses distribute based on the elastic properties of the layers**
  - **Increasing layer thickness allows the gold to carry more of the load**
- **Stresses are highest in the nickel plating**

Plastic Strain – Medium Pin (R = 400 µm)



- **Thickening of gold film moves the location of peak (Hertzian) shear towards the gold coating**
  - **Results in zone of plastic deformation entering gold film**

- **Plastic deformation within the film may lead to grooving and increase frictional coefficients**

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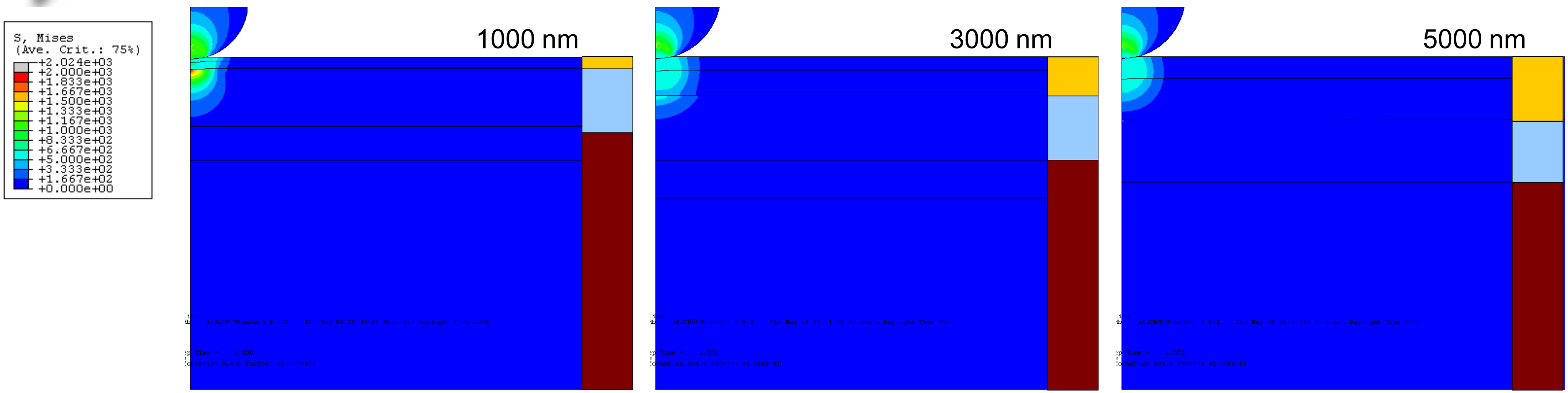
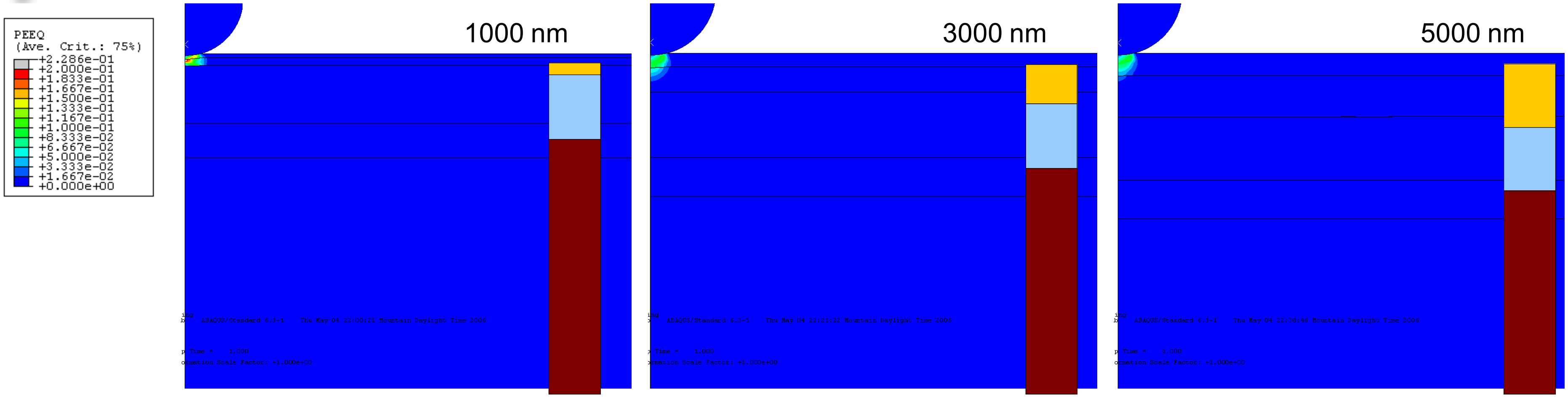
Mises Stress – Small Pin (R = 5 μm)



- **5 μm ~ MEMS scale contact**

- **Confined stresses**
  - **But localized in the near-surface**
  - **Small probe tip results in large stress gradients**

Plastic Strain – Small Pin (R = 5 μm)



- **Film in all cases is plastically deformed through the thickness**
- **Plasticity is truncated at the (harder) nickel interface**

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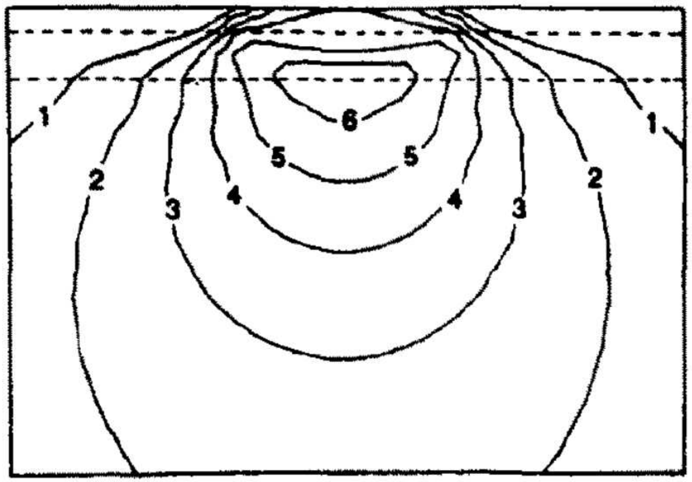
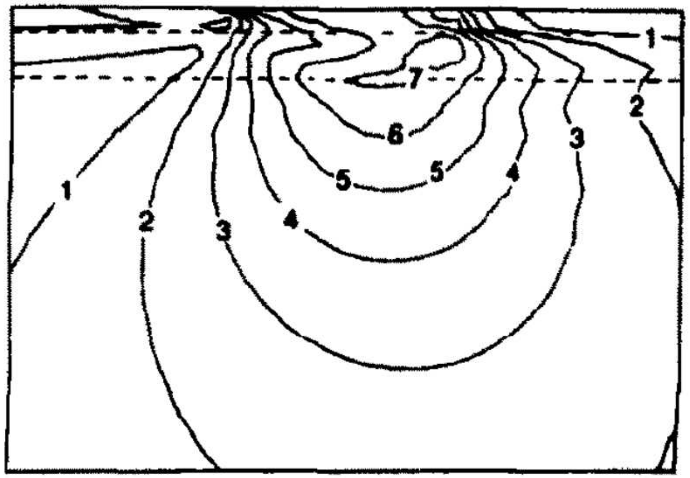
Shift in contour due to sliding

Sliding direction





- **Sliding shifts the stress contours towards the surface**
  - **Brings peak shear closer to the gold coating**
  - **Increases likelihood of plastic flow (and subsequent grooving) in gold film**

Tian and Saka – Wear (1991)

Conclusions

- Hard gold coatings are useful as functional electrical contacts for sliding applications
  - Reduce friction by a factor of ~3
- Thickness of the coating dictates (in part) the sliding stresses
- FEM implies that increase in frictional coefficient is due to peak shear moving into the gold coating
  - Smaller (sharper) pins move peak shear towards (and into) Au film

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Acknowledgements and Questions

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Questions?