

# NLBB Newsletter

Nanoprobe Laboratory for Bio- & Nanotechnology and Biomimetics (NLBB)

W390 Scott Laboratory, 201 W. 19<sup>th</sup> Avenue

The Ohio State University, Columbus, Ohio 43210-1142 USA

**Advancing the State-of-the-Art in Nanotribology, Nanomechanics, and Nanomaterials Characterization**

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## Director's Report

by: Professor Bharat Bhushan  
Ohio Eminent Scholar and  
The Howard D. Winbigger Professor

### Goals and Scope



NLBB's main goals are to carry out fundamental studies in the interdisciplinary areas of bio/nanotribology, bio/nanomechanics and bio/nanomaterials characterization and applications to bio/nanotechnology. The

scope of the research includes the development of theoretical models, development of sophisticated instrumentation and techniques, fabrication of nanostructures, and the acquisition of research data for fundamental understanding. Measurement of mechanical and electrical properties of nanostructures is carried out. Self-assembled monolayers and perfluoropolyether lubricant and ionic liquid films are developed for micro/nanostructures. Biomolecular films are studied for biomedical applications. In particular, bioadhesion, friction and wear issues are addressed. Another main goal is to develop bio-inspired nanostructured surfaces. There is a large activity on superhydrophobic and self-cleaning surfaces with low drag (Lotus effect) and interfaces with smart adhesion (Gecko feet). There are also research activities in nanoprobe based data recording technology and beauty care products (hair, hair conditioner, and skin cream). Instrumentation used in the lab includes atomic force microscopy/scanning tunneling

microscopy (AFM/STM), microtriboapparatus, nanoindenter, and industrial simulators.

The research activity is truly interdisciplinary, embodying materials science, physics, physical chemistry, biomedical engineering, biotribology, lubricant rheology, mechanics, applied mathematics, and bio/nanomaterials characterization and applications to bio/nanotechnology and biomimetics.

### Facilities and Equipment

The Nanoprobe Laboratory is housed in Scott Laboratory. The laboratory occupies more than 5700 square feet of space. Office space includes offices for the two faculty members, a secretary, six visiting scientists/industrial fellows, and 16 graduate students. Part of the laboratory is environmentally controlled and contamination controlled to a specification of Class 100. The air tables are used to provide vibration isolation.

The laboratory is equipped with many pieces of sophisticated research equipment including a scanning tunneling microscope, five atomic force microscopes, noncontact optical profiler, stylus profiler, nanoindenter, ultra-high vacuum tribotest apparatus, microtriboapparatus, and scanning ellipsometer, and contact angle measurement apparatus. The other pieces of equipment and facilities include vapor and liquid coating-deposition facilities, pin-on-disk continuous sliding test apparatus, reciprocating sliding test apparatus, microhardness tester, optical microscope, metallurgical sample

preparation and polishing facility, particle counter, microbalance, and environmental chambers.

Central facilities for micro/nanofabrication of structures are used for bio/nanotechnology and biomimetics research. An easy access exists to various physical and chemical analysis facilities such as scanning electron microscope, scanning transmission electron microscope, EDS, scanning Auger spectrometry, X-ray photon spectroscopy, time-of-flight SIMS, DTA, DSC, TMA, TGA balances, porosimeter, NMR, FTIR, mass spectrometry, laser spectroscopy, and computer controlled mechanical test equipment.

The department has extensive computer facilities. In addition, the University maintains the Ohio Supercomputer Center. All of the campus computers are connected electronically.

### **Technical Report**

2009 has been a busy and productive year for the Nanoprobe Laboratory for Bio- & Nanotechnology and Biomimetics.

### **Sponsors**

#### **Industrial**

Corning  
INSIC (HP/Quantum)  
MicroMed  
Technova

#### **Government Sponsors**

European Union  
Institute for Materials Research  
National Institute of Health

#### **Instrumentation Support**

Physik Intrumente  
Veeco Instruments

**Following is a partial list of ongoing projects at NLBB:**

### **Nanotribology and Nanomechanics**

- Normal and Lateral Force Calibration Techniques for AFM Cantilevers
- AFM-Based Nanotribological and Electrical Characterization of Ultrathin Wear-Resistant Ionic Liquid Films
- Nanotribological Properties of Novel Lubricants for Magnetic Tapes

### **Bio- & Nanotechnology**

- Influence of Water on the Interaction Between Graphite and Carbon Nanotubes
- Boundary Slip and Nanobubble Study in Micro/Nanofluidics with Atomic Force Microscope
- Morphology and Mechanical Properties of Block Copolymer Films for Bone Regeneration Applications (with Prof. S. Schricker, College of Dentistry)
- Friction and Wear of New Dental Materials (with Prof. S. Schricker, College of Dentistry)

### **Biomimetics**

- Lotus Effect: Roughness-Induced Superhydrophobic Surfaces
- Mechanically Durable Superhydrophobic, Self-Cleaning, and Low-Drag Surfaces with Hierarchical Structure
- Gecko-Inspired Hierarchical Structures for Reversible Adhesion

### **Beauty Care Products**

- Adhesion, Friction, and Wear Characterization of Skin and Skin Cream Using Atomic Force Microscopy

### **Batteries Aging**

- Aging Mechanisms in Lithium-ion Batteries (with Profs. S. Babu, G. Rizzoni, and Y. Guezennec, College of Eng.)

## NLIM Publications

### Technical Papers (from 2008)

1. Bhushan, B., "Nanotribology, Nanomechanics and Nanomaterials Characterization," (invited), *Philosophical Transactions of the Royal Society A* **366**, 1351-1381 (2008); **A figure on the cover page.**
2. Bhushan, B., "Nanotribology and Nanomechanics in Nano/Biotechnology," (invited), *Philosophical Transactions of the Royal Society A* **366**, 1499-1537 (2008).
3. Tambe, N. S. and Bhushan, B., "Nanoscale Friction and Wear Maps," (invited), *Philosophical Transactions of the Royal Society A* **366**, 1405-1424 (2008).
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5. Bhushan, B., "Nanoscale Characterization of Human Hair and Hair Conditioners," (invited), *Progress in Materials Science* **53**, 585-710 (2008).
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11. Bhushan, B., "Nanotribology of Carbon Nanotubes," (invited), *Journal of Physics: Condensed Matter* **20**, 365214 (14 pp) (2008).
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17. Bhushan, B. and Ling, X., "Integrating Electrowetting into Micromanipulation of Liquid Droplets," *Journal of Physics: Condensed Matter* **20**, 485009 (10 pp) (2008).
18. Koch, K., Bhushan, B., and Barthlott, W., "Diversity of Structure, Morphology, and Wetting of Plant Surfaces," (invited), *Soft Matter* **4**, 1943-1963 (2008); One of the most cited articles of 2008 and 2009.
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### **Book Chapters**

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9. Bhushan, B. and Hahm, C. D., "Capacitance Devices for Film Thickness Mapping, Measurement Methods Using Same," U.S. Patent No. 6,459,280, Oct. 1, 2002.
10. Bhushan, B. and Hahm, C. D., "Liquid Dielectric Capacitor for Film Thickness Mapping, Measurement Methods Using the Same," U.S. Patent No. 6,504,386, Jan. 7, 2003.
11. Bhushan, B. and Hahm, C. D., "Liquid Dielectric Capacitor for Film Thickness Mapping," U.S. Patent No. 6,717,419 B1, April 6, 2004.
12. Bhushan, B. and Hahm, C. D., "Pin and Cup Devices for Measuring Film Thickness," U.S. Patent No. 6,724,199 B1, April 20, 2004.
13. Bhushan, B. and Hahm, C. D., "Method for Measuring Film Thickness Using Capacitance Technique," U.S. Patent No. 6,756,791 B1, June 29, 2004.
14. Pelz, J. P., Lee, D. T., and Bhushan, B., "Direct, Low Frequency Capacitance Measurement for Scanning Capacitance Microscopy," U.S. Patent No. 6,856,145 B2, Feb 15, 2005; Japanese Patent Pending; European Patent Pending.
15. Pelz, J. P., Lee, D. T., and Bhushan, B., "Method for Measuring NM-Scale Tip-Sample Capacitance," U.S. Patent No. 7,023,220 B2, April 4, 2006.
16. Bhushan, B. and Nosonovsky, M., "Hydrophobic Surface with Geometric Roughness Pattern," U.S. Patent Pending.
17. Bhushan, B., Jung, Y. C., and Nosonovsky, M., "Hierarchical Structures for Superhydrophobic Surfaces and Self-Cleaning and Methods of Making," U. S. Patent Pending.

#### **Editor of Book Series**

1. Avoris, P., Bhushan, B., Bimberg, D., von Klitzing, K., Sasaki, H., and Wiesendanger, R., *NanoScience and Technology Series*, Springer-Verlag, Heidelberg, Germany, 2004-.
2. Bhushan, B., *Mechanics and Materials Science Series*, CRC Press Inc., Boca Raton, Florida, 1993-2002.
3. Bhushan, B., *Advances in Information Storage Systems*, American Society of Mechanical Engineers, New York, Vol. 1-5, 1991-1993; World Scientific Publishing Co. Inc., River Edge, New Jersey, Vol. 6-10, 1994-99.

#### **Editor-In-Chief of a Journal**

1. *Microsystem Technologies* (with B. Michel), Springer-Verlag Berlin-Heidelberg, Vol. 8, 2002-; formerly, *Journal of Information Storage and Processing Systems*, Birkhauser Boston (A Division of Springer-Verlag), Vol. 1-3, 1999-2001.

#### **Editorial Advisory Board**

1. Honorary Member, The Research Board of Advisors, *The American Biographical Institute*, Raleigh, North Carolina (1996-).
2. *Journal of Friction and Wear*, The National Academy of Sciences, Belarus (1998-)
3. *International Journal of Surface Science and Engineering*, Inderscience Publishers (2006-).
4. *International Journal of Materials and Structural Integrity*, Inderscience Publishers (2006-).
5. *International Journal of Nanosystems*, Inderscience Publishers (2006-).
6. *Advances in Tribology*, Hindawi Publishing Corporation (2007-).
7. *The Open Mechanical Engineering Journal*, Bentham Open (2007-).
8. *Research Letters in Nanotechnology*, Hindawi Publishing Corporation (2008-).
9. *Journal of Nanotechnology*, Hindawi Publishing Corporation (2008-).
10. *The Open Ceramic Science Journal*, Bentham Science Publishers (2008-).
11. *The Open Polymer Science Journal*, Bentham Science Publishers (2008-).
12. *The Open Surface Science Journal*, Bentham Science Publishers (2008-).
13. *The Open Condensed Matter Physics Journal*, Bentham Science Publishers (2008-).
14. *The Open Colloid Science Journal*, Bentham Science Publishers (2008-).

#### **Fifteenth Sponsors Meeting**

The Fifteenth Sponsors' Meeting was held on, August 4-5, 2008. Representatives from eight companies attended the review. Seventeen presentations were made.

## Short Courses Taught

1. "Nanotribology and Nanomechanics and Applications to MEMS/NEMS, BioMEMS/BioNEMS and Biomimetics (1 day course)," **SPIE Photonics West**, San Jose, California, Jan. 22, 2008.
2. "Nanotribology and Nanomechanics and Applications to MEMS/NEMS, BioMEMS/BioNEMS and Biomimetics (3 days course)," College of Engineering, **National University of Colombia**, Medellin, Colombia, (attended by more than 150 people from all over Colombia), Aug. 2008.
3. "Nanotribology and Nanomechanics and Applications to MEMS/NEMS, BioMEMS/BioNEMS and Biomimetics (3 days course)," College of Engineering, **Andes University** and College of Physics, **Distrital University**, Bogota, Colombia (attended by more than 100 people from all over Colombia), Aug. 2008.

## Students Updates

We presently have one postdoctoral fellows/visiting senior scientists, five Ph.D., and two M.S. graduate students. Following students graduated in 2007-08:

### Ph.D.

1. Shaobiao Cai, "3D Numerical Modeling of Dry/Wet Contact Mechanics for Rough, Multilayered Elastic-Plastic Solid Surfaces and Effects of Hydrophilicity/Hydrophobicity During Separation with Applications," Ph.D. Thesis, Dept. of Mech. Eng., Feb. 2008.

### M.S.

1. Indira P. Seshadri, "In-Situ Tensile Deformation and Surface Charging Characterization of Human Hair with Atomic Force Microscopy," M.S. Thesis, Dept. of Mech. Eng., April 2008.

## Student Ph.D. Theses Abstracts

Full theses can be found on the web at <http://www.mecheng.osu.edu/nlbb>

### **Shaobiao Cai, "3D Numerical Modeling of Dry/Wet Contact Mechanics for Rough, Multilayered Elastic-Plastic Solid Surfaces and Effects of Hydrophilicity/Hydrophobicity During Separation with Applications"**

Adhesion, friction/stiction and wear are among the main issues in magnetic storage devices, microelectromechanical systems (MEMS/NEMS), and other commercial devices having contacting interfaces with normal or tangential motion. Relevant parameters, i.e., layer thicknesses and their mechanical properties for the contact solid surfaces, the roles of meniscus and viscous forces for separation of surfaces from liquid films, need to be studied to provide a fundamental understanding of the phenomenon and the physics of the experienced problems. The simulation of contact mechanics and the modeling of separation of two surfaces with and without liquid mediated contacts are effective ways to investigate these issues.

In the simulation of contact mechanics, a numerical three-dimensional (3D) rough multilayered contact model is developed to investigate the effects of roughness, stiffness, hardness, layer thicknesses, load, coefficient of friction, and meniscus contribution of elastic-perfectly plastic solid surfaces. The model is based on a variational principle in which the contact pressure distributions are those that minimize the total complementary potential energy. The quasi-Newton method is used to find the minimum. The influence coefficients of the displacements and stresses for a multilayered contact model are determined using the Papkovitch-Neuber potentials with a Fast Fourier Transform (FFT) based scheme. Contact analysis of multilayered structures under both dry and wet conditions with and without sliding which simulates the actual contact situations of those devices is performed to identify and obtain optimum design parameters including materials with desired mechanical properties, layer thicknesses, and to predict and analyze the contact behavior of devices in operation.

In the modeling of separation of two surfaces with liquid mediated contacts, numerical models of normal and tangential separation of smooth or rough surfaces are developed. The analyses for both forces during normal and tangential separation of hydrophilic and hydrophobic smooth or rough surfaces with symmetric and asymmetric contact angles, and viscous force effects during tangential separation are presented. The important design parameters, i.e., separation distance, initial meniscus height, separation time, contact angle, and roughness are analyzed. The analyses provide a fundamental understanding of the physics of separation process and insights into the relationships between both the forces. Implications of these analyses in macro/micro/nano technologies are discussed.

Applications of the 3D multilayered rough contact model to magnetic storage devices and applications of the model of separation of two surfaces from liquid thin film to macro/micro/nano technologies are discussed.

## Student M.S. Theses Abstracts

Full theses can be found on the web at <http://www.mecheng.osu.edu/nlbb>

### **Indira P. Seshadri, "In-Situ Tensile Deformation and Surface Charging Characterization of Human Hair with Atomic Force Microscopy"**

Strong beautiful hair is universally desired across various cultures. Hence, the ways in which cleaning conditioning, grooming and styling processes affect the strength, feel and manageability of hair is of interest to beauty care science and technology. Human hair is a complex nanocomposite biological fiber. In this thesis, experiments are performed to better understand mechanical and electrical properties of human hair fibers.

Human hair fibers experience tensile forces during many grooming and styling processes. Hence, characterizing the tensile response of human hair fibers is of considerable interest. The effect of tension on human hair is studied using an atomic force microscope (AFM) and a custom built tensile sample stage. The tensile sample stage allows loading a single hair fiber in tension. In the methodology used here, straining of the hair fiber is stopped intermittently and a marked control area is imaged with the AFM at different strains, upto break point. Morphological changes and deformation that occur with increasing strain are studied. Stress strain data is also simultaneously captured by the sample stage. To understand the effect of damage and treatment on hair fibers virgin, chemically damaged, virgin conditioner treated and chemically damaged conditioner treated, Caucasian hair fibers are studied. To understand differences between damaging processes, mechanically damaged hair is also studied and compared to chemically damaged and virgin hair. Hair from different ethnic types is known to have significantly different properties. In order to understand this difference better, the tensile response of virgin Caucasian, Asian and African hair is investigated. The wet tensile response of hair is particularly important to explain the effect of wet combing and wet styling processes. Also by studying the wet tensile properties, pathways of penetration of water molecules into the hair fiber can be explained. Hence, virgin damaged and treated hair fibers soaked in water are subjected to tension, and a control area is imaged intermittently. While tension experiments are good baseline studies, most grooming processes are not simple tension. In order to better simulate grooming processes, fatigue tests are carried out, where a single hair fiber is subjected to fatigue. The fatigued fiber is then tested and imaged in tension. Mechanisms for all observed results are proposed.

Another property of interest is the surface charge of human hair. Surface charge of hair has a significant effect on manageability, feel, and appearance. For this reason, controlling charge buildup to improve these factors is an important issue in the commercial hair care industry. Previous studies have looked at static charging characteristics of hair on a macroscale. In this study, static charging characteristics of hair are studied on a nanoscale with an AFM. Surface charge is created on hair by rubbing a control area with a voltage biased AFM tip, to which a small voltage bias is applied. The resulting charge distribution is characterized by measuring the surface potential of the control area in situ with Kelvin probe microscopy. The rubbing load is progressively increased, and the effect of this increase on the charge build up is assessed. Virgin, damaged and conditioner treated hair samples are studied, for a better understanding of charge build up and dissipation. Relevant mechanisms are discussed.

## **Technical Seminars**

We invite industrial members to visit the NLBB and present seminars. If you would like to give a seminar, please contact Professor B. Bhushan.

## **Honors and Awards (B. Bhushan)**

- Jan. 2005-  
Apr. 2006** On the Road to Low-Friction Micro Devices, Some Bumps – covered by **New York Times** (1/27/05), CNETNews.com (1/19/05), **ABCNews.com** (1/26/05), TV Channel 10 CBS News (1/26 – 1/27/05), Toledo Blade (1/31/05), High-Technology Materials Alert (1/28/05); **South China Morning Post** (2/1/05), Globe and Mail.com (2/16/05), Columbus Dispatch (3/15/05), Materials Performance (3/05), News in Engineering (Spring 2005, Fall 2006); Feature in ME News (Fall 2005); and numerous web sites. Selected as **The Research Story of the Year 2005** of the Ohio State University – Science Coalition (an Organization of Universities) meeting attended by University Presidents; **Readers Digest**, Canada (4/06, p. 85).
- Sept. 05-  
March 2008** Nanotechnology Confronts the “Bad Hair Day, Tests New Conditioner – covered by Nanotechnology Now (9/7/05), **Hindustan Times** (9/10/05), **Discovery News for the Discovery Channel** (9/20/05); **India West** (9/30/05); **Times of India** (9/30/05); Tech Comm (10-11/05), **TV Channel 10, Columbus CBS News** (11/27/05); **Materials Today** (11/05); **News in Engineering** (Autumn 2005); **Tech News** (Fall 2005); **Futurist** (1-2/06); **BBC Focus, TV Discoveries and Breakthroughs Inside Science** (1/06); **Allure** (3/06, p. 178); **TV Channel 7, San Francisco, ABC News** (5/5/06); **Nanowerk Spotlight** (5/23/06); **New York Daily News** (6/14/06); **Bourne Report Radio Show** (3/23/08) and numerous websites.
- Oct. 07** Ohio Researchers Look to Animal Kingdom (Gecko) for Inspiration – covered by **The Plain Dealer**, Cleveland (10/28/07).

# PLAN TO ATTEND

## July 27-28, 2009: NLBB Sixteenth Annual Research Meeting and Short Course of Nanoprobe Laboratory for Bio- & Nanotechnology and Biomimetics

The purpose of the annual meeting is to present the leading-edge interdisciplinary research carried out in the past year. All presentations will be made by the students, post-docs, and visiting scientists in the lab. In addition, a short course comprising of three one-hour lectures will be given by Prof. Bhushan during the morning of the first day of the meeting. Industrial attendees are welcome to make technical presentations.

Please visit NLBB homepage for the latest list of publications and updates on the Annual Research Meeting. If you are attending, please send the [registration form](#). If you have any questions, please feel free to contact me at the address on this page.

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