Tribology

Room: 617 - Session TR1+MN-WeA

Surfaces and Interfaces in MEMS

Moderator: J.A. Harrison, United States Naval Academy

1:40pm **TR1+MN-WeA1 Glassy-like Behavior of GaAs Nanomechanical Oscillators at Millikelvin Temperatures**, ***S.B. Shim***, *S.W. Cho*, Seoul National University, Korea, *N. Kim*, *J. Kim*, Korea Research Institute of Standards and Science, *Y.D. Park*, Seoul National University, Korea

We report on the mechanical properties of single crystalline GaAs doubly-clamped beam resonator structures characterized by magnetomotive techniques in millikelvin temperatures. Clean nanomechanical GaAs resonators are realized from a lattice-matched GaAs/InGaP/GaAs heterostructures without plasma etching processing with typical quality (Q) factor of ~ 17,400 at 45 mK with resonance frequency of 15.816 MHz. We find dissipation (Q^{-1}) to have weak temperature dependence ($\sim T^{0.32}$) as compared to Si nanomechanical resonators of similar size ($\sim T^{0.36}$).[1] Furthermore, we find shift in the resonance frequency as function of temperature to be nontrivial with a crossover behavior (i.e. at low temperatures shift in the resonance frequency is positive with increasing temperature and at high temperature (T > ~1 K), negative). Such observations are similar to those observed in sound attenuation experiments in disordered glass systems.[2] We will also discuss other possible dissipation mechanisms as well as the effect of differing surface conditions and treatments.

[1]G. Zolfagharkhani et al., PRB 72, (2005).
[2]W.A. Phillips, Rep. Prog. Phys. 50, 1657 (1987).

2:00pm **TR1+MN-WeA2 MEMS Tribology in Extreme Environments[1]**, ***J. Krim***, North Carolina State Univ., *M. Aggleton*, Univ. of California at Irvine, *C.J. Brown*, North Carolina State Univ., *J.C. Burton*, Univ. of California at Irvine, *D.A. Hook*, North Carolina State Univ., *J. Wenner*, Univ. of California at Irvine, *M.T. Dugger*, Sandia National Labs, *A. Morris*, WiSpry, Inc., *J.E. Rutledge, P. Taborek*, Univ. of California at Irvine **INVITED**

Microelectromechanical systems, MEMS, have become a remarkably successful technology since the beginnings of MEMS development 30 to 40 years ago. However the overwhelming majority of MEMS are used near room temperature and atmospheric pressure. Consequently there is little empirical data to guide the design of MEMS for use in environments such as space where low pressures and cryogenic temperatures must be tolerated. In addition, it is well known that friction and wear severely constrain MEMS design. MEMS that have sliding contact between surfaces have shorter lifetimes and lower reliability than MEMS that do not. We have measured the characteristics of two microelectromechanical systems, namely a silicon sidewall tribometer and an RF MEMS direct contact switch, at cryogenic temperatures and in ambient gas environments below atmospheric pressure, and report on the tribological issues and possible solutions for operation of MEMS in such extreme environments.

[1] This work has been supported by EXTREME FRICTION AFOSR MURI #FA9550-04-1- 0381, and partially by Sandia National Laboratories. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE- AC04-94AL85000.

2:40pm **TR1+MN-WeA4 Performance of RF MEMS Switch Contacts at Cryogenic Temperatures**, ***C.J. Brown***, *J. Krim*, North Carolina State University, *A.S. Morris III*, wiSpry, Inc.

A series of experiments were performed to characterize RF MEMS switch performance under variable pressure, atmospheric conditions and temperature. A vacuum system was constructed allowing for switch operation in cryogenic temperatures and pressures in the miliTorr range. Vacuum environments were chosen to limit stiction failures due to moisture; however the switches encountered bouncing problems at closure for low pressures. Helium and nitrogen were chosen as substitute atmospheres to lower stiction failure rates while circumventing switch bouncing issues. Contact resistance measurements were taken across a temperature range of 77 to 293 Kelvin using both gasses. Results showed no differences in contact resistance due to atmospheric conditions except at cryogenic temperatures. Contact resistance values were observed to be lower at cryogenic temperatures but are orders of magnitude higher than values predicted for constriction resistance in gold asperity contacts. Results obtained across the cryogenic temperature range support the conclusions of previously published work at high temperatures, which asserted changes in contact resistance were due mostly to the presence of thin films on the contacts.[1] Additionally, the data indicates these films are less mobile at cryogenic temperatures. Application of the asperity-heating model indicates contact voltages can applied which selectively disassociate films from the contact surface while not softening the gold asperity contacts. This research is funded by AFOSR MURI Grant No. FA9550-04-1-0381.

[1] B. Jensen, L. Chow, K. Huang, K. Saitou, J. Volakis and K. Kurabayashi, "Effect of nanoscale heating on electrical transport in RF MEMS switch contacts," J. Microelectromechanical Systems, vol. 14, no. 5, pp. 935-946, 2005.

3:00pm **TR1+MN-WeA5 Macro-, Micro-, and Nano-scale Lubrication using Alcohol Vapor: Implications to MEMS.**, *D.B. Asay*, Pennsylvania State University, *M.T. Dugger*, Sandia National Laboratories, ***S.H. Kim***, Pennsylvania State University

Friction, adhesion, and wear are dramatically affected by the environment in which surfaces come into contact. In the case of an alcohol vapor environment, the silicon surface reacts to form an alkoxide. Shearing these surfaces also produces higher weight oligomers. These molecules are continuously replenished in the contact region, drastically reducing wear and friction provided that the alcohol vapor pressure is near or above the vapor pressure required for monolayer coverage. At these conditions, the lubricating layer protects the silicon surfaces with little to no wear observed. Tribological properties are reported at the nanoscopic (AFM), mesoscopic (MEMS), and macroscopic (tribometer). In all cases, the vapor successfully lubricates and minimizes wear. In the case of MEMS sidewall friction, the lifetime of the device is radically increased.

4:00pm **TR1+MN-WeA8 MEMS Reliability in Harsh Environments**, ***R. Maboudian***, *C. Carraro*, University of California at Berkeley **INVITED**

Many applications require sensors and actuators that can survive harsh environments, including high temperature and high relative humidity. This presentation will examine the behavior of polycrystalline silicon based micro-electromechanical systems in a variety of harsh environments. Then, the effectiveness of self-assembled monolayers and silicon carbide for enhanced MEMS reliability under these conditions will be discussed.

4:40pm **TR1+MN-WeA10 Water Vapor Effects on the Lubrication of Silicon MEMS by Alcohol Vapor**, ***M.T. Dugger***, Sandia National Laboratories, *D.B. Asay*, Pennsylvania State University, *J.A. Ohlhausen*, Sandia National Laboratories, *S.H. Kim*, Pennsylvania State University

Adhesion, friction and wear have been the greatest limitations to development of robust MicroElectromechanical Systems (MEMS) that rely on contact between surfaces. Chemisorbed monolayers such as alkyl and amino-silanes have been successful in creating initially-free structures, but have not demonstrated adequate long duration operation in sliding contacts, and recent studies suggest that they degrade with long term static exposure to water vapor in storage. A new lubrication approach has been demonstrated on silicon surfaces, which consists of alcohol molecules in the vapor phase that form a friction and wear reducing film dynamically, preferentially at contact locations. ToF-SIMS analysis of wear tracks from pin-on-disk experiments suggest formation of high molecular weight oligomers where the stress is highest. Experiments with MEMS tribometers result in a factor of at least 10^5 increase in operation life without failure, and no wear or debris formation. Practical device operation requires lubrication in the presence of some concentration of water vapor inside sealed packages. Friction experiments in environments containing 400 ppm alcohol and 1000 ppm H_2O show that lubrication by alcohol is inhibited at these relative concentrations.

[*]Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

5:00pm **TR1+MN-WeA11 Monolayer Degradation and Sidewall Tribometer Studies of Vapor Phase Lubricants for MEMS**, ***D.A. Hook***, Sandia National Laboratiories, North Carolina State University, *S.J. Timpe*, Sandia National Laboratiories, University of California Berkeley, *M.T. Dugger*, Sandia National Laboratories, *J. Krim*, North Carolina State University

Long hydrocarbon and fluorocarbon-based monolayers have been widely used in MEMS applications to prevent release related stiction as well as adhesion as devices are stored for long periods of time.[1] It has also been observed that the presence of these monolayers lowers the coefficient of friction in tribological contact. However these same contacts cause rapid degradation of these monolayers.[2] The loss of the monolayers contributes to an increase in the adhesive contact force and leads directly to device failure whether it be unpredictable operation of the device or complete cessation of movement. This study reports on degradation of (tridecafluoro-1,1,2,2-tetrahydrooctyl)tris(dimethylamino)-silane (FOTAS) monolayers on normal as well as sliding contacts in MEMS interfaces. The degradation of the monolayer in the normal loading case was probed by measuring the change in adhesive force of the contact over the course of 300,000 normal loading cycles. In the sliding experiment a decrease in oscillation amplitude was used to probe the status of the monolayer. The onset of monolayer degradation was observed in the normal contacting experiment after approximately 80,000 normal contacting cycles, while in the case of sliding degradation was observed almost instantaneously. Work funded by the AFOSR Extreme Friction MURI and Sandia National Labs MESA Project. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

[1]Srinivasan, U., Houston, M.R., Howe, R.T., Maboudian, R., "Alkyltrichlorosilane-Based Self-assembled Monolayer Films for Stiction Reduction in Silicon Micromachines", Journal of Microelectromechanical Systems 1998, 7, 252-260.

[2]DePalma, V., Tillman, N., "Friction and Wear of Self-Assembled Trichlorosilane Monolayer Films on Silicon", Langmuir 1989, 5, 868-872.

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