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Dual Surface Modifications of Silicon Surfaces for Tribological Application in MEMS

Duc-Cuong Pham, R. Arvind Singh and Eui-Sung Yoon[†]

Nano-Bio Research Center, Korea Institute of Science and Technology, Seoul 130-650, Korea

Abstract: Si (100) surfaces were topographically modified i.e. the surfaces were patterned at micro-scale using photolithography and DRIE (Deep Reactive Ion Etching) fabrication techniques. The patterned shapes included micro-pillars and micro-channels. After the fabrication of the patterns, the patterned surfaces were chemically modified by coating a thin DLC film. The surfaces were then evaluated for their friction behavior at micro-scale in comparison with those of bare Si (100) flat, DLC coated Si (100) flat and uncoated patterned surfaces. Experimental results showed that the chemically treated (DLC coated) patterned surfaces exhibited the lowest values of coefficient of friction when compared to the rest of the surfaces. This indicates that a combination of both the topographical and chemical modification is very effective in reducing the friction property. Combined surface treatments such as these could be useful for tribological applications in miniaturized devices such as Micro-Electro-Mechanical-Systems (MEMS).

Keywords: Micro, friction, photolithography, silicon, tribology

1. Introduction

Nano/micro-scale tribology plays an important role in many emerging fields, such as MEMS [1,2]. MEMS are comprised of elements that are small in size and operate at nano/micro-scales. At these scales of size, the ratio of surface area to volume is high and therefore, the surface forces such as adhesion and friction strongly influence the tribological behaviour of the MEMS elements. These forces are critical as they decrease the performance and consequently reduce the durability of MEMS devices [1,2].

Silicon is a popular MEMS material; however its tribological properties are poor, which is mainly due to its high interfacial energy [3,4].

In order to improve the performance of silicon, different surface modification approaches have been undertaken such as chemical modifications and topographical modifications [4].

In this investigation, we studied the effect of the combination of both, the topographical and as well the chemical modifications on the micro-friction property of Si (100) surfaces.

2. Experimental

The Si (100) surfaces were topographically modified into patterns using photolithography and DRIE (Deep Reactive Ion Etching) fabrication techniques. The patterned shapes included micro-pillars and micro-channels. The various steps involved in the fabrication of the Si (100) micro-patterns are shown in Fig. 1. The fabrication procedure of the patterns is briefly explained below.

As the first step, a photoresist (AZ7220, AZ Electronic Materials Ltd.) is spin coated on silicon wafer of thickness 500 microns. After soft-baking, the photoresist film is exposed to UV light. Next, the wafer with the photoresist film is immersed into a developer solution (CD30). After this step, the wafer is rinsed in de-ionized (DI) water and is dried using a spin drier. Following this step, hard-baking is done. After which, the wafer is etched by DRIE method and the photoresist is removed by microwave plasma asher. This final step gives the required micro-patterns.

Figure 2 shows the top-view images of the two different kinds of Si (100) micro-patterns taken using an optical microscope, namely (A) micro-pillars and (B) micro-channels. The dimensions of the micro-patterns are: micro-pillars (diameter: 10 mm) and micro-channels (width: 10 mm). The

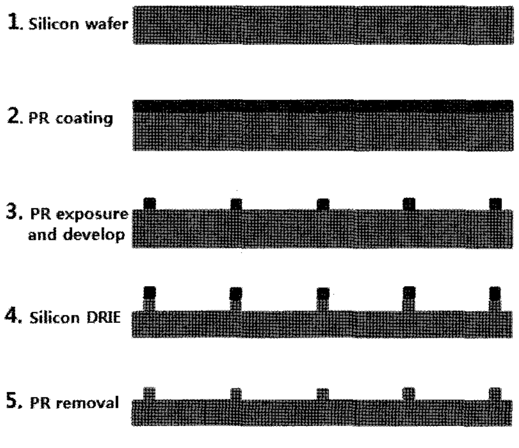

Fig. 1. The steps involved in the fabrication of Si (100) micro-patterns using photolithography and DRIE (Deep Reactive Ion Etching) fabrication techniques.

[†] Corresponding author; esyoon@kist.re.kr
Tel: +82-2-958-5651, Fax: +82-2-958-6910

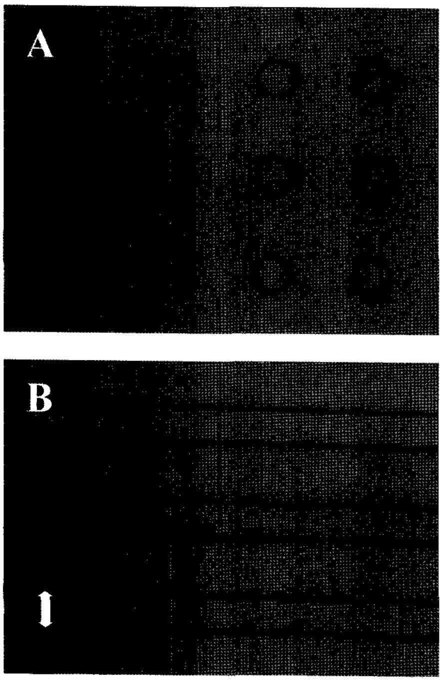

Fig. 2 Top-view images of the Si (100) micro-patterns taken using an optical microscope: (A) micro-pillars and (B) micro-channels.

height of these patterns: 5 mm and the pitch (distance between the centers of any two individual pillars/channels): 30 mm.

The micro-patterns were chemically treated by coating a thin DLC film (thickness: 100 nm) using a plasma-assisted chemical vapor deposition method. The test specimens included the bare Si (100) flat surface, the DLC coated Si (100) flat surface, the uncoated Si (100) micro-patterns and the DLC coated Si (100) micro-patterned surfaces. All these surfaces were tested for their micro-friction property against soda lime balls (diameter: 1 mm) at micro-scale using a ball-on-flat type micro-tribotester. In the friction tests, the sliding speed and the normal load were kept constant at 1 mm/sec and 3 mN, respectively. The scan length was kept constant at 3 mm. Each test was conducted for about 15 minutes. Friction was estimated as an average of the steady state friction values from more than five test repeats. All experiments were conducted in a clean room, at controlled temperature of 24±1°C and relative humidity of 45±5%. In the case of micro-channels (uncoated and coated), tests were conducted in two different directions, namely, along the length of the ridges (parallel scan) and across the length of the ridges (orthogonal scan).

3. Results and Discussion

Figure 3 (a) shows the results of the micro-friction tests of the bare Si (100) flat surface and those of the uncoated Si (100) micro-patterns (MP: Micro-pillars, MC-PS: Micro-channels parallel scan, MC-OS: Micro-channels orthogonal scan). Figure 3 (b) shows the results of the micro-friction tests of the DLC coated Si (100) flat surface and those of the DLC coated Si (100) micro-patterns (MP: Micro-pillars, MC-PS: Micro-channels parallel scan, MC-OS: Micro-channels orthogonal scan).

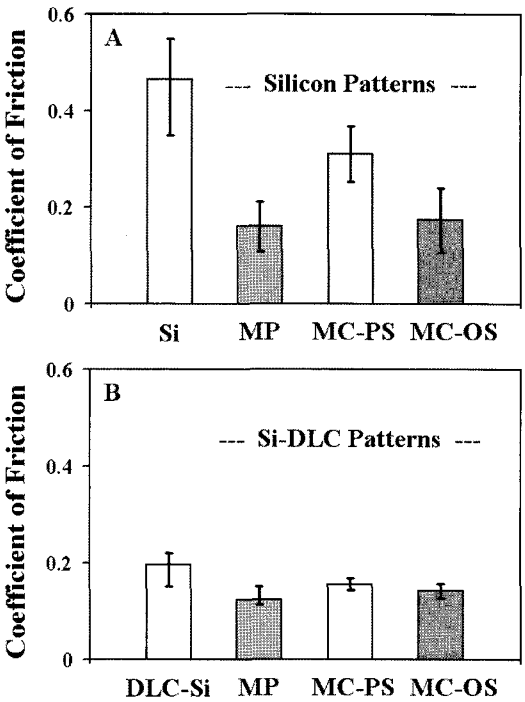

Fig. 3. (A) Micro-friction test results of bare Si (100) flat surface and topographically modified uncoated Si (100) surfaces (MP: Micro-pillars, MC-PS: Micro-channels parallel scan, MC-OS: Micro-channels orthogonal scan). (B) Micro-friction test results of DLC coated Si (100) flat surface and DLC coated patterns (MP: Micro-pillars, MC-PS: Micro-channels parallel scan, MC-OS: Micro-channels orthogonal scan).

From these two figures, it could be seen that the bare Si (100) flat surface exhibited the highest value of coefficient of friction (CoF), when compared to those of the rest of the test specimens. Si (100) is a poor tribological material, which is mainly due to its higher interfacial energy (hydrophilic nature) [3,4]. The DLC coated Si (100) flat surface showed a CoF value lesser than that of the bare Si (100) flat surface. It was observed that both, the bare Si (100) flat surface and the DLC coated Si (100) flat surface exhibited wear [4]. Amongst these two surfaces, the bare Si (100) flat surface showed considerable wear [3,4]. DLC films are good tribological materials and are known to reduce friction and wear, as they are relatively hard and exhibit low surface energies (semi-hydrophobic nature) [3,4].

From Figure 3 (a), it could be seen that the topographically modified uncoated Si (100) surfaces exhibited CoF values lesser than that of the bare Si (100) flat surface. This result could be understood by considering the fundamental law of friction given by Bowden and Tabor [5]. According to the law, friction force is directly proportional to the real area of contact [5]. In the present case, the uncoated patterned surfaces exhibit lower friction values when compared to the bare Si (100) flat surface due to the fact that they project reduced real area of contact. It is well-known that the patterning of surfaces causes a reduction in the real area of contact when the size of the asperities (pillars/channels in the present case) are considerably smaller than that of the counterface slider (glass ball in the present case) [6,7].

From Figure 3 (a), it could also be observed that the friction behavior of the uncoated micro-channels is dependent on the sliding direction. As seen from the figure, the CoF value along the length of the ridges (parallel scan, MC-PS) is higher than across the ridges (orthogonal scan, MC-OS). In the case of the micro-channels, when the counterface ball slides in the parallel direction the contact with the ridges is a continuous one. On the other hand, when the ball slides orthogonally the contact is discontinuous. Hence, when the ball slides in the parallel direction, the contact area is larger when compared to the other sliding direction [8]. This results in higher CoF value for the parallel scan (MC-PS) when compared to the orthogonal scan (MC-OS).

From Figure 3 (b), it could be seen that the DLC coated Si (100) patterns showed considerable reduction in the CoF values when compared to the DLC coated Si (100) flat surface. The coated patterned surfaces did not exhibit any wear. Comparing the CoF values of the coated Si (100) patterns with those of the bare Si (100) flat surface, DLC coated Si (100) flat surface and uncoated patterned Si (100) surfaces, it could be seen that the surfaces with combined treatments of both the topographical and chemical modifications have the most enhanced tribological behavior. Further, the friction behavior of chemically treated micro-channels was found to be strongly dependent on the sliding direction, and this behavior is easily understood on similar lines of the behavior of the uncoated Si (100) micro-channels, as explained earlier.

4. Conclusions

Topographical modification of a surface renders a reduction in its friction property owing to the reduction in the real area of contact, whereas chemical modification reduces friction by lowering the interfacial energy. The present investigation clearly shows a combination of these two kinds of modifications is much more effective in reducing the friction of surfaces. Taking Si (100), a traditional MEMS material (which does not have good tribological properties), as an example, we have shown that a combined surface treatment that includes topographical and as well chemical modifications to Si (100) improves its micro-tribological property. This combined approach could prove as a promising solution to reduce friction between the elements of miniaturized devices such as MEMS, which are in relative motion.

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References

1. Bhushan, B., "Nanoscale tribophysics and tribomechanics", Wear 225, pp. 465-492, 1999.
2. Bhushan, B., "Springer Handbook of Nanotechnology", Springer-Verlag, Berlin, Heidelberg, p. 983, 2004.
3. Yoon, Eui-Sung, Singh, R. Arvind, Oh, H. J, Kong, Hosung., "The effect of contact area on nano/micro-scale friction", Wear 259, pp. 1424-1431, 2005.
4. Singh, R. Arvind and Yoon, Eui-Sung., "Friction of chemically and topographically modified Si (100) surfaces", Wear 263, pp. 912-919, 2007.
5. Bowden, F. P, Tabor, D., "The friction and lubrication of solids", Clarendon Press, Oxford, pp. 90-121, 1950.
6. Yoon, Eui-Sung, Singh, R. Arvind, Kong, Hosung, Kim, B, Kim, D.H, Suh, K.Y, Jeong, H.E., "Tribological properties of nano/micro-patterned PMMA surfaces on silicon wafer", Proc. World Tribology Congress III, Washington DC, USA, September 12-16, 2005, Washington Hilton, Paper Number WTC2005-63964.
7. Yoon, Eui-Sung, Singh, R. Arvind, Kong, Hosung, Kim, B, Kim, D.H, Suh, K.Y, Jeong, H.E., "Tribological properties of bio-mimetic nano-patterned polymeric surfaces on silicon wafer", Tribology Letters 21, pp. 31-37, 2006.
8. Singh, R. Arvind, Pham, Duc-Cuong, Yoon, Eui-Sung, Jeong, Hoon Eui and Suh, Kahp Y., "Nano-channel topography for reduction of adhesive and friction forces", # F3/E1-3, Session F3/E1, ICMCTF 2007, San Diego, USA, April 23-27, 2007, p. 30.