THE OHIO STATE UNIVERSITY

Development of Fundamental Understanding of Friction and Wear Mechanisms by Atomic-Scale Tribological Studies of Ceramic Materials and Multilayered Thin Films

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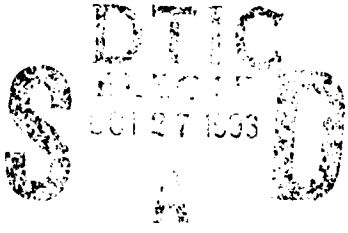

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Annual Report
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FY93 End of Fiscal Year Letter
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ONR CONTRACT INFORMATION

Contract Title: Development of Fundamental Understanding of Friction and Wear Mechanisms by Atomic-Scale Tribological Studies of Ceramic Materials and Multilayered Thin Films

Performing Organization: The Ohio State University

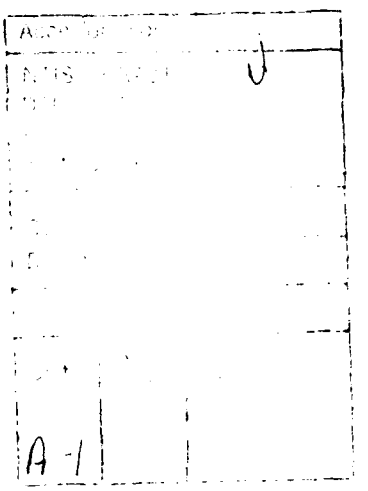
Principal Investigator: Bharat Bhushan

Contract Number: N00014-93-1-0067

R & T Project Number: TRI9304---01

ONR Scientific Officer: Peter P. Schmidt, Code 1131

Enclosure (1)



A. DESCRIPTION OF THE SCIENTIFIC RESEARCH GOALS

Objective of the ongoing research program is to develop fundamental understanding of the friction and wear mechanisms through atomic-scale and micro-scale tribological studies of bulk ceramic materials and multilayered thin films in dry and boundary-lubricated conditions. We are studying the friction, scratching/wear and indentation behavior of *engineering surfaces* on *atomic and microscales* using an atomic force microscope (AFM)/friction force microscope (FFM) and a nanoindenter. For comparisons, we are also conducting macro friction and wear tests on selected test specimens using a conventional pin-on-disk tribotester. Ceramics with various crystalline structures and multilayered thin films with a range of thicknesses and mechanical properties are planned for studies. Effect of thin layers of bonded and unbonded lubricant films on selected samples will be studied. A multiasperity contact model is being developed to predict the friction and wear for a multilayered solid in contact with another solid surface. The input to the model will be the measured micromechanical properties and 3-D surface topography statistics. This model will allow us to define an optimum surface for low friction and wear. A generalized fractal analysis will be developed to characterize surface roughness using scale independent parameters.

Understanding of friction and wear mechanisms on an atomic scale could potentially result in new material combinations and finishing processes with ultra-low friction and wear.

B. SIGNIFICANT RESULTS IN THE PAST YEAR

We have made significant advances in several areas. We have developed AFM/FFM as an instrument for micro/nano tribological studies. We have used it for studies of multilayered thin-films and ceramic materials. We have shown that local variations in microscale friction for engineering surfaces correspond to the local slope suggesting that ratchet mechanism is responsible for this variation. Atomic-scale friction of cleaved HOPG graphite was measured. We found that periodicity in the friction profile was same as the periodicity of the graphite structure. We further noted that there was a shift in the maxima of the topography and the friction. Based on the interatomic potential, we developed a theory to calculate interatomic forces. We found that predicted maxima of the normal and lateral forces were shifted comparable to the measurements. We have developed AFM as a tool to measure scratch and wear resistance of ultra thin films. Using AFM, we were able to study evolution of wear. We found that wear is initiated at the texture grooves present on the coated surface. AFM has been modified for nanoindentation hardness measurements. Hardness with an indentation depth as low as 1 nm can be measured! AFM has also shown to be useful for nanofabrication.

A Commercial nanoindenter has been installed and is fully operational. Work on the multiasperity contact model has initiated. A generalized fractal analysis has been developed. This analysis allows the surface characterization in terms of parameters which are measurements instrument independent and unique for each surface.

C. PLANS FOR NEXT YEAR'S RESEARCH

AFM/FFM instrumentation developed at OSU and a commercial nanoindenter will be pivotal in our future micro/nanotribological studies. A number of samples are planned to be studied. In order to study the effect of structure on microtribology, single-crystalline, polycrystalline and amorphous structures will be studied e.g. single/poly Si, alumina/titanium carbide, silicon carbide, Mn-Zn ferrite, amorphous glass and glass ceramics. Selected samples will be prepared with at least two different roughnesses. Various single-layered and two-layered thin films with a range of mechanical properties and thicknesses will be studied. Some of the film materials will include DLC, zirconia and MoS_2 with thicknesses ranging

from 1 to 1000 nm. In the case of multilayered thin films, the effect of film thickness, a soft film over a hard film and a hard film over a soft film on the interface failure will be studied. Effect of thin layers of bonded and unbonded lubricants on bulk ceramic and coated substrates will be studied.

Development of multiasperity contact will continue. Tools and techniques necessary to measure mechanical properties and roughness profiles required for the model, are fully operational. We plan to apply new generalized fractal analysis to many engineering surface to demonstrate its utility in the real world.

We expect to make significant progress towards our stated goals which may become a pioneering contribution in the emerging field of micro/nanotribology. Set up and maintaince of the research facility and the associated research would not have been possible without ONR funding.

D. LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

1. Papers Published in Refereed Journals

1. J. Ruan and B. Bhushan, "Atomic-Scale Friction Measurments Using Friction Force Microscopy: Part I- General Principles and New Measurement Techniques," *Journal of Tribology*, Trans. ASME (in press).

2. B. Bhushan and J. Ruan, "Atomic-Scale Friction Measurements Using Friction Force Microscopy: Part II - Application to Magnetic Media," *Journal of Tribology*, Trans. ASME (in press).

3. B. Bhushan , V.N. Koinkar and J. Ruan, "Microtribology of Magnetic Media" (invited), *Journal of Engineering Tribology, Part J*, Proceedings of the I. Mech. E. (in press).

4. Bhushan, B. and Koinkar, V.N., "Tribological Studies of Silicon for Magnetic Recording Applications" (invited), *Journal of Applied Physics* (in press).

5. J. Ruan and B. Bhushan, "Atomic-Scale Friction and Microfriction of Graphite and Diamond Using Friction Force Microscopy" *Journal of Applied Physics"*, submitted for publication.

6. S. Ganti and B. Bhushan, "Generalized Fractal Analysis and its Applications to Engineering Surfaces", *Tribology Trans.*, submitted for publication.

7. B. Bhushan and V.N. Koinkar, "Picoindentation Hardness Measurments Using Atomic Force Microscopy", *Applied Physics Letters*, submitted for publication.

2. Non-Refereed Publications and Published Technical Reports

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3. Presentations

a. Invited

1. Plenary Lecture - "Tribology of Thin Films and Bulk Ceramics and Their Applications to Magnetic Storage Devices", Vth International Symposium: INTERTRIBO'93, Bratislava, SR, August 1993.

2. Plenary Lecture - "Microtribology and its Applications to Magnetic Storage Devices", EUROTRIB, 6th International Congress on Tribology, Budapest, Hungary, August - September 1993.

3. Keynote Speaker- "Microtribology and its Applications to Magnetic Storage Devices",The First International Colloqium: Micro-tribology '93, Laliki, Poland, September 1993.

4. B. Bhushan and V.N. Koinkar, "Tribological Studies of Silicon for Magnetic Recording Applications," MMM Conference, Minneapolis, November 1993. (International travel was not charged to ONR contract.)

b. Contributed

1. "Atomic-Scale Friction Measurments Using Friction Force Microscopy: Part I- General Principles and New Measurement Techniques," ASME/STLE Tribology Conference, New Orleans, October 1993.

2. "Atomic-Scale *Friction* Measurements Using Friction Force Microscopy: Part II - Application to Magnetic Media," ASME/STLE Tribology Conference, New Orleans, October 1993.

4. Books (and sections thereof)

E. LIST OF HONORS/AWARDS

F. PARTICIPANTS AND THEIR STATUS

1. Craig T. Gerber, B.S./M.S. Student, Department of Mechanical Engineering.

2. John Lowry, M.S. Student, Department of Mechanical Engineering.

3. Vila N. Koinkar, Ph.D. Student, Department of Mechanical Engineering.

4. Steven T. Patton, Ph.D. Student, Department of Physics.

5. John Monahan, M.S. Student, Deparment of Mechanical Engineering.

G. OTHER SPONSORED RESEARCH DURING FY'93

1. "Development of Diamond Coatings for Reduction in Friction and Wear of Automotive Components," Center for Automotive Research, The Ohio State University, $25,000.

2. Industrial Consortium "Computer Microtribology and Contamination Laboratory," $55,000. One month salary charged to this account.

3. "Ultra-High Density Recording-Magnetic Disk and Tape Tribology," ARPA/NSIC, $150,000. One month salary charged to this account.

H. SUMMARY OF FY93
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS/PARTICIPANTS
(Number Only)

		ONR	non ONR
a.	Number of Papers Submitted to Referred Journal but not yet published:	6	11
b.	Number of Papers Published in Refereed Journals:		7
c.	Number of Books or Chapters Submitted but not yet Published:		2
d.	Number of Books or Chapters Published:		1
e.	Number of Printed Technical Reports & Non-Referred Papers:		
f.	Number of Patents Filed:		1
g.	Number of Patents Granted:		
h.	Number of Invited Presentations at Workshops or Prof. Society Meetings:	4	
i.	Number of Contributed Presentations at Workshops or Prof. Society Meetings:	2	9
j.	Honors/Awards/Prizes for Contract/Grant Employees: (selected list attached)		
k.	Number of Graduate Students and Post-Docs Supported at least 25% this year on contract grant:	5	
	Grad Students: TOTAL	5	3
	Female		
	Minority	3	
	Post Doc: TOTAL		5
	Female		
	Minority		4
l.	Number of Female or Minority PIs or CO-PIs		
	New Female		
	Continuing Female		
	New Minority		
	Continuing Minority		

Enclosure (4)