Tribology Focus Topic
Room: Tesuque - Session TR+MN+NS+SS-WeM

Influence of Atmosphere, Temperature, and Materials on Friction
Moderator: J.D. Schall, Oakland University

8:00am **TR+MN+NS+SS-WeM1 'Demystifying' Gas Phase Lubrication: Tribochemistry, Third Bodies and Competition**, ***I.L. Singer***, Naval Research Laboratory **INVITED**

Gas phase lubrication, also called vapor phase lubrication, refers to processes in which the gas surrounding a sliding (or rolling) contact contributes to lubrication [1]. It has wide ranging applications from internal combustion engines to MEMS. Some gases simply condense on surfaces, others decompose and deposit lubricating films on the surface, e.g, hydrocarbon films decompose and deposit graphite. Some can be made to react *on* the surface, as do various monomers that tribopolymerize and form lubricious third bodies at the contact. Alternatively, gases can react *with* the surface to form films; the most ubiquitous example is the oxide film formed on metals, which prevents (on earth, but not in outer space) surfaces from weld upon contact. Reaction films have been studied extensively by surface scientists; less well understood are tribofilms, films formed by rubbing action. Another important component to the lubrication process is film removal, which can occur during sliding or rolling; the competition between film formation and film removal always needs to be considered. In some cases, gas lubrication provides low friction and low wear; in other cases, it can increase friction and wear. In this talk, I will review gas phase lubrication processes and present several gas phase lubrication studies that still mystify me.

[1] For overview, see http://nsfafresh.org/wiki/index.php?title=Gas_Phase_Lubrication

8:40am **TR+MN+NS+SS-WeM3 Understanding Vapor Phase Lubrication Mechanism of Alcohol for MEMS and Other Materials**, ***S.H. Kim***, Pennsylvania State University

Microelectromechanical systems (MEMS) are usually fabricated from silicon-based materials which have poor tribological properties such as high friction, high adhesion, and low wear-resistance. We have recently demonstrated unprecedented success of MEML lubrication using alcohol vapor. The main difference of alcohol vapor phase lubrication (VPL) from other coating-based approaches is that it allows continuous replenishment of lubricant molecules from the vapor phase, rather than relying on one-time loaded coating layers. In our precious studies, we have observed tribochemically-formed polymeric species. Then, an interesting question is if the polymeric species is responsible for effective lubrication or not. This talk addresses the origin of tribochemical reaction products and the lubrication mechanism for alcohol VPL for silicon oxide surfaces. In summary, the tribochemical polymerization appears to be associated with the substrate wear process occurring due to insufficient adsorbate supply or high mechanical load. The tribochemical reactions do not seem to be the primary lubrication mechanism for vapor phase lubrication of SiO_2 surfaces with alcohol, although they may lubricate the substrate momentarily upon failure of the alcohol vapor delivery to the sliding contact.

9:00am **TR+MN+NS+SS-WeM4 Mechanistic Aspects of Vapor Phase Lubrication of Silicon**, ***M.T. Dugger***, *J.A. Ohlhausen, S.M. Dirk*, Sandia National Laboratories

9:20am **TR+MN+NS+SS-WeM5 Tribological Study of Octadecylphosphonic Acid Self-Assembled Monolayers Across Velocity Regimes**, *O. Matthews, S. Barkley*, Luther College, *C. Bouxsein, M. Deram, N. Eigenfeld*, St. Olaf College, *A. Poda, W.R. Ashurst*, Auburn University, *B. Borovsky*, St. Olaf College, ***E. Flater***, Luther College

Microelectromechanical systems (MEMS) are critically-limited by interfacial phenomena such as friction and adhesion. The most common method of reducing friction between MEMS surfaces is the use of molecularly-thin self-assembled monolayer (SAM) coatings. Typically silicon MEMS have been coated with silane-based SAMs, such as octadecyltrichlorosilane (OTS), and have resulted in some modest improvement in device performance and lifetime. Continued progress in the development of MEMS may require new materials systems to be implemented. Through a collaborative effort, we investigate the frictional properties of octadecylphosphonic acid monolayers deposited on aluminum oxide surfaces across speed regimes. Measurements using an atomic force microscope (AFM) and a nanoindenter-quartz crystal microbalance are performed each with a microsphere-terminated probe. This allows for a comparative study with similar contact sizes, pressures, surface roughness, and interfacial chemistry. Speeds between the different instruments range from microns per second to meters per second. Preliminary AFM friction vs. load and friction vs. velocity measurements are presented, with the goal of investigating phosphonate SAM/ metal oxide systems as alternative MEMS materials.

9:40am **TR+MN+NS+SS-WeM6 Triboelectrification and Triboplasma Generation and its Application for Surface Modification**, ***S.V. Singh***, *P.K. Michelsen, Y. Kusano*, Technical University of Denmark

Triboplasma gas discharges are often induced by triboelectrification around a sliding contact. Only an empirical classification is available for triboelectrification, whereas a detailed physical mechanism behind it is still unknown. Laboratory triboplasmas are mostly characterized by using optical diagnostics, and the optical emissions are reported to be observed mostly in ultraviolet region, corresponding to nitrogen emission lines. These measurements do not directly address triboelectrification. Here we present the evidence of electrostatic charging at the sliding contact and gas break down between the contacts through electrical measurements. Furthermore, the applicability of triboplasma for surface modification on polymeric materials was studied. Two capacitive probes were used for the investigation of a triboelectrification and triboplasma generated in a pin-on-rotating disk apparatus. These probes were mounted above the disk and on the pin, respectively. Measurements show a clear evidence of tribocharging, charge decay and triboplasma generation. Several combination of sliding contact materials with tendency to gain opposite charging and different sliding speeds, as high as 1000 rotation per minute, were carefully chosen. In addition, influence of different gas environment and pressure were investigated. Triboplasma induced surface modifications were characterized by water contact angle and X-ray photoelectron spectroscopy measurements.

10:40am **TR+MN+NS+SS-WeM9 Friction at Cryogenic Temperatures**, ***S.S. Perry***, University of Florida **INVITED**

There are a number of applications where operation over a wide temperature range is required for device success. These extreme conditions are often the motivation for variable temperature studies in tribology; however, a paucity of relevant tribology data exists for temperatures below 273 K.

In the range from 300 K to 100 K the friction coefficient of various solid lubricants has recently been shown to increase with decreasing temperature. Molecular scale measurements employing an atomic force microscope over a temperature range from 140 K to 750 K at a vacuum level of $2x10^{-10}$ torr have identified a temperature activated behavior of the friction and friction coefficient for the solid lubricants graphite and molybdenum disulfide. These molecular scale experiments were performed under conditions for which interfacial sliding was confirmed, interfacial wear was absent, and the role of adsorbed contaminants could be dismissed.

The potential influence of interfacial wear as well as the mechanism underlying the measured temperature dependence will be discussed.

11:20am **TR+MN+NS+SS-WeM11 *In-Situ* Scanning Auger Analysis of a Tribological Wear Scar in UHV Conditions**, ***B.P. Miller***, *O.J. Furlong, W.T. Tysoe*, University of Wisconsin-Milwaukee

Lubrication of sliding copper-copper interfaces for use in brushes in electrical motors provides a particular challenge. Not only is a reduction in friction and wear required, but also allowing for high conductivity through the contact. Therefore, a self-limiting tribofilm is essential. The following explores the surface chemistry and tribology of dimethyl disulfide (DMDS) on copper surfaces to establish whether it is sufficiently reactive to potentially form a tribofilm near room temperature as required for lubrication of the sliding copper-copper contact in an electric motor. The surface chemistry and decomposition pathways of DMDS on copper surfaces are analyzed using temperature-programmed desorption (TPD), reflection-absorption infrared spectroscopy (RAIRS) and X-ray photoelectron spectroscopy (XPS). It is shown that DMDS reacts to form methyl thiolate species on the copper surface at room temperature. After heating to about 430K, methane and C_2 hydrocarbons desorb leaving molecular sulfur adsorbed onto the surface. A UHV tribometer chamber was equipped with a scanning electron gun having a ~100 micron diameter spot size. DMDS was dosed in the gas phase while performing friction measurements so that *in-situ* elemental analysis of the wear scar could be made. An increase in the sulfur signal is witnessed inside compared to outside of the tribological wear scar. A depth profile Auger analysis of the sample showed selective diffusion of sulfur into the bulk only inside the wear scar attributed to tribologically induced effects. This novel method of analysis can give important insights into the fundamentals of tribological systems.

11:40am **TR+MN+NS+SS-WeM12 First Principles Calculations and Atomistic Simulations of Tribology at Sliding Molybdenum Disulfide Surfaces**, *T. Liang, S.R. Phillpot, **S.B. Sinnott***, University of Florida

Molybdenum disulphide is the most commonly used solid lubricant coating in aerospace applications. In this work, we carry out first principles density functional theory (DFT) calculations of the potential energy surface between two MoS_2 surfaces and examine the influence of oxidation on the results. In addition, we present the results of a recently developed empirical many-body potential for Mo and S systems and examine nano-scale friction between sliding MoS_2 surfaces using classical molecular dynamics (MD) simulations. In particular, MD simulations of interfacial sliding at various loads, temperatures and sliding directions are carried out. The loads and friction forces are extracted to calculate the friction coefficient of the MoS_2 as a function of temperature, and the results are compared to experimental pin-on-disk measurements of MoS_2 coatings and atomic force microscopy measurements on single crystal MoS_2 surfaces. The results from both the DFT calculations and the MD simulations help us to better understand the origins of lubricity on MoS_2.

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