Tribology of Composite Au-MoS$_2$ Films at Varying Contact Stresses

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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-MoS₂ films for such low contact stress applications. Higher contact stress pin-on-disk tests (Sm = 730 MPa) showed that low Au-MoS₂ 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 (Sm = 0.3 MPa) showed that higher Au-content films outperformed low Au-MoS₂ 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 MoS₂ 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.

**14. ABSTRACT**

**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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Outline

• Background
• Description of Apparatus
  – Multitarget rf magnetron sputter deposition system: Au, MoS₂
  – CS(E)M Tribometer; Purged with purified N₂
  – 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 MoS₂ 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, lubrious, adherent films could provide a boon for sliding electrical contacts in vacuum (and terrestrial?) environment
  – Slip Rings
  – Switches & Relays
  – Connectors

• Behavior of sputter-deposited MoS₂-based films at low contact stress not well-characterized: What parameters are important?
RF Sputter-Deposition System
CS(E)M Pin-on-Disk Tribometer
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 \times 10^{-9} Torr (1.33 \times 10^{-7} Pa)**
  - Simultaneous deposition of Au & MoS₂ using RF magnetrons
    - Au: 60-200W (0.7 - 2.0 W/cm²) - partially unbalanced
    - MoS₂: 100-200W (1.2 - 2.0 W/cm²)
  - Continuous stream of purified Ar (< 1 ppm H₂O, O₂, CO, etc.)
    - Chamber pumped continuously
    - During deposition, Ar pressure ≈ **3 \times 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 N₂**
  - High contact stress, 8mm ball on disk: **S_m = 730 MPa (106 ksi)**
  - Low contact stress, 0.8 diam flat on disk: **S_m = \sim 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**
Auger Depth Profiles of Au-MoS$_2$ Films

38% Au/ 62% MoS$_2$

Au/MoS$_2$ with 38% Au

76% Au/ 24% MoS$_2$

Au/MoS$_2$ with 75% Au
Friction of Au/MoS$_2$ Films
Tested at High $S_m$
Friction of Au/MoS$_2$ Films
Tested at High $S_m$
Friction of Au/MoS$_2$ Films
Tested at Low $S_m$
Auger Analysis in Wear Track of Au/MoS$_2$ Film (38% Au) after High $S_m$ Test

- 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
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
Auger Analysis in Wear Track of Au/MoS$_2$ Films after Low $S_m$ Test

38% 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$_2$
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
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 ($S_m \approx 0.1$ 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
LABORATORY OPERATIONS

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