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FRICTION AND WEAR PROPERTIES OF MICRO TEXTURED SURFACES IN BOUNDARY LUBRICATED SLIDING

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In the present study, the friction and wear properties of boundary lubricated textured surfaces were investigated. The capability of textured surfaces to feed lubricant into the interface of a sliding contact and to isolate wear particles was studied and related to the properties of the textured surfaces. Well-defined surface textures were produced by lithography and anisotropic etching of silicon wafers. Different widths and distributions of parallel groves were manufactured and subsequently the wafers were PVD coated with thin wear resistant TiN or DLC coatings, retaining the substrate texture. The surfaces were evaluated in reciprocating sliding against a ball bearing steel ball under starved or boundary lubricated conditions.

Keywords : surface texture, friction, starved lubrication, boundary lubrication, DLC, TiN

1. INTRODUCTION

The introduction of specific textures on a sliding surface, involving flat and smooth lands interrupted by local depressions, is a known approach to improve its tribological properties. One of the functions of the undulations is to trap wear particles. The elimination of wear debris from the interface reduces the ploughing component of friction [1,2]. Another important effect of the surface depressions is to act as reservoirs for lubricants, capable of feeding the lubricant directly between the two contacting surfaces [3,4]. The endurance of the lubricant can then be prolonged and the amount of deformation in the sliding process minimised. Thus the friction is reduced and the lifetime of the contact increased.

The many examples of tribological contact situations that have been improved by texturing include traditional lubricated mechanical components (e.g. honed cylinder surfaces), aerodynamically lubricated magnetic hard disks [5] and forming tools such as rolls for sheet metal forming [6].

The high precision, high resolution and freedom in the choice of shapes, make etched silicon wafers an interesting alternative for optimisation and fundamental studies of the effect of surface textures. To achieve suitable wear properties the etched surfaces have to be coated by a suitable tribological thin film.

In this study the influence of textures was investigated on PVD coated TiN and DLC surfaces. The use of high precision anisotropically etched silicon surfaces as a substrate minimises the influence of coarse edges and other unintended topographical features. The aim of this investigation was to further improve the knowledge of the relation between surface texture and tribological properties in starved and boundary lubricated sliding.

2. EXPERIMENTAL

2.1 Micromechanical fabrication of silicon substrates

Silicon wafers (100) were thermally oxidised in wet oxygen atmosphere to obtain a silicon dioxide (SiO_2) layer of approximately 1 μm to be used as a protecting layer during etching. The oxide layer was patterned with quadratic and striped openings aligned along the <110> directions using standard photolithographic techniques. The silicon was then anisotropically etched in potassium hydroxide (KOH) (40g/100ml) at 80 °C. Finally, the remaining oxide was removed in an HF-solution (1:10, HF:H_2O). The walls of the depressions are slowly etching <111> planes with an angle of 54.7 ° from the load bearing surface.

The size and lateral distribution of the undulations are defined with micrometer precision by the lithographic process. The patterns include squares placed in a quadratic array pattern and parallel grooves. Both grooves and squares were manufactured to three different widths; 5 μm, 20 μm and 50 μm, all to a depth of 5 μm and consistently distributed to keep a load bearing area ratio of 75%.

2.2 Deposition of DLC and TIN films

Either DLC (diamond like carbon) or TiN coatings, both of approximately 1 μm thick, were deposited on the textured silicon substrates and on corresponding flat reference surfaces using standard Baltzers Sandvik PVD processes.

2.3 Tribological evaluation

The test series comprised one flat, three grooved and three surfaces with square depression of each of the two coating types. The grooved surfaces were oriented with the grooves perpendicular or parallel to the sliding direction. The squares were oriented with two sides close to perpendicular to and two sides parallel to the sliding direction. All tests involved reciprocating sliding against a ball bearing steel ball of 10 mm diameter. One series of three parallel tests was run under starved lubricated conditions to 20 000 or 200 000 cycles and one series of three parallel tests was run under boundary lubricated conditions to 200 000 cycles. A normal load of 5 N was applied with a spring and the normal and friction forces were measured by strain gauges. The sample was oscillating with a stroke of 2.5 mm at a frequency of 5 Hz and the tests were performed at room temperature.

Before each test, the ball and the flat were cleaned in acetone and ethanol and blown dry with nitrogen to remove residual dust, grease and other solid contaminants so as to keep the surface conditions as constant as possible.

Prior to each starved lubricated test, a part of the ball was coated with an approximately 10 μm thick film of poly-alpha-olefin without additives. To achieve relatively well-defined and reproducible oil film thickness, the ball was pressed onto a saturated filter paper with a load of 2 N five times, leaving a repeatable sized spot of oil film on the ball. The lubricant was restricted to this very small volume to emphasize the ability of the textured surfaces to retain the oil within the contact area. In the boundary lubricated tests, a drop of oil was applied to the flat surface before each test. In this way the contact area was constantly fed with oil.

3. RESULTS AND DISCUSSION

3.1 TiN coated surfaces

In *starved lubricated* sliding against the TiN coated surfaces the friction coefficient starts at a value of 0.1 and after a time, which seem independent of the surface texture, the friction rises to a value of 0.5. The textured surfaces wear the ball more than do the flat. Figure 1 shows the surfaces after 20 000 cycles, while the friction coefficient was still low.

While *boundary lubricated,* the friction coefficient stays stable at 0.1 through the whole experiment, although the ball suffer from severe wear also in this case.

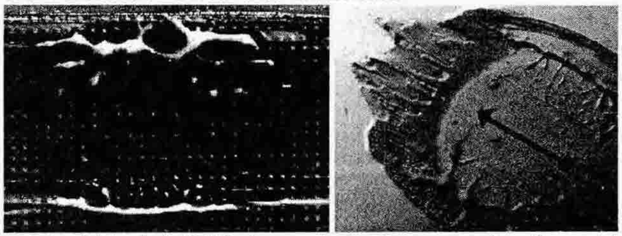

Fig. 1 The left SEM picture shows the textured surface with 20 μm wide square depressions after 20 000 cycles under starved lubrication. The depressions are filled up with oil and wear debris. The right picture shows the corresponding ball surface with a worn plateau surrounded by a mixture of wear particles and oil. Arrows indicate the sliding direction.

3.2 DLC coated surfaces

Under *starved lubrication* of DLC coated surfaces, a clear improvement of the friction and wear behaviour was shown by some of the textures, see examples in figure 2. A low and stable friction of around 0.05 and no noticeable wear was achieved by the grooved surfaces oriented perpendicular to the sliding direction with a groove width up to 20 μm and with the 5 μm square depressions. For the flat surface and all the other textures, the friction was less stable and varied between 0.1 and 0.2. These coatings were worn and sometimes partly spalled off.

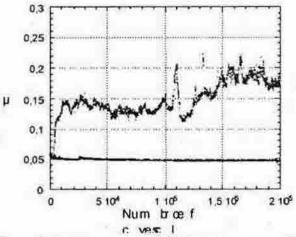

Fig. 2 The friction coefficient as a function of number of cycles for a 20 μm square depression surface (grey) and a surface with 20 μm wide grooves oriented perpendicular to the sliding direction (black).

The *boundary lubricated* DLC surfaces all showed a stable friction coefficient of 0.08 – 0.10 during all 200 000 cycles. When the grooves were oriented along the sliding direction the coating spalled off over large parts, while when oriented perpendicular no cracks or damage was found, see Fig. 3. The surfaces with square depressions spalled for squares wider than 5 μm.

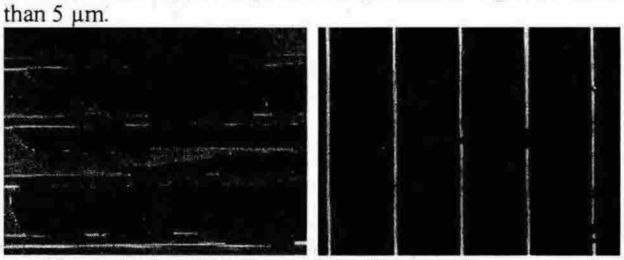

Fig. 3 Textured surfaces with 20 μm wide grooves after 200 000 boundary lubricated cycles. Arrows indicate the sliding direction of the ball.

4. CONCLUSIONS

The TiN coated textured surfaces wear the steel ball more than do the un-textured. The wear particles agglomerate in the depressions and rather rapidly fill them up. Under the *starved lubrication*, the low friction conditions last shorter on textured surfaces than on the flat.

The DLC coated textures showed very interesting results. Under the *boundary lubricated conditions with generous oil supply*, the friction was rather insensitive to the texturing (consistently μ was 0.08–0.1), while the tendencies to coating spallation was strongly coupled to the choice of texture. Under the *starved lubrication condition*, the most successful textures (5 and 20 μm groves and 5 μm depressions) exhibited considerably lower friction (μ 0.05) than in the boundary lubricated case. For the flat surface and the three coarser textures, the limited amount of lubricant was not sufficient to keep the friction low and stable, but it rapidly rose to 0.1–0.2.

5. ACKNOWLEDGEMENTS

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