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VAPOR PHASE LUBRICATION OF GOLD/GOLD INTERFACES

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ABSTRACT

The extension of current micro-satellite development efforts calls for a reduction in size by up to two orders of magnitude. Such a reduction in size necessitates the development of novel actuators, switches, and sensors operating on the micron length scale. The leading technology for creating such devices involves microfabrication processes currently used in the production of integrated circuits. Devices generated by these means are referred to as Micro-Electro-Mechanical Systems (MEMS). While many challenges remain in the design and production of MEMS, a critical aspect of their successful deployment involves lubrication of the devices to prevent wear and permanent, undesired adhesion (seizure) of the miniature moving parts. Results from research addressing the vapor phase lubrication of gold-gold contacts, modeling interfaces expected to be encountered in future RF MEMS devices, will be presented. Such interfaces will require high frequency intermittent contact, the absence of irreversible interfacial adhesion, the general absence of sliding within the contact, and the requirement of electrical conductivity upon contact. Work in this area has focused on the use of alklythiols as a means of controlling interfacial adhesion. Experiments have been carried out using atomic force microscopy to characterize adhesion as a function of alkylthiol chain length. In addition, these experiments have incorporated the simultaneous measurement of interfacial currents to explore load versus conductivity relationships. These measurements have been supported through measurements of surface composition through correlated quartz crystal microbalance (QCM) and X-ray photoelectron spectroscopy (XPS) measurements.

INTRODUCTION

There have been a number of methods to lubricate MEMS devices proposed and tested and several review articles have been published describing these efforts.[1,2] There are two complicating factors that differentiate the lubrication of MEMS from other tribological systems. (1) The choice of materials (substrates and coatings) is restricted by the necessity of incorporating materials directly into the microlithography process or depositing the lubricious material by techniques not requiring line of sight. (2) The length scales or dimensions of the device components are sufficiently small that capillary forces prevent the use of liquid lubricants. An additional aspect of MEMS tribology involves the wide range of potential devices and the conditions under which they will operate (load, speed, duration, etc). For RM MEMS devices, electrical conductivity between contacting surfaces is also required and presents a significant challenge with respect the management of tribological issues.

Recent investigations have aimed to establish the correlation between molecular order and density in the leading tribological candidate system entailing self-assembly of alkane chains. While there is widespread discussion of such an approach, little effort has been made to establish detailed protocols for the procedure. In the absence of such efforts, wide variability in performance is to be expected. Attention is now being turned to potential solutions for vapor phase lubrication of MEMS-based RF switches

The intent of the research described here has been to develop a fundamental understanding of the merits and detriments of vapor phase lubrication of RF MEMS devices that involve intermittent electrical contacts. Specifically, this work has sought to establish the correlation between adhesion and contact resistance as function of interfacial film thickness and composition of monolayers deposited at gold-gold contacts.

RESULTS AND DISCUSSION

The experimental approach for characterizing the effectiveness of vapor phase lubrication schemes entails the correlated measurement of surface chemical composition and interfacial friction and adhesion. In order to insure relevance to MEMs applications, the measurements have been conducted on the micron scale with atomic force microscopy (AFM).

Microscopy experiments have entailed the simultaneous mesurement of adhesion and current as a function of the uptake from the gas phase of alkanethiols to gold surfaces. These surfaces have been comprised of thin gold films deposited on Si(100) substrates and gold coated microspheres (5.1 micron diameter) attached to the end of Si_3N_4 AFM cantilevers. Namely, these experiments have sought to determine the relevant molecular details of the optimal vapor phase lubricant. For example, alkanethiols possessing long alkane chain lengths are known to form well-packed monolayers on flat gold thus producing lower interfacial adhesion, but also possess significantly lower vapor pressure than shorter chain thiols. In addition, the longer chain length will introduce complications to interfacial conductivity required in RF MEMS. An example of the influence of chain length on interfacial adhesion for the contact of a Si_3N_4 tip and solution deposited alkanethiols on a gold flat are shown in Figure 1 and illustrates the desirable benefit of longer chains with respect to adhesion.

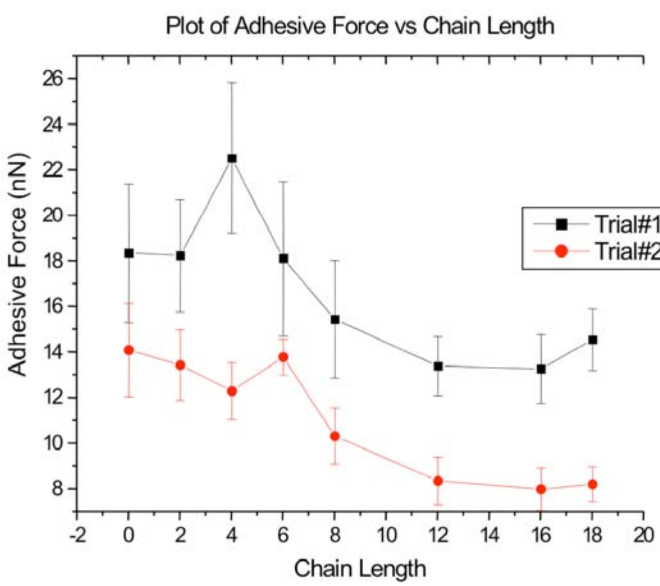

Figure 1. Measurements of interfacial adhesion as a function of chain length for alkanethiols deposited from ethanol solutions on gold. A zero chain length represents the adhesion experienced for a bare interface.

A second issue with respect to vapor phase lubrication entails the delivery of lubricant to the interface. We have employed QCM measurements to determine the mass uptake on gold surfaces as a function alkanethiol chain length. In these measurements, a helium carrier gas has been bubbled through hexane solutions of the different alkanethiol at a flow rate of 2 cc/min. Representative data of the uptake of ethanethiol is shown in Figure 2, illustrating the relatively rapid uptake of the vapor phase lubricant as well as the saturation of the interfacial film. Following these measurements, surfaces were subjected to XPS measurements to determine the relative thickness of the interfacial films, and in turn allowing determinations of film densities.

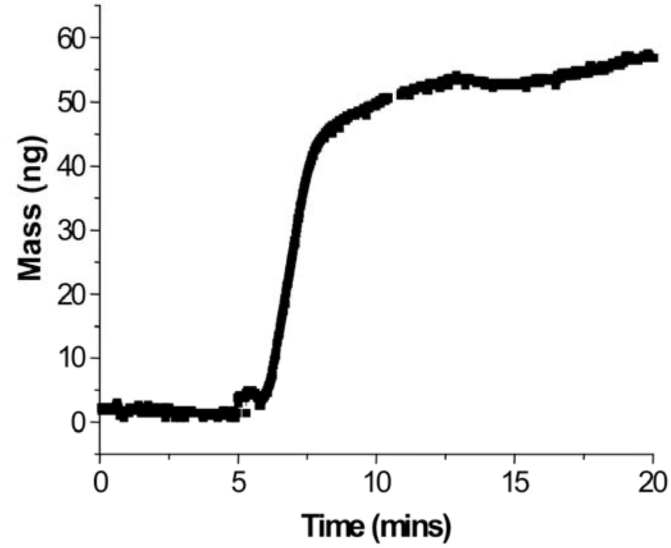

Figure 2. QCM measurements of the mass uptake on a gold electrode from a gas phase flux of ethanethiol in a helium carrier gas. The 5 min mark represents the switching point from pure to helium to the gas mixture.

Additional results will be presented from concurrent AFM measurements of interfacial adhesion and current as a function of the uptake (time dependent) of alkanethiols of varying chain length. These experiments have been enabled through the incorporation of a gas flow cell into the AFM setup.

ACKNOWLEDGMENTS

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