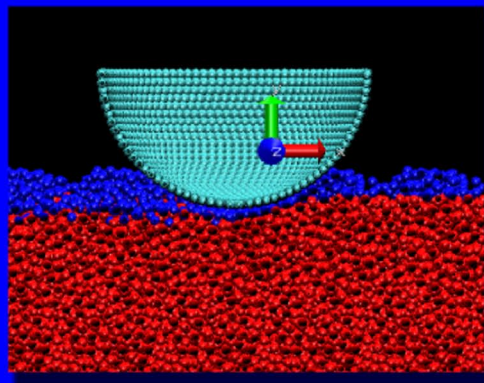
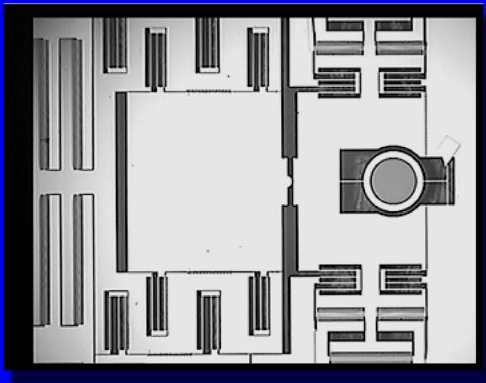
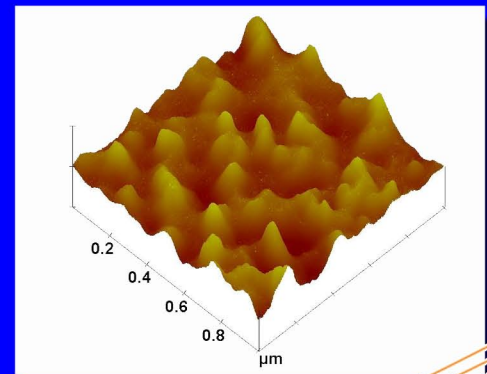
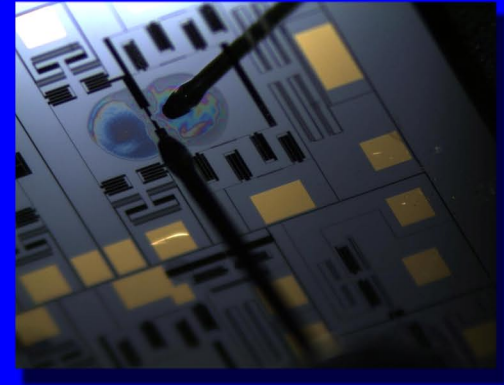


# NANO-TRIBOLOGY AND RELATED MATERIALS ISSUES IN MEMS

13-14 MAY 2010



ORGANIZED & HOSTED

By



Department of Mechanical Engineering  
National University of Singapore

**Workshop**  
**on**  
**“Nano-tribology and related Materials Issues in MEMS”**

Technical Programme and Abstracts

13-14 May 2010

Singapore

Organized and Hosted

by

Department of Mechanical Engineering, NUS, Singapore

Published by

Publication Office

**Local Organizing Committee of “Nano-Tribology and related Materials Issues in MEMS”,  
Singapore**

**Workshop Secretariat**

Professional Activities Center

Faculty of Engineering

Block E1, #05-15,

10 Kent Ridge Crescent

Singapore 119260

Tel: (65) 6516 5113; Fax: (65) 6874 5097

Email: [memstribos@nus.edu.sg](mailto:memstribos@nus.edu.sg) (*contact for registration for the workshop*)

**A workshop on**

**Nano-Tribology and related Materials Issues in MEMS**

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## Welcome Message

The organizing committee would like to extend warmest welcome to the participants of this workshop which is first of its kind in Singapore organized by the Department of Mechanical Engineering, National University of Singapore. We have the honour of hosting talks by some of the leading researchers in the area of nano-lubrication with application in Microsystems. We look forward to our interactions and discussions during the workshop. We thank our invited speakers for their time and support. We sincerely hope that this meeting will catalyse our work in the area of nano-tribology in the future.

The committee would like to thank all the sponsors who have generously provided financial support for this workshop. Finally, we thank the Singapore National Research Foundation (NRF) for providing the CRP grant (Award no. NRF-CRP 2-2007-04) that made all the research works presented from NUS in this workshop possible.

Local Organizing Committee

Workshop on “Nano-tribology and related Materials Issues in MEMS”

## Local Organizing Committee

### **Workshop Co-Chairs**

Sujeet Kumar SINHA (NUS)

Seh Chun LIM (NUS)

### **Members**

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Seh Chun LIM (NUS)

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Nalam SATYANARAYANA (NUS)

## Technical Programme

<b>13<sup>th</sup> May 2010-Thursday</b>	
14.00-14.10	Welcome and Opening Remarks by <b>Co-Chairs of the workshop</b> Venue: <b>Lecture Theatre 1</b>
14.10-14.20	Welcome message by <b>Prof Chan Eng Soon</b> , Dean, Faculty of Engineering, NUS Chair: <b>Sujeet K Sinha</b> ; Venue: <b>Lecture Theatre 1</b>
14.20-15.00	Plenary talk by <b>Prof Takahisa Kato</b> , University of Tokyo, Japan: <i>“Formation of arrayed Au nanoparticles on SiO<sub>2</sub>/Si substrate by use of dewetting phenomenon: - An example of bottom-up technologies in MEMS-”</i> Chair: <b>Sujeet K Sinha</b> ; Venue: <b>Lecture Theatre 1</b>
15.00-15.30	Networking Tea Break
	<b>Session I</b> Chair: <b>Sujeet K Sinha</b> ; Venue: <b>EA-02-11</b>
15.30-16.00	<b>Prof Erjia Liu</b> , Nanyang Technological University, Singapore: <i>“Nanofriction by Reciprocating Sliding”</i>
16.00-16.30	<b>Prof Junyan Zhang</b> , The Chinese Academy of Sciences, China: <i>“The structure and tribological behaviors of nanostructure thin films”</i>
16.30-17.00	<b>Dr Shigeki Kawai</b> , University of Basel, Switzerland: <i>“Detection of lateral forces and formation of atomic chains”</i>
	<b>Session II</b> Chair: <b>Dai Ling</b> ; Venue: <b>EA-02-11</b>
17.00-18.00	Short introduction to Poster Presentations
19.00	Dinner

<b>14<sup>th</sup> May 2010- Friday</b>	
8.30-9.00	Morning Tea
	<b>Session III</b> Chair: <b>N. Satyanarayana</b> ; Venue: <b>EA-02-11</b>
9.00-9.30	<b>Dr Yasuhisa Ando</b> , AIST, Japan: <i>“Reducing friction force on silicon surface using submicron- to atomic-scale geometry effects”</i>
9.30-10.00	<b>Dr Sean J. O’Shea</b> , IMRE, Singapore: <i>“Microfabricated sleds for friction studies”</i>
10.00-10.30	<b>Prof Seong H. Kim</b> , The Pennsylvania State University, USA: <i>“Vapor Phase Lubrication- Nanotribology Fundamentals and MEMS Applications”</i>
10.30-11.00	Breakfast and Networking Tea Break
	<b>Session IV</b> Chair: <b>Sean O’Shea</b> ; Venue: <b>EA-02-11</b>
11.00-11.30	<b>Dr Davy Cheong</b> , IMRE, Singapore: <i>“Probing the complexities of Friction in sub micron contacts between two pristine surfaces”</i>
11.30-12.00	<b>Dr Dai Ling</b> , NUS, Singapore: <i>“Atomistic Simulation of Polymer Nanotribology”</i>
12.00-12.30	<b>Mr Leong Jonathan</b> , NUS, Singapore: <i>“A Novel Method of Lubrication of Micro-Electro-Mechanical Systems”</i>
12.30-13.30	Lunch
13.30-14.15	<b>Lab Tour:</b> Nano-Tribology and Bio-Mimetics Lab, Department of Mechanical Engineering, NUS (Led by <b>N. Satyanarayana</b> )
	<b>Session V</b> Chair: <b>Yasuhisa Ando</b> ; Venue: <b>EA-02-11</b>
14.15-14.45	<b>Prof Norio Tagawa</b> , Kansai University, Japan: <i>“Lubricant Depletion Characteristics Induced by Rapid Laser Heating in Thermally Assisted Magnetic Recording”</i>
14.45-15.15	<b>Dr Arvind Singh</b> , NUS, Singapore: <i>“Robust Tribological Solutions for Silicon and Polymer Based MEMS/NEMS”</i>
15.15-15.45	Networking Tea Break

	<p><b>Session VI</b></p> <p>Chair: <b>R. Arvind Singh</b>; Venue: <b>EA-02-11</b></p>
15.45-16.15	<b>Dr Thomas Reddyhoff</b> , Imperial College, UK: <i>“Lubrication of High Sliding MEMS”</i>
16.15-16.45	<b>Dr Yew Yong Kin</b> , NUS, Singapore: <i>“Simulation of frictional behavior of polymer-on-polymer sliding”</i>
16.45-17.15	<b>Dr Myo Minn</b> , NUS, Singapore: <i>“Pre-modifications of Si surface to enhance the wear durability of PFPE nano-lubricant”</i>
17.15-17.30	Wrap up by Co-Chairs
17.30-18.00	<p>Poster Session</p> <p>Venue: EA-02-Foyer</p>
19.00	<p>Workshop Banquet Dinner &amp; Closure</p> <p>Host: <b>Prof Chew Yong Tian</b>, Head, Department of Mechanical Engineering, NUS</p> <p>A dinner talk with <b>Prof. Seong Kim</b></p> <p>(<a href="http://www.che.psu.edu/faculty/kim/">http://www.che.psu.edu/faculty/kim/</a>) The Pennsylvania State University, USA</p> <p>Title of the Talk: <i>“Surprise, but no surprise – learning from macroscale tribology for microscale innovation”</i></p>

## Abstracts of Presentations

### Plenary Talk

#### Formation of arrayed Au nanoparticles on SiO<sub>2</sub>/Si substrate by use of dewetting phenomenon - An example of bottom-up technologies in MEMS-

**Takahisa KATO**<sup>#</sup>

Surface Science and Tribology Laboratory (SSTL), The University of Tokyo, Japan  
[katox@mech.t.u-tokyo.ac.jp](mailto:katox@mech.t.u-tokyo.ac.jp); <http://www.sstl.t.u-tokyo.ac.jp/>

**Yasuhiko KOJIMA**

ELIONIX INC., Japan; [kojima@elionix.co.jp](mailto:kojima@elionix.co.jp)

We developed an electron-beam induced nanoparticle formation (EBINF) technology, where Au thin film on a SiO<sub>2</sub>/Si substrate was melted and broken into particles of several nanometers in size by an irradiation of electron-beam, and the density of scattered Au nanoparticle of over 1T dots/in<sup>2</sup> was achieved by controlling the Au film thickness and irradiation condition of electron-beam. By the analysis of dominant wavelength and average diameter of nanoparticles, it was found that the nanoparticles were formed through spinodal dewetting process, namely the surface waves generated on the melted Au film were amplified by the surface energy balance.

Two-dimensionally arrayed nanoparticles were then formed in the same way but by using a SiO<sub>2</sub>/Si substrate with two-dimensionally arrayed pits. The dewetting process was forced to start at the edge of each pit, where the chemical potential, which is proportional to surface curvature, is considerably high compared to the smooth surface, and nanoparticles were formed among pits. An application example of arrayed nanoparticles is for an optical sensor. The glass prism with arrayed Au nanoparticles induces the localized surface plasmon resonance (LSPR) and changes the reflectance spectrum, which is sensitive to the environmental conditions of the nanoparticles.

We emphasize the importance of bottom-up technologies as shown in this report because most of the actual devices for mechanical, optical, electric or magnetic uses etc. must have large area of active or reactive sites. Knowledge and experience of surface science and nanotribology could be helpful to the development of bottom-up technologies in MEMS.

**<sup>#</sup>Speaker's Biography:** Professor Takahisa Kato received Dr of Engineering from the University of Tokyo (UT) and began to work mainly in the area of hydrodynamic lubrication at UT in 1982; then he worked in the area of molecular-scale lubrication at the National Institute of Advanced Industrial Science and Technology (AIST) from 1999 till 2005, following which he moved back to UT as a full Professor. His current interests include total tribosystems including surface improvement by hard coatings and molecular film (SAM), instability of molecularly thin liquid/metal film etc. He is the Leader of Surface Science and Tribology Laboratory (SSTL) of UT. He received numerous best paper awards from JSME, JAST, ASME and IMechE. He has published more than 100 papers in reputed international journals in the areas of Tribology, Surface science etc.

## Invited Oral Presentations

### Nanofriction by Reciprocating Sliding

**Erjia Liu**<sup>#</sup>

*School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore*  
Tel: +65 6790 5504, Fax: +65 6792 4062  
E-mail: mejliu@ntu.edu.sg

The effect of friction is due to physical interactions between bodies or objects moving relatively to each other. As a consequence of friction, the process of motion and the dynamic behavior of a system are influenced or disturbed and part of the energy of motion is dissipated. The friction force caused by interfacial adhesion between the asperities of mating surfaces is proportional to the real area of contact and the shear strength of the contact. The coefficient of friction between two real surfaces in contact is dependent on the slope of the asperities of a surface having a smaller slope. Reciprocating sliding at small displacement amplitude with lateral force microscopy (LFM) is suitable for locally identifying the nanoscale friction behaviour of materials.

**Keywords:** Nanofriction, Reciprocating sliding, Lateral force microscopy

**#Speaker's Biography:** Dr. Erjia LIU has been with Nanyang Technological University (NTU), Singapore since 1997 and is currently an Associate Professor and Professor-in-charge of Tribology Laboratory with the School of Mechanical and Aerospace Engineering (MAE), NTU. He received his bachelor degree in materials engineering from Harbin University of Science & Technology, China, master degree in materials engineering from Harbin Institute of Technology, China, and PhD degree in metallurgy and materials engineering from Catholic University of Leuven, Belgium. He has coauthored more than 90 journal publications and more than 80 conference papers. He has been a professional member of the Institute of Materials, Minerals & Mining (IOM3), UK since 2001, a chartered engineer (CEng), UK since 2001, and an EXCO member of the Institute of Materials (IoM), East Asia since 2002. He has chaired the Symposium: Electrochemistry of Thin Films cum the biennium International Conference on Technological Advances of Thin Films & Surface Coatings (ThinFilms) since 2002, co-chaired the Young Persons' World Lecture Competition (YPWLC) organized jointly by the IoM, East Asia and IOM3, UK in 2007, and has been the organizing committee members of several conferences and symposia since 1996. He was a co-editor of a special issue of Thin Solid Films (TSF) in 2009 and a co-editor of a special issue of Journal of Nanoscience and Nanotechnology (JNN) in 2010. His research interests include thin films and coatings, carbon materials, nanocomposites, nanotribology, and electrochemistry.

## The structure and tribological behaviors of nanostructure thin films

**Junyan Zhang**<sup>#</sup>

*State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics,  
Chinese Academy of Sciences, Lanzhou 730000, China*

Nanostructure bestows different properties to materials, especially to thin films, due to the difference in small scale structure. Some nonhydrogenated carbon and carbon nitride films containing a high number of  $sp^2$  bonds exhibit very interesting properties, such as high hardness (up to 55 GPa) combined with an extreme elasticity (elastic recovery of 85%). The combination of a hard and at the same time an elastic material has been attributed to a “fullerene-like” microstructure. The fullerene-like materials composed of graphene multilayers, onions and nanotubes together with amorphous structures have been already synthesized by different physical vapor deposition techniques. Here, we reported that fullerene-like nanostructure hydrogenated carbon films can also be fabricated by plasma chemical vapor deposition—pulsed glow discharge. The fabricated fullerene-like nanostructure hydrogenated carbon films possess high hardness and high elasticity, more importantly, the films exhibit ultra-low friction under ambient condition with 20% relative humidity.

Organic thin films such as self-assembled monolayers or multilayers are studied widely as surface protective films for MEMS. The reliability of the organic thin films is a key factor for the application. The way to solve this problem is to design and fabricate thin film with certain structure. The organic thin films with hydrogen bond network structure demonstrated significant reliability since the structure enhanced the stability of the films by in-plane cross-linking. Furthermore, the order of the hydrogen bond network is also an important factor to the microtribological behaviors of the films that weak or random hydrogen bond network would make the density of the films loosen reflected with higher friction coefficient and shorter durability.

**<sup>#</sup>Speaker’s Biography: Junyan Zhang** received his BS degree in chemistry in 1990 from Lanzhou University in China. Then he joined Lanzhou institute of Chemical Physics, Chinese Academy of Sciences, where he received MS degree in 1997 and Ph.D. in 1999. He then did his postdoctoral researches at the University of California at Berkeley with David Bogy, the University of Alabama with Shane Street, and Rice University with Vicki Colvin. In 2005, he was offered a titled professorship, Hundreds Talent Program, of chemistry and material science and engineering at Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences. In 2007, he spent 3 months in Argonne National Lab with Ali Erdemir as guest scientist. He delivered 9 invited talks on international conferences, published more than 100 peer reviewed papers and filed 17 patents. His current research concerns the design and fabrication of nanostructured carbon film with super low friction and biomimetic surface engineering.

## Detection of lateral forces and formation of atomic chains

**Shigeki KAWAI, Alexis BARATOFF, Ernst MEYER**

Department of Physic, University of Basel, Switzerland

Corresponding Author: shigeki.kawai@unibas.ch, Tel: +65 6700 1111

Friction is one of the most important topics in MEMS devices due to the increased surface ratio. Atomic force microscopy drastically reduced the contact area, and studying of the atomic scale friction became possible. Especially since the first atomically resolved imaging was demonstrated in 1995,[1] non-contact atomic force microscopy has been used for investigating the atomic-scale tip-sample interaction.

Recently, we demonstrate the detection of the atomic lateral force interaction between tip and sample via the torsional resonance frequency shift of a rectangular cantilever.[2] In this method, the tip apex is dithering in the lateral direction, and the lateral tip-sample interaction can be directly detected. An extremely high sensitive detection enabled the force measurement of below 20 pN and corresponding potential was around 3 meV on Graphite(0001).

Setting ultra-small amplitude is mandatory to detect the tip-sample interaction directly, and the measurement situation is close to the thermal equilibrium. In this case, formations of atomic scale chain become possible. We measured the mechanical properties of the atomic chain, and the quantized mechanical response was observed.

[1] F. J. Giessibl, Science 267, 68 (1995).

[2] S. Kawai, Th. Glatzel, S. Koch, B. Such, A. Baratoff, and E. Meyer, Phys. Rev. B 81,085420 (2009).

**#Speaker's Biography:** Shigeki Kawai achieved his doctor degree of Engineering in the University of Tokyo in September 2005. During his PhD, he has built a special ultra-high vacuum non-contact atomic force microscope for improving the resolution by usage of high-resonance frequency cantilevers. He stayed one year in the same group (Professor Kawakastu-group, Institute of Industrial Science, the University of Tokyo), and then started the project of development of low-temperature atomic force microscopy with Professor Hans Hug in Swiss Federal Laboratories for Materials Testing and Research in November 2006. Then he moved to the group of Professor Ernst Meyer in University of Basel in April 2008. His current work focuses on measurements of atomic contacts by non-contact atomic force microscopy at room temperature and low temperature.

## Reducing friction force on silicon surface using submicron- to atomic-scale geometry effects

**Y. Ando<sup>1,#</sup>, Y. Tamura<sup>2</sup>, K. Hiratsuka<sup>2</sup>**

<sup>1</sup>National Institute of Advanced Industrial Science and Technology (AIST),

<sup>2</sup>Faculty of Engineering, Chiba Institute of Technology

Friction force is proportional to the normal load as stated by Amontons-Coulomb's law. For a micro load such as often found in micro electromechanical systems (MEMS), Amontons-Coulomb's law is not valid due to the effect of the adhesion force between the contacting surfaces. It is, therefore, important to determine the tribological properties of silicon surface under micro loads. In this paper, we clarify the adhesion force caused by condensed water and examine the dominant factors for friction coefficient. First we measured the pull-off force using atomic force microscope (AFM) under various atmospheric conditions including in a high vacuum. At a spherical and flat contact, the pull-off force was proportional to the curvature radius of the spherical surface and was irrespective to the relative humidity. At a flat and flat contact, the pull-off force changed with the relative humidity. Second, friction force was measured between 8 kinds of metal pin and silicon substrate with a native oxide film. Results showed that the friction coefficient increased when the interatomic distance of the metal approached 3.1 Å, which corresponds to the interatomic distance of SiO<sub>2</sub>.

**#Speaker's Biography:** Yasuhisa Ando received his PhD degree in mechanical engineering in 1997 from the Tokyo Institute of Technology, Tokyo, Japan. He is currently the leader of the tribology group at the National Institute of Advanced Industrial Science and Technology. He is interested in micro/nano tribology and is recently applying micro fabrication techniques to studies on tribology and related science fields.

## Microfabricated sleds for friction studies

Yee Chong LOKE, Xiaosong TANG, Sunil S. KUSHVAHA, Pin LU, Sean J. O'SHEA<sup>#</sup>

Institute of Materials Research and Engineering, Singapore 117602  
[s-oshea@imre.a-star.edu.sg](mailto:s-oshea@imre.a-star.edu.sg)

We will show results from our recent efforts to study the sliding (under dry conditions) of microfabricated structures. The structures are called “sleds” and consist of rectangular slabs of silicon with three protruding tips which contact the supporting surface. Data will be shown for modeling the movement of the sled, and methods presented for measuring the movement and friction of the sled on a surface. The long term objective is to make the sleds move with very low, yet user defined, friction and preliminary results showing controllable actuation of the sled motion will be shown.

The interacting surfaces of the sled are single asperities, and thus we also undertake AFM studies because AFM mimics the sliding of nanoscale point contacts. We will discuss our preliminary UHV AFM results attempting to measure localised temperature changes during sliding.

<sup>#</sup>**Speaker's Biography:** Sean O'Shea received his BSc and PhD in Physics from Sydney University, Australia. Subsequently he undertook research in various areas of nanoscale science at Cambridge University, UK from 1989 to 1998, where he was appointed a Royal Society University Research Fellow. From 1999 he has been at the Institute of Materials Research and Engineering (IMRE), Singapore. His research interests are in Nanotechnology (chiefly scanning probe microscopy), MEMS, and the creation and application of new bio-sensors.

## Vapor Phase Lubrication – Nanotribology Fundamentals and MEMS Applications

**Seong H. Kim**<sup>#</sup>,

Department of Chemical Engineering, The Pennsylvania State University  
University Park, PA 16802

No matter how small the mechanical devices are, lubrication is needed. In fact, the need for good lubrication becomes even larger as the physical size decreases. This is because the surface area-to-volume ratio becomes larger at smaller scales so that surface forces such as adhesion and friction are more significant than body forces such as gravity. Microelectromechanical systems (MEMS) fall in this category. MEMS are usually fabricated from silicon-based materials using lithographic techniques. However, silicon has poor tribological properties such as high friction, high adhesion, and low wear-resistance. Without proper lubrication methods being developed yet, commercially available MEMS are presently limited to the ones that do not contain sliding or rubbing parts. In order to enable a full spectrum of mechanical motions in MEMS, a good boundary lubricant is needed to reduce adhesion, lower friction, and prevent wear. Various lubrication approaches have been investigated to prolong the operation lifetime of MEMS. They include self-assembled monolayers (SAMs), perfluoropolyethers (PFPEs), bound-plus-mobile phase lubricants, and ionic liquids. Although these approaches show some improvements in MEMS lubrication, they do not yet work sufficiently enough to allow the operation of MEMS with sliding parts for an extended life-time. As an alternative to the coating-based boundary film lubrication approach, the vapor-phase lubrication (VPL) has recently been proven to be very promising. The main difference of VPL from other lubricant coating approaches is that it allows continuous replenishment of lubricant molecules from the vapor phase, rather than relying on one-time loaded coating layers. The alcohol VPL can also be applied to diamond like carbon (DLC) surfaces to reduce wear. The fundamental mechanisms responsible for alcohol VPL as well as practical demonstration with MEMS will be addressed in this talk.

**<sup>#</sup>Speaker's Biography: Dr. Seong H. Kim** is currently an associate professor in department of chemical engineering at Pennsylvania State University. He received his BS and MS degrees in Chemistry from Yonsei University in Korea in 1990 and 1992, respectively. He worked at Korea Research Institute of Chemical technology in 1992-1993 before he moved to the US for his PhD study. He earned the PhD degree in Chemistry from Northwestern University, Evanston, IL, in 1998. He worked as a postdoctoral fellow at University of California at Berkeley and Lawrence Berkeley National Laboratory from 1998 until he joined the Penn State faculty in 2001. His main research interest lies in surface and interfacial science, including nanotribology, gas-solid interactions, surface chemical imaging, superhydrophobicity, and nanomanufacturing. He published 82 peer-reviewed journal articles, 6 peer-reviewed book chapters, and 11 peer-reviewed proceedings. He is an active member of American Chemical Society, American Vacuum Society, American Institute for Chemical Engineers, and Society for Tribologists and Lubrication Engineers.

## Probing the complexities of Friction in sub micron contacts between two pristine surfaces

**Davy CHEONG Wun Chet**<sup>#</sup>

Institute of Materials Research and Engineering, Singapore 117602  
[davy-cheong@imre.a-star.edu.sg](mailto:davy-cheong@imre.a-star.edu.sg)

Amonton's Law of Friction describes the sum effect of many mechanisms of friction working simultaneously on many different length scales. The understanding of the mechanisms governing friction is still far from complete. In this theoretical study, atomistic simulation is used to show the different mechanisms of non-wear friction in effect as the contact area between two pristine surfaces changes from a few atomic radii to a few orders of nanometers. The various mechanisms of friction results in different friction stresses generated between the surfaces.

**#Speaker's Biography:** Cheong Wun Chet Davy is a senior research engineer at the Institute of Materials Research and Engineering, A\*Star. He is also currently an adjunct assistant professor at the National University of Singapore. His research interests include atomistic simulations of nanostructures, soft matter and nanotribology. He obtained his PhD in mechanical engineering from the University of Sydney in 2003. It was during his PhD research that he became interested in nanotribology while working with Prof K L Johnson of Cambridge University.

## Atomistic Simulation of Polymer Nanotribology

**L. DAI<sup>#</sup>, Sujeet K. SINHA, V.B.C. TAN**

Department of Mechanical Engineering, National University of Singapore, Singapore

Molecular dynamics was used to model the sliding between two polyethylene surfaces, and the tribology characteristics were analyzed. With a hard slider on a soft substrate, the friction behavior has an obvious dependence on the sliding rate. The instantaneous friction coefficient shows regular stick-slip behavior at slow sliding. With increasing the sliding speed, the regularity of the stick-slip cycles was disturbed, and finally transferred into thoroughly dynamic friction at high sliding rate. Higher pressure from the slider flattens the substrate surface, and thereby reduces the friction coefficient. When two soft surfaces contacted, the friction was enhanced due to stronger interfacial interlock. Melting surface was observed at high sliding rate, which led to the transformation from stick-slip to dynamic friction. The behavior of diffusion-induced polymer chain interlock was interpreted as the key factor that determines the interface tribology. The interlock behavior was a complex process, and was influenced by many factors, such as polymer chain structure, surface stiffness, sliding speed, temperature, pressure. These factors were well analyzed to display an overall mechanism that controls the nano-structured polymer interface tribology. It was considered a great pace from previously reported critical velocity determined friction behavior of simple atomic layered models.

**<sup>#</sup>Speaker's Biography: Dr. Dai Ling** obtained B.S. degree from Shanghai Jiaotong University in China, and Ph.D. degree from National University of Singapore. He is majoring in the modeling and simulation of materials, covering from atomistic scale to bulk size, by means of quantum mechanics, molecular dynamics and finite element methods. He has got quite many journal and conference publications in the area of metals, ceramics, polymers, semiconductor materials and modeling methodology investigations. He is now working as a Research Fellow at the National University of Singapore.

## A Novel Method of Lubrication of Micro-Electro-Mechanical Systems

**L. Y. Jonathan<sup>#</sup>, V. Harikumar, N. Satyanarayana and S. K. SINHA<sup>\*</sup>**

<sup>\*</sup>Corresponding Author: [mpesks@nus.edu.sg](mailto:mpesks@nus.edu.sg), Tel: +65 6516 4825

Lubrication of Micro-Electro-Mechanical Systems (MEMS) has been an issue in the microsystems industry, limiting their designs and usage in commercial applications. The size and scale of such devices cause the affecting forces to deviate from those of macro-scale, tending more toward atomic attraction forces, van der Waals forces and electrostatic forces of the substrate. Lubrication of MEMS devices rely heavily on modification of surface energies using self-Assembled Monolayers (SAMs) and other chemical processes, to reduce the adhesion, stiction and friction forces between interacting surfaces. Conventional lubrication techniques are often inapplicable to the micro-scale, and common lubricants used in industrial application are incompatible with devices of this size.

The lubrication of sidewalls of MEMS device has been particularly difficult due to the inaccessibility of the surfaces for application and analysis – typical gaps between sidewalls of components range between 10 – 40  $\mu\text{m}$ . Other studies have also shown that the surface reactions on MEMS sidewalls are different from those that occur on exposed plane surfaces. Common lubrication methods often involve complex chemical processing and hermetic packaging for devices, thereby increasing production and material costs. Viscous forces involved in the application of lubricant are also a concern. Techniques such as vapour deposition cover entire exposed plane surfaces of MEMS which can firstly be undesirable as they would affect functionality of devices, and secondly have not been proven to effectively coat the sidewalls of MEMS. Replenishment of lubricant also demands that the device is operated in a specific customized and sealed/closed environment.

A novel method of local application of lubricant to a MEMS device has been conceptualized and scientifically tested on Si surfaces under reciprocating sliding wear as well as actual MEMS devices (U.S. Patent Pending 61/314,627). Using this method, visual confirmation of lubrication of sidewalls or in-plane surfaces are possible, as well as a localized application of lubricant to specific points, avoiding critical areas which may be affected by the electrical properties of the lubricant or failure caused by stiction due to the surface tension forces. Automation of the process is also possible with implementation of mechanized stages and components. Stiction and friction forces have been found to be effectively reduced, allowing device components to come into contact with each other or experience relative motion after contact with no visible signs of wear.

<sup>#</sup>**Speaker's Biography: Jonathan** is currently a Research Engineer with the Department of Mechanical Engineering, National University of Singapore. He obtained his B.Eng (Hons) degree in 2008 from the National University of Singapore, with his honours' thesis in modification of substrates to improve polymer film adhesion. Current research interests include lubrication of microsystems, particularly MEMS, the study of surface modifications and their effects on lubrication and tribology, and polymer films as forms of lubrication."

# Lubricant Depletion Characteristics Induced by Rapid Laser Heating in Thermally Assisted Magnetic Recording

**Norio TAGAWA**<sup>a,#</sup> and **Hiroshi TANI**<sup>a</sup>

<sup>a</sup>Department of Mechanical Engineering, High Technology Research Center,  
Kansai University, Osaka, Japan  
Corresponding Author: [tagawa@ipcku.kansai-u.ac.jp](mailto:tagawa@ipcku.kansai-u.ac.jp) Tel: +81-6-6368-0874

Thermally assisted magnetic recording (TAMR) is one of the novel technologies that are employed for achieving magnetic recording densities greater than 1 Tb/in<sup>2</sup>. However, with regard to this novel technology, it has been suggested that there exists a critical head-disk interface (HDI) issue that is associated with the use of ultra-thin liquid lubricant films on the disk surface. This problem is attributed to the fact that these films are heated to high temperatures using laser beams in order to reduce the magnetic coercivity.

In this study, fundamental research on lubricant depletion due to rapid laser heating in TAMR systems was conducted for cases in which the lubricant film thickness is greater than one monolayer. First, the effects of lubricant film thickness on lubricant depletion were investigated using a conventional lubricant, Zdol2000. The lubricant depletion characteristics due to rapid laser heating were found to largely depend on the lubricant film thickness. Lubricant depletion mechanisms were also studied. It was suggested that the lubricant depletion mechanism involves the evaporation of the mobile lubricant molecules. Another mechanism involves the thermocapillary stress effect induced by the disk surface temperature gradient resulting from the non-uniformity of the laser spot intensity distribution. In addition, the effect of laser irradiation duration on lubricant depletion was investigated using both continuous and 350-kHz pulsed laser irradiations, because actual TAMR systems will require pulsed laser irradiation with durations of the order of a few nano-seconds. Therefore, the differences between the fundamental lubricant depletion characteristics of continuous and pulsed laser irradiation are discussed based on the experimental results obtained in this study.

**#Speaker's Biography: Norio Tagawa** received his BE and ME degrees in mechanical engineering from Tohoku University, Sendai, Japan in 1973 and 1975, respectively. In 1986, he earned PhD degree in mechanical engineering from the University of Tokyo, Tokyo, Japan. From 1975 to 1997, he was with NEC Corporation. He joined the Department of Mechanical Engineering at Kansai University, Osaka, Japan in 1997, where he is currently a professor. His current research includes nano-mechatronics and nano-tribology related to information storage devices as well as MEMS/NEMS.

## Robust Tribological Solutions for Silicon and Polymer Based MEMS/NEMS

**R. Arvind Singh**,<sup>\*,#</sup> Nalam Satyanarayana,<sup>\*</sup> Tanu Suryadi Kustandi,<sup>\*\*</sup> and  
Sujeet Kumar Sinha<sup>\*</sup>

<sup>\*</sup>Department of Mechanical Engineering, National University of Singapore,  
9 Engineering Drive 1, Singapore 117576

<sup>\*\*</sup>Institute of Materials Research and Engineering, A\*STAR,  
3 Research Link, Singapore 117602

Silicon is a popular MEMS/NEMS material. However, it does not have good tribological properties, owing to its high surface energy and brittle nature. In recent times, SU8 polymer has found its niche as a MEMS/NEMS material due to the ease of fabricating micro/nano-components and its biocompatible nature. In this talk, a simple yet robust two-step method capable of enhancing the tribological properties of silicon and SU8 materials will be presented. The method involves chemical modification of polymeric films using plasma treatment and subsequently treating the surfaces with a nanolubricant. As the solution to silicon based MEMS/NEMS, SU8 thin films (thickness ~ 500 nm) spin coated on silicon surfaces were modified as per the two-step method. On the other hand, as the solution for SU8 based MEMS/NEMS, the surfaces of SU8 thick films (thickness ~ 50  $\mu\text{m}$ ) treated as those in the fabrication of SU8 micro/nano-components, were modified as per the two-step method. Tribological investigation of the modified surfaces in comparison with those of the unmodified (bare silicon, SU8 thick film) showed that the modified surfaces had superior tribological properties. The modified surfaces exhibited low surface forces (stiction and friction) and high wear durability when compared to the unmodified surfaces. The improvement in the tribological properties of the modified surfaces is attributed to the reduction in surface energy, chemical bonding of the nanolubricant and the excellent lubrication property of the nanolubricant, respectively. Looking at the results arising from the investigation, the two-step method is proposed as an effective solution to enhance the performance of MEMS/NEMS actuators.

<sup>#</sup>**Speaker's Biography: Dr. R. Arvind Singh** received his Ph.D. in Tribology from the Indian Institute of Science (IISc), Bangalore, India, in 2002. Later, he joined the John. F. Welch Technology Center (GE India Technology Center), Bangalore, India, as a Materials Scientist in the GE Aircraft Engines Group. He was a Visiting Scientist at the Nano-Bio Research Center, Korea Institute of Science and Technology (KIST), Seoul, South Korea between 2004-2009. His research interests are in the field of Biomimetics and Micro/Nano-Tribology. In 2007, his work on introducing the concept of "Lotus Effect" to MEMS/NEMS Tribology, was recognized as the ground-breaking work and the paper detailing this work was awarded the "The First Surface Engineering Best Paper Award" by the Surface Engineering Technical Committee (SETC) of The Society of Tribologists and Lubrication Engineers (STLE), USA. The work was also highlighted in the Handbook of Fundamentals of Friction and Wear on the Nanoscale (NanoScience and Technology Series, Springer-Verlag 2007). His article entitled, "Biomimetics: The Science of Imitating Nature" featured as a Cover Story in the February 2009 issue of Tribology & Lubrication Technology (TLT), the official technical magazine of STLE. To his credit, he has several international publications in the field of Biomimetics and Micro/Nano-Tribology. He is currently a Research Fellow at the Department of Mechanical Engineering, National University of Singapore (NUS). (Contact: [r.arvindsingh@gmail.com](mailto:r.arvindsingh@gmail.com); [mperas@nus.edu.sg](mailto:mperas@nus.edu.sg))

## Lubrication of High Sliding MEMS

**Tom REDDYHOFF**<sup>a,#</sup>, Ingrid KU<sup>a</sup>, Andrew HOLMES<sup>b</sup>, Hugh SPIKES<sup>a</sup>.

<sup>a</sup>Department of Mechanical Engineering, Imperial College, London.

<sup>b</sup>Department of Electrical Engineering, Imperial College, London.

Corresponding Author: [t.reddyhoff@imperial.ac.uk](mailto:t.reddyhoff@imperial.ac.uk), Tel: +44 207 5947236

One of the most significant advances in technology in recent years has been the development of micro-electromechanical systems or MEMS. A major problem with MEMS devices is the difficulty of lubricating sliding parts, since the lubrication regimes of the macroscale cannot be directly transferred to the microscale. As a result, surface treatment methods and self-assembled monolayers are commonly used. However, other methods of lubrication should also be considered. Liquid lubrication, which is effective at the macroscale, is generally dismissed in MEMS as it is believed to produce too much viscous drag. The objective of the work is to investigate effective lubrication for MEMS with high sliding parts.

A new tribometer has been developed to measure friction and film thickness under conditions that are representative of MEMS. The tribometer consists of a rotating silicon disc loaded against a stationary silicon disc. The stationary disc has a structured surface produced using Deep Reactive Ion Etching (DRIE). Friction and film thickness values were measured using laser displacement techniques.

Hydrodynamic tests have been carried out on a range of surface geometries and lubricating fluids. Results for hydrocarbon lubricants show that friction increases with sliding speed and decreases with increasing applied normal load, which is in accord with hydrodynamic theory. Here, experimental results have been validated by comparison with a finite difference solution of Reynolds equation. Reasonable agreement is seen between theory and experiment.

When sufficiently low viscosity lubricants are used, friction coefficients less than 0.1 are observed even at high speeds. At low speeds however, severe boundary friction occurs. For this reason, the use of friction modifier additives has been investigated. It is shown that amine additives blended with lubricating liquids are effective in attaching to the silicon surfaces and significantly reduces friction at low speeds.

Wear of silicon MEMS surfaces has also been studied under a range of conditions. It has been shown that the nature and severity of wear is extremely sensitive to the condition of surfaces. For instance, the exposure to ambient air of clean specimens prior to rubbing reduces wear due to the action of lubricious airborne contaminants. In addition, lubrication of MEMS by ferromagnetic fluids and by vapour replenishment has been investigated.

**#Speaker's Biography:** Tom is a member of the Tribology Group at Imperial College, where he has worked as a research associate for Professor Hugh Spikes since 2006. Before this he completed a PhD at The University of Sheffield developing ultrasonic techniques to study lubricant films. He is currently involved in several projects looking at various aspects of lubrication. He is particularly interested in the lubrication of Micro-Electro-Mechanical-Systems. He is secretary of the Institute of Physics Tribology Committee.

## Simulation of frictional behavior of polymer-on-polymer sliding

**Y.K. Yew<sup>#</sup>, Myo Minn, S.K. Sinha, V.B.C. Tan**

*Department of Mechanical Engineering, National University of Singapore,  
9 Engineering Drive 1, Singapore 117576, Singapore*

The frictional behavior of most materials at the nanometer scale is generally different from that observed for macroscopic scale friction. At the macroscopic scale, frictional interaction can be generalized by Amonton's law which defines the coefficient of friction of two sliding materials as simply the ratio of friction force to applied normal load. We show that the frictional sliding between two polymer blocks deviates from the classical law of Amonton because adhesion forces are shown to play a vital role in friction mechanism. Our simulation results show that the friction force scales linearly with the normal load even at the molecular scale. As the friction force may be of a finite value at zero load, the coefficient of friction should be obtained from the gradient of the friction force versus normal load graph. Some fundamental parameters, i.e. density and molecular weight, were observed to affect polymer-polymer frictional behavior and adhesion. A very low frictional sliding of polymer-on-polymer system can be obtained with two blocks of low density and high molecular weight polymers, as shown by our simulation. Our present study also suggests that adhesion force is more dominant than normal load force at the nanometer scale.

**#Speaker's Biography:** Y.K. Yew is a Research Fellow in Material Group, Department of Mechanical Engineering, National University of Singapore. He graduated from National University of Singapore in 2007 with a PhD.

# Pre-modifications of Si surface to enhance the wear durability of PFPE nano-lubricant

**Myo Minn<sup>#</sup>, Nalam Satyanarayana and Sujeet K. Sinha\***

Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576

\*Corresponding Author: E-mail: [mpesks@nus.edu.sg](mailto:mpesks@nus.edu.sg)

Perfluoropolyether (PFPE) has been an extensively researched and industrially used nano-lubricant for Micro-electro-mechanical-systems (MEMS). Even though PFPE films have shown good improvement in reducing the friction and adhesion forces of Si surface to a large extent, they have demonstrated very low wear durability. We have been working on improving the tribology of PFPE films by suitable pre-modification of Si surface prior to PFPE coating. We will present some successful methods which have improved the tribology of PFPE films on Si to a greater extent (especially wear durability) and are very promising for long-term usages in MEMS and other micro-systems.

The friction and wear durability of perfluoropolyether (PFPE) film on Si substrate is studied with and without the assistance of some intermediate layers such as self-assembled monolayers (SAMs), hydrogen-termination, functionalized polyethylene (fPE) using ball-on-disc experiments. Three different SAMs, one with non-reactive terminal group (octadecyltrichlorosilane (OTS)) and the other two with reactive terminal groups (3-aminopropyltrimethoxysilane (APTMS) and 3-glycidoxypropyltrimethoxysilane (GPTMS)), are chosen and formed on Si substrate by self-assembly. Hydrogen terminated layer is formed on Si substrate by immersing the substrate into hydrofluoric acid. A very thin (~15 nm) functionalized polyethylene (fPE) film is successfully attached to Si substrate via a reactive benzophenone layer. For a comparison, PFPE is directly coated onto bare Si and its tribological properties are evaluated. PFPE overcoating has shown remarkable increase in the wear resistance when it is coated on reactive APTMS/GPTMS SAMs and little increase on OTS SAM. The presence of hydrogen terminated layer onto Si can also enhance the wear resistance to several orders. A significant improvement in the wear durability is observed in the case of benzophenone interfacial layer as the film did not fail when test against 4 mm diameter Si<sub>3</sub>N<sub>4</sub> ball at a normal load of 70 mN and liner sliding speed of 0.052 m/s.

**<sup>#</sup>Speaker's Biography: Myo Minn** studied in Yangon Institute of Technology (Myanmar) from 1995-2002 and received the Bachelor of Engineering degree in Electronic. He received his MSc and PhD degrees in Material Science and Engineering in 2005 and 2010 respectively, from the National University of Singapore. Currently, he is working as a researcher in NUS.

## Invited Poster Presentations

### Adhesion force studies at different temperatures using UHV-AFM

**Sunil S. KUSHVAHA<sup>a</sup>, Khai Yuen LOOI<sup>b</sup>, Wulf HOFBAUER<sup>a</sup>, YeeChong LOKE<sup>a</sup>, Sean O'SHEA<sup>a</sup>**

<sup>a</sup> Institute of Materials Research and Engineering, A\*STAR (Agency for Science, Technology and Research), Singapore

<sup>b</sup> Department of Mechanical Engineering, National University of Singapore  
Corresponding Author: [kushvahas@imre.a-star.edu.sg](mailto:kushvahas@imre.a-star.edu.sg), Tel: +65 6874 8045

In this study we measured the adhesion force between atomic force microscope (AFM) Si tips with and without diamond coating and mica in ultra-high vacuum (UHV). In ambient AFM measurements, the dominant force is often the meniscus force associated with the formation of a liquid capillary between the two surfaces. The adhesion force measurement in UHV eliminates the meniscus force allowing a clearer measurement of the fundamental surface forces. Si cantilevers were cleaned in buffered hydrofluoric solution to remove the oxides and contaminations before loading in UHV system. In most cases, tip wears off or diameter changes after measuring surface forces. To get the consistent measurements, we employed diamond coated tips to minimize the artifacts. We found that the adhesion force between Si tip and mica sample decreases with sample temperature whereas with diamond coated tip, adhesion force increases with temperature. The adhesion force between diamond coated tips and poly vinyl alcohol (PVA) on silicon substrate decreases with temperature.

**#Speaker's Biography:** Sunil Singh Kushvaha is currently working as a research engineer in Institute of Materials Research and Engineering (IMRE), Singapore. He obtained his PhD in Physics from National University of Singapore (NUS) in 2008. His current research interest is in scanning probe microscopy related works in ultra-high vacuum and superlubricity machines. He is author or co-author of 15 international journal papers and 2 book chapters.

## **A Tomlinson based model for two-tip sled in atomic-scale friction**

**Pin LU<sup>#</sup>, Yee Chong LOKE, Xiaosong TANG, Sunil S. KUSHVAHA, Sean J. O'SHEA**

Institute of Materials Research and Engineering, Singapore 117602  
[lup@imre.a-star.edu.sg](mailto:lup@imre.a-star.edu.sg)

Atomic-scale friction between a sharp tip and the sample surface in atomic force microscope (AFM) measurements have been well studied as a single point-contact using the Tomlinson model. In MEMS or NEMS applications however, the friction of two or multiple nano-scale point contacts with the surface may occur.

In this work, we present our recent theoretical studies on a two-tip MEMS system to begin to understand the nano-scale tribology properties of multiple point contacts. Based on Tomlinson model, the equations of motion for the system are established and solved. With the results obtained, the variations of the stick-slip motion of the system with different parameters, such as sled or tip stiffness, potential energy and sled velocity, are discussed. Qualitatively, the two-tip Tomlinson model shows results very similar to the one tip model. We do observe, however, significant differences between the one and two tip models when there are differences in the energy potential acting on each tip in the two tip case. These theoretical modeling and simulation results may help in understanding the sliding motion of multiple tip sliding MEMS systems.

## Design and Fabrications of sliding MEMS Devices to Study the Friction and Sliding Mechanism

**Xiaosong TANG<sup>a,#</sup>, Yee-Chong LOKE<sup>a</sup>, Pin LU<sup>a</sup>, Sunil Kushvaha<sup>a</sup>, Sinha Sujeet KUMAR<sup>b</sup>, Sean O'SHEA<sup>a</sup>**

<sup>a</sup> Institute of Materials Research and Engineering, A\*STAR (Agency for Science, Technology and Research), Singapore

<sup>b</sup> Department of Mechanical Engineering, National University of Singapore  
Corresponding Author: [s-oshea@imre.a-star.edu.sg](mailto:s-oshea@imre.a-star.edu.sg), Tel: +65 6874 8077

In MEMS, sliding surfaces are generally avoided because of our lack of control of friction and wear. This severely restricts the design and control the motion of the MEMS devices. We seek alternatives that would allow sliding MEMS devices to be manufactured. Our efforts address fundamental issues using AFM and theory, and practical approaches using a prototype microfabricated structure with sharp contact to the sliding surface, or we call it “sled”. The key concept is not to avoid friction but to study it and use it within a MEMS actuation scheme.

With our efforts, the sleds are designed and fabricated based on the finite-element methods. The sleds are made by the single crystal silicon plates with different thickness (3 micron and 200nm). Underneath the sled plates are 3 hard and sharp tips, either made by silicon or by silicon nitride. Those tips are used to minimize the contact area and to realise the ultra-low friction between the sled and the underneath surface. During initial test, we have demonstrated that the released sleds can be mechanically actuated. The motion of the sleds and the friction mechanisms are under further study.

**#Speaker's Biography:** Xiaosong Tang received his BSc. degree from Xi'an Jiaotong University in 1994 and MEng. degree from Cornell University in 2001. He is presently a senior research officer in Institute of Materials Research & Engineering (IMRE), Singapore. He has contributed to setup the cleanroom facility in IMRE and is involved in the design of the state-of-art cleanroom in Fusionopolis. His expertise is in the design and fabrication of MEMS devices. He is currently pursuing his part-time PhD study under the guidance of Prof. Sujeet at NUS and Dr. Sean at IMRE. His research area are to integrate the fabrication processes with the atomic force microscopy technology to study the friction and superlubricity, and to conduct research in the related modeling, simulation, design and testing of micro-systems.

## **Bio-inspired Surfaces for Tribological Application in MEMS/NEMS Devices**

**Lin Siyuan,<sup>\*</sup> R. Arvind Singh,<sup>\*</sup> Nalam Satyanarayana,<sup>\*</sup> Tanu Suryadi Kustandi,<sup>\*\*</sup> and Sujeet K. Sinha<sup>\*</sup>**

<sup>\*</sup>Department of Mechanical Engineering, National University of Singapore,  
9 Engineering Drive 1, Singapore 117576

<sup>\*\*</sup>Institute of Materials Research and Engineering, A\*STAR,  
3 Research Link, Singapore 117602

In this work, a biomimetics approach was undertaken in the view of providing effective solutions for the tribological issues found in Micro/Nano-Electro-Mechanical Systems (MEMS/NEMS) made from silicon (Si) material. The underlying principle in the 'Lotus Effect' was applied, by topographically and chemically modifying Si surfaces (combined modification). Topographical modification included fabrication of nano-textures and micro-patterns on SU8 polymeric thin films spin coated on Si surfaces. The nano-textures were created by exposing the polymeric films to plasma and micro-patterns were fabricated using the Nano-Imprint-Lithography (NIL) technique. Chemical modification included coating of a nanolubricant. Tribological investigation was conducted on modified and un-modified Si surfaces, using a Nano-Tribo-Tester. Results showed that the polymeric micro-patterns coated with the nano-lubricant had the best tribological properties, as they exhibited stiction and friction values lower by eight times and five to six times respectively, when compared to those of the un-modified Si surfaces. In addition, no recognizable wear was observed on the modified samples after the tests. Based on these findings, the method of combined surface modification was proposed as the most effective tribological solution for Si surfaces used in MEMS/NEMS devices.

## **Frictional properties of thin functionalized polyethylene film on Si with different modifications**

**Myo Minn, Yanadi S. Gunawan Soetanto<sup>#</sup> and Sujeet K. Sinha\***

Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore  
e-mail: mpesks@nus.edu.sg

A very thin functionalized polyethylene (fPE) film is successfully attached to Si substrate via a reactive benzophenone (Ben) layer. The presence of fPE promotes the wear durability of Si/Ben/fPE to 1000 cycles compares with 100 cycles of Si/Ben under 40 mN applied load and 500 rpm sliding speed. As an enhancement, perfluoropolyether (PFPE) is applied as a top mobile lubricant layer coated onto Si/Ben and Si/Ben/fPE and reveals their tribological properties under the same experimental conditions. A significant improvement in the wear durability is observed as Si/Ben/PFPE fails at 250,000 cycles and Si/Ben/fPE/PFPE does not fail till one million cycles. Si/Ben/fPE/PFPE can withstand the maximum applied load of 150 mN that provides the PV limit of 106.6 MPa ms<sup>-1</sup>.

**#Speaker's Biography:** Yanadi Sutan Gunawan Soetanto is currently an ultimate-year Mechanical Engineering (ME) undergraduate in National University of Singapore (NUS). His research interest is in works related to materials failure analysis.

## Design, fabrication and characterization of a microtribometer

**Yu Hongbin<sup>a,#</sup>, Zhou Guangya<sup>a</sup>, Sujeet K. Sinha<sup>b</sup>, Leong Yonghui, Jonathan<sup>b</sup>, and Chau Fook Siong<sup>a</sup>**

<sup>a</sup>Micro/Nano Systems Initiative Technology, Department of Mechanical Engineering, National University of Singapore, Singapore 117576

<sup>b</sup>Material laboratory, Department of Mechanical Engineering, National University of Singapore, Singapore 117576

E-mail: yhb\_hust@yahoo.com

A microtribometer based on MEMS technology has been presented for characterizing the sidewall friction. It consists of two parts - one is sliding component, the other is contact component. During operation, the sliding component is actuated to move laterally, while the contact component is used to provide contact force as well as the resultant friction. Considering the compatibility with the mainstream fabrication process, electrostatic comb-drive type actuator is adopted in current design. At the same time, a grating structure is used for displacement sensing, in which one end of the grating is directly connected to the sliding component, whilst the other end is fixed onto the substrate via suspending beam. The lateral movement of the sliding component will induce grating rotation, as a result, changing the transmission angle of laser beam diffracted from the grating. By detecting the laser spot movement with position sensitive diode (PSD), any variation of the movement amplitude under different working statuses can be detected in real-time. The microtribometer has been successfully fabricated using standard SOI process flow and some experimental results have also been presented.

**#Speaker's Biography:** Yu Hongbin received a BS in mechanical engineering, MS in electrical engineering and PhD in optical engineering from Huazhong University of Science and Technology, China, in 1999, 2002 and 2006, respectively. He is currently a research fellow at Micro/Nano Systems Initiative Technology with the Department of Mechanical Engineering, National University of Singapore. His research interests involve the design, simulation and fabrication technology of microelectromechanical devices and optofluidics.

## Polymer jet printing to create micro textures of SU8 on Si surface: Optimization and tribological property evaluation

**Tay Nam Beng<sup>#</sup>, Jithin Zachariah Mathew, Myo Minn, Sujeet K. Sinha<sup>\*</sup>**

Department of Mechanical Engineering, National University of Singapore, Singapore

<sup>\*</sup>Corresponding Author: [mpesks@nus.edu.sg](mailto:mpesks@nus.edu.sg)

Polymer jet printing (PJP) could be used to create customized surface patterns on any substrate by employing different polymers such as SU-8 or functionalized polyethylene. For example, PJP could be used to fabricate micro lenses, microfluidic channel, microstructure molding and other biomimetics texturing like finger print texturing.

In tribological applications, PJP could be used to create different surface textures which eventually reduce friction and increase wear durability of components. Therefore, in the present work, we have studied the formation of different textures of SU8 on Si with the objective of improving the tribological properties of Si (reducing friction and wear). Studies on the print quality of Si substrates with different surface pre-treatments were conducted. Tests conducted on non-treated surfaces showed that the SU8 polymer solution tends to spread on the printed surface instead of forming rigid three dimensional features of textures, i.e. the polymer wets the surface and also bigger drop diameters were observed. Appropriate surface treatments such as APTMS (3-aminopropyltrimethoxysilane) & OTS (octadecyltrichlorosilane) SAM (self-assembled monolayer) coatings could be used to control the wettability of polymer solution with the substrate and also drop geometry so as to obtain the customized textures. In addition to the surface condition of the substrate, a proper selection of solvent for the polymer is required to optimize the texturing features.

Tribological properties such as coefficient of friction and wear durability of the optimized SU8 pattern (with varying pitch) on Si were evaluated using a CSM nano-tribometer (ball-on-disk set-up). The printed substrates were cured by specific methods for optimum duration so as to obtain the desired surface properties. After proper curing, sliding tests were done against a 2 mm diameter Si<sub>3</sub>N<sub>4</sub> ball at varying normal loads and sliding velocities. It was observed that the pitch of SU8 pattern on Si substrate has a great effect on the coefficient of friction and wear durability, and the associated mechanisms will be discussed. The present work infers that PJP can find several applications in the area of improving the tribology of a particular substrate by proper selection of the polymer, jetting parameters, proper pre-treatment of the substrate and optimized texturing.

**#Speaker's Biography:** Tay Nam Beng is currently working as a research engineer in the NUS, Material laboratory, Department of Mechanical Engineering. Before joining NUS, he was working in Hewlett Packard (Singapore) printer cartridges failure analysis laboratory. Currently, he is working on the polymer jet printing application.

## Improving the Tribology of UHMWPE Thin Film Coated on Si using Air-plasma Pre-treatment of Si Surface

**M. Abdul Samad<sup>#</sup>, N. Satyanarayana and Sujeet K. Sinha<sup>\*</sup>**

Department of Mechanical Engineering, National University of Singapore, Singapore

<sup>\*</sup>Corresponding Author: [mpesks@nus.edu.sg](mailto:mpesks@nus.edu.sg)

Surface condition in terms of the cleanliness, the chemical properties and the topography play a very important role in determining the thin film properties. Air-plasma treatment has proven to be a very cost effective and an environmental friendly process which influences the surface cleanliness, the chemical functionality and the topography of the treated substrate. In the present study, the effect of the air-plasma pre-treatment of the Si substrate on the tribological properties of a thin film of ultra high molecular weight polyethylene (UHMWPE), was studied. Coefficient of friction and wear life were evaluated by using a ball-on-disk configuration in which a 4 mm diameter Si<sub>3</sub>N<sub>4</sub> ball was slid against the coated sample. Water contact angle measurement, scratch tests, AFM topography studies were used to characterize the adhesion strength between the film and the Si surface. FESEM and EDS analysis were used to evaluate the wear track morphology. Considerable increase in the wear life was observed after the air-plasma pre-treatment of the Si substrate prior to the coating. This improvement was attributed to the increase in the adhesion strength between the film and the substrate.

**<sup>#</sup>Speaker's Biography: Mohammed Abdul Samad** is currently a Research Scholar with the Department of Mechanical Engineering, National University of Singapore. He obtained his Bachelor of Engineering (B.E.) degree from Osmania University, India and went on to do get his M.S degree from King Fahd University of Petroleum & Minerals, KSA. His research interests include but are not limited to tribology of polymer films, micro & nano lubrication of mechanical components and lubricating strategies applied to MEMS and data storage systems.

## Acknowledgements

The Local Organizing Committee of the workshop thanks the below sponsors for their generous financial support:

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