AFRL-SR-BL-TR-99-

0097

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 28, 1999	Final Technical Report (1/15/95 - 11/30/98)

4. TITLE AND SUBTITLE
Vapor-Phase Lubricants: Nanometer-Scale Mechanisms and Applications to Sub-micron and Rotating Machinery.

5. FUNDING NUMBERS
AFOSR # F49620-95-1-0201

6. AUTHOR(S)
Jacqueline Krim, P.I.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Northeastern University, Department of Physics, Boston, MA 02115

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Hugh C. De Long, Program Manager
Air Force Office of Scientific Research
AFOSR/NL
801 North Randolph St., Room 732
Arlington, VA 22203-1977

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 Words)***

Vapor-phase lubricants: Nanometer-scale mechanisms and applications to sub-micron and rotating machinery *was the beginning segment of a new program supported by AFOSR involving a set of experiments seeking to explore the molecular-scale properties of vapor-phase lubricants in well-defined contact geometries. During the 10.5 month grant period, two ultra-high vacuum chambers were customized for the specific proposed studies, and all personnel involved were trained in Ultra-High Vacuum (UHV) and quartz microbalance techniques. The construction and training period is now complete, and a series of measurements have been performed. These include measurements of the uptake rate of the lubricant TBPP on Fe as a function of temperature, and a series of measurements of the nanomechanical properties of a number of potential lubricants for Micro-Electro-Mechanical Systems (MEMS) applications by means of a combined quartz microbalance/scanning tunneling microscopy technique.*

19990401 056

14. SUBJECT TERMS

UMBER OF PAGES: 7,
ding cover page

RICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

(1) Final Technical Report:

VAPOR-PHASE LUBRICANTS: NANOMETER-SCALE MECHANISMS AND APPLICATIONS TO SUB-MICRON AND ROTATING MACHINERY

AFOSR grant # F49620-98-1-0201 **Reporting Period: 1/15/98 – 11/30/98**

PI: Jacqueline Krim, Northeastern University *
PI Address: Physics Dept., Northeastern University, Boston, MA 02115

**Present address: Physics Department, Box 8202, North Carolina State University, Raleigh, NC 27695-8202*

(2) **Objectives.** A set of experimental studies involving vapor-phase lubricants in controlled environmental conditions and well-defined contact geometries have been performed. The goal of the first proposed study was to verify and quantify at nanometer length scales the fundamental mechanisms which are believed to underlie the lubricating properties of TBPP/iron, a system which is of current interest to the Air Force on account of its potential for lubricating in extreme temperature environments. In particular, Auger Spectroscopy, Quartz Crystal Microbalance and Scanning Tunneling Microscopy measurements are being performed on the lubricant, as well as a number of control systems, at various stages of the lubricant's formation on a pure iron surface. A second proposed study involves characterization of the nanotribological behaviors of ethylene/Pt, and TBPP/Fe in a simple nanomechanical system consisting of a scanning tunneling microscopy tip sliding along the surface electrode of a quartz crystal microbalance.

(3) **Status of Effort.** The reporting period covers 10.5 months of work performed at Northeastern University (the work has been continued by the P.I. at North Carolina State University). During this period, we customized two ultra-high vacuum chambers for the specific studies to be performed. These included adaptations of an existing chamber for transfer of the sample to a newly purchased ultra-high vacuum scanning tunneling microscope, and adaptations associated with the high temperature operation of a quartz microbalance. As a newly initiated grant, with new personnel, the beginning months were also dedicated to training of the new group members in ultra-high vacuum techniques and the operation and construction of quartz crystal microbalances in ultra-high vacuum environments. This phase is now comple, and the new ultra-high vacuum scanning tunneling microscope (purchased with DURIP funds) has been installed in the main system. The entire system moreover has been remounted on a vibration isolation frame to accommodate the scanning tunneling microscope. (Figure 1)

(4) A second vacuum system is complete, and is now being used for studies of ethylene/Pt with a combined quartz crystal microbalance /scanning tunneling microscope. These studies are intended to probe the nanomechanical properties of lubricants which may have applications to MEMS technology.

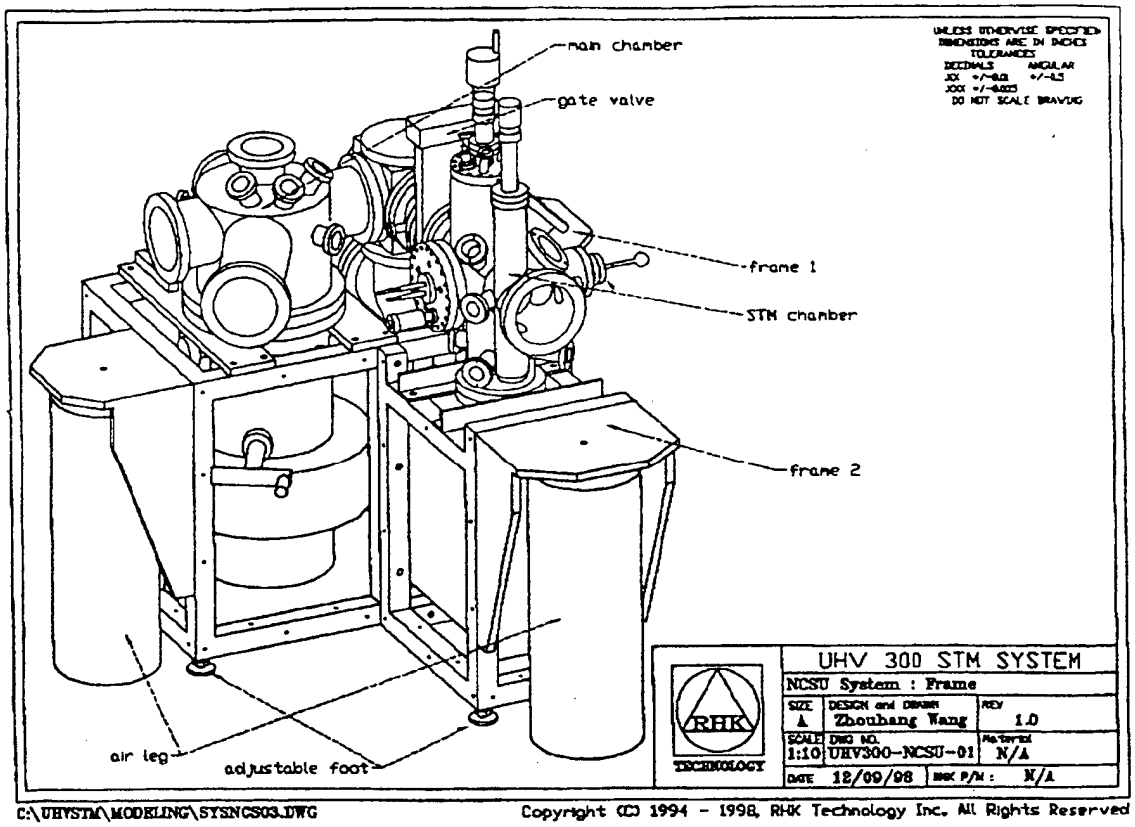


Figure 1: Schematic of the new additions to the existing chamber. The STM addition is now in place and the entire system has been mounted on vibration isolation legs.

(5) **Accomplishments/New Findings:** Our studies of TBPP/Fe have commenced and we are currently measuring uptake rates of TBPP at various temperatures. Our studies of combined STM/QCM have demonstrated that a single asperity contact can be made in sliding contact at realistic sliding speeds. Our newest finding is that the tip can be employed for sliding with billions of passes, and then used to image the sliding contact region in areas as small as tens of atoms in lengthscale. This demonstrates the usefulness of the technique far beyond the system of specific interest. It allows **any** lubricant/metal substrate combination to be tested at realistic sliding conditions for lubrication/wear properties. This has immediate application to improving the tribological performance of MEMS systems. Moreover, this approach has proven to be far superior to that of an AFM/surface contact. The STM image depicted below was recorded on a silver film which deposited on the surface of a QCM and then exposed to oxygen. The brighter region of the image corresponds to an area which

while the QCM was oscillating. After 10 billion passes, the area has been cleared of oxygen. (Figure 2) We have rank ordered a number of systems according to both the slipperiness of the contact and the durability of the overlayer:

(a) Chrome with an oxygen overlayer: Highest shear strength (highest friction); highest durability (> 10 billion passes)
(b) Silver with an oxygen overlayer: Medium shear strength; durability about 10 billion passes
(c) Ethylene/Pt: Low shear strength, durability about 100 million passes.

We therefore have observed a direct relation between the friction at an interface and the length of time which the surface layer will remain intact. We are now in the process of quantifying these results.

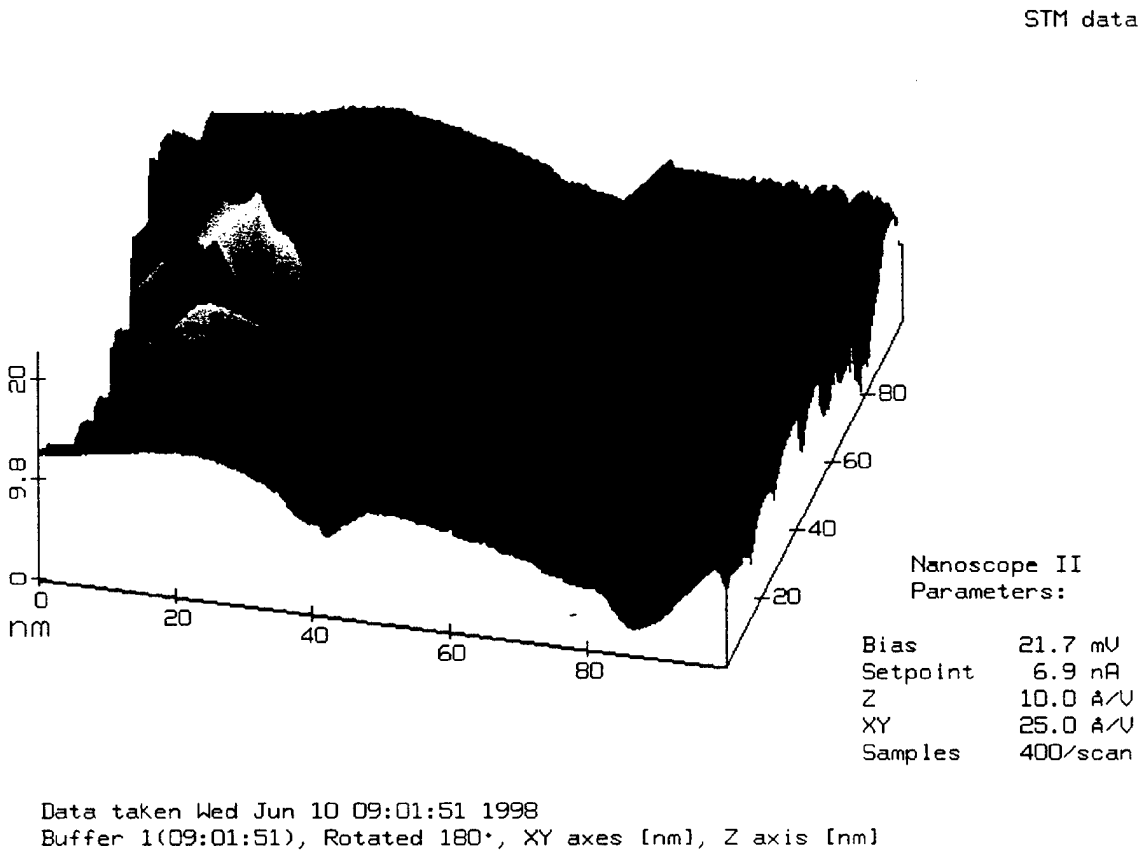


Figure 2: STM image of a silver film exposed to oxygen and then subjected to 10 billion passes associated with the rubbing action of a combined QCM/STM.

(6) Personnel Supported fully or partially: Graduate students: Mohammed Abdelmaksoud and Angela J. Dayo; Post Doctoral personnel: Kurt Ketola and Brian

Mason. (Ketola and Dayo were outgoing group members who trained incoming members Abdelmaksoud and Mason) Faculty: Jacqueline Krim, (1 month summer salary) Other personnel associated with this effort: Timothy Hussey, the Northeastern University condensed matter technician (paid by NU), and Hy Carrel, an undergraduate summer assistant.

(7) Publications:

(1) *Fundamentals of Friction*, J. Krim, guest editor MRS Bulletin, **23**, (June 1998)

(2) *Energy Dissipation in Interfacial Friction*, M.O. Robbins and J. Krim, in Ref. 1.

(3) *Contact Resistance Modeling and Measurements of an Electrostatically Actuated Micromechanical Switch,* S. Majumder, N.E. McGruer, P.M. Zavracky, G. A. Adams, R. H. Morrison and J. Krim, submitted to MEMS symposium of ASME Meeting, Nov. 1998

(8) Interactions/Transitions:

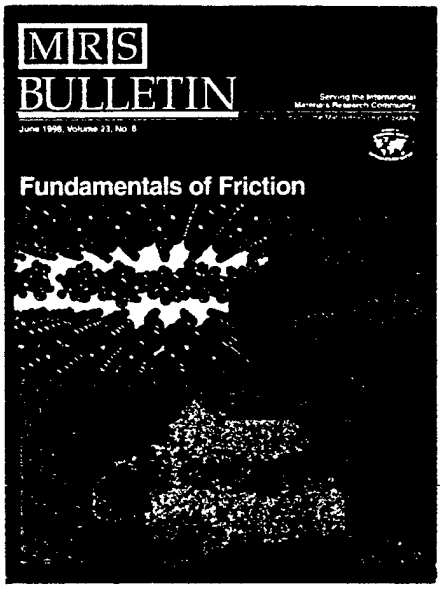
(a) Colloquia/ Seminars
(1) 2/98 Physics Dept., University of Maryland, Baltimore, MD
(2) 2/98 Physics Dept., Wayne State University, Detroit, MI
(3) 3/98 Physics Dept., University of Virginia, Charlottesville, VA
(4) 4/98 Holyoke College, Five-College Lecturer, Holyoke, MA
(5) 5/98 USArmy Research Base, Natick, MA
(6) 5/98 Physics Dept., Northeastern University, Boston, MA
(7) 5/98 Physics Dept., Massachusetts Institute of Technology
(8) 9/98 Physics Dept., Haverford College, Haverford, PA
(9) 10/98 Physics Dept., Rutgers University, Piscataway, NJ
(10) 12/98 Physics Dept., Univ. of New Mexico, Albuquerque, NM

Invited talks at Conferences, where this work is included:
(1) 7/98 Gordon Conference on Chemistry at Interfaces, Meriden, NH
(2) 8/98 14th Int. Vacuum Congress, Birmingham, England
(3) 11/98 American Vacuum Society, National Symposium, Baltimore, MD
(4) 3/99 American Chemical Society National Symposium, Anaheim, CA
(5) 9/99 Complex Fluid Interfaces, Pisa, Italy

(b,c) Consultations/Transitions: This work is being carried out in close coordination with N. H. Forster at Wright-Patterson AFB, OH. Preliminary and final results are immediately conveyed to Forster, in order to speed the intermediate steps before introducing the technology into high speed rolling element bearings intended for use in gas turbine engines. The work is also coordinated with AFOSR funded efforts by A. Gellman to assure the accuracy of the work through comparisons in independent laboratories. The work was summarized at the June 1998 AFOSR/ONR/NSF tribology workshop, where Krim was able to closely consult on the project with Gellman and Forster. The MEMS-related work is being performed in close collaboration with groups who fabricate micromechanical switches.

(9) New Discoveries, inventions or patent disclosures: (none)

(10) **Honors/awards:** In addition to the invitation by the Materials Research Society to be guest editor for a special issue on friction, the PI was selected for the distinguished visitor lecture series at Haverford College, PA, and the five-college Lecture series at Holyoke College.



MRS June 1998 Bulletin on
Fundamentals of Friction
J. Krim, Guest Editor