Nanotribology and Nanomechanics of MEMS/NEMS and BioMEMS/BioNEMS Materials and Devices

Bharat Bhushan
Ohio Eminent Scholar and The Howard D. Winbigler Professor
Director, Nanotribology Laboratory for Information Storage and MEMS/NEMS
The Ohio State University, 650 Ackerman Road, Suite 255
Columbus, Ohio 43202 USA
bhushan.2@osu.edu http://rclsgi.eng.ohio-state.edu/nlim

MEMS/NEMS and BioMEMS/BioNEMS include a variety of sensors, actuators, and complex micro/nanodevices for industrial, consumer, defense, and biomedical applications. MEMS/NEMS devices are made from single-crystal silicon, LPCVD polysilicon and other ceramic films, and polymers. BioMEMS/NEMS devices involve biomaterials; many use PDMS or PMMA polymers for their construction. Many devices involve relative motion, and in those cases tribology and mechanics are of importance[1-3]. The scale of operation and large surface-to-volume ratio of the devices result in very high retarding forces such as friction and adhesion that seriously undermine the performance and reliability of the devices[4-6]. For BioMEMS/BioNEMS, adhesion between biological molecular layers and the substrate, and friction and wear of biological layers may be important[6,7]. Materials used in various devices must exhibit desirable micro/nanoscale tribological and mechanical properties. There is a need to develop lubricants and identify lubrication methods that are suitable for these devices. Measurement and evaluation of mechanical properties of micro/nanoscale structures is also essential to help address reliability issues. Using atomic-force-microscopy-based techniques, we have performed nanotribological and nanomechanics studies of materials and devices and have explored the use of various surface coatings and surface treatments and lubrication approaches for silicon based and PDMS and PMMA surfaces. Scaling effects in adhesion, friction, and wear have been measured and a comprehensive model for scale effects in friction and wear due to adhesion/deformation, and meniscus effects has been developed. To improve adhesion between biomolecules and the silicon based surfaces, chemical conjugation as well as surface patterning have been used. In the area of biomimetics, we have measured surface roughness present on lotus and other leaves and characterized the surface films to understand the mechanisms responsible for superhydrophobicity (high contact angle). We have developed a model for surface-roughness-dependent contact angle and optimum distributions have been developed for superhydrophobic surfaces. Nanopatterned surfaces have been fabricated which exhibit superhydrophobicity. Geckos' feet have the hierarchical structure capable of smart adhesion – the ability to cling on different smooth and rough surfaces and detach at will. An adhesion model for multilevel hierarchically structured spring systems in contact with rough surfaces has been developed to predict adhesion enhancement as a function of structure. Device level devices on various devices including digital micromirror devices for optical projection displays have been carried out.

In the area of nanomechanics, AFM based techniques have been developed and used for measurements of mechanical properties of nanostructures, made of silicon, silica and polymers, and scaling effects have been studied. A finite element analysis has been used to model deformation of nanostructures to study the effect of surface roughness and scratches on stresses.

[1] Bhushan, B., Israelachvili, J.N., and Landman, U., "Nanotribology: Friction, Wear and Lubrication at the Atomic Scale," *Nature*, Vol. 374, 1995, pp. 607-616.
[2] Bhushan, B., *Handbook of Micro/Nanotribology*, second ed., CRC Press, 1999.
[3] Bhushan, B., *Nanotribology and Nanotmechanics – An Introduction,* Springer-Verlag, Heidelberg, Germany, 2005.
[4] Bhushan, B., *Tribology Issues and Opportunities in MEMS,* Kluwer Academic Publishers, Dordrecht, 1998.
[5] Bhushan, B., Fuchs, H., and Hosaka, S., *Applied Scanning Probe Methods*, Springer-Verlag, Heidelberg, 2004.
[6] Bhushan, B., *Springer Handbook of Nanotechnology, second ed.*, Springer-Verlag, Heidelberg, Germany, 2006.
[7] Bhushan, B., Tokachichu, D. R., Keener, M. T., and Lee, S. C., "Morphology and Adhesion of Biomolecules on Silicon Based Surfaces," *Acta Biomateriala*, Vol. 1, 2005, pp. 327-341.