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Tribology of Composite Au-MoS_2 Films at Varying Contact Stresses

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14. ABSTRACT

Solid-lubricant coatings for sliding electrical contact applications like slip-ring assemblies have very different requirements from typical applications like ball bearings and cutting tools: they have significantly lower contact stresses and sliding speeds. We are optimizing the performance of sputter-deposited nanocomposite Au-MoS_2 films for such low contact stress applications. Higher contact stress pin-on-disk tests (S_m = 730 MPa) showed that low Au-MoS_2 films (i.e., 22 to 38 at% Au) outperformed those with higher Au content (i.e., ≥55 at% Au). In contrast, low contact stress disk-on-disk tests (S_m ~0.3 MPa) showed that higher Au-content films outperformed low Au-MoS_2 films. These results, along with Auger Nanoprobe post-test analysis, indicate that Au provides structural integrity for the films in the high-contact-stress tests, while optimizing the MoS_2 transfer rate in the low-contact-stress tests. The results are promising for sliding electrical contacts because high-Au films not only perform the best tribologically, but also exhibit the highest electrical conductivity.

15. SUBJECT TERMS
Solid Lubricants, Molybdenum Disulfide, Friction and Wear Testing, Slip Rings, Sliding Electrical Contacts, Nanocomposite Coatings, Auger Electron Spectroscopy, RF Sputter Deposition

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Tribology of Composite Au-MoS_2 Films at Varying Contact Stresses

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1 May 2003

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Outline

- Background
- Description of Apparatus
  - Multitarget rf magnetron sputter deposition system: Au, MoS_2
  - CS(E)M Tribometer; Purged with purified N_2
  - Auger Nanoprobe
- Friction Testing
  - Testing at two contact stresses for 2000m
  - Pin-on-disk (only disk coated): 730 MPa (106 ksi) mean Hertzian stress
  - Disk-on-disk (only one disk coated): ~0.1 MPa (15 psi) mean Hertzian stress
- Analysis of Wear Track/ Transfer Films: Auger Nanoprobe
- Summary/ What's Next

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Background

- Sputter-deposited MoS_2 films used in space and ground applications are generally moderately high contact stress
  - Actuators (solar array drives), deployment mechanisms, gimbal bearings
  - Cryogenic lubrication applications (Launch vehicle engines)
  - Used increasingly for cutting/forming tools, etc.
- Conductive, lubricious, adherent films could provide a boon for sliding electrical contacts in vacuum (and terrestrial?) environment
  - Slip Rings
  - Switches & Relays
  - Connectors
- Behavior of sputter-deposited MoS_2-based films at low contact stress not well-characterized: What parameters are important?

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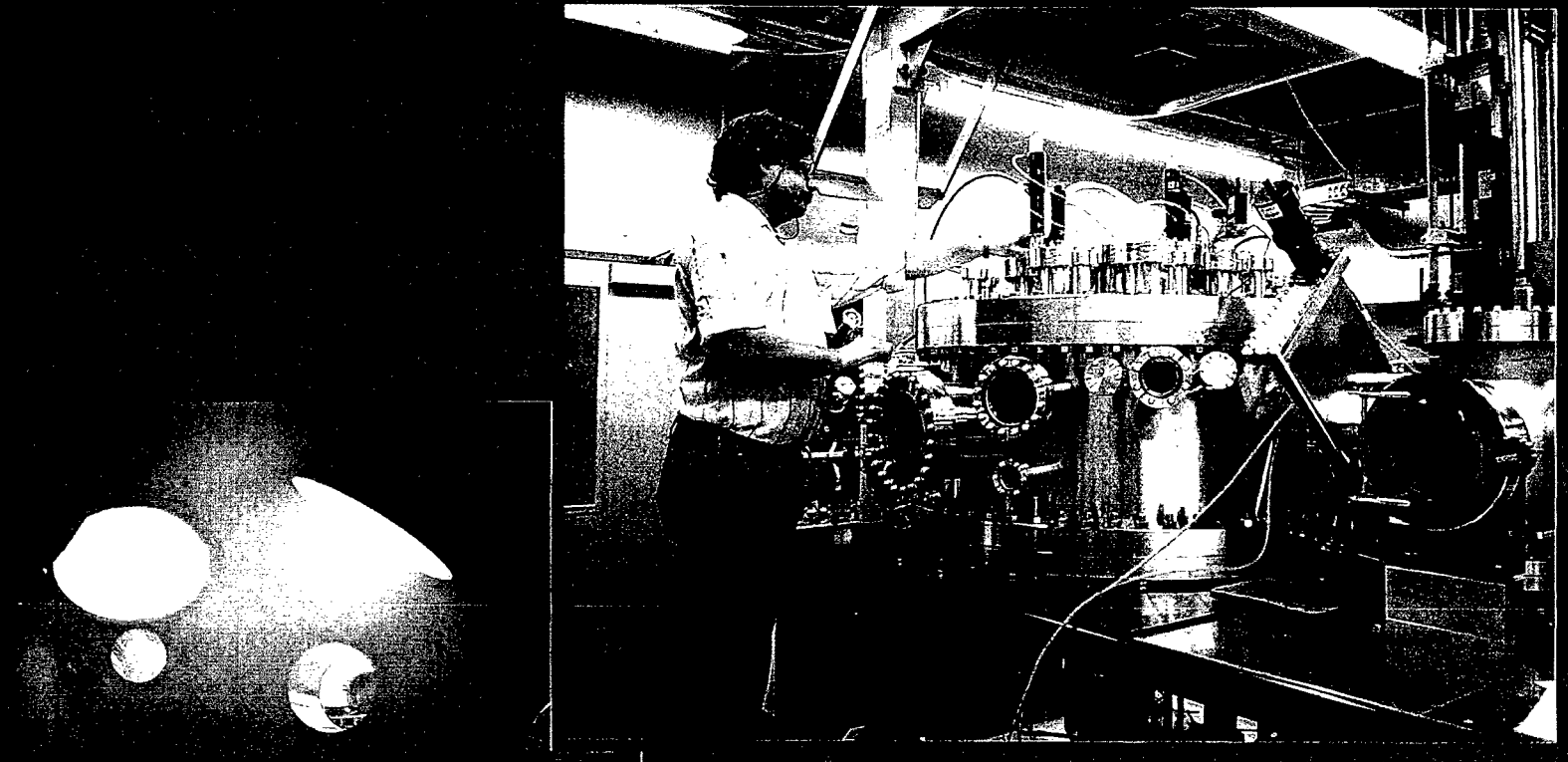
RF Sputter-Deposition System



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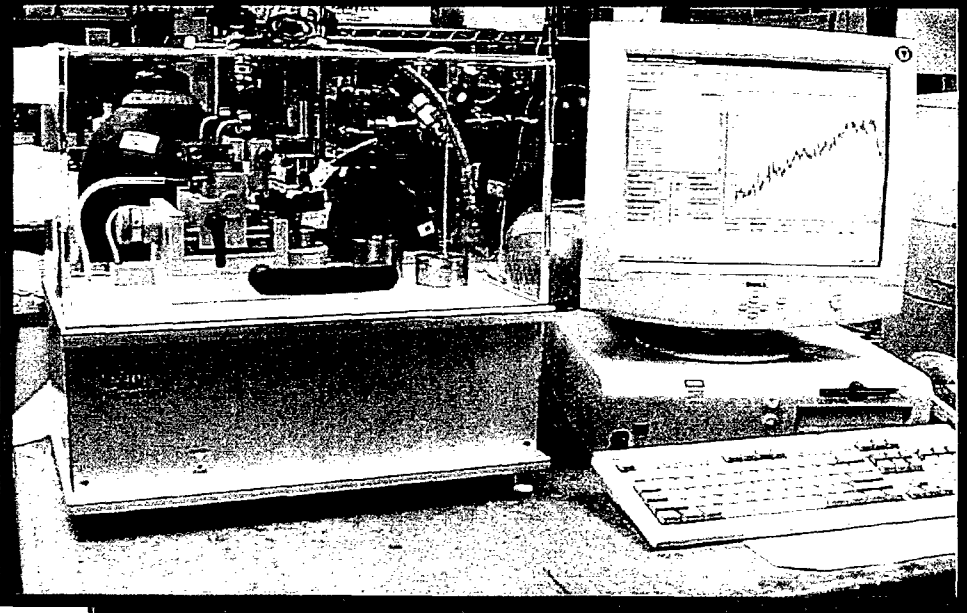
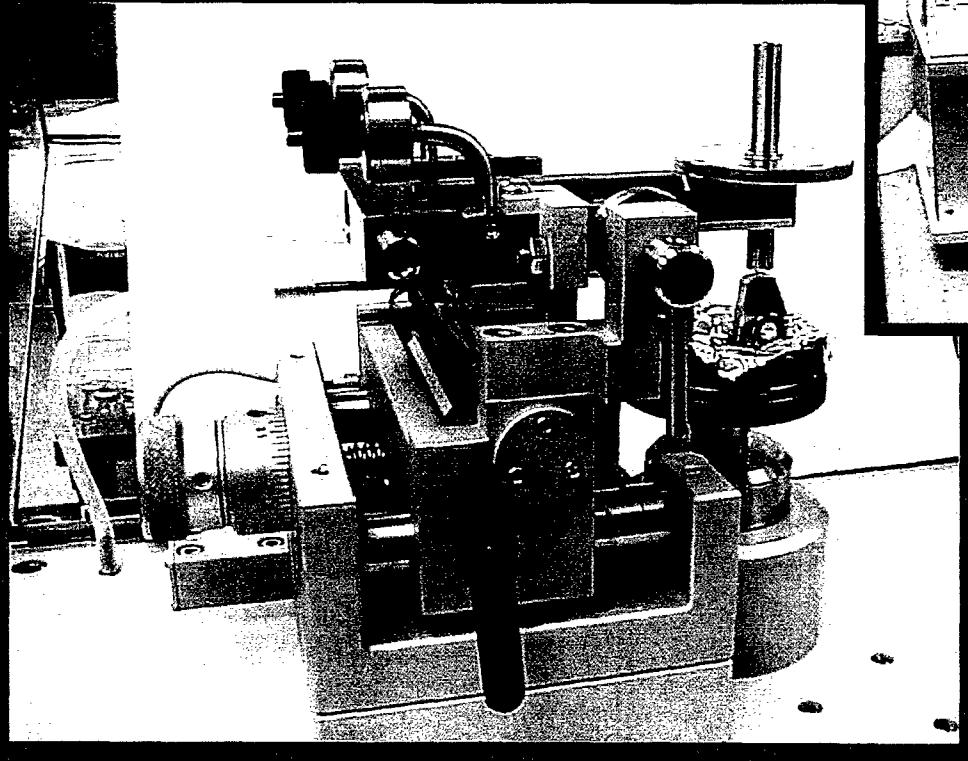
CS(E)M Pin-on-Disk Tribometer





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Experimental Details

- **Sputter-Deposition Thin Film Growth Parameters**
  - Upper and lower specimens are 440C steel
    - Cleaned before deposition/testing in Brulin 815GD/ Heptane
  - Thin film growth chamber base pressure: 1_10^{-9} Torr (1.33_10^{-7} Pa)
  - Simultaneous deposition of Au & MoS_2 using RF magnetrons
    - Au: 60-200W (0.7 - 2.0 W/cm^2) - partially unbalanced
    - MoS_2: 100-200W (1.2 - 2.0 W/cm^2)
  - Continuous stream of purified Ar (< 1 ppm H_2O, O_2, CO, etc.)
    - Chamber pumped continuously
    - During deposition, Ar pressure ≈ 3_10^{-3} Torr (0.4 Pa)
  - Substrate on rotating table during thin film deposition
- **Friction testing under 5 N load, 8 cm/s, 2000 m goal, in purified N_2**
  - High contact stress, 8mm ball on disk: S_m= 730 MPa (106 ksi)
  - Low contact stress, 0.8 diam flat on disk: S_m= ~0.1 MPa (15 psi)
    - Similar to contact stresses in slip ring/brush contacts
- **PHI 680 Nanoprobe with Ar ion gun: Pre-, Post-wear test analysis**

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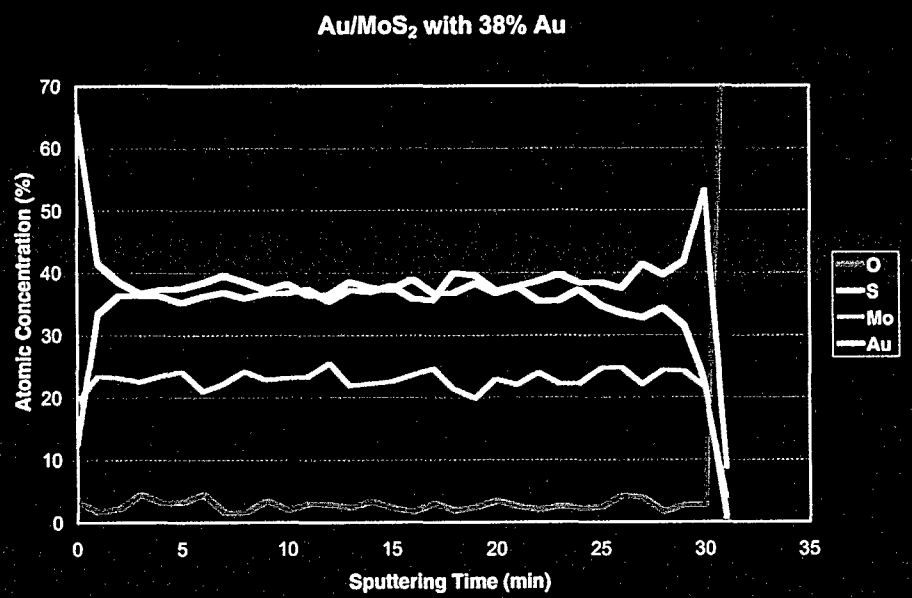
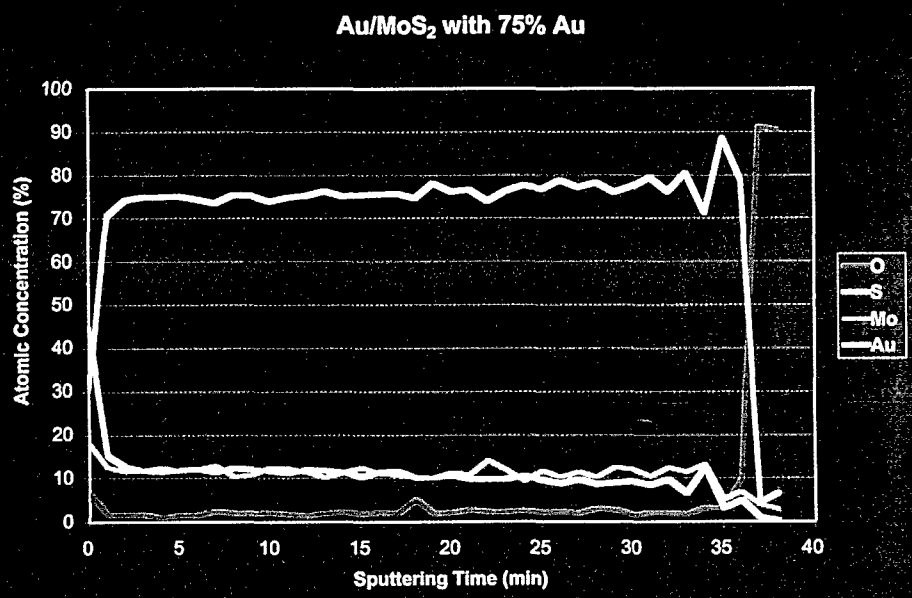
Auger Depth Profiles of Au-MoS_2 Films

38% Au/ 62% MoS_2



76% Au/ 24% MoS_2



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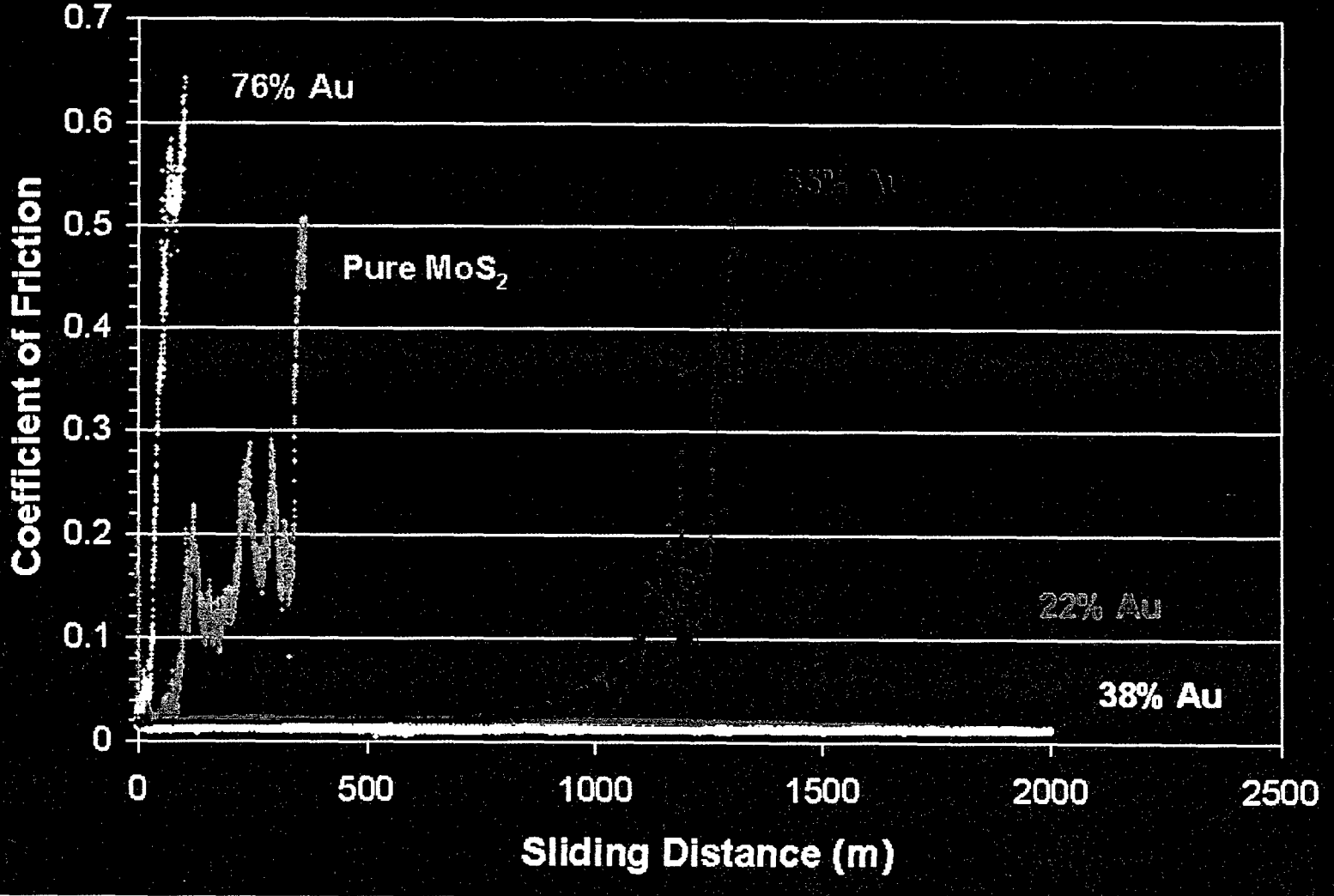
Friction of Au/MoS_2 Films Tested at High S_m



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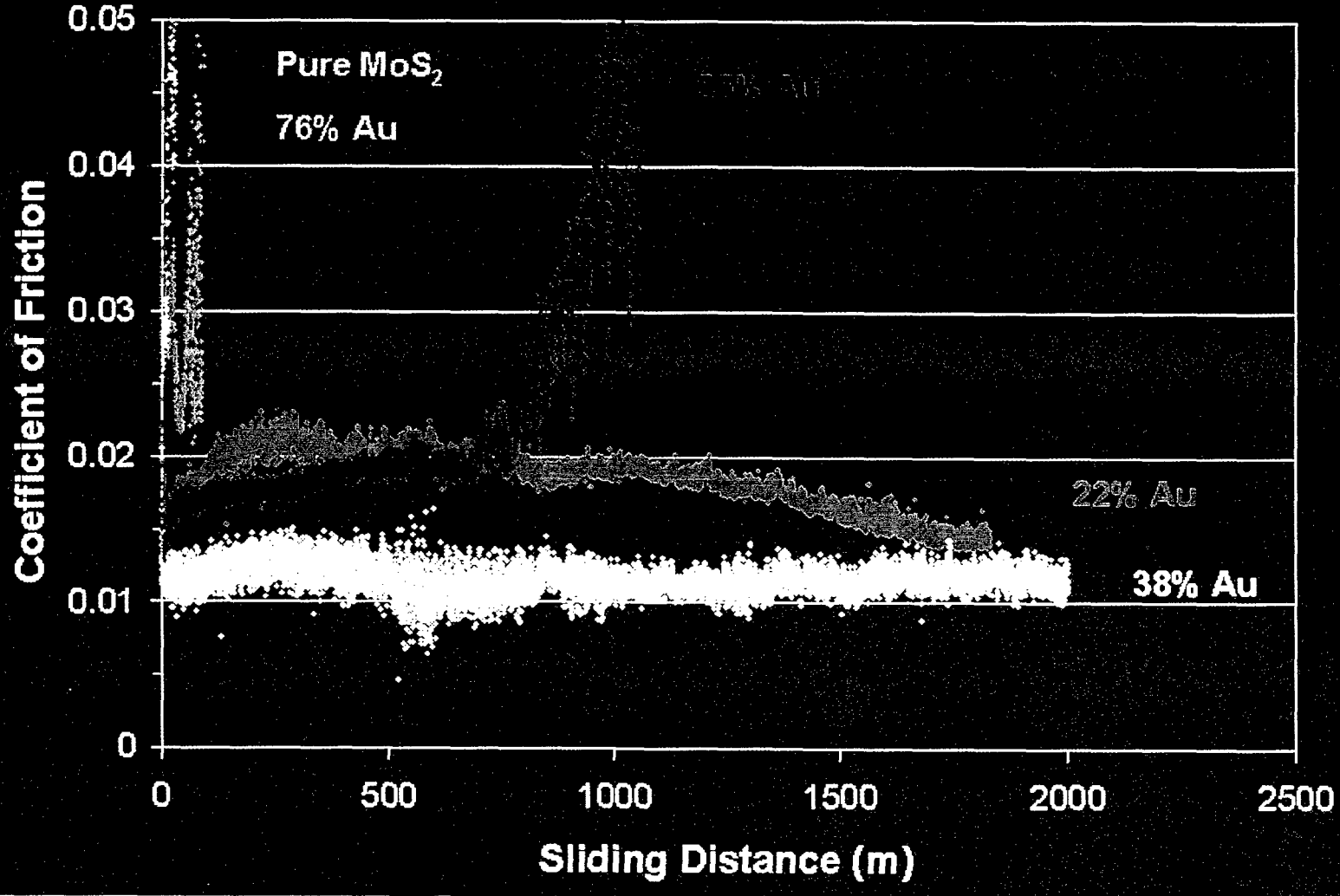
Friction of Au/MoS_2 Films Tested at High S_m



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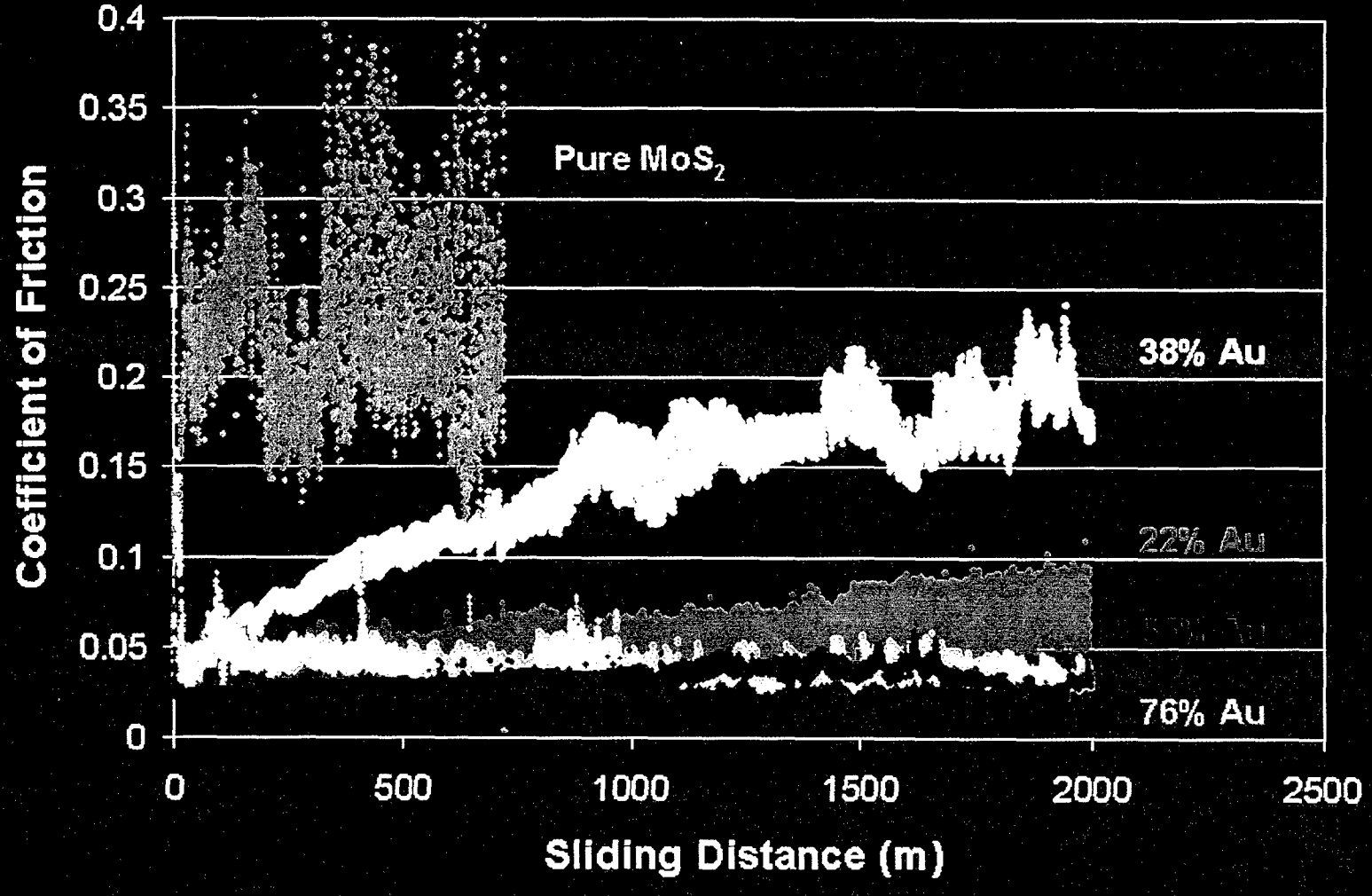
Friction of Au/MoS_2 Films Tested at Low S_m



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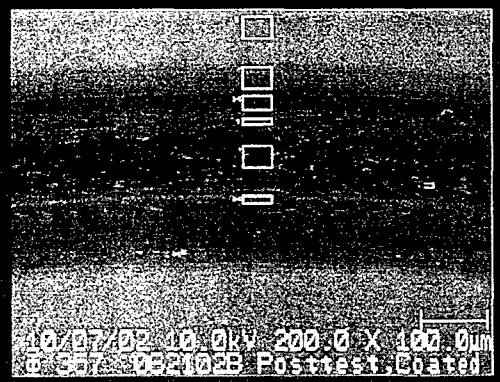
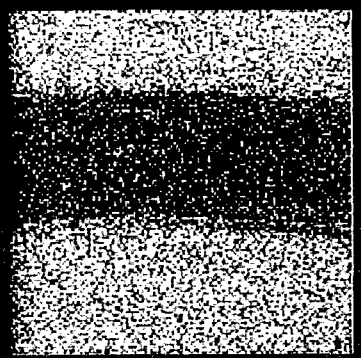
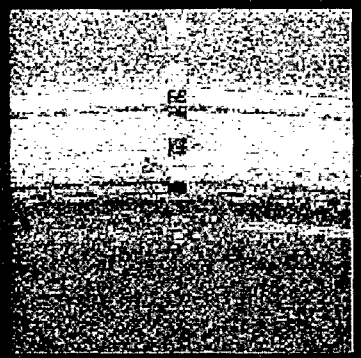
Auger Analysis in Wear Track of Au/MoS_2 Film (38% Au) after High S_m Test



SEM Image



Au Auger Map



S Auger Map

- Thin MoS_2 layer provides lubrication
- Underlying Au/MoS_2 film provides support (wear resistance)
- Detection of MoS_2 on surface of film is typical of Au/MoS_2 films prior to failure

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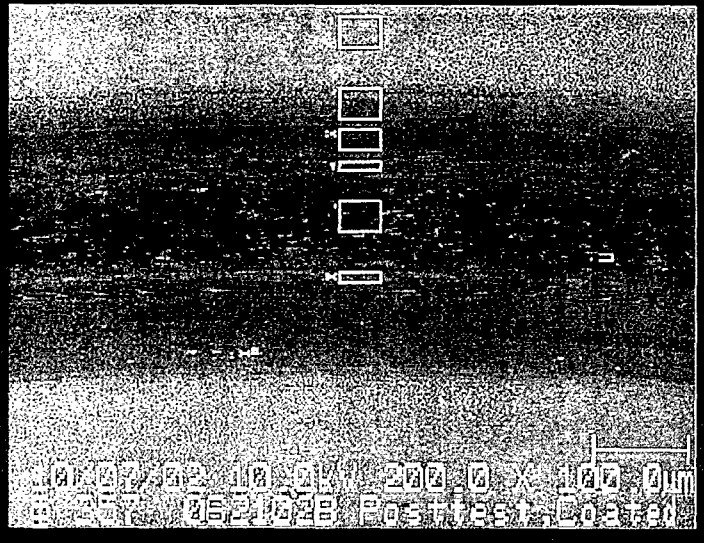
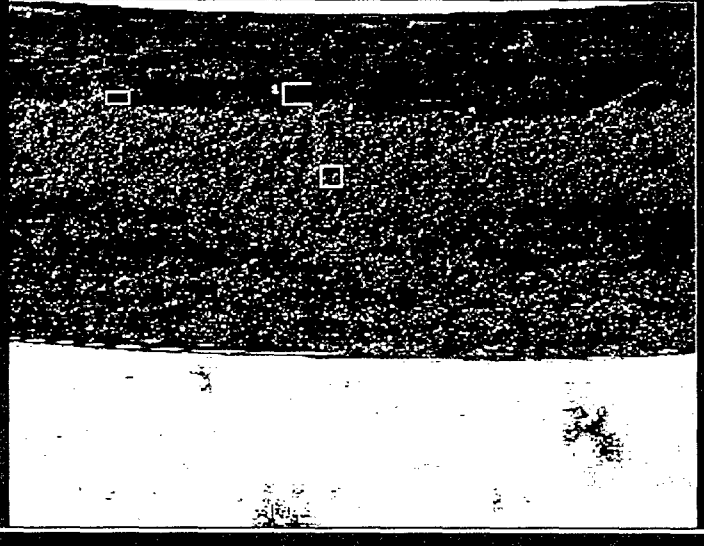
Wear Tracks on Au/MoS_2 Films after High S_m Tests



38% Au

- Mostly MoS_2 in track
- Small substrate peak seen only in track center
- Au detected only outside track



76% Au

- Little MoS_2 in track
- Substrate peak seen throughout track
- Au detected only outside track

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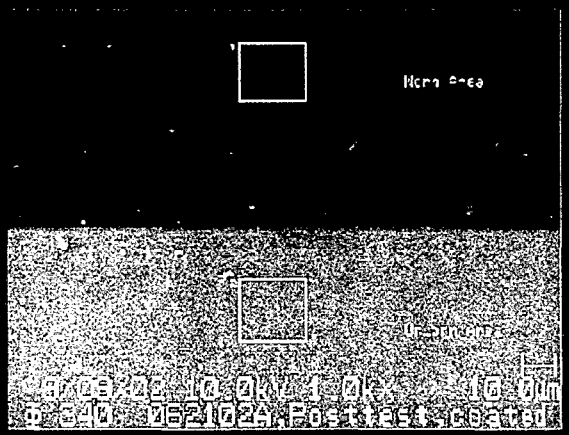
Auger Analysis in Wear Track of Au/MoS_2 Films after Low S_m Test

38% Au



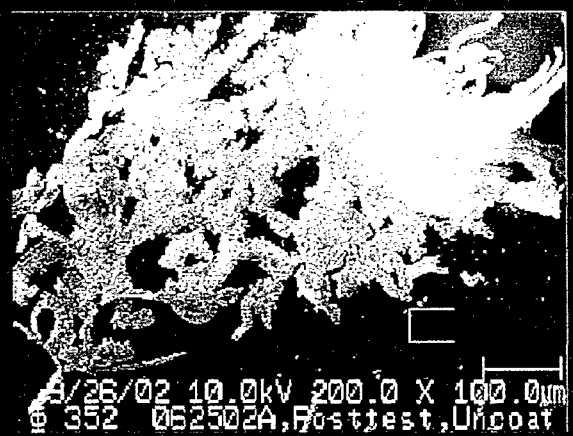
76% Au

Coated disks:

Auger shows significant MoS_2 remains in the contact region; little Au detected

Uncoated disks:

Auger shows that surfaces of transfer films on uncoated disks are mostly MoS_2



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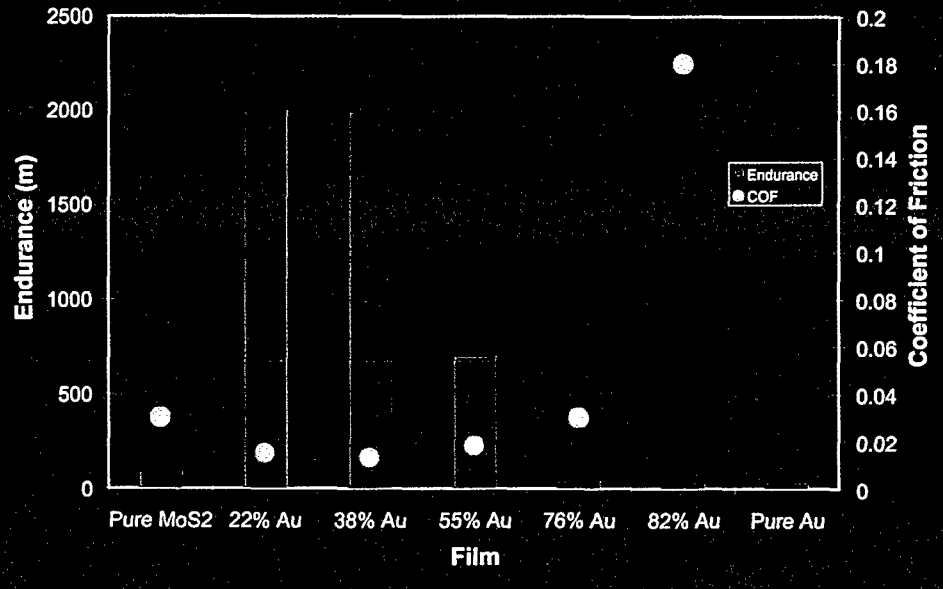
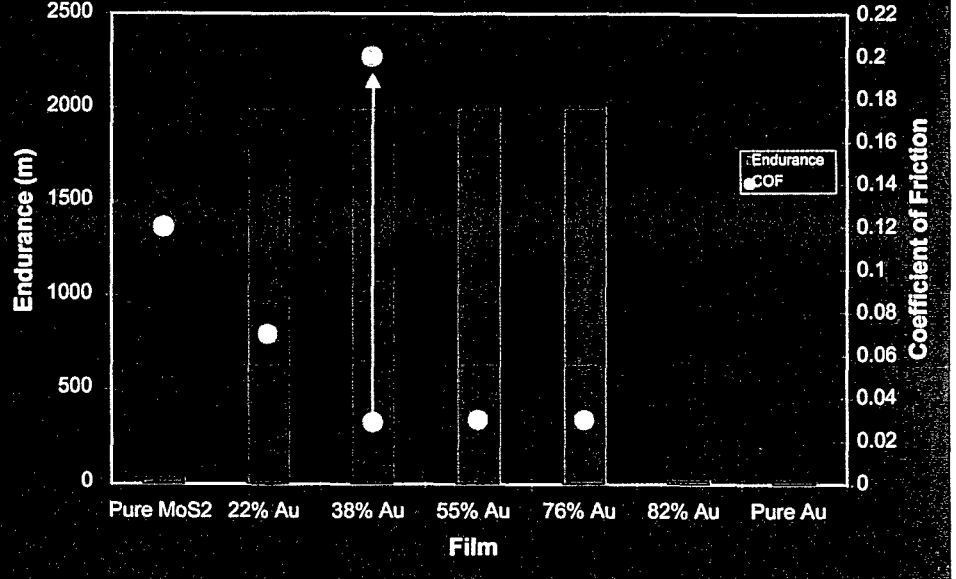
Summary of Friction/Endurance Testing

High Contact Stress



Low Contact Stress



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Discussion

- At high contact stress, sputter-deposited MoS_2-based films work best in conditions that:
  - Allow lubricating layer and transfer film that are *thin* and *uniform*
  - Subsurface (unworn) part of film is fracture-tough
- E.g., previous Aerospace studies varying gaseous test ambient
  - Oxygen improves transfer film formation
  - Water causes thick, uneven transfer film formation
- High contact stress; allows MoS_2 to shear
  - Low metal: dense, hard, fracture tough, environmentally stable films
  - High metal: soft films, high wear
  - No metal: high wear
- Low contact stress; does not allow MoS_2 to shear as readily
  - High metal: limits transfer of lubricant
  - Low or No metal: excessive lubricant transfer (wear)/ patchiness

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Summary

- Testing at *high* contact stress (S_m= 730 MPa or 106 ksi) up to 2000 m
  - Low friction (0.01 to 0.02) throughout test for films with 22%-38% Au
  - Low friction (0.02), but limited endurance for film with 55% Au
  - Low endurance for films with 76%-82% Au, pure Au, and pure MoS_2
- Testing at *low* contact stress (S_m= ~0.1 MPa or 15 psi) up to 2000 m
  - Lowest friction (0.03) for films with 55% and 76% Au
  - Higher (and increasing) friction (0.07 to 0.2) for films with 22%-38% Au
  - Rapid failure for film with 82% Au, pure Au , and pure MoS_2
- Post-test Auger nanoprobe: Interface lubricated by thin MoS_2 film
- Best low-S_m performance for high Au content → Best electrical conductivity
- Next studies: Nanohardness, Conductivity, Thickness of lubricating layer, Slip ring tests

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