Atomic wear governed by synergic energy: the roles of tribochemistry and electrochemistry

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In this study, the role of tribochemistry and electrochemistry in the nanowear behavior on silicon substrate against SiO_2 microsphere were studied by using an EC-AFM. By introducing tribochemical reactions at the tribological interfaces, the threshold dissipated energy for material removal reduces significantly to 5.6% (~4 × 10^4 kcal/mol) of that in purely mechanical wear case (~7 × 10^5 kcal/mol). And the value can be further reduced with the assistance of electrochemical corrosion. The findings provide a new paradigm to regulate atomic wear process through utilizing the synergy of multi-source energy.

Keywords: Material removal; Multi-source energies; Tribochemistry; Electrochemistry;

1. Introduction

Tribochemical wear that causes atomic attrition before material yield has attracted lots of attention due to its critical role in ultra-precision manufacturing, micro-electromechanical system (MEMS) and reliable microscopy.[1] As a chemical means or processes initiated from contact interface, the potentiality of tribochemical reactions must be determined by the states of treated surface and the external energy (such as mechanical energy and electric energy).[1] Further understanding of regulating tribochemical reactions could provide insights into reducing friction and wear (in MEMS applications) or improving machining efficiency (in nanomanufacturing).

2. Methods

By using an atomic force microscope with an electrochemical cell (EC-AFM, Bruker, Icon), the tribochemical removal between SiO_2 microsphere and silicon surface was conducted in electrolyte solution (3% wt.% sodium chloride solution), as shown in Figure 1. During the tests, the displacement amplitude was set as 500 nm, the sliding velocity was 2 μm/s, and the applied voltage was constant at 1.5 V.

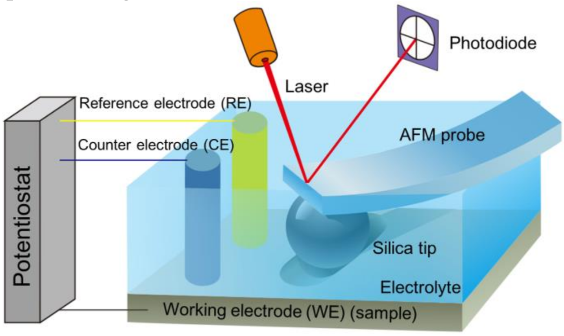

Figure 1: Schematic illustration of the tribochemical removal on silicon surface against a silica microsphere (R ~ 1 μm) attached to an AFM cantilever in EC-AFM system.

3. Discussion

Different from mechanical removal processes involving abrasion, fracture, or plastic deformation, the tribochemical wear relies on the shear-induced hydrolysis reaction of Si substrate with existing water molecules in the sliding environment. Quantified wear results on silicon surface indicates that tribochemical removal rate follows the Arrhenius kinetics law depended on the stress-assisted chemical reactions which is described as a thermally activated atom-by-atom removal process with the lower energy barrier reduced by external mechanical energy. Tribochemical wear (~4 × 10^4 kcal/mol) consumes only 5.6% dissipated energy of mechanical wear case (~7 × 10^5 kcal/mol), which is attributed to the reduced energy barrier of Si–Si bond breakage and no lattice distortion underneath the machined area. And this value is further reduced by introducing electrochemistry. Figure 2 shows the simplified energy coordinate along the dissociation of Si–Si bond at silicon substrate. Tribo/Electrochemical reactions induced by applied mechanical/electrical energy promote the wear rate by reducing the energy barrier: $E_a = E_{Thermal} - E_{Tribochemistry} - E_{Electrochemistry}$, through lowering the activated energy and increasing the initial energy, respectively.

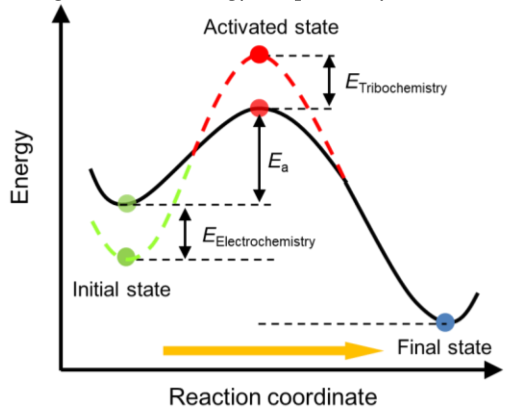

Figure 2: Schematic energy diagram along the reaction coordinate leading to the dissociation of Si–Si bond at silicon surface with the assistant of tribochemical and electrochemical reactions.

4. References

[1] Chen, L. et al., "Nanomanufacturing of silicon surface with a single atomic layer precision via tribochemical reactions" Nat. Commun, 9, 2018, 1542.