Application of Biomimetic Surfaces for MEMS Tribology

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Abstract

"Biomimetics" is the study and simulation of biological systems with desired properties. In recent times, biomimetic surfaces have emerged as novel solutions for tribological applications in micro-electro-mechanical systems (MEMS). These biomimetic surfaces are attractive for MEMS application as they exhibit low adhesion/friction and wear properties at small-scales. In this paper, we present some of the examples of biomimetic surfaces that have potential application in small-scale devices.

1. Introduction

Nature has inspired scientists and researchers world-wide to create/modify surfaces, as novel means to find solutions for real-time applications. In the field of Tribology, the "Lotus Effect" has been of prime inspiration towards the fabrication of surfaces with low adhesion/friction and wear properties. Such biomimetic surfaces could be potentially applied in MEMS devices. MEMS are miniaturized devices that are built at small-scales. At these scales, critical surface forces such as adhesion and friction significantly oppose the smooth operation of MEMS elements that are in relative motion. In addition, these devices are made of silicon and polysilicon materials whose tribological properties are not good. Therefore, there arises a need to modify silicon surfaces in order to enhance their tribological performance at nano/micro-scales. In this paper, we present examples of bio-inspired surfaces fabricated on silicon wafers, which exhibit excellent tribological characteristics at nano/micro-scales, and can be applied to MEMS. The examples include nano/micro-scale polymeric patterns and dually modified silicon surfaces.

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2. Experimental

Biomimetic surfaces with nano/micro-scale asperities that mimic the protuberances of Lotus leaves were fabricated using capillary force lithography [1,2]. The dual modification of silicon surfaces includes the fabrication of micro-pillars using photolithography technique, and subsequently coating them with diamond-like carbon (DLC) and Z-DOL (perfluoropolyether, PFPE) thin films. The DLC film with 100 nm thickness was coated using a plasma-assisted chemical vapor deposition method. The Z-DOL film was coated using the dip coating method. The biomimetic surfaces were tested for their adhesion and friction properties using an AFM and micro-tribotester.

3. Results and discussion

Fig. 1 (a) shows an image of the surface of a real Lotus leaf. The protuberances and the wax on them make the surface of the leaf, superhydrophobic in nature. Fig. 1 (b) shows a nano-patterned polymeric surface, which mimics the surface of a Lotus leaf [1]. At nano-scale, this surface exhibits significant reduction in adhesion and friction forces compared to those of bare silicon surfaces, owing to its hydrophobic nature and reduced real area of contact [1]. Directly replicated surfaces of the real Lotus leaves (Fig. 1 (c)) also show similar results at micro-scale [2]. Bio-inspired nano/micro-patterns such as these are promising tribological solutions as they provide significant reduction in surfaces forces at small-scales.

In the past, it was observed that the micro-friction property of real lotus leaf in its fresh condition was significantly lower than that when tested in its naturally dried condition [3]. Such an occurrence was attributed to the presence of wax in its fresh form, which acts like a lubricant at the surface, and thereby reduces the friction. Taking a clue from the above observation, we undertook dual modification of silicon surfaces (topographical: fabrication of micro-pillars, and subsequently, chemical: DLC/Z-DOL coatings). Fig. 1 (d) shows an optical image of silicon micro-pillars, which were chemically modified.

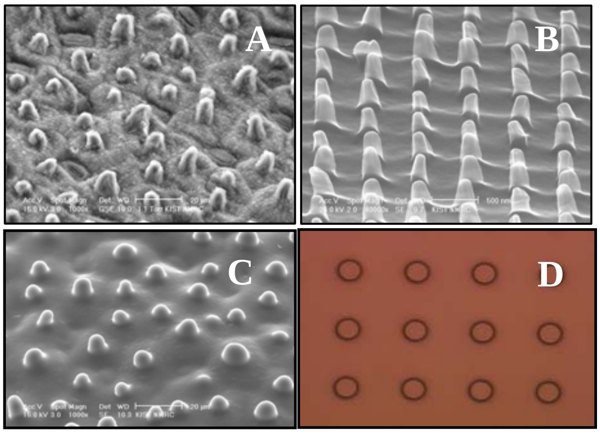

Fig. 1 (A) Real Lotus leaf, (B) Polymeric nano-patterns, (C) Polymeric micro-patterns and (D) Si micro-pillars.

Fig. 2 shows the values of the coefficient of friction of the dually modified silicon surfaces in comparison with those of the bare silicon surfaces and topographically modified silicon surfaces (Si-MP). It could be seen from the figure that the dually modified surfaces (DLC-MP and ZDOL-MP) show significant reduction in friction values when compared to those of the bare silicon surfaces and silicon micro-pillars (Si-MP). Such an excellent behavior of the dually modified surfaces is attributed to the combined effect of the reduction in the contact area (geometrically through patterning of the surfaces) and the anti-friction/wear properties of the DLC thin film, and due to the lubricity of the Z-DOL film. Along with the earlier mentioned polymeric nano/micro-patterns, the dually modified surfaces are also highly attractive as tribological candidates for miniaturized devices (MEMS).

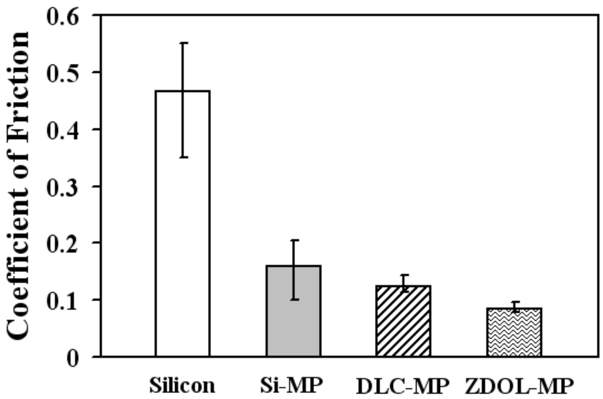

Fig. 2 Micro-scale friction data of dually modified silicon surfaces. (MP: micro-pillars).

4. Conclusion

Development of biomimetic surfaces involves the application of the design principles of biological surfaces. In this paper, we have briefly presented some examples of biomimetic surfaces that exhibit excellent tribological properties at small-scales. It is envisioned that these surfaces would find their application in MEMS devices, as they could enhance the tribological performance of the MEMS elements that undergo relative motion.

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