Bioinspired Solutions for MEMS Tribology

R. Arvind Singh
Kumaraguru College of Technology (KCT), India

S. Jayalakshmi
Kumaraguru College of Technology (KCT), India

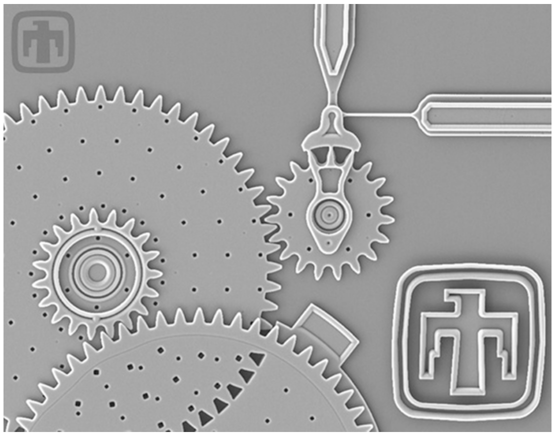
INTRODUCTION

Micro-Electro-Mechanical Systems (MEMS) are miniaturized devices that perform intelligent functions. They can be classified as: (i) sensors based, which have sensing elements and (ii) actuators based, which have elements that undergo mechanical motion. Micro-motors/engines, micro-gears and micro-shutters are examples of actuators based devices. Figure 1 shows a micro-gear made from silicon (http://www.sandia.gov/mstc/_assets/images/mems/gallery/gears/1.jpg). In these devices, tribological issues such as adhesion, friction and wear strongly manifest, which undermine the mechanical motion of MEMS elements (Kim, Asay, & Dugger, 2007). Therefore, it is imperative to solve these tribological issues in order to realize smooth operation and increased operating lifetimes of actuators based MEMS. Conventionally, thin films/coatings have been researched for their application to MEMS as solutions to mitigate the tribological issues. Examples include self-assembled monolayers (SAMs), diamond-like carbon (DLC) coatings, polymers and perfluoropolyether films (PFPE) (Bhushan, 2001). In recent years, bioinspired approaches have attracted attention as better alternative solutions for MEMS. This chapter highlights bioinspired approaches that are promising tribological solutions for actuators based MEMS devices.

BACKGROUND

MEMS are built at micro/nano-scale. At these scales, the ratio of surface area to volume is high. Hence, body forces such as inertia and gravity become insignificant. In contrast, surface forces such as capillary, van der Waals, electrostatic, and chemical bonding dominate. These surface forces cause adhesion at the interface of contacting MEMS elements. Amongst these forces, the capillary force that arises due to the condensation of water from the environment is the strongest. Further, adhesion strongly influences friction at micro/nano-scale (Maboudian & Howe, 1997). The magnitude of these surface forces is comparable with those that drive the motion of MEMS elements, thereby rendering the elements completely inoperable. MEMS are traditionally made from silicon due to availability of the

Figure 1. MEMS micro-gear made from silicon. (http://www.sandia.gov/mstc/_assets/images/mems/gallery/gears/1.jpg). In MEMS devices, tribological issues such as adhesion, friction and wear strongly manifest and undermine the mechanical motion



DOI: 10.4018/978-1-5225-2255-3.ch038

process knowledge developed for the material in semiconductor industries. However, silicon does not have good tribological properties (Bhushan, 2001). Silicon due to its inherent hydrophilic nature experiences high surface forces, and because of its brittle nature it undergoes severe wear. Thus, the improvement of tribological performance of silicon is the key to realize the smooth operation of actuators based MEMS. Williams and Le have presented an excellent review on the tribological issues in MEMS devices (Williams & Le, 2006).

Tribological properties of materials at micro/nano-scale are evaluated using atomic force microscopes (AFM) and micro-tribo testers. With these instruments, contact conditions similar to those in MEMS can be easily simulated (loads ~nN to μN-mN; area ~few hundreds of nm^2).

CONVENTIONAL SOLUTIONS

The gap between moving elements in MEMS is usually about few microns. Hence, solid lubricants (e.g. graphite, MoS_2, WS_2) or liquid lubricants (e.g. oils, greases) cannot be applied in MEMS devices as their sizes are of the same order as those of MEMS elements. Due to this reason, thin films/coatings with thickness less than few microns have been investigated for their application as 'boundary lubricants' for MEMS. Table 1 shows the water contact angle (CA) values, nano-scale adhesion force and nano-scale friction coefficient (μ_n) of silicon (Yoon et al., 2005). The table also shows CA values and nano-tribological properties of thin films/coatings, namely diamond-like carbon (DLC), Z-DOL (commercial name for perfluoropolyether, PFPE), and OTS (octadecyltrichlorosilane) SAM (Yoon et al., 2005; Liu & Bhushan, 2003, Liu, Ahmed, & Scherge, 2001; Singh & Yoon, 2007). The adhesion values given in the table were obtained from force-distance curves measured using AFM. In some cases, the values are taken from the negative intercepts in the friction force versus normal load plots. The nano-scale friction coefficient (μ_n) is estimated as the slope of friction force versus normal load.

Surface energy of a material is indicated by the contact angle between a water droplet and its surface (water contact angle is inversely proportional to surface energy (Bain, Evans & Whitesides, 1989). From Table 1, it is seen that the adhesion values of the test materials are inversely dependent on their CA values. Silicon is hydrophilic in nature and thereby it supports strong capillary force that causes high adhesion. This in turn increases its friction, which retards the motion of actuators. In contrast, DLC, Z-DOL and OTS have higher CA values. This means that they have lower surface energies and sustain lower surface forces. When applied to actuators these materials are capable of promoting smooth motion.

Table 1 shows micro-scale friction coefficient (μ_m) and durability (i.e. the number of cycles for the onset of wear) of the test materials (Yoon et al., 2005; Liu & Bhushan, 2003, Liu, Ahmed, & Scherge, 2001; Singh & Yoon, 2007). At micro-scale, silicon undergoes severe wear within a short duration of time, i.e. it has low durability (< 100 cycles). Figure 2 shows a worn surface of silicon tested at micro-scale. Wear in the case of DLC, Z-DOL and OTS begins only after hundreds of cycles of sliding, which indicates good durability. These boundary lubricants have distinct mechanisms that promote good tribological properties. By nature they are semi-hydrophobic/hydrophobic, due to which adhesion and friction get reduced to a great extent. In DLC films, in addition to their semi-hydrophobic nature, the formation of transfer layer on the counterface surfaces lowers friction and wear (Erdemir et al., 1996). Z-DOL has fluorine atoms which makes its hydrophobic. Fluorine atoms have larger van der Waals radii that support molecular scale order under shear thereby making Z-DOL a good lubricant (Bhushan, 2001). In OTS, the molecular chains act as molecular springs and reduce friction (Liu & Bhushan, 2003). When these boundary lubricants are applied to silicon MEMS, the tribological performance of the devices can be considerably enhanced.

7 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage:
www.igi-global.com/chapter/bioinspired-solutions-for-mems-tribology/183757

Related Content

Methodological Considerations of Qualitative Email Interviews
Kimberly Nehls (2013). *Advancing Research Methods with New Technologies (pp. 303-315).*
www.irma-international.org/chapter/methodological-considerations-qualitative-email-interviews/75952

Distance Education in Times of COVID-19 in Mexico: The Case of the Instituto Politécnico Nacional at the Postgraduate Level
Edgar Oliver Cardoso Espinosa, María Elena Zepeda Hurtado and Jésica Alhelí Cortés Ruiz (2021). *Handbook of Research on Analyzing IT Opportunities for Inclusive Digital Learning (pp. 172-191).*
www.irma-international.org/chapter/distance-education-in-times-of-covid-19-in-mexico/278960

Performance Analysis of Hard and Soft Clustering Approaches For Gene Expression Data
P. K. Nizar Banu and S. Andrews (2015). *International Journal of Rough Sets and Data Analysis (pp. 58-69).*
www.irma-international.org/article/performance-analysis-of-hard-and-soft-clustering-approaches-for-gene-expression-data/122779

Bipolar Model in Collective Choice
Ayeley P. Tchangani (2018). *Encyclopedia of Information Science and Technology, Fourth Edition (pp. 7282-7291).*
www.irma-international.org/chapter/bipolar-model-in-collective-choice/184425

Object-Driven Action Rules
Ayman Hajja and Zbigniew W. Ras (2015). *Encyclopedia of Information Science and Technology, Third Edition (pp. 1197-1206).*
www.irma-international.org/chapter/object-driven-action-rules/112516